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Research Article

Parametric Multi objective Optimization of universities buildings: study of laboratory space in Giza Egypt

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Abstract:

In light of the rapid progress in building simulation technology and performance-based parametric design, optimizing building performance is one of the modern concerns that aims to control a number of design variables with a number of objective functions, which helps in finding ideal design solutions through the genetic engine based on genetic algorithms in search, intersection and mutation processes. This research dealt with optimizing laboratory space performance. The research analytical approach of multi-objective performance optimization in international university buildings, to study the methods and approaches that were followed to achieve the required improvement, algorithms used, objectives set and design variables were monitored and analyzed in the study of university buildings and how to improve their performance, the practical approach through the application of methodology deduced from analytical study using Rhino7 ,Grasshopper, and ladybug and Honeybee tools, Wallacie genetic solver used to optimize laboratory performance to optimize the energy use intensity , maximizing thermal comfort and maximizing daylighting and visual comfort the optimum solutions showed energy use minimization by 20 % and enhancing of thermal comfort by 2% and daylighting enhancement by 62% , with balanced solutions

1. Introduction

Digital simulation based on quantitative and qualitative performance represents the technological basis for emerging performance. Through the overlaying of different analytical assessments, design alternatives can be compared to determine a solution that achieves optimal performance. However, the designer creates a design hypothesis that is entered into the computer (the model). The computer software models the assumed design behavior and output metrics for cost and performance based on a few relevant criteria and the designer's expertise, most available building performance simulation software, whether for structural, lighting, acoustic, thermal, or airflow analysis, requires high accuracy, i.e., detailed modeling. This means they are rarely used in conceptual design development.[1] (Marsh, 1997) Evolutionary algorithms use multi-objective performance optimization challenges involve a number of competing or conflicting objectives in a highly complex search for optimal solutions. Examples include minimizing energy consumption while maximizing thermal comfort, minimizing energy consumption while maximizing natural light, minimizing costs while minimizing solar irradiance, and so on. [2] (Toutou, 2018) Architects utilize multi-objective building performance optimization to better define the design problem through a set of parameters and criteria involving multiple variables. It is difficult to define all variables using a single criterion. Instead of obtaining a single alternative that achieves only one of the parameters, there are a set of alternatives (trade-offs) that fulfill several parameters and criteria to achieve the objective, as illustrated by the Pareto Front.[3] (Shan, 2023) This set of solutions represents a space of possibilities, and the optimal solutions among them are those that best fulfill the objective function, facilitating decision-making and the development of new solutions and scenarios.[4] (Tuhus-Dubrow, 2010)

2. Literature Review

Evolutionary computation, including genetic algorithms, has been a subject of research since the late 1950s, with the concept of simulating evolutionary processes to solve problems that arose before the advent of computers. However, genetic algorithms did not begin to gain popularity until the early 1970s, thanks to the work of John Holland at the University of Michigan in 1960. Their widespread use did not occur until the 1990s, and evolutionary algorithms emerged through the work of Ingo Rechenberg at the Technical University of Berlin in 1960.[18] (Bäck, 2018) Genetic algorithms are an effective tool for multi-objective optimization as the key advantage of genetic algorithms in multi-objective optimization is their ability to handle multiple conflicting objectives simultaneously. For example, a designer might want to optimize multiple objectives, such as reducing weight, increasing strength, and minimizing the costs of a particular system, by generating a set of potential solutions and then developing them through a series of genetic processes like selection, crossover, and mutation, which mimic the biological process of natural selection. During evolution, the individuals best suited for reproduction are selected, and their genes are combined to create a new generation, which is then evaluated based on its fitness for the objectives. The process continues until the desired solution is obtained. It relies on a list of initial results or solutions that utilize biologically inspired mechanisms to optimize the outcome.[21] (Weise, 2009) Alongside numerous advances in genetic algorithms, recent developments in evolutionary algorithms include four other techniques inspired by different natural systems: memetic algorithms, particle swarm optimization, and ant colony systems. Examples include how ants find the shortest route to a food source and how birds reach their destination during migration. The behavior of such species is guided by learning, adaptation, and evolution, and a range of frequently selected solutions are used. [21](Weise, 2009) The Pareto front, which represents the selection of optimal solutions among different objectives, represents the best possible solution that cannot be improved upon further. It is a valuable tool for decision-makers. [19] (Back, 2002 IEEE transactions on Evolutionary Computation) which is a three-dimensional space of solutions produced in conjunction with the various simulation processes of the applied algorithms.[20] (Gossard, 2013)

This study aimed to improve the efficiency of cooling systems in laboratory buildings by simulating and analyzing the operational performance of a solar thermal cooling system compared to a conventional system based on compressed natural gas. The research utilized EnergyPlus software to simulate annual thermal performance, along with GenOpt to mathematically optimize the selection of the optimal operating capacity for the instantaneous electric water heater in the hybrid system. The results showed that relying on solar energy reduces final natural gas consumption by 57.91%. Furthermore, the introduction of an instant electric water heater achieves operating cost savings of up to 49.69% compared to a conventional system. The hybrid system remains the most viable option when a gas network is available, achieving a cost reduction of 27.62% compared to a fully gas-based

system and 12.14% compared to a system equipped with an electric water heater. The software used includes EnergyPlus (for thermal and operational simulations), GenOpt (for mathematical optimization), and Google SketchUp and OpenStudio for creating 3D structural models of the building under study[5] (Nasruddin, 2015)

Another study on evaluating the thermal performance of ventilation systems in research laboratories focuses on assessing the efficiency of ventilation systems used in academic laboratories from an occupational health and safety management perspective, taking into account the various functional and environmental requirements of laboratory buildings. The main variables were: Air Change per Hour (ACH. The results indicate the need for a balanced strategy to determine the ideal ventilation rates that achieve full protection for users by effectively removing hazardous chemical pollutants, energy efficiency by reducing energy consumption associated with ventilation and air conditioning systems without sacrificing safety standards, and environmental sustainability achieved by reducing emissions and negative environmental impacts.[6] (Memarzadeh, 2009)

In a study to optimize the performance of a school in Turkey, focusing on a single-objective energy efficiency (EUI) optimization process to reduce energy use intensity (EUI) through enhancements based on building envelope variables, a building model is created in Rhino software and defined in Grasshopper software. An energy model is then developed using the Honeybee plugin to evaluate the building's energy performance. After the parametric model was established, the optimization process for both Istanbul and Ankara models began to reduce the EUI value using Galapagos, the Grasshopper evolutionary solution plugin. Compared to the baseline scenario, although the U-values for both the wall and glass were lower in the optimized solutions, the fact that there were no significant differences in the EUI values revealed that various variables beyond building envelope elements should be evaluated during the design process for school-type projects. For future studies, it is believed that evaluating different performance metrics related to daylight, thermal comfort, cost, lifecycle analysis, etc., along with a multi-objective optimization process, will help inform design decisions that will be effective for school-type projects in different climatic zones.[7] (Aksin, 2021)

In an example of improving classroom design in Tehran by optimizing energy consumption and visual comfort, a two-stage process was implemented. The first stage involved multi-objective optimization of classroom design and energy consumption related to artificial lighting, taking into account climatic conditions and aiming to meet renewable energy requirements and user satisfaction. Solutions were developed where classrooms are divided into independent active lighting zones. Octopus utilizes the SPEA-2 algorithm, providing optimal solutions and delivering superior results. Among the findings, compared to other design variables, WWR (Wide Wavelength) can significantly impact cooling and heating energy, UDI (Daylight Intensity) and DA (Daily Light) measurements, and electric lighting energy. Building orientation also significantly affects ASE (Atmospheric Energy) and thermal comfort for users. Furthermore, the wall inclination angle plays a vital role in determining DA levels**.** [8](Bakmohammadi, 2020)A comprehensive comparative study was conducted between different software programs specifically used for building performance optimization (Building Performance Simulation - BPS), monitoring the frequency of use of various optimization techniques and algorithms, including artificial intelligence, in multi-objective optimization (Figure 3-26). The results showed a significant reliance on genetic algorithms, followed by Performance Simulation Optimization (PSO) algorithms. More recently, a systematic study of multi-objective window design optimization was presented, considering energy consumption, thermal comfort, and visual performance. Window design characteristics included orientation angle, geometric dimensions, and glazing materials. The research addressed the trade-off between energy demand, thermal comfort, and visual comfort. For this purpose, the window design optimization method was based on the NSGA-II Energy Plus Genetic Engine. The concept was applied to a case study of an office room located in a humid subtropical climate in China, considering various window characteristics and defining three design objectives. The model generates a Pareto interface for optimal solutions and illustrates the distribution of values for the different window design characteristics.[9] (Nguyen, 2014)

3. Research Problem

University buildings in Egypt suffer from significant uncertainty regarding the use of lighting, electrical appliances, and the control of comfortable cooling and ventilation systems, as well as energy consumption. The research problem lies in: "**Demonstrating that balanced solutions between energy performance, thermal comfort, and daylighting can be achieved using multi-objective optimization**." This research study

addresses the development of a methodology for university spaces through a multi-objective process to achieve better building performance by improving energy consumption density (EUI) parameters, building materials, and thermal comfort through a set of different variables related to

4. Objective

The main objective of this research is to develop a methodology for multi-objective performance optimization of laboratory spaces by identifying several variables that improve the energy efficiency, thermal comfort, and natural lighting of alternatives developed during the design phase.
The resulting design alternatives are considered a set of optimal or near-optimal tradeoff solutions that satisfy conflicting performance determinants such as energy efficiency, thermal comfort, and natural lighting.Using **analytical approach** to identify the approaches, standards, and metrics that can be used to evaluate building performance in multi-objective building performance improvement, through the analysis of a group of buildings and studies that were conducted on university buildings and multi-objective performance improvement was carried out on them. And **practical approach** Mult objective optimization using genetic algorithm

5. Methodology

1. Defining the study objectives by identifying the tools used for data collection.
2. Defining the study scope by establishing a set of criteria for selecting the projects to be studied.
3. Identifying the fixed and variable design variables affecting performance improvement projects in energy efficiency, building envelope efficiency, and internal system efficiency, with the aim of increasing thermal comfort and natural lighting.
4. Comparatively analyzing these projects to determine the extent to which they achieve the initial objectives set for improving building performance.
5. Developing a general framework and methodology for the analytical study.

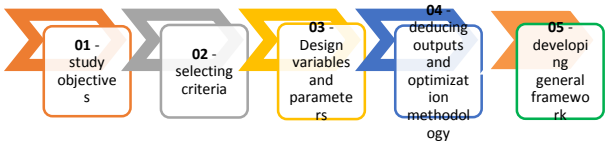


Figure 1 *methodology Source Author*

6. Sample selection criteria

Based on the study's objectives, the universities were selected as follows:
First, the projects were chosen to cover different regions of the world to increase the realism of the results and the diversity of choices. Then, leading universities in different regions were identified to determine which universities had implemented developments to reduce their carbon footprint and improve energy efficiency in each region. **Second**, the building improvements were chosen to be standardized, comprehensive, or deep-rooted, rather than simply commissioning.

6.1. Identifying the tools used in data collection

This analytical study answers the research questions: What criteria and standards can be used to evaluate building performance in multi-purpose building improvement? The objective is to collect data on university buildings that have been modernized through improvements in multiple elements, and to monitor the technologies used and the improvement methodologies and tools implemented in international buildings. The criteria for selecting the research sample are as follows: Buildings are chosen from leading universities that meet the basic criteria and fulfill the study's objectives:
1- They must hold an environmental assessment certificate.
2- They must play a significant role in innovating in the field of sustainable university architecture.
3- They must be in diverse regions to ensure a variety of sustainable strategies are employed.
4- Projects that demonstrate improvements in the building envelope, building materials, or energy consumption are included.
5- Projects that have been modernized or redesigned within the last ten years are selected.

6.2 Case Study Universities

Seven architectural projects were selected that met the criteria and fulfilled the study's objectives, as follows:
1- University of California, Charlotte, College of Arts and Architecture, NewYourk.
2- Laboratory building at Jinan University, Shandong Province, China.
3- Jiangsu Vocational Institute of Architectural Technology, Xuzhou, China.
4- Junan University of Kunming, China.
5- Changan University, Shaanxi Province, China.
6- Norwegian University of Science and Technology (NTNU), Norway.
7- Isfahan University of Technology, Iran.

Table 1 *University of California, Charlotte, College of Arts and Architecture, NewYourk*

<table>
<tr><td colspan="2">1- University of California, Charlotte, College of Arts and Architecture, NewYork. [10],[11] (Charlotte., 2025) (Futrell, 2015)</td><td colspan="2">College of Architecture Design Building</td></tr>
<tr><td colspan="2">Objective Functions
To reduce energy consumption while maximizing the use of daylight in classrooms.
Results
The optimized designs for each facade provided specific ranges for window sizes, glass properties, ceiling height, and lengths of shading systems/lighting racks to balance thermal energy consumption and natural light levels within comfort limits.</td><td colspan="2"></td></tr>
<tr><td colspan="2">Fixed parameters (not subject to optimization)</td><td colspan="2">Design variables (subject to improvement)</td></tr>
<tr><td colspan="2">Building materials and heat transfer coefficient values (wall, floor, ceiling, window)
Climate data (Charlotte, North Carolina weather)
Occupancy schedule and density
Lighting energy consumption intensity
Appliance energy consumption intensity
Ventilation and leakage rates
Surface reflectivity characteristics (ceiling, walls, floor)
These inputs define the range of design solutions evaluated in terms of energy performance and natural lighting.</td><td colspan="2">Roof Height (CH)
Cross-Light Transmittance (CWLT)
Solar radiation Cross-Light Transmittance (CWST)
Width of upper window (CWW)
Direct Light Transmittance (DWLT)
Direct Solar Transmittance (DWST)
Exterior Awning Length (ESL)
Reflective Shelf Length (LL)
Vertical View Window Transmittance (VWLT)
Vertical Solar Transmittance (VWST)
Window Width (WW)</td></tr>
<tr><td>Area</td><td>sustainability</td><td>Type of optimization</td><td>platform</td></tr>
<tr><td>90 m^2</td><td>American guidelines (ASHRAE, DOE) and lighting standards (UDI),</td><td>Optimizing two-objectives using PSO and Hooke-Jeeves algorithms with Pareto analysis</td><td>EnergyPlus Radiance GenOpt</td></tr>
<tr><td>Inputs</td><td>Method</td><td>Outputs</td><td></td></tr>
<tr><td>18</td><td>BI OBJECTIVE</td><td>100 = 10 × 10 solution</td><td></td></tr>
</table>

Table 2 *Laboratory building at Jinan University, Shandong Province, China*

<table>
<tr><td>2- Laboratory building at Jinan University, Shandong Province, China[12] (sun, 2018)</td><td>Laboratory Building</td></tr>
<tr><td>Objective Functions
Reduce annual energy consumption (air conditioning, heating, and lighting)
Increase natural lighting efficiency to improve visual comfort and meet required lighting standards Improve natural ventilation for thermal comfort
Results
The optimized exterior shading design of the building resulted in a significant improvement in lighting and ventilation and a 6% energy saving.</td><td></td></tr>
<tr><td>Fixed parameters (not subject to optimization)</td><td>Design variables (subject to improvement)</td></tr>
<tr><td>Structural type (concrete frame)
Exterior wall and insulation material (concrete walls with thermal insulation layers), Window type and configuration (Low-E hollow glass and aluminum with a thermal transmission coefficient of 2.7), Open area ratio for ventilation (percentage of openable window area 0.5), Reflectance of floor, walls, roof, and sunshade (reflectance values: floor 0.5, walls 0.8, roof and sunshade 0.9), Climatic conditions of the city (Jinan, China), Occupancy schedule and functional distribution of floors</td><td>Type of external shading (fixed horizontal for the south facade / movable slats for the east and west facades)
Dimensions and position of the sunshade (distance between the slats and the top window rim and slat length in millimeters, e.g. 600–1000 mm for the south), angle and direction of the shading slats for the east and west facades (number, position, length and angle of the slats), window area and window-to-floor ratio for each functional room according to orientation, arrangement and location of openings to improve natural ventilation (openable windows), material selection (roof insulation board/windows/)</td></tr>
</table>

2- Laboratory building at Jinan University, Shandong Province, China[12] (sun, 2018)		Laboratory Building	
Area	sustainability	Type of optimization	platform
150 m^2	Chinese standard for natural lighting in buildings GB 50033-2013	Triple improvement for energy, lighting, and ventilation	Design Builder PHOENICS
Inputs	Method	Outputs	
5	MULTIOBJECTIVE	100 individuals per generation x 15 generations = 1500	

Table 3 *Jiangsu Vocational Institute of Architectural Technology, Xuzhou, China.*

3- Jiangsu Vocational Institute of Architectural Technology, Xuzhou, China.[13] (Zhao, 2022)		Laboratory and administrative Building	
Objective Functions **Reduce** annual energy consumption **Maximize** daylighting performance Maximize photovoltaic performance **Results** If the LEED standard is achieved at 75% (i.e., 75% of the room area achieves an acceptable level of natural lighting), the lowest annual energy consumption of the building is approximately 310,000 kWh, while the highest reaches 350,000 kWh.			
Fixed parameters (not subject to optimization)		Design variables (subject to improvement)	
population density of the building (number of users: 52), lighting system used (lighting power 9,689 W/m²), area of external walls, type of climate and weather conditions (temperate humid climate), fixed structural features (building system - three floors - floor height 3 m), some specifications of roofs, floors and fixed equipment.		Main building orientation Window-to-wall ratio (north, south, east, west) Window height Glass material (light transmittance, heat transfer coefficient) Exterior wall material (insulation types and wall constructions (7 types)) Curtain wall dimensions and characteristics (length, height, deflection coefficients, glass and frame ratios, opening area ratios for oriented walls (percentage per side)	
Area	sustainability	Type of optimization	platform
1642 m2 for the whole building	local and international code standards, such as the Chinese energy-saving standard GB50189-2015 and the global LEED standard for indoor lighting.	Multi-objective optimization using NSGA-II Genetic Algorithm algorithms for Pareto analysis.	Autodesk Revit Dynamo Optimo Green Building Studio (GBS
Inputs	Method	Outputs	
11	MULTIOBJECTIVE	150 solutions	

Table 4 *Junan University of Kunming, China.*

4- Junan University of Kunming, China.[14] (chen, 2025)	Laboratory and administrative Building
Objective Functions Maximizing UDI_avg Difference in annual solar radiation **Results** **Reducing** solar heat gain in summer by up to 98% in critical areas, the best results are associated with using horizontal blades with a simple rotation angle, achieving a balance between thermal and photovoltaic performance.	
Fixed parameters (not subject to optimization)	Design variables (subject to improvement)

4- Junan University of Kunming, China.[14] (chen, 2025)		Laboratory and administrative Building	
The main window's dimensions (1.85 m x 2.0 m) are considered. The layout of the interior walls, the interior balcony area, and the bathroom's role in reducing radiation and light exposure are also considered. The reflectivity of the interior surfaces (ceiling 0.75, walls 0.6, floor 0.3) is a factor. The natural ventilation system and the absence of air conditioning or active heating are also factors.		fin depth: Between 0.10 and 0.45 meters fin spacing: Between 0.10 and 1.00 meters fin angle: Between -90 and +90 degrees fin orientation: Horizontal/Vertical	
Area	sustainability	Type of optimization	platform
28.8 m2 laboratory	The Chinese code "Technical Code for Building Shading Engineering" JGJ 237-2011 serves as a classification basis for types of shading solutions,	Multi-objective optimization using NSGA-II Genetic Algorithm algorithms for Pareto analysis.	Rhino Grasshopper Radiance Wallacei TOPSIS Method
Inputs	Method	Outputs	
4	MULTIOBJECTIVE	50 generations x 50 individuals = 2500	

Table 5 *Changan University, Shaanxi Province, China.*

5- Changan University, Shaanxi Province, China[15] (liu, 2024)		Students center Building	
Objective Functions Reduce annual energy consumption **Results** **Reducing** The total annual energy consumption was reduced by 58.8%, annual hours of thermal discomfort decreased from 2179 to 1024 hours, the PMV index improved to 0.5~0.89 (Level II according to the Chinese standard), and the thermal dissatisfaction rate of users decreased to 11.2%..			
Fixed parameters (not subject to optimization)		Design variables (subject to improvement)	
Building operating schedules: Lighting and equipment operating times (8:00 AM to 10:00 PM, 7 days a week), actual occupancy rates, and natural and mechanical ventilation rates. Indoor activity and thermal behavior specifications: Activity rate 70 W per person, clothing resistance (CLO 0.5 in summer, CLO 1.2 in winter). Energy source for equipment, heating, and air conditioning: Based on electricity and central gas, with no system changes during the upgrade process. Local requirements: Limits for the heat transfer coefficient of walls and ceilings.		Exterior wall insulation thickness and type: such as XPS/EPS/rock wool, 100 or 150 mm thick. Roof insulation thickness and type: such as XPS/EPS/rock wool, 100 or 150 mm thick. Exterior window glazing type: (standard double glazing, Low-E coated glazing, glass type and thickness). Horizontal shading length on the south/west facade: no shading or lengths of 0.5-1-1.5 meters.	
Area	sustainability	Type of optimization	platform
10700 m^2 whole building	Chinese code "Energy Efficiency of Public Buildings GB50189-2015 Design Standard for	Multi-objective optimization using NSGA-II Genetic Algorithm algorithms	Rhino, Grasshopper Octopus, Ladybug Honeybee
Inputs	Method	Outputs	
11	MULTIOBJECTIVE	50 generations x 50 individuals = 2500	

Table 6 *Norwegian University of Science and Technology (NTNU), Norway.*

6- Norwegian University of Science and Technology (NTNU), Norway [16] (Taveres-Cachat, 2019)	Laboratory and administrative Building
Objective Functions Results: Reducing total annual energy demand Maximizing electricity production by photovoltaic panels Maximizing the availability of continuous natural lighting in indoor spaces	

6- Norwegian University of Science and Technology (NTNU), Norway [16] (Taveres-Cachat, 2019)	Laboratory and administrative Building		
Results The best solutions were those that achieved the highest **balance** between lighting independence, electricity production, and overall energy **reduction**, and they included a vertically varying **distribution** of blades and gradual change angles according to window height.			
Fixed parameters (not subject to optimization)	Design variables (subject to improvement)		
Interior and exterior material properties: Wall reflectivity (0.5), floor (0.2), roof (0.7), glass transmittance 65%, shading structure reflectivity 65%, PV material reflectivity 10%. Number and type of shading blades are fixed. Building occupancy: Activity schedules are fixed according to the Norwegian Code. Location and climate: Oslo, Norway, using data from a typical climate year (EPW). Building model: Rectangular room 48 m² (6 m × 8 m × 2.7 m), south-facing with two 6 m² windows.	Angle, number, and distribution of louvers. Louvre blade tilt angle: The angle of each louver can be adjusted individually to 0°, 15°, 30°, or 45°. Vertical position of the louver on the window: Each louver can be freely distributed along the vertical axis within the window's boundaries (from 20 cm to 1.2 m), provided there is no overlap. Number of louvers used in the system: The methodology tested different configurations (10, 13, 16, and 19 louvers) and optimized the position and angle variables for each louver within each case.		
Area	sustainability	Type of optimization	platform
28.8 m^2	The Norwegian code for improving energy efficiency	single-objective optimization using SPEA Genetic Algorithm	Rhino, Grasshopper Octopus, Ladybug Honeybee
Inputs	Method	Outputs	
32	Single-OBJECTIVE	18 generations x 100 individuals per generation = 1800 solutions	

Table 7 *Isfahan University of Technology, Iran.*

7- Isfahan University of Technology, Iran. [8](bakmohammadi, 2020)	classroom
Objective Functions Reduce annual heat consumption. Maximize thermal comfort. Maximize natural light. Minimize the percentage of hours of natural light exceeding the required reference value (300 lux) throughout the year. Minimize the percentage of areas receiving more than 1000 lux for more than 250 hours annually (to combat glare). Minimize the likelihood of visual glare for users (aiming for a range below 0.35) to ensure visual quality. **Results**	

7- Isfahan University of Technology, Iran. [8](bakmohammadi, 2020)		classroom	
A **reduction** of over 28% in total annual energy consumption (heating + electricity). An **increase** in thermal comfort from 85.2% to 87.3%. **Improved** natural lighting and visual comfort indicators.			
Fixed parameters (not subject to optimization)		Design variables (subject to improvement)	
Site climate, air conditioning system, typical room dimensions Usage program and operating schedule Equipment loads (lighting, equipment, people): Ventilation and leakage rates: Natural ventilation per person and per space for Honeybee. Case material data and type: Wall, ceiling, floor, and insulation materials according to ASHRAE 3B climate (Tehran) recommendations: Exterior wall: U-value according to code Glass: Three options (single, double, triple clear).		Building orientation Panel depth: Between 0.10 and 0.45 meters Values: 0, 45, 90, ... etc. (Number of angles) Wall inclination angle Values: -30 to +30 degrees Number of windows 1 to 7 windows Window-to-wall ratio Values: 20%, 30%, ... up to 80% Glazing material Several types (double, triple,) for each louver within each case.	
Area	sustainability	Type of optimization	platform
70 m^2	ASHRAE 55-2010 IESNA LM-83-12: : ASHRAE 55 EN 15251 IESNA LM-83-12 ،LEED v4	Multi-objective optimization using NSGA-II Genetic Algorithm algorithms for Pareto analysis.	Rhino, Grasshopper Octopus, Ladybug Honeybee
Inputs	Method	Outputs	
30	MULTIOBJECTIVE	2800	

Table 8 *Components of the deduced Framework for improving multi-objective university buildings*

Measurement	**factor**	
Building orientation	Design variables (subject to improvement)	**1**
Wall inclination angle		
Window/panel number		
Window wall ratio		
Glazing type		
Wall type and material		
Insulation type and thickness		
Fenestration direction		
Fenestration number, depth, direction		
Same unit dimensions	Fixed parameters (not subject to optimization)	**2**
Class or building operating schedule (number of hours of use - operating seasons)		
The immutable properties of some basic building materials		

Structural system specifications		
Reduce annual energy consumption (heating/lighting)	Objective Functions	**3**
.Reduce electric lighting levels to enhance natural light		
Maximize annual thermal comfort indices (typically CTR or PMV-PPD)		
Maximizing optical comfort indicators (UDI – DA – minimization of DGP)		
Energy consumption intensity (EUI, TEUI, LEUI), total annual consumption	Sustainability standards used	**4**
Thermal comfort: The percentage of hours in which thermal comfort is .achieved based on ASHRAE 55 or PMV-PPD standards		
Visual comfort DA, UDI, ASE, DGP, LEED daylight credits		
Economic and environmental indicators (cost or carbon emissions)		
ASHRAE 55	Green buildings codes, rating systems	**5**
(European) EN 15251		
(Daylighting) IESNA LM-83-12 و LEED v4		
Chinese energy code		
Norwegian Energy Code		
(parametric simulation) Grasshopper + Rhino	Optimization and simulation programs and tools	**6**
(lighting, thermal simulation Ladybug & Honeybee		
(Energy simulation) EnergyPlus		
(Precisely simulating the properties of glass) LBNL Window		
(Light and glare analysis) Radiance, Daysim, Evalglare		
(genetic solver (SPEA-2, NSGA-II) Wallacei or Octopus	Type of multi-objective optimization algorithms	**7**
Studies have often produced between 1500 and 3000 initial solutions .(per generation and several generations)	Number of solutions output generated	**8**
From these, approximately 10 to 20 optimal solutions (Pareto Front) .were selected for final comparison and descriptive analysis		

7. Analytical study conclusion

The study aimed to analyze several projects in different countries and monitor the achievement of standards affecting energy efficiency and environmental quality in university buildings. These standards were used in multi-objective optimization to identify design variables subject to improvement, fixed parameters not subject to improvement, sustainability elements, methodologies, and shared codes that influenced this optimization methodology. The goal was to achieve various objectives, including reducing energy consumption, maximizing thermal comfort, and optimizing natural lighting. The study also aimed to identify different indicators for each project in terms of energy savings targets, total cost, type of building upgrades, comfort measurements and rates, variable factors, applications used, and the type of algorithms employed.The study concluded that the most

common elements of university building upgrades are related to improving air conditioning, heating, and ventilation systems and equipment, which may be linked to improvements to the building envelope. Other key improvements include improving the efficiency of electrical equipment, lighting systems, and service and mechanical systems. It was found that improving the building envelope can save up to 15% of energy consumption. A significant reduction in total annual energy consumption (in one study: up to 48% reduction in electric lighting consumption), increased thermal and visual comfort to levels competitive with international standards, improved natural light distribution and reduced glare without the need for additional external shading systems in many scenarios. The most significant influences on design efficiency were: building orientation, window-to-wall ratio, and glass types.A multi-criteria analysis is conducted using simulation software (Ladybug, Honeybee, Radiance, Open Studio) to assess the impact of design changes on thermal and visual comfort and annual energy consumption for each proposed design solution. Key performance indicators (KPIs) are defined (Minimize Energy use intensity (EUI Maximize Adaptive comfort Annual thermal comfort ratio (ATCR), Maximize visual comfort Daylight Autonomy (DA), Maximize Useful daylight Illuminance (UDI), Maximize Spatial Daylight Autonomy (sDA).

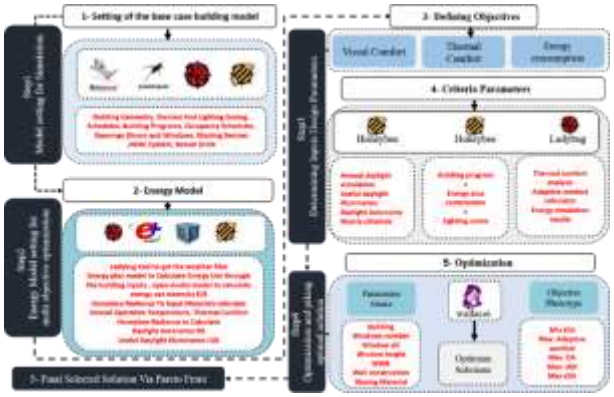


Figure 2 *Flowchart optimization Framework deduced from the analytical study*

8. Case study Helmy Science Building



Figure 3 *Layout Helmy Building for Medical Sciences – Zewail University*



Figure 4 *Side views Helmy Building for Medical Sciences – Zewail University*

8.1 Case study identification

The Helmy Institute for Medical Sciences (HIMS) is a major research center within Zewail City of Science and Technology. Built in 2016, the building faces north, with the laboratories also oriented northward. It utilizes a dual-module layout and multiples thereof, featuring finger-shaped corridors and service areas located opposite these corridors. It consists of three floors (ground, first, and second) as shown and contains a group of laboratories and seminar rooms. The building's laboratories include general laboratories, biology

laboratories, genomics laboratories, biology laboratories, aging laboratories, X-ray and robotics laboratories, stem cell laboratories, and microbiology laboratories. The building has a basement and three upper floors, with a total of 33 laboratories. The laboratories occupy 37% of the building's total area. The laboratories are all biological in nature, and the building's total area is approximately 13,200 square meters.The functional zoning, as shown in Figure (5), depicts the research labs (which form the heart of the building and include specialized units for aging, genomics, stem cells, and infectious disease research). Service areas include cold storage rooms for samples and sterilization rooms. Administrative and academic spaces include offices for researchers and small lecture halls. (Seminars)

Facade Materials: Double Glazing Used extensively to provide natural daylighting for the laboratories while minimizing heat gain. This is high-performance (Low-E) glass. Figure (6)

Exterior Cladding: A combination of engineered stone or GRC (glass fiber reinforced concrete) with aluminum panels, providing a durable and robust appearance. Louvers: Used to protect the south and east facades from direct sunlight, reducing air conditioning loads.

Interior Finishing Materials: As it is a medical and research building, the finishing materials adhere to strict Clean Room Standards. Laboratory flooring is vinyl or epoxy, which are antibacterial, chemical-resistant, easy to clean, and anti-static (for sensitive equipment). Heavy-duty granite or porcelain is used in the corridors and lobby.Walls are double-glazed with antibacterial paint. For fungi in the laboratories, suspended ceilings (metal tiles or moisture-resistant gypsum board) are used to cover the complex HVAC ducts required for the laboratories. Sustainability: The building was constructed in accordance with green building standards, meaning the use of energy-efficient LED lighting and air conditioning systems, and environmentally friendly building materials

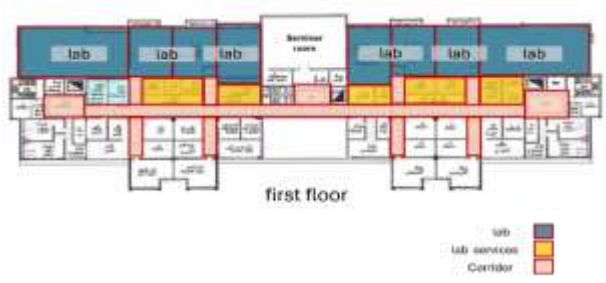


Figure 5 *building zoning*



Figure 6 *building façade*

8.3 Building parameters

Location building located in October city – Egypt at 29.94521111629221, 31.063473230724632

Climate data were analyzed using standard weather data (.EPW) files for Giza, Egypt (Energy Plus Weather File - EPW, Typical Weather Year - TMY). The building is located in Giza Governorate at 28.7666°N, 29.2321°E. Model A figure (7) Floor height: 4.2 m, laboratory area: 77.4 m². Model B height: 4.3 m, model area: 99 m². Percentage of openings in the facade: 18.5%: 17%.

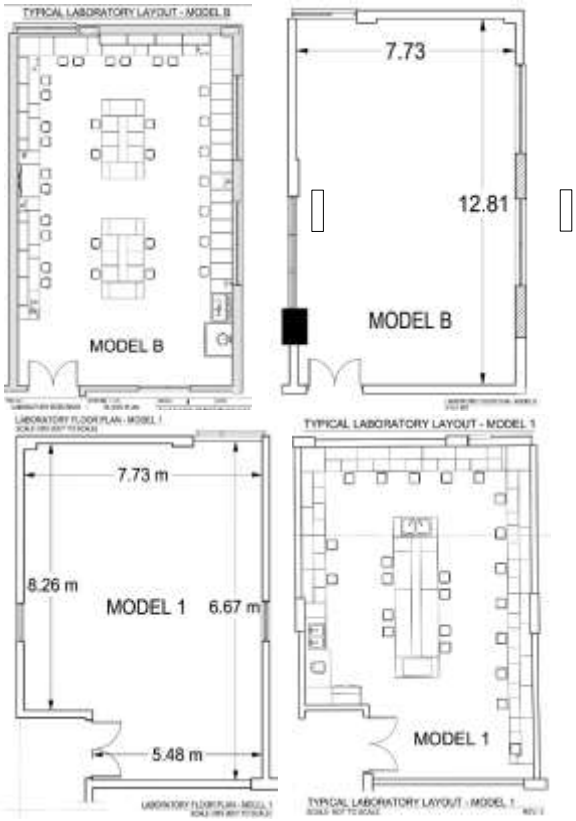


Figure 7 *laboratory model A and model B*

8.4 Building Materials Data

The interior walls consist of 12 cm thick double interior walls with a 6 cm gap. The exterior walls are 25 cm thick with a thermal transfer coefficient of 1.29 W/(m²·K),table (11&12) indicates the best alternatives for building materials in the walls,

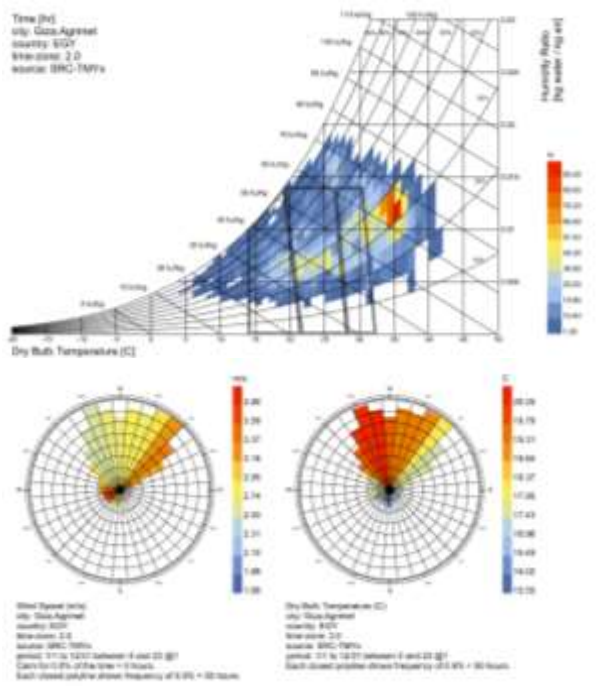


Figure 8 *Psychometric map of Giza Governorate and the wind rose*

ceilings, and glass to select materials that improve performance. Thermal and energy consumption are reduced, as a group of materials was selected and tested on the basic state and it was found that they reduce energy consumption and achieve thermal and light comfort.A typical laboratory with a north-facing orientation analyzed, resulting in an energy use intensity (EUI) of 248.86 kWh/m². The cooling load was 16413.9 kWh, the heating load 3811.1 kWh, the lighting load 1363.84 kWh, and the equipment load 1013.88 kWh. An energy simulation was performed, showing that cooling loads are the most energy-intensive, given a laboratory area of 90 m². The EUI analysis confirms that cooling loads are the highest. The figure represents monthly energy consumption, showing that the highest consumption occurs during the summer months due to solar energy gain and cooling loads, while the lowest consumption occurs during the autumn and winter months. Figure (9)



Figure 9 *Annual energy consumption of Helmy Science Building*

8.6 Comfort Simulating

Figure (10) shows that the peak heat gain periods in summer are June 21 and August due to the high temperatures, so comfort was calculated based on these periods. Figure (11) shows that the average PMV temperature is slightly warm, and the average operating temperature in the area is 26°C. Consequently, the energy consumption of the air conditioning system increases significantly during these periods to achieve the required thermal comfort in the laboratory. For the Average Expected Vote (PMV) used to measure comfort in air-conditioned spaces, and the Adaptive Comfort used to analyze comfort in non-air-conditioned spaces, the Annual Thermal Comfort Ratio (ATCR) is 57.30%, which does not meet the comfort model. The average operating temperature is a weighted average of air temperature and average radiant temperature (MRT). It represents the combined effect of air temperature and radiant heat exchange between the human body and surrounding surfaces. The average operating temperature of 34.8°C, measured on June 21, does not meet the adaptive comfort models during working hours according to the ASHRAE 55 acceptance limit of 90% for laboratories.

8.7 Daylight simulation

Daylight simulations were conducted over a full year. Internal loads and schedules were determined according to the actual building and the standard values for higher education buildings, with a minimum illumination level of 500 lux at the working level, 80 cm above ground. A daylight performance analysis grid was simulated at a single level, resulting in a set of analysis points: a 0.5 m × 0.5 m grid at a working level height of 0.8 m, with 210 sensor points on the grid. The daylight availability (DA) metric was 16.3%, which is lower than the standard percentage Figure (12). Useful daylight illuminance (UDI) was used to assess the quality and quantity of natural daylight in a space where the minimum illuminance is 100 LT > 100 TU > 3000 UT (Figure 5-34). Useful daylight illuminance was 9.37% for UDI between 500–3000 UT, 16.4% for UDI < 100 UT, and 0% for UDI > 3000 UT. While general laboratory lighting standards are around 500 lux, with a spatial

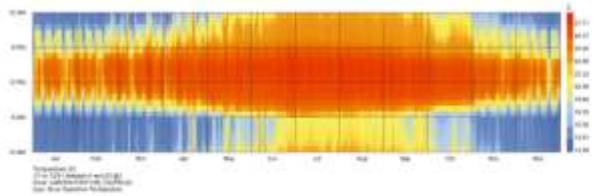


Figure 10 *Annual operating temperature calculated from the monthly average outside air temperature*

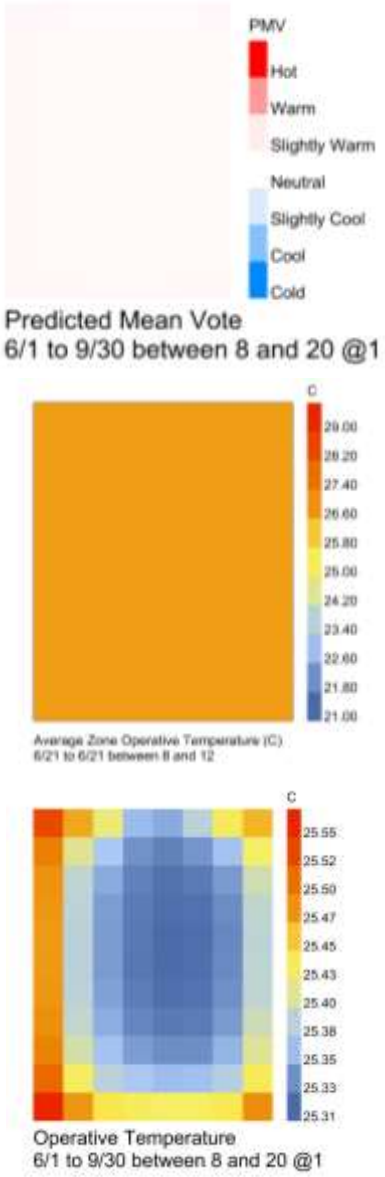


Figure 11 *Operating temperature from 1/6 to 30/9 from 8 am to 20 pm, average area temperature 27°C, PMV for laboratory room*

daylight independence ratio (sDA) of 7%, the goal would be to have at least 75% of the floor area illuminated with 300 lux (sDA300/50%). In this case, the laboratory will not experience glare problems.

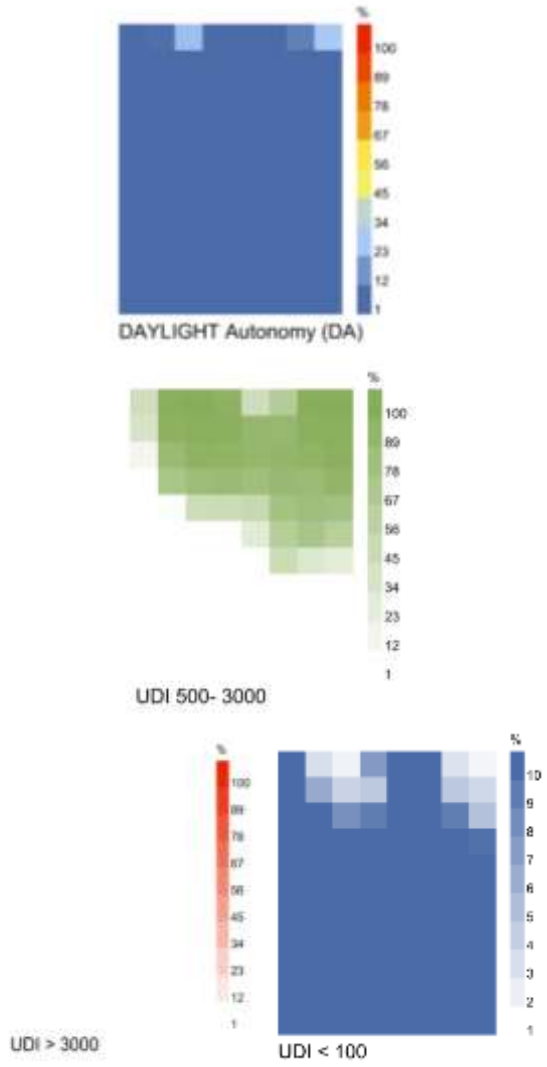


Figure 12 *Analysis of natural (DA) and beneficial (UDI) lighting*

8.8 Simulation results

Table (9) shows the values and results of the simulation for the case study. The design variables in Table (10) and the settings and adjustment of the genetic engine in Table (11&12) will be used to start the multi-objective optimization process. The design variables have been changed, with some variables being modified according to the north face of the laboratory and the depth of the breakers being reduced.

Table 8 *Design parameters used in objective functions*

Metric	Value	unit
EUI	248.8	Kwh/m2
Heating	3811.12612	kwh
Cooling	16413.90496	kwh
interior lighting	1363.84476	kwh
electric equipmentال	1013.88152	kwh
ANNUAL THERMAL COMFORT RATIO (ATCR)	57.385845	%
DAYLIGHT AUTONOMY (DA) %	0.163812	%
UDI 100 – 3000	9.376686	%

UDI < 100	16.429765	%
UDI > 3000	0	%
SDA 50%	7	%

Table 9 *Design parameters alternatives*

Number of values	attributes	Design variables
4	0.0، 0.02،0.05، 0.09 م	Shade depth
10	0.1 to 1	Distance between shades
12	1to 12	Shade count
2	Horizontal /vertical	Shade direction
11	50to 50 incidents10	Shade angle
64	%18 to 82 incidents %4	WWR
6	ASHREA 2019 .The wall r values are 0.81, 1.4, 1.5, 1.6, 2.6, 5.8	R-value ($m^2 \cdot K/W$)
5	5types of glass ASHREA 2019 Generic Low-E Glass, Generic Window Air Gap, Generic Window Argon Gap, Low E TINT 6MM, U 0.32 SHGC 0.22 Simple Glazing, COATED POLY-55 3.7, 3.8, 1.8, 2.6, 5.8	U-value glass W/m2. K
5	3.4, 3.2, 3, 2.8, 2.6	window height
5	0.5,1, 1.5, 2, 2.5	Sill height
177		total

Table 10 *Material Alternatives used for each element of the building*

U-value W/m^2K	R-value ($m^2 \cdot K/W$)	Thickness cm	material	
1.29	0.77	30	Double wall 12 cm and 6 cm gap	External wall
1.291	0.77	29	Double wall: red brick + 5 cm insulation	
0.484	2.06	30	Double wall: red brick + 6 cm insulation	
0.646	1.54	25	Single wall made of cement bricks, 25 cm	
1.07	0.927	27	A 25 cm red brick wall with 2 cm insulation	
1.29	0.77	30	Double wall 12 cm	Internal wall
0.64	0.18	5	Cement tiles	External roof
0.59	0.75	2	Cement	
1.6	0.6	5	sand	
5.9	0.168	0.08	insulation	
1.11	0.9	15	Reinforced concrete	
5.26	0.19	0.15	plaster	
5.25	0.19	2	vinyl	floors
1.5	0.6	2	red granite	
0.59	0.75	2	mortar	
1.6	0.6	5	sand	
1.11	0.9	0.15	Reinforced concrete	
5.26	0.19	0.15	plaster	

Table 12 *Glass Alternatives used*

U-value W/m^2K	reflectivity	Thermal conductivity	SHGC	Thickness mm	Glass types	
5.778	0.75	0.89	0.82	3	Clear aluminum sliding single non-reflective glass - tinted opaque glass	glass
3.779	0.71	1.0	0.202	6	Low-emissivity glass	

2.665	0.75	0.98	0.72	1.2	Low-emissivity glass with air gap	
2.66	0.75	0.95	0.63	1.2	Low-emissivity glass with an argon spacer	
3.8	0.75	1.0	0.39	6	Dark low-emissivity glass	
2.66	0.75	0.95	0.72	6	Low-emission reflective double glazing	
1.8	0.75	1.0	0.22	6	Coated poly 55	

8.9 Optimization Results

An optimization was performed on the typical lab model to optimize the design variables and expand the range of design variables to suit the north facade. The genetic optimizer continued optimization for 9 hours and produced 200 solutions, including 65 optimal, non-dominated Pareto front solutions across 20 generations, with 10 solutions per generation. Figure (13) and Table (13) show the genes of the optimal solutions selected for the typical floor laboratory. Figure (15) shows the optimal Pareto front solutions in the solution space, and Figure (14) shows the parallel coordinates of the objective functions, where the optimal solutions are shown on the south axis and the results of the non-optimal solutions on the north axis. The solutions in Figure (15) show a significant change in the distribution of breakers and the ratios of openings in the facade, and the appearance of compound and horizontal breakers. Table (14) shows the Objective functions before and after optimization and optimization ratios for each objective function. Pareto front solutions in Figure (**13**) depicts the laboratory performance problem's 5th-dimensional objective space, which includes five energy efficiency targets (EUI, ATCR, DA, UDI, and sDA) The X, Y, and Z axes indicate the objective functions, respectively. The Pareto Front component calculates the non-dominance value for any generation within the population and draws the pareto front for any given generation**.**

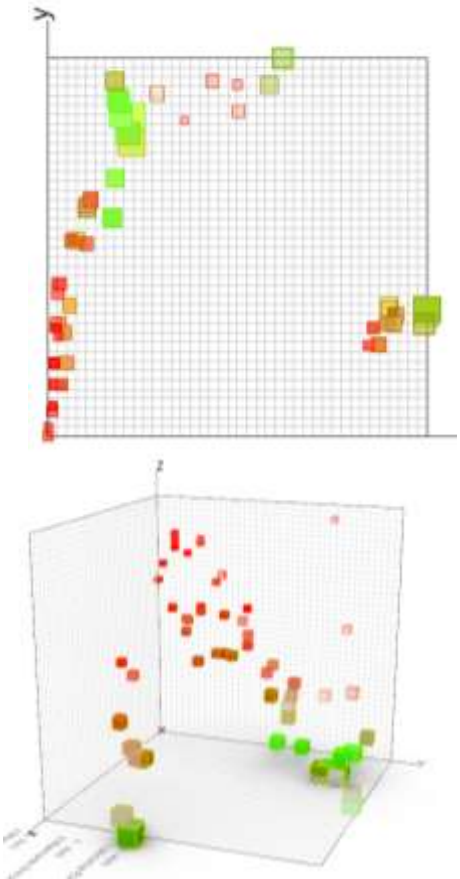


Figure 13 *Pareto front solutions in target space, laboratory, recurring role, Helmy building*

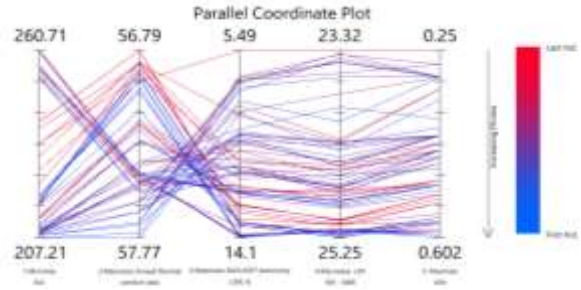


Figure 14 *parallel coordinates for the objective function, a recurring floor plan, Helmy Building*

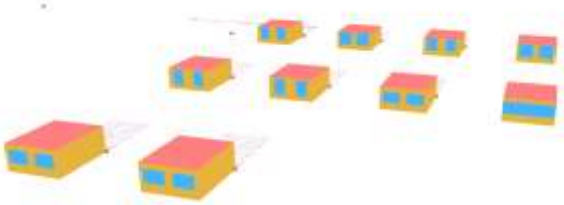


Figure 15 *Optimum pareto front solutions generated from optimization*

Table 11 *pareto front solutions genomes*

	shade depth	dist. Between shade	shade count	Louver Angle	WWR	R-Wall	U value glass	win height	win sill	shade depth
{0;1}	0	0.3	5	50	38	2	3.8	3	1.2	v

{1;4}	0	0.3	9	50	50	2	3.8	3	1.2	v
{3;9}	0	0.3	5	50	38	2	3.8	3	1.2	v
{7;9}	0	0.3	9	50	50	2	1.8	3	1.2	v
{9;6}	0.09	0.3	12	-10	34	2	2.6	3	0.88	v
{10;9}	0.02	0.3	12	-10	34	2	2.6	3	0.88	v
{13;6}	0.05	0.3	9	0	34	2	2.6	2	1.32	v
{15;1}	0.09	1	9	0	50	2	2.6	2	1.3	H
{17;5}	0.15	0.2	3	0	34	0.77	1.8	2	1.4	H
{19;9}	0.15	0.9	3	0	34	1.5	1.8	2	1.37	v

Table 12 *Objective functions before and after optimization*

Base case results	Optimum solution results	Optimization ratio %	Objective function
260.7	207.71	20	EUI Kwh/m^2
56.7	57.7	1.7	ANNUAL THERMAL COMFORT RATIO (ATCR)
5.4	14.1	62	DAYLIGHT AUTONOMY (DA) %
23.3	25.2	8	UDI 100 - 3000
25	60	58	SDA 50%

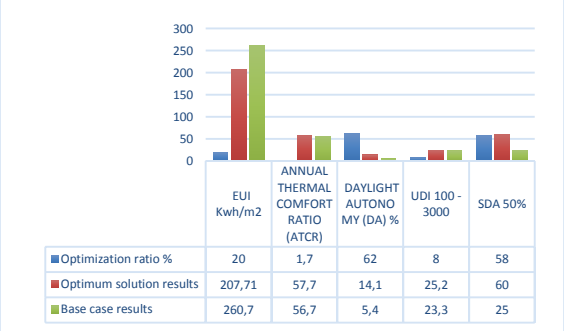


Figure 16 *Baseline functions, achieved objective functions, and optimization ratio for the typical lab of the Helmy Building*

9. Results

This research follows an integrated framework aimed at balancing competing objectives to reduce energy consumption while maximizing thermal and visual comfort. The process is divided into four sequential phases: the preparation phase, which includes gathering comprehensive building data such as construction specifications, operating schedules, and current energy consumption patterns; the design and simulation phase, in which a three-dimensional parametric digital model is developed, allowing control over variables such as window-to-wall ratios (WWR), glass types, shading devices, openings and their dimensions, wall resistance, and glass thermal conductivity; the optimization phase, where genetic algorithms (NSGA-II via the Wallacei engine) are applied to explore 200 design solutions, creating a Pareto front; The multi-objective optimization process resulted in significant performance improvements across five key indicators: energy consumption intensity, annual thermal comfort ratio, Daylight Autonomy, Useful daylight illuminance, and spatial natural light independence. The optimization successfully reduced energy consumption intensity by 20%, an increase of ATCR by 1.7%, an increase in DA of 62%, increase of UDI of 8% and increase of 58% in sDA that represents balanced solutions between different objectives that enhance building performance as shown in figure (16)

10. Conclusion

This research focused on representing the details of parametric based optimization using genetic algorithms in Grasshopper with ladybug and

Honeybee tools Wallacie genetic optimizer. focused on developing a methodology for multi-objective performance optimization of laboratory spaces by identifying several variables that improve the energy efficiency, thermal comfort, and natural lighting of alternatives developed during the design phase. The resulting design alternatives are considered a set of optimal or near-optimal tradeoff solutions The used metrics for daylighting and energy performance and thermal comfort were EUI, sDA, ATCR respectively, the research used analytical approach by analyzing university buildings optimization studies and projects, where the architectural design of universities laboratories and student buildings was optimized from a multi-objective optimization perspective, aiming to reduce energy consumption and achieve maximum thermal and visual comfort for users. And applied the method in practical approach by generating parametric model, simulations, and multiple scenarios were used to arrive at optimal designs that meet sustainability goals, while also examining the interrelationship between design variables. Significant reductions were achieved in total annual energy consumption reduction by 20%, and thermal and visual comfort levels were raised to comply with international standards. The most significant influences on design efficiency were building orientation, window-to-wall ratio, and glass type.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.
- **Use of AI Tools:** The author(s) declare that no generative AI or AI-assisted technologies were used in the writing process of this manuscript.

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