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Heating and cooling energy consumption prediction model for a residential apartment considering design parameter

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Abstract— **A substantial portion of the total energy is consumed by buildings, and the number of residential structures in Morocco has significantly risen. Consequently, it is crucial to focus more on energy consumption in residential buildings. Furthermore, accurately predicting energy consumption in these residential buildings is of great importance. The current study has developed a predictive model for residential building energy consumption by employing multivariate model construction and weather data. The study involved predicting the energy consumption for heating and cooling in apartment buildings in order to assess the influence of the building envelope structure on energy conservation and indoor thermal comfort. The study has established a confirmed relationship that demonstrates the dependencies of energy consumption on various design variables within the envelope systems of residential buildings. This relationship was then used to create a predictive model for heating and cooling energy consumption. As a result . The Increasing the thermal transmittance values led to a 25% - 27% increase in heating energy consumption. In contrast, cooling energy consumption decreased by 8% to 26% when thermal transmittance was increased. This demonstrates that the developed model can swiftly estimate energy usage for apartment buildings using basic information about design variables. Moreover, it can readily identify the most crucial design factor for creating more energy-efficient residential building designs.**

Keywords—energy consumption, residential buildings, predictive model, heating and cooling.

I. INTRODUCTION

Many energy-saving regulations worldwide primarily emphasize improving the thermal insulation of building envelopes to reduce heating consumption, even in regions with hot summer climates. This pattern is also evident in the latest Moroccan construction thermal regulations, known as RTCM [1]. Within the framework of RTCM, there are provisions related to thermal insulation for the building envelope, and this includes the adoption of double glazing. These measures are designed to ensure that energy consumption remains within predefined limits, which are contingent on the climatic zone in which the building is located. It is widely recognized, as demonstrated by numerous studies in the literature, that thermal insulation plays a significant role in impeding heat loss. However, it can also pose a risk of overheating, particularly in regions characterized by hot summer climates[2].

Given the energy consumption within the residential building sector, nearly 50% of the energy is allocated to heating and cooling operations for ensuring thermal comfort[3]. Among the design factors impacting heating and cooling loads in residential buildings, the design of building envelopes stands out as the most influential parameter. This encompasses envelope materials, structure, window dimensions, and similar elements[4]. These variables in envelope design also have a substantial impact on thermal comfort within indoor spaces. Additionally, it is crucial to take into account not only these design factors and construction materials but also external factors like climate characteristics[5].

Various research endeavors have explored the energy efficiency of residential buildings concerning envelope systems. As per Pan et al.'s study, the thermal characteristics of building envelope systems significantly influence both heat gain and heat loss in residential structures, and these key parameters may vary across seasons[6]. Consequently, adopting a comprehensive approach that integrates these design parameters is crucial for addressing the distinct requirements of different seasons. Moreover, it is essential to account for the dynamic relationship between building envelopes and climatic conditions[7].

The primary goal of this research is to evaluate the energy performance and environmental impact of the study location in a Mediterranean climate. This will be achieved through the use of transient multi-zone simulations. The research specifically focuses on developing accurate construction models that are tailored to the unique energy demand of each case. Various simulations are being explored, alongside in-depth parametric studies to analyze the impact of passive techniques and their effectiveness in enhancing energy efficiency, even though they may lead to increased energy use.

The analyses being conducted encompass the effects of thermal mass in walls, roofs, and insulation. It's worth noting that this study holds particular relevance for Morocco because its current thermal regulation program primarily focuses on the building envelope. Consequently, this research will serve as a valuable tool for assessing the potential and hierarchy of energy efficiency practices in Moroccan buildings.

II. Methodology Description

A. Data collection

In this section, it is essential to highlight that climate data, particularly weather-related information, plays a critical role in dynamic building simulations and the accurate assessment of energy demand. Specifically, solar radiation and ambient temperature are utilized as key input parameters in the study, focusing on various locations within the Mediterranean climate, including Tetuan, Tangier, Larache, and Al-Hoceima[8]–[12].

Given these climate characteristics, the comfort zone for residents in a Mediterranean climate in Morocco would likely involve adapting to the seasonal variations in temperature and precipitation. Housing designs and lifestyle choices may take into account the need for heating during the winter and cooling strategies for the hotter summer months. Additionally, outdoor living and the use of natural ventilation are often integral parts of the lifestyle in regions with a Mediterranean climate.

B. Building Materials and Insulation

To gather information regarding the design variables of an apartment building, we have selected an apartment in Tetuan. You can find a detailed floor plan in Table I, and a visual representation of the apartment in Figure 1, along with a description.

Fig.1 The selected apartment in Tetuan site[2].

The heating and cooling equations for a building are typically complex and involve multiple factors. The most common equation used to estimate heating and cooling energy consumption for a building is the energy balance equation.

TABLE I. The specification of the envelope systems of the apartment.

	Components	U-values $(m^2.K)$	Conductivity (KJ/h.m.K)	Density $(kg.m^{-3})$
Model .1				
Extrenal walls	Briq25-ALV	5.773	1.12	720
	Brick37_ALV	1.172	0.79	782
Ground	Paving	4.348	7.2	2450
	Cement screed	5.003	3.6	1700
Roof	Cement mortar	1.028	0.32	200
Model .2				
Extrenal walls	Briq-cr_35	0.915	1.80	720
	Bricq_cr_75	0.860	1.70	720
Ground	Paving	3.258	8	3000
	Cement screed	4.103	4.1	2000
Roof	Cement mortar	1.028	0.32	200
Model .3				
Extrenal walls	Briq_pl_300	0.840	3.97	1700
	Briq_pl_105	0.758	4.22	1700
Ground	Mixed grade sand	4.348	7.2	2450
	Cement screed	5.003	3.6	1700
Roof	Cement mortar	1.028	0.32	200

This equation takes into account various parameters, including the building's thermal properties, outdoor weather conditions, and the efficiency of the heating and cooling systems. Here's a simplified representation of the energy balance equation:

Heating Energy Equation:

$$Q\_heating = (T\_inside - T\_outside)\ x\ U\ x\ A$$

Where : Q_heating is the heating energy required (W).T_inside is the desired indoor temperature (in °C)T_outside is the outdoor temperature (°C).U is the overall heat transfer coefficient (W/m²·K). A is the surface area of the building envelope (m²).

Cooling Energy Equation:

$$Q\_cooling = (T\_outside - T\_inside)\ x\ U\ x\ A$$

Where:Q_cooling is the cooling energy required (W).

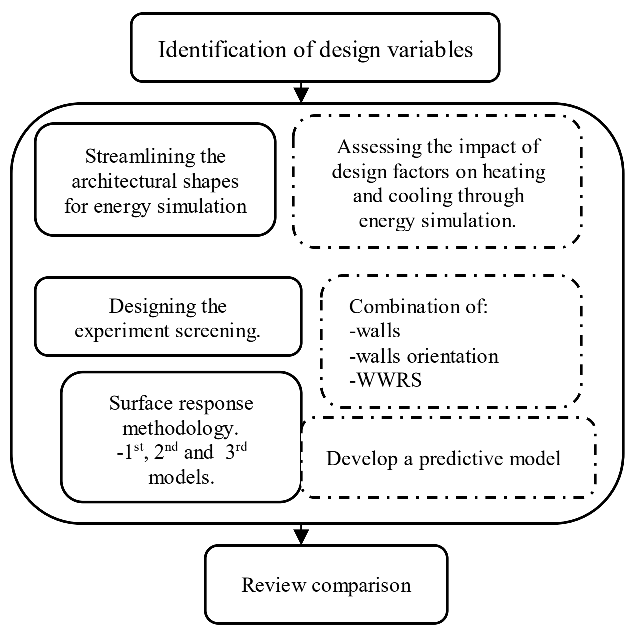


Fig.2: The outline of the methodology.

These equations provide a simplified representation of the heating and cooling energy requirements for a building. In practice, more detailed models and simulations are used to account for factors such as insulation, thermal mass, HVAC system efficiency, and occupancy patterns.

In this research, numerous design variables were chosen. An analysis of the correlation between the design factors and heating/cooling energy consumption was conducted to investigate a predictive model for energy consumption in residential buildings. The model created was calculated using data on heating and cooling energy. To validate its effectiveness, assessments of annual and monthly heating and cooling energy consumption were carried out to identify the most suitable models as seen in Figure.2.

III. RESULT AND DISCUSSION

To validate the predicted energy consumption using the three selected models and variations in weather data, Transys software, a simulation tool designed to optimize energy-efficient building designs through scenario applications, was utilized. The comparisons for heating and cooling energy were conducted within this software platform. This approach allows for a thorough assessment of the accuracy and reliability of the energy consumption predictions while accounting for different scenarios and weather variations.

The results obtained from the analysis exhibit consistent physical characteristics in terms of building orientation[2], shape, and internal heat gains. The primary distinctions among them can be traced to variations in the composition of external and internal walls, the roof, the ground, and the layers involved.

Several trial construction models have been employed to systematically evaluate and assess the influence of the building envelope structure on energy conservation and indoor thermal comfort. These assessments encompass the estimation of factors such as indoor temperatures, monthly heating and cooling requirements, and the total annual energy consumption. Outside air temperature presented in Fig.3, represent the ambient temperature in the external environment. It represents the thermal condition of the air surrounding a building, outdoor space. it’s can fluctuate over the course of the year, and it has a significant impact on heating and cooling requirements in buildings and is crucial for effective climate control, energy management, and comfort.

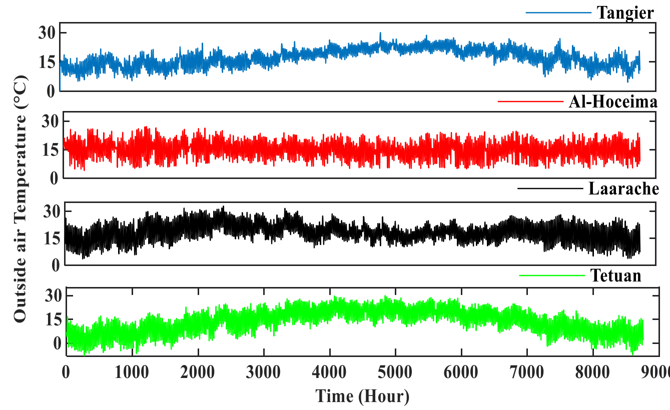


Fig.3 Outside air temperature distribution of Tangier, Al-Hoceima, Laarache and Tetuan sites.

For more detailed information, the temperature variations in the proposed study are depicted in Figure 4, covering a typical seasonal period, including winter, and summer. Figure 4 (A, 20-21 July 2019) displays the external temperature distribution for the Tetuan site on a typical summer day. The external temperature fluctuates in a range of approximately 17°C to 29°C.

In contrast, the internal temperature variations in the first typical summer day model are closer to 27°C, which aligns with the set-point temperature for summer comfort. These internal temperature fluctuations are notably more subdued.

However, the third model exhibits significant temperature fluctuations, indicating a higher degree of heat gains within the building.

In Figure 4 (B, 20-21 December 2019), we observe the indoor/outdoor temperature distribution for a typical winter day. The temperature dynamics in the three models are as follows:

- In the first model, the internal temperature closely mirrors the external temperature with a minor reduction in fluctuation.
- The second model exhibits an internal temperature with an average value of approximately 19°C, signifying a substantial reduction in temperature fluctuations.
- The third model maintains an internal temperature with an average value of around 23°C.

It's important to note that the HVAC system controller regulates the set-point temperature for comfort, striving to maintain it at all times.

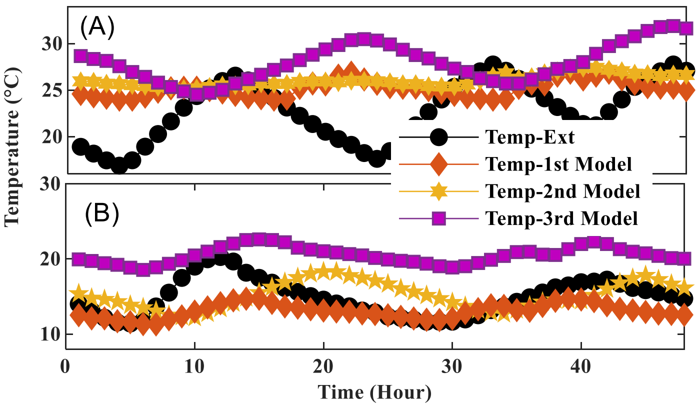


Fig.4 The temperature evolution of the simulated residential building over typical days of summer, and winter seasons.

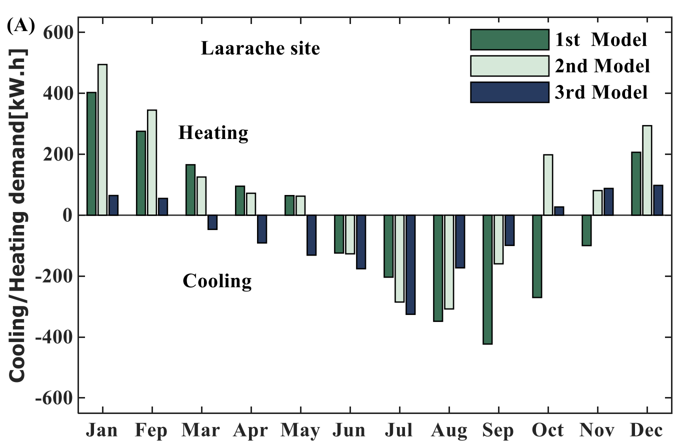
The monthly heating and cooling demands for the proposed construction models in the study are depicted in Figure 5, with variations observed throughout different seasons. Here are the key points from Figure 5:

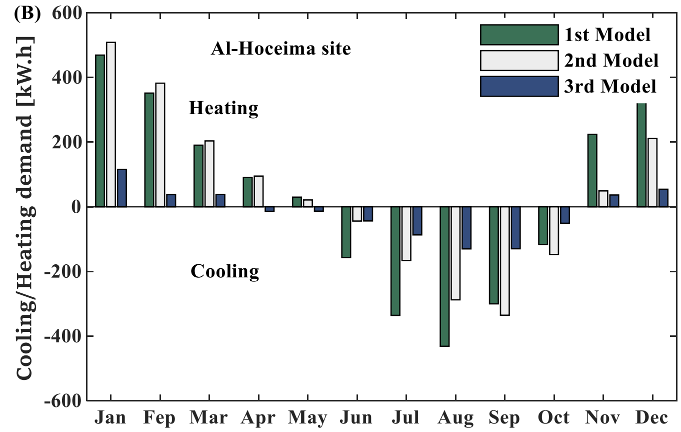
- **Larache Site** (A): The Larache site exhibits a notable variation in thermal behavior across all typical seasons, with a need for cooling throughout the year.

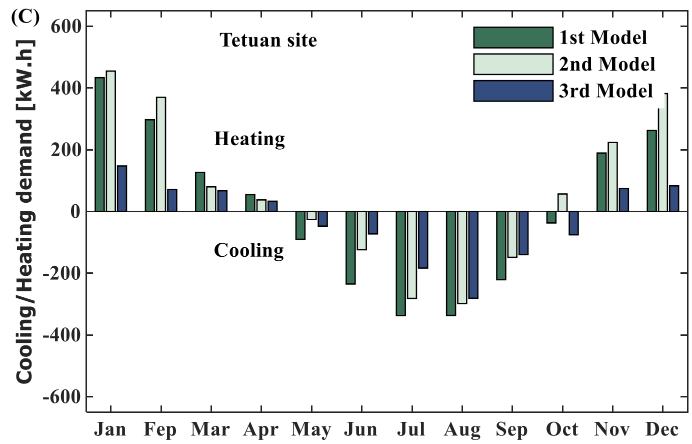
- **1st and 2nd Models:** These models consistently require the highest cooling demand, except for October. This suggests that the cooling needs are relatively high in these models, with a slight reduction in October.

- **3rd Model**: In contrast, the 3rd model shows a significant reduction in cooling demands, making it an attractive and energy-efficient option.

These findings highlight the importance of model selection and its impact on heating and cooling demands,







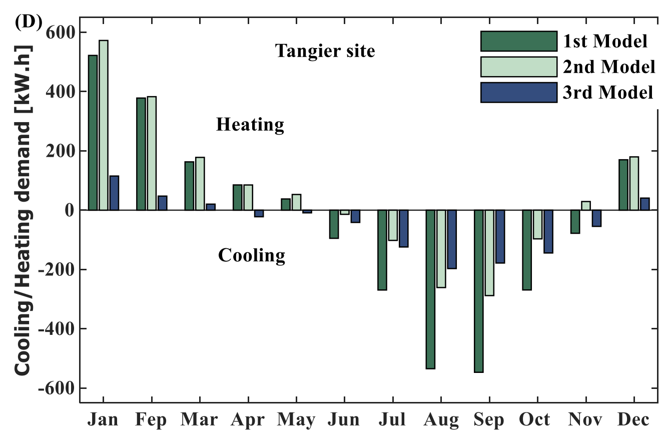


Fig.5 The monthly heating and cooling energy demands of residential buildings in four cases in the northern region of Morocco.

with the 3rd model standing out as a favorable choice due to its reduced cooling requirements.

In terms of heating demand, the 2nd model exhibits significantly higher requirements compared to the 3rd model. The 1st model is somewhat similar to the 2nd model with a slight reduction in demand. It's evident from the data that the heating demand decreases during three typical seasons, except for the spring season.

For the Al-Hoceima site, monthly heating and cooling demands are presented for three different construction models. All three models show considerable energy demand, particularly in cooling energy. However, the 3rd model demonstrates a marginal impact on heating and cooling energy requirements compared to the 1st and 2nd models. It's worth noting that the 3rd model stands out as the most appropriate choice for reducing energy demand. This is evident from the figures, highlighting the 3rd model's suitability compared to the previous models.

As a reminder, the Tetouan site features a Mediterranean climate with the influence of oceanic conditions, resulting in a more moderate climate. In comparison to the Larache and Al-Hoceima sites, the Tetouan site experiences greater variations in energy demand, as illustrated in Figure 5 (c). The results indicate a reasonable level of control over both cooling and heating energy demand.

The energy efficiency measures applied in the 1st and 2nd models have a minimal impact, particularly on cooling requirements. The 3rd model exhibits performance that is roughly equivalent to the heating demand. Figure 5 (d) demonstrates the monthly variations in heating and cooling energy demand for the Tetouan site. Notably, the most significant variations in energy demand, especially for cooling, occur during the summer period.

The 3rd model stands out as the most suitable model for reducing energy demand when compared to the previous models. In general, both the Larache and Tetouan sites exhibit more favorable energy consumption profiles compared to Al-Hoceima and Tangier. Specifically, the heating needs are more appropriate for the Tetouan site when compared to the other case studies.

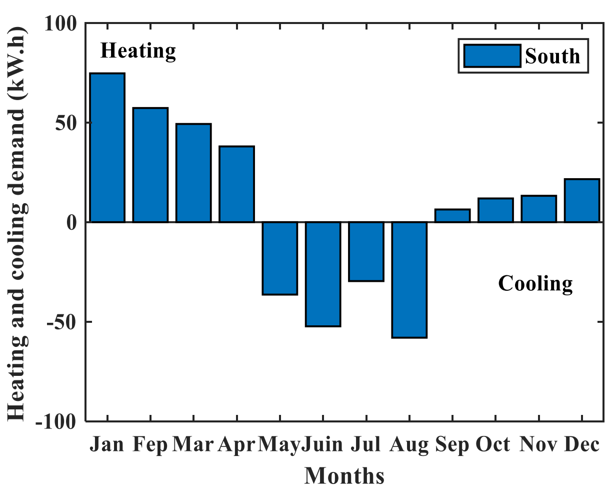


Fig 6. Suitable orientation case and daily profile of an apartment building.

Figure 7 displays the most favorable orientation, Model 3, which results in optimal heating and cooling demands. It is evident that energy consumption is minimized when the building is oriented to the South, in contrast to other orientations, where energy consumption is higher. This indicates that the southern orientation results in a notably higher energy consumption.

For better clarity, Figure 7 provides an overview of the total annual heating and cooling energy demands for residential buildings utilizing different construction models in the Mediterranean climate.

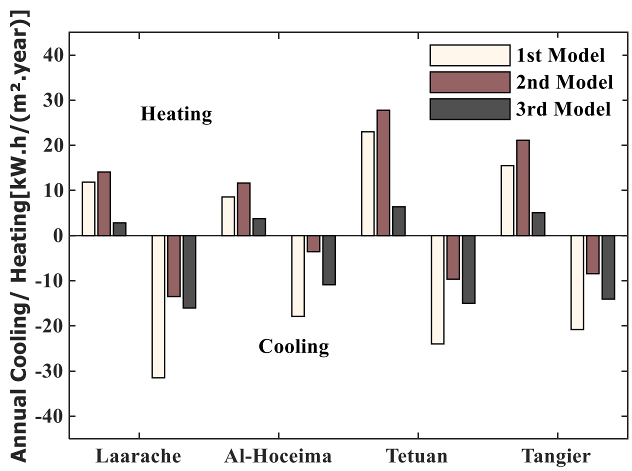


Fig.7 The total annual heating and cooling demands for the 1st, 2nd, and 3rd models

From the figure, it is evident that the 2nd and 3rd models exhibit similar annual cooling requirements, with a slight reduction in the 2nd model. In terms of annual heating demands, the 1st and 2nd models are quite comparable. However, the 3rd model stands out by significantly reducing the load compared to the two preceding models. These findings underscore the potential energy efficiency benefits of the 3rd model in terms of annual heating and cooling energy demands.

IV. CONCLUSION

In this study, a residential building with intermittent occupancy was simulated and validated based on the structural concept adopted in the northern regions of Morocco, specifically Larache, Al-Hoceima, Tetouan, and Tangier. The simulations took into account lighting, appliances, and internal heat gains as input parameters for dynamic modeling. The TRN-Build multi-zone software, Type-56 of the TRNSYS platform, was utilized to estimate the heating and cooling demand needs. The goal was to identify the most suitable model that offers optimal heating and cooling energy demand for the fourth study location in Morocco.The study examined and assessed various energy efficiency measures, including the building's structural materials, natural ventilation, window properties, internal temperature control, and heating/cooling systems. As a result, the 3rd Model was identified as the most appropriate choice, featuring external and internal wall, roof, and ground insulation. This model significantly reduces annual energy requirements independently of the specific study locations. The reduction in annual energy needs ranges from 19.67%. As demonstrated, the created model can swiftly predict energy consumption for apartment buildings using basic design variables. Additionally, it can readily identify the most crucial design factor, facilitating the development of a more energy-efficient design for residential buildings.

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