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Enhancing Thermal Comfort in Social Housing: A Parametric Sensitivity Analysis in Response to Climate Change in Guelma, Algeria.

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Abstract

In response to the pressing need to mitigate climate change impacts on residential buildings, this paper investigates the imperative task of enhancing thermal comfort. This study takes a close look at social housing in Guelma, Algeria, using a case study framework, and explores how climate change impacts it through the application of sensitivity analysis and a parametric approach. It investigates how climate scenarios, insulation, and window features influence thermal comfort, using tools like Rhinoceros, Grasshopper, Ladybug, and Honeybee, along with Excel's Two-Variable Data Table. The research highlights the effect of rising temperatures due to climate change projections for the 2050s and 2080s on thermal comfort. It underscores the essential roles of insulation and windows in achieving comfort. Improved insulation and specialized glazing create stable indoor environments, reducing occupant discomfort. This research has broad implications for guiding eco-friendly and comfortable indoor space design and emphasizes the responsibilities of architects, designers, and policymakers in promoting sustainable and climate-resilient building practices. Guelma, Algeria's social housing serves as a real-world example illustrating the challenges posed by changing climate conditions.

Keywords: *Climate Change, Social Housing, Thermal Comfort, Sensitivity Analysis, Parametric Approach.*

Nomenclature	
IPCC	Intergovernmental Panel on Climate Change
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
TMY	Typical meteorological year
EPW	Energy plus weather file
SA	Sensitive analysis
HVAC	heating, ventilation and air-conditioning
ASHRAE	American society of heating, cooling, and air conditioning engineers
ANSI	American National Standards Institute
HadCM3	Hadley Centre Coupled Model, version 3
DDC	Data Distribution Centre

Introduction

In the context of sustainable development and in alignment with the conclusions of the Intergovernmental Panel on Climate Change (IPCC) (6ème rapport du GIEC, 2022.), the building sector has emerged as a pivotal player with the potential to significantly contribute to

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the mitigation of global warming. Recognized as a critical lever for reducing the environmental impact of human activities, the building sector has become a focal point of attention. This context underscores the urgent need for the design of sustainable architecture(Kirati et al., 2023). It has become increasingly evident that the static and permanent forms of traditional architecture are no longer well-suited for use in the face of the profound and ongoing changes in our climate. Nowhere is this more evident than in Algeria, a country that mirrors the challenges faced by many developing nations. Within Algeria, the residential sector stands out as a major energy consumer (Bilan_energetique_2021.), making it a focal point for addressing the pressing issue of sustainable building design.

At the heart of this challenge lies the complex issue of harmonizing architectural design with the specific environmental and climatic conditions of a region. The lack of this harmony has triggered a genuine crisis, marked by the erosion of aesthetic and creative values and the neglect of essential functional aspects, all while failing to account for the compatibility of the built environment with its natural surroundings. To address this multifaceted challenge and the associated risks to humanity, researchers (Gercek & Durmuş Arsan, 2019,Hopfe & Hensen, 2011, Menberg et al., 2016, Mukkavaara & Shadram, 2021, Al-Obaidy et al., 2022)have embarked on a two-fold approach. On one front, there is a compelling need to enhance our understanding of global warming and climate change and their implications for the built environment. Concurrently, the application of sensitivity analysis, coupled with the importance of parametric design, has proven to be indispensable in the realms of decision support and building performance assessment(R. M. Sakiyama et al., 2021). This is particularly pertinent when considering that the energy demands and environmental performance of buildings are highly sensitive to the evolving dynamics of future weather conditions. It is, therefore, essential to incorporate climate-specific considerations into the earliest stages of building design and rely on comprehensive sensitivity analyses, aided by the parametric design approach.

By integrating the issues of climate change (Farah et al., 2019, Li, 2021, Roux et al., 2016), building energy performance, and thermal comfort (Yukai Zou, et al., 2021) (Mohamed Kamar et al., 2019; Omidvar & Kim, 2020; Sakhri et al., 2022). This research aims to provide vital insights for the optimization of residential buildings in anticipation of changing climate conditions. The results of this study have the potential to significantly influence design decisions and policies related to sustainable construction, ultimately contributing to the creation of more comfortable and environmentally responsible indoor environments for occupants. Within this overarching context, research on thermal comfort, with a specific focus on the Predicted Mean Vote (PMV) model and the PPD (ANSI/ASHRAE Standard 55-2017.), emerges as of paramount importance. The PMV model (Dyvia et Arif ,. 2021), renowned for its capacity to assess thermal comfort by accounting for an array of variables encompassing ambient temperature, humidity, air velocity, and building characteristics, stands as a pivotal tool in the field. Yet, in the face of the multifaceted challenges posed by climate change, it is imperative to delve deeper into the sensitivity of this model to varying climatic conditions.

This study is precisely designed to fulfill this goal, aiming to unravel the complex interactions between potential climate changes and their influence on the thermal comfort of buildings. Through the meticulous application of sensitivity analysis, our objective is too precise the key parameters that govern the model's response to climatic variations. By weaving together, the intricate threads of climate change, building energy performance, and thermal comfort, this research endeavors to yield insights for the optimization of residential buildings in anticipation of the forthcoming climate realities. The implications of this study are far-reaching, potentially reshaping design decisions and policies pertinent to sustainable construction. Ultimately, our efforts are geared toward the creation of indoor environments that are both more comfortable and more ecologically responsible for their inhabitants.

The study's objective is to identify the key parameters influencing thermal performance in Guelma, Algeria's climatic region. This comprehensive investigation considers both the present weather conditions and the anticipated future weather climates, which will be generated using the CC World Weather Generator through the Morphy method (Rodrigues et al., 2023). The research will span the estimated lifespan of a building, set at 60 years (Ji et al., 2021). To achieve this objective, parametric design principles will be applied, focusing on the enhancement of thermal comfort within the context of social housing. The investigation will also assess the implications of climate change. Sensitivity analysis, specifically employing the Two-Variable Data Table method in Microsoft Excel, will be utilized to identify the critical parameters. This approach aims to inform and guide design decisions, ultimately contributing to the creation of a more sustainable and climate-resilient built environment.

Methodology

This research was developed in several distinct phases, (see Figure 1). It commences with the collection of essential data, including historical climate information for Guelma, Algeria's current weather conditions and future climate projections generated by the CC World Weather Generator through the Morphy method (Pouriya & Umberto, 2019). Simultaneously, data on existing social housing designs in the region are assembled. The subsequent step involves the formulation of a parametric design framework tailored to social housing in Guelma, enabling a wide range of design parameters to be flexibly adjusted. Following this, sensitivity analysis is carried out using Microsoft Excel, specifically utilizing the Two-Variable Data Table method. This involves selecting critical design parameters and climate-related variables, defining various parameter value ranges, and assessing the thermal performance of each scenario using the PMV and PPD models. The results are meticulously analyzed to identify paramount parameters influencing thermal comfort amidst the context of climate change. These findings guide recommendations for optimizing social housing design, and the research culminates in a comprehensive discussion of the practical implications. The paper concludes by summarizing key outcomes and suggesting prospects for future research in this domain. The proposed method is explained in details in the following subsections.

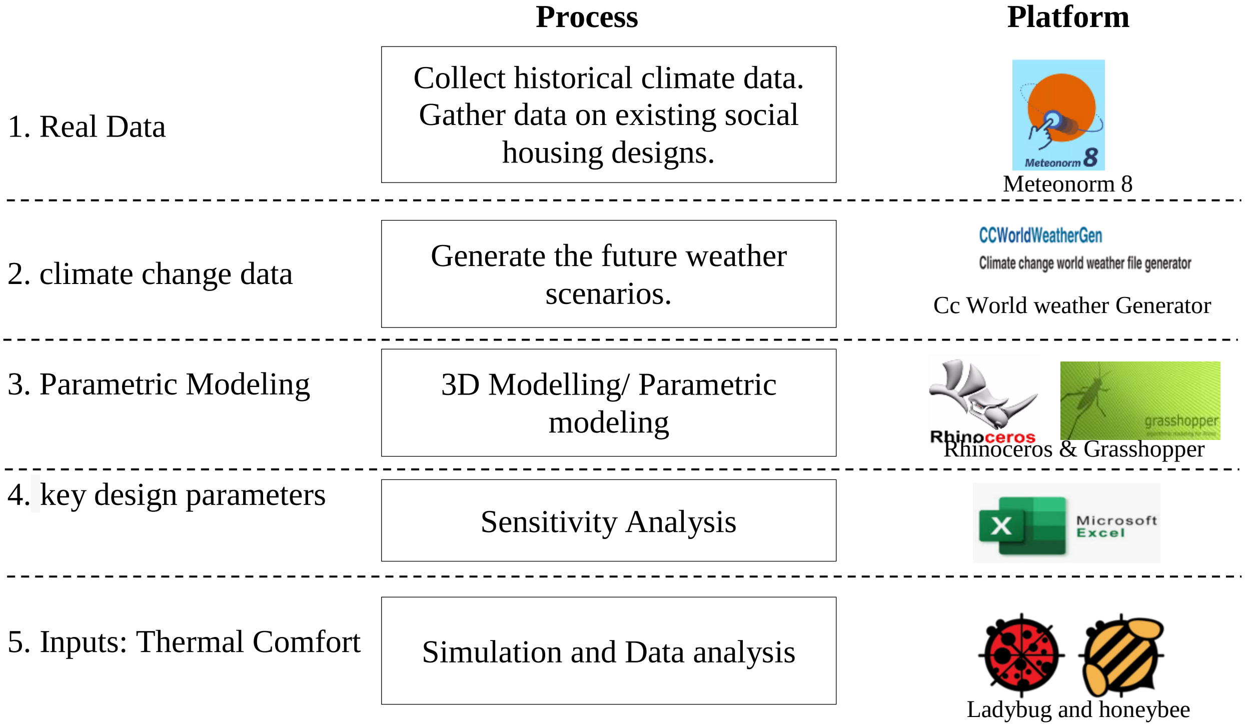


Figure 1. Schematic description of the workflow.

2.1. Generate the future weather scenarios

Meteorological parameters play a crucial role in influencing a building's energy demand and thermal comfort. The impact of climate change on the building sector has garnered increasing attention from researchers across related fields. Numerous studies have investigated building performance evaluation trends. For instance, (Andrić et al., 2016) research underscores the significance of considering climate change and building renovations when assessing long-term heat demand. It also highlights the potential of sustainable district heating solutions to adapt and remain effective in a changing environment.(Jentsch et al., 2008) emphasizes the growing importance of simulation packages for evaluating building performance, particularly in terms of energy efficiency and occupant comfort. The paper highlights a significant challenge related to the use of current industry-standard weather files for building simulations. These files are often inadequate for assessing the potential impacts of climate change, especially in relation to the risks associated with summer overheating. This underscores the importance of incorporating future weather conditions or climate change in the simulation process.

This paper presents a method for creating future weather data using the Climate Change World Weather File Generator (CCWorldWeatherGen)(*Manual_weather_tool.2017*). This tool leverages IPCC TAR model summary data obtained from the HadCM3 A2 experiment ensemble, which can be accessed through the IPCC Data Distribution Centre (DDC). CCWorldWeatherGen streamlines the generation of climate change weather files tailored for building performance simulation programs. It is an Excel-based tool and has the capability to transform "present-day" EPW weather files into climate change EPW or TMY2 files, ensuring compatibility with a wide range of building performance simulation programs.

The underlying procedures for weather file generation in CCWorldWeatherGen are rooted in the "morphing" methodology, specifically designed for adapting weather data to climate change scenarios. Additionally, this tool incorporates calculation routines for producing simulation-ready EPW and TMY2 files. This comprehensive approach represents a significant advancement in effectively addressing the challenges associated with climate change within the domain of building performance analysis.

Weather files for the 2050s and 2080s were generated based on the HadCM3 A2 scenario. These files will be employed in the thermal performance evaluation of buildings. Initially, an EPW file representing the current weather conditions of the region, spanning the period from 2007 to 2021, was chosen as a foundational dataset. This file serves as the basis for the morphing method, which will ultimately yield a climate change EPW weather file. This process is a critical step in preparing the necessary weather data for evaluating the thermal performance of structures in the context of evolving climate conditions.

2.2. Parametric approach

In Jabi's (Jabi, 2013) definition, parametric design is described as "an algorithmic thinking-based process that enables the expression of parameters and rules which, collectively, define, encode, and clarify the relationship between design intent and design response." Other perspectives have placed constraints on the scope of parametric design. (Zboinska, 2015)narrows parametric design down to a design approach that exclusively relies on algorithmic processes, considering it as a subset of algorithmic design. Similarly, (Elghandour et al., 2019.) state that parametric design is a code-based design approach that facilitates the generation of multiple design instances without the need for manual model recreation. (*Thesis - Khelil.2021.*)defines parametric design as an innovative approach to digital design that allows for the generation of complex geometric shapes through the exploitation of extensive data, which can be environmental, acoustic, social, structural, urban, and more. This approach enables the creation and control of intricate and adaptable forms but simultaneously demands a substantial mastery of the artistic and technical challenges associated with designing these shapes.

In Our paper, Parametric design principles are used to identify and assess the critical parameters influencing thermal comfort. This involves systematically varying and analyzing different parameters to understand their impact on thermal performance.

2.3. Sensitive analysis

The recent literature on building design increasingly emphasizes the use of sensitivity analysis to comprehend how climate change impacts the performance of buildings. These studies combine tools for simulating building performance with sensitivity analyses to enhance the design and renovation of buildings, all with the objective of achieving sustainable performance and resilience in the face of evolving climate challenges.

The study by (Pang et al., 2020) delves into the application of sensitivity analysis (SA) in building performance analysis, addressing the intricate nature of building systems with diverse parameters. It summarizes prior research on SA in this context, visualizes typical parameters for analysis, and provides insights into SA methods and tools.

Referring to the study conducted by (Delgarm et al., 2018), which employs sensitivity analysis, this study evaluates a methodology using a standard room model across various Iranian weather conditions. The results reveal that window size is the primary driver affecting cooling, heating, and overall energy consumption while glazing visible transmittance exerts the most substantial impact on lighting energy. This approach provides a valuable tool for enhancing building energy efficiency during the initial planning stages.

For our case study, a Two-Variable Data Table in Excel used to perform sensitivity analysis for building performance, specifically focusing on thermal comfort using the PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) models. In this scenario, we will consider climate change under the HadCM3 A2 scenario with six variables. Let's consider one variable as the climate change scenario (HadCM3 A2) and the other as a design variable (e.g., insulation level), and we'll calculate the impact on thermal comfort parameters (PMV and PPD). Results are presented in the fourth section.

2.4. Thermal performance metric

ASHRAE 55 *(ANSI/ASHRAE Standard 55-2017.*) places significant emphasis on thermal performance metrics, particularly the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) models, especially in the context of conditioned buildings with active heating and cooling systems. These models take into consideration the occupants' observed thermal sensations, making them widely recognized as the most commonly used thermal comfort indices(Cheung et al., 2019).

In conditioned buildings, the assumption is that observed thermal sensation ratings within the range of -1 to +1 indicate thermal satisfaction, while ratings outside this range signify thermal dissatisfaction. This assumption applies to the interior of buildings equipped with operational heating and cooling systems. However, for naturally ventilated buildings, the Predicted Percentage of Dissatisfied (PPD) model plays a vital role in quantifying the level of discomfort experienced by occupants. This strong focus on PMV and PPD highlights ASHRAE 55's thorough approach to ensuring that thermal comfort is effectively addressed in building design and operation.(*ANSI/ASHRAE Standard 55-2020*.)

The evaluation of thermal comfort metrics through the PMV and PPD models involved a simulation process. This simulation was executed using Rhino software, along with its associated plug-ins, including Grasshopper, Ladybug, and Honeybee. The results obtained from this simulation are detailed in the fourth section of the report, covering the analysis of both the current weather file and the future weather files corresponding to the 2050s and 2080s scenarios.

Base case

The case study involves a social housing residential building located in the southwestern part of Guelma, Algeria, as depicted in Figure 2. This building is part of a comprehensive urban planning project that encompasses around 600 apartments. To maintain consistency in the analysis, a specific building block was chosen from this development, consisting of five floors, with each floor housing four apartments. The selected room for evaluation and simulation is situated on the intermediate floor, specifically on the third floor, with a floor area of 19.47 square meters.

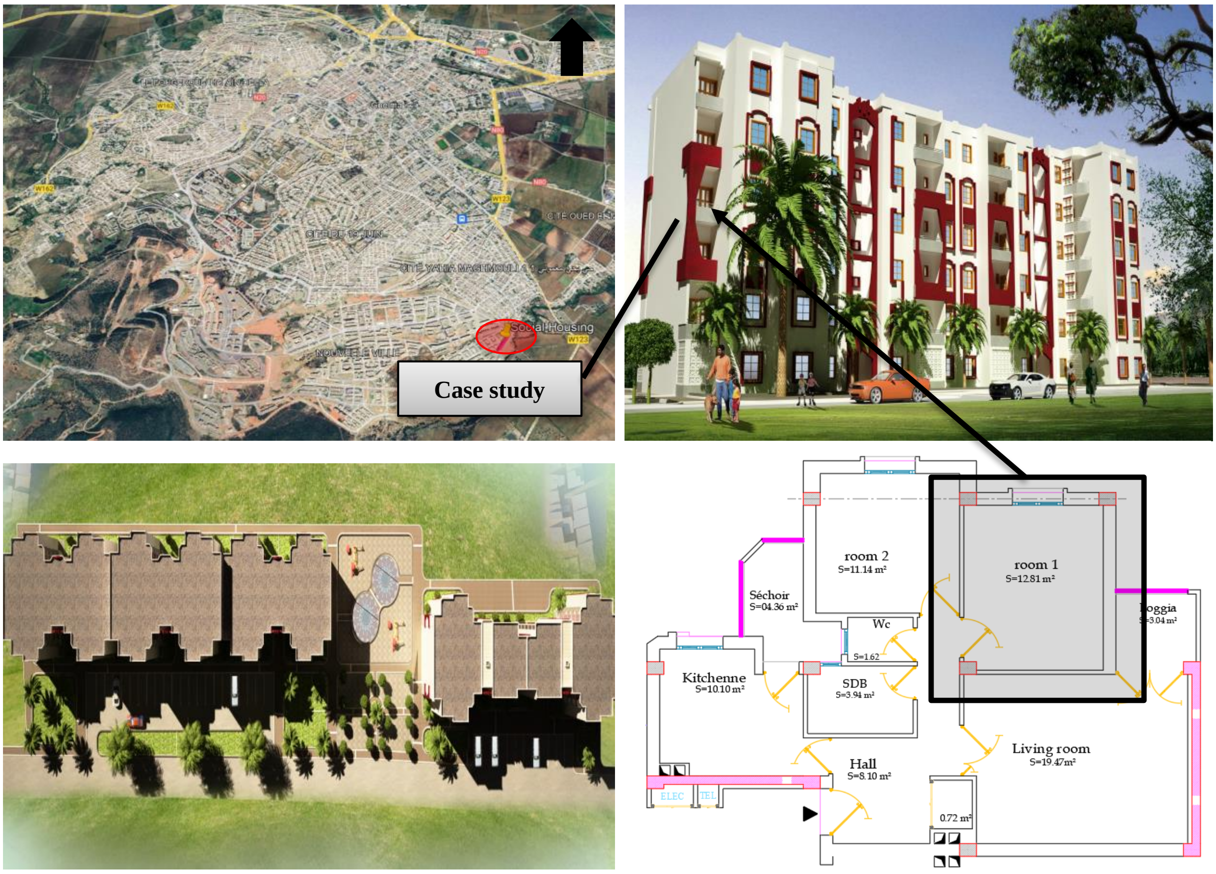


Figure 2. (a) School situation plan, (b) 3d model of the base case (c) Views of the building (d) selected room plan.

Guelma, Algeria, is characterized by a hot-summer Mediterranean climate (Csa) following the Köppen classification (*Köppen Classification*, 2007). To conduct the simulation, a typical meteorological year (TMY) file was generated using Meteonorm 8 software and subsequently imported into the Ladybug plug-in, as illustrated in Figure 3. This TMY file, spanning 14 years, is detailed in Table 1. It's worth noting that the summer season experiences an average temperature of approximately 27°C, with July and August being the hottest months. Conversely, the coldest month, January, records an average temperature of around 8-10°C.

This climatic data is of paramount importance during the design phase to ensure that occupants' thermal comfort is not compromised.

Table. 1. Selected years of each month in the Weather Year for the period of 2007–2021 (TMY file)

Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
2011	2014	2015	2013	2014	2014	2008	2008	2008	2012	2008	2021

The prevailing wind direction in the area is predominantly from the north, accounting for 12.5% of the observed frequency. Additionally, the directions of WNW, NNE, and NE exhibit a similar frequency, approximately 12%.

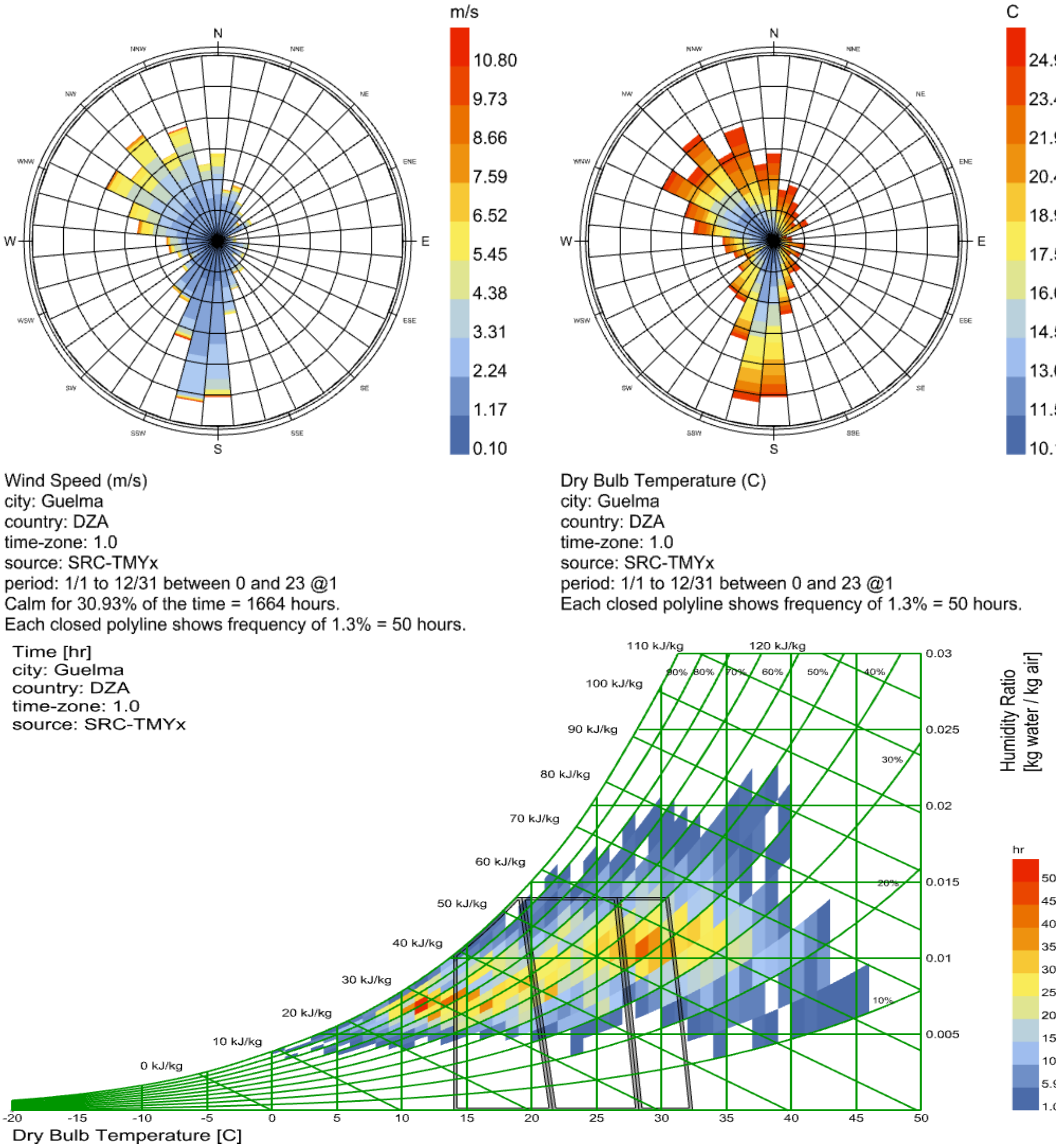


Figure 3. (a) Wind speed, (b) dry Bulb Temperature (c) Psychometric chart.

3.1. *The Base Case Analysis*

To assess the performance of the base case room, a thermal comfort metric, specifically the PMV and PPD, was chosen for year-round evaluation. This simulation was executed using the Honeybee and Ladybug plugins, maintaining certain constant parameters: a density of 0.3

people per square meter, HVAC set points of 26°C for cooling and 20°C for heating, and indoor temperature ranges of 22°C to 28°C for natural ventilation. Infiltration intensity was set at 0.00015 $m^3/s/m^2$. Climate data came from the TMY file and a future weather file spanning 2050 to 2080. Building geometry was created in Rhinoceros 3D, and Grasshopper was employed to implement EnergyPlus materials for the building envelope. For the base case, single-glazed windows with clear glass were utilized, and the exterior wall consisted of a hollow brick cavity wall with a 30cm air gap. The results of this analysis are presented in the following section.

Results and discussion

In this section, we delve into the comprehensive results regarding future weather generation and the thermal comfort, specifically focusing on the PMV and PPD models. Additionally, the outcomes of the sensitivity analysis for the base case are elaborated upon and thoroughly examined. This includes the following:

4.1. Projections for future typical years and trends in outdoor temperature variations.

Future typical years for Guelma, Algeria, were generated using the CC World Weather Generator, which is applied for the 2050s and 2080s, as shown in Table 2. a comparative view of the annual average temperature values between the (TMY) and the future weather file.

Table. 2. A comparative view of the annual average temperature under different weather file.

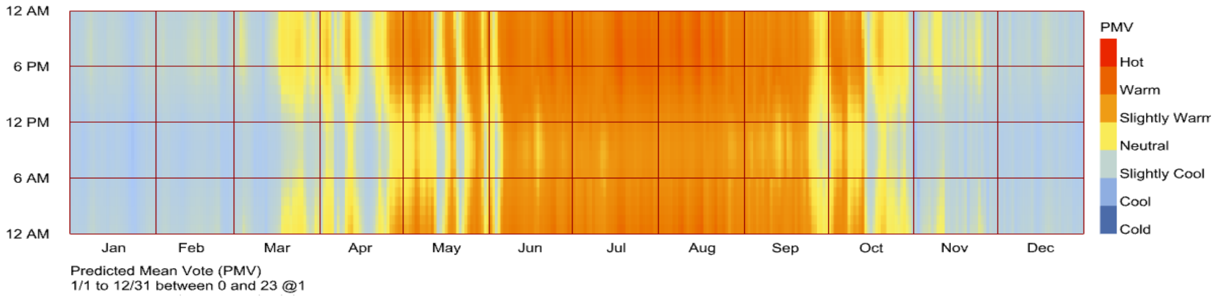
20.3Average Temperature (°c)	Months	Jan	Feb	Ma	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
	TMY	10.5	10.9	13.6	16.7	20.5	25.1	28.4	28.0	24.5	20.9	15.4	11.7
	2050s	11.7	12.0	14.6	17.8	22.0	27.0	30.3	29.9	26.2	22.4	16.8	12.9
	2080s	13.0	13.5	16.2	19.6	24.1	29.0	32.4	32.2	28.5	24.3	18.5	14.4

The results indicate a trend of increasing temperatures in the coming years. Currently, the annual average temperature is recorded at 18.8°C, with an expected 7.97% increase by 2050, reaching 20.3°C. For the 2080s, a 17.55% increase is anticipated, leading to an average temperature of 22.1°C. These results highlight the urgent need for adaptable building design solutions to guarantee occupant thermal comfort.

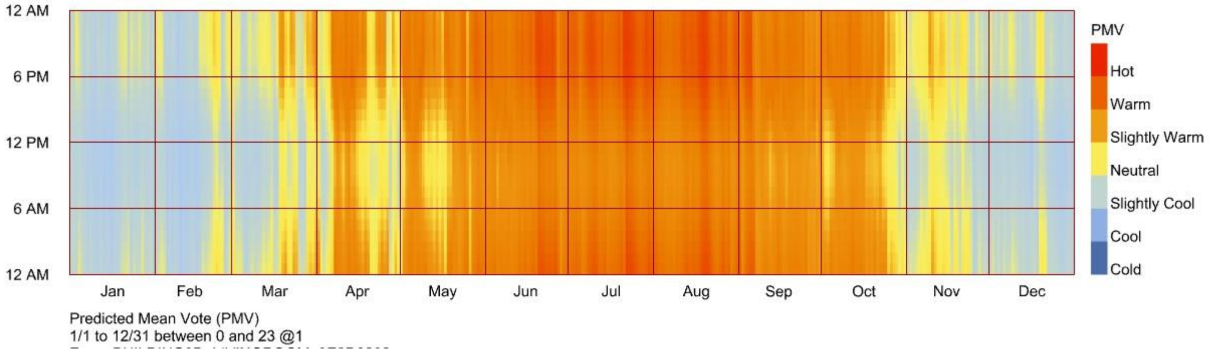
4.2. Indoor thermal performance of the base case

As shown In Figure 4, the PMV model assigns scores on a scale ranging from -3 to +3 (with -3 representing extreme cold and +3 indicating extreme heat). Environmental data, encompassing air temperature, radiant temperature, humidity, airspeed, and clothing insulation, sourced from the EPW file, containing current weather conditions and the future weather files for the 2050s and 2080s, were utilized as essential inputs. Additionally, the analysis took into account factors such as a metabolic rate set at 1 to represent a resting seated person and occupant preferences.

Under TMY



Under 2050s scenario



Under 2080s scenario

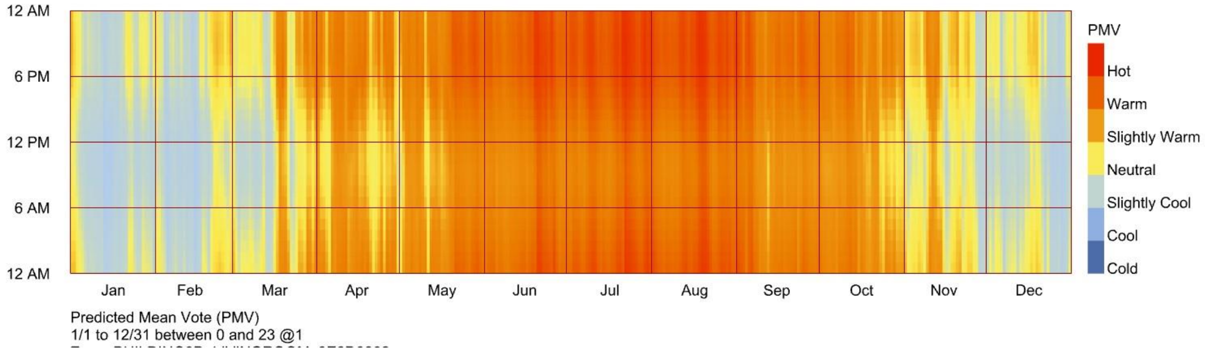


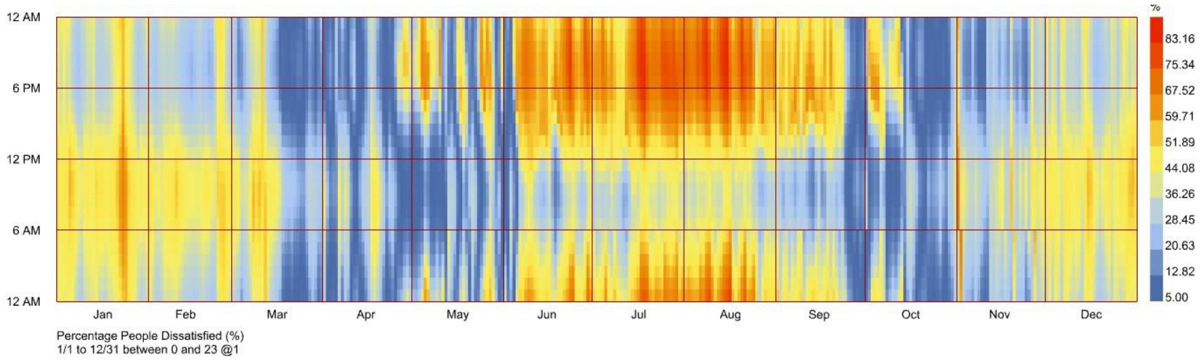
Figure 4. Predicted Mean Vote model, for the selected room under different weather conditions.

The PMV values obtained under current weather conditions, which deviate from the established comfort range, indicate a misalignment with the desired thermal comfort standards. Consequently, the calculated 12.56% thermal comfort level signifies the proportion of occupants expected to experience comfort within the predefined PMV range. These outcomes form a fundamental basis for subsequent examination and discussion, suggesting the potential necessity for adjustments or enhancements to achieve the desired comfort range. This pattern remains consistent, with minor variations, in the projections for future scenarios in the 2050s and 2080s. In these scenarios, a slight increase in thermal comfort by 5% and 15%, respectively, is observed.

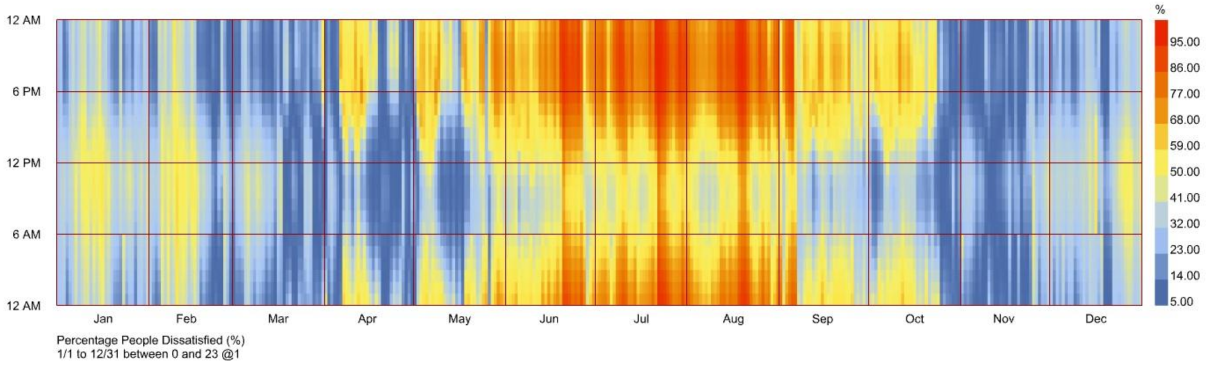
In Figure 5, the results from the PPD model provide insights into the percentage of occupants who may experience dissatisfaction with the thermal conditions. The PPD model aims to maintain a low percentage of dissatisfied occupants, typically ranging from 5% to 10% throughout various rooms. This suggests that the majority of building occupants are likely to find the thermal comfort satisfactory.

Elevated PPD percentages, such as the recorded 87.47% under current conditions, with a subsequent reduction of 0.82% and 2% in the 2050s and 2080s, respectively (resulting in values of 86.75% and 85.42%), indicate that thermal conditions in the rooms may not meet the expectations of the majority of occupants. To address this, it's crucial to identify and rectify specific factors contributing to the discomfort experienced by a small proportion of individuals. This could involve immediate adjustments, such as optimizing air vent positioning or offering personalized climate control options.

Under TMY



Under 2050s scenario



Under 2080s scenario

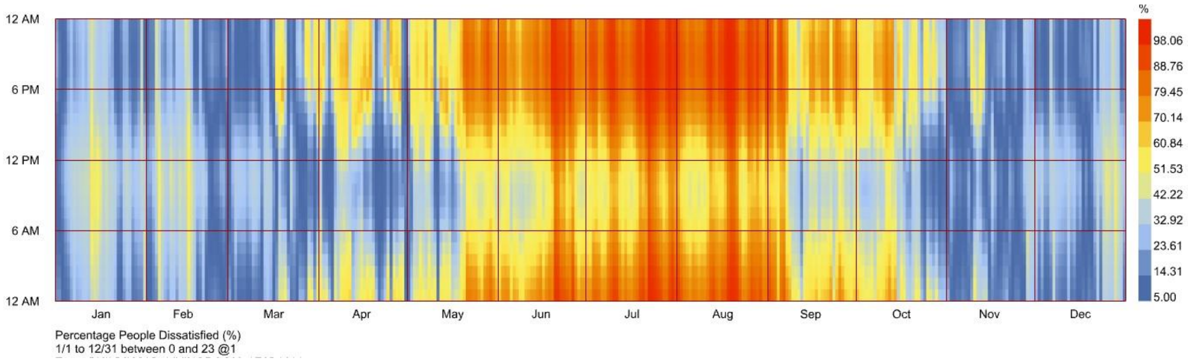
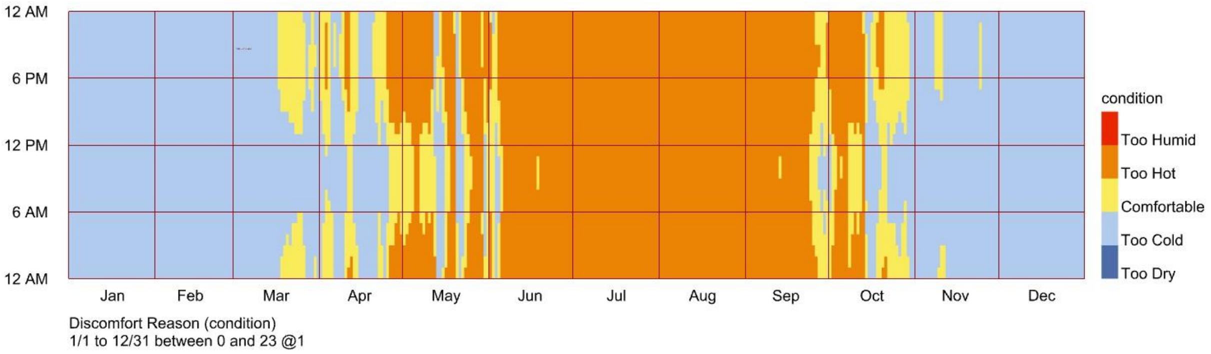


Figure. 5 Predicted Mean Vote model, for the selected room under different weather conditions.

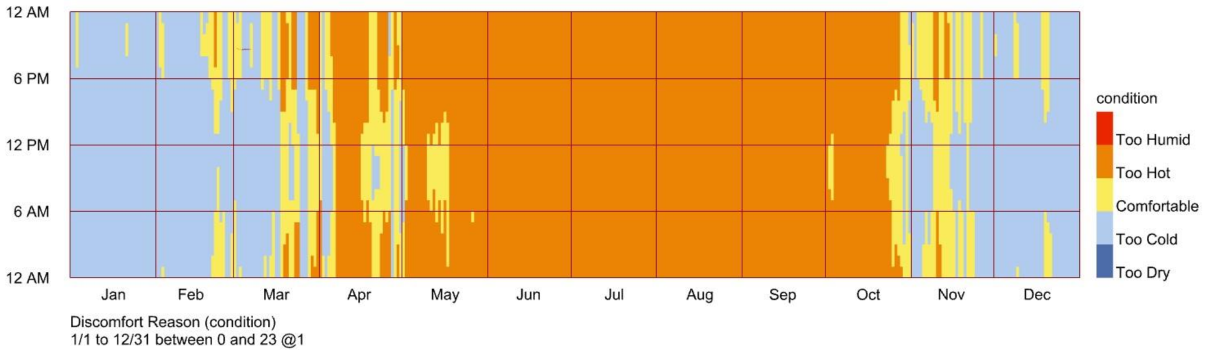
These results are not consistent with thermal comfort standards such as ASHRAE Standard 55 or ISO 7730, where a PPD of 85% or higher indicates a significant level of discomfort among building occupants.

In Figure 6, the Discomfort Reason model reveals a significant contrast between the percentages of hot and cold sensations under typical TMY weather conditions. The hot sensation percentage stands at 39.86%, while the cold sensation percentage is slightly higher at 47.61%. However, this relationship undergoes a noteworthy transformation in future scenarios. Under the 2050s and 2080s conditions, the hot sensation percentage increases to 33.79% and 54.89%, respectively, corresponding to heat sensation percentages of 53.33% and 61.74%. In contrast, there was a decrease in the cold sensation percentage by 29.80% and 50.26% in the 2050s and 2080s, resulting in values of 33.42% and 23.68%, respectively. This decrease in cold sensation is attributed to the rise in temperature, as previously mentioned. These shifts underscore the critical importance of accounting for climate change, which markedly differs from the current situation and necessitates proactive adaptation strategies.

Under TMY



Under 2050s scenario



Under 2080s scenario

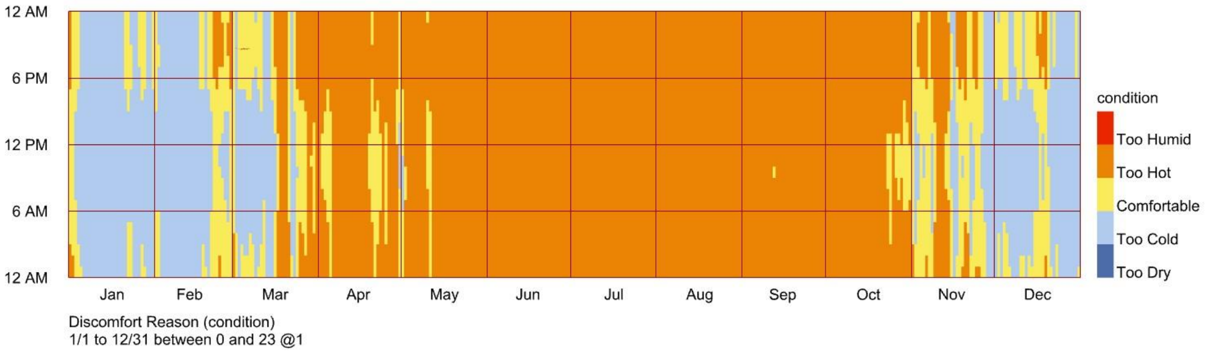


Figure. 6 Discomfort Reason (condition), for the selected room under different weather conditions.

The results from both the PMV and PPD models offer a holistic evaluation of the building's thermal comfort. The PMV results signal those thermal conditions generally fall short of comfort standards, while the low PPD percentages suggest a higher level of dissatisfaction among occupants. Collectively, the PMV and PPD models underscore the importance of enhancing the building's thermal comfort. Additionally, these findings highlight the necessity for localized adjustments to cater to the preferences of a minority of occupants. This data serves as valuable guidance for building management in their efforts to improve thermal comfort for the majority of occupants and ensure a pleasant indoor environment.

4.3. Sensitivity analysis results

After a general evaluation of the analysis results, the performance simulation results have been utilized for sensitivity analysis to observe the relation between the outcomes and the input parameters. Then, the most sensitive variables are listed for proposing better design decisions.

A Two-Variable Data Table in Excel was used to perform sensitivity analysis for building performance, specifically focusing on thermal comfort using the PMV and PPD models. In this scenario, we will consider climate change under the HadCM3 A2 scenario with six variables. Let's consider one variable as the climate change scenario (HadCM3 A2) and the other as a design variable, and we'll calculate the impact on thermal comfort parameters (PMV and PPD).
Input Variables:
Climate Change Scenarios (HadCM3 A2) - These could be different emissions scenarios.
Insulation Level - Representing the building's thermal properties.
Glazing characteristics: representing the variations in transparent surfaces
Output Variables:
PMV (Predicted Mean Vote) - A measure of thermal comfort.
PPD (Predicted Percentage of Dissatisfied) - Another measure of thermal comfort.
We performed a sensitivity analysis to evaluate the impact of climate change scenarios (HadCM3 A2), insulation levels, and variations in transparent surfaces on thermal comfort parameters (PMV and PPD) in a building. The table below provides results for different combinations of these variables:

Table. 3. Sensitivity analysis results under different weather file.

Climate Scenarios	Insulation Level	Window Type	PMV Results	PPD Results
Current Climate	Low Insulation	Tinted Glass	-1.5	20%
Current Climate	Medium Insulation	Reflective Glass	-0.9	15%
Current Climate	High Insulation	Low-E Glass	-0.5	8%
Hadcm3 A2 Scenario 1	Low Insulation	Tinted Glass	-2	22%
Hadcm3 A2 Scenario 1	Medium Insulation	Reflective Glass	-1.3	17%
Hadcm3 A2 Scenario 1	High Insulation	Low-E Glass	-1	11%
Hadcm3 A2 Scenario 2	Low Insulation	Tinted Glass	-2.2	24%
Hadcm3 A2 Scenario 2	Medium Insulation	Reflective Glass	-1.8	14%
Hadcm3 A2 Scenario 2	High Insulation	Low-E Glass	-1.2	12%

The analysis reveals significant trends: PMV values exhibit variation influenced by climate scenarios, insulation levels, and window glass types, generally indicating that as insulation improves, PMV approaches thermal neutrality, signifying enhanced comfort. Correspondingly, PPD values display a consistent pattern, with higher insulation and more favorable climates contributing to reduced occupant dissatisfaction. The transition from the "Current Climate" scenario to the "HadCM3 A2 Scenarios" results in heightened dissatisfaction, primarily due to less favorable climatic conditions. Notably, these findings underscore the pivotal role of insulation and the characteristics of the window glass in maintaining thermal comfort, as higher insulation levels lead to a more stable indoor environment and a subsequent reduction in occupant dissatisfaction.

Conclusion

This research paper explores the critical intersection of climate change, building energy performance, and thermal comfort, with a specific focus on a social housing project in Guelma, Algeria. As the world grapples with the challenges posed by climate change, it is evident that the building sector plays a pivotal role in addressing environmental concerns. The paper emphasizes the need for sustainable architecture, highlighting the inadequacy of traditional building forms in the face of climate change. The research incorporates sensitivity analysis and parametric design principles, crucial tools for assessing building performance and optimizing design decisions. The results show that climate change has a significant impact on thermal comfort, with rising temperatures necessitating adaptive design solutions.

The analysis utilizes the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) models to gauge thermal comfort. The findings indicate that the existing thermal conditions in the building fall short of comfort standards. Despite an increase in thermal comfort under future climate scenarios, there remains a substantial level of dissatisfaction among occupants. The results emphasize the importance of localized adjustments to enhance comfort for all building users. Sensitivity analysis provides valuable insights into the relationship between key variables such as climate scenarios, insulation levels, and window characteristics. It highlights the role of insulation and glazing in maintaining thermal comfort, with higher insulation levels and improved window characteristics contributing to more stable indoor environments and reduced occupant dissatisfaction.

In summary, this research underscores the pressing need for climate-responsive building design and proactive adaptation to climate change. By understanding the intricate connections between climate scenarios, building design parameters, and thermal comfort, this study offers essential guidance for achieving more sustainable and resilient building practices. The implications of this research extend to informing future design decisions and policies, ultimately contributing to the creation of indoor environments that are not only more comfortable but also more ecologically responsible for their inhabitants, a crucial step towards mitigating the impact of climate change.

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