Cihan University-Erbil Scientific Journal (CUESJ)

RESEARCH ARTICLE

Enhancing Energy Efficiency in Hot Climates through Wall and Roof Insulation Techniques

Saya J. Rashid, Faten R. Yaseen

Department of Architecture, College of Engineering, Salahaddin University, Erbil- Kurdistan Region, Iraq

ABSTRACT

In the past two decades, energy consumption worldwide has increased by more than 30%. In hot weather countries where temperature reaches high levels, thermal insulation materials have recently been highly considered due to their low thermal conductivity. This results in a substantial reduction in the demand for energy in building HVAC systems and its related negative impacts on the surrounding environment. The aim of this study is to determine the optimum construction technique used in buildings to enable energy saving with minimal occupation of space. This research focused on the role of wall and roof materials on the energy efficiency of a building. The research adopted mathematical calculations for finding the U-value of wall and roof insulating materials. The results showed that the cavity walls with insulation material and the cavity roof with air gap and insulation material are optimum solutions to be used in buildings. This study recommended considering long-term energy savings to substantiate the effectiveness of these materials in conserving energy for buildings.

Keywords: Energy efficient, hot climates, insulation techniques, thermal insulation

INTRODUCTION

In the past 30 years, energy consumption becomes the most significant issue globally, as the desire in thermal comfort buildings improvement increasingly. This energy is mostly obtained from fossil fuels, which contribute CO_2 to the atmosphere that can increase the greenhouse effect and promote global warming.[1] Energy consumption demand in the Iraqi Kurdistan region, like in all other countries, has increased gradually. Moreover, previous work has shown that residential neighborhoods in Kurdistan adopt more than half of the electricity supply (about 60% demand in building) for cooling and heating.[2] Applying the strategy of energy efficiency is another alternative to construct buildings in the long sustainable term. The global environment is less affected by minimal energy consumption.[3]

The envelope of a building is a crucial component that governs the whole building performance by regulating the interaction between interior environments and adverse external environmental factors that directly influence the energy efficiency of building.[4] As a result of shade temperatures rising between 40°C and 50°C during summer months in the region, the climate inside buildings often becomes undesirable, which means more electricity used for air conditioning to cool building spaces.[1] Similarly, the coldness of winter requires more energy for active heating, provided the minimal standards regarding thermal insulation for buildings. The demand for both cooling and heating is much higher compared to what it would have been with better thermal insulation.[5] Therefore, improving the overall performance of a building depends on the selection and application of environmentally friendly materials for the building envelope.[6-8] Different varieties of insulating materials are available, many of which provide the same insulation properties but vary in price and material content.[9] The thermal performance of a building's envelope is dictated by the thermal properties of the materials, which are characterized by their capacity to absorb or release solar heat, as well as the overall U-value of the respective layers, including insulation.[10]

LITERATURE REVIEW

Researches deliberated the energy efficiency in buildings to reduce energy consumption from different visions. Pacheco *et al*. highlight the importance of integrating design

Corresponding Author:
Saya J. Rashid, Department of Architecture, College of Engineering, Salahaddin University, Erbil- Kurdistan Region, Iraq.
E-mail: saya.rashid@su.edu.krd

Received: December 12, 2024
Accepted: May 27, 2025
Published: July 15, 2025

DOI: 10.24086/cuesj.v9n2y2025.pp18-25

elements such as orientation, shape, envelope systems, and passive heating and cooling techniques to optimize thermal performance and reduce energy consumption.[11] In a related study, Al-Sanea *et al*. examined the impact of insulation location on the thermal efficiency of building walls under stable periodic conditions, utilizing weather data from Riyadh. The findings indicated that the positioning of the insulation layer showed minimal impact on the daily average transmission load.[12] Ghabra *et al*. found that, through building simulations, thermal material walls with specific glazing characteristics were the most energy-efficient façade for tall residential buildings in Saudi Arabia, showing the significant impact of façade design on energy efficiency.[6] In addition, other studies have provided empirical evidence that incorporating air gaps within composite walls and optimal insulation thickness drastically reduces heat loss, offering economic and environmental benefits through life-cycle cost analysis.[13] In a related study, Li *et al*. used the inverse parameter estimation method to estimate U-values in solid walls, finding significant deviations in measured values, which suggests that conventional standardizing models may not accurately capture essential building physics.[14] Moraekip conducted a performance analysis of various building envelope types in Cairo, revealing that conventional external walls significantly contribute to heat transfer. However, introducing thermal insulation blocks resulted in significant improvements in energy efficiency.[15] In another approach, Al-Yasiri and Szabó studied the impact of varying thicknesses of expanded polystyrene insulation combined with phase change materials (PCM) under sweltering summer conditions, using metrics like maximum indoor temperature reduction to assess thermal performance.[7] Similarly, Vakilinezhad and Khabir explored advanced coatings, such as PCMs and thermochromic materials, to improve façade thermal performance and energy efficiency, finding that the arrangement of wall layers and insulation thickness had a significant effect on annual energy consumption.[16] Furthermore, Kaddouri *et al*. evaluated the effectiveness of bio-based insulation materials – hemp wool, wood fiber, and expanded cork – in a residential building in Al-Hoceima, Morocco, revealing that hemp wool insulation significantly reduced energy demands for both heating and cooling, while improving indoor temperatures throughout seasonal changes.[17] Although Luo *et al*. designed specialized walls to simulate the thermal performance of a six-story student apartment model, showing that precast insulation walls with external insulation performed better in terms of thermal efficiency and energy savings than sandwich insulation forms across various climate zones.[8]

Energy efficiency measures for buildings are approaches through which the energy consumption of a building can be reduced while maintaining or improving the level of comfort in the building. The material is one of the factors that effect on thermal comfort in buildings, also contributing to reducing heating, cooling demand. The objective of this study is to determine the impact of thermal insulation materials in buildings, enabling effective energy savings with minimal occupation of space. This research has focused on the effect of wall and roof materials on the energy efficiency of a building.

TERM DEFINITION

Thermal Conductivity (K)

Thermal conductivity is the rate of constant state transfer of energy (W) through a unit area of a one-meter-thick identical material, directed perpendicular to equilibrium planes, resulting from a unit (1K) temperature gradient across the sample.[18] It measures a material's effectiveness in conducting heat. Thus, comprehending the thermal conductivity values enables a quantitative assessment of the effectiveness of different thermal insulation materials.[10,19-22]

Thermal Conduction C-value

Thermal conduction, which connoted as C-value, represents the transmission of heat through a solid material, quantified as heat flow (W) per unit surface area of a component, with a temperature differential of 1 K between its opposing surfaces. It resembles thermal conductivity, but pertains to a specific thickness of material. Thermal conductance is expressed in watts per square meter per kelvin (W/m^2K).[9]

Thermal Resistance R-Value

Thermal resistance quantifies the impediment to heat transfer due to the inhibition of conduction, convection, and radiation. It is a function of the material's thermal conductivity, thickness, and density. Thermal resistance, or R-value, is denoted in (m^2-K/W).[10]

Thermal Transmittance U-Value

Thermal Transmittance connoted as U-Value, quantifies the rate of heat transmission through a building's external envelope, represented as a U-value. Heat consistently travels from warmer areas to cooler areas, with each material in the building's external envelope conducting heat at varying rates. Materials with low U-values transport heat slowly and are hence effective insulators.[21] Understanding the method of calculating U-values for a building may be beneficial in relation to efforts aimed at enhancing energy efficiency. The initial step is to determine the thermal conductivity k (W/m K) of each material used in the building.[10] Subsequently, compute the thermal resistance R (m^2K/W) for each material as outlined below:

$$R = \frac{t}{k}(m^2K/W) \quad (1)$$

where t is the thickness of each material.

The U-value of a building element made of multiple layers is given by:

$$U = \frac{1}{(R1 + R2 + R3 + \ldots + R8)}(W/m^2K) \quad (2)$$

Thermal Insulation

Thermal insulation is a material or a combination of materials that, when properly applied, obstructs the transmission of heat by conduction, convection, and radiation. It obstructs heat flow into or out of a structure because of its high thermal resistance.[10] The interplay of convection, radiation, and conduction determines the total effectiveness of insulation, as shown by the apparent thermal conductivity, which reflects the lack of pure conduction, especially at high temperatures.[22]

METHODOLOGY

The research methodology involved analyzing previous research that assessed the properties of materials influencing energy demand and proposed optimal design solutions, while also considering the cost of each material in the local market. This study employed a mathematical methodology to assess the thermal conductivity of construction materials utilized in walls and roofing across several scenarios to determine the U-value for each situation, subsequently comparing these values to identify an optimal design solution for structures. The data were taken in Ashrae standard,[23] the U.S. DOE standard,[24] and a relevant research study to get approximate results.

To obtain the U-value, these steps were followed:

1. Determine the thickness of the layers materials with type, and the thickness of each material.
2. Determine the thermal conductivity k value for each material, which is taken from the ASHRAE standard and the U.S. DOE standard, then using equation (1) to calculate the R value,

   $R = \frac{t}{k}(m^2K/W)$ (1), where t is the thickness of each material.
3. Determine the U-Value by using equation 2 for each case.

   $$U = \frac{1}{(R1 + R2 + R3 + \ldots + R8)}(W/m^2K) \qquad (2)$$
4. Comparison between the U-values to obtain the best case.

Wall

Walls are a crucial component of a building envelope, serving as barriers against external conditions while providing thermal and acoustic insulation without compromising architectural esthetics. The thermal resistance (R-value) of walls is a vital factor affecting a building's thermal performance and energy efficiency. A high R-value signifies exceptional insulation efficiency, leading to less energy usage for heating and cooling. An external wall must demonstrate critical attributes such as structural integrity, stability, durability, moisture resistance, and temperature resistance to function properly.[25] External wall insulation is an established method for improving energy efficiency, as it diminishes heat transmission and extends thermal retention within the building envelope.[26] The efficiency of wall insulation is represented by the U-value, which quantifies the rate of heat transfer through a unit area of wall per degree of temperature differential (measured in watts per square meter per kelvin, $W/m^2 \cdot K$). A diminished U-value signifies superior insulation efficiency, resulting in decreased thermal transfer through the wall.[21]

The present study compares between three types of wall envelopes (traditional wall-cavity wall with an air gap, and cavity wall with insulation material). The U-value of each type was compared to determine the optimum type of wall layer. The ASHRAE handbook of fundamentals shows comprehensive lists of wall types as well as the thermal properties of building and insulation materials. The properties of wall materials and their costs are shown in Table 1.[22-24]

Traditional wall

This wall style is prevalent in areas including concrete blocks of 0.20 m, externally coated with 0.025 m of cement plaster and internally finished with approximately 0.025 m of gypsum, as illustrated in Figure 1. The outcome of the U-value is presented in Table 2.

Cavity wall with air space (gap)

A cavity wall consists of two walls separated by a continuous air gap and interconnected by metal connections for structural integrity. The thermal resistance of an airspace varies with its thickness. In thinner airspaces, resistance is reduced due to enhanced conduction. In thicker airspaces, convection currents may develop, which can also decrease thermal resistance by facilitating heat transfer. Some individuals selected a wall composed of two concrete blocks (0.15m, 0.10m) with an air cavity between them, as seen in Figure 2. The value of U for this type is 1.288 w/m^2K, as detailed in Table 3.

Cavity wall with insulation material

This wall features a double wall system with insulating material located between the layers. This is accomplished by either completely filling the existing cavity, such as through an injection of Polystyrene foam, or partially by incorporating a board

Table 1: Properties of wall materials[22]

Material	K (W/m.k)	P (kg/m³)	C (J/kg.K)	Material cost ($/m³)	Insulation ($/m³)
HWHCB (200 mm)	1.05	1105	840	-	-
Plaster board	0.17	800	1090	-	-
Cement plaster	0.72	1865	840	-	-
Polystyrene (molded)	0.036	20	1215	42.67	1.60
Polystyrene (extruded)	0.032	26	1215	69.33	1.60
Polystyrene (injected)	0.032	20	1215	50.67	1.60
Rock wool	0.042	30	837	48.00	1.60
Glass fiber	0.038	24	837	45.33	1.60
Polyurethane (board)	0.024	30	1590	138.67	1.60

Table 2: Properties of the wall materials (Authors)

Material	Thickness (m)	(K) Value W/m-K	(R) Value (m^2K/W)	(U) Value W/m^2K
Concrete Block	0.20	1.05	0.19	
Cement plaster	0.025	0.72	0.034	
Gypsum	0.025	0.22	0.113	
Inside air			0.13	
Outside air			0.04	
Total			0.507	1.972

Table 3: Properties of cavity wall materials (Authors)

Material	Thickness (m)	(K) Value W/m-K	(R) Value (m^2K/W)	(U) Value W/m^2K
Concrete block	0.15	0.96	0.156	
Concert block	0.10	0.81	0.123	
Cement plaster	0.025	0.72	0.034	
Gypsum	0.025	0.22	0.113	
Air gape			0.18	
Inside air			0.13	
Outside air			0.04	
Total			0.776	1.288

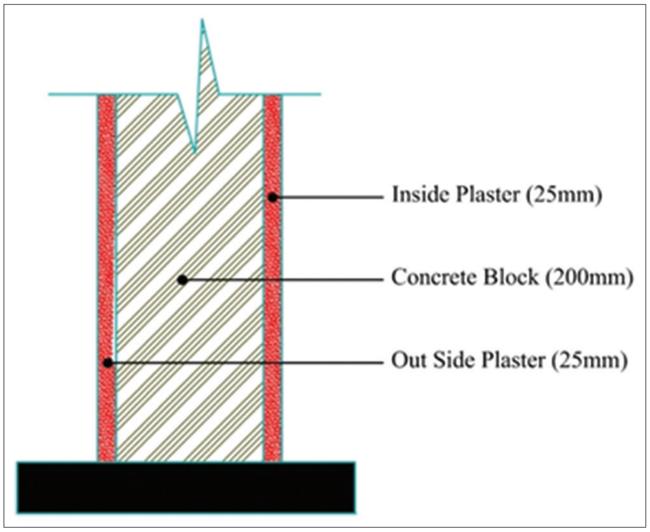

Figure 1: Layers of traditional wall (Authors)

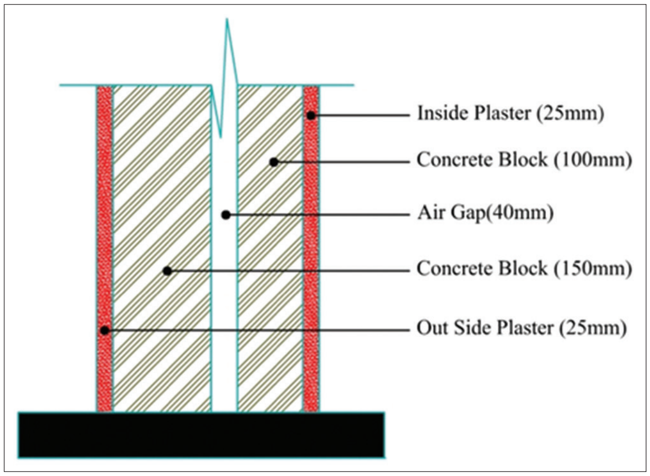

Figure 2: Cavity wall with air gap (Authors)

of insulation material during the construction phase. In the absence of insulation, the entire cavity functions as an air space of limited thickness, across which heat is transmitted through conduction, convection, and radiation.[10] This study selected a wall composed of two concrete blocks, each with a thickness of 0.15 m and 0.10 m, and an insulation cavity of 0.04 m filled with polystyrene between them, as seen in Figure 3. The U-value for this kind is 0.46 W/m^{2}K, as detailed in Table 4.

Roof

The roof is one of the most critical components of the structure. The thermal insulation of the roof is crucial for minimizing incoming heat change, as significant heat transfer transpires through the roof.[6] Generally employed construction techniques in Kurdistan mostly utilize reinforced cement concrete as the roofing component, characterized by elevated heat conductivity. Moreover, advanced technologies have facilitated the implementation of thinner concrete slab construction, with thicknesses ranging from 0.15 m to 0.20 m. The roof is adjacent to the upper section of the building, serving to shield it from precipitation, wind, solar radiation, and temperature fluctuations. Approximately 25% of thermal loss transpires through a building's roof.[15] A breakdown in the roof design may impact other components of the structure. To enhance roof designs, it is essential to precisely assess the transmission load through roofs under dynamic conditions

Table 4: Characteristics of insulated cavity walls (Authors)

Material	Thickness (m)	(K) Value W/m-K	(R) Value (m^2K/W)	(U) Value W/m^2K
Concrete block	0.15	0.96	0.156	
Concert block	0.10	0.81	0.123	
Cement plaster	0.025	0.72	0.034	
Gypsum	0.025	0.22	0.113	
Insulation (Polystyrene)	0.05	0.032	1.56	
Inside air			0.13	
Outside air			0.04	
Total			2.156	0.46

for various geometrical configurations, insulation types, and environmental factors.[27] Table 5 shows the properties of roof material.

Traditional Roof

The roof type adopted in Kurdistan is mostly a flat roof. The standard materials employed in roofing components in Kurdistan include gypsum, reinforced concrete, and tiles, as illustrated in Figure 4.

The U-value for this kind, based on the calculation standard for each roof layer, is approximately 5.02 W/m^2K, as indicated in Table 6.

Roof Construction with Insulation (Polystyrene)

This roof style has a typical structure with insulation material, specifically polystyrene, as shown in Figure 5. It comprises reinforced concrete with a thickness of 0.15 m. The U-value is around 4.21 W/m^2K. Table 7.

Cavity Roof with Air Gap

This style of roof has a concrete slab with a thickness of 0.15 m, featuring an air gap and a suspended ceiling [Figure 6]. The U-value is 3.96 W/m^2K [Table 8].

Cavity Roof with Air and Insulation

This type of roof is similar to a cavity roof, including an air gap, with the additional incorporation of insulation material as shown in Figure 7. As a result, the U-value is (0.55 W/m^2K) as shown in Table 9.

Table 5: Characteristics of roofing materials[12]

Material	K (W/mk)	P (kg/m³)	C (J/kg K)
Tile	0.84	1900	840
Mortar bed	0.72	1860	840
Membrane	0.50	1700	1000
Foam concrete	0.20	640	840
Reinforced concrete	2.30	2411	800
Air space	1.06	1.1	1007
Cement plaster	0.72	1860	840
Heavyweight concrete	1.73	2243	840
Molded polystyrene	0.033	38	1280

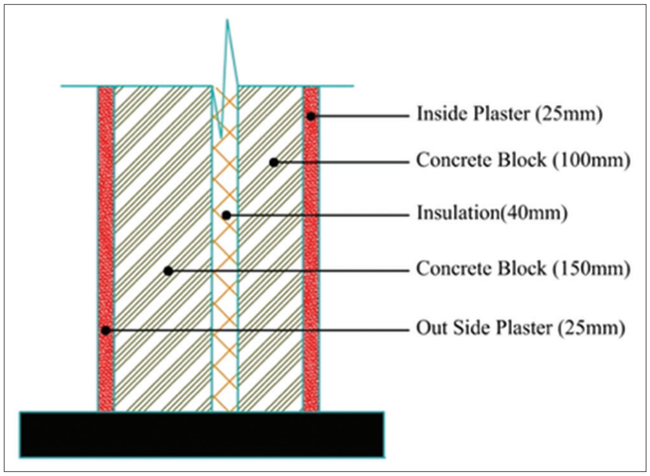

Figure 3: Cavity wall with insulation material (Authors)

RESULTS AND DISCUSSION

This study employs the U-value as the principal criterion for assessing the thermal performance and energy efficiency of building materials. The data presented in Table 10 highlights the greater thermal sensitivity of roofs compared to walls, emphasizing the critical role of roof insulation in energy conservation. The U-value of typical walls is 1.97 $W/m^2 \cdot K$, whereas cavity walls with airspace and walls with insulation demonstrate enhanced performance, with U-values of 1.28 $W/m^2 \cdot K$ and 0.46 $W/m^2 \cdot K$, respectively. These findings confirm that insulated cavity walls offer markedly superior thermal efficiency, substantially reducing heat transfer and energy demand.

The study indicates that U-values for roofs vary significantly based on material characteristics and design combinations. The traditional roof has a U-value of 5.02 $W/m^2 \cdot K$, highlighting its limited thermal resistance. In contrast, roofs incorporating polystyrene insulation achieve a modest improvement, with a U-value of 4.21 $W/m^2 \cdot K$. Further reductions are observed in cavity roofs with an air gap, with a U-value of 3.96 $W/m^2 \cdot K$. The optimal configuration is the

Table 6: Characteristics of conventional roofing materials (Authors)

Material	Thickness (m)	(K) Value W/m-K	(R) Value $(m^2K\ /\ W)$	(U) Value $W\ /\ m^2K$
Tiles	0.03	0.84	0.035	
Mortar bed	0.05	0.72	0.07	
Gypsum Plaster	0.025	0.72	0.034	
Reinforce concrete	0.15	2.30	0.06	
Total			0.199	5.02

Table 7: Properties of roof with insulation material (Authors)

Material	Thickness (m)	(K) Value W/m-K	(R) Value $(m^2K\ /\ W)$	(U) Value $W\ /\ m^2K$
Tiles	0.03	0.84	0.035	
Mortar bed	0.05	0.72	0.069	
gypsum plaster	0.025	0.72	0.034	
Reinforced concrete	0.15	2.30	0.065	
Insulation (polystyrene)	0.05	1.557	0.033	
			0.237	4.21

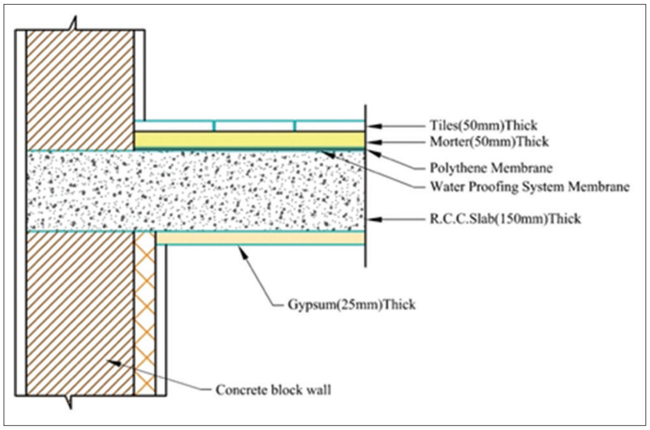

Figure 4: Conventional roof layers material (Authors)

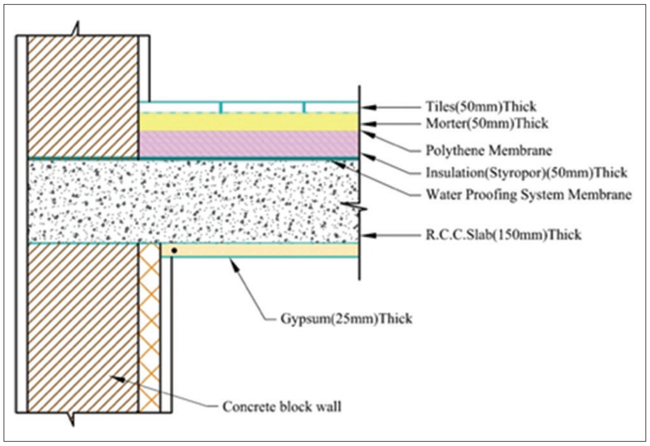

Figure 5: Roof with insulation polystyrene (Authors)

cavity roof featuring both an air gap and insulation, resulting in a remarkably low U-value of 0.55 W/m²·K.

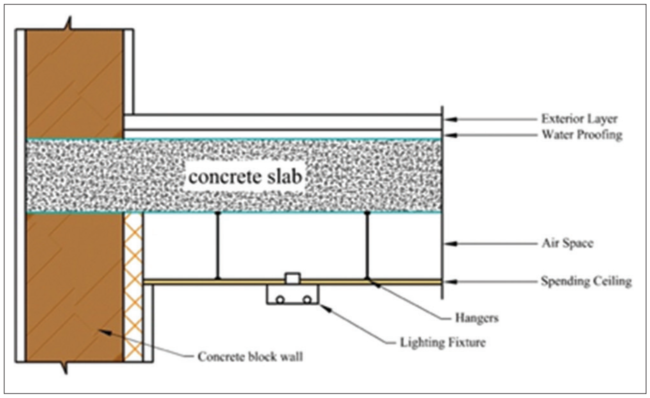

Figure 6: Cavity roof with air gap (Authors)

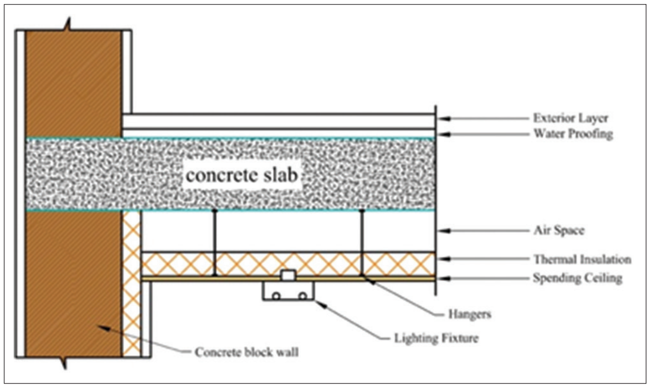

Figure 7: Cavity roof with airspace and insulation material (Authors)

The comparison research highlights the substantial benefits of insulated cavity roofs compared to other options, since they significantly improve thermal resistance and decrease the consumption of energy. These results validate the critical importance of integrating advanced insulation

Table 8: Properties of roof material with air gap (Authors)

Material	Thickness (m)	(K) Value W/m-K	(R) Value $(m^2K\ /\ W)$	(U) Value $W\ /\ m^2K$
Tiles	0.03	0.84	0.035	
Mortar bed	0.05	0.72	0.069	
Gypsum spending	0.025	0.72	0.034	
Reinforce concrete	0.15	2.30	0.065	
Air gap	0.05	1.06	0.047	
			0.252	3.96

Table 9: Properties roof with air gap and insulation material (Authors)

Material	Thickness (m)	(K) Value W/m-K	(R) Value $(m^2K\ /\ W)$	(U) Value $W\ /\ m^2K$
Tiles	0.03	0.84	0. 035	
Mortar bed	0.05	0.72	0. 069	
gypsum spending	0.025	0.72	0. 034	
Reinforce concrete	0.15	2.30	0. 065	
Air gap	0.05	1.06	0. 047	
Insulation (styropor)	0.05	0.032	1. 56	
			1. 81	0.55

Table 10: Results of the U-value of wall and roof (Authors)

Types	Name	(U) Value $W\ /\ m^2K$
Types of wall construction	Traditional wall	1.97
	Cavity wall with air gap	1.28
	Cavity wall with insulation	0.46
Types of roof construction	Traditional roof	5.02
	Roof construction with insulation (styropor)	4.21
	Cavity roof with air gap	3.96
	Cavity roof with air and insulation	0.55

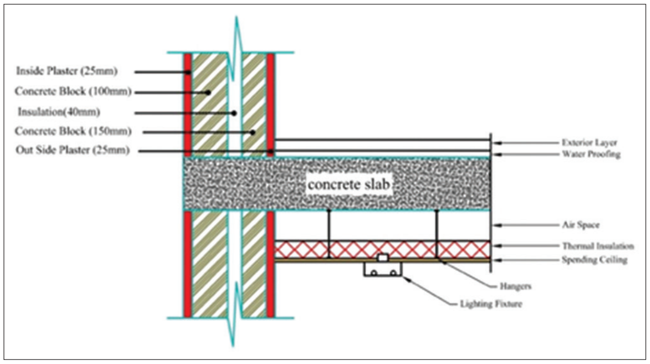

Figure 8: Optimum solution of wall and roof (Authors)

techniques in both wall and roof designs to achieve optimal energy efficiency in buildings, particularly in hot climate regions.

CONCLUSION

Present research indicates that a lower U-value of materials correlates with a reduced heating load in buildings, and conversely, a higher U-value result in an increased heating load. This study has concentrated on the insulating materials accessible in the Kurdistan market. During the assessment of thermal conductivity values of materials in walls and roofs, various scenarios with distinct outcomes were noted. The optimal performance of the wall and roof depicted in Figure 8 is achieved with a cavity wall incorporating polystyrene insulation, exhibiting a U-value of 0.46 W/m^{2}K, and a cavity roof featuring an air gap and polystyrene insulation, which has a U-value of 0.55 W/m^{2}K, both proving more effective than conventional methods. Moreover, substantial disparities were noted between the insulated cavity wall and the insulated cavity roof. Prioritizing insulating materials and other solutions, such as cavity systems with insulation materials, which is advisable to successfully lower U-values and improve energy efficiency in buildings. The thermal insulation within a structure is crucial for energy conservation. The conventional roof and wall components elevated total thermal transmittance; however, the incorporation of insulation in these parts of building decreases the U-factor. This research recommended that material selection should consider long-term energy savings to substantiate the effectiveness of these materials in energy conservation for buildings.

REFERENCES

1. D. Mazzeo, G. Oliveti and N. Arcuri. Definition of a new set of parameters for the dynamic thermal characterization of PCM layers in the presence of one or more liquid-solid interfaces. *Energy Build*, vol. 141, pp. 379-396, 2017.
2. KRG Ministry of planning and UNDP. Building the Kurdistan

region of building the Kurdistan region of Iraq. In: *Empowered Lives. Resilient Nations*. KRG Ministry of planning and UNDP, New York, 2012.

3. R. A. Kudhaer, M. M. Salman and H. K. Jarallah. Review of the use of sustainable materials in the production of building units. *Journal of Engineering and Sustainable Development*, vol. 28, no. 4, pp. 550-560, 2024.
4. F. Kuznik and J. Virgone. Experimental assessment of a phase change material for wall building use. *Applied Energy,Elsevier*, vol. 86, no. 10, pp. 2038-2046, 2009.
5. I. Abdulrahman. *Energy Efficient Buildings in a Hot and Dry Climate: Improvement of Traditional Houses in Kurdistan Region*; 2014. Available from: https://api.semanticscholar.org/corpusid:128043658 [Last accessed on 2023 Apr 06].
6. N. Ghabra, L. Rodrigues and P. Oldfield. The impact of the building envelope on the energy efficiency of residential tall buildings in Saudi Arabia. *International Journal of Low Carbon Technologies*, vol. 12, no. 4, pp. 411-419, 2017.
7. Q. Al-Yasiri and M. Szabó. Building envelope-combined phase change material and thermal insulation for energy-effective buildings during harsh summer: Simulation-based analysis. *Energy for Sustainable Development*, vol. 72, pp. 326-339, 2023.
8. X. Luo, D. Xu, Y. Bing, Y. He and Q. Chen. Thermal performance and building energy simulation of precast insulation walls in two climate zones. *Buildings*, vol. 14, no. 9, p. 2612, 2024.
9. J. Donnelly. *Energy Efficiency in Traditional Buildings*. Dublin, Published by Stationary Office, 2010. Available from: https://www.yumpu.com/en/document/view/36967728/energy/efficiency/in/traditional/buildings-dublin-city-council [Last accessed on 2023 Jun 24].
10. M. S. Al-Homoud. Performance characteristics and practical applications of common building thermal insulation materials. *Build Environ*, vol. 40, no. 3, pp. 353-366, 2005.
11. R. Pacheco, J. Ordóñez and G. Martínez. Energy efficient design of building: A review. *Renewable and Sustainable Energy Reviews*, vol. 16, no. 6, pp. 3559-3573, 2012.
12. S. A. Al-Sanea, M. F. Zedan, S. A. Al-Ajlan and A. S. Abdul Hadi. Heat transfer characteristics and optimum insulation thickness for cavity walls. *Journal of Thermal Envelope and Building Science*, vol. 26, no. 3, pp. 285-307, 2003.
13. P. Parthasarathy and S. K. Narayanan. Effect of hydrothermal carbonization reaction parameters on. *Environmental Progress Sustainable Energy*, vol. 33, no. 3, pp. 676-680, 2014.
14. F. G. N. Li, A. Z. P. Smith, P. Biddulph, I. G. Hamilton, R. Lowe, A. Mavrogianni, E. Oikonomou, R. Raslan, S. Stamp, A. Stone, A. J. Summerfield, D. Veitch, V. Gori and Oreszczyn, T. Solid-wall U -values: Heat flux measurements compared with standard assumptions. *Building Research and Information*, vol. 43, no. 2, pp. 238-252, 2015.
15. E. M. Moraekip. Energy efficiency optimization in residential buildings using thermal insulation blocks case study in Cairo, Egypt. *JES Journal of Engineering Sciences*, vol. 51, no. 3, pp. 184-201, 2023.
16. R. Vakilinezhad and S. Khabir. Energy optimization for façade retrofit design of residential buildings in hot climates using advanced materials. *Energy and Buildings*, vol. 317, p. 114417, 2024.
17. H. Kaddouri, A. Abidouche, M. S. H. Alaoui, I. Driouch and S. Hamdaoui. Impact of insulation using bio-sourced materials on the thermal and energy performance of a typical residential building in morocco. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, vol. 117, no. 1, pp. 43-59, 2024.
18. C. Baglivo, P. M. Congedo, M. Di Cataldo, L. D. Coluccia and D. D’Agostino. Envelope design optimization by thermal modelling of a building in a warm climate. *Energies (Basel)*, vol. 10, no. 11, p. 1808, 2017.
19. J. Kośny. *PCM-Enhanced Building Components*. Springer, Berlin, 2015.
20. J. Kosny, D. W. Yarbrough and W. A. Miller. Use of PCM enhanced insulation in the building envelope. *Journal of Building Enclosure Design*, vol. 2008, pp. 55-59, 2008.
21. S. A. Al-Sanea and M. F. Zedan. Optimum insulation thickness for building walls in a hot-dry climate. *International Journal of Ambient Energy*, vol. 23, no. 3, pp. 115-126, 2002.
22. S. A. Al-Sanea and M. F. Zedan. Heat transfer characteristics and optimum insulation thickness for Hordi roofs using a pseudo one-dimensional dynamic model. *International Journal of Ambient Energy*, vol. 27, no. 2, pp. 85-98, 2006.
23. Ashrae Standard. *ASHRAE Handbook 2001 Fundamentals*. vol. 53.Ashrae Standard, United States, pp. 1689-1699, 2001.
24. U.S. DOE. *Increasing Efficiency of Building Systems and Technologies September 2015*. Ch. 5. US Energy Department, United States, pp. 1-505, 2015.
25. S. B. Sadineni, S. Madala and R. F. Boehm. Passive building energy savings : A review of building envelope components. *Renewable and Sustainable Energy Reviews*, vol. 15, no. 8, pp. 3617-3631, 2011.
26. A. kanaan and A. Ramazan. Sustainable passenger terminals in airport buildings passenger terminals in Baghdad international airport-case study. *Journal of Engineering and Sustainable Development*, vol. 24, no. 5, pp. Ar-12-Ar-33, 2020.