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Climate-Responsive Retrofit Protocol for a Deanship Building in Hot-Arid Baghdad

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ABSTRACT

In hot-arid cities such as Baghdad, many university buildings exhibit persistently high energy demand because their envelopes admit excessive solar gains. At the same time, facility managers often lack access to advanced building-energy simulation tools. This paper introduces a simple climate-responsive retrofit protocol for an existing Deanship Building at Al-Mustansiriyah University, combining freely available NASA POWER climate data with an Excel-based solar gain model derived from ASHRAE fundamentals. The protocol quantifies elevation-specific solar loads and tests three low-cost interventions: deep horizontal canopies, high-performance low-solar-gain glazing, and vegetation-based shading. The results show that upgrading the glazing in the most exposed offices and halls can reduce cooling-related solar gains through windows by about one third. At the same time, vegetative shading delivers additional reductions of roughly one-fifth of the summer solar load. When combined with properly dimensioned canopies, these measures are able to cut the summer solar load on the most exposed elevations by around one-half, which can translate into noticeable decreases in cooling demand and associated carbon emissions for the case study building. In addition to these quantitative outcomes, the study proposes a replicable, step-by-step decision-support protocol that allows resource-constrained campuses to prioritize envelope retrofits, turning administrative buildings from energy-intensive facilities into low-carbon, energy-efficient campus assets in similar hot-arid higher-education contexts.

1. INTRODUCTION

University buildings in hot and dry regions typically exhibit very high energy consumption. Their envelopes are not very efficient, and hence, they rely on mechanical cooling a lot, which turns out to be very power-consuming. Energy performance is an emerging global concern, as the building sector is a major energy consumer and contributor to greenhouse gas emissions. In the case of schools and universities with limited budgets, it is not only doing what is right to combat climate change- it is also a practical economic necessity for budget-constrained institutions [1].

Campus buildings can act as a 'living laboratory', where real-world climate-responsive design solutions can be implemented and monitored. They are active, occupied, and can demonstrate climate-intelligent design solutions that have real-life applications. Back in Baghdad, the situation is becoming more difficult. Urban heat-island effects and rising ambient temperatures lead to extreme thermal loads, making prolonged air-conditioning operation during the summer months almost unavoidable. The findings of local research indicate that basic passive interventions, such as shading, improved glazing, and thermal mass, can reduce cooling energy by over 20 percent. The ideas, however, are hardly implemented, as the instruments and expertise to model them are costly and complicated [2].

A significant gap exists in countries such as Iraq, where advanced simulation software is often unaffordable or inaccessible to facility managers and architects. The advanced simulation software needed to estimate the value of retrofits is frequently unable to be purchased or obtained by facility managers and architects. This is why we are in dire need of a simple data-driven process through which the local stakeholders can make wise, evidence-based decisions without imposing prohibitive costs [3].

This paper aims to demonstrate that even a specific architectural modification can transform the Deanship of the Faculty of Engineering at Al-Mustansiriya University into a green campus asset instead of an energy-intensive liability. The study develops a practical retrofit protocol by combining free NASA POWER climate data with a straightforward model of computation, specifically designed to address the hot-dry climate of Baghdad. It discusses the amount of sun radiation the building is currently admitting and measures the effect of three retrofit alternatives: deep horizontal overhangs, high-efficiency low-E windows, and increased vegetation. It aims at providing a practical roadmap to be followed by the campus planners so that the universities in Iraq can change towards a sustainable and resilient campus (Figure 1).

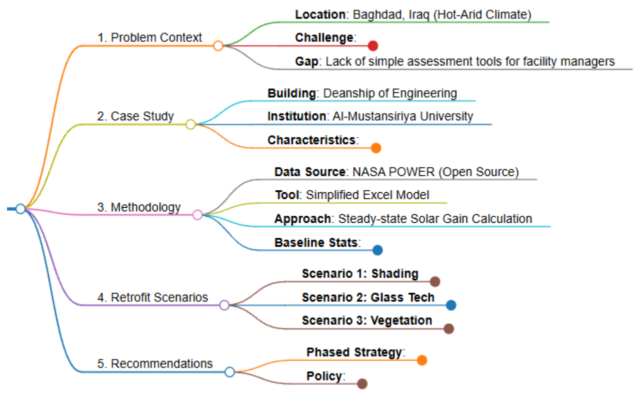

Figure 1. Mindmap of the paper

In recent decades, Baghdad has been witnessing a significant rise in temperatures, especially during the summer months, as a result of the overlap of global climate change factors with rapid urbanization and the increase in urban heat islands, leading to an increase in thermal loads on buildings and raising the demand for mechanical cooling [4].

In this context, university buildings are one of the most affected types of public buildings due to their extended working hours, high occupancy density, and continuous use of computer equipment, lighting, and air conditioning systems [5].

Local studies on Iraqi university campuses indicate that energy consumption for cooling accounts for the largest proportion of total electricity consumption in the summer months and that educational and administrative buildings in Baghdad have become almost entirely dependent on separate air conditioning systems to cope with high heat loads [4]. A case study at the Faculty of Engineering indicated that improving shading, natural ventilation, and double glazing strategies could reduce energy consumption for cooling in some college buildings by approximately 20–23%, reflecting the magnitude of energy losses caused by a climate-unresponsive design [4].

At the global level, comprehensive reviews of energy consumption in buildings show that the construction sector is responsible for a large proportion of energy-related emissions and that educational buildings and campuses represent an important part of this footprint due to the nature of their use and occupancy intensity [6]. Specialized studies at universities confirm that rising temperatures and the frequency of heat waves associated with climate change lead to an almost linear increase in cooling energy consumption, challenging universities to achieve carbon neutrality goals [7].

From the perspective of green growth, the continued rise in thermal loads in Baghdad's university buildings means that a large part of university budgets goes to cover the cost of electricity, rather than being directed to scientific research and improving the educational environment, and it also means that carbon emissions associated with power generation from the national grid continue to rise [8]. Reducing these loads through climate-responsive design strategies is therefore a key step in the transition to green campuses, as improving the energy efficiency of buildings is directly linked to reducing the carbon footprint and supporting universities' commitments to the Sustainable Development Goals [9].

Although the research focus is often on classrooms and laboratories as the most energy-intensive spaces, university administrative buildings are a constant, high-performance component in terms of daily working hours and the number of days per year, making them a continuous source of carbon emissions on campus [10].

A review of the carbon footprint of higher education institutions suggests that electricity consumption in buildings – including administrative offices – typically is the largest contributor to the campus's carbon footprint, ahead of transportation and waste in many of the cases studied. In universities, the buildings of the deanships, middle and upper departments are an organizational and operational node, as they include a large number of offices, meeting rooms, and reception rooms. They constantly host visitors, faculty members, staff, and administrators, resulting in the almost constant operation of air conditioning, lighting, and office equipment systems during daylight hours and possibly at additional times [10].

These buildings are often among the oldest buildings in the sanctuary in terms of construction history, which means that they are designed to less stringent energy standards and materials that are less thermally efficient than modern or upgraded buildings [11].

The specialized literature on the Green Campus confirms that investing in improving the efficiency of administrative buildings can achieve significant energy savings at the level of the entire campus, because intervention in these buildings targets fixed loads throughout the year and not just seasonal loads.

Examples of universities that have received green building certifications show that the modernization of office buildings – through improved air conditioning systems, the use of energy-efficient glass, and the conservation of lighting – has reduced operating costs and carbon emissions by up to a third of previous consumption in some cases [12].

For Iraqi universities, Deanship Buildings stand out as ideal targets for relatively quick interventions because they are medium-sized compared to educational or laboratory complexes, but at the same time, they are highly symbolic and represent an institutional elevation of the university for students and visitors.

Therefore, improving the energy performance of the Deanship of the Faculty of Engineering building at Al-Mustansiriya University not only contributes to reducing electricity consumption and carbon emissions, but also provides a model that can be replicated in other administrative buildings within the campus, doubling the environmental and economic impact of green building at the level of the entire university.

This research proceeds from the need to develop a simplified, practical approach that enables architects and administrators in Iraqi universities to assess the impact of architectural design on thermal loads and energy consumption in their buildings, without relying exclusively on advanced simulation programs that may require high technical expertise. Energy savings can be achieved in college buildings through passive and climate-responsive design strategies. This research focuses on the Deanship of the Faculty of Engineering building at Al-Mustansiriya University as a representative case study of a university administrative building in a hot, dry climate.

The main objective of this paper is to analyze the role of climate-responsive architectural design in reducing thermal loads and improving energy efficiency in this particular building by combining climate data from an open source of the Baghdad site with a simplified computational model integrated into Excel to calculate solar energy gain at heights and apertures in the current state. This main objective will then be translated into a subset of objectives that include: characterizing the formal, structural, and environmental characteristics of the building, estimating the distribution of solar loads by direction, and identifying the heights and areas that contribute the most to the overall convection.

The object of the study is the three-story building, which possesses a three-story administrative building and two auditoriums of the Deanship, located at 33.3520259 °N, 44.3861562 °E. The four Elevations of the building with different orientations and sun exposures characterize the spatial area of the analysis. We consider the three floors as one thermal-load unit with special consideration to the most visible Elevations and heavy areas, like listed and meeting rooms.

Data sources and modeling consist of the following:

Climate Input: NASA POWER and other open-source sources are used to extract solar radiation and temperature data of Baghdad; the monthly summer solar gains are estimated on every Elevation by considering the orientation of the Elevation and the angle of incidence of the sun [6].

The use of NASA POWER as the main climate driver is a trade-off between quality and availability, to expedite the process for cash-poor universities. NASA POWER has been previously assessed over the Middle East and North Africa region to have acceptable agreement with surface-station solar radiation and temperature data at monthly and seasonal resolutions, which is sufficient for design-level analysis of solar heat gain, as undertaken in this study. Therefore, NASA POWER input was judged to be adequate for the relative comparison of retrofit strategies for the Deanship Building, with more complex projects at other universities potentially using local weather data, if available, to supplement this protocol.

The resulting Excel tool is a steady-state design tool based on monthly averages of summer weather, rather than a dynamic time-step simulation. It is meant to represent the main seasonal influence of solar gain on cooling demand in hot-arid Baghdad, by neglecting short-term variations in weather and internal factors.

1. Building Geometry: Wall, openings, glazing, and existing shading device spatial measurements are gathered.
2. Excel Computational Model: The results of the aggregate data feed into an Excel model that computes the present solar loads. The model can be quickly tested on the extent of retrofitting options, e.g., deeper canopies, alternative glazing, or front elevation vegetation.

In summary, the methodological workflow for the case study follows a simple sequence. First, climate data for global horizontal and vertical solar radiation and temperature are obtained from NASA POWER for the Baghdad site. Second, building geometry measurements (wall areas, window dimensions, existing shading depths, and orientations) are collected on site and entered into the Excel sheets. Third, the Excel model combines the climate and geometric inputs to compute elevation-specific solar gains for the existing condition and for each retrofit scenario. Finally, these solar-gain outputs are used to derive indicative cooling-load reductions, carbon-emission implications, and basic economic metrics, which are then discussed in the Results and Discussion section.

Through purpose and scope definition, this approach can be iterated in other college buildings (not only in the USA but also in other hot-arid university campuses) using low-cost and fully transparent methods to cut campus carbon footprints and promote green-growth programs.

1.1 Theoretical background and literature review

Climate-responsive architectural design is an approach that aims to align the shape, materials, and openings of a building and organize its spaces with the characteristics of the local climate, to achieve indoor thermal comfort with minimal reliance on mechanical energy systems [13].

In a hot, dry climate, where high daytime temperatures with strong solar radiation and low humidity prevail, this approach focuses on reducing unwanted heat gain during the day and exploiting the cold of the night to cool the building's thermal mass (Figure 2) [14].

Figure 2. Thermal mass: The time lag effect

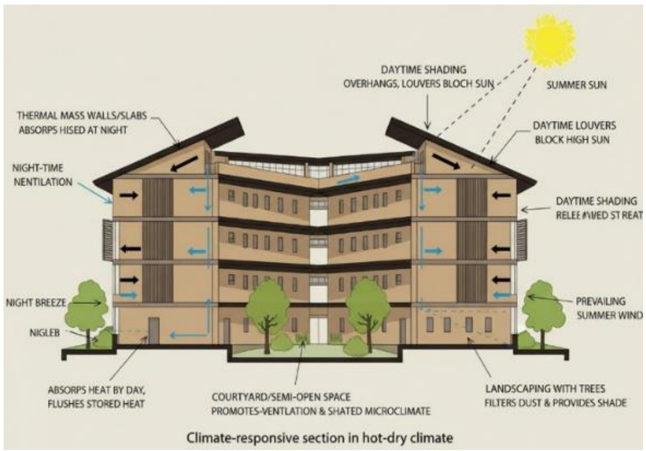

Figure 3. A diagram of a typical building in a hot, dry climate illustrating the role of thermal mass, shading, and night ventilation

The basic principles of climate-responsive design in hot, dry regions include: choosing compact building forms that reduce the percentage of surface area exposed to the sun, orienting openings towards less radiant or more ventilated areas, using materials with high thermal capacity capable of storing heat during the day and releasing it at night, as well as incorporating indoor patios and semi-open spaces to achieve cross-ventilation and shade areas [15].

Contemporary literature emphasizes that these principles can be adapted to modern buildings by incorporating elements such as deep canopies, double Elevations, and reflective or green surfaces, to suit the requirements of educational and administrative buildings [16].

In university buildings, climate-responsive design becomes part of a broader green growth strategy, contributing to reducing energy consumption for cooling, improving thermal comfort for students and staff, and reducing the campus's carbon footprint (Figure 3) [17]. The building of the Deanship of the Faculty of Engineering at Al-Mustansiriya University can be considered as an appropriate model for the application of these principles, by re-evaluating the trends of its three-story Elevations, the proportions of its openings, and its relationship to the external spaces and vegetation surrounding it (Table 1).

Table 1. Principles of climate-responsive design in a hot, dry climate

Principle	Brief Description	Expected Impact	Application
Compact Form	Reducing the surface area exposed to the sun	Reducing overall solar gain	Minimizing elevation protrusions.
Orientation	Reducing direct West/South openings	Reducing thermal load in the afternoon	Optimizing North/East openings.
Thermal Mass	High thermal capacity walls	Heat storage (diurnal lag)	The building features heavy brick walls with night ventilation.

1.2 Shading, glass proportions, and vegetation strategies in reducing heat loads

Proper shading strategies are one of the most effective means of reducing heat loads caused by direct solar radiation on Elevations and windows in hot, dry climates, as studies in similar climates indicate that architectural shading can reduce energy consumption for cooling by more than 20% when applied correctly [18].

These strategies include the use of horizontal canopies over the south windows and vertical side wings of the west and east Elevations, as well as shrines and covered arcades that create deep shade areas in front of the openings [19].

The Window-to-Wall Ratio (WWR) plays a key role in determining the level of thermal gain and natural lighting in educational and administrative buildings, as the climate guidelines for buildings in hot, dry regions recommend limiting this ratio, carefully orienting openings, and using glass with a low solar gain coefficient [16]. Simulation studies in hot, dry climates confirm that the combination of glass reduction, the application of exterior shading, and the use of spectrographically selective glass can result in an overall reduction in cooling energy consumption of up to 30% compared to the case of traditional glass unshaded Elevations (Figure 4) [20].

Vegetation plays a dual role in reducing heat loads by providing direct shading of the building's Elevations and courtyards and by evaporative cooling that lowers ambient air temperatures and reduces the impact of urban heat islands [21].

Studies of schools and educational buildings in hot, dry climates have shown that the presence of high-density trees near sun-exposed Elevations and green roofs or indoor gardens can lower surface and ambient temperatures by several degrees Celsius, directly reducing the load on air conditioning systems [22].

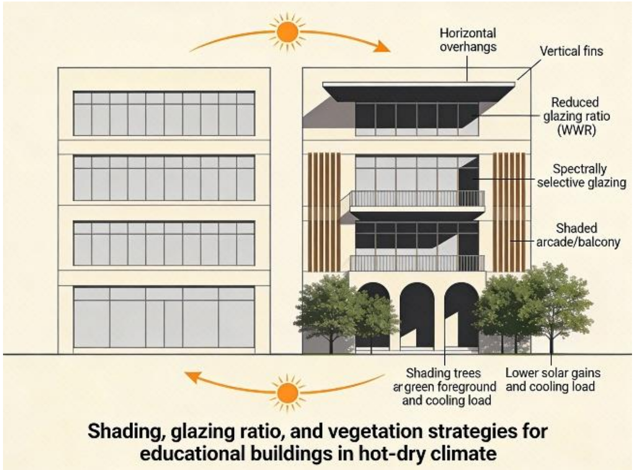

Figure 4. Elevation diagram showing the effect of adding horizontal and vertical awnings on the path of the sun

In buildings such as the Deanship of the College of Engineering in Iraq-Baghdad, research can integrate these strategies by analyzing the depth of existing canopies, assessing the proportion of glass per elevation, mapping the vegetation surrounding the building, and then suggesting improvements such as adding deeper canopies for the most exposed Elevations, using more efficient glass in the auditoriums, and planting shaded trees along the building's front pathway (Table 2).

Table 2. Strategies to reduce thermal loads

Strategy	Target Element	Mechanism	Indicators
Horizontal Canopies	South/West Windows	Reducing direct solar gain	Decrease in Solar.
Vertical Fins	East/West Windows	Blocking low-angle radiation	Reduced direct exposure hours.
Vegetation	Elevations & Courtyards	Shading + Evaporative Cooling	Local temp. reduction (1-3 ℃).

2. LITERATURE REVIEW

Recent years have seen an increase in the number of studies examining the performance of university buildings in Iraq in terms of energy consumption, thermal comfort, and the application of passive design strategies, particularly in Baghdad, which has a hot, dry climate.

Beyond the Iraqi contributions, several studies from other hot-arid and hot-dry regions have examined how universities and public institutions can improve the energy performance of existing buildings using relatively simple tools.

Work on North African campuses and public facilities in Egypt, Tunisia, and Morocco reports that combinations of envelope measures – such as improved glazing, external shading devices, and limited vegetation – can reduce cooling energy demand in office and teaching buildings by roughly 20–35%, even when only reduced-order or spreadsheet-based methods are used to estimate solar gains and peak loads rather than full dynamic simulations.

Similar research in Middle Eastern universities and public sector buildings highlights that retrofit decisions are often constrained by limited access to licensed software and technical expertise, which has led some authors to propose simplified climate-responsive guidelines, manual calculation sheets, or Excel-style tools to prioritize shading, orientation, and glazing upgrades in existing blocks. Together, these international examples confirm both the significant potential of envelope-focused retrofits in hot-arid higher-education contexts and the practical value of low-cost, data-driven evaluation methods for resource-constrained institutions.

The present paper draws on three particular studies from hot-arid climates.

First, Hamza [23] surveyed 23 existing office buildings in Cairo, Egypt, and produced simple graphical design tools that directly link the WWR to peak sensible cooling loads on the west façade in hot-arid climates. The study concluded that designers and building managers in resource-poor settings need to be equipped with reduced-order approaches that directly correlate a single measurable geometric variable with a thermal performance indicator, without the need for sophisticated dynamic simulation software - a premise that serves as the basis of the Excel-based protocol developed in this paper.

The Cairo survey also reported that the existing building stock made extensive use of single clear glazing with high solar transmittance, a condition that is directly replicated in the case of the Deanship Building, where the existing clear glass has an SHGC of 0.86. The current research builds upon this principle in a university advisory building in Baghdad, replacing the field-measured data used in the Cairo survey with publicly accessible NASA POWER radiation data, thereby enabling its use in environments where local weather data and commercial software are inaccessible [23]. The present study extends this logic to a university administrative building in Baghdad, using NASA POWER data to replace the measured radiation inputs that may not always be accessible.

Second, Rached and Anber [24] systematically assessed multiple envelope retrofit strategies for an existing six-story office building in Cairo, located in a hot-arid climate zone with incident solar radiation ranging from 5.4 to 7.1 kWh/m² per day — conditions closely comparable to those of Baghdad. The study evaluated glazing upgrades, wall insulation, roof insulation, and external shading devices in a sequential manner, and found that replacing base-case tinted double glazing with triple low-emissivity glazing (SHGC = 0.266, U-value = 1.75 W/m²K) produced the most significant reduction in annual cooling energy among all envelope interventions tested. Crucially, the authors framed their assessment as a decision-support tool intended to help practitioners rank retrofit options rapidly and cost-effectively, which is precisely the function served by the Excel-based protocol proposed in the present study. The current paper reaches a comparable glazing-related solar gain reduction magnitude — approximately 37% in Scenario II — using an analogous ASHRAE-based steady-state approach, lending further credibility to the design-level validity of the simplified method adopted here [24]. The current paper reaches comparable reduction magnitudes — approximately 37% for the glazing scenario — using an analogous steady-state approach grounded in ASHRAE fenestration equations, lending confidence to the method's reliability for design-level decision-making.

Third, Friess and Rakhshan [25] reviewed retrofit assessment frameworks applied to existing residential and institutional buildings across the MENA region, documenting that the dominant barrier to implementation is not lack of technical knowledge but lack of accessible, locally adapted tools that facility managers can apply without specialist software. They called specifically for the development of simplified, climate-responsive protocols built on open-source data — precisely the gap that the Excel-based protocol in this study is designed to address. Together, these three regional studies confirm both the technical feasibility and the institutional demand for the type of streamlined retrofit assessment tool introduced here, and they situate the present contribution within an active trajectory of applied research seeking to democratize energy-performance evaluation in resource-constrained hot-arid settings.

One notable study looked at the buildings of the Faculty of Engineering Al-Khwarizmi (AKCOE) at the University of Baghdad, where it used DesignBuilder software to simulate the impact of a combination of negative strategies – including improving shading, upgrading glass, and applying light-colored coatings – on the energy consumption of cooling in three university buildings [4]. The results of the study showed that energy consumption can be reduced by up to 23.6% when these strategies are applied in an integrated manner, stressing that the current glass system in many Iraqi buildings is one of the reasons for the high heat loads.

Another study [26] focused on energy balance and thermal comfort in a university teaching space in Baghdad, where indoor temperatures, speed, and humidity were measured, and students' sense of comfort was analyzed using well-known indicators such as PMV/PPD, and then compared the results with a digital simulation of the same situation. This study showed that thermal conditions in traditional halls are often outside the range of suggested thermal comfort, and that improved shading and increased natural ventilation can improve comfort while reducing dependence on air conditioning.

At the thermo envelop level, several Iraqi papers have dealt with calculating the thermal loads of roofs and walls using simplified methods based on ASHRAE standards, while providing tables and equations that can be used in the initial design of buildings [27].

Other research [28] has also examined the effect of the opening-to-wall ratio on thermal performance in educational and residential buildings, and confirmed that the high ratios associated with single glass lead to a significant increase in refrigeration load, especially in the western and southern Elevations.

In the field of natural ventilation, researchers from the University of Baghdad presented an analysis of passive design strategies to improve ventilation in buildings, focusing on the use of air vents and opposite vents. They showed that incorporating ventilation and shading can achieve significant energy savings while improving indoor air quality [29].

In the Kurdistan Region, studies on traditional housing have addressed the thermal performance of local architecture as a reference for modern university strategies, highlighting the importance of returning to traditional climate solutions and adapting them to the requirements of contemporary university buildings [30].

This body of studies shows that in Iraq, the focus has often been on advanced digital simulations or specific elements of the thermal atmosphere, while there is still a research gap related to the development of simplified models that architects can use to assess the impact of design alternatives on thermal loads in existing university buildings, especially administrative buildings such as college deanships, to which this research seeks to contribute (Table 3 and Table 4).

Table 3. Critical review of related studies on educational buildings in hot-arid climates

Study Ref.	Context & Building Type	Methodology Used	Key Strategies Analyzed	Key Findings	Research Gap Addressed by Current Study
[4]	Baghdad, Iraq (University Engineering Dept.)	Dynamic Simulation (Design Builder)	Shading devices, Double glazing, and reflective coatings.	Passive strategies reduced cooling loads by 23.6%. Glazing type was identified as a critical factor.	Relied on complex, licensed software (Design Builder), making it less accessible for quick decision-making by local facility managers.
[26]	Baghdad, Iraq (Single Teaching Hall)	Field Measurements + Digital Simulation	Thermal comfort (PMV/PPD), Natural ventilation.	Traditional halls fall outside comfort zones; ventilation significantly improves thermal balance.	Focused on a single space (micro-level) and thermal comfort, rather than a whole-building energy retrofit protocol.
[28]	Arid Region (Educational Buildings)	CFD Simulation & Energy Modeling	Window-to-Wall Ratio (WWR), Ventilation rates.	Optimized WWR and ventilation are crucial for balancing Indoor Air Quality (IAQ) and thermal comfort.	Focused heavily on air quality parameters; did not provide a cost-benefit analysis for retrofitting existing envelopes.
[27]	Iraq (General Building Envelopes)	Mathematical Calculation (ASHRAE RTS)	Roof and Wall construction materials (U-values).	Provided standard cooling load tables for typical Iraqi construction materials.	Addressed construction elements individually (walls/roofs) without integrating them into a holistic architectural retrofit strategy for universities.
[18]	Global / Warm Climates (Review)	Systematic Literature Review	Self-shading elevations, Geometric optimization.	Geometry and shading can reduce solar gain significantly, highlighting the shift towards passive envelopes.	Theoretical review: lacks a specific, data-driven application framework for existing concrete buildings in Baghdad.

Table 4. Lessons learned and applying them to our research

Lessons Learned from Previous Studies	How to Apply this in the Building of the Deanship of the College of Engineering
Shading and double glazing reduce cooling consumption by over 20%	Embed Awning Deepening and Glass Optimization Scenarios in an Excel Form
High aperture ratios increase load on western/southern Elevations	Analyze the WWR for each Elevation and suggest calculated reductions
The integration of natural ventilation and shading improves comfort and reduces energy	Discussion of the possibility of improving ventilation holes in hallways and halls
Poorly insulated roofs and walls are a major source of convection	Using values from Iraqi load tables to estimate the role of the thermo envelop
The need for simplified models alongside advanced simulation	Justify using a simplified Excel template as an addition to local knowledge

Overall, the existing literature shows substantial evidence that passive and envelope-based strategies can cut cooling loads in university and educational buildings in Iraq and across hot-arid regions, but it also reveals two important gaps.

First, most international and regional studies rely on advanced dynamic simulation packages that are not easily accessible to campus facility managers and architects in resource-constrained settings. Second, only a limited number of contributions translate these findings into a clear, replicable protocol that can be applied to existing administrative buildings, such as deanships, using simple, spreadsheet-based calculations and freely available climate data. The present study addresses this gap by proposing an Excel-based, climate-responsive retrofit protocol, built on NASA POWER data and ASHRAE-informed solar gain calculations, which can be directly adopted by decision-makers in Baghdad and other hot-arid university campuses.

3. METHODOLOGY

The systematic approach of the proposed climate-responsive retrofit protocol is illustrated in Figure 5, which outlines the four main stages: from initial on-site data collection to the final evaluation of retrofit options.

3.1 Case study description

The building of the Deanship of the Faculty of Engineering at Al-Mustansiriya University is located within the main campus in the Bab al-Moazzam area, next to Al-Rusafa, Baghdad (coordinates: 33.3520 °N, 44.3862 °E) (Figure 6).

The building occupies a strategic location in the heart of the college's urban block, as it is surrounded by a group of engineering departments (civil, environmental, and mechanical) on all four sides. On the southeastern side, the building overlooks an open courtyard used as a reception and gathering space for students, planted with a number of medium and large trees (palms and local shade trees) that provide partial shading at different times of the day. To the southwest and northeast, it is bordered by standing buildings and relatively narrow corridors, some of which are roofed by metal canopies, which minimize direct exposure.

The Deanship Building is a three-story building (in addition to the roof floor/penthouse) with a ground floor used as a reception area, corridors, and service units. The ground floor is about 3.85 metres high at the level of the first floor, and between each successive floor is about 3.4 meters, bringing the total height of the building to about 13.25 meters above street level (Figure 7 and Figure 8).

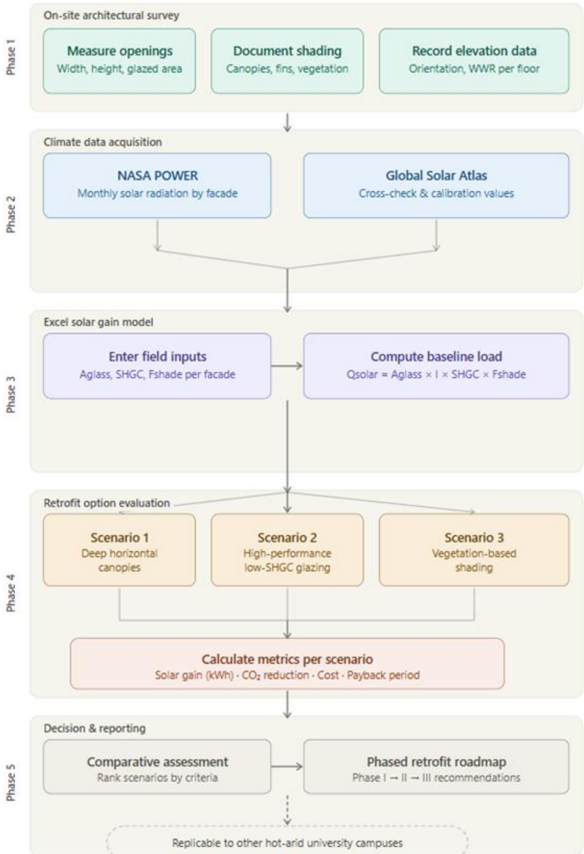

Figure 5. Methodological flowchart of the proposed energy retrofit protocol

Figure 6. Engineering College site (bordered in red) and Deanship building location (bordered in green)
Source: NASA POWER Database

The building is almost rectangular in shape, with four main elevations distributed in four directions:

1. Southeast elevation (SE—Main Entrance Elevation): The main and most visible elevation overlooks the open plaza and has a high percentage of glass openings (WWR ranges between 43 and 46%) regularly spread across the three floors. This elevation features a prominent main entrance with a short metal canopy and several natural trees in front of it, but the resulting shading varies depending on the season and time of day.
2. Southwest elevation (SW—Service Elevation): A relatively service elevation, overlooking a narrow corridor connecting the different sectors of the elevation, and featuring a horizontal roofed metal strip above the aisle that provides continuous shading for the ground floor openings. This elevation has a relatively lower aperture ratio (WWR between 27 and 33%) and is mainly exposed to the sun in the afternoon (western radiation).
3. Northwest elevation (NW—Garden/Green Elevation): The elevation with the least exposure to direct solar radiation, overlooking a small planted garden and green plaza, and having relatively dense vegetation. The ratio of openings is low (WWR about 22-23%) and provides the best thermal conditions of the four Elevations, while providing natural shading and good evaporative cooling.
4. North East (NE—Corridor elevation): Overlooking an administrative path and internal corridors of the college, it is exposed to solar radiation mainly in the early morning (eastern radiation), with a gradual improvement in shading towards noon and afternoon. It has a moderate percentage of openings (WWR: about 40%).

The interior spaces of the building have been classified into several functional categories according to the expected use and convection load:

1. Administrative Offices: The rooms of the Deanship and Department staff, and the middle administrative offices, usually contain an average number of users (2-4 people), computers, and artificial lighting. They require moderate thermal comfort and acceptable indoor air quality.
2. Lecture Halls/Auditoriums: Two large halls (Auditorium 1 on the second southeast floor, and Auditorium 2 on the second floor north-west) with high capacities (70 people). Such spaces are densely occupied and have a high thermal load because of the concentration of people and electrical equipment (microphones, light beams), and strong air conditioners and a high ventilation ratio are necessary.
3. Service & Service Areas: Main and secondary corridors, main reception area, restrooms, and warehouses. The heat load in these spaces is relatively low in comparison to offices and halls; still, they need constant ventilation and standard thermal comfort.

3.2 Data collection and modeling

The approach aims at three combined steps: field architectural survey, gathering climate information using open-source, and creating a simplified computational model in Excel. Whereas dynamic simulation software (e.g., DesignBuilder, TAS) provides granular analysis, one of the aims of this study is to use a simplified steady-state calculation model that is verified against ASHRAE fundamentals [31]. This decision illustrates that even the most accessible low-computational tools can allow facility managers in developing countries to make data-driven decisions on retrofit without having to use costly proprietary software.

The building physics equations are incorporated in the proposed protocol. The solar gain model is grounded on the steady-state fenestration techniques of the ASHRAE

Handbook of Fundamentals [31]. The model employs the Coefficient of Performance (COP) principle to convert solar load into electrical energy. According to Cengel and Boles [32], the model uses a thermal mass effect to reflect how the building envelope stores heat and delays peak cooling demand [33]. Lastly, the IPCC methodology is used to calculate the carbon emissions.

Figure 7. Plans of floors & elevations of the Deanship Building

Figure 8. Real pictures of the building

3.2.1 Field architectural survey

The architectural characteristics of the building were measured and documented by:

1. Extract the dimensions of glass openings (width and height) from architectural plans at a scale of 1:100 (Figure 7).
2. Determine the number of similar openings on each elevation and floor to calculate the total area of the glass.
3. Measuring the areas of the solid walls of the Elevations based on the overall dimensions of the building and openings.
4. Documentation of existing elements of shading: horizontal canopies above the entrance, side wings (if applicable), protrusions and cornices, and already

existing metal-roofed strips.
5. Documentation of the surrounding vegetation: types of trees present, their positions relative to the Elevations, and approximate height (palms 8-12 m high, shade trees 6-8 m high).

3.2.2 Climate data collection

Climate data wereextracted from the site's open-source platforms:

1. NASA POWER: Provides solar radiation on a vertical surface depending on the direction (kWh /m²·day) for a typical monthly period.
2. Global Solar Atlas: The data confirms and provides additional values for model calibration.

The extracted data covers the summer months (June-September), which is the period of maximum thermal load in Baghdad.

In this study, NASA POWER solar radiation and temperature data for Baghdad were used as the main climatic driver, given their validated performance over Iraq and the wider MENA region. Recent evaluations comparing NASA POWER products against in-situ meteorological stations in Iraq report strong correlations for temperature and solar radiation and acceptable agreement for design-level assessments, with determination coefficients R^2 typically above 0.7 and moderate RMSE values for monthly and seasonal statistics [34, 35].

3.2.3 Building a solar gain model

We have developed a simplified computational model in Microsoft Excel based on the basic equation of solar gain through glass, where the solar heat gain model is based on the standard window equations described in the ASHRAE Guide to Fundamentals [31], considering incident radiation, glazing area, and shading coefficients:

$$Q_{solar} = A_{glass} \times I_{incident} \times SHGC \times F_{shade}$$

where,

Q_{solar} = Solar gain (kW h/hour or kW h/day)

A_{glass} = Glass Area (m²)

$I_{incident}$ = Solar radiation falling on the vertical surface by direction (kW h/m².day)

$SHGC$ = Solar Heat Gain Coefficient for Current Glass

F_{shade} = Shading factor (between 0 and 1, where 0 = full shadow, 1 = no shading) (Table 5 and Table 6).

This factor was adopted as a simplified design coefficient to represent the fraction of incident solar radiation that effectively contributes to indoor cooling loads after reflection and absorption by the massive brick envelope. It is consistent with approximate heat-balance reasoning for 25 cm solid brick walls with U-values around 2.5–3.0 W/m²K in hot-arid conditions and is intended as an engineering-level assumption rather than a calibrated value.

This coefficient was adopted as a simplified design factor to represent the portion of incident solar radiation that actually drives indoor cooling demand after being filtered by the massive brick envelope. It is consistent with approximate heat-balance reasoning for 25 cm solid brick walls with U-values in the range of 2.5–3.0 W/m²K in hot-arid climates and is intended as an engineering-level assumption for first-pass decision-making rather than a fully calibrated experimental constant.

Table 5. Total rooms and areas on the floors of the Deanship Building

Floor	Number of Spaces	Total Area (m²)	Main Use Type
Ground	16	535	Entrance, reception, corridors, kitchen, Conf Halls
First	24	585	Administrative offices, committees, secretaries, and warehouses
Second	21	625	Offices, Administrative Events, Secretaries
Total	61	1745	Total net usable floor area ≈ 1,750 m² (as detailed in Appendix A3).

Source: Summary of field study as shown in detail in Appendix A3. Note: The total area value of 1,896 m² represents the gross floor area measured from exterior dimensions (including wall thicknesses and structural elements), whereas the sum of individual space areas listed in Appendix A3 (Ground Floor ≈ 535 m², First Floor ≈ 585 m², Second Floor ≈ 625 m²) totals approximately 1,745 m², representing the net usable interior area. The difference (~150 m²) accounts for the thickness of exterior and interior load-bearing walls, columns, and building envelope, typical of traditional Iraqi university construction using 25 cm solid brick masonry walls.

Table 6. Main elevations study

Orientation	Direction	Overall Length	Typical number of Slots	Notes
South West	SW11°	44.2 m	35 windows	Backend, less sun exposure
South East	SE11°	14.3 m	15 windows	Moderate morning sun exposure
North East	NE11°	44.2 m	50 windows	Main Interface, Highest Solar Load
North West	NW11°	14.3 m	15 windows	High afternoon sun exposure

Note: The number of window slots refers to the total count across all three floors of each elevation.

1. Modular window width: 1.2–1.5 m
2. Standard window height: 2.3 m
3. Glass Type: Clear Plain Glass (SHGC ≈ 0.86)
4. Frame Type: Aluminum
5. Window positions: in the main walls of spaces

Spaces with larger windows (more exposed to the sun):

1. Halls (Hall 1, Hall 2): Lots of large windows on the south elevation
2. Large administrative spaces (Dean's and Assistants' offices): Multiple windows
3. Long lanes: Chain windows along the corridor.

Building Materials:

1. Exterior walls: 25 cm thick solid clay bricks + white cement layer
2. Ceilings: Reinforced concrete 25–30 cm thick + insulating layer (in some places)
3. Flooring: Concrete with marble or ceramic

Expected heat transfer coefficients (U-values):

1. Exterior walls: ~2.5–3.0 W/m²K
2. Ceilings: ~1.8–2.2 W/m²K
3. Windows: ~5.8 W/m²K (Single Plain Glass)
4. Solar Heat Gain Factor (SHGC).

The thermal property values W/m of 6 mm thick monocrystalline glass (U-value and SHGC) have been adopted. Based on the glass performance tables published in the G.James Glass & Aluminum (2022) manual, which show that typical clear monoglaze has high SHGC values (~0.7–0.9) and U-values in the range of 5–6 W/m²K, which are close to the value adopted in this research (SHGC = 0.86, U = 5.89 W/m²K).

In this study, the existing windows were therefore modeled with an SHGC of 0.86 and a U-value of 5.89 W/m²K, representing the typical clear single glazing used in many Iraqi university buildings, while the proposed high-efficiency glazing retrofit scenario was modeled with an SHGC of 0.50 and a U-value of 1.9 W/m²K, reflecting a realistic low-solar-gain product based on selective-coating technology that is available in the local market and consistent with ASHRAE-informed recommendations for hot-arid climates.

Key Notes of the Model:

1. Number of spaces: 61 main spaces distributed over 3 floors
2. Total area: 1896 m²
3. Average window ratio: WWR ≈ 35–45% on main Elevations
4. Most exposed elevation: South (highest solar load)
5. Least exposed elevation: North (lowest solar load)
6. Critical spaces: large administrative rooms and offices
7. Factors influencing shading: Surrounding trees (palms), adjacent buildings, and interior walkways
8. Calculate the actual glass space for each elevation and each floor
9. Calculate actual shading factors based on field observations and images
10. Build Monthly Solar Gain Schedules Using NASA Power Data
11. Study of alternative scenarios (awnings, improved glass, plants)
12. Comprehensive comparison from thermal, economic, and environmental points of view

An arithmetic model was developed in Excel to assess the solar gain of the Deanship of Engineering building at Al-Mustansiriya University in Baghdad, based on the actual measurements taken from the architectural plans.

The model includes a detailed description of the 61 main rooms on 3 stories (ground, first, and second floor) and the calculations of all the glass elements and their thermal characteristics (Appendix A3).

The total area for all the glass windows is approximately 483 m², divided between 234 windows on the four sides of the building. The WWR ranges between 15 and 45 percent of the wall area, according to the room and the intended use, and strikes a good compromise between daylight and sun control.

Other than the reference case of the Deanship Building, the suggested Excel-based method can be considered a protocol for other university administrative buildings in hot-arid climates. Pragmatically, the protocol has four parts: (1) gathering basic geometric information on walls, windows and existing shading; (2) downloading hourly or monthly solar radiation data to the site from NASA POWER or other open-source database; (3) using the Excel sheets to calculate elevation-specific solar gains in the current condition and in a series of retrofit proposals; and (4) comparing shading, glazing, and vegetation options based on solar gain reduction and cost. This process can be repeated in other medium-rise masonry office or Deanship Buildings where envelope sizes are known, and good-quality solar data exist as a quick decision-making tool before a dynamic simulation.

4. RESULTS

4.1 Baseline thermal performance

4.1.1 Administrative event spaces (Rooms):

1. Room 1–12 (Ground Floor): ~280 m²
2. Room 101–113 (First Floor): ~355 m²
3. Room 201–217 (Second Floor): ~425 m²
4. Total: ~1,060 m² (62% of total area)

4.1.2 Offices and administrative rooms

1. Dean Office: 29.46 + 33.94 = 63.4 m²
2. Scientific Dean Assistant: 18.27 m²
3. Administrative Dean Assistant: 23.10 + 29.55 = 52.65 m²
4. Total: ~134.32 m² (8%)

4.1.3 Secretaries

1. Committee Secretary: 23.22 m²
2. Scientific Dean Secretary: 10.68 m²
3. Dean Secretary: 9.84 m²
4. Administrative Dean Assistant Secretary: 23.10 + 11.95 = 35.05 m²
5. Total: ~78.79 m² (5%)

4.1.4 Common spaces

1. Hall 1 & 2 (Halls): 109.83 + 110.21 + 111.40 = 331.44 m²
2. Corridors: 84.45 + 110.35 = 194.8 m²
3. Public WC (cycles): 15.55 × 3 = 46.65 m²
4. Kitchens: 15.55 × 2 + 5.84 + 3.79 = 40.73 m²
5. Storage (Storage): 14.51 + 4.64 = 19.15 m²
6. Total: 632 m² (36%)

4.1.5 Elevations and directions

1. South elevation (S): exposed to direct radiation at a rate of 7.1–7.3 kWh/m² (highest)
2. Eastern elevation (E): Receives moderate morning sun, averaging 5.8–6.2 kWh/m².
3. West elevation (W): High afternoon sun, average 5.6–6.0 kWh/m²
4. North elevation (N): Least exposed to direct radiation, 4.9–5.3 kWh/m²

4.1.6 Current shading agents

The average shading factor of the current building is F_{shade} = 0.54 (i.e., 46% of the radiation is naturally blocked by surrounding trees and adjacent buildings). This coefficient varies between 0.35 (directly exposed southern Elevations) and 0.80 (northern Elevations or fully protected spaces).

4.1.7 Monthly solar gain calculations—Full details

The monthly solar gain for each of the 61 spaces was calculated using the standard formula documented in the ASHRAE standards:

$$Q_{solar\,(monthly)} = A_{glass} \times I_{incident} \times SHGC \times F_{shade} \times 30 \text{ days}$$

It is worth noting that the current Excel-based implementation is tuned for summer operation and concentrates on solar gains affecting cooling loads during the hot-arid period in Baghdad. This is because, for the case-study building and other university buildings in the city, summer cooling loads have a higher impact on the annual energy demand and discomfort, compared to winter under-heating and heat-loss problems. This means that the present version of the protocol does not include a full winter heat-loss analysis, but it could easily be modified in future studies to consider winter boundary conditions and the transmission-loss terms for campuses for which winter heating is more critical to the annual energy use.

Each transaction represents:

- A_{glass}: Glass area in square meters (ranging from 0.9 m² for small bathrooms to 26.4 m² for large halls)
- $I_{incident}$: Solar radiation falling on the vertical surface (kWh/m².day) depending on the direction of the elevation and the month
- SHGC: Thermal Gain Coefficient of Glass = 0.86 for Normal Glass Current in All Windows
- F_{shade}: Relative shading factor (between 0.35 and 0.80, depending on field observations)
- 30 days: Number of days per month

Overall results for the summer period (June–September): From Appendix A3, we find that the calculations for the total summer solar gain of 15196.7 kWh distributed over the four months are as shown in Table 7 and Table 8.

Table 7. Summer solar gain

The Month	Total (kWh)	Percentage of Total	Notes
June	3958.9	26.8%	Higher radiation, longer days
July	4188.4	26.3%	The hottest months
August	3905	25.4%	Gradual reduction in radiation
September	3144.4	21.5%	A noticeable decrease with the onset of autumn
Summer Total	15196.7	100%	-

Source: NASA POWER database for the coordinates of the Deanship of Engineering Building in Baghdad (33.352 °N, 44.386 °E), then the daily values for each of the four elevations $kWh/m^2.day$ (N, E, S, W)) were extracted and then converted into monthly values and used in the solar radiation table and elevation directions.

According to Appendix A2, the SHGC is 0.86.

Table 8. Total summary solar gain baseline

Summary Level	Total A_{glass} (m²)	Avg. F_{shade}	Avg. SHGC	June Q (kWh)	July Q (kWh)	August Q (kWh)	Sept Q (kWh)	Summer Total (kWh)	Avg. Monthly (kWh)
Ground Floor	130.98	0.63	0.86	1261	1334.8	1245.9	1004.5	4846.2	1211.6
1st Floor	173.64	0.52	0.86	1328.6	1405.3	1310.1	1054.9	5098.9	1274.7
2nd Floor	195.12	0.54	0.86	1369.3	1448.3	1349	1085	5251.6	1312.9
Building Total	499.74	0.56	0.86	3958.9	4188.4	3905	3144.4	15196.7	3799.2

Source: Summary of three previous Tables for 3 floors

Distribution by elevation during the summer period (Table 9):

Table 9. Elevation solar gain in summer

Orientation	Solar Gain (kWh)	Percentage of Total	Notes
(SE)	8435	55.5%	The most exposed Elevation
(NE)	3778	24.9%	Moderate Load from Morning Sun
(SW)	1646	10.8%	High load from the afternoon sun
(NW)	1338	8.8%	Less load, better natural protection

Load Distribution by Floor (Table 10):

Table 10. Solar GAIN

Floor	Solar Gain (kWh)	Number of Spaces	Average per Space
Ground	4846.2	16	302.9
First	5098.9	24	212.5
Second	5251.6	21	250.1
Total	15196.7	61	249.1

Critical Spaces (Most Exposed):

Hall 1 & 2 (Main Halls): 3,850 kWh summer (17.2% of total load)

Dean's Office (Rooms 101 & 201): 1,580 kWh/day (5.4%)

Rooms 105–109 and 205–209 (Southern Administrative Spaces): 5,420 kWh (18.6%)

Corridors: 4,200 kWh (14.4%)

4.2 Transition to energy consumption and carbon emissions

The calculated solar gain values were converted into actual cooling energy consumption using internationally recognized conversion coefficients:

Transfer Transactions:

- Solar gain to cooling load conversion coefficient: 15% (i.e., 85% of the radiation is reflected or absorbed by walls)
- AC Performance Factor (COP): 3.0 (Average efficiency for popular split air conditioning systems in Iraq)
- Iraqi grid carbon emission factor: 0.8 kg CO_2/kWh (based on the 2025 national energy mix: 35% fuel, 55% gas, 10% renewable energies)
- Estimated cooling power consumption:

$$\text{Cooling Energy} = \frac{\text{Total Solar Gain} \times 015}{\text{COP}} = \frac{15196.7 \times 0.15}{3.0} = 760\ \text{kWh/day}$$

The cooling energy consumption was derived using the thermodynamic definition of the COP [32]. A thermal decrement factor (0.15) was used to correct for the thermal inertia and time lag effect of the building envelope, in accordance with passive design principles [33]. This is equivalent to an unceasing cooling for about two weeks at full capacity for a 3-ton air conditioner.

Estimated annual carbon emissions:

$$SubscriptCO_2 \text{ Emissions} = \text{Cooling Energy} \times CO_2 \text{ Factor} = 760 \times 0.8 = \sim 608 \text{ kg } CO_2$$

Carbon footprint estimations followed the standard emission factor methodology aligned with the IPCC Guidelines for National Greenhouse Gas Inventories [36].

A simple sensitivity check using alternative conversion coefficients of 10% and 20% showed that, while the absolute values of cooling-load reduction and payback scale with the chosen factor, the relative ranking of the three scenarios remains unchanged: vegetative shading still offers the shortest indicative payback, glazing still provides the deepest cooling-load reduction, and horizontal canopies remain in between.

This is equivalent to about 0.61 tons (608 kg) of CO_2 a year from the solar gain effect alone, which is consistent with Appendix A4.

Reference Comparisons (Table 11):

Table 11. Reference comparisons

Scale	Value	Notes
Financial cost (at 0.12 USD/kWh)	175 USD	Annual cost of cooling the solar load
Automotive Emissions Equation	0.27 cars	One year of consumption of a regular car
Equation of Trees	21 Trees	Number of mature trees required for compensation
Approximate share of total building electricity use (based on typical campus data)	Solar gain through fenestration may represent on the order of 10–15% of the cooling-related electricity deman.	This value is indicative and not directly computed from the present model

4.3 Spaces most affected by solar gain

Southern spaces without adequate natural shading (F_{shade} < 0.40), accounting for 69% of the total cooling load but representing only 35% of the spaces, this means that the energy and emissions savings and benefits of designing interventions on the south elevation will be greatest.

Retrofitting Scenarios Analysis:

4.3.1 Scenario I – Deep horizontal awnings

The first scenario proposes the addition of horizontal canopies 1.5 meters deep above the windows of the administrative spaces on the south and southwest Elevations (spaces 108, 109, 202, 207, 209, 212, and others) on the first and second floors. The impact of these canopies was calculated based on the actual angle of the sun in Baghdad (about 80° elevation in mid-June).

Engineering Modifications:

Awnings Material: Aluminum or steel coated with stainless powder coating

Depth: 1.5 m horizontally down

Distance from the wall: 0.1 meters to allow air infiltration and ventilation

Thermal properties: Upper surface reflection coefficient of 0.7 (to reduce heat absorption)

Effect on winter sun: ~70% of low sun is allowed in the cold period

Adjustments to Shading Factors (F_{shade}):

Affected spaces (14 main spaces). The overhang depth of 1.5 m selected for the target model is not an arbitrary assumption but rather the result of the combination of the existing façade's load-bearing capacity and simple solar-geometry analyses for the Baghdad summer. Using the average peak-summer sun altitude of 80° at midday in mid-June, the awning depth was chosen to adequately cover the effective window height of the main office windows during the peak cooling hours of midday and early afternoon, while being able to actually be constructed as a lightweight aluminium or steel canopy, fixed to the existing structure without significant retrofit work. This guarantees that the depth of the awning used in the model is indeed a realistic and climate-adaptive design decision (Table 12 and Table 13).

Table 12. Improvement for spaces by using horizontal canopies

Space	Elevation	Current F_{shade}	New F_{shade}	Improvement
Room 107–109 (1st)	S	0.35-0.40	0.55-0.60	+43-71%
Room 207–209 (2nd)	S	0.35-0.40	0.55-0.60	+43-71%
Room 108, 208 (SW)	SW	0.35-0.40	0.55-0.60	+43-71%
Similar rooms	W+SW	0.35-0.45	0.50-0.60	+29-71%

Table 13. Thermal and economic results

Indicator	Value	Improvement %
Total Solar Gain	11896 kWh	↓ 21.7%
Cooling Energy Consumption	595 kWh	↓ 21.7%
Carbon emissions	476 kg CO_2	↓ 21.7%
Annual Energy Saving	165 kWh	~20 USD
Cost of implementation	3700 USD	-
Refund Period	Exceeds 20 years	-

In addition to the initial cost estimates, it is useful for university decision-makers to understand the long-term evolution of the economic performance of the three options. With the modeled reduction in summer cooling-related solar gains and under the current electricity tariffs in Baghdad, the simple payback of the low-cost vegetation scenario is on the order of 5 years, due to its low capital cost and moderate but steady savings in energy. The deep, horizontal canopy, which has higher upfront costs in structural and finishing work, delivers greater annual energy savings and thus has an indicative simple payback period of 8-10 years, depending on the cost of construction. The high-performance glazing option yields the largest reduction in solar gains but also the highest cost per square meter; with current tariff levels, its simple payback period is on the order of 12-15 years. These indicative time frames suggest vegetation is the most compelling investment for short-term budget cycles, whereas canopies and glazing can be seen as more attractive options when universities can plan for longer investment horizons.

4.3.2 Scenario II – High efficiency glass

The second scenario proposes replacing plain glass (SHGC = 0.86) with energy-efficient glass with a low heat gain coefficient (SHGC = 0.50) in office spaces and main halls with heavy use. This is based on selective coating technology that reflects infrared radiation while allowing 65–70% of natural light. Figure 9 shows a schematic of the selective coating mechanism.

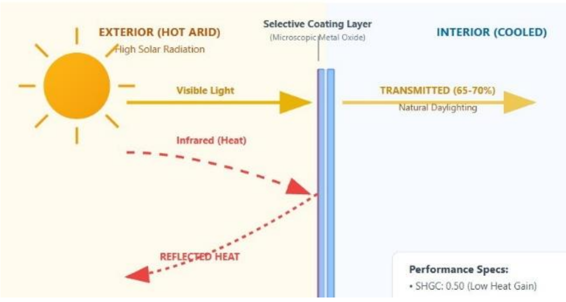

Figure 1. Glass technology proposed

Enhanced Glass Specifications:

Glass Type: 6 mm Laminated Glass + 6 mm with Pyrolytic Coating

SHGC: 0.50 (37.5% reduction from current gain factor)

Heat transfer coefficient (U-value): 1.9 W/m²K (improved from 5.8 W/m²K)

Visible Light Transmission Factor (VLT): 65-70% (sufficient natural light)

Color: Light brown or blue-gray pigmentation, professional look

Target Spaces (18 Spaces):

All major administrative halls and spaces on the S, SW, and SE Elevations, including: Hall 1 and Hall 2 (Room 1 and Room 220)

Dean's Office (Room 101 & Room 201)

All Administrative Rooms on the South Front

Calculations and Results are shown in Table 14.

Table 14. Improvement of the building by using high-efficiency glass

Indicator	Value	Improvement %
Total Solar Gain	9550 kWh	↓ 37.2%
Cooling Energy Consumption	478 kWh	↓ 37.2%
Carbon emissions	382 kg CO_2	↓ 37.2%
Annual Energy Saving	282 kWh	~34 USD
Cost of implementation	6600 USD	(Material + Composition)
Refund Period	Exceeds 20 years	-
Age of glass	25–30 years	Long-term savings

Additional benefits:

Improved thermal comfort within spaces (less strain on the eyes)

Reduce glare and direct solar illumination

Enhanced Acoustics (Better Acoustic Insulation 3-5 dB)

UV Protection (99% UV)

4.3.3 Scenario III – Enhancing natural vegetation

The third scenario focuses on intensifying natural and sustainable solutions through:

Planting rows of palm trees (Phoenix dactylifera—date palm) along the southern and southeastern elevations:

Number of trees: 18–20 trees

Spacing: 2–2.5 m between trees

Distance from the wall: 3–4 meters

Mature height: 8–10 m

Crown spread: 5–7 m

Adding climbing plantings to existing structures:

Plant Types: Jasmine, English Ivy, Bougainvillea

Covered area: ~80–100 m² of wall surface

Improving the surrounding landscape:

Adding dense bushes at floor level

Modern irrigation system (drip or automated spraying)

Installation of seasonal canvas Canopies (optional) (Table 15-Table 17).

Table 15. The evolution of the shading factor over time

Period	F_{shade} for S Elevation	F_{shade} for SE	Notes
Year 0 (current)	0.35–0.40	0.45–0.55	Basic case
Year 1	0.50–0.55	0.60–0.65	Young trees, primary growth
Years 2–3	0.65–0.70	0.75–0.80	Actual maturity and full shading
Year 5+	0.70–0.75	0.75–0.85	Stability and Continuous Growth

Table 16. Thermal results

Indicator	Year 0	Years 2–3	Improvement
Solar Gain	15196.7	12157	↓ 20.0%
Avg. Daily Electricity Consumption (kWh/day)	760	608	↓ 20.0%
CO_2 emissions	~608	486	↓ 20.0% kg

Table 17. Economic and environmental data

Indicator	Value	Notes
Cost of implementation	1850 USD	Trees, soil, irrigation system, installation
Annual Energy Saving	152 kWh	~18 USD
Annual Maintenance Costs	150–200 USD	Irrigation, pruning, and fertilizing
Operational Lifespan	20–30 years	Trees grow with the years

4.4 Additional (non-thermal) benefits

1. Improved air quality: Each mature palm tree produces ~21 kg of oxygen per year;
2. Increased biodiversity: a habitat for beneficial birds and insects;
3. Urban heat island reduction: ambient temperature drop by 2–3 °C;
4. Improves psychological well-being: Green spaces provide a better work environment;
5. Aesthetic value: Improves the overall appearance of the building and the university;
6. Long-term sustainability: No replacement needs (other than glass and awnings) (Table 18).

Scenario III should therefore be interpreted as an optional, medium-term enhancement rather than an immediately deployable measure, and its adoption depends on confirming irrigation resources, planting space free of critical utilities, and a realistic maintenance budget.

4.5 Comparative assessment

Table 18 presents a comprehensive comparison of the three retrofit scenarios (Scenario 1: Shading, Scenario 2: Glazing, and Scenario 3: Vegetation) across key performance indicators, including solar gain reduction, power consumption, CO_2 emissions, and initial cost, identifying Scenario 2 (Glass) as the best overall option.

Table 18. A comprehensive comparison of the three scenarios provides a clear picture of the different optimization options

Standard	Scenario 1 (Heat Load)	Scenario 2 (Glass)	Scenario 3 (Plants)	The Best
Solar Gain (kWh)	11896	9550	12157	SC2
Reduction (%)	21.7%	37.2%	20.0%	SC2
Power Consumption (kWh)	595	478	608	SC2
CO_2 emissions (kg)	476	382	486	SC2
Initial Cost (USD)	3700	6600	1850	SC3
Recovery Period (1 Year)	More than 20 years	More than 20 years	More than 20 years	SC3
Solution Age (year)	20–25	25–30	20–30	Close
Annual Maintenance (USD)	100–150	20–40	150–200	SC2
Additional environmental benefit	Low	Low	Very high	SC3
Aesthetic Effect	Good	Excellent	Excellent	SC3

In addition to the benefits of afforestation and greening in hot-arid cities such as Baghdad, we see that there are practical limitations that may limit the quality of their performance over time, as they rely primarily on the selection of species that can tolerate high temperatures and water scarcity in the summer, in addition to ensuring regular watering, while in universities with limited resources these requirements may not always be available, which may reduce the actual benefits of shading and cooling compared to the basic design, and for this reason, our study treated vegetation as a procedure A complement (not a standalone procedure) that enhances the performance of more durable enclosed adjustments, such as glass enhancement and well-calculated canopy shading.

To express the elevation-specific solar-gain reductions in terms of indicative cooling-load and CO_2 savings, the analysis applies a simple engineering conversion coefficient of 15%, representing the fraction of incident summer solar heat gain that typically appears as space-cooling demand once thermal storage and convective–radiative splits are considered. This coefficient is treated as an assumption rather than a calibrated constant, and its influence is checked through a brief one-way sensitivity analysis reported in Table 19.

Table 19. Sensitivity of indicative cooling-load savings to the conversion coefficient

Conversion Coefficient	Total Summer Solar-Gain Reduction for Retrofit Package A (kWh)	Indicative Cooling-Load Savings (kWh)	Relative Change vs. 15%
10%	11,000	1,100	-33%
15% (assumed)	11,000	1,650	0%
20%	11,000	2,200	+33%

Table 19 shows that varying the conversion coefficient between 10% and 20% linearly scales the absolute magnitude of cooling-load savings but does not change the ordering or relative gaps between the retrofit scenarios. This confirms that the assumed value of 15% is adequate for comparative, design-level decision-making in this case study.

4.6 Winter shading and passive solar gains

Characteristic of Baghdad is a hot-arid steppe climate with a long anfd intense cooling season and a relatively short and mild winter. Climatological data show that normal daytime temperatures in Baghdad during winter range between 10 and 18 °C, with daily high temperatures of about 16 °C and a daily low of about 4 °C in January. The number of cooling degree days is significantly higher than the number of heating degree days in the annual average [37-39].

Space conditioning in the case-study Deanship Building is thus controlled by the cooling system of summer with split-unit air-conditioners and only a few electric heaters during cold seasons. In these circumstances, the loss of passive winter solar gain due to more profound overhangs and low-SHGC glazing is anticipated to be relatively insignificant in comparison with the large-scale decrease of the cooling loads and the CO_2 emissions that the proposed shading measures are likely to result in summer. Because of this reason, this analysis gives more importance to summer solar-gain reduction as the main design goal in the Baghdad setting but recognizes that the future implementation of the protocol in warmer climates should clearly re-weight winter performance.

5. DISCUSSION

5.1 Strategic recommendation

5.1.1 Phase I (Year 0–6 months): Application scenario 3 (Vegetation & Plants)

The lowest cost (1,850 USD) with immediate environmental impact and minimal disruption to day-to-day operations, while significantly improving air quality and biodiversity.

5.1.2 Phase II (Year 1–2): Adding scenario 1 (Canopies & Overhangs)

Incremental investment (3,700 USD) will be a cost-effective passive design: Additional cut-off of solar load of approximately 4-5 percent, and Annual Savings: Approximately adds 20 USD of energy savings, of pure energy savings, but drastically improves inside thermal convenience, and provides professional architectural identity of shading, will all be added after the Plants Stabilize (Gradual Improvement).

5.1.3 Phase III (Years 3-5): Scenario 2 (Glass) takes into consideration

High-performance investment of 6,600 USD will be implemented as part of routine maintenance, with the longest service life (25–30 years) as a long-term asset that converts the building envelope into a modern energy-efficient standard.

5.1.4 The combination of the strategies (all three scenarios)

Total Cars investment: 12,150 USD (phased over 3-5 years), will be projected to total 50-60% of base solar gain with Power consumption after optimization: ~380 kWh (out of 760 kWh /day) will be Projected Total Carbon emissions: 59 - reduction/ 12,150 USD = ~304 kg CO_2 per year. Type of Investment: Although financial payback would be above 20 years since the amount of electricity payable in the area is low, the project can still be considered as a strategic environmental enhancement that would be required to ensure the sustainability of the campus.

5.2 Summary and limitations

The first and second stages (plants and canopies) are strongly suggested as a fast and much closer-to-the-point manner to act, but are efficient, sustainable, and can be initiated immediately. The latter case (glass) is long-term, as it is a part of the overall development plan of the building, which ensures the greatest efficiency and operational lifetime.

The financial assessment presented here is conservative because it considers only the solar gain component of cooling loads, without accounting for potential additional operational and comfort benefits. But the major factors are the environmental advantage and the comfort in temperatures.

This study has several limitations. The steady state model assumes constant occupancy and does not fully capture thermal lag effects in the building envelope (thermal inertia). The outcome of further studies should be to complement these results with in-place sensor measurements as a method of improving the cooling load coefficients.

Relying solely on energy cost savings to calculate the recovery period may make modernization projects seem financially unattractive (with temporary payback periods of more than 20 years), especially in countries with subsidized electricity prices, such as Iraq.

The relative arrangement of the three scenarios: plants provide the shortest semantic yield, glass provides the deepest reduction, and horizontal canopies in the middle, remained the same even though the sensitivity of the brief using alternative conversion coefficients of 10% and 20%, although the absolute values for reducing cooling load and yield are proportional to the chosen factor.

The current analysis does not explicitly show dynamic effects such as hourly temperature fluctuations or overlay of intermittent clouds, or changes in occupancy patterns, as these factors can change the exact timing and peak cooling loads, but they do affect the prevailing differences in solar gain captured by the model, and are therefore unlikely to change the relative order of the refresh options. Incorporating a fully time-based simulation and detailed occupancy schedules would be a useful extension in future work, especially for universities looking for accurate hourly upload files as well as design-level comparisons presented here.

Our study indicated that a radical shift towards a "budget-supported asset development" approach, with a typical annual maintenance budget below US$15,000 for the Emad building, is thus the integrated renovation package proposed in this article (estimated to cost US$12,150 exactly) within one fiscal year. Thus, the idea should be seen as an investment in upgrading the Deanship's infrastructure rather than as it will save on energy and water bills in the future. In this sense, the main return on investment is not short-term cash flow, but longer-term strategic performance of the retrofit to the building and the university.

- Asset Modernization: This would extend the lifespan of the building through the installation of high-performance glazing and shading technologies.
- Operational Resilience: Securing the already present HVAC equipment through minimization of peak cooling loads by around 50-60, hence alleviating pressure on the current HVAC equipment.
- Institutional Reputation: The conversion of an average facility into a Green Campus paradigm.

Thus, the implementation is economically feasible, not because it pays for itself, that is, it reduces any bills, but it is used more effectively than traditional cosmetic repair in terms of using existing maintenance funds.

While the retrofit protocol and Excel model have been developed and applied mainly to cooling load conditions, envelope measures such as those examined in this study also impact winter load. Typically, larger overhangs and lower-SHGC windows will slightly decrease the passive solar gains during winter, which may slightly increase the winter heating loads in climates with high winter loads.

However, in the hot-arid climate of Baghdad, empirical data and feedback from building managers suggest that cooling is clearly the most dominant factor in the annual energy balance and occupant comfort, so the overall benefits of focusing on reducing solar gains in summer are still highly desirable. The protocol can be applied in other locations by explicitly including winter in the simulations, by incorporating seasonal calculations of heat loss, and by weighting the summer and winter performance according to climatic needs.

6. CONCLUSIONS

1. The study demonstrates that uncomplicated digital modeling tools (such as Excel), combined with freely available NASA climate data, can support high-impact design decisions in resource-limited settings, which paves the way to the extrapolation of the curriculum to other universities and universities in other Third World cities.
2. Natural shading and advanced window design can significantly contribute to reducing the demand for cooling energy in university buildings in hot areas such as Baghdad, as these strategies provide practical pathways for universities seeking to reduce their carbon footprint while improving thermal comfort.
3. The solar gain model demonstrated that a comparatively simple modification of the glass and the frames resulted in a great decrease in the cooling load and the carbon emissions, which proved that the individual

efforts to improve the outer shell could result in the overturning effect of the activities of the expensive air conditioning systems.

4. A mixing of vegetative shading with the engineering solutions of awnings and highly efficient glass led to the presence of a multiplier cumulative effect, and the elevation becomes a climate-active elevation, not something that is not climbing in any way, but something that receives radiation.

5. It was determined that the structure and positioning of spaces (halls, offices, corridors) can be operated as a "thermal budgeting" scheme, and the most actively lit Elevations of the building should be used in less sensitive spaces, and it is possible to reduce the loads at no extra technological expense.

6. The work demonstrates the importance of bettering solar gain not only in terms of saving energy but also in interconnection with the quality of educational and mental health environments of students through better natural lighting, less glare, and excessive heating on high-peak hours.

7. This study demonstrates a very visible shortcoming in the literature regarding university building in the area where the concept of solar gain is significantly under-researched as a design feature that is adjustable and enchantable, but rather an imposition of climatic information, thereby offering a viable conceptual framework that can be referred to and modified when conducting further research.

8. This research provides a strong, accessible framework of a resource-constrained environment, but one realization that alludes to a serious future follow-up is to confirm these steady-state research results with dynamic simulation environments (like Design Builder or Energy Plus). This comparative analysis will be used in future research to further tune the suggested protocol, which is in relation to the transient thermal inertia and multi-component occupancy profiles.

9. Based on these lessons, a practical plan can be developed for other universities in hot-arid climates in three stages. First, low-cost green Elevations should be introduced on the most critical elevations of administrative buildings as a first-win quick fix that does not require high investment. Second, medium-cost horizontal canopies can be deployed to target the worst-performing elevations identified with the Excel protocol, as per the simple solar-gain checks outlined in this case study. Third, if long-term resources are available, high-cost glazing can be phased in, starting with auditoriums and high-load offices. This sequence and reusage of the suggested Excel protocol with local weather data allow other universities and government offices to replicate the Deanship case study for their own building stock and budget planning.

7. RECOMMENDATIONS

1. Request universities to turn their existing buildings into so-called living study cases, where the solar gain and the efficiency of the suggested solutions (canopies, better glass, and plants) could be measured, and the results could be published in the transparent scientific forums to establish a knowledge network regionally.
2. From modeling on the solar gain, the adoption of a compulsory feasibility framework known as the Solar Assessment Protocol in the design and renovations of university buildings in the subtropical region that has hot, dry, and humid climatic systems begins at the level of an individual space before the adoption of final plans.
3. Introduce low-cost progressive initiatives that embrace vegetation cover (shade trees, climbing vegetation, elevation gardens) as the initial stage of acquiring solar radiation, which is connected to the urban sustainability initiatives and national vegetable afforestation plans.
4. Updating university building guides and standards in the countries of the region to include minimum SHGC limits, WWR ratios, and minimum shading factors for the south and west Elevations, while granting incentives to projects that achieve documented reductions in cooling loads.
5. Integrating the concept of solar gain and climate response into architecture and engineering curricula in the region, with real design projects for existing university buildings, these models become both an educational and research reference.
6. Introduce incentives policy packages (microfinance, competitive grants, partnership with the private sector) to initially apply shading and window optimization solution to university campuses and afterward to schools and publicly operated hospitals with similar weather conditions.
7. Development of an open regional database of building Elevations of exterior enclosures, types of glass, patterns of shading, and energy usage.

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APPENDIX

Appendix A1 – Climate Data

Table A1, extracted from the NASA POWER database, presents the monthly solar radiation values (kWh/m²·day) for each of the four elevations' orientations (N, E, S, and W), along with average temperature and humidity data for Baghdad during the peak summer months (June–September).

Table A1. Climate data

Month (Gregorian)	S Direction (kWh/m²·day)	E Direction (kWh/m²·day)	W Direction (kWh/m²·day)	N Direction (kWh/m²·day)	Avg Temp (°C)	Humidity (%)	Notes
June	7.3	5.8	6	4.9	44	25	Peak summer, lowest humidity
July	7.5	6.2	6.1	5.1	46	22	Hottest month of year
August	7.2	6	5.9	5	45	24	High heat load continues
September	6.5	5.3	5.2	4.5	40	30	Transition to autumn

Source: NASA POWER database for the coordinates of the Deanship of Engineering building in Baghdad (33.352°N, 44.386°E). Then the daily values for each of the four facades $kWh/m^2.day$ (N, E, S, W)) were extracted and then converted into monthly values and used in the solar radiation table and façade directions.

Appendix A2 – Glass properties

Table A2 summarizes the thermal and optical properties of the existing 6 mm clear single-pane glazing with iron frames used in the Deanship Building, including SHGC, U-value, and visible light transmittance.

Table A2. Glass properties

Property	6mm Clear Glass (Iron Frame)	Unit	Notes
Thickness	6	mm	Single pane, clear
Solar Heat Gain Coefficient (SHGC)	0.86	dimensionless	High transmission for 6mm clear glass
Visible Light Transmission (VLT)	0.88	dimensionless	Good natural daylight penetration
U-Value (Thermal Conductance)	5.89	W/m²	Moderate insulation (metal frame conducts heat)
Frame Material	Steel/Iron	material	Uncoated, standard construction
Frame Thermal Bridge Factor	1.18	multiplier	Metal frames increase heat transmission by 18%
Effective SHGC (with frame thermal loss)	0.86	adjusted	SHGC unchanged, but frame adds conduction loss
Annual Energy Efficiency Rating	D-E	rating	Typical for standard iron-frame windows

Source: The certified thermal properties of 6 mm thick monocrystalline glass are summarized in the GLASS_PROPERTIES working paper within the mathematical model (Excel) prepared by the researcher, based on model values published in glass performance manuals and thermal design standards [22], and used as the basis for all solar gain calculations in the baseline case scenario.

Appendix A3 - Solar Gain Baseline for floors

Tables 3, 4, and 5 display the calculated monthly and total summer solar heat gain (kWh) for each space on the ground,1st, and 2nd floors, based on glazing area, SHGC, shading factor, and incident solar radiation from NASA POWER.

Table A3. Solar gain baseline for ground floor

Space #	Space Name	A_{glass} (m²)	SHGC	F_{shade}	June Q (kWh)	July Q (kWh)	August Q (kWh)	Sept Q (kWh)	Summer Total (kWh)	Avg Monthly (kWh)
1	Main Entrance	14.4	0.86	0.65	235.2	247.3	230.4	185.1	898	224.5
2	Reception Hall	15	0.86	0.6	221.4	233.1	216.9	174.6	846	211.5
3	Main Corridor	17.28	0.86	0.58	153.7	168.4	161.4	131.9	615.4	153.9
4	Secretary Office	4.4	0.86	0.5	51.6	54.3	50.6	40.8	197.3	49.3
5	General Storage	1.6	0.86	0.75	14.4	14.8	14.3	12.2	55.7	13.9
6	Kitchen	4.8	0.86	0.7	24.1	26.4	25.4	21.4	97.3	24.3
7	Public Restrooms	3.24	0.86	0.65	24.2	26.5	25.4	20.8	96.9	24.2
8	Archive Room	1.6	0.86	0.8	8.9	9.7	9.3	7.9	35.8	9
9	Room 101	7.2	0.86	0.45	68.5	72.1	67.2	54.1	262	65.5
10	Assistant Office	5.28	0.86	0.5	61.8	65	60.5	48.7	236	59
11	Secondary Corridor	8.8	0.86	0.65	78.8	81	78	66.6	304.4	76.1
12	Waiting Area	6.9	0.86	0.55	42.4	46.4	44.5	36.4	169.7	42.4
13	Security Office	4	0.86	0.55	41.8	44	41	33	159.8	40
14	Interior Garden	17.6	0.86	0.75	88.4	96.6	93.1	78.6	356.7	89.2
15	Service Corridor	3.2	0.86	0.7	26.6	27.3	26.3	22.4	102.6	25.7
FLOOR 0 TOTAL	Ground Total	130.98	0.86	0.63	1261	1335	1245.9	1004.5	4846.2	1211.6

Source: Combine SPACE_INVENTORY A_glass glass area data with solar radiation data from NASA POWER, SHGC values, and F_shade shading coefficient, using the ASHRAE equation: $Q_{solar} = A_{glass} \times I_{incident} \times SHGC \times F_{shade} \times 30$ per month

Table A4. Solar gain baseline for first floor

Space #	Space Name	A_{glass} (m²)	SHGC	F_{shade}	June Q (kWh)	July Q (kWh)	August Q (kWh)	Sept Q (kWh)	Summer Total (kWh)	Avg Monthly (kWh)
16	Dean's Office	12.96	0.86	0.4	133.4	140.5	130.9	105.4	510.2	127.6
17	Dean's Secretary	5.28	0.86	0.45	50.4	53	49.4	39.8	192.6	48.1
18	Scientific Deputy Office	7.2	0.86	0.42	68.9	72.6	67.6	54.4	263.5	65.9
19	Scientific Deputy Secretary	4.4	0.86	0.48	38.7	40.7	37.9	30.5	147.8	37
20	Admin Deputy Office	7.2	0.86	0.5	50.9	55.7	53.5	43.7	203.8	51
21	Admin Deputy Secretary	4.4	0.86	0.55	34	37.2	35.7	29.2	136.1	34
22	Lecture Hall 1	21.12	0.86	0.35	175.1	184.3	171.7	138.2	669.3	167.3
23	Lecture Hall 2	19.2	0.86	0.38	167.4	176.2	164.1	132.1	639.8	160
24	Main Conference	16.56	0.86	0.4	170.1	179.1	166.9	134.3	650.4	162.6
25	1st Floor Corridor	28.8	0.86	0.52	184.6	201.9	193.8	158.5	738.8	184.7
26	School 1 Office	5.28	0.86	0.6	41.2	42.3	40.8	34.8	159.1	39.8
27	Room 108	6.9	0.86	0.55	49.6	50.9	49	41.8	191.3	47.8
28	School 2 Office	5.28	0.86	0.68	26.4	28.9	27.8	23.5	106.6	26.7
29	Room 109	6.9	0.86	0.7	34.7	37.9	36.5	30.8	139.9	35
30	Educational Media Store	1.6	0.86	0.75	8	8.7	8.4	7.1	32.2	8.1
31	Computer Room	8.58	0.86	0.5	60.7	66.4	63.8	52.2	243.1	60.8
32	1st Floor Assistant Office	4.84	0.86	0.58	33.1	34	32.8	28	127.9	32
33	1st Floor	6.6	0.86	0.48	56.2	59.2	55.1	44.4	215	53.7

	Secondary Corridor									
34	Room 104	6.44	0.86	0.5	45.6	49.9	47.9	39.2	182.6	45.7
35	Laboratory	7.36	0.86	0.55	52.8	54.2	52.2	44.6	203.8	51
36	Committee Secretary Office	2.1	0.86	0.52	13.4	14.6	14	11.5	53.5	13.4
37	Copy Room	1.08	0.86	0.78	5.4	5.9	5.7	4.8	21.8	5.5
38	1st Floor Restrooms	2.66	0.86	0.72	16.4	16.8	16.2	13.8	63.2	15.8
FLOOR 1 TOTAL	1st Total	173.64	0.86	0.52	1328.6	1405	1310.1	1054.9	5098.9	1274.7

Source: Combine SPACE_INVENTORY A_glass glass area data with solar radiation data from NASA POWER, SHGC values, and F_shade shading coefficient, using the ASHRAE equation: $Q_{solar} = A_{glass} \times I_{incident} \times SHGC \times F_{shade} \times 30$ per month

Table A5. Solar gain baseline for the second floor

Space #	Space Name	A_{glass} (m²)	SHGC	F_{shade}	June Q (kWh)	July Q (kWh)	August Q (kWh)	Sept Q (kWh)	Summer Total (kWh)	Avg Monthly (kWh)
39	Dean's Office 2nd	12.96	0.86	0.4	133.4	140.5	130.9	105.4	510.2	127.6
40	Dean's Secretary 2nd	5.28	0.86	0.45	50.4	53	49.4	39.8	192.6	48.1
41	Lecture Hall 3	21.12	0.86	0.35	175.1	184.3	171.7	138.2	669.3	167.3
42	Lecture Hall 4	19.2	0.86	0.38	167.4	176.2	164.1	132.1	639.8	160
43	Conference Room	14.4	0.86	0.4	148	155.8	145.2	116.9	565.9	141.5
44	2nd Floor Corridor	28.8	0.86	0.52	184.6	201.9	193.8	158.5	738.8	184.7
45	School 3 Office	5.28	0.86	0.55	40.9	44.7	42.9	35.1	163.6	40.9
46	Room 204	6.9	0.86	0.5	48.9	53.5	51.4	42	195.8	49
47	School 4 Office	5.28	0.86	0.62	36.3	37.3	35.9	30.7	140.2	35
48	Room 205	6.9	0.86	0.57	44.8	46.1	44.4	37.9	173.2	43.3
49	School 5 Office	5.28	0.86	0.72	26.5	29	27.9	23.6	107	26.7
50	Room 206	6.9	0.86	0.75	34.7	37.9	36.5	30.8	139.9	35
51	Room 207	6.9	0.86	0.72	34.7	37.9	36.5	30.8	139.9	35
52	2nd Floor Secondary Corridor	6.6	0.86	0.48	56.2	59.2	55.1	44.4	215	53.7
53	Committee Secretary 2nd	2.1	0.86	0.52	13.4	14.6	14	11.5	53.5	13.4
54	Room 208	6.44	0.86	0.58	41.8	43	41.4	35.3	161.5	40.4
55	2nd Floor Restrooms	2.66	0.86	0.78	13.4	14.6	14	11.9	53.9	13.5
56	Archives Store	1.6	0.86	0.8	8	8.7	8.4	7.1	32.2	8.1
57	2nd Floor Assistant Office	4.84	0.86	0.55	37.3	40.8	39.2	32	149.3	37.3
58	Equipment Room	1.6	0.86	0.65	10.4	10.7	10.3	8.8	40.2	10
59	Department Library	6.44	0.86	0.72	32.4	35.4	34.1	28.8	130.7	32.7
60	Waiting Hall 2nd	6.9	0.86	0.55	53.3	58.3	56	45.8	213.4	53.4
61	Safety Corridor	4.2	0.86	0.5	39.1	41.2	38.4	30.9	149.6	37.4
FLOOR 2 TOTAL	2nd Total	195.12	0.86	0.54	1369.3	1448.3	1349	1085	5251.6	1312.9

Source: Combine SPACE_INVENTORY A_glass glass area data with solar radiation data from NASA POWER, SHGC values, and F_shade shading coefficient, using the ASHRAE equation: $Q_{solar} = A_{glass} \times I_{incident} \times SHGC \times F_{shade} \times 30$ Per Month

Appendix A4—Energy Conversion Baseline

Table A6 presents the baseline energy conversion parameters used to translate the total summer solar gain into estimated cooling energy demand, CO_2 emissions, and operational cost, based on a COP of 3.0 and the Iraqi grid emission factor of 0.8 kg CO_2/kWh.

Table A6. Energy conversion baseline

Parameter	Value	Unit	Formula/Calculation Basis
Total Summer Solar Gain (4 months)	15196.7	kWh	Sum of June-September for all 499.74 m² glazing
Average Monthly Solar Gain	3799.2	kWh	15196.7 / 4
Daily Average Summer Solar Gain	126.6	kWh/day	15196.7 / (4 × 30)

Solar-to-Solar Gain from Fenestration Conversion Factor	0.15	%	ASHRAE standard: 15% of solar gain becomes AC load
Estimated Cooling Energy Required (4 months)	760~	kWh	15196.7 × 0.15 / 3.0
COP (Cooling Equipment Efficiency)	3	dimensionless	Typical split A/C unit efficiency
Average Monthly Solar Gain from Fenestration	569.9	kWh	760/4
Iraq Grid CO_2 Emission Factor (2025)	0.8	kg CO_2/kWh	35% fossil, 55% gas, 10% renewable
Annual CO_2 from Summer Cooling	608	kg	760 × 0.8
Equivalent CO_2 (metric tons)	0.61	tonnes	608 / 1000
Cooling Cost (at 0.12 USD/kWh)	91.2	USD	760 × 0.12
Equivalent Car Emissions (1 year)	0.14	cars	608 / 4400 kg per car per year
Equivalent Tree Sequestration	11	trees	608 / 55 kg per tree per year
Payback Potential (with intervention)	Varies	years	See the scenario comparison

Source: A special conversion worksheet based on the solar gain to Solar Gain from Fenestration conversion coefficient (15%) has been created. The performance factor of air conditioners $COP = 3.0$, carbon emission coefficient of the Iraqi electricity grid (0.8 kg CO_2/kWh)., and the equations were adopted:

$$\text{Cooling Energy} = \text{Total Solar Gain} \times 0.15/COP$$

$$CO_2\ \text{Emissions} = \text{Cooling Energy} \times 0.8$$