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ASSESSMENT OF OVERHEATING RISK IN FREE-RUNNING RESIDENTIAL BUILDINGS IN PALESTINE UNDER FUTURE CLIMATE

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Abstract

This paper addresses the impact of climate change on residential buildings in Palestine, which recently faced an increased risk of overheating. The study investigates the effect of the thermal properties of the building envelope of a single detached house on increasing the building's resilience to climate change. The overheating risk is evaluated using ASHRAE 55 standard under typical historical and future years (2035, 2065, and 2090) based on RCP-4.5 and RCP-8.5 emission scenarios in three climate zones in Palestine (2A,3A and 2B based on ASHRAE 169-2020). The simulation results reveal that the Medium Energy Efficient Building (MEEB) is more effective in enhancing the thermal comfort of the building compared to the Low Energy Efficient Building (LEEB). However, the risk of overheating increases in future climates, particularly in vulnerable populations and specific locations in the hot, dry zones, such as 2B. This necessitates the implementation of combined mitigation strategies, including both active and passive cooling strategies, highlighting the importance of improving the building’s indoor environment and envelope. The findings emphasize the need to incorporate the impact of climate change into building design to ensure energy efficiency, thermal comfort and promote climate-resilient buildings.

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Keywords: building performance, climate change, MEEB, overheating risk, Palestine.

1. Introduction

Climate change has already caused widespread impacts and losses worldwide, leading to more frequent and intense extreme weather events. According to the recent IPCC 6th report, global warming is expected to continue, with a high probability of exceeding a 1.5°C increase during the 21st century, which would make it harder to limit warming below 2°C under higher emissions scenarios [1]. These changes contribute to the occurrence of compound heatwaves, which are projected to become more frequent and have long-term impacts. These impacts adversely affect people's health and well-being [1], [2], [3]. Additionally, rising temperatures have resulted in increased mortality rates [4], [5]. The heat-health problem varies from country to country, and countries like Palestine lack mortality data for individual cities or provinces, especially for reasons of climate-related mortality. This underscores the urgent need to conduct studies on climate change to aid in adapting to the changing climate [5]. Extreme heatwaves have a significant impact on the energy performance and indoor thermal conditions of buildings, making it crucial to estimate the risk of overheating in buildings worldwide, as in the case of Gaza, a large sample of residential buildings has been assessed; the study examined the overheating risk in residential buildings using simulations [6]. Such studies are important for understanding how heatwaves affect thermal comfort, as people spend a significant amount of time indoors, ranging between 65-90% [7].

The Eastern Mediterranean region, including the Middle East and North Africa (MENA) region, is a climate change hotspot, experiencing faster warming than other areas [8]. A recent study's findings showed that Palestine has an annual mortality rate of 43 heat-related deaths [9]. The study also predicted an increase in mortality by the end of the century due to a combination of climate change and high population growth. Therefore, efficient mitigation strategies are required [9]. Palestine, along with its neighbouring countries in the Mediterranean region, has experienced extreme weather and faces

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challenges in achieving sustainability due to its vulnerability to climate change, lack of natural resources, and high energy prices. Among all sectors, the building sector is the most challenging in terms of sustainability [10]. Using appropriate materials in the building envelope is crucial to enhancing the thermal efficiency of climate-resilient buildings in Palestine [11].

Efforts to improve building efficiency are crucial in mitigating their contribution to global warming. Achieving high energy building efficiency (HEEB) in residential buildings involves implementing various strategies, including insulation, smart HVAC systems, and renewable energy technologies [12]. Monna et al. research has focused on evaluating the impact of climate change on building energy performance, drawing on the latest IPCC scenarios and findings from the AR6 report. Some studies have emphasized the importance of assessing building energy performance and its influence on indoor thermal comfort in Palestine [13]. Additionally, other studies have highlighted the significance of considering different insulation materials and thicknesses, as well as investigating the performance of lightweight but insulated walls under diverse climatic conditions in Palestine [14].

This study aims to evaluate the risk of overheating in residential buildings using a whole-building simulation model for historical and future weather data with two levels of thermal properties of the building envelope, referred to as Medium Energy Efficient Buildings (MEEB) and Low Energy Efficient Buildings (LEEB), in three climate zones in Palestine.

2. Methodology

2.1. Building geometry

A single-detached house with two floors, 40% of window-to-wall ratio and 197m^2 of total floor area is selected for evaluating the impact of climate change on indoor overheating, Tis building represents a typical Palestinian construction style [3] consist of stone, concrete, and hollow concrete blocks exterior wall and a concrete flat roof/floor.

Fig. 1. (a) first floor; (b) ground floor

2.1.1. Building envelope

The following are the scenarios of the existing residential building case study that were chosen:

- Scenario 1 (S1) low energy efficiency building – LEEB: The building without insulation.
- Scenario 2 (S2) Medium energy efficiency building- MEEB: The thermal properties represent the typical building with additional changes in the building envelope.

The details of the building envelope assemblies are shown in Table 1, which illustrates the overall thermal transmittance of the building envelope for the master bedroom (MBR) with an area of 17.36m^2.

Table 1. Overall thermal transmittance of building envelope assemblies- MBR.

Item	Layers- S1, Zone: MBR	LEEB U (W/m^2.K)	Layers- S2 Zone: MBR	MEEB U (W/m^2.K)
Exterior wall	Limestone 40mm Mortar 30mm Hollow-block 200mm Plaster 20mm	2.4	Limestone 40 mm Mortar 30 mm Hollow block 200 mm Foam Polyurethane 60mm Hollow block 100 mm Plaster 20 mm	0.40
Ground floor	Concrete 250mm Sand 70mm Mortar 30mm Ceramic10mm	2.4	Concrete 250mm Polystyrene90mm Sand 70mm Mortar 30mm Ceramic10mm	0.40
Flat Roof	Bitumen 5mm Sand concrete for roof 70mm Reinforced concrete 250mm	2.0	Bitumen 5mm Sand concrete for roof 70mm Reinforced concrete 250mm Foam Polyurethane90mm	0.27
Window	Single glass	5.8 SHGC 0.75	Double glass, air 13mm	1.6 SHGC 0.55

2.1.2. Settings for whole building simulation- Overheating risk

The building relies on natural ventilation to remove the excessive heat by opening 50% of the windows area when the indoor temperature is higher than 23 °C and the indoor temperature is higher than the outdoor temperature. Also, the interior shading (blind roll) is used to reduce the possible solar heat gain during the day. Simulations were conducted for the hottest room, which is the master bedroom (MBR).

2.2. Thermal comfort criteria

To evaluate the risk of overheating in naturally conditioned spaces, the temperature ranges for operative conditions are evaluated following ASHRAE 55-2017 [15]. The maximum acceptable operative temperature is determined by Equation 1. If Equation 2 yields an operative temperature higher than the upper limit temperature, it indicates the occurrence of overheating. The Upper 80% acceptable limit:

$$T_{c,up} = 21.3 + 0.31 * T_{om} \quad (1)$$

$$T_o = (T_d + T_{mrt})/2 \quad (2)$$

The overheating risk for the two cases (S1 and S2) was analysed and simulated using historical year (TMY data 1961-1990). The formulas were used for the analysis: T_{om} is the monthly mean outdoor air dry-bulb temperature (°C), T_o is the operative temperature (°C), T_d is the indoor air dry-bulb temperature (°C), and T_{mrt} is the mean radiant temperature of the zone (°C).

2.3. Future weather data

Currently, WeatherShift™ [16] is one of the weather morphing tools available to researchers, it is widely used by researchers studying buildings' energy performance [17]. WeatherShift™ used to generate future years 2035 (2026-2045), 2065 (2056-2075), and 2090 (2080-2099) based on the Representative Concentration Pathways (RCP) scenarios (RCP 4.5 and 8.5) that were defined in the IPCC Assessment Report 5 (AR5) and utilized to simulate meteorological variables for the years. The RCP 8.5 scenario assumes the highest levels of temperature and CO_2 emissions by the end of the 21st century, as it remains unclear whether carbon dioxide emissions will decrease or not in the future [18], [19].

2.4. Simulation scenarios

Three different climatic zones in Palestine were chosen for the historical and future assessment of overheating risk on residential buildings, which are: Qalqilya (2A-hot and humid), Jerusalem (zone 3A - warm and humid), and Jericho (hot and dry- for zone 2B), as specified in the ASHRAE climatic data [20] that corresponds to the ARIJ data zones (Qalqilya - Zone 5, Jerusalem - Zone 3, Jericho - Zone 1) [21]. Historical simulations were conducted for all three zones based on and the two building scenarios (S1 - LEEB, S2 - MEEB). Similarly, for future simulations, evaluations were based on the ASHRAE 55 standard and future weather data projections using RCP-4.5 and RCP-8.5 emission scenarios for the years 2035, 2065, and 2090, assuming a 50% median warming scenario.

A total of 24 cases are modelled using DesignBuilder tool for three locations in Palestine and two scenarios condition.

3. Results and Discussion

3.1. Overheating risk evaluation under historical simulation

Fig. 2 shows a comparison of the overheating hours between the LEEB and MEEB scenarios in three locations (Jerusalem, Qalqilya, and Jericho) for historical evaluation. Results show that buildings with low thermal properties of the building envelope (LEEB) experience significantly higher overheating hours compared to buildings with high thermal properties of the building envelope (MEEB), with a difference of 50–100% depending on the building's location. The overheating hours in a building located in cold cities (Jerusalem and Qalqilya) were about 526 hours and 765 hours, respectively, which represent 15% and 23% of the summer period from May 1st to September 30th. However, Jericho Zone had the worst scenario among the three locations, with overheating hours representing 88% (3150 hr) of the summer period. By improving the thermal properties of the building envelope, the overheating hours were reduced from 526 hr to 0 hr in Jerusalem, to 56 hr in Qalqilya, and to 48% (1718 hr) in Jericho. These results are consistent with the results of the sensitivity analysis conducted by Baba et al. [22].

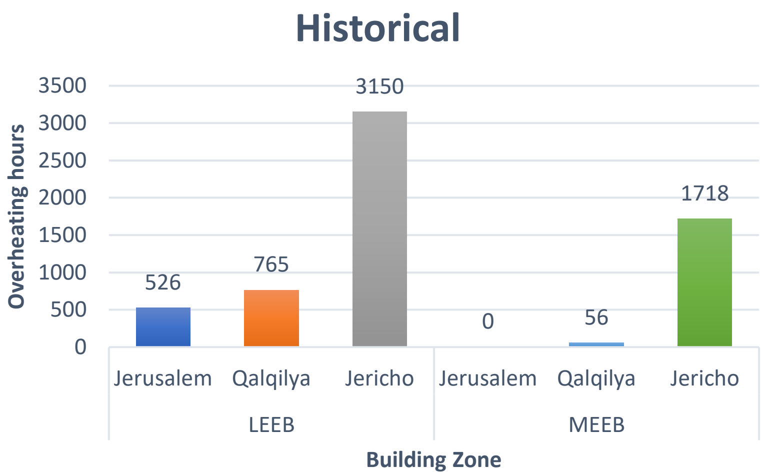

Fig. 2. Overheating hours for LEEB and MEEB under historical simulation

3.2. Overheating risk evaluation under future climate simulation

Fig. 3 presents the effect of climate change on the MEEB building in three different locations. Simulations are conducted under the RCP 4.5 and 8.5 emission scenarios for short-term (2035), mid-term (2065), and long-term (2090) future years.

Under 2035- RCP 4.5 scenario, the overheating hours in Jerusalem and Qalqilya are slightly increased, where the MEEB building would perform better than the LEEB building for the same locations, as the historical simulations had already proved the overheating risk. However, in Jericho, the number of overheating hours may increase by up to 66% (2408 hrs). The results show the number of overheating hours is significantly increased under the RCP 8.5 scenario for the three locations, with the highest probable occurrence of overheating in Jericho at 70% (2515 hrs) compared to RCP-4.5.

Under the mid-term evaluations representing the year 2065, the number of overheating hours may keep increasing under both RCP 4.5 and 8.5 scenarios, highlighting the best case in Jerusalem and the worst case in Jericho, where the overheating hours may represent 87% (3163 hrs) of the summertime. By 2090, the number of overheating hours may increase up to 77% (2786 hrs) of summertime under the RCP 4.5 scenario, and the percentage of 100% overheating occurrence may be recorded for (3612 hrs) under the worst scenario of RCP 8.5 for MEEB building. Under future climates, some chosen designs that have natural ventilation and interior shading may be insufficient to mitigate the risks of overheating.

The study's results highlight the urgent need for appropriate mitigation measures in building designs, as they play a crucial role in enhancing the performance of residential buildings in Palestine and promoting sustainable building practices. To counter the increasing trend of overheating and reduce overheating hours during intense heatwaves, a combination of passive and active cooling strategies should be considered. The study indicates that the current condition of Low Energy Efficient Buildings (LEEB) is insufficient, while the Medium Energy Efficient Building (MEEB) case needs further development, especially in zones like Jericho. Considering the impacts of climate change and overheating in building design is vital as a proactive measure. Evaluating the overheating risk of existing buildings and implementing effective strategies can mitigate risks and ensure a safe and comfortable indoor environment, thus promoting the construction of climate-resilient buildings.

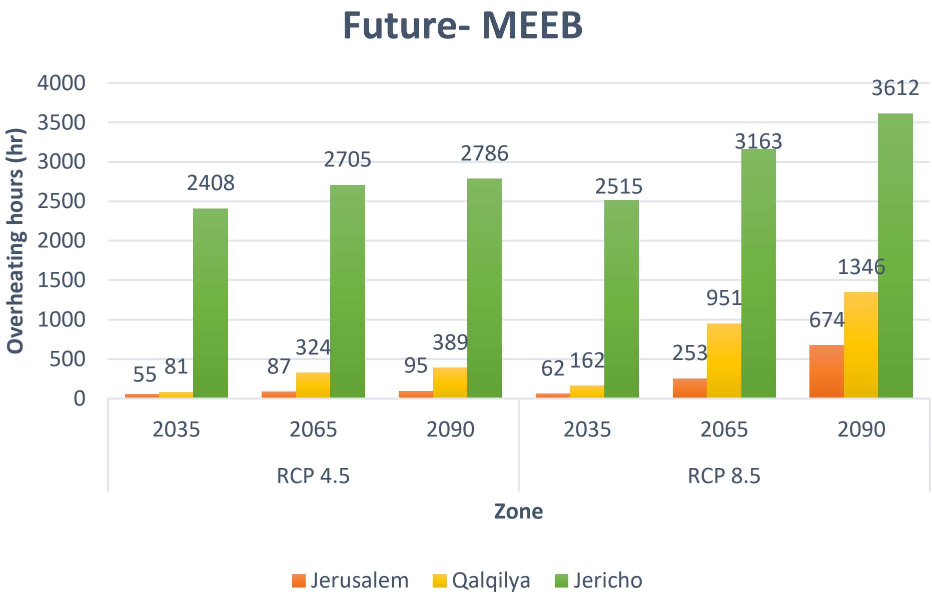

Fig. 3. Overheating hours in MEEB buildings under future climate

4. Conclusions

This paper evaluates the overheating risk in residential buildings in Palestine, considering the effect of thermal properties of the building envelope, i.e., medium energy efficient buildings (MEEB) and low energy efficient buildings (LEEB). The assessment also includes the effect of climate change on the indoor thermal condition under historical and future years in three Palestinian climate zones, i.e. Qalqilya, Jerusalem, and Jericho. Future weather data are generated based on the RCP 4.5 and RCP 8.5 emission scenarios for the years 2035, 2065, and 2090. The study utilises the Designbuilder simulation tool to conduct whole-building simulations and analyze the overheating risk.

The results indicate that MEEB buildings demonstrate greater adaptability to overheating risks compared to LEEB buildings. The proposed MEEB buildings type proved to be climate-resilient and more efficient in addressing overheating concerns in Qalqilya and Jerusalem during the selected summer period. Overall, different climate zones in Palestine are susceptible to overheating, and the MEEB building type is particularly effective in addressing this issue in Jerusalem and Qalqilya. However, additional mitigation measures such as exterior shading and efficient cooling systems are necessary for regions like Jericho, where the risk of overheating is more severe. It is recommended to employ a combination of passive and active cooling strategies to mitigate these risks. In conclusion, the study emphasizes the importance of considering the impacts of climate change on building design and performance. It underscores the need to evaluate the overheating risk in existing buildings and develop strategies to mitigate it, ensuring a safe and comfortable indoor environment while promoting the construction of climate-resilient buildings.

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