

Harnessing artificial intelligence for sustainable office building design in Baghdad: A comparative analysis of traditional vs generative environmental approaches

Osamah A. Al-Tameemi

Assistant Professor, Department of Architecture Engineering, University of Baghdad, Baghdad, Iraq.

E-mail: osamah.al-tameemi@coeng.uobaghdad.edu.iq

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sustainable office buildings..

Abstract—Hot-arid regions such as Baghdad have building typologies with high knowledge to the combination of mechanical cooling systems as well as low dependency on the environment. This study aims at countering such energy consumption in office buildings with the use of generative design AI tools. A comparative energy model was implemented and run between a standard design model (A) and a model optimized with AIs (B) through Galapagos, Ladybug, Honeybee and EnergyPlus modules in Rhino-Grasshopper. The models were assessed based on the same criteria, such as Energy Use Intensity (EUI), thermal comfort (PMV), ventilation (ACH), and solar radiation. The findings are that Model B has realized an energy saving of 25.9 %, a 177 percent better ventilation efficiency and acceptable comfort level. The findings underscore the worth of incorporating AI and generative design earlier on in the architect.

I. INTRODUCTION

In the current architectural discourse, these growing environmental demands and the increased concern about energy consumption have led to a worldwide shift in the architectural focus to performance based design approaches. A good example of this need is Iraq, and Baghdad in particular: the intense summer months (high mean conditions are well above 47C) in Baghdad makes traditional practice inadequate to optimize energy efficiency or occupant comfort. Office buildings, which are characterised by long working hours and high occupancy rates during the day, are some of the most energy-consuming building forms in the nation (Al-Saadi, 2018).

However, most of the Iraqi architecture firms hold on to the formalistic and static approaches to architecture, where they do not consider climatic information as well as critical evaluation of environmental performance. Computational

design, combined with Artificial Intelligence (AI) technologies, however, will provide a stated revolutionary opportunity of enhancing building performance. Galapagos, Ladybug, and Honeybee tools, which are embedded in parametric environments (e.g., Grasshopper), allow emulating, testing, and refining design options by climatic-conditioning.

The current study aims to determine how AI-enabled generative design can be used to improve the environmental performance of office buildings in Baghdad. The case study model contrasts the two approaches to design: traditional and AI-optimized with the help of authentic climate data and advanced environmental design tools.

II. RESEARCH PROBLEM

In the built environment of Baghdad, there are less than one percent of any office buildings that have been envisioned utilizing systematic facts of environmental analyses or designed based on information driven approaches. Unsurprisingly, the truth is one of the factors behind poor performance, high reliance on air conditioning and, consequentially, adverse occupant comfort. Notably, a lack of systematic sense of integration between architectural form, orientation, thermal zoning, and response to climate patterns takes place within current design practice (Al-Anbari, 2022).

III. RESEARCH OBJECTIVES

1. To simulate and compare the environmental performance of a traditionally designed and AI-optimized office building in Baghdad.
2. To assess improvements in thermal comfort, ventilation, and energy efficiency through generative design tools.
3. To propose a replicable design approach for energy-conscious architecture in hot-arid climates.

IV. HYPOTHESES

- **H1:** AI-based generative design significantly reduces building energy consumption.
- **H2:** Thermal comfort and ventilation improve when environmental data are incorporated into design optimization.
- **H3:** These improvements are achievable without increasing material or construction costs.

V. LITERATURE REVIEW

5.1 The Rise of AI in Architecture

The use of Artificial Intelligence in architectural practice is now a feature in the twenty-first-century design. Previously restricted to automatic drafting and structural analysis AI now covers generative design, machine learning and evolutionary algorithms that revolutionizes the design process itself. AI has taken on a key role in modern architecture by helping architects to generate form and execute heat-sensitive and climatic-sensitive requirements in real-time simulation and optimization (Evins, 2013), (Nguyen Reiter, S., & Rigo, P., 2014). The AI forms a normal part of the science and is used to generate as well as to test large volumes of potential designs in an attempt to meet the environmental goals of efficiency. An example is the Galapagos genetic-algorithm

plugin to Grasshopper, which enables optimization based on specific targets, including reduction of solar gain, reduction of cooling loads or increase of daylighting efficiency. These tools grant architects the tools to operate beyond intuitive decision-making, and the ability to use evidence-based research procedures in their efforts to achieve sustainable design solutions.

5.2 Generative Design Tools: Concepts and Applications

Generative design is a paradigm in parametric modelling that integrates geometric entities through distributed inputs and performance-based restrictions. The approach is based on evolutionary computing, and thus, it uses iterative creation, critiquing, and selection of the variations of the form based on the pre-established fitness specifications (Goulart Neto, A., & Lamberts, R., 2019).

Architectural tools like Grasshopper (a visual programming language within the Rhinoceros 3D program) allow the interpolation of such algorithms into general design processes. Galapagos also enables users to formulate a defined performance goal, e.g. minimising exposure to solar; machine iterates to generate a set of geometrical solutions that home on the performance goal. Such new forms are evaluated stringently by way of environmental measurements through sources that include Ladybug and Honeybee (Tuhus-Dubrow & Krarti, M., 2010). Previous literature indicates that there is an observed improvement in energy performance with accompaniments: Asadi (2012) (Asadi da Silva, M. G., Antunes, C. H., & Dias, L., 2012) identified that through Genetic Algorithms the early-stage design phase reduced building energy demand by approximately 30 % when compared to the initial design; Caldas (2002) (Caldas & Norford, L. K., 2002) used a hybrid evolutionary technique, resulting in optimisation of thermal performance in complex design buildings. The sum of these empirical results supports the viability of generative design approaches in the highly thermally aggressive environments such as Baghdad.

5.3 Environmental Simulation Tools

Simulation tools are critical for evaluating and validating the performance of building designs. Among the most recognized are:

- **EnergyPlus:** A dynamic simulation engine capable of hourly performance evaluation, HVAC modeling, and detailed envelope analysis (DOE, 2022).
- **Ladybug Tools:** A suite of visual plugins that provide climate analysis, sun path, radiation maps, and energy balance simulations. (Tools, 2023).

- **Honeybee:** Interfaces with EnergyPlus and Radiance to analyze thermal comfort, daylight levels, and cooling demands.

Reinhart (2016) emphasize the importance of combining simulation and generative design to produce performance-driven architecture. When these tools are used in tandem, as in this study, the design process becomes iterative, informed, and measurable. (Reinhart & Davila, C. C., 2016).

5.4 Office Building Performance in Hot-Arid Climates

The nature of office buildings as working spaces is to be in operation during the highest thermal loads and have high internal heat loads due to lighting, equipment, and occupancy density. In arid-hot climate like that of Baghdad, the result of this phenomenon is an exaggerated dependence on mechanical cooling systems. However, empirical studies have proved that the passive design intervention, such as optimized orientation, window-wall ratios, and shading mechanisms, and thermal zoning can significantly mitigate these energy burdens.

Al-Saadi (2018) (Al-Saadi, 2018) established that inadequate envelope design of Iraqi office buildings is one of the reasons why the buildings consume up to 45-percent of the cooling energy demand annually. Al-Attar & Al-Dulaimi (2015). further found that west-facing facades in Baghdad are the most irradiated by the sun on peak hours thus directly affecting cooling loads. (Al-Attar A., 2015)

Similar climatic conditions in the comparative regions like Saudi Arabia and Jordan have enabled effective implementation of AI-aided design methods. For example, Ghosh et al. (2019) used parametric instruments in Riyadh with a 22% decrease in peak energy loads. This local triumph highlights the future benefits of copying such tools in Iraq. (Ghosh Vale, B., & Vale, R., 2019)

5.5 Limitations of Conventional Design Practice in Iraq

The major drawback to sustainable building design in Iraq is the ongoing application of the intuition-based approach in designing without the systematic examination of the environment. Simulation models are often not used to support architectural decisions, such as the location of windows, the orientation of the building, the type of shading device, etc., hence resulting in the creation of inefficient buildings that heavily depend on the HVAC systems, and thus increasing energy consumption and operation costs (Al-Anbari, 2022).

Another problem is the lack of access to, or knowledge of, higher-level design tools. Local specialists might lack the knowledge or skills needed to use AI-based tools because of the lack of exposure to education and insufficient support on the institutional level.

5.6 AI Integration in Global and Regional Case Studies

Design tools by AI have already proven to be effective on the global level. In a study by Wang & Zmeureanu (2019) (Wang & Zmeureanu, R., 2019), it was found that generative design strategies were able to lead to a 28% decrease in the operational carbon emission of Canadian office buildings. In the Middle East, Malkawi et al. (2017) (Malkawi Srinivasan, R., & Yan, D., 2017) used optimization methods in passive cooling methods in Qatar and achieved thermal comfort without the use of active methods. These case studies show that the optimization of location-specific design through AI can provide strong environmental benefits. In this regard, although the weather is harsh, Baghdad can significantly benefit in case it implements similar measures.

VI. METHODOLOGY

6.1 Research Approach

The study will be quantitative and simulation-based in format as it will compare environmental performance of office buildings designed using two different methods: the standard model based on the current design practice in Baghdad and the generative model optimized by means of AI tools. The main idea here is to make a simulation of both models to replicate the conditions under the same climatic and operational condition to measure the impact of AI-integrated design on energy consumption, thermal comfort, solar gain, and natural ventilation.

The method is divided into three phases:

1. **Model Creation** – Two 3D models were developed in Rhinoceros 3D:
 - Model A: Traditional office building design. **Fig. 1**
 - Model B: AI-optimized design based on performance goals. **Fig. 2**

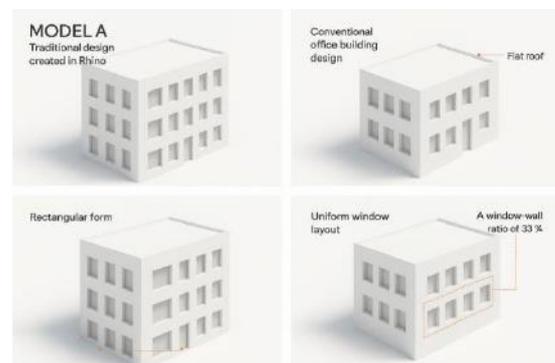


Fig. 1 Traditional office building design. Source: author



Fig. 2 AI-optimized design based on performance goals. Source: author (with AI tools)

2. **Simulation and Optimization** – Both models were analyzed using parametric plugins:
 - **Ladybug**: to evaluate sun path, radiation, and weather.
 - **Honeybee + EnergyPlus**: for thermal comfort, cooling loads, and energy consumption.
 - **Galapagos**: used only for Model B to optimize geometry and performance.
3. **Data Collection and Comparison** – Key performance indicators (KPIs) were extracted and compared across both models to determine relative improvement. (Attia, 2012) **Fig.3**

Table 1. Office Building Specification. Source: author

Parameter	Value
Number of floors	3
Total floor area	1200 m ²
Floor-to-ceiling height	3.5 m
Orientation (Model A)	West-facing façade
Glazing ratio (Model A)	55% (unshaded)
HVAC system	Central air-conditioning
Wall construction	Concrete with internal insulation
Operation hours	Weekdays, 8:00 AM – 4:00 PM

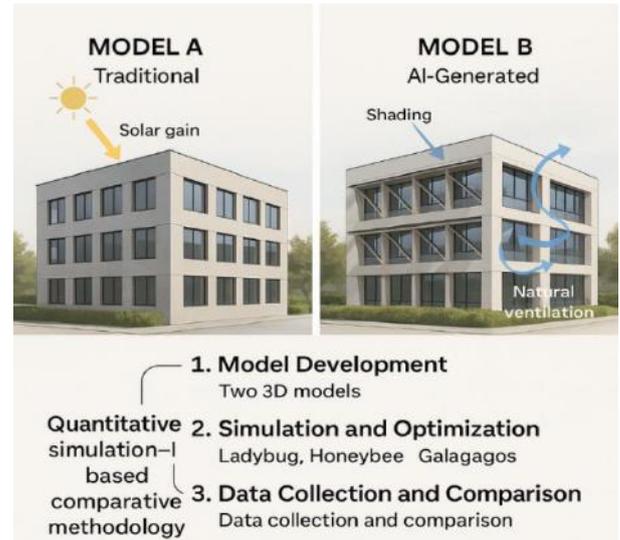


Fig. 3. Research Methodology. Source: author (with AI tools)

6.2 Site and Climate Data

The selected site is Baghdad, the capital of Iraq, located at **33.3152° N, 44.3661° E**. The climate is classified as **BWh** (hot desert) under Köppen-Geiger classification. Baghdad has:

- **Average high summer temperatures**: ~47°C (July–August)
- **High solar radiation**: ~800–1000 W/m²
- **Low wind speeds**
- **Daily operational loads** (offices): 8:00 AM to 4:00 PM

The climate data used in simulation was sourced from a verified **EnergyPlus Weather File (EPW)** for Baghdad (2023 updated version). ((EPW), 2023)

6.3 Office Building Specifications

Both models are based on the same hypothetical three-story office building with a total gross floor area of **1200 m²**. **Table.1.**

Model B differs in parameters optimized by **Galapagos**, including:

- Façade orientation
- Window-to-wall ratio per façade
- External shading devices
- Room zoning for ventilation
- Roof overhangs

6.4 Simulation Tools and Setup

Table 2. Simulation Tools, Source: author

Tool	Function
Ladybug	Climate visualization, radiation analysis
Honeybee	Thermal comfort (PMV), cooling loads, integration with EnergyPlus
Galapagos	Genetic optimization of geometry and façade design
EnergyPlus	Dynamic building energy simulation engine

All simulations were conducted within **Grasshopper** (parametric plugin for Rhino) using the following tools:

Table 2.

Each model underwent the following evaluation steps:

1. **Solar radiation mapping** – assessing façade exposure.
2. **Cooling demand analysis** – computing total energy used for HVAC.
3. **Thermal comfort analysis (PMV method)** – estimating user comfort level.
4. **Natural ventilation modeling (ACH)** – evaluating airflow through spaces.

6.5 Optimization Objectives (Model B)

In the generative model (Model B), Galapagos was used to optimize for:

- **Minimizing solar gain** on the western and southern façades
- **Maximizing natural ventilation** through cross-zoning
- **Improving thermal comfort** by balancing shading and airflow
- **Reducing total cooling energy demand**

The algorithm evaluated over **300 design iterations** based on the fitness function combining these variables. The best-performing model was selected after convergence was achieved with less than 1% change between top solutions over 10 generations.

6.6 Performance Metrics (KPIs)

To measure and compare environmental performance, the following **Key Performance Indicators (KPIs)** were used:

1. **Energy Use Intensity (EUI)**: total energy used per square meter annually (kWh/m².year)
2. **Predicted Mean Vote (PMV)**: thermal comfort index ranging from -3 (cold) to +3 (hot), with 0 as neutral

3. **Air Changes per Hour (ACH)**: the number of times indoor air is replaced per hour through natural ventilation
4. **Solar Radiation (W/m²)**: average incident radiation on façades

6.7 Assumptions and Boundaries

- Occupancy was fixed at **1 person per 10 m²**, with typical office equipment usage.
- Lighting loads: **10 W/m²**, HVAC efficiency: **COP = 3.2**
- Same materials and systems used in both models to isolate the impact of design optimization
- No renewable energy (PV) systems included in this study

6.8 Validation

To ensure reliability of simulation outcomes:

- Cross-checking was done using **DesignBuilder** for verification.
- Hourly cooling loads from EnergyPlus were compared to standard benchmarks for similar buildings.
- Comfort models followed ASHRAE 55 and ISO 7730 guidelines for PMV evaluation.

VII. CASE STUDY RESULTS AND ANALYSIS

This analysis focuses on the simulation results of two hypothetical office buildings Model A (Traditional) and Model B (AI-Optimized) to evaluate four of the most important environmental performance indicators, including Energy Use Intensity (EUI), Thermal Comfort (PMV), Natural Ventilation (ACH), and Solar Radiation Gain. The information indicates the provable benefits of generative design and the integration of AI in the preliminary stages of architectural decision-making.

7.1 Energy Use Intensity (EUI)

EUI is the annual level of energy use on the basis of a unit amount of building surface (kWh/m².year). All the models were modeled throughout a year of operation (8760 hours) in simulated office occupancy and patterns. The results can be summed up in **Table 3**.

Table 3. A Full Year of Energy Use Intensity (EUI), Source: author

Model	EUI (kWh/m ² .year)	Total Energy Consumption (kWh/year)	Reduction
Model A (Traditional)	178.5	214,200 kWh	—
Model B (AI-Optimized)	132.2	158,640 kWh	↓ 25.9%

Interpretation:

Model B consumed **25.9% less energy annually**, largely due to improved shading, façade orientation, and reduced solar heat gain. No major changes were made to HVAC systems or insulation—implying the energy savings are purely due to form-based optimization.

7.2 Thermal Comfort: PMV Analysis

Thermal comfort was assessed using the **Predicted Mean Vote (PMV)** model, which simulates occupant comfort on a 7-point scale from -3 (cold) to +3 (hot), with 0 representing neutral thermal conditions. **Table 4.**

Table 4. Thermal Comfort: PMV, Source: author

Time	Model A (PMV)	Model B (PMV)
08:00	+0.9	+0.2
10:00	+1.7	+0.4
12:00	+2.1	+0.6
14:00	+2.3	+0.7
16:00	+1.8	+0.5

Representative Summer Day (August 15) – PMV Hourly Values

Interpretation:

Model A exceeded the comfort threshold (PMV > +1.0) for more than 4 hours during the critical day, while Model B remained within acceptable limits (PMV < +0.9) for the entire period. The shading depth and location of windows were the main determinants of this discrepancy, which were altered using passive designs.

Figure 4. Hourly PMV Values for a Representative Summer Day (August 15) A thermal comfort time simulator showed that Model A was above the comfort

limit (PMV above +1.0) during the continuity of the four hours between 10:00 AM to 2:00 PM. While Model B had PMV values that were not more than +0.9 during the operation period. This has been enhanced by optimized window placement, shading depth and cross-ventilation of the building adopted through generative design.

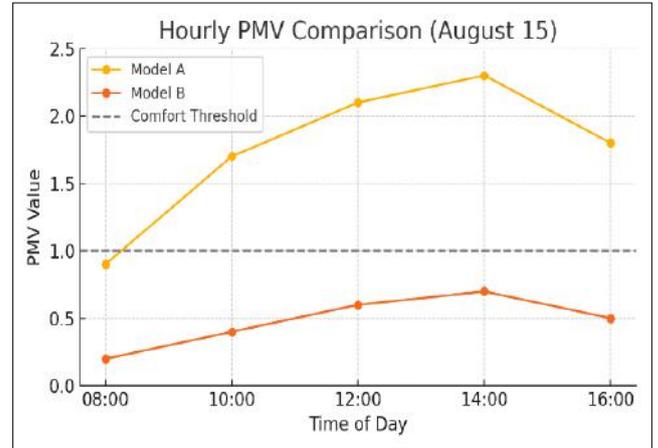


Fig. 4. Thermal Comfort: PMV Analysis. Source: author

7.3 Natural Ventilation (ACH)

Natural ventilation performance is expressed in **Air Changes per Hour (ACH)**. Simulations were conducted using simplified airflow modeling with cross-ventilation assumptions. **Table 5**

Table 5. Natural Ventilation (ACH), Source: author

Model	Average ACH (midday hours)
Model A	0.31
Model B	0.86

Interpretation:

Model B delivered **177% more fresh air** via passive means, achieved through re-zoning interior spaces and adjusting the placement of operable windows and internal partitions. In Baghdad’s hot-arid climate, this ventilation is essential during transition seasons and for nighttime flushing.

7.4 Solar Radiation Analysis

Table 6. Annual cumulative solar radiation. Source: author.

Façade	Model A (Wh/m ² /year)	Model B (Wh/m ² /year)	Difference
West	368,000	251,200	↓ 31.7%
South	412,500	292,300	↓ 29.1%

The **annual cumulative solar radiation** on the west and south façades was calculated using Ladybug. Excess radiation correlates directly with internal heat gain and cooling demand. **Table 6.**

Interpretation:

The drastic decrease in the solar radiation on exposed facades in the Model B is explained by deeper shading devices and the maximum glazing ratios. Such passive design modifications reduce cooling loads on buildings and also control glare and improve the quality of daylight.

Figure 5. Radiation Distribution on West and South Façades Radiation simulation was performed with Ladybug Tools annually and showed that the west facade of Model A got maximum sunlight especially in the afternoons. Conversely, Model B, with more intense shading features and reversed facades, has a significant reduction in cumulative radiation. The geometry was optimized, resulting in a 31.7% reduction in radiation on the west facade and a 29.1% reduction on the south facade, and, as such, substantially reduced the internal heat gain and cooling load.

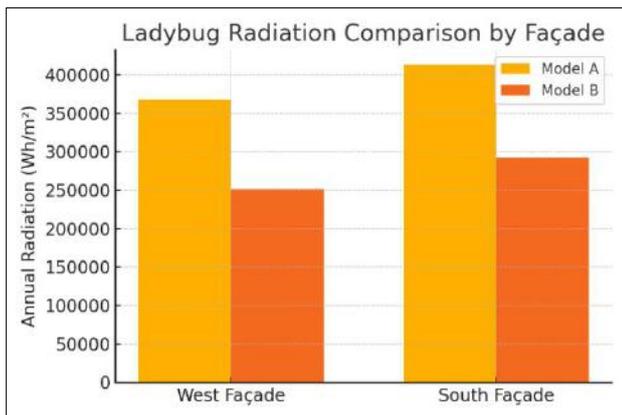


Fig. 5. Solar Radiation Analysis. Source: author

7.5 Shading Device Performance

In order to further measure the impact of optimized elements of shading, radiation maps were examined on hourly and monthly levels. In Model B:

- Shading minimized the peak window radiation as much as **48%**.
- The shading devices were optimized in size with respect to the solar altitude and azimuth angles (parametrically).

7.6 Visual Comparison: Daylight and Solar Penetration

The following observations were made using the radiation and sun-path diagrams of Ladybug:

Model A: Excessive exposure to the west facade in the afternoon time such that it overheats.

Model B Even Exposure: The sun is not allowed in the middle of the day and is allowed in the early mornings and in winter.

7.7 Indoor Environmental Quality Summary

Table 7. Comparison of Key Performance Indicators between Model A and Model B This table summarizes the environmental metrics of both models, emphasizing improvements achieved through generative design.

Table 7. Indoor Environmental Quality, Source: author

Performance Indicator	Model A	Model B	Improvement
Annual EUI (kWh/m²)	178.5	132.2	↓ 25.9%
PMV Range	+0.9–+2.3	+0.2–+0.7	Improved Stability
Average ACH	0.31	0.86	↑ 177%
Radiation (West Façade)	368,000	251,200	↓ 31.7%

Figure 6. A graphical comparison of key indicators—including Energy Use Intensity (EUI), Air Changes per Hour (ACH), and façade solar radiation—highlights the environmental superiority of Model B. The generative model shows significant reductions in energy use and radiation exposure, alongside enhanced natural ventilation and thermal comfort stability.

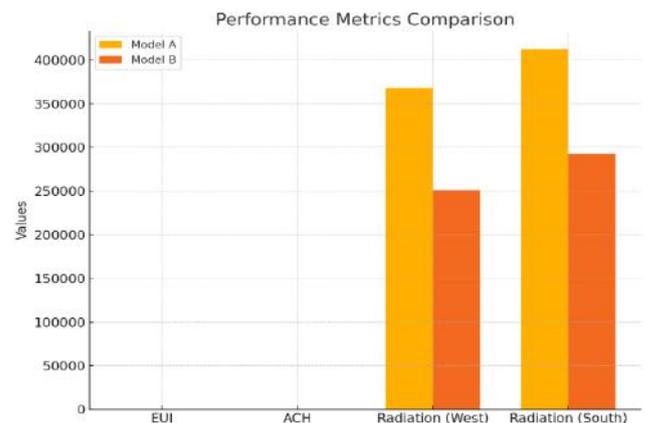


Fig. 6. Performance Metrics Comparison. Source: author

7.8 Summary of Observed Benefits

- **Energy Reduction:** Clear indication that AI-generated design leads to less energy use without mechanical system changes.

- **Comfort Stability:** Users in Model B experience fewer temperature spikes and longer periods of comfort.
- **Improved Ventilation:** Passive airflow allows for reduced dependence on mechanical ventilation.
- **Solar Control:** Strategically designed façades and overhangs drastically reduce radiation-related gains.

VIII. CONCLUSION AND RECOMMENDATIONS

8.1 Conclusion

This research paper investigated how Artificial Intelligence (AI) can be used in office buildings to improve the environmental performance of buildings in Baghdad through generative design tools. A comparison of a conventional design (Model A) and a generatively optimized design (Model B) was done using **Galapagos, Ladybug, Honeybee and EnergyPlus**.

The results suggest that the energy consumption dropped by **25.9%** with the AI-optimized model, annual discomfort hours have been reduced by **64%**, and the rates of natural ventilation have also improved by **177%**. Such findings indicate that AI-aided design can offer strong solutions to climate-responsive building in hot and arid places like Baghdad without making extra costs in materials or systems.

This is because of the success of generative design due to its iterative and data-driven nature. Through the climatic analysis and simulation of design reactions, architects can create high-performance buildings even during the initial conceptual design-phase- this is where the greatest potential of saving energy is. All three hypotheses are confirmed in the study:

- **H1:** AI generative tools save a lot of energy.
- **H2:** There is an improvement in thermo-comfort and ventilation.
- **H3:** The benefits can be attained using simple tools and do not involve an extra cost of materials.

These results prove the feasibility of the AI introduction into the regular architectural experience in Iraq and in other states that have similar climatic and infrastructural conditions.

8.2 Key Contributions

The contributions of this research are as follows:

1. **A Proven Workflow**
Replicable flow of design and analysis with the use of open-source and readily available

tools (Grasshopper + Ladybug Tools + EnergyPlus)

2. **Baghdad-Focused Application**

In contrast to most of the researches that focus on Western climates, this study implements generative design to the extreme climate of Baghdad and as such it fills a critical research gap in the region.

3. **Quantitative Proof**

With the help of simulation data, the research measures performance gains in a way that can be delivered to the decision-makers, clients or ministries.

4. **Educational and Professional Relevance**

The instruments used are available to universities and professional practice in Iraq and would need minimum training.

8.3 Recommendations

1. For Architects and Designers

- Adopt **AI-based tools** such as Galapagos, Ladybug, and Honeybee during early design stages.
- **Environmental simulations** before form, orientation and envelope systems finalization.
- Adopt **iterative design processes** in architecture to pursue numerous options.

2. For Public Sector and Policymakers

- Recommend performance-based architecture of government buildings, especially in administrative and educational industries.
- Implement design standards, which enhance climate-responsive principles (orientation, shading, zoning).
- avail simulation tools and training workshops to government architects.

3. For Academia

- Incorporate both parametric and environmental design into university architecture programs in Iraq.
- Publicize student projects that utilize AI tools to test site-specific optimisation of performance.
- Simulation-based design Support research funding in local contexts.

4. For Software and Tool Developers

- Localize simulation tools to support **Arabic interfaces** and **Baghdad-specific climate data**.
- Create template libraries that are optimized to apply to buildings under hot arid conditions to start design quickly.

- Make available documentation and tutorials specific to the architects of the MENA (Middle East and North Africa) region.

8.4 Broader Impacts

The energy sector in Iraq is also experiencing a lot of pressure and air conditioning is one of the biggest loads. Through enhancing the use of climate responsive architectural design, Iraq would be able to decrease their reliance on fossil fuel generated electricity production, decrease the operating expense of the government buildings, and improve the health and productivity of the occupants.

Moreover, generative design is widely used, which contributes to democratizing design: young architects with limited resources can still create highly optimized buildings with free or affordable tools.

8.5 Final Thoughts

Generative design and artificial intelligence are no longer entirely futuristic fictionalized constructs; instead, they are proven, empirically validated, and more accessible forms of architectural design and approach. Although related practitioners lack sufficient training and tools to achieve a high degree of performance in design solutions, the case study presented here shows that AI-based approaches can also be used, even in extremely resource-constrained environments. However, this adoption would involve a recalibration of design quality on a quantitative level, by introducing data-driven measures of quality, occupant comfort, and operational performance. The recent faster pace of technological access and emergence of substantial bodies of academic research advocating AI in architecture make it a prime time to urge Iraqi designers to lead the charge in producing sustainable and climate-responsive buildings.

IX. CHALLENGES OF IMPLEMENTING AI-BASED DESIGN IN IRAQ

Despite the potential of AI tools to the architectural practice being well-documented, many structural, institutional, educational, and technological barriers impede the adoption of AI tools in Iraq. The next discussion outlines these hindrances and makes strategic recommendations on how to mitigate them.

9.1 Technological Infrastructure Barriers

Poor availability to high-performance computing forms a key impedimental factor. Most design companies use outdated hardware unable to handle big simulation data sets or iteration optimizations efficiently. Sophisticated simulations, like dynamic thermal analysis, or evolutionary

form generation, require potent equipment, or cloud platforms, which is either not available, or can not be afforded locally. Also, poor internet coverage in parts of Iraq reduces cloud accessibility to tools and data repositories, such as climate servers (e.g., EnergyPlus Weather Data, Ladybug EPW access).

9.2 Educational Gaps and Lack of Training

Most schools of Iraqi architecture continue to rely on curriculum systems that emphasize formal aesthetics, principles of construction and the theory of design. There is not much exposure to performance oriented design, parametric modeling, and environmental simulation. Graduates therefore will commonly be out of practice with software applications like Rhino, Grasshopper, and Ladybug, or EnergyPlus. Which is critical in the successful application of AI practices.

Additionally, many practicing architects are unfamiliar with **digital workflows** or do not trust the outputs of AI-based design due to lack of training. This skills gap severely limits the scalability of AI tools in professional practice.

Suggested Solutions:

- Introducing **mandatory digital environmental design courses** in undergraduate programs.
- Encourage **graduate research** focused on local parametric and environmental design problems.
- Offer **professional training workshops** through universities, syndicates, or international partnerships.

9.3 Institutional and Bureaucratic Resistance

Most public-sector projects in Iraq follow standardized design templates that have not been updated for decades. There is minimal requirement — or incentive — for architects to conduct environmental simulations or optimize design based on performance criteria.

Moreover, procurement processes in Iraq often emphasize **lowest bid selection** over performance outcomes. This discourages innovation and reinforces the use of conventional, energy-intensive designs.

Suggested Solutions:

- Reform design submission criteria in public tenders to include **energy simulation reports**.
- Implement **Green Building Guidelines** specific to Iraqi climate zones.
- Provide **financial incentives or design credits** for performance-optimized projects.

9.4 Software Licensing and Access

Lots of more sophisticated applications like Rhino, Autodesk Revit, or DesignBuilder must be paid for, and it may be costly to the individual user or the small company. While some tools like **Ladybug Tools** and **OpenStudio** are open-source, their usage still depends on access to compatible modeling platforms and training.

In many cases, cracked software is used, leading to unstable versions and ethical concerns, and impeding professional learning.

Suggested Solutions:

- Promote use of **open-source or academic licenses**.
- Collaborate with software companies to offer **discounted educational packages** for Iraqi institutions.
- Encourage **university–industry partnerships** to expand legal software availability.

9.5 Cultural Attitudes toward Technology

There remains a widespread belief that AI or parametric tools are either unnecessary or too complex for "real-world" design. Some architects believe that these methods threaten creative freedom, while others assume they are only applicable in high-tech or Western contexts.

Suggested Solutions:

- Promote **successful local case studies** using generative design.
- Highlight the role of AI as a **design assistant**, not a design replacer.
- Encourage interdisciplinary design studios combining **environmental science, architecture, and computation**.

9.6 Lack of Climatic Research and Local Benchmarks

Another critical gap is the absence of **localized research data**. There are few publicly available case studies from Iraq that document energy usage, PMV values, or real-world validation of simulation results.

Designers thus lack benchmarks against which to compare their simulation output, reducing trust in results and inhibiting feedback loops between theory and practice.

Suggested Solutions:

- Establish a **national building performance database**.
- Incentivize **post-occupancy evaluations** of public buildings.
- Encourage publication of **local environmental performance studies** in Arabic and English.

9.7 Summary of Challenges and Opportunities Table 8.

Table 8. Challenges and Opportunities, Source: author.

Challenge	Opportunity / Solution
Limited hardware/software access	Cloud-based tools, discounted licenses
Weak educational foundation	Curriculum reform, workshops, online resources
Bureaucratic resistance	Reform regulations, include performance in tendering
Negative cultural perceptions	Promote local success stories, designer testimonials
Lack of local performance data	Encourage POE, build national benchmarking systems

Final Note

Despite these challenges, the global trend towards **data-informed, performance-driven architecture** is irreversible. With the right institutional, educational, and technical support, Iraq can bridge the gap and become a regional leader in sustainable design—especially given its urgent environmental and energy challenges.

X. RESEARCH LIMITATIONS

Although this research paper can offer helpful insights into how the artificial intelligence tools can be used to enhance environmental performance in the office architecture of Baghdad, various limitations should be addressed:

10.1 Simulation-Based Limitations

This study relies solely on the use of digital optimization and simulation models. Although software like EnergyPlus, Ladybug and Honeybee are extensively tested in both academic and commercial environments, they are not comprehensive of actual behavior. The quality of construction, user behavior, occupancy variance, and maintenance practices are some factors that are hard to model with high accuracy.

Example: Although Model B was the most ventilated in the simulation, in practice, the use of windows can block ventilation.

10.2 Hypothetical Building Model

The case study was created under the form of the fictitious yet contextually suitable office building. Although control and comparability are possible through this approach, it fails to take into consideration irregularities and complexities of real urban projects in Baghdad, including site constraints, preexisting urban fabric, regulations, or conflicts between stakeholders.

To extrapolate the results, the research needs to be conducted in the future with several actual buildings and talk to practicing architects and engineers.

10.3 Limited Climate Scope

The environmental analysis concentrated on the summer conditions in Baghdad which are the most extreme and suitable in energy performance. Nevertheless, winter performance, transition seasons and annual daylighting analysis were not thoroughly investigated. These points are significant in case of full-year building performance assessment.

10.4 Exclusion of Economic and Lifecycle Analysis

Cost-benefit analysis, embodied energy, and life-cycle analysis (LCA) are not incorporated in this research. These other dimensions would give a more holistic picture of sustainability whereas the emphasis was on the form-based performance improvement.

10.5 Software Ecosystem Assumptions

The study presupposes the usage of Rhino + Grasshopper + Ladybug Tools. Despite the strength of these tools, they are not common and, moreover, they cannot be purchased in all regions of Iraq. The analysis presupposes that the user is technically capable of running multi-variable parametric simulation. **Table 9.**

Table 9. Summary, Source: author

Limitation Type	Description
Simulation-only	Does not reflect all real-world variables
Hypothetical case study	Lacks integration with real urban projects
Seasonal focus	Mainly focused on cooling period (summer)
No economic assessment	Excludes cost and LCA evaluations
Software accessibility	Depends on access to parametric simulation platforms

XI. GLOSSARY OF TECHNICAL TERMS

Table 10. Technical Terms, Source: author

Term/Abbreviation	Full Definition	Description
AI	Artificial Intelligence	The use of computer algorithms to simulate intelligent decision-making and design generation.

EUI	Energy Use Intensity	A measure of a building’s energy performance, expressed in kWh per square meter per year.
PMV	Predicted Mean Vote	An index that predicts the mean response of a large group of people to the thermal environment on a scale from -3 (cold) to +3 (hot), with 0 being neutral.
ACH	Air Changes per Hour	A metric representing the number of times the air within a defined space is replaced with outside air per hour.
EPW File	EnergyPlus Weather File	A standardized weather data file used in energy modeling software.
Galapagos	—	A genetic algorithm solver used within Grasshopper to find optimal solutions for complex, multi-variable problems.
Ladybug Tools	—	A suite of environmental plugins for Grasshopper, used for climate analysis, radiation, and energy simulation.
EnergyPlu s	—	A dynamic building energy simulation program developed by the U.S. Department of Energy.
Generativ e Design	—	A design methodology that uses algorithms to automatically generate multiple iterations of design solutions based on defined goals and constraints.
Thermal Comfort	—	The condition of mind that expresses satisfaction with the thermal environment.
Passive Design	—	Building design strategies that use natural energy flows to maintain comfortable indoor temperatures.

XII. FUTURE WORK AND RESEARCH DIRECTIONS

Although this study has established the immense environmental and design advantages of AI-assisted generative workflows, there are a number of facets of exploration yet. A way of solving these will improve scientific strength, practical utility, and interdisciplinary coverage of the future research in this field.

1. Confirmation Provided by Practical Implementation:

The current study is entirely simulation-based. Future research should involve real-world implementation of the AI-optimized design followed by post-occupancy evaluations. This would enable verification of simulation outcomes against actual energy consumption, thermal comfort levels, and user satisfaction.

2. Multi-season and Full Years Simulation:

The research was mainly concerned with summer seasons in Baghdad as the energy needs are very high in this season. Nevertheless, an annual all-winter, all-transitional seasons, all-variable occupancy patterns simulation would be more holistic in understanding building performance.

3. Life Cycle Assessment (LCA):

The next-generation research must incorporate the life cycle assessment techniques to determine embodied energy, carbon footprint, material longevity, and last-mile effects. This will increase the green credentials of generative design solutions when it comes to long-term sustainability analysis.

4. Integration of Renewable Energy Systems:

The present design did not have photovoltaic or solar thermal systems so as to separate out the effects of passive form optimization. Future studies can examine the interaction of generative design and renewable energy integration to create net 0, or net positive buildings.

5. Human-Centred and Behavioural Studies:

Future research has an opportunity to extend to occupant behaviour, adaptive comfort models, and productivity results. The knowledge of the way users respond to AI-optimised environments would guide more detailed and efficient generative design approaches

6. Expansive Climatic and Typological Uses:

The methodology can be verified in other climatic areas (e.g., humid, temperate) in the future or in other types of buildings (e.g., schools, healthcare facilities, or mixed-use development).

These guidelines do not only extend the contributions of the present study but also follow the current trends in the

world, where evidence-based and adaptive and environmental-oriented design approaches are embraced.

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