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Thermal Mass and Low-Tech Air Cooling as Ecological Climate Adaptation: Simulating Overheating Mitigation in German Multistorey Buildings

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Abstract. This paper explores strategies to retrofit the existing building stock with effective cooling solutions to address the growing challenge of heat waves under future climate conditions. In Germany, many multistorey apartment buildings constructed after the Second World War experience interior temperatures during summer heat waves that exceed comfort thresholds, often reaching intolerable levels. These buildings typically lack air conditioning; nevertheless, extreme heat waves are growing more frequent and intense due to climate change. Insulation and energy efficiency have historically been the main focuses of efforts to improve building performance in order to keep buildings warm during the winter, active cooling was not a priority as heat waves were minor in the past. The study illustrates how passive cooling strategies, such as using thermal mass and low-tech ventilation systems, can improve indoor temperatures in existing buildings. By employing simulation tools, the paper intends to demonstrate the effectiveness of these measures in reducing indoor overheating in summer, in turn supporting the development of practical, climate-responsive retrofit approaches. How much can passive techniques like increased thermal mass and low-tech or natural ventilation lower summertime overheating in typical post-war and modern apartment buildings? Can these measures effectively prepare existing buildings for the more severe heat waves expected to occur in the coming years and decades? By using "Climate Studio" software, thermal simulations were conducted to study indoor environments, with a focus on temperature, humidity, and airflow. Thermal mass enhancement and passive (primarily nocturnal) ventilation techniques were modeled to test a variety of retrofitting options. These simulations helped identify best practices, which in turn led to the development of adaptable design guidelines for wider application. The study illustrates how passive ventilation and thermal mass can drastically lower indoor temperatures. During the majority of summer heat waves, the simulated scenarios successfully maintained indoor temperatures within the thermal comfort range. By achieving temperature reductions of roughly 5 to 7°C when compared to outdoor conditions. However, a few exceptional periods were identified where indoor temperatures rather briefly exceeded comfort limits during extreme heat events. The combination of passive ventilation and thermal mass proves to be a key strategy for effectively and ecologically reducing indoor overheating in existing buildings. However, many factors like the structural capacity to add thermal mass and the feasibility of implementing features like cross-ventilation, ventilation shafts, or other related passive design strategies. directly affect whether or not these practices can be applied on existing structures. While general guidelines for successful retrofitting can be developed, their application must be carefully adapted to the specific characteristics and constraints of each building.

Keywords: Climate change adaptation, ecological retrofitting, natural ventilation, passive cooling, thermal mass

INTRODUCTION: GROWING FREQUENCY AND INTENSITY OF OVERHEATING DUE TO CLIMATE CHANGE

Over the past two decades, Central Europe has witnessed a noticeable rise in the number and severity of summer heat waves, a trend expected to accelerate due to climate change. In Germany, these extreme temperature events are becoming an increasing concern for housing, especially in multistorey apartment buildings built after World War II, since most of these buildings were built with little to no protection against overheating during the warmer months. Because they do not usually have air conditioning, indoor temperatures can reach uncomfortable or even dangerous levels quickly during heat waves.

The common approach to building efficiently in Germany has centered on winter insulation to preserve heat in the colder seasons, which was an understandable priority in a temperate climate. However, this focus has left a gap in readiness for extreme summer conditions, which are no longer rare. Older buildings of the post war era, particularly those built between the 1950s and the 1990s, often lack both the infrastructure and design features necessary to manage high internal heat loads. With climate models expecting longer, hotter summers in the coming years, this issue is no longer marginal – it is becoming central to the discussion about how we adjust existing buildings to new environmental conditions.

This study explores whether simple, low-tech, passive strategies – such as using thermal mass and natural or low-energy ventilation–can lower indoor temperatures by offering effective building techniques which do not rely on mechanical systems. Instead, to stabilize indoor temperatures they use the building's physical features and natural air ventilation, especially at night. The idea is simple: building's mass efficiently absorbs heat of the interior spaces during the day while it is cooled down at night when temperatures are colder.

The study explores this by examining three separate apartment buildings which reflect various eras: one from the 1960s, one from the mid-1990s, and a more recent example from 2025. By using Climate Studio (a thermal simulation tool), each building was examined under both present and future climate conditions in order to determine how different retrofit scenarios impact indoor comfort. These included combining the two methods, adding passive ventilation pathways, and increasing the structure's thermal mass.

The main question is whether such strategies can help prepare Germany's post-war and modern residential buildings for the increasingly hot summers we can expect in the future. More specifically: Can passive measures alone effectively reduce overheating in these buildings? Can these workable solutions be applied widely while considering constraints found in the real world, such as user behavior and building structures?

The following section starts with a review of the background and policy context, then examines chosen case studies and the simulation methods applied. Results are shown and discussed, with a focus on indoor comfort levels both before and after passive measures were applied. This is followed by discussion of key challenges and opportunities, before concluding with essential takeaways and recommendations for future research.

BACKGROUND

Germany's building stock reflects decades of climate-responsive thinking – but mostly with a focus on keeping heat in. Especially since the 1970s, energy performance standards have emphasized insulation, airtight envelopes, and energy-saving heating systems, all in response to the oil crisis and rising concerns about winter energy use. Structures are shaped by this legacy, buildings are constructed and renovated with thermal protection for cold months as the number one priority till this day. However, with summer heat waves becoming more frequent every year, this winter-focused approach is starting to show its limits.

In the past, summer overheating was rarely considered a design approach in Germany. Air conditioning was viewed as unnecessary in residential settings and often dismissed for being environmentally unsound and energy-intensive. As a result, most older apartment buildings – those constructed between the 1950s and 1990s – lack any form of active cooling. Due to their light construction techniques, their layouts are often compact, and their thermal inertia is limited. This can result in severe overheating during hot weather when combined with increasingly airtight retrofits [1]. The effects are already noticeable. In recent summers, indoor temperatures in many residential units have exceeded 30°C for continued periods, leading to health risks, particularly for sensitive age groups such as the elderly or young children. Heat-related mortality has increased, and public health organizations are now paying closer attention to thermal comfort in buildings–not just in winter, but throughout the year.

Retrofitting existing buildings to better handle with high summer heat waves presents some challenges. Mechanical cooling systems, while technically effective, come with high energy demands and risk increasing the very emissions that contribute to climate change. Moreover, adding air conditioning to existing buildings can be expensive, invasive, and unfeasible – especially heritage-protected structures or highly populated urban areas.

This has inspired developing attention in passive cooling strategies [2], which aim to lower temperatures indoors using non-mechanical means. One of the key methods is thermal mass, which is the ability of solid building materials to absorb and slowly release heat, another technique is the use of natural or low-energy ventilation, especially at night when outdoor air is cooler. These strategies depend on a building's form, materials, and orientation rather than any added technologies [3]. They are remarkably relevant in retrofitting contexts, where structural interventions need to be cost-effective, practical, and environmentally responsible. While the theoretical potential of passive cooling is widely known, there is still a need for case-specific simulation and validation. Every building is different: orientation, construction method, window size, local climate, and user behavior all influence how effective a passive retrofit can be. This study addresses that gap by simulating how specific combinations of thermal mass enhancement and passive ventilation might perform in three representative apartment buildings in Germany–built in different eras and facing varying future climate scenarios [4].

METHODOLOGY

To assess how passive strategies such as increased thermal mass and natural ventilation could help mitigate indoor overheating, this study used a simulation-based approach. The goal was not only to measure potential temperature reductions but also to understand how different building types might respond under current and future summer conditions. Three multistorey residential buildings in Germany were selected as case studies. Each building represents a distinct era of post-war construction and typical urban housing development. The selection was intended to cover a range of construction methods, thermal properties, and ventilation potentials–providing insight into how passive cooling strategies might perform across different building typologies. All thermal simulations were conducted using Climate Studio, a precise software platform integrated into Rhino/Grasshopper that supports dynamic building performance and simulating indoor temperatures, airflow, and humidity over time. Similar combined approaches have been evaluated in previous comparative case studies [5]. Two climate scenarios were modeled: Current climate (2024 baseline) using historic weather data. Future climate (2075) using projections (as explained below). The projected climate conditions in the year 2075 are based on downscaled regional climate models assuming of a high-emissions trajectory. This scenario is designed to mirror extended heatwaves and increased average summer temperatures. All climate data used for these estimates follow the methodology of Crowther et al [6] who identified future climate equivalents by matching predicted conditions with present climates of other cities. Based on his approach, the climate of Gelsenkirchen in 2075 is expected to be like present-day Lyon or Milan under the (RCP4.5 scenario, a medium-emissions trajectory). For this study, the climate data of Milan has been chosen as a representative analogue. In the same way, Reuter et al [7] show that cities such as Aachen (which today has a very similar climate to Mannheim) are projected to develop a climate comparable to that of present-day Dijon. Underestimated emissions scenarios and regional downscaling, Berlin's future climate is projected to approximate the current climate of Toulouse, France, characterized by warmer summers, milder winters, and altered precipitation patterns (RCP4.5 scenario) [8].

Each building was modeled with consistent assumptions for internal loads, residence schedules, and window operation patterns. Simulations were run for the entire summer season from May to September. Thermal comfort was evaluated using commonly accepted thresholds (such as 28°C) and by calculating the number of hours above comfort levels [9].

Several passive retrofit interventions were simulated and compared to a reference case for each building. Enhanced thermal mass was modeled by adding internal masonry, natural clay panels or drywall boards with phase changing material (PCM). Passive night ventilation was modeled assuming operable windows or cross-ventilation at night. This allowed heat accumulated during the day to be released. Collective strategies combined thermal mass and night ventilation to estimate potential synergistic effects. The simulations aimed to identify which measures, or combinations of measures, consistently improved indoor summer comfort. Particular attention was given to peak temperature reductions, the duration of overheating, and the feasibility of implementing these measures in existing buildings. For each scenario, simulation outputs were analyzed in terms of: reduction in indoor temperatures relative to outdoor peaks; change in overheating hours compared to the baseline; and variation in performance across different climate years and building types. The results provided a data-driven basis to evaluate which passive measures are effective and replicable under future climate conditions.

SITES

Building 1: A 1960s apartment block in Gelsenkirchen, representative of early post-war mass housing.

FIGURE 1. Building 1 in Gelsenkirchen, 2025 Model

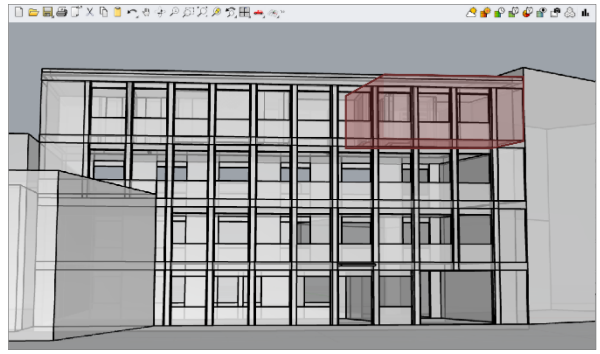

FIGURE 2. Building 1 in Gelsenkirchen, Simulation, Top Floor, Analyzed Unit (Red)

Building 2: A mid-1990s structure located near Mannheim, reflecting pre-millennium insulation standards and building practices.

FIGURE 3. Building 2 in Mannheim, 2025 Model

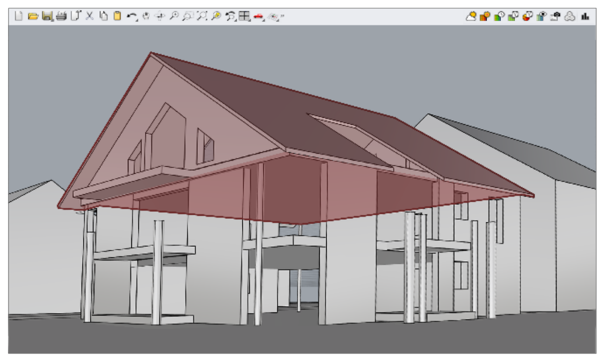

FIGURE 4. Building 2 in Mannheim, Simulation, Top Floor, Analyzed Unit (Red)

Building 3: A recently built (2025) apartment building in Berlin, compliant with current energy codes but not equipped with active cooling.

FIGURE 5. Building 3 in Berlin, 2025 Model

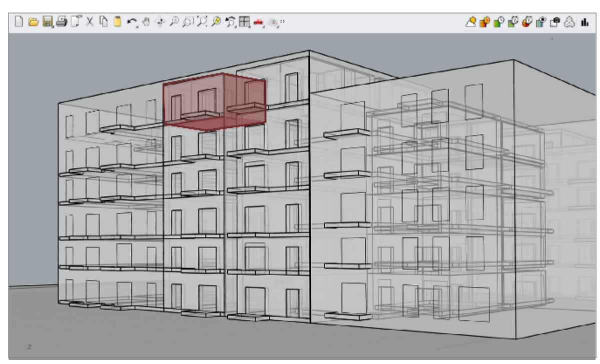

FIGURE 6. Building 3 in Berlin Simulation Model, Top Floor, Analyzed Unit (Red)

SIMULATION RESULTS OF BASELINE / EXISTING SITUATION

The simulation results provide a detailed assessment of the thermal performance of the three selected multistorey residential buildings located in Gelsenkirchen (1960s), Mannheim (1990s), and Berlin (2025) under both current (2024) and projected future (2075) climate conditions. By modelling a series of passive retrofit interventions, this study assesses their effectiveness in reducing indoor overheating during summer heat waves, focusing on temperature reductions, overheating hours, and the practical suggestions of each strategy. The results emphasize the possibility of thermal mass improvement and passive ventilation techniques to maintain indoor thermal comfort, while also recognizing limitations during extreme heat events.

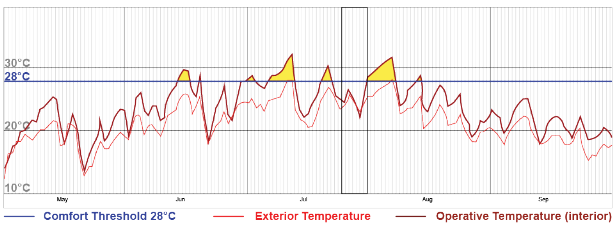

FIGURE 7. Simulation example with summer heat waves (yellow), building 1, May - Sep 2024 (daily average temperatures)

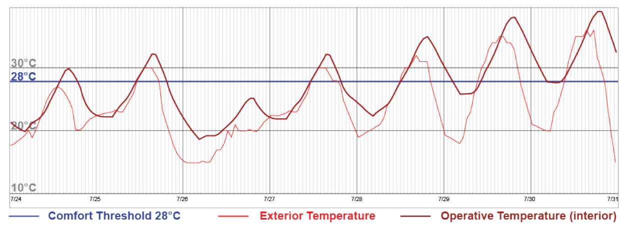

FIGURE 8. Simulation example of building 1 during the hottest week in 2024 with peak temperatures reaching up to 39 °C

Figure 7 shows the interior and exterior temperatures during the period of May to September, in which it becomes evident that summer heat waves are rising temperatures above the comfort zone. However, the graphic of Figure 7 shows only the day/ night average temperature and not the daily heat peaks. Therefore, we have illustrated the huge difference between day and night in Figure 8, which shows the hottest daily peaks reaching up to 39 °C.

The simulations, conducted for the summer period (May to September) in 2024, showed major overheating issues in all three buildings, particularly in upper-floor apartments. The 1960s building in Gelsenkirchen, made out of a reinforced concrete skeleton and limited ventilation possibilities, showed the highest number of overheating hours. The 1990s building in Mannheim, with sensible insulation but poor airflow, proved only slightly better performance. Even the 2025 building in Berlin, designed with modern energy standards, recorded a significant thermal stress due to overheating due to the absence of active cooling and still limited natural ventilation.

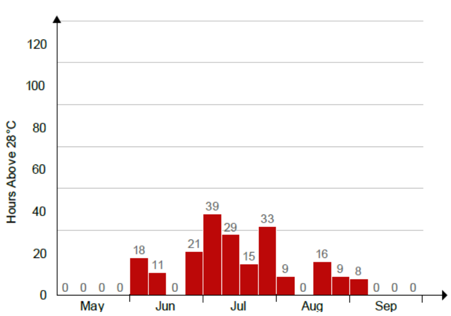

FIGURE 9. Building 1, 2024

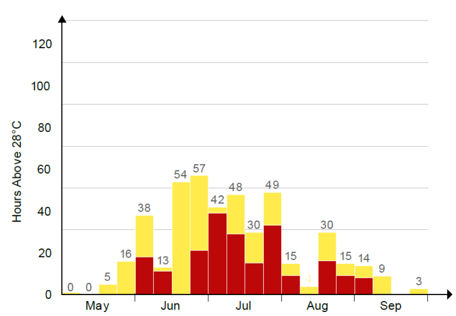

FIGURE 10. Building 1, 2075

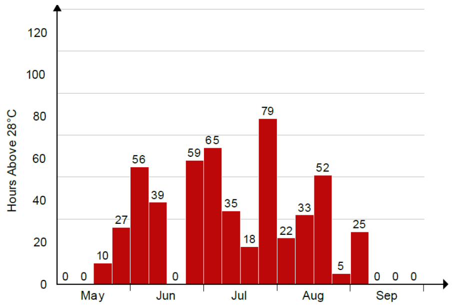

FIGURE 11. Building 2, 2024

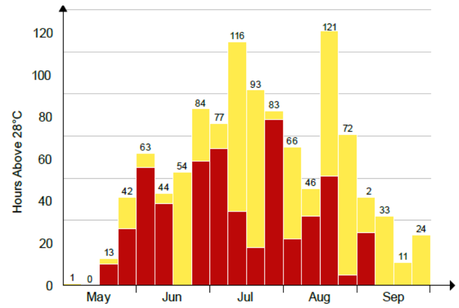

FIGURE 12. Building 2, 2075

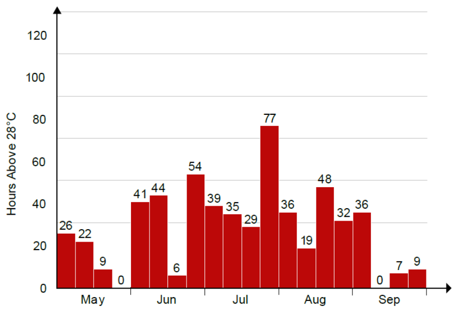

FIGURE 13. Building 3, 2024

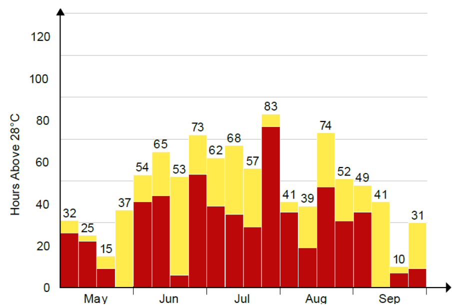

FIGURE 14. Building 3, 2075

Under the 2075 climate situation, overheating became significantly more severe (Figures 10, 12, and 14). The increase of overheating is illustrated in yellow color. As we can see from the images above, there is an urgent need to reduce the overheating, especially of the upper floors of inner city multistorey buildings.

PROPOSED INTERVENTIONS

To address overheating in existing multistorey residential buildings, this paper examines a set of passive and low-tech retrofit practices. These interventions aim to improve indoor thermal comfort during increasingly frequent and intense summer heat events projected for 2075.

To avoid reliance on active cooling systems, the strategies focus on enhancing the building's natural climatic resilience. They draw on principles of thermal mass, natural ventilation, and solar protection.

Solar Shading

External shading elements are added to reduce solar gains. Depending on building orientation and façade geometry, fixed devices such as overhangs and vertical fins are combined with adjustable systems like exterior blinds. These elements are designed to block high-angle summer sun while maintaining sufficient daylight and outward visibility. Durable, low-maintenance materials are used to ensure long-term functionality with minimal upkeep.

Improved Glazing Systems

Old windows are replaced with modern glass units. These have low-emissivity coatings, insulated frames, and better solar control. This helps keep heat out in summer. It also keeps warmth in during the heating season. The change reduces temperature swings and improves the building's overall efficiency.

Activation of Thermal Mass

Where possible, the building's existing thermal mass – like concrete slabs and masonry walls – is used to better control indoor temperature. This is done by exposing these surfaces and helping them absorb and store heat during the day. The methods include removing suspended ceilings or carpeted floors so the air can touch the heavy materials directly.

Night Ventilation

To help thermal mass cool the building, nighttime ventilation is used as a passive method. Windows that can open and other controlled openings let cooler outside air in during the night. This pushes out the heat that built up during the day. The method works well in temperate climates (like the German climate) where the temperature drops a lot after sunset and during the night [10]. It also needs little technical effort, except for people to open windows accordingly.

Enhancing Cross-Ventilation

Natural airflow gets better when the building's layout and openings are planned well. Often, cross-ventilation does not work fully because air paths are blocked or doors are closed. Small changes, like adding transom openings or letting air move through stairwells and hallways, can improve passive cooling a lot. These steps are inexpensive and can be adjusted to fit each building.

Use of Materials with High Thermal Storage Capacity

In spaces exposed to overheating and high solar exposure, such as upper-floor units or specific rooms, additional materials with high heat capacity are added to help moderate temperature peaks. Natural clay panels or modular elements containing phase-change materials are used as internal linings to enhance thermal inertia. These solutions are reversible, low-emission, and suitable for retrofit scenarios without major construction work [11], as well as for new planned buildings.

The proposed interventions have been selected for their practical significance, adaptability to existing building types, and ecological compatibility. Each strategy is assessed through simulation to evaluate its effectiveness under future summer conditions. Taken together, these measures provide an achievable way toward a more climate-resilient housing stock.

SIMULATION RESULTS AND PERFORMANCE ANALYSIS OF ENHANCED BUILDINGS

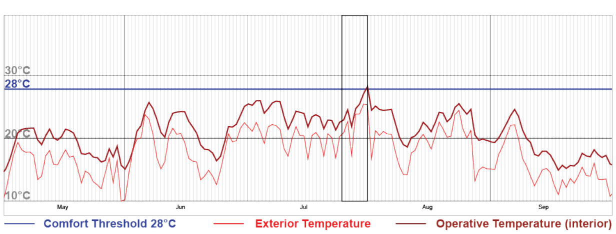

FIGURE 15. Simulation example with summer heat Waves, Enhanced Bdg, building 1, May - Sep 2024

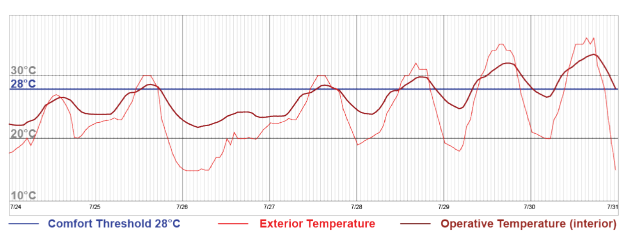

FIGURE 16. Simulation example of building 1 during the hottest week in 2024 after enhancement

Figure 15 shows that the heat waves are below the comfort zone. However, Figure 16 shows the hottest daily peaks during day/night reaching up to 34 °C. By modelling and testing a virous combination of passive cooling strategies like enhanced thermal mass, night ventilation, cross-ventilation, solar shading, and improved glazing, to assess their impact on indoor thermal comfort. Figures 17, 19, and 21 present the indoor temperature profiles for the retrofitted buildings in 2024, while Figures 18, 20, and 22 show performance under the 2075 climate scenario. Adding thermal mass, such as exposed concrete slabs or clay panels, drastically reduced indoor temperature swings. Night ventilation, assisted by secure feasible windows, significantly enhanced the cooling effect of thermal mass by clearing out stored heat during cooler nighttime hours. External shading devices, such as fixed overhangs and adjustable blinds, reduced solar heat gains.

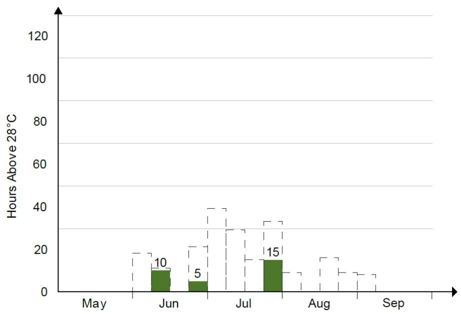

FIGURE 17. Enhanced Bdg. 1, 2024

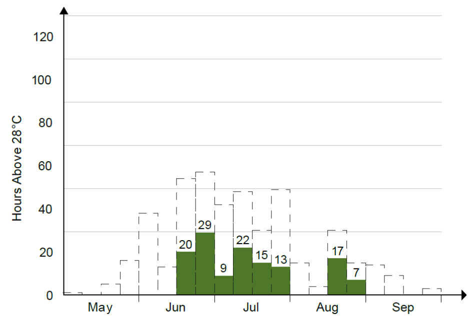

FIGURE 18. Enhanced Bdg. 1, 2075

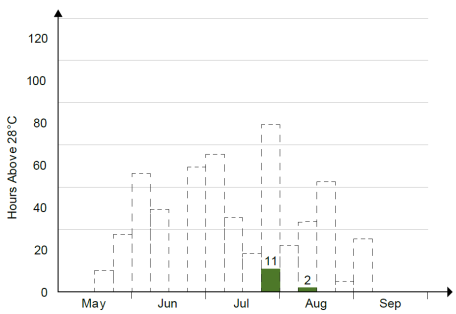

FIGURE 19. Enhanced Bdg. 2, 2024

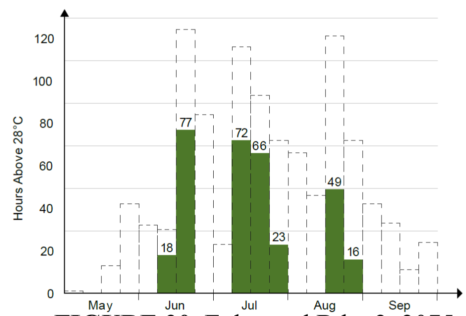

FIGURE 20. Enhanced Bdg. 2, 2075

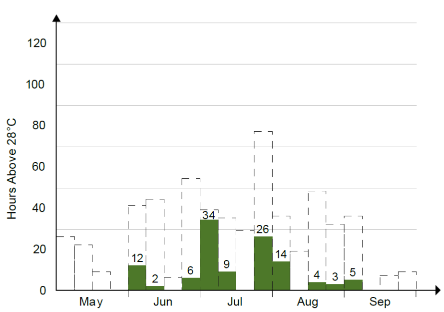

FIGURE 21. Enhanced Bdg. 3, 2024

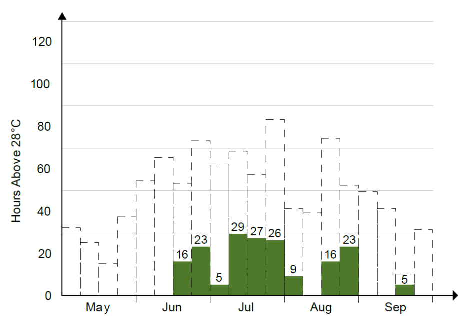

FIGURE 22. Enhanced Bdg. 3, 2075

By modelling and testing a virous combination of passive cooling strategies like enhanced thermal mass, night ventilation, cross-ventilation, solar shading, and improved glazing, to assess their impact on indoor thermal comfort. Figures 17, 19, and 21 present the indoor temperature profiles for the retrofitted buildings in 2024, while Figures 18, 20, and 22 show performance under the 2075 climate scenario. Adding thermal mass, such as exposed concrete slabs or clay panels, drastically reduced indoor temperature swings. Night ventilation, assisted by secure feasible windows, significantly enhanced the cooling effect of thermal mass by clearing out stored heat during cooler nighttime hours. External shading devices, such as fixed overhangs and adjustable blinds, reduced solar heat gains.

DISCUSSION

Our simulations show that passive cooling strategies work well. We focused on combining thermal mass enhancement with passive ventilation. These methods can significantly reduce overheating in German multistorey residential buildings. We consistently observed temperature drops of roughly 5 to 7°C compared to outdoor conditions. This allows indoor comfort to be maintained during most summer heat waves. The findings demonstrate the powerful potential of these low-tech solutions. These are ecologically sound approaches to prepare existing buildings for climate challenges ahead.

The findings highlight a critical oversight in traditional German building design. Even modern structures suffer from this problem. Our 2025 Berlin building meets current energy efficiency standards. Yet it still is exposed to considerable thermal stress from overheating.

Our baseline simulations painted a stark picture. They underscore the urgent need to adapt the existing building stock. This is especially true for upper floors of inner-city multi-story buildings. Without changes, these spaces will experience dangerous indoor temperatures.

The interventions we studied – solar shading, improved glazing, activating thermal mass, night ventilation, enhancing cross-ventilation, and integrating materials with high thermal storage capacity – worked well both alone and together. They worked even better when connected. The synergetic effect of these strategies is especially efficient, similar combined effects have been reported in earlier comparative case studies [5]. Night ventilation greatly increases the cooling power of thermal mass by removing stored heat. This approach turns the building itself into a cooling system, as it uses the building's natural qualities and environmental cycles, and provides a sustainable alternative to mechanical cooling systems that consume large amounts of energy.

However, putting these strategies into practice on a large scale has real challenges. Structural capacity is a major concern. Adding significant thermal mass, like new masonry or concrete, may not always be possible without extensive and expensive structural changes. The urban environment plays a key role. Dense city areas can block wind flow and thus reduce the potential of cross-ventilation. This can result from local wind patterns, nearby buildings, or noise that stops occupants from opening windows at night. The addition of features like large operable windows or ventilation shafts depends on each building's layout. Apartments with a single orientation or few exterior walls may not achieve effective natural ventilation.

Our study shows that passive retrofitting is both ecological and practical. It performs well despite some challenges. Active cooling systems, such as air conditioning, consume large amounts of energy, produce operational emissions, and are costly to install. Passive measures align better with sustainability goals [12]. They reduce reliance on fossil fuels. They have lower carbon footprints. They also prevent the "rebound effect," where increased cooling demand offsets energy savings.

During extreme heat, indoor temperatures occasionally exceeded comfort levels. However, these events were less frequent and severe than in baseline scenarios. This indicates that passive strategies may not fully prevent discomfort during heatwaves but substantially reduce its frequency and intensity, making them a strong first line of defence.

Our research shows the importance of a building-specific adaptation approach. One solution cannot work for all buildings. We can create general guidelines for retrofitting. However, these guidelines must be carefully adapted to each building's unique features. This includes its design, structure, and surrounding environment. This method will work better, be more energy efficient, save money, and make Germany's existing buildings stronger against future climate problems.

CONCLUSION AND OUTLOOK

This study shows that passive cooling is highly effective in Germany. With the application of passive design principles, buildings can be kept cool while using little energy. Buildings can be made cooler by using thick walls that store heat and allowing fresh air to flow at night. This works without expensive air conditioning.

Computer simulations confirm that these simple methods are highly effective. They help buildings cope with hot weather. This is important as summers are becoming hotter.

The concepts in this study are practical, not theoretical. They work for many different buildings. Tests included using walls that store heat during the day and release it at night. Cool night air was also used to ventilate buildings. Smart window shades that block sunlight were found to be highly beneficial.

These results are relevant for various groups. Policymakers should integrate these cooling strategies into building regulations. They should also provide funding for building upgrades. Current regulations focus mainly on winter heating. Equal attention must be given to summer cooling. Architects and engineers should design upgrades that benefit the environment. Solutions should reduce carbon emissions and have measurable impact. Building owners should invest in such measures. The research provides strong justification. These strategies improve comfort and health. They reduce energy costs over time. They increase property value as the climate changes.

Passive cooling works well for most hot days. However, extreme heat waves remain challenging. Future research must address this issue in greater depth. Methods must be improved for the hottest days. Strategies for applying these solutions across many urban buildings must be developed. Technical performance is not the only factor, since costs have to be considered as well and actual patterns of home use must be understood. Government policies should accelerate adoption.

As the climate continues to warm, the need to update buildings with smart, eco-friendly methods becomes even more urgent than before, as it is essential for a comfortable and sustainable future.

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