Performance-Based Material Selection in Future Housing: A Mediterranean Climate Case

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Abstract. Designers constantly develop materials with different technical properties to provide optimum indoor comfort conditions with minimum energy consumption. Ensuring indoor thermal comfort conditions in residential buildings, where people spend a significant portion of their time, is a challenge that must be addressed. In recent years, the climate crisis (CC) has caused temperatures to rise, particularly in warm climate regions. The study proposes a computational framework for a residential model that demonstrates optimal thermal performance for at least 50 years in hot climate regions affected by the CC. Within the scope of the study's objective, it primarily focuses on a residential building in Balıkesir that exhibits the characteristics of the Mediterranean climate type (CSA), a hot climate type. Honeybee performed energy simulations for the residential building under current climate conditions and a 2080 weather scenario generated by Meteonorm. The results showed that the building's energy consumption would increase by 12% in 2080. Within this scope, the study optimised the residential building envelope and interior design parameters. Furthermore, the study aimed to compare the effectiveness of the Genetic Algorithm (GA), frequently used in architectural design problems in the literature, with different algorithms by employing the GA and the RbfOpt algorithm.

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1 Introduction

The construction sector holds significant potential in energy consumption and sustainability worldwide [1]. Energy used to ensure indoor comfort throughout a building's life cycle accounts for a substantial proportion of total energy use. Building envelope elements influence heat transfer between indoor and outdoor spaces. Failure to select appropriate building envelope elements during the design phase increases the energy required to achieve optimal thermal comfort indoors. Ensuring indoor thermal comfort with minimum energy consumption in residential buildings, where people spend a large part of their lives, is a challenge that must be overcome. In this context, early studies in the literature estimated building energy performance using mathematical equations [2]. With the advancement of technology, building energy simulations have been used in energy performance predictions. In this process, designers have attempted to reach the correct result through simulations by changing building design parameters through trial and error. Today, optimisation techniques perform energy simulations on millions of different design alternatives during the building design phase and present the proposal that provides optimal performance [3].

In simulation and optimisation studies, weather data for the location of the building is essential. Studies in the literature mostly use weather data in epw format based on the Typical Meteorological Year (TMY). This format, obtained by examining the region over 20-30 years, contains hourly data on temperature, humidity, solar radiation, wind speed/direction, pressure, and cloud cover for the region [4]. However, the climate crisis (CC) and the greenhouse effect are causing increased air temperatures and duration of sunshine [5, 6, 7]. This situation will increase the energy required to ensure thermal comfort indoors, especially in hot climate regions during the summer months. The United Nations Sustainable Development Goal 11 (UN SDG 11) aims to achieve carbon-neutral cities. Considering that residential buildings serve for 50+ years, rising air temperatures should be considered during the design phase, especially in hot climate regions. Therefore, this study draws attention to optimising residential design parameters in future weather scenarios.

Table 1 shows the differences between studies conducted in the literature on energy consumption and this study. Studies in the literature that aim to minimise energy consumption mostly do not consider the increase in air temperatures due to the CC effect. [8] aimed to quantitatively determine the energy-saving potential at the design stage using dynamic façade materials. In this context, the study utilised parametric modelling and constrained optimisation approaches. It developed different façade material design procedures based on two case studies in the USA. The study's results showed that geometry optimisation achieved energy savings of up to 2%, while material optimisation achieved savings of up to 19% [8]. Zeng aimed to optimise the design and control aspects of adaptive building façade systems. A finite-difference (FD) model was developed in the MATLAB environment to achieve this goal. The developed FD model can run up to 84% faster than packaged simulation software. The results show that the model accelerates the design and control optimisation processes. Table 1 highlights studies in the literature investigating the effect of building materials on building energy performance based on TMY weather data. Unlike similar studies, this work aims to develop a computational framework for residential design in Balıkesir, which has a CSA climate type, considering the 2080 weather scenario. The study is novel in that it uses future weather scenarios to select building materials. In this context, the study considered an existing residence in Balıkesir.

Table 1. Energy optimisation studies in the literature.

Ref.	Method	Building Type	Weather Data	Objective
This Study	Galapagos (GA) – Opossum EnergyPlus	Residential	Future	Total Energy Consumption
[8]	Brute Force Search Algorithm(Sequential Search)- EnergyPlus	Office	Current	Energy demand
[9]	Genetic Algorithm- EnergyPlus	Office	Current	Energy cost
[10]	Evolutionary algorithm (Galapagos)/ANN- EnergyPlus	Office	Current	Energy demand
[11]	Non-Dominated Sorting Genetic Algorithm 2- TRNSYS	Office	Current	Energy demand, IEQ
[12]	Particle Swarm Optimization with Generalized Pattern Search- EnergyPlus	Office	Current	Energy demand

When Case Building was constructed in 1993, current sustainability and climate change adaptation criteria were not considered during the design process. Simulating this building's energy consumption in 2080 is essential for improving the performance of the existing building stock in future climate scenarios. The International Energy Agency's 2021 report states that 80% of the buildings used in 2050 have already been built [13]. This means that the existing building stock, guided by certifications such as LEED, BREEAM, DGNB, etc., will be more resilient to future climate conditions thanks to "green buildings", high-performance facades, passive design principles and renewable energy integration [14]. The study aims to improve the energy performance of a building constructed in 1993 under the influence of climate change, thereby also targeting the improvement of the existing building stock.

2 Material and Method

The study aims to propose a residential building that provides optimal thermal comfort indoors, taking into account the rising air temperatures under the influence of CC. Within the scope of the study objective, a residential building in Balikesir, which has a CSA climate type, was examined. Primarily, for the datalogger model calibration, air temperature and relative humidity were recorded in this building between 26.12.2024 – 31.12.2024 dates. Within the scope of the study objective, the living area measured in the residence was modelled parametrically in Rhino/Grasshopper. Meteonorm v8 created a 2080 weather scenario of Balikesir based on RCP 4.5 greenhouse gas emissions. Honeybee identified the increase in energy consumption under current conditions using the residence's current climate data and 2080 weather scenarios. Galapagos and Opossum optimised energy consumption by balancing the specified parameters. Figure 1 shows the study workflow.

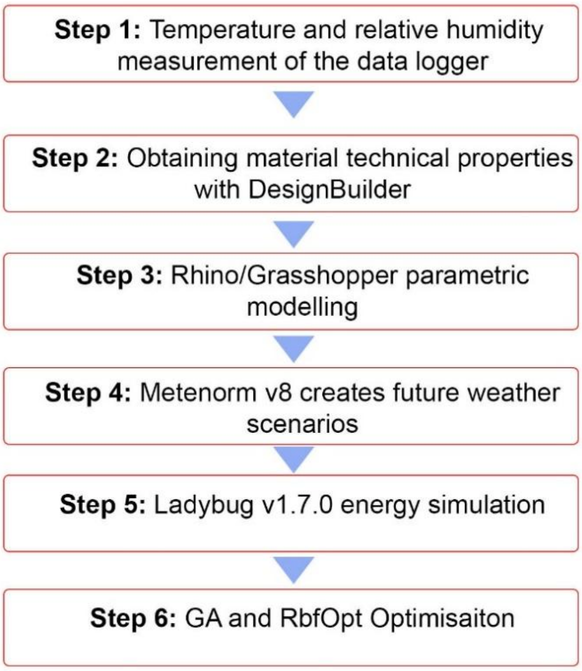


Fig. 1. Workflow of the study.

The datalogger primarily measured temperature and humidity in the residence. Meteonorm v8 created a weather scenario for Balıkesir for the year 2080. Ladybug v1.7.0 calculated the residential building's current and future energy consumption using its parametric model, showing a 12% increase in energy consumption over 50 years. The computational framework optimised the building envelope elements, resulting in a 11% reduction in future energy consumption.

2.1 Balikesir Climate and Case Building

The Köppen-Geiger climate classification indicates that Turkey has 13 distinct climate regions. Balıkesir, where the fieldwork was conducted, is located in the very dry and hot summer climate (CSA) region of this classification [15]. The General Directorate of Meteorology notes that between 1937 and 2017, the lowest average temperature in January in Balıkesir was 4.8 °C, while the highest temperature in July was 24.8 °C, and also points out that temperatures are on an upward trend [16].

The residence subject to the field study was constructed in 1993 using a reinforced concrete frame system. The residence is located on the 5th floor of the apartment building. The floors above and below the residence serve the same function and are actively used. Figure 2 shows the relationship between the residence and its surroundings.

Fig. 2. Location of the case building.

The building makes an angle of approximately 135 degrees with respect to the north. As can be seen in Figure 3, the south facade of the building is adjacent, and there are windows only on the north and south facades. As can be seen in the figure, the ground floors of the investigated building and adjacent structures are for commercial use, and the upper floors are for residential use. The investigated building consists of 1 basement floor + ground floor + mezzanine floor + 6 normal floors.

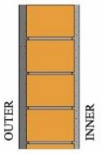
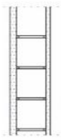
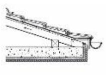
Fig. 3. South façade of the case building.

The ground floor of the building contains a total of 4 commercial shops, while the basement floor houses shops and shared storage areas. There are two flats on the standard floors, which are positioned along the north-south axis (Figure 4). The flat under consideration in the site survey is located on the east side of the building. The gross area of the apartment under examination is 76.80 m², and its net area is 67.21 m². The apartment's balconies are enclosed and used as a winter garden. The gross volume of the apartment is 199.68 m³, and its net volume is 174.75 m³. As shown in the floor plan in Figure 4, this flat consists of a living room, a room, a bedroom, a bathroom, a corridor, a toilet, and two winter gardens. The data logger took measurements in the room facing the south side of the building.

Fig. 4. Normal floor plan of the case building.

The exterior wall material of the building is aerated concrete. There is no insulation material in the walls. The interior walls are brick. The floors are reinforced concrete and 20 cm thick. The roof consists of tiles, bituminous waterproofing, roof boarding, and beams running from the outside to the inside. PVC double-glazing has been used in the building. Table 2 shows the technical properties of the building envelope elements. The u-values of the materials have been calculated in the DesignBuilder.

Table 2. Base Case materials thicknesses and thermal values.

Base Case Materials				
Component	U-value W/m² - K	Material	Conductivity	Thickness (m)
External Wall  	0.878	Cement/Plaster/ Mortar	0.35	0.040
		Aerated Concrete Block	0.240	0.190
		Gypsum Plastering	0.40	0.025
Interior Wall 	2.194	Cement/Plaster/ Mortar	0.72	0.72
		Brick	0.72	0.72
		Gypsum Plastering	0,400	0.400
Internal Floor	1.420	Flooring Blocks	0.14	0.14
		0,3 in Shingles		
		Concrete, Reinforced (with %2 steel)	2.50	2.50
		Gypsum Plastering	0,40	0,40
Pitched Roof 	0.374	Clay Tile (roofing)	1.00	1.00
		MW Stone Wool	0.040	0.040
		Roofing Felt	0.19	0.19

2.2 Datalogger Measurement

A data logger is a device that records data such as temperature and humidity from sensors. The data logger can be fully utilised to analyse stress levels on operators or test subjects during individual processes or individual stages of a work process. The data logger performed measurements in the south-facing room during case building between 26 December 2024 and 31 December 2024. The study utilised data from a limited period during the calibration process. This constitutes a limitation of the study. However, collecting data over a long period presents a disadvantage in terms of time. The primary objective of calibration is to demonstrate the reliability of the simulation-based optimisation process. The validation of the model using data from the limited time period was sufficient for consistency, and future studies could conduct longer-term measurements to improve the accuracy level of the model. Figure 5 shows the Onset Hobo data logger used to record data in the study.

Fig. 5. Onset Hobo Datalogger.

2.3 Computational Framework

The study developed computational optimisation to achieve its objective. Within this scope, it primarily modelled the south-facing room where on-site measurements were taken using Rhino/Grasshopper in a parametric manner. Meteonorm v8 created Balıkesir's 2080 weather scenario in epw format, taking into account the CC effect. Using the current status of the Honeybee case building, the study examined the change in the building's energy consumption over a 50-year period using Balıkesir's current climate data and 2080 weather scenarios. In addition, the study compared simulation results using current weather data for model calibration with on-site measurement results.

The Galapagos GA and Opossum RbfOpt algorithms have each run the Single Objective Optimisation (SOO) process separately. The algorithms aimed to reduce Total Energy Consumption (TEC) by balancing the parameters shown in Table 3. In this context, the optimisation used 20 generations and 50 populations. Optimisation automatically stops after 1000 iterations. The optimisation process includes 2 test runs and 1 final run for each algorithm. The work performed the test runs at 200 iterations and checked whether any errors had occurred during the process. The study also recorded the times taken by both algorithms to reach the best model. Thus, the results also evaluate the algorithms in the material selection problem for residential buildings.

Table 3. Optimised parameters.

Parameter	Unit	Values
Exterior Wall Thickness	m	[0.10 – 0.30]
Interior Wall Thickness	m	[0.10 – 0.20]
Exterior Roof Thickness	m	[0.08 – 0.20]
Floor Thickness	m	[0.10 – 0.25]
Glass Transmittance	%	[0.1 – 0.9]

3 Results

The data logger measured temperature and relative humidity in the residence subject to the field study during the heating period over one week. Figure 6 shows the temperature values in °C and relative humidity values in % obtained by the data logger as a result of the measurements. The data logger measured a maximum temperature of 22.39 °C and a minimum temperature of 17.44 °C. The highest relative humidity level indoors was 57.55%, while the lowest was 32.95%.

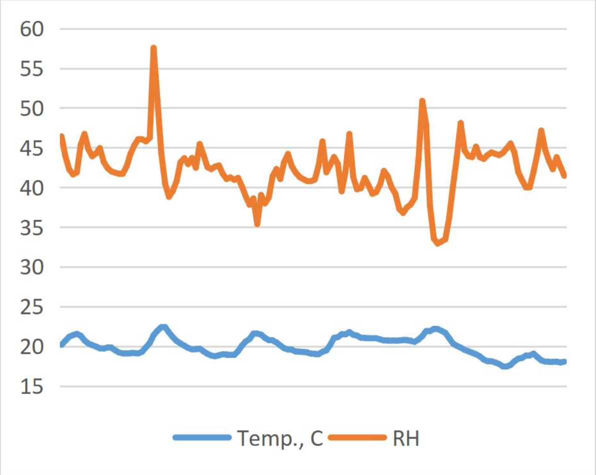


Fig. 6. Temperature (°C) and relative humidity (%) values measured by the data logger.

The Ladybug v1.7.0 plug-in performed energy simulation using the parametric model of the residence based on the EnergyPlus platform. The simulation process primarily utilised Balıkesir's current weather scenario. The study compared the simulation with actual simulation data. The study based its calibration process on the ASHRAE Standard's error margins of MBE (6.15%) and CVRMSE (12.15%). According to these values, the model is reliable.

Meteonorm v8 has created a 2080 weather scenario for the province of Balıkesir based on RCP4.5. Based on the current model, the Ladybug v1.7.0 plug-in has performed an energy simulation using Balıkesir's future weather scenario. The study compared the results of simulations using Balıkesir's current and 2080 weather data. The results show that energy consumption increased by approximately 12% over 50 years due to the CC effect. This highlights the importance of using future weather data in the simulation process.

GA and RbfOpt have optimised the residential design parameters in Table 3. The study has documented the optimisation process. Figure 7 shows the time the algorithms took to reach the best result in the first 1000 iterations. The best proposal obtained by RbfOpt has a TEC of 675.001,074, while GA's is 674.934,515. GA reached its best proposal within the first 200 iterations. The energy consumption results of both algorithms are broadly similar. This indicates that the material selection problem can produce values close to the optimal solution in performance improvement using both the GA and RbfOpt algorithms. GA converges faster than RbfOpt and, being a population-based optimisation method, scans the solution space more quickly, thus reaching a solution faster [17]. Since it provides results with similar accuracy and in a short time, GA becomes essential in making early design decisions.

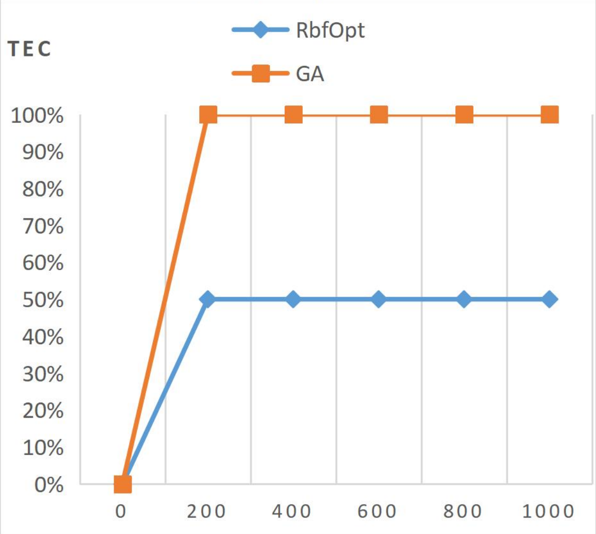


Fig. 7. Comparison graph of GA and RbfOpt algorithms.

Table 4 shows the parameters of the models that achieved the best performance due to the optimisation process carried out by GA and RbfOpt. The table shows that RbfOpt has greater internal/external wall thicknesses. The exterior roof thickness of GA's best model is approximately twice that of RbfOpt. The floor thickness of both models is similar. Furthermore, the glass transmittance of the model obtained by GA is greater.

Table 4. Optimised models.

Parameter	GA	RbfOpt
Exterior Wall Thickness	24	29
Interior Wall Thickness	8	19
Exterior Roof Thickness	21	11
Floor Thickness	13	14
Glass Transmittance	0.84	0.66

4 Conclusion

UN SDG 11 aims to achieve net-zero emission cities. In this context, the efficient use of energy in buildings is crucial for reducing carbon emissions. Homes, where people spend most of their lives, are responsible for significant energy consumption. Designers can reduce energy consumption by correctly planning building envelope elements. Building energy simulations are essential in this context. Optimisation methods, which have developed alongside technological advances, enable the evaluation of millions of design proposals. However, rising air temperatures due to the CC effect will prevent simulation results from providing accurate performance over 50 years. Considering that residential buildings serve for at least 50 years, using future weather scenarios in simulations will ensure that the model obtained will continue to perform accurately.

The study optimises building envelope design parameters for a residential building in Balıkesir with a CSA climate type (hot climate) to provide optimum thermal performance with minimum energy over 50 years. In this context, the GA and RbfOpt algorithms were used to carry out the optimisation process. The study recorded the optimisation process. According to the records, the model proposed by GA consumes less energy than the one proposed by RbfOpt. Although the model obtained by RbfOpt has thicker internal/external walls than the one proposed by GA, the thinner roof thickness resulted in higher energy consumption.

This study has created a 2080 weather scenario for Balıkesir under the influence of the CC effect and achieved an 11% reduction in energy demand by optimising materials in this scenario. In this sense, the study provides an innovative contribution to the literature compared to existing facade/material-based research. Studies addressing energy performance mainly consider current climate data. Like most studies in the literature, [18] states that energy savings of 14–36% can be achieved by using electrochromic glass on the west facade, and current weather data was also used. [19], which investigated the effects of shifting towards green facade applications and reduced annual energy consumption by 10.6%. It also did not use future weather scenarios in its study. Despite reporting that cooling loads could increase by 91–116% between 2020 and 2080 [20], this study achieved 11% energy savings using 2080 weather scenarios.

This study highlights the necessity for designers to consider the increased air temperatures and duration of sunshine in hot climate regions due to the CC effect. The study only considers energy performance. Furthermore, the study was conducted only on a single plot area. These points are the limitations of this study. Future studies could improve energy, thermal, lighting, and ventilation performance by using future weather scenarios. In addition, future studies could offer design recommendations for entire regions with hot climate types, rather than focusing on a single plot point.

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