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# A Comparative Study between Jordanian Overall Heat Transfer Coefficient (U-Value) and International Building Codes, With Thermal Bridges Effect Investigation

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**Abstract**

Depletion of fossil fuel and the environmental effect associated with the use of it have made the topic of "thermal insulation regulations" a major concern in country Jordan and worldwide. This paper reviews the overall heat transfer coefficient U-value in Jordanian code for the building envelope, which represents how much the building envelope transfer heat to the outside environment. U-value was reviewed with respect to the following factors, heating degree days, the heating load required to achieve thermal comfort. Based on the review a new U-value of 0.65 W/m$^2$.K was proposed and it was found that this value reduces the energy demand almost 50%. Moreover, the thermal bridge effect was investigated and it was found that an obvious increase in the U-value is present when having thermal bridges; this will affect the energy demand, almost 200%.

**Keywords:** building envelope, energy efficiency, Jordanian and international building code, heating degree-day, heating and cooling loads

## 1. Introduction

### *1.1 Introduce the Problem*

The concept of the thermal transmittance of the enclosure (U-value) is defined as the coefficient of heat transmission (air to air) through a building component or assembly. It is equal to the heat flow rate per unit area per unit temperature difference between the warm side and cold side air films (Btu/ ft$^2$. F) in the United Kingdom and the USA, whereas the unit of (W/m$^2$.K) is used in the rest of Europe.

The thermal envelope transmittance is directly regulated by two parameters: the transmittance limit, which depends on the enclosure type ($U_{max}$), and the average transmittance limit, which depends on the location of the enclosure ($U_{med}$). German, British, and "Passivhaus" standard only regulate the $U_{max}$ parameter, while the USA only regulates the $U_{med}$ parameter. In contrast, Spain and France set the maximum allowed transmittance of the envelope joints. In all the countries studied, except the UK, the envelope transmittance value limits are stated, and thus the planned facilities are considered in the calculation of the energy consumption and $CO_2$ emission (Rodríguez-Soria et al., 2014. P. 78).

Jordanian thermal insulation building code was issued in 2002 to introduce the thermal insulation concept for the Jordanian building industry. At that time fuel price was very cheap and affordable, nowadays, after almost 15 years this code has to be updated to overcome the fuel price increase and to improve Jordanian people lifestyle. In this paper, Jordanian thermal insulation codes will be compared with each of ASHRAE, European norms, and Saudi Standard. The links between the elemental U-value and the combined U-value will be identified. Even more, this paper will improve the understanding of the existing thermal insulation code and its effect on the estimated annual heating demand per square meter for Jordan regarding the international rates.

### *1.2 Literature review*

Building codes regulate building construction in each country, these codes require review and update over the years. Authors (Alimohammadisagvand, et al., 2016. pp. 275-287) investigated thermal energy storage with a ground source heat pump in detached residential houses in a cold climate. This was achieved using a cost-optimal solution based on demand response (DR) actions. Authors (Berry and Davidson, 2016, pp. 157-166) reviewed the inputs and assumptions of economic models to improve the economics of building by changing the building energy code in Australia. Authors (Echeverría[1] et al., 2016, pp.841) investigated building performance from 2006 until 2016 in Spain to face the challenge of climate change. Energy Effeiciency in building is very important for sustainable city design and planning. Authors (Alkhalidi et al., 2018, ppp125-132) investigated micro climatic control for building to save energy and control temperature. Authors (Alkhalidi and Hassan, 2018, pp. 1-10) investigated the energy reduction methods around the world in commercial buildings was investigated, to find out the best solution for minimizing electricity demand of Al-Ahliyya Amman University. Authors (Koirala and Bohara, 2020) investigated the effects of energy efficiency policy in the residential sector using panel data of 48 contiguous states starting from 1970 to 2017.

Authors investigated thermal comfort in buildings and climatic zoning to improve people's lives for several years. Recently, Authors, (Manu et al., 2018, pp. 55-70) investigated thermal comfort across multiple climate zones in India by using a newly proposed model called India Model for Adaptive Comfort (IMAC). It was found that according to the IMAC model, the neutral temperature in naturally ventilated buildings varies from 19.6 to 28.5°C for 30-day outdoor running mean air temperatures ranging from 12.5 to 31°C. (Moral et al., 2017, pp. 881-889) investigated the climatic zoning for the calculation of the thermal demand of buildings in Extremadura (Spain). The proposed method allows a more accurate climatic zoning of any region in agreement with the Spanish legislation on energy efficiency in buildings, which would enhance the setting of thermal demand rates according to the actual climatic characterization of the area in which a particular municipality is located.

Building thermal performance and energy simulation were investigated in the literature. Authors (Nahlik et al., 2016, pp. 04016043), used an energy simulation model to estimate how quickly indoor air temperature changes when building archetypes are exposed to extreme heat. Building age and geometry (which together determine the building envelope material composition) are found to be the strongest indicators of thermal envelope performance. (Tyagi et al.,2016,pp. 44-52) investigated the thermal performance assessment of encapsulated phase change material based on the thermal management system to reduce peak energy demand in buildings. This experimental work was done to shift the peak time cool energy demand for off-peak time. Authors (Aïssani et al., 2016, pp. 272-284) investigated the impact of four common workmanship errors on the thermal performance of insulation panels. A coupling between experimental measurements and finite element modeling allows us to evaluate the effective thermal conductivity of insulations in the presence of defects. Authors (Alkhalidi et al. 2016, pp. 29-35) investigated the effect of glass properties on 4 and 20 story buildings in Jordan for total, heating and cooling, loads for variable glass-wall ratios using HAP Software.

Authors (Alkhalidi et al., 2020, pp. 287-298) investigated an existing aquaponics facility in Jordan, named Khodra, which is used to evaluate the cooling and heating profiles to provide the best environment for plants and fish to thrive. A replica of the 'Khodra' facility will be simulated to be built in Qatar. Authors (Alkhalidi and Hatuqay, 2020, pp. 101286) investigated and develops energy-efficient and low-cost residential units that can be implemented around the world through a green and sustainable criterion for choices. Authors (Alkhalidi and Aljolani, 2020, pp. 319-327) described an integrated design approach to improve the energy and water efficiency of the mid-rise residential buildings in Jordan using the eQUEST energy simulation tool. Authors (Alkhalidi et al., 2020) investigated three climate zones to study the different factors that play a significant role in choosing the location of the shelter. Authors (Alkhalidi and Zaytoun, 2020, pp. 14-161) investigated the enhancement of the thermal comfort inside such buildings, architects need lightweight thermal storage.

Several Authors had reviewed Jordanian building codes and buildings in the Middle East. Authors (Jaber and Ajib, 2011, pp 1829-1834) discussed an assessment of the best orientation of the building, windows size, thermal insulation thickness from the energetic, economic and environmental point of view for a typical residential building located in the Mediterranean region. The results show that about 27.59% of annual energy consumption can be saved by choosing the best orientation, the optimum size of windows and shading device and optimum insulation thickness was proposed and presented by (Mohsen and Akash, 2001, pp. 1307-1315), used the results of a recent survey on energy consumption in the residential sector of Jordan to evaluate energy conservation in residential buildings. It was found that space heating accounts for 61% of the total residential energy consumption with kerosene as the most popular fuel used for heating. In light of the fact that only 5.7% of dwellings in Jordan's urban areas have been provided with wall insulation and none with roof thermal insulation, the heating loads were calculated for a typical single house using different insulation materials. It was shown that energy savings up to 76.8% can be achieved when polystyrene is used for both wall and roof insulation. Authors (Awadallah et al., 2009, pp. 1) described the criteria for developing the new energy-efficient building code for Jordan. In addition, the authors described some of the architectural aspects of the design of energy-efficient buildings within the context of the building codes of Jordan.

The Jordanian National Building Law of 1993 was prepared to introduce the concept of adding insulation to the Jordanian building. This was due to the fact that the concept of adding thermal insulation to the building was new to the Jordanian building industry. Now after about 24 years, the thermal insulation concept had become popular and the authors think that it is time to improve this code to be comparable to worldwide codes. Research papers found in the literature did not compare the Jordanian code to international codes, even more, the energy consumption for building heating was never compared to other countries.

Poor craftsmen in insulation work cause some components of the building envelope to have higher thermal conductivity than the rest of the envelope. These components are called thermal pass, heat bridges, cold bridges, or thermal bridges (Binggeli, 2003). Thermal bridges have an effect on space heating and cooling load for the building, even more, they can cause some condensation in the building envelope that may result in thermal discomfort (Arena, 2016). The effect of thermal bridges significantly affects the U value in the building envelope that will consequently affect the energy consumption in the building. This effect was investigated by Zedan et al. (Zadan, 2016, pp. 560) results indicate that yearly and monthly cooling loads increase almost linearly with the thermal bridge to wall area ratio (Rodríguez-Soria, 2014, pp.78-90).

This paper will first, compare Jordanian code to the international codes. Second, the energy consumption for building heating worldwide will be used as an indicator to select the new U-value to be used in the code. Third, new U-values will be proposed. In addition, the effect of thermal bridges in the building will be investigated.

## 2. Methodology

The U-value will be investigated using three different approaches. First approach: investigate the U-value of each component (walls, window…etc.). Second approach: Average U-value (the building as a whole). The third approach will be based on the maximum values for the heat demand of a building.

### *2.1 First Approach: Elemental U- Values (Walls, Window…etc.)*

U-value specified in Jordanian building thermal insulation code will be compared to the European Union standard (CEN) (Rodríguez-Soria, 2014, pp. 78-90), Saudi Arabia building code (The Saudi Building Code, 2007), and American standard (ASHRAE) (ANSI/ASHRAE Standard 90.2, 2007). Table 1 shows the U-value for each element of the envelope as follows,

Table 1. Elemental U-value (W/m$^2$.K).

| | **Wall contact with outside air** | **Wall contact with an unheated wall** | **Ceiling contact with outside air** | **Ceiling contact with an unheated wall** | **Door contact with outside air** | **Door contact with an unheated wall** | **Window contact with outside air** | **Window contact with an unheated wall** | **Floor contact with outside air** | **Floor contact with the unheated wall** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Jordan** | 0.57* | 2 | 0.55 | 1.2 | 2.7 | 2.7 | 3.1 | 3.1 | 0.8 | 1.2 |
| **KSA zone 3** | 0.45 | _____ | 0.27 | _____ | 2.84 | _____ | | 2.67 | _____ | 0.27 |
| **UK** | 0.45 | 0.6 | 0.2 | 0.6 | 3 | 3.3 | 3 | 3.3 | 0.35 | 0.6 |
| **Germany** | 0.5 | 0.35 | 0.22 | 0.35 | 0.7 | 0.7 | 0.7 | 0.7 | 0.5 | 0.35 |
| **USA Min** | 0.115 | 0.071 | 0.022 | 0.021 | 0.39 | 0.39 | 0.35 | 0.35 | 0.026 | 0.033 |
| **USA Max** | 0.63 | 0.244 | 0.084 | 0.038 | 0.39 | 0.39 | 0.67 | 0.67 | 0.089 | 0.09 |

* Overall U-value for external wall combined with windows and doors equals 1.6 W/m2.K.

Based on the values presented in Table 1. it is obvious that the Jordanian thermal insulation code is the highest as compared to most other countries.

*2.2 Second Approach: Average U-Value (The Building as A Whole)*

The U-value for the whole building could be calculated using the Average U-value or U-value combined. The combined U-value can be calculated and used as a reference.

$$Ucombined = (U_1 \times A_1 + U_2 \times A_2 + \cdots + U_n \times A_n)/A_{total} \quad (1)$$

A typical room is shown in Fig. 1, will be used as a reference room, for calculation purposes. Room dimensions are 2m X 1m X 3m, with 2 windows of 25% from the wall area, and the door of 10% from the wall area, total envelope area =22 $m^2$. Based on the literature review and most building codes, regulations are based on two types of the U-value; either assembly or elemental U-value, the former is for elements with direct contact with outside air and the latter is for elements with contact with unheated space. Based on that this paper will investigate the U-value for two cases. First, 100% of walls are exposed to the outside air and, second 50% of walls are exposed to the outside air.

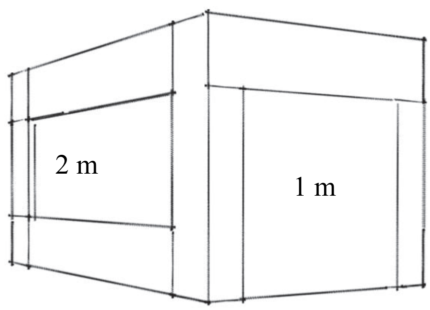


Figure 1. A typical room used for calculations

First, 100% of walls are exposed to outside air; U- values used in these calculations are available in thermal insulation code for direct contact with outside air using Eqn.1.

Table 2. Combined U- value (W/m2.K) for both cases 100% and 50% of walls exposed to the outside air.

| | **Jordan** | **KSA zone 3** | **UK** | **USA min-value** | **USA max-value** | **Germany** |
|---|---|---|---|---|---|---|
| **100% of walls are exposed to the outside air.** | 1.28 | 1.06 | 1.14 | 0.17 | 0.51 | 0.53 |
| **50% of walls are exposed to the outside air.** | 1.6 | - | 0.95 | 0.12 | 0.24 | 0.44 |

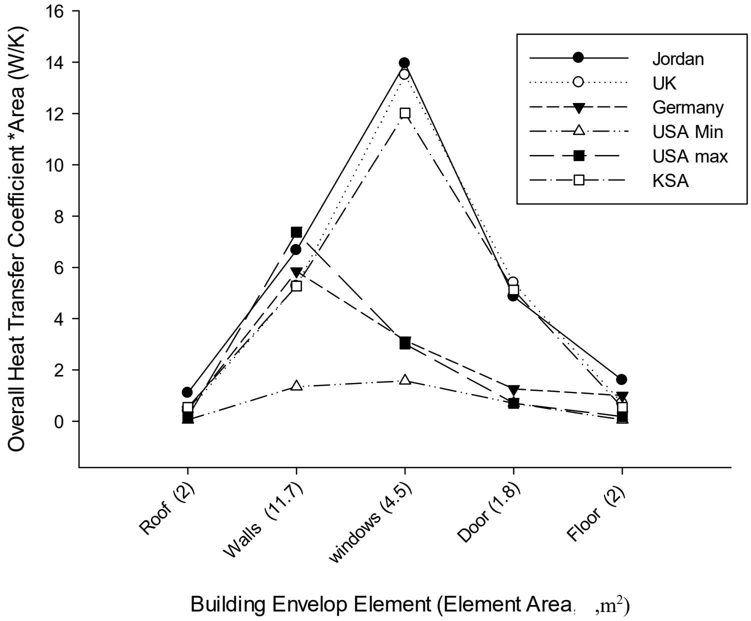


Figure 2. Element U-value (W/m2.K) * Element area (m2) of the typical room suggested for comparison 100% walls exposed to the outside air

The U- value presented in Table 2 showed that the U- value in the Jordanian code is the highest among all other codes presented in Table 2 for both cases of 100% or 50% exposure to the outside air. To analyze these results in more depth, each element will be investigated separately. The results are presented in Fig. 2 for 100% of building envelopes exposed to outside air and Fig.3 for 50% of building envelope exposed to the outside air.

The elements U-value multiplied by the area of that element, for the case of 100% of building envelope exposed to outside air, are presented in Fig. 2. The figure showed that the Jordanian building code has almost the highest value as compared to other codes. The highest U-value in Jordanian code was for the windows. Based on the results shown in this Fig. 2 it is highly recommended to improve the U values for the windows in the Jordanian code.

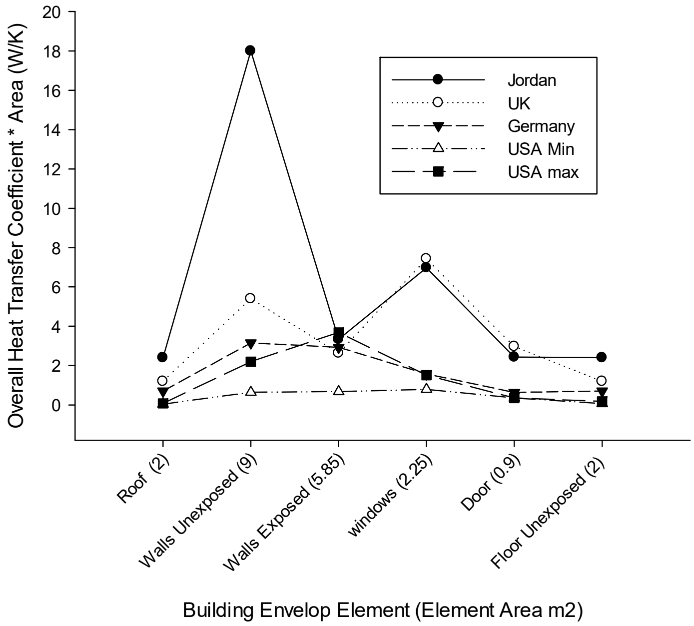


Figure 3. Element U-value (W/m$^2$.K) * Element area (m$^2$) of the typical room suggested for comparison for 50% of walls exposed to the outside air

The element U-value multiplied by area for the case of 50% of the building envelope exposed to outside air is presented in Fig. 3. Results showed that the unexposed walls U-value is the highest ever if compared to all other codes. It is worth mentioning that U-values in some countries increases when the area exposed to outside air decreases and in others vice versa, depends on the weighted U-value. In general, that increase is proportional to the temperature difference as can be interpreted from equation 2.

$$\dot{Q} = UA(T_i - T_\circ) = \frac{A(T_i - T_o)}{R} \quad (2)$$

*2.3 Third Approach: Maximum Values for Heat Demand of a Building*

The heating demand for buildings is investigated in this section as well as the US and European climatic zones including energy consumption. Moreover, heating degree-days (HDD) will be compared to different climatic zones, energy consumption, HDD.

According to the MURE study, the European Union is divided into 12 climatic zones with respect to the Energy flow through an outer wall in the given country under the requirement of the respective thermal insulation regulations. According to ASHRAE, The US is divided into 8 climatic zones with respect to the Average Annual Outdoor Dry-bulb Temperature. The Jordanian code also has been divided into 3 zones, and the base used, was not mentioned in the code.

Actual annual heat demand for different European countries is shown in Fig. 4, kWh/m$^2$/a along with HDD values for each zone that has been calculated (Eichhammer and Schlomann, 1998), results are presented in Fig. 4. HDD and heat demand is plotted on the x and y-axis respectively, the circle area represents the annual heating demand of each country.

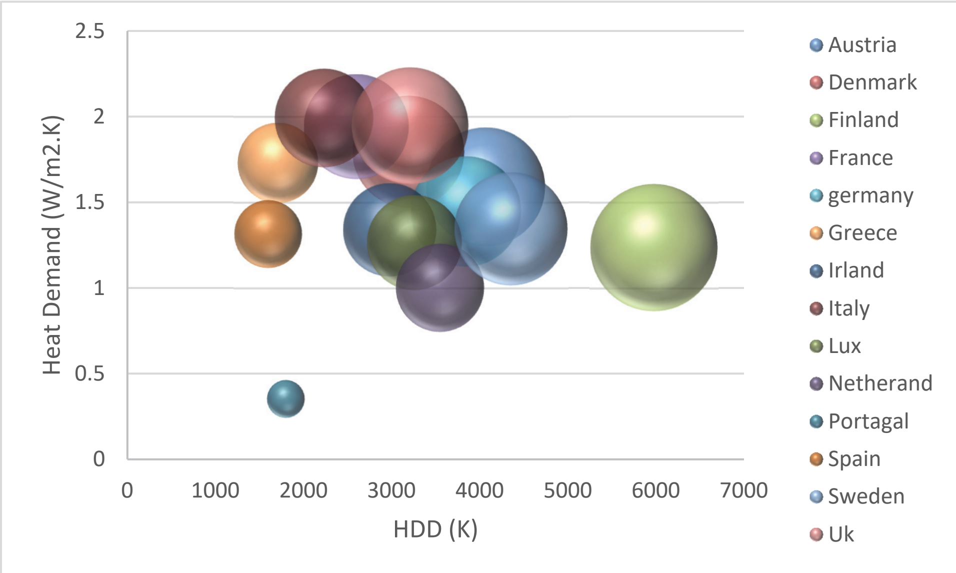


Figure 4. Heat Demand (W/m$^2$.K), HDD , Heating Load (kWh/m$^2$/a) for European countries (Eichhammer and Schlomann, 1998)

Figure 4 shows the variation of heat demand with HDD for different countries. These results will be cross referenced to the energy consumption in different climatic zones. Results are shown in figure 5.

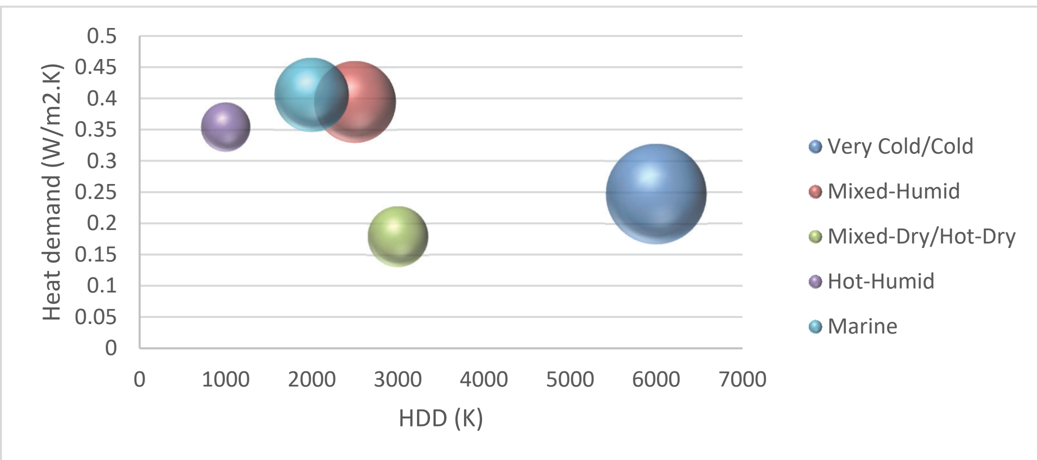


Figure 5. Heat Demand (W/m2.K), HDD , Heating Load (kWh/m2/a) for USA zones (U.S. Energy Information Administration)

In figure 5, the heating demand and heating load for building in the United States zones are presented. It is worth mentioning that the building is used in the calculation of Fig. 5 includes all areas heated and unheated. This area includes a basement, garage, and attic. That explains the relatively low heating demand and heating load in the USA if compared to Europe.

*2.4 Jordanian Building Code U-Value Review*

Heating degree-days in Jordan for most cities calculated are based on18 c˚, and cooling degree days are based on 10 c˚, it was found that HDD are less than 1000 (K. day). Based on that, Jordan has to have heat demand very close to Spain in Europe and comparable to the hot humid region according to US classification. As mentioned before that the energy demand is considered low due to the area used in the calculation. Therefore, the heat demand for Spain is 1.3 W/m$^2$.K and 0.35 W/m$^2$.K for the hot humid region. In this paper, the authors will suggest a new U-value for country Jordan.

Actual Jordanian building scheme was investigated and it was found that walls U-value can be reduced to 0.24 W/m$^2$.K by using Polyurethane= 6 cm insulation panels between outside stone and internal concrete hollow block. Roof U-value can be reduced to 0.24 W/m$^2$.K using Polyurethane k= 0.019 W/m.K (Sprayed) with a thickness of 7 cm. Without changing the code given value for floor U-value =0.24 W/m$^2$.K, door U-value=2.7 W/m$^2$.K, window U-value=3.1 W/m$^2$.K, the overall U value for the typical building is given in Table 3.

Table 3. Overall U-value calculated for the typical building

| **100% of walls Exposed to the outside air** | **U** | **Area** | **Jordan U* A** |
|---|---|---|---|
| **Roof (2m$^2$)** | 0.24 | 2 | 0.48 |
| **Walls(18m$^2$)** | 0.24 | 11.7 | 2.808 |
| **Windows 0.25** | 1.6 | 4.5 | 7.2 |
| **Door 0.1** | 1.8 | 1.8 | 3.24 |
| **Floor (2m$^2$)** | 0.24 | 2 | 0.48 |
| | | 22 | 0.65 |

As shown in Table 3 U-value combined =0.65 W/m$^2$.K, this gives a minimum heating load of 1.9 kWh/m$^2$/year and a maximum heating load of 12.4 kWh/m$^2$/year in different climatic zones in Jordan. The heat load saving was about 50% using the new suggested U-value. These numbers are comparable to EU countries.

## 3. Thermal Bridges

In this section, thermal bridges that appear most of the time in walls are going to be investigated. Four types of thermal bridges can exist at column angles, at the joints of the outer walls with the ceiling (roof), at the joints of the outer walls with the floor, or over the area of the window in the inner walls.

According to a short survey answered by experts in building construction it was found that column angles has the biggest effect on the wall thermal insulation. Therefore, a sample of residential Buildings was collected and studied.

Columns as thermal bridges are made of metal and concrete with an assumed U- value =2.46 W/m$^2$.Kbased on concrete mix with no insulation. Thermal bridge area ratio to the total wall area were estimsated for the initial calculation to compose an approximated percentage of the thermal bridge through the wall.

Table 4. Thermal bridge ratio from envelope Area based on case studies of actual buildings in Jordan.

| **Thermal bridge area ratio to the total wall area** |
|---|
| **15%** |
| **20%** |
| **25%** |
| **30%** |

Table 4 presents the thermal bridge ratio from the envelope is for different case studies in Jordan, it is obvious in the table that this ratio constitutes 15-30%. This has to be taken into consideration and counted for in the next calculations. Now, back to U-value investigation. Regarding the thermal bridge effect on the U-value, and energy demand. To study that effect, the typical house module will be used again but with thermal bridges. Some values were assumed for thermal bridges based on thermal bridge construction material:

Table 5. Thermal bridge assumed U-value for each country

| County | U-thermal bridge W/m².K |
|---|---|
| **Jordan** | 2.46 (Estimated form Concrete thermal Conductivity) |
| **UK** | 1.2[31] |
| **US min** | 3.3[27] |
| **US max** | 6[27] |
| **Germany** | 2.2[32] |

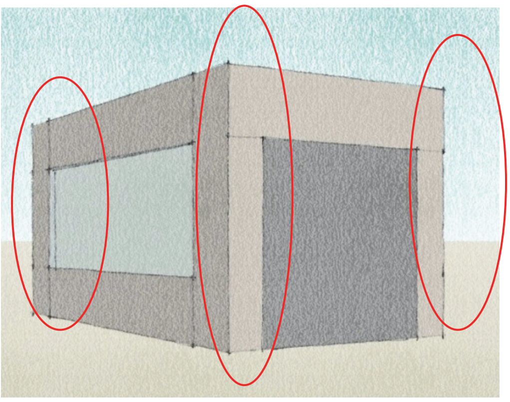

Figure 5. Thermal bridge common locations in the building

Figure 6 shows the common location of thermal bridges in the building envelope. During construction contractor usualy do not pay attention to insulate the vertical and horizontal coulms in buildings. In Table 6, a comparison between the U-value with and without thermal bridges is presented, it is obvious that having thermal bridges will increase the U-value by 36 % for country Jordan and 80 % for country Germany. An obvious increase in the U-value with a thermal bridge will affect energy demand, almost double.

Table 6. Comparison (U-value without thermal bridge & U-value with thermal bridge)

| | Jordan | UK | USA min-value | USA max-value | Germany |
|---|---|---|---|---|---|
| **Combined /average U-value without thermal bridge** | 1.28 | 1.14 | 0.17 | 0.51 | 0.53 |
| **Combined /average U-value with thermal bridge** | 1.74 | 1.33 | 0.95 | 1.8 | 0.95 |

*3.1 Thermal Bridge Correction Factor*

In the previous section, the thermal bridge effect was very clear. Correction of the U-value is introduced in Figure 7 to account for the thermal bridge effect. This chart, based on wall area and thermal bridge area ratio, will help to control the thermal insulation U- value to have a better overall U-value and therefore less annual heating demand.

A figure is a powerful tool for engineers that provides a rule of thumb approximation for the correction factor needed as well as the corresponding energy demand. In order to use the chart, one can follow the following steps: Estimate range for $U_{\text{thermal bridge}}$ /$U_{\text{thermal insulation}}$ along with the range for $A_{\text{thermal bridge}}$ / $A_{\text{total}}$, then find the correction factor.

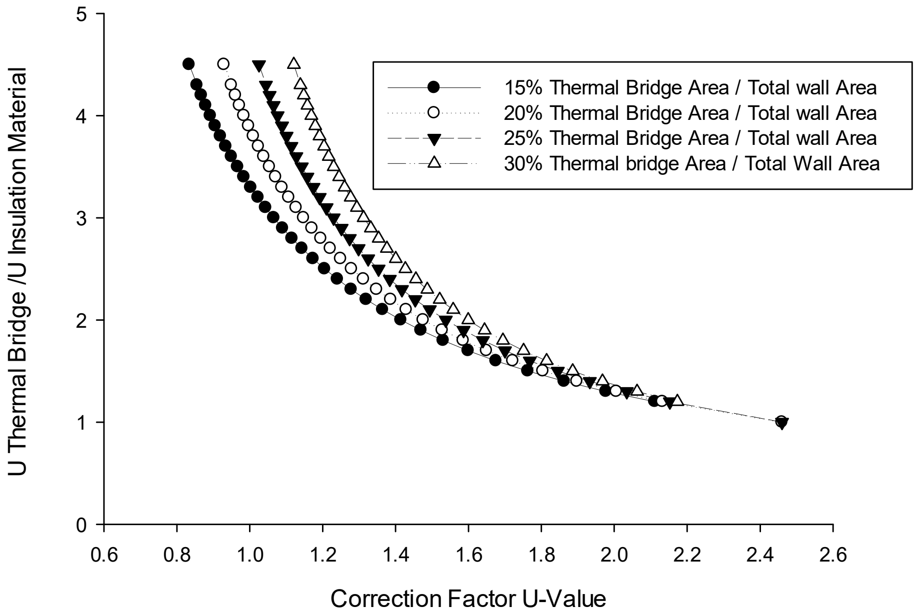


Figure 6. U-value correction factor based on the area and U-value ratio.

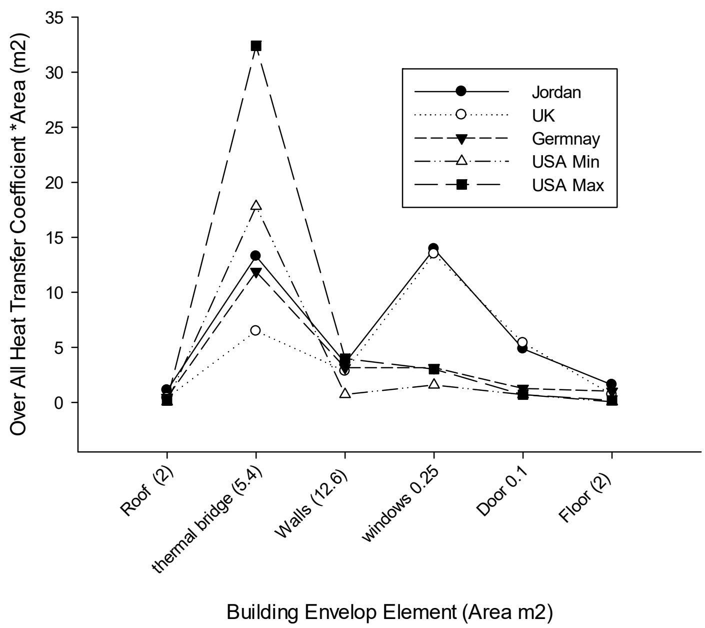


Figure 7. Elemental U-value 100% of wall exposed to outside air with the thermal bridge

Figure 8 shows that the thermal bridge effect has a major impact on the U-value. Actually it compresses the major factor in heat transfer coefficient

## 4. Conclusion

The U-value elemental approach showed that the Jordanian U-value is the highest among all other countries used for comparison. The unexposed wall in the Jordanian code got the highest U-value compared to all other countries. Windows and doors U-value in Jordanian code are one of the highest worldwide. Moreover, the building overall U-value in Jordanian code is one of the highest among other countries in this study.

The minimum heat demand consumption in European countries and the USA climatic zones. These values are used as a reference to the suggested U-value for country Jordan. The suggested U value limit the energy consumption to values comparable to international values. It could save almost 50% of energy consumed.

The effect of thermal bridges on the U-value was investigated. It was found that the thermal bridges have a significant impact on the U-value that will almost double the heating load. Finally, a new approach to account for thermal bridge effects is proposed and presented.

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