

The Cognition of the Architectural Styles Role on Thermal Performance in Houses of Semi-Arid Climates: Analysis of Building Envelope Materials

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Abstract The envelope of buildings has an important role in controlling the energy consumption in buildings. The climatic changes and depletion of conventional sources make this fact important. This paper endeavors to estimate the thermal performance (steady-state) condition of a range of houses envelope with different architectural styles in Northern Iraq. The study examines the potential of the building envelope materials to control heat loss/gain through calculating U-Value (Heat transfer coefficient value). The capacity of the building's envelope materials to maintain indoor temperature is a goal to perform thermal comfort and decrease energy usage. The potential of buildings envelope materials for each architectural style in terms of their thermal performance has been identified and the results have been determined. Reconcile the new materials and technologies with old vernacular materials and techniques, would grant effective design potential. Finally, the recommendations to develop new envelopes have been suggested to reduce energy consumption in future houses.

Keywords U-Value, Building Envelope, Semi-Arid Climate, Northern Iraq- Khanaqin

1. Introduction

Buildings consume about 40% of global energy, and they emit approximately one third of carbon dioxide emission to the atmosphere [1]. About 50% of the energy the building needs is spent to achieve thermal comfort, therefore, heat exchange with the outer environment is pivotal in buildings [2]. Buildings' heat gain/loss could be different from building to another, depending on construction materials. In single-story buildings, heat exchange occurs through external walls and windows by 45%, while 42% of this exchange takes place through the roof and floor slab, whereas air leaks are responsible for 13%. In the multi-story building, 70% of heat exchange happens through outer windows and walls, and 13% through the basement slab and roof, while, 17% of exchange of heat with outside occurs through air leaks [3]. Thus, from previous data, we can understand that from 83% to 87% of the heating/cooling energy depends on the envelope of buildings. The reduction of energy consumption in the building sector considers the inexpensive way to mitigate CO₂ emissions, when it is compared with other sectors [4].

The study addresses the following questions; is there any relation between the development of architectural style and the U-value of their envelope in Kurdistan of Iraq? And how much the contemporary design in the buildings is aware of the thermo-physical properties in the envelope. The main objectives to answer previous questions are through; 1) identification of the main categories of envelope design according to the building style (vernacular, early modern, and contemporary); 2) studying thermo-physical properties for the envelopes in these styles of buildings. The methodology to approach the research is carried out by selecting a study region "town of Khanaqin" in the Kurdistan region of Iraq. The climatic characteristic of the Semi-Arid climate has been applied to the climatic zone for the study region depending on Köppen climate classification. Different types of houses' envelope have been investigated in the study region. Heat transfer coefficient value for the building's envelope is considered as the estimated tool to predict the energy consumption condition inside the buildings based on 'Steady-state' (the heat flow is no longer variable).

1.1. Building Envelope Properties

The building's envelope is defined as a part of the building that physically separates the interior environment from the outside or exterior environment [5]. The building envelope includes four main elements; Fenestration (doors & windows), Roofs, Walls, and Floors (ground contact zones). In addition to these main elements, the envelope could contain thermal insulation; thermal mass; external shading devices, etc. [6]. To design buildings envelope many considerations should be involved. The envelope must be prepared to achieve structural function and meet the seismic condition, as well as aesthetic value [5]. The building envelope properties could affect thermal and acoustic comfort as it can attenuate surrounding environment noise [7]. Energy efficiency in the building can be enhanced by developing passive or active strategies for energy efficiency. Development of the physical characteristics of building's envelope to maintain thermal comfort inside the building is classified under passive strategies while maintaining thermal comfort through artificial ventilation, air conditioning (HVAC) system, etc., known as active strategies.

1.2. Thermal Characteristics of Building Envelope

The energy balance in the building depends significantly on the design of the building envelope materials. Often, it is possible to reduce an active heating and cooling system usage, simply by changing the construction materials of the building envelope. Thermal characteristics of the envelope materials in buildings determine the rate of heat exchange [8]. The envelope materials in the building drive a significant role in thermal

comfort and energy consumption inside the building. The incidence of solar radiation on the envelope surface will be absorbed by the external surface of the building and flow through the envelope materials to reach the inner surface. Many factors are involved in the thermal performance of an envelope. According to CIBSE (Chartered Institution of Building Services Engineers), the (dynamic- state) thermo-physical assessment requires the calculation of four parameters: Surface Factor; Decrement Factor; Admittance value (Y-value); In addition to heat transfer coefficient value (U-value), which is used as a tool for (steady-state) thermo-physical assessment [9]. The study will focus on the (steady-state) condition, accordingly, the definition of (U-value) is mentioned in the next section with elucidation and elaboration, see section '1.4'. The Admittance value is defined as, the material potential to interchange heat with space for each degree difference in temperature that the temperature of space deviates from its average value. While 'surface factor' is the proportion of solar radiant heat flow re-radiated to the interior space to the heat flow incident upon the exterior surface. 'Decrement Factor' is the relationship between the inside and outside swing in daily temperature [10]. Hence, the thermal resistance of the envelope material affects the rate of heat transfer through that envelope. As much as a heat transfer coefficient value known by U-value is better, thermal performance will be better [11]. The building's envelope plays a significant role in maintaining interior temperatures, consequently, it determines the energy required to maintain thermal comfort because of its position as a thermal barrier. Therefore, minimizing heat transfer through the buildings' envelope is a pivotal part to reduce heating and cooling inside the building.

1.3. Insulation Materials' Places for Building Envelope

Two factors are very important in walls insulation, which are; location and thickness of the insulation. In hot climates, the insulation places on the exterior face of the building envelope (roof and exterior walls), so, the thermal mass of the envelope will not respond with the external environment and will maintain the indoor environment thermally. Using polystyrene insulation with '4' centimeters on the outer walls and in the same time using vermiculite concrete on the top of roofs reduces the usage of energy inside the building by almost 15% [12]. In another hand, applying air cavities inside the exterior walls or in the roof ceiling will decrease the heating load inside the building significantly. The basic rule for pragmatic thermal mass is to determine the envelope insulation place within the building. One of the effective walls thermally is the masonry wall. It is functional during warm season and cold season too. In warm season it stores solar heat during the daytime and releases it to the out ambient at nighttime (when the outside temperature drops more than inside temperature). In cold seasons it absorbs

heat from interior sources and re-radiates the heat to the inside at night when the temperature falls [13]. Insulation of masonry walls from inside is, thermally makes the wall separated from internal direct and indirect heat gains by solar radiation through glazing, or indoor heating produced by an active system or occupants, etc., respectively. Thus, inner insulation on the wall's mass is less active to maintain indoor thermal comfort during the warm season. Uninsulated masonry walls are thermally inactive, because they are introducing summer heat gains into the building, and letting internal heat to be released out in winter without good control of heat exchange through the envelope. Accordingly, in the cold season when the heating is demanded, the savings of heating load for the integral insulation (insulation within the wall) are better than the other types of insulation placing. However, in the cooling demand inside the building integral insulation had better function than placing the insulation on the interior face of the wall, and for lower cooling demand the outer insulation is the optimum [14].

1.4. U-value

'U-value' is known as the density of heat flux through a particular structure divided by the difference in ambient temperature on each side of the structural element in a steady-state case. Its unit is expressed by Watts per square meter per degree difference in temperature ($W / m^2 \text{ } ^\circ C$) [15]. The steady-state heat flow through the material is called conduction. The R-Value (thermal resistance per unit area) is a prevalent technique used for assessing material thermal performance. This reflects heat flow resistance under "steady-state" conditions [10]. The primary stage is to define conductivity k ($W / m \text{ } K$) of each material of the envelope, as shown in equation (1). This step should be taken depending on the tables published as BS EN 12664, and BS EN 12939, etc. Next stage is calculating the R (m^2K / W) thermal resistance for growing material;

$$R = (t)/k \quad (1)$$

Where; (t) is the envelope materials thickness for the building. The U-value is the inverse of R- value, as demonstrated in equation (2), where; the equation for single material is;

$$U = (1)/R \quad (2)$$

And for multiple materials combining the envelop equation (3) applies:

$$U = (1)/ [(A_i + R_1 + R_2 + \dots + R_x + A_e)] \quad (3)$$

Where;

A_i = the transfer resistance of heat on the inner surface (m^2K/W).

A_e = the transfer resistance of heat on the outer surface (m^2K/W), [16].

As much as the U-value amount less means the material thermal resistance to heat flow is higher when the amount

of U-value is less. Heat transfer is related to the difference between outside and inside temperature, solar radiation incidence on the envelope, and the total outer surface area of the building. Moreover, the envelope thermal potential depends on three factors, namely; thermal mass or the potential of heat storage; U-value; and their exterior finish material (light color reduces the absorption of solar heat and the opposite for dark color) [10]. Accordingly, U-value is one of the main factors to estimate the effective thermo-physical material for the envelopes in buildings, which allows the researchers to understand the thermal potential in the building. However, it is not the only factor to evaluate thermal performance of the envelope accurately under realistic conditions.

1.5. Turkish Standard (TS 825)

The thermal insulation drives a key role in reducing energy demands in buildings, which provide the advantages on many sides; environment, economics, and occupant's thermal comfort. Turkey has achieved new Standards in 1998, called TS 825, which has been applied legally on the buildings after May 2000 [17]. U-values of several building elements in the various climatic regions of Turkey have been measured [18]. The estimated - value of the window, floor, roof, and walls of buildings in the four different climatic regions of Turkey are shown in table 1.

Table 1. Recommended (U values) for the four regions of Turkey (TS 825) Source: [18]

	U _{wall} (W/m K)	U _{Roof} (W/m K)	U _{Floor} (W/m K)	U _{Window} (W/m K)
Region 1	0.70	0.45	0.70	2.4
Region 2	0.60	0.40	0.60	2.4
Region 3	0.50	0.30	0.45	2.4
Region 4	0.40	0.25	0.40	2.4

This standard can be a good guideline for the evaluation of building envelope thermal potential in the neighboring countries, which have similar climatic characteristics, especially the countries which are not having such specific construction standards.

1.6. Semi-Arid Climates

A semi-arid climate or steppe climate according to Köppen climate classification is the climate of the territory that faces precipitation below the potential of "Evapotranspiration", however, not extremely. It is the intermediates condition between desert climates (BW) and humid climates [19]. The Köppen climate codes Semi-Arid climate for cold semi-arid as (BSk), and warm semi-arid as (BSh), [20]. See figure 1.

Figure 1. Koppen-Geiger climates classification, shows Semi-Arid Climate zones [20]

To understand the difference between (BSh) and (BSk) there is Isotherm line delineates the border between them. This Isotherm is a line connecting points with the same temperature at a specific time or period. Commonly (BS) is characterized by a mean yearly temperature of 18 °C, or an average temperature of 0°C or -3°C in the cold season. Any location temperature higher than this isotherm is classified as (BSh), and below the given isotherm is classified as (BSk). [19].

2. Methods

The methodology in this research can be divided into three main stages;

First Stage: The review of literature, to identify key information that could help in determining the thermo-physical properties for the building envelope and recognizing the benchmarks factors to assess the envelope thermal performance.

Second Stage: The quantitative method has been conducted in the methodology, through calculating U-value for different parts in buildings envelopes, based on the “steady-state” condition of heat flow through construction materials. Several residential buildings (houses) envelopes with different ages and architectural styles have been investigated for this purpose. Houses with vernacular, early modern, and contemporary styles were observed in different places inside the town of ‘Khanaqin’. Houses have been selected for the evaluation because; the majority of the buildings in the town are

houses. ‘Khanaqin’ as a part of the Northern region in Iraq has been chosen as a case study based on several considerations; 1) The Town is the hottest area in the Northern Iraq region in the summer, where reaches above 50 °C in the summer. Khanaqin region climatic classification according to Koppen is characterized by Subtropical-Steppe climates (BSh); 2) ‘Khanaqin’ is an old city, therefore many styles of architecture, construction techniques, and different construction materials can be found inside the town. This gives the facility to investigate a different type of building envelopes throughout expanded history; 3) The city and the region of study (Kurdistan of Iraq), heavily using the electricity to maintain heating and cooling in the buildings, and the region suffering from a shortage of electricity supply. Hence, reducing the heat exchange through the envelope will participate in solving the electricity shortage problems. Buildings' thermal standards and codes in the region of study are not established. Turkey's location is geographically close to the region of the study and some regions of Turkey's climatic conditions similar to the climate in the ‘Kurdistan of Iraq’. Thus, the estimated values of TS 825 standards especially the recommended U-values were considered for evaluating the best U-value for building envelope in this study. Turkish standard has divided Turkey into four climatic regions. One of the region's climatic characteristics is harmonized with the climatic characteristic of the study area, which is ‘Region 4’ that is described in table (2) because it is considered inner- land and not coastal area [18].

Table 2. Monthly average external temperature values (oC) for using it in calculations of heat loss and condensation for the different regions, [18].

Month	Region one	Region two	Region three	Region four
Jan.	8.4	2.9	-0.3	-5.4
Feb.	9.0	4.4	0.1	-4.7
Mar.	11.6	7.3	4.1	0.3
Apr.	15.8	12.8	10.1	7.9
May	21.2	18.0	14.4	12.8
Jun.	26.3	22.5	18.5	17.3
Jul.	28.7	24.9	21.7	21.4
Aug.	27.6	24.3	21.2	21.1
Sept.	23.5	19.9	17.2	16.5
Oct.	18.5	14.1	11.6	10.3
Nov.	13.0	8.5	5.6	3.1
Dec.	9.3	3.8	1.3	-2.8

Third stage: the finding evaluation for the different U-value of envelope elements (external walls, roofs, floors, and windows) in the different architectural style of buildings was carried out. The results showed that the envelopes thermo-physical properties in each type of the buildings progressively from old types to the contemporary ones.

2.1. The Study Area



Figure 2. Kanaqin location within Kurdistan region and Iraq [22]

‘Khanaqin’ is located in north-eastern Iraq and southeast of Kurdistan. It is Adjacent by Iran from the east, and Halabja district from the north, Kalar district is located on the west side, while the rest of Iraq is located in the south, as shown in figure 2. The total area of the

‘Khanaqin’ is around 3915 square km, and the area of the town only is 1288 square km. The total population in this town is estimated by 175,000 people, and its elevation is 183 meters above mean sea level [21].

‘Khanaqin’ is one of the most important areas that contain a lot of important minerals as well as oil. In the town the first oil refinery was found in 1926 and was named ‘Alwand Refinery’ on the name of the river which divides the town into west and east banks [23].

2.1.1. The Case Study Climate context

Study region is a part of Northern Iraq’s region which is characterized according to the ‘Koppen’ climatic classification by semi-arid climate, mountainous (high-land) region, and cold in winter, and dry in summer. Generally, the area influenced by the Mediterranean climate, so its precipitation takes place in spring and winter. The higher average temperature in a month is 33.30 °C in July and the lower average monthly temperature is 5.7 °C in January. The average annual relative humidity is 56.5%, [24]. The maximum daily temperature may reach as high as 50 °C in hot summer periods, while the minimum daily temperature can drop to under zero in cold winters [25].

2.2. Observation of Sites

Field observations were carried out for different types of houses styles (fig. 3) from several historical periods in three selected sectors of the town of Khanaqin. Selected sectors consider the oldest sector ‘Hamidia’ (going back to end of nineteenth century), and mid-age sector 1930’s to 1960’s ‘Mazra’a’, and contemporary sector ‘Mamostayan’.

2.2.1. Vernacular Houses in the Old Sector “Hamidia”

The buildings in this sector are majority residential, with few commercial buildings ‘shops. A maximum number of floors in this sector are two stories, most of them were built at the end of the 19th century or very beginning of the twentieth century, and the buildings were almost abandoned because of their dilapidating condition. In vernacular building’s thick outer walls (around one meter) had been observed, and the timbers had been used in the roofs to support the thick soil layer above the straw mat. See figure 4.

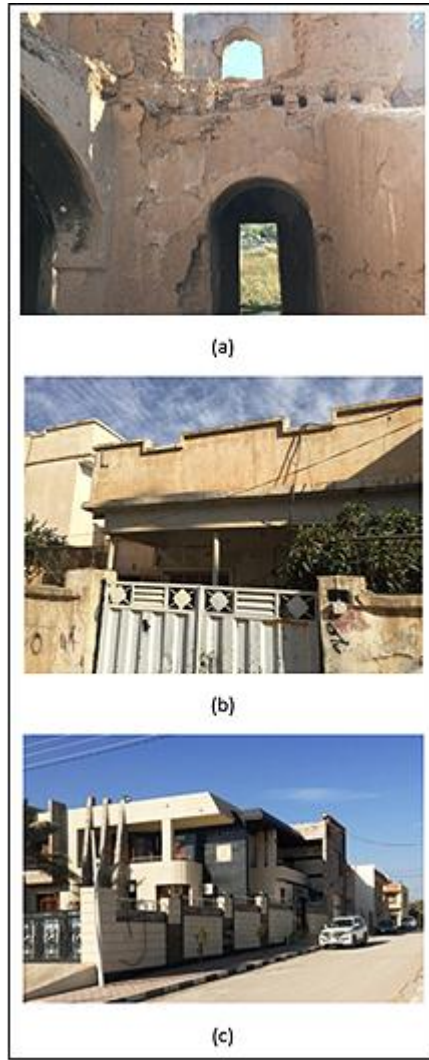


Figure 3. Architectural style in Khanaqin, (a) Vernacular house, (b) early modern house, (c) Contemporary house (By Author)



Figure 4. (a) Exterior walls of Vernacular buildings. (b) The roof in vernacular buildings. (By Author).

U-values were calculated for the entire parts of the envelope (Exterior Walls, Roofs, Floors, and Windows) to evaluate the thermal potential of the envelope for these buildings' types through U-value.

The standard conductivity for each single material has been taken from TS 825's tables. A site visit has been carried out to measure the thickness of the materials for each part to divide that thickness on the conductivity to obtain the resistance. The mathematical calculation for the U-value demonstrated the results of 0.454, which is considered a relatively good heat coefficient value compared with TS 825's Standards of Turkey. Moreover, the U-value for the roof has been calculated and evaluated in these vernacular buildings, and the results showed not climatic responsive U-value based on TS 825's Standards of Turkey, where the heat coefficient value was 1.14

(W/m^2K). The floors in these buildings consist of three main layers which are imported suitable compacted embankment or stone chips (Sand, gravel, crushed stone), and a layer of gypsum mortar has been placed on it, then covered by flat burnt- bricks known locally by 'Farshi'. U-value for the floor has been evaluated in these buildings based on the construction layers, and it was found equal to 1.515 (W/m^2K), and that indicates a relatively weak U-value in the roof for this climate in these styles of buildings. The windows of the vernacular buildings encompassed single glazing and wooden frame. Accordingly, the windows U-value in the vernacular house was found based on TS 825's. The result referred to very weak climatic responsive U- Value for the windows, where found 5.1 (W/m^2K). See table 3.

Table 3. U- values for the external walls, Roof, floor material and window type in the vernacular buildings

Exterior Walls Building material					
No.	Types of material	(t)Thickness of the material (m)	(k)Thermal conductivity (W/mK)*	(R) Thermal resistance (m K/W). See Eq. (1)	U- Value for the whole wall (W/m ² K). See Eq. (3)
1	Flat Brick-burnt (Farshi)	0.25	0.81	0.309	$U_{\text{wall}}=1/(A_i + 1/R_1 + 1/R_2 + 1/R_3 + A_e)**$ $U_{\text{wall}}=1/(0.13 + 0.309 + 1.625 + 0.098 + 0.04) = \mathbf{0.454}$
2	Adobe	0.65	0.40	1.625	
3	Gyps plastering (with aggregate)	0.05	0.51	0.098	
Roof Building material					U- Value for the whole roof (W/m ² K). See Eq. (3)
1	Straw	0.02	0.058	0.345	$U_{\text{Roof}}=1/(A_i + 1/R_1 + 1/R_2 + 1/R_3 + A_e)**$ $U_{\text{Roof}}=1/(0.13 + 0.345 + 0.125 + 0.233 + 0.04) = \mathbf{1.14}$
2	Plywood	0.025	0.20	0.125	
3	Clay	0.35	1.500	0.233	
Floor Building material					U- Value for the whole floor (W/m ² K). See Eq. (3)
1	(stone chips)	0.25	0.700	0.357	$U_{\text{Floor}}=1/(A_i + 1/R_1 + 1/R_2 + 1/R_3 + A_e)**$ $U_{\text{Floor}}=1/(0.17 + 0.357 + 0.071 + 0.062 + 0) = \mathbf{1.515}$
2	Gypsum mortar, lime-based gypsum mortar	0.05	0.70	0.071	
3	Burnt Brick 'Farshi'	0.05	0.81	0.062	
Window type					U- Value for the window (W/m ² K).*
1	Wooden processing window with single glass				5.1

*From the TS 825's tables, pages (35-51)

** A_i , A_e are internal and external surface thermal transmission (convection) resistance values for external walls= 0.13 and 0.04 (W/m²K), respectively, from TS 825.**Table 4.** U- values for the envelope in the traditional or early modern buildings

Exterior Walls Building material					
No.	Types of material	(t)Thickness of the material (m)	(k)Thermal conductivity (W/mK) *	(R) Thermal resistance (m K/W). See Eq. (1)	U- Value for the whole wall (W/m ² K). See Eq. (3)
1	Gypsum Plaster	0.03	0.70	0.043	$U_{\text{wall}}=1/(A_i + 1/R_1 + 1/R_2 + 1/R_3 + A_e)**$ $U_{\text{wall}}=1/(0.13 + 0.043 + 0.444 + 0.016 + 0.04) = \mathbf{1.485}$
2	Burnt Brick	0.36	0.81	0.444	
3	Cement mortar plaster	0.025	1.60	0.016	
Roof Building material					U- Value for the whole roof (W/m ² K). See Eq. (3)
1	Gypsum Plaster	0.015	0.70	0.021	$U_{\text{Roof}}=1/(A_i + 1/R_1 + 1/R_2 + 1/R_3 + A_e)**$ $U_{\text{Roof}}=1/(0.13 + 0.021 + 0.148 + 0.133 + 0.04) = \mathbf{2.12}$
2	Burnt Brick	0.12	0.81	0.148	
3	Clay (Soil)	0.20	1.500	0.133	
Floor Building material					U- Value for the whole floor (W/m ² K). See Eq. (3)
1	(stone chips)	0.20	0.700	0.286	$U_{\text{Floor}}=1/(A_i + 1/R_1 + 1/R_2 + 1/R_3 + A_e)**$ $U_{\text{Floor}}=1/(0.17 + 0.286 + 0.048 + 0.021 + 0.019 + 0.0) = \mathbf{1.838}$
2	Plain Concrete	0.08	1.650	0.048	
3	Cement mortar Screed	0.04	1.400	0.021	
4	Mosaic tiles	0.025	1.300	0.019	
Window type					U- Value for the window (W/m ² K). *
1	Aluminum Processing with single glass				5.9

2.2.2. Residential Sectors in “Mazra’a”

The majority of these buildings are holding an early modern style. The exterior walls, commonly, constructed with 36 cm thick burnt bricks as masonry units and plastered by cement mortar from exterior face, while plastered white gyphs from the interior face. The U-value for the exterior wall has been evaluated in the early modern buildings and found equal to 1.485 (W/m²K), which showed that it is not meeting the climatic requirement in the region. The roofs in these buildings have been constructed by interlocking burnt bricks with the help of ‘I beam’ far one meter from each other. The roofs in these buildings are still using the vernacular system in putting a layer of thick soil on the roof of the building. U-value for the roof has been calculated in the early modern buildings, and the results have shown that the U- Value is 2.12 (W/m²K). This number shows a poor thermal resistance in front of the climatic needs in this area, according to TS 825’s Standards of Turkey. The floor in these types of buildings had been built by Mosaic tiles fixed on the mortar screed cement layer above a layer of plain concrete upon the layer of stone chips. Therefore, the floor U-value was evaluated in early modern buildings, and the result was weak to respond to the climatic requirement and found equal to 1.838 (W/m²K). The windows generally in traditional buildings as well as early modern ones in ‘Khanagin’ had been manufactured by the single glass (un-coated) and wooden frame protected from outside by banditry iron bars. The U- Value of the windows in these houses was found not responding to the climatic requirement as the same situation in vernacular buildings, where the U-value was 5.9 (W/m²K). See table ‘4’.

2.2.3. Contemporary Sector in “Mamostayan”

The majority of the houses is contemporary and built in the 21st century after 2003, constructed with new construction material and new design style. The contemporary houses either build-up by burnt bricks or concrete blocks and exterior walls are covered by stone. To calculate U-value for the exterior walls at contemporary houses, a concrete block has been involved

and second time burnt bricks have been applied and found equal to 2.237 (W/m²K) and 1.901 (W/m²K), respectively, as shown in table 5. Both types of walls demonstrated the worst U- Value compared with previous architectural styles. The roofs of contemporary buildings generally consist of reinforced concrete slab, plastered by gypsum from inside the building and covered from outside either by bituminous insulation membrane known ‘ISOGAM’ (0,01 mm aluminum foil bituminous pulp) or covered by a layer of concrete tiles Known (Shtygar). ‘Shtygar’ tile is setting on a layer of sand and high-density styrofoam between the concrete slab and the concrete tiles. However, the latter type of roof does not prevail in contemporary buildings in Khanagin and the reason behind that is the cost of this type because it needs more material and costs more time. See figure 5.

Accordingly, the U-value for the roof has been evaluated in the contemporary buildings for both types of materials and was found equal to 2.92 (W/m²K) for the first type, which is not meeting the climatic requirements based on TS 825’s Standards of Turkey. The U-Value for the second type of roofs was 0.462 (W/m²K), which was found successfully responding to the climatic requirements as per TS 825’s Standards of Turkey. Also, the result demonstrates that the polystyrene materials that used in the roofs demonstrate an effective solution to improve U-value for the roofs. Regarding the floor materials which are usually used in contemporary buildings is granite or marble on the layer of screed cement mortar spread on a layer of plain concrete upon layer of crush stone. Thus, the floors U-value evaluation in the contemporary buildings, the result showed 2.584 (W/m²K), which considers the worse U-Value in all the tested buildings. In contemporary buildings, windows have two types either plastic with double glass which the U-value was found 2.9 (W/m²K), or Plastic with single glass which was found 3.4 (W/m²K). Therefore, U-value evaluation for the windows in the contemporary buildings, according to TS 825’s tables, demonstrates the two main types of windows are not adequate to overcome the climatic characteristic in this region. See table 5.

Table 5. The U- values for the envelope elements in contemporary buildings (Developed by Author)

Exterior Walls Building material (Type 1)					
No.	Types of material	(t)Thickness of the material (m)	(k)Thermal conductivity (W/mK)*	(R) Thermal resistance (m K/W). See Eq. (1)	U- Value for the whole wall (W/m ² K). See Eq. (3)
1	Gypsum Plaster	0.03	0.70	0.043	U wall=1/ (Ai +1/R1+1/R2+1/R3+ Ae)** U wall=1/(0.13+ 0.043+0.217+0.017+0.04)= 2.237
2	Concrete block wall	0.20	0.92	0.217	
3	Sedimentary stone	0.04	2.30	0.017	
Exterior Walls Building material (Type 2)					U- Value for the whole wall (W/m ² K). See Eq. (3)
1	Gypsum Plaster	0.03	0.70	0.043	U wall=1/ (Ai +1/R1+1/R2+1/R3+ Ae)** U wall=1/(0.13+ 0.043+0.296+0.017+0.04)= 1.901
2	Burnt Brick	0.24	0.81	0.296	
3	Sedimentary stone	0.04	2.30	0.017	
Roof Building material (Type 1)					U- Value for the whole roof (W/m ² K). See Eq. (3)
1	Gypsum Plaster	0.01	0.70	0.014	U wall=1/ (Ai +1/R1+1/R2+1/R3+ Ae)** U Roof=1/(0.13+0.014+0.08+0.079+0.04) = 2.92
2	Reinforced Concrete	0.20	2.500	0.080	
3	(ISOGAM)	0.015	0.19	0.079	
Roof Building material (Type 2)					U- Value for the whole roof (W/m ² K). See Eq. (3)
1	Gypsum Plaster	0.01	0.70	0.014	U wall=1/ (Ai +1/R1+1/R2+1/R3+ Ae)** U Roof=1/(0.13+0.014+0.08+0.079+ 0.043+ 1.666+ 0.086+ 0.024+0.04)= 0.462
2	Reinforced Concrete	0.20	2.500	0.080	
3	(ISOGAM)	0.015	0.19	0.079	
4	Sand	0.03	0.70	0.043	
5	Styrofoam	0.05	0.03	1.666	
6	Sand	0.06	0.70	0.086	
7	Concrete tiles 'Shtygar'	0.04	1.650	0.024	
Floor Building material					U- Value for the whole floor (W/m ² K). See Eq. (3)
1	(stone chips)	0.10	0.700	0.143	U Floor=1/ (Ai +1/R1+1/R2+1/R3+ Ae)** U floor=1/(0.17+0.143+0.048+0.021+0.005+0)= 2.584
2	Plain Concrete	0.08	1.650	0.048	
3	Cement mortar Screed	0.03	1.400	0.021	
4	Granite	0.015	2.800	0.005	
Window types					U- Value for the window (W/m ² K). *
1	Plastic processing with double glass 6mm (un-coated)				3.4
2	Plastic processing with double glass 6mm (E-low, coated)				2.9

Table 6. Comparing the standards with the existing U-value in the houses at Khanaqin

No.	Items	U _{wall}	U _{Roof}	U _{Floor}	U _{Window}
1	TS 825 Standard for (Region 4)	0.40	0.25	0.40	2.4
2	Vernacular houses	0.45	1.14	1.52	5.1
3	Early modern type houses	1.49	2.12	1.84	5.9
4	Contemporary houses	2.24/1.90	2.92/0.46	2.58	3.4/ 2.9

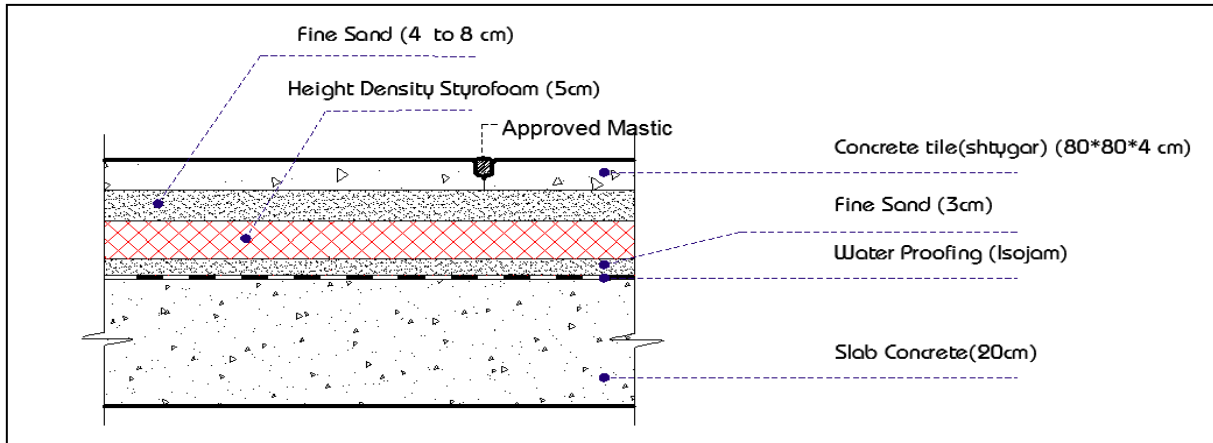


Figure 5. Shtygar for building roofs in contemporary houses in Khanaqin (By Author)

3. Discussion

Conventional envelope in three houses with different architectural style in 'Khanaqin' was evaluated thermo-physically from different places inside the town through assessment of U-value for the whole envelope. The result had been compared with the Turkish standard TS 825. See table '6'.

The results demonstrate that the houses in different periods with several building styles didn't meet the requirement of the climate in this region based on the standards of TS 825. The findings have shown U-value of the outer walls of vernacular houses is only the one that is closed to the standards and registered 0.45 ($\text{W}/\text{m}^2 \text{K}$). This returns to the role of 'Adobe' utilized in the outer walls, which made a significant improvement in the U-Value. Other building styles with more new construction materials didn't reach the requirement. For example, the exterior walls for the building of the early modern style which are newer than vernacular buildings style in the town by 30 to 50 years had U-value 1.49 ($\text{W}/\text{m}^2 \text{K}$). The contemporary architectural style, which started to be constructed in the town at the beginning of the twenty-first century, had worse U-value for exterior walls of the buildings, which registered 2.24 and 1.90 ($\text{W}/\text{m}^2 \text{K}$). The U-value for the roof materials showed that neither vernacular buildings nor the early modern houses met the standards. However, in the contemporary style roofs, two types of U-value have been gained, one of them was very far from the standards, and the other met the required U-value. The reason behind that was the use of polystyrene foam as insulation material, which makes a big improvement in the U-value of the roof, where U-value for the roof was 2.92 and because of the insulation material dropped to 0.46. In the case of windows, the application of new material in windows demonstrates improvement in U-values progressively, with the help of contemporary materials. The vernacular buildings registered very poor U-value in the window which was 5.1 ($\text{W}/\text{m}^2 \text{K}$). In the early modern styles of buildings, the

U-value registered 5.9 ($\text{W}/\text{m}^2 \text{K}$) because of the usage of the Aluminum (metal) window system. However, because of applying the double glazing, and adding 'E-low' material in the styles of the contemporary building, the U-value reached 3.4 and 2.9 ($\text{W}/\text{m}^2 \text{K}$), respectively. However, it couldn't meet the requirement as per the standard which is 2.4 ($\text{W}/\text{m}^2 \text{K}$) for the windows responding to the similar climatic character of 'Khanaqin' which is located in the hot region in Kurdistan of Iraq called 'Garmian' (means the warm region in the local language). As per the ST 825 standards tables, to reach the appropriate U-value, the E-Low coated glass and 9mm thick double glass are required. Moreover, in case the aluminum proceeding used then aluminum with an insulation bridge is recommended [18]. Thus, the study demonstrates that vernacular buildings meet the required heat transfer coefficient value (U-value), partially and not in all the envelope elements (only the exterior walls) getting advantages from 'Adobe' as a building unit. Also, the new buildings with newly designed materials almost didn't meet the U-value requirements unless applying the insulation materials such as polystyrene foam, which showed a very effective design role, when applied in the roofs. The windows had been showing that through new materials in the glazing system the U-value could be improved progressively.

4. Conclusions

Based on the TS 825 Turkish Standards, several materials U-values were applied to be calculated and compared in the different architectural styles of houses in 'Khanaqin'. Three different styles in architecture have been involved to be tested, from different ages of the city of 'Khanaqin'. First is the vernacular architecture style, the second style was the early modern architectural style, and the third style was the contemporary architecture style. The study focused on houses as the most prevailed type of buildings in the region of study. The results demonstrated

that the construction materials were used and are still used in the different architectural styles of houses envelope are not well designed to meet the requirement of the local climate, where the U-value of the envelope materials in different architectural styles and periods showed a weakness compared with the standards to be adaptive to climate needs. However, some particular materials in vernacular architecture such as 'Adobe' in the external walls demonstrated an effective role in controlling heat loss/gain. In the same context, polystyrene foam which was applied in the roofs at contemporary houses has shown the effective potential to dominate the heat reciprocation between indoor and outdoor. Moreover, contemporary materials in the windows with new technologies demonstrated good ability in this context too. The assessment implemented based on calculating (U-Value) in the (steady-state) condition of building envelope materials. The use of energy in new buildings needs more energy than the old buildings due to the weak U-value of construction materials because designers now rely on the use of active systems to achieve thermal comfort, and they neglected the passive design which reduces energy use.

According to the findings in this study, the author reached several recommendations to develop the existing and future building envelopes, which are;

1. Introduction of the insulation material such as polystyrene foam to improve the U- value in the envelope, especially for floors and roofs is recommended for reducing energy demands in the building, through improving thermal performance. But the placing of these insulation materials should be identified based on a climatic characteristic, as explained in point number '5', below.
2. To take the wisdom from the thermal properties of some vernacular materials like 'Adobe' to re-design the contemporary exterior walls are recommended.
3. To effectively respond to the climatic needs in the study area, it is recommended to use double glazing and e-low in the windows, provided that the thickness of the glass is 9 mm or more, to achieve the required U-value, which meets the climatic requirements. If the aluminum proceeding windows are applied, then the 'Insulation Bridge' is recommended too.
4. Avoiding 'hollow concrete blocks' as a masonry unit without applying additional insulation materials, because of the low thermal potential of this masonry unit for responding to the regional climatic characteristics.
5. According to the theoretical analysis and literature review, the insulation material that would be added to the exterior envelope is the best for controlling heat exchange in the study area climate during the summer. However, the integral insulation is good for controlling and distributing the heat gain in summer and winter. Accordingly, integral insulation is recommended in the region of the study.
6. It is very important to start thinking seriously to establish local standards for the Kurdistan region of Iraq, to encompass the own environmental and regional characteristics. In this case, a more realistic evaluation of the building's thermal performance can be obtained.

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Conflict of Interests

The Authors declare no conflict of interest.

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