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Original Research Article

Comparison of the influences of exterior walls on the thermal comfort of dwellers and selection of optimal materials in hot and semi-arid climates: A case study of Dezful

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Abstract

To achieve sustainable construction in residential building industry and to reduce energy consumption and create comfort conditions for residents in various climates, it is required to examine the exterior shell of buildings serving as the main interface between the interior and exterior spaces. This research, thus, aims to examine the thermal behavior of bearing and non-bearing walls used in the city of Dezful. They are made of perforated brick, clay block, Hebelex block (AAC) and Lica block. It also aims to study the thermal insulations of ETICS and XPS in order to identify comfort conditions inside the space using the ASHRAE 7-point scale. The present research seeks to explore how the thermal behavior of materials incorporated into exterior walls influences heat transfer to interior spaces and the thermal confrontation of residential building dwellers in Dezful. The research adopts a quantitative comparative approach and bases its analysis on secondary and field studies, simulating 12 types of walls in the hot and semi-arid climate of Dezful using the Design Builder software. The results suggested that simulation outputs in the dynamic mode did not match the sustainable conditions in the studied climate. The method adopted to calculate stable conditions indicated that the wall with the lowest thermal conductivity coefficient would have the most optimal behavior. Contrastingly, the wall with the highest thermal capacity would be the most effective in achieving thermal comfort for dwellers under unstable conditions. The results of the evaluations and analyses revealed that data on the thermal transfer of exterior walls varied under stable and unstable conditions, and calculations made under stable conditions needed to be replaced by unstable conditions. The following results were obtained based on the comfort conditions of the 12 studied walls demonstrated in the PMV diagram and considering the dominant need for cooling in the studied climate: a) XPS and ETICS heat-insulated walls did not perform well, and b) walls made with clay blocks, perforated bricks, and Hebelex and Leca blocks without heat insulation performed better, among which Leca blocks with no heat insulation indicated the best thermal behavior in terms of energy consumption and thermal comfort.

Keywords:
Thermal comfort,
Exterior wall,
Thermal insulation,
Energy consumption reduction,
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Extended Abstract

1. Introduction

In the context of the Energy Performance of Buildings Directive (EPBD), accurate input data about the actual thermal performance of the external wall of a building as a communication shell between the indoor and outdoor spaces is of great importance to determine the energy performance of the building. It is essential to predict the energy performance of buildings based on policies and decisions related to energy efficiency measures and energy-saving goals. In this regard, estimating the thermo-physical characteristics of the external walls of buildings as a result of the need for energy audits and energy performance examinations is essential. To improve the thermal performance of buildings, the thermo-physical properties of common materials and their effect on the indoor temperature and the comfort conditions of the residents have been investigated and compared in laboratory conditions and without ventilation.

2. Research Methodology

The present research adopts a quantitative comparative approach and bases its analysis on secondary and field studies, simulating 12 types of walls in the hot and semi-arid climate of Dezful using the Design Builder software.

3. Results and discussion

Modeling is done in the software derived from the defined scenario. The indoor temperature of the building is affected by three factors including the performance of the materials against the heat of the sun and the temperature of the surrounding air, ventilation (natural), and the entry of sunlight into the space. The more the area of the external wall is exposed to air and radiation, the more heat transfer will occur, but the floor area does not affect this process. For this purpose, considering the worst conditions and simplifying the modeling, a rectangular cube test model was used with useful dimensions of 4m in length, 3m in width, and 3m in height. The four sides of the model are free and exposed to radiation and air temperature. Since the only research variable is the effect of the performance of the materials on the indoor temperature, to obtain more accurate information, the modeling was done without any holes, windows, and cooling and heating systems. The materials used in the fixed floor and ceiling and the samples with thermal insulation were added to the floor and ceiling layers.

The 12 experimental models studied included two groups of load-bearing walls (A) and non-load-bearing walls (B, C, D). They were examined and evaluated in three stages: a) walls without thermal insulation (A1, B1, C1, D1), b) walls with XPS thermal insulation (A2, B2, C2, D2), and c) walls with ETICS thermal insulation (A3, B3, C3, D3). The materials used in load-bearing walls are perforated bricks (A). In non-load-bearing walls, materials such as clay blocks (B), AAC blocks (C), and LECA blocks (D) were used. The climatic conditions were defined by loading the Dezful climate file on the software to perform simulation under real conditions. The results of the simulation indicate that, in stable and unstable conditions and climate changes in hot and cold seasons and the difference between night and day temperatures, the walls have different rates of

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thermal resistance (R) and thermal capacities (C) based on their heat exchange coefficient (U-value). This can be interpreted with the results obtained from the DesignBuilder software, the insulating properties of the materials, and the thermal mass of the walls. When the specific heat (CP) and density (ρ) are high and the thermal conductivity coefficient (λ) is low, the wall acts as a capacitor, and the heat transfer time from the outside to the inside increases. This process leads to the optimum behavior of the wall.

According to the stable conditions, walls with more resistance and less heat exchange are the most optimum option for use in buildings. Based on the results of the simulation, in the first stage, among the walls without thermal insulation, D1, C1, B1 and A1 with slight differences, the D1 wall (Leca block without thermal insulation) showed the most optimum thermal behavior. In the second stage, with the addition of thermal insulation XPS (D2, C2, B2, A2), the D2 wall (Leca block with thermal insulation XPS) showed the most optimum thermal behavior. In the third stage, among the walls with thermal insulation ETICS (D3, C3, B3, A3), the D3 wall (Leca block with thermal insulation ETICS) showed the most optimum thermal behavior. The walls behave more based on what is expected from their thermal conductivity coefficient in winter months, compared to the summer. The results obtained from the indoor temperatures of the modeled spaces are different from the results obtained from the stable state calculations.

Walls with thermal insulation do not find enough time to exit the incoming heat during the day in the hot season and with the shortening of the night. On consecutive days, the indoor temperature increases until there is a significant difference between the internal and outdoor temperatures. The constant movement of heat occurs from the hot side to the cold side, and the temperature is always transferred in one direction from inside to outside in the cold season. However, in the hot season, the building shell is exposed to movement in two directions, from outside to inside during the day and from inside to outside during the night. This is an issue that challenges the initial predictions obtained from the studies of stable conditions. This phenomenon can be understood by comparing the behavior of walls in three stages of simulation. Although the presence of thermal insulation in the wall does not completely prevent the transfer of heat to the indoor space, it greatly reduces the movement of heat in the wall depending on its resistance. For this reason, the heat exchange coefficient of walls with ETICS thermal insulation is very different from that of walls with XPS thermal insulation. However, in unstable conditions, they show similar behavior in cold and hot seasons. In the cold season, the indoor temperature is within the range of thermal comfort. This eliminates the need for heat. In the hot season, the walls with ETICS insulation, especially from May to September, and the walls with XPS thermal insulation are far from the comfort curve. Additionally, higher heat exchange coefficient transfer heat from inside to outside occurs more in walls without thermal insulation than in those in the cold season. Thus, the need for heating increases in the cold season. In the hot season, due to a two-way heat exchange, the indoor temperature is closer to comfort conditions, and the need for cooling decreases.

Given Fanger's theory and the simulation results, it can be concluded that the comfort conditions in A1, B1, C1, and D1 walls in April, May, September, and October are within the range of thermal

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comfort. The walls are placed between -2.02 to +2.02 comfort (cool-hot) in the remaining months of the year, which requires cooling and heating. The samples constructed with A2, B2, C2, and D2 walls are in the range of -1.81 to 11.4. The heating requirement of these walls is lower than that of the walls without thermal insulation. However, the mean indoor temperature increases to the point where it exceeds the very hot phase of Fanger's theory from May to September due to the thermal mass of the materials. This event indicates a significant increase in the need for cooling. April and October are the months when comfortable conditions exist in these walls. The samples A3, B3, C3, and D3 walls are within the satisfactory range of comfort conditions in the four months of April, November, February, and March. Being in the range of -1.2 to +5.27 indicates a reduction in the level of heating. Also, due to the intolerable conditions of May to October, when the mean indoor temperature is higher than the outdoor temperature, the need for cooling is predicted to increase significantly.

Based on the results of the previous studies and the present one, it is concluded that the calculations with the thermal conductivity coefficient in stable conditions cannot provide acceptable results, and the effect of heat capacity on the heat exchange coefficient (U) should be added in the calculations. The thermal insulation properties and thermal capacity have different roles in the thermal behavior of an entire external wall. These two thermo-physical properties of materials determine the level of heat exchange. Thus, it can be stated that, among the types of walls measured, the walls of the first stage (with materials without thermal insulation) perform better in the hot and semi-arid climate of Dezful. Among them, the wall with Leca blocks without thermal insulation (D1) is considered the best option to achieve thermal comfort and reduce energy consumption.

4. Conclusion

Investigating indoor temperature changes and calculations in stable and unstable boundary conditions indicate that the calculations based on the thermal conductivity coefficient of materials can be relied upon in controlled and laboratory climate conditions. However, in unstable boundary conditions, density and heat capacity are also considered in addition to thermal conductivity coefficients. Thus, materials with higher heat capacity and lower density transmit less heat. Also, thermal insulation does not prevent the transmission of heat but reduces it to a great extent. Thus, the resistance of the materials due to the two-way exchange of heat in the hot and semi-arid climate of Dezful is useful to the point where it allows heat to pass from the inside space to the outside environment at night in the hot season. Therefore, ETICS and XPS thermal insulations do not have proper performance in this climate. Considering the changes in the indoor temperature of the space and the thermal comfort conditions based on Fanger's theory and the need for cooling the area among the studied walls, the walls of the first stage (materials without thermal insulation) have a more appropriate performance in this climate. The comparative results indicate that the most optimum wall is the D1 wall with a Leka block and without thermal insulation, followed by the C1 wall with a Heblex block without thermal insulation and the A1 wall with perforated bricks without thermal insulation. The use of these walls meets the need for air conditioners with less power for larger areas. Accordingly, the economic pressure imposed on the household is reduced in addition to reducing fossil fuel consumption. If conditioning is added to the issue, the results may be different. This can be addressed as a new topic in future studies.

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