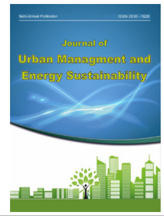
Journal of Urban Management and Energy Sustainability (JUMES)

Homepage: http://www.ijumes.com



CASE STUDY RESEARCH PAPER

Optimizing Building Wall Heat Transfer in Tehran Local Buildings with an Approach to Thermal Transmittance Quantity Calculation

Ashkan Hassani[1] Shooka Khoshbakht Bahramani*[2]

1 Ph.D. Candidate, Faculty Arts and Architecture, Central Tehran Branch, Islamic Azad University, Iran
**2 Assistant Professor, Faculty Arts and Architecture, Central Tehran Branch, Islamic Azad University, Iran*

ARTICLE INFO

Article History:
Received 2024-07-11
Revised 2024-10-24
Accepted 2024-11-17

Keywords:
Building Energy performance, building envelope, energy-efficient component, Tehran city, thermal conductivity assessment, thermal transmittance.

DOI: 10.22034/ijumes.2024.2035333.1233

ABSTRACT

This study investigates wall heat transfer, including the optimization of wall layers in Tehran's buildings. This paper represents that poor wall structure has a positive effect on energy costs and thermal comfort, as well as negative environmental degradation because of using fossil fuels. The paper addresses the great relevance of thermal transmittance to building energy performance and underlines the necessity for a theoretical and practical analysis and experimental measurement of thermal behavior of building components. In aspect of methodology of the current research, five common wall details in Tehran local buildings are investigated, and their insulating options are evaluated on the basis of Iranian building regulations. The thermal physique formulas are the main tools used to calculate each wall's thermal transmittance qualities, and the results are presented under specific temperatures. This article presents the findings of the heat transfer calculation for each wall type and discusses the variables and equations used in the calculation procedure. The new formula relations are established on the U-value, which is counted as the basis thermal property. This study plays a critical role in the optimization of thermal transmittance of wall layers in energy-efficient buildings. It has reviewed a wide range of studies related to wall heat transfer in various environmental conditions in Tehran. As the main potential of this research, it will help architects and designers select appropriate wall details that are energy-efficient, especially in insulation materials. Further research work might also be extended to other Iranian cities with different climates, considering eco-friendly insulation materials.

Running Title: Optimizing Building Wall Heat Transfer in Tehran Local Buildings

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
31	10	06

*Corresponding Author:
Email: *sho.khoshbakht@iauctb.ac.ir*
Phone: +9809121712023
ORCID: https://orcid.org/0000-0002-6987-9987

INTRODUCTION

The existence of multiple building elements and the amount of heat transfer from each one is a key factor in determining the amount of thermal transmittance of buildings at a certain time. Identifying the actual thermal performance of a building envelope—as one of the building elements—is crucial for energy audits when decisions are made concerning energy refurbishment and the implementation of energy-saving measures regarding appropriate and cost-effective building technology selection (Teni, Krstić, & Kosiński, 2019). Furthermore, the thermal transmittance of the wall is among those aspects that most affect energy consumption (Bienvenido-Huertas, Moyano, Rodríguez-Jiménez, & Marín, 2019). In addition, heat transfers through the building envelope (walls, windows, and roofs) is a key factor that affect the thermal comfort criterion(Alfarawi, Omar, El-Sawi, & Al Jubori, 2022). Based on this fact and insufficient attention to the building wall structure leads to higher expenditures from excessive energy usage and of those within the interior area, especially in Tehran. The analysis of building walls is conducted in both quantitative and qualitative aspects. Also, the different types of insulation and their influence have been extensively studied in several research studies. However, the inadequate study conducted on the development of building wall insulation materials in Tehran, the capital of Iran, is being highlighted as a concern. The lack of enough quantitative knowledge to this issue has resulted in a detrimental effect on insulation levels and the transmission of thermal energy. Consequently, this is expressed as a research gap on this subject. Therefore, the major objective of this research is to conduct a quantitative study on the heat transfer values of building walls (specifically external walls) in Tehran. In regarding to the mentioned aim, the current study is being assessed whole wall components and elements, and then, they would be categorized to determine the identified gap.

Wall thermal transmittance

The impact of thermal transmittance on the energy performance of a building indicates the importance of the materials used in construction (Schiavoni, D'Alessandro, Bianchi, & Asdrubali, 2016). The theoretical and practical wall performance can vary, particularly in high-performance constructions (Long & Ye, 2016). A considerable amount of building energy usage is directly related to the transmittance of wall layers (Soares et al., 2019). As the topic is being investigated, an intersection between engineering prowess and environmental stewardship is found. Fundamentally, the thermal transmittance of the wall, which is represented by the U-value, determines the rate at which heat is conducted through a structure. In the context of building energy performance, experimental measurements are crucial to better understand thermal behavior and gain more information about building components by using measurement systems, heat flows, and air speed in both internal and external environments (Evangelisti, Scorza, De Lieto Vollaro, & Sciuto, 2022). The ability of a material to reduce the thermal transformation quantity is directly correlated with its low U-value. In other words, a lower U-value indicates a material with stronger thermal resistance, which means that the material plays an effective role in preventing heat from passing through the wall (Alkhalidi, Kiwan, & Hamasha, 2021). Buildings, as one type of common energy consumers, represent both challenges and solutions. The thermal performance of the wall enhancement can significantly contribute to a reduction in energy consumption in the built environment (Marushchak & Pozniak, 2022). It is noteworthy that the that wall thermal transmittance is counted as a multi-aspect procedure that must be recognized. This involves the use of non-destructive laboratory and on-site methodologies to recognize the thermal transmittance and behavior of walls, windows, and other construction elements using novel materials and methods (Soares et al., 2019), which requires a careful relationship between material science, architectural design, and engineering skills (Kishore, Bianchi, Booten, Vidal, & Jackson, 2021). In the next section, more effective substitutes for conventional choices are introduced, including foam boards and fiberglass batts that are being used as new insulation materials (Mikulica & Labaj, 2016); however, the landscape is evolving, and phase-change materials (PCMs) and novel composite insulation are examples of these developments. For instance, by storing thermal energy and releasing it when needed, PCMs have been demonstrated to improve building energy performance in an impactful manner, which leads to more suitable thermal management and lower energy usage (Aghakhani, Ghaffarkhah, Arjmand, Karimi, & Afrand, 2022). These materials enhance insulation in the first place and provide opportunities for thinner and more space-efficient construction. In accordance with the building wall surface, it becomes obvious that achieving a thermal resistance wall is beyond the technical challenge and is a collective responsibility (Suvalov, Lomp, & Kalamees, 2023). Defining a solution for wall heat transmittance is necessary for a multidisciplinary strategy that includes players from several industries. To manage wall heat transmittance, a multidisciplinary strategy comprising architects, engineers, and other industry actors is essential (Alfarawi et al., 2022). Establishing a practical framework that architects can use to make appropriate insulation choices is essential. In accordance with a study conducted in 2020, with the goal of testing and developing an appropriate procedure to evaluate one of the envelope's characteristic properties, this study focuses on thermal transmittance of the opaque component. Using this method, the wall thermal transmittance of a few buildings in Reggio Calabria, Italy was measured. A shorter analysis time is needed to create new products; however, environmental tests are costly and time-consuming (Jamal, Boukendil, Abdelbaki, & Zrikem, 2020).

Wall layer optimization

This study investigated three commonly used types of insulation materials and a homogenous multilayer building exterior wall structure, and examined the impact of insulation type and thickness on the dynamic thermal characteristics of external wall structures in Japan. According to the results, the type of insulation used and its thickness have a considerable effect on thermal transmittance (Yuan, 2018). Based on another study that evaluated the thermal insulation performance of metal-framed lightweight walls, the primary envelope solutions were identified. The thermal transmittance of a typical façade module is optimized by analyzing the thermal bridges at the first point, and then the quantity of thermal transmittance of lightweight metal-framed walls is calculated using a specialized finite element method (FEM) tool (De Angelis & Serra, 2013). In the research entitled "Comparative analysis of building insulation material properties and performance," which was published in Renewable and Sustainable Energy Reviews, experimental tests and software simulations using a numerical approach were conducted assess the thermal performance of some insulation materials. After comparison, the results presented the strengths and limitations of each insulation type. In accordance with these findings, 50–60% of the comfort of the interior space environment can be attributed to the insulating layer on the envelope wall (Kumar, Alam, Zou, Sanjayan, & Memon, 2020). In the paper entitled "Thermal Performance Assessment of External Wall Construction for Energy-Efficient Buildings," a standard wall structure that is practical in Libyan residential buildings is found through the use of a numerical method. This study began by examining various extended wall construction techniques and materials that are frequently used in energy-efficient design. Finally, polystyrene insulation was extended to the outer wall, and the considerable achievement of this research showed a valuable heat transmittance rate (Alfarawi et al., 2022). In the article entitled "Optimizing the Evaluation of Thermal Transmittance with the Thermometric Method Using Multilayer Perceptron," the authors investigated the application of artificial neural networks, especially multilayer perceptions, in enhancing the accuracy and efficiency of thermal transmittance evaluation using the thermometric method (Bienvenido-Huertas, Rubio-Bellido, Pérez-Ordóñez, & Moyano, 2019) In the article entitled "Configuring Wall Layers for Improved Insulation Performance," the configuration of wall layers is being examined through a combination of theoretical models, software simulations, and practical experiments. The objective is to determine the best material and layer combination to reduce heat transfer in one aspect and increase insulation efficiency in the other (Bond, Clark, & Kimber, 2013). In the article entitled "Impact of Insulation Type and Thickness on the Dynamic Thermal Characteristics of an External Wall Structure," the researcher investigates how the choice of insulation material and its thickness influence the dynamic thermal behavior of an external wall. Using this method, the contribution of effective strategies for energy-efficient building design was determined (Yuan, 2018). According to research entitled "Thermal Inertia Characterization of Multilayer Lightweight Walls: Numerical Analysis and Experimental Validation", researchers conducted an investigation about lightweight concrete wall insulation layers' to optimize both transient situations and steady-state temperature conditions. The purpose of this study was to examine the thermal inertia behavior of walls in relation to various insulation layer types (del Coz-Díaz, Álvarez-Rabanal, Alonso-Martínez, & Martínez-Martínez, 2021). To investigate the air layer and its thickness in double solid walls, a study entitled "Numerical simulation of coupled heat transfer through double solid walls separated by an air layer" assessed the thermal emissivity of a double wall with an air layer. As a result, the study concluded that an air layer with a thickness of 5 cm could be a useful method for efficiently reducing energy consumption (Evola et al., 2020). In another research entitled "Investigating the Impact of Exterior Window Shutters on Indoor Climate Conditions in Humid and Temperate Climate" expresses that flexible envelope based on some variables, having an inlet area of 12.5% to 25% could produce better inner climate (Milad, Shahin, & Seyed Majid Mofidi, 2023).

Heat Transfer

The influence of building materials and the efficient quality of construction are two aspects related to buildings that are greatly affected by heat energy transmission. Numerous investigations have been conducted to examine the quantity of heat transfer via construction materials and identify strategies for minimizing heat loss from these materials (Abhishek Bhardwaj 2021). In an article entitled "Thermal behavior improvement of building materials using expanded polystyrene," the investigator explored the use of expanded polystyrene (EPS) as a key element in improving the thermal behavior of building materials. The research mentioned that expanded polystyrene can effectively reduce heat transfer through conduction (Ayed, Baddadi, Dellagi, Bouadila, & Lazâar, 2022). Another important factor is sustainable development, which is considered a new platform that emphasizes the economy, trade, and industry that supports the environment and nature, and thermal transmission could significantly affect it. (Hosseini Rostami, Baharestani, Sheikhi, & Malekafzali, 2019).

Theoretical Framework

The thermal performance of building walls forms a vital component in the general energy efficiency of buildings. A developed theoretical framework incorporates aspects on wall thermal transmittance, optimization of wall layers, and heat transfer dynamics that provide a more detailed and systematic approach to how material selections and methods of construction can be made to count toward energy performance.

- **Wall Thermal Transmittance:** Wall thermal transmittance (U-value) measures heat flow through wall layers, influencing energy efficiency. Low U-values indicate strong insulation, essential for high-performance buildings (Schiavoni et al., 2016; Alkhalidi et al., 2021; Marushchak and Pozniak, 2022).
- **Optimization of Wall Layers:** Insulation materials (foam boards, fiberglass, PCMs) and air layers in double walls can improve energy efficiency. PCMs excel by storing and releasing

thermal energy. Numerical analyses like finite element methods help compare materials under various conditions (De Angelis and Serra, 2013; Kumar et al., 2020; Evola et al., 2020).

- **Material Innovation in Thermal Management:** Advanced materials like PCMs and composite insulations support effective thermal performance with thinner walls, while sustainable options like EPS improve insulation with minimal environmental impact (Mikulica and Labaj, 2016; Ayed et al., 2022).
- **Heat Transfer in Building Materials:** Minimizing heat transfer (conduction, convection, radiation) in lightweight walls requires good insulation for optimal thermal inertia in different conditions (del Coz-Díaz et al., 2021).
- **Multidisciplinary Wall Optimization:** A collaborative approach among architects, engineers, and scientists in selecting materials and methods tailored to local climate and building needs is crucial for energy-efficient designs (Alfarawi et al., 2022; Jamal et al., 2020).

MATERIALS AND METHODS

This investigation process is being done in three main steps: typical wall selection, thermal transmittance properties analysis, and thermal transmittance calculation. In the first stage, it is important to choose the walls to carry out the calculation process, and it is based on the Tehran building wall typology. After checking the thermal physics characteristics of each of the thermal insulation and materials, the thermal properties of each of them will be calculated based on the thermal physics formulas. And in the last step, using the algebraic operations of the formulas, the relationship between the heat transfer rate and the wall area is calculated for each of the wall typologies.

Typical wall selection

In this part, five typical wall details are introduced in a local building in Region 1 of Tehran. (Fig. 1a) presents the shape of the units selected based on the Tehran typology plan. There are numerous walls in the plan, and the northern wall is the chosen part. The chosen wall length is 10.40 m, as shown in (Fig. 1b). The typical wall is implemented on the basis of three main categories, which include indoor layers, core layers, and outdoor layers. Table 1 presents the layers, and (Fig. 1c) shows typical wall layers graphically. Indoor layers contain a gypsum panel (2 cm of thickness) and gypsum and soil (3 cm of

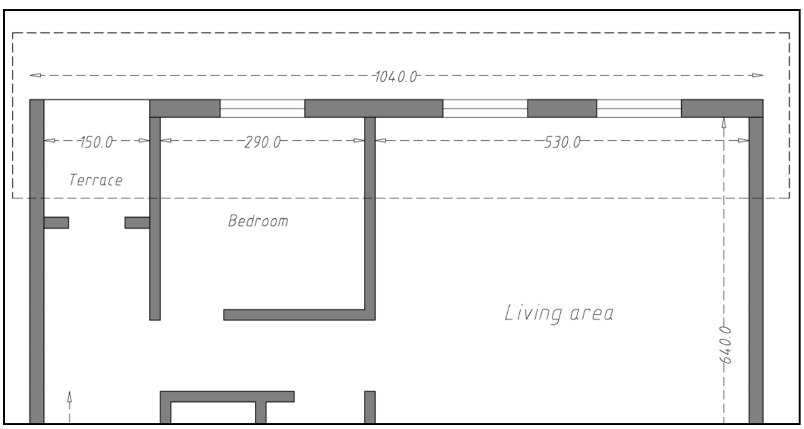


Figure 1a: building unit plan

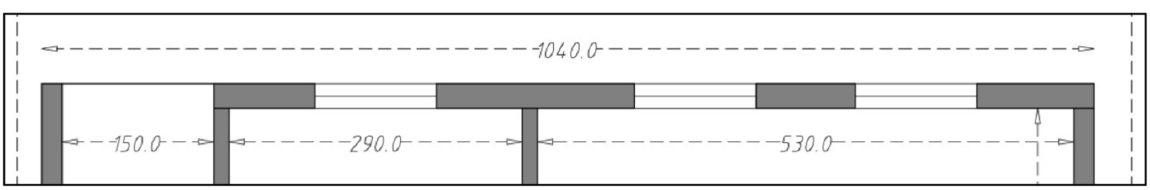


Figure 1b: selected wall zooming.

thickness). The core layer is shaped from a cement block (10.5 cm of thickness), and the outdoor layer is made from cement plaster (3 cm of thickness) and façade stone (2 cm of thickness). First, it is necessary to determine the most useful insulation materials in typical Tehran building walls locally. Because of that, five types of insulation layers are chosen on the basis of the Iranian building code (the National Building Code). (Figs. 2 to 6) present five insulation layers in the customized typical wall detail, and Table 2 presents the properties of these insulations. (Tab. 1)

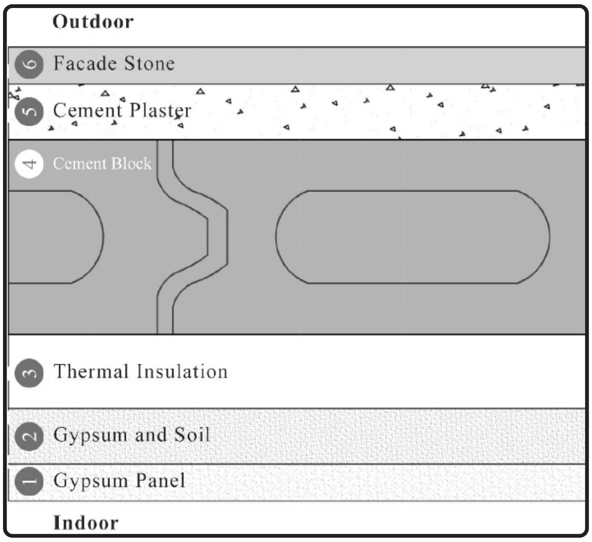


Figure 1c: typical building wall layers.

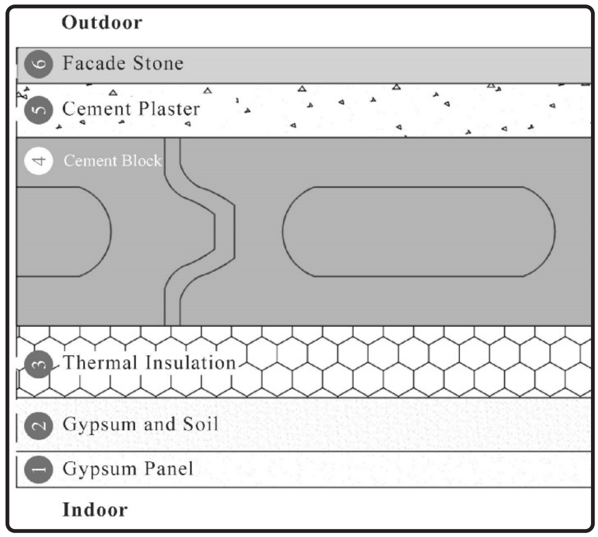


Figure 2: Typical Building wall with Polystyrene insulation.

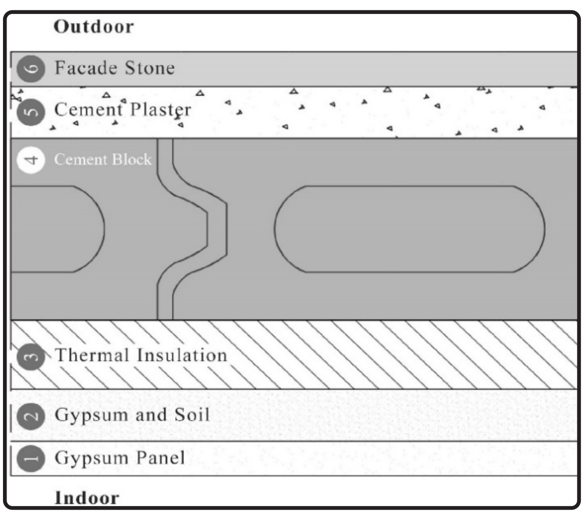


Figure 3: Typical Building wall with Fiberglass insulation.

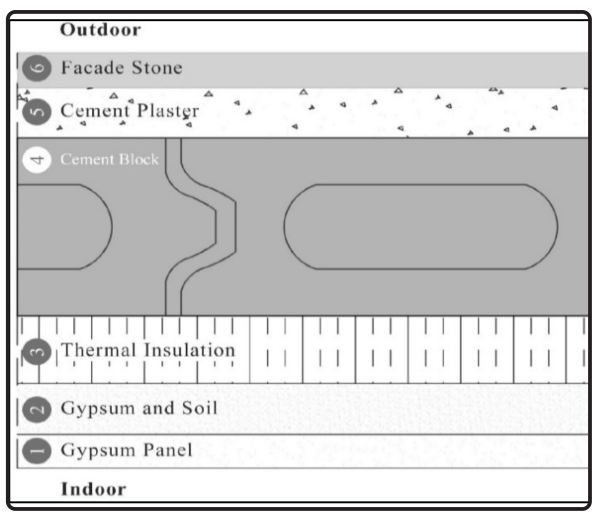


Figure 4: Typical Building wall with Rockwool insulation.

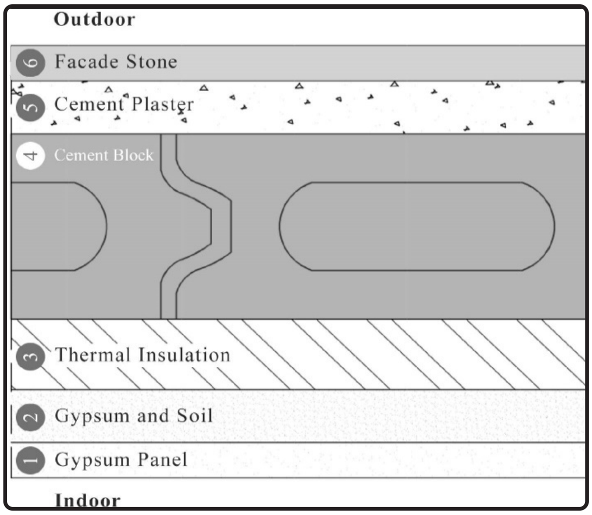


Figure 5: Typical Building wall with Calcium Silicate insulation.

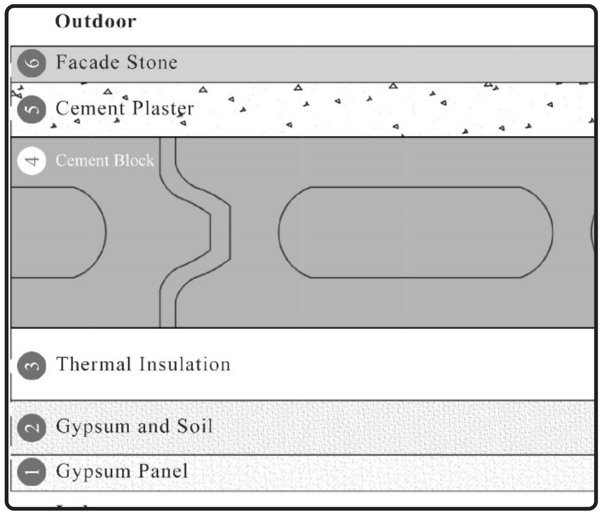


Figure 6: Typical Building wall with Polyethylene insulation.

Table 1: Wall model layers' properties

	Material	Situation	Thickness (m)	K (W/m.K)	R-Value (m².K/W)	U-Value (W/m².K)
1	Gypsum Panel	Indoor	0.02	0.56	0.03	28.00
2	Gypsum and Soil		0.03	1.10	0.02	36.66
3	Thermal Insulation		-		-	-
4	Cement block	Core	0.105	0.70	0.15	6.66
5	Cement Plaster	Outdoor	0.03	1.00	0.30	33.33
6	Façade Stone (Granite)		0.02	1.73	0.01	86.50

Table 2: thermal transmittance calculation condition

	Wall Type	U-Value (W/m².K)	Area (m²)	ΔT (°C)	T (s)
1	Wall type 01	0.55	17.60	10	3600
2	Wall type 02	0.56			
3	Wall type 03	0.91			
4	Wall type 04	1.36			
5	Wall type 05	1.38			

Table 3: Insulation layers' thermal properties

	Material	Thickness (m)	K (W/m.K)	R-Value (m².K/W)	U-Value (W/m².K)
1	Polystyrene	0.04	0.034	1.17	0.85
2	Fiberglass	0.04	0.36	0.11	9.00
3	Rockwool	0.04	0.035	1.14	0.87
4	Calcium Silicate	0.04	0.084	0.47	2.10
5	Polyethylene	0.04	0.40	0.10	10.00

Wall Types Area Calculation

In the first stage, basic part of calculation should be determined, so based on the selected sample of building wall which presented in (Fig. 1a – 1c), the wall area calculation is needed. As presented in mentioned Figures, the wall dimensions include length and height which are determine 10.40 meters and 2.70 meters. therefore, the whole wall area can be calculated (Eq. A). Then, the area related to the windows and terrace should be reduced (Eq. B and C), and in this way, the net wall area is being calculated (Eq. D).

$$Entire\ wall\ area = 10.40 * 2.70 = 28.08\ m^2$$

Equation (A)

$$Windows\ area = (1.30*1.20)+(2.00*1.20)+(2.00*1.20)$$
$$= 1.56\ m^2 + 2.4\ m^2 + 2.4\ m^2 = 6.36\ m^2$$

Equation (B)

$$Terrace\ area = 2.40 * 1.70 = 4.08\ m^2$$

Equation (C)

$$Net\ wall\ area = 28.08\ m^2 - 6.39\ m^2 - 4.09\ m^2 = 17.60\ m^2$$

Equation (D)

So the wall area which is effective in the next parts of the calculations is 17.60 square meters.

Wall Types Thermal Properties

In the next step, calculation of the wall thermal properties should be conducted which include Thermal resistance rate and Thermal transmittance rate. The R-value (Thermal resistance rate) and U-value (Thermal transmittance rate) determine thermal transfer properties of each wall, and the quantity of these two factors is calculated through a calculation process based on Formulas A-C. insulation layers' effect is not considered in this part.

According to the relation between thermal resistance and thermal transmittance, the first factor that needs to be calculated is thermal resistance. Formula (A) shows us the method by which it is possible to calculate the thermal resistance (R-value rate). in this formula, it would need to know each wall layer thermal resistance rate (based on the Iranian building regulation code), and add them together:

$$R_{Total} = R_{Layer\ 1} + R_{Layer\ 2} + R_{Layer\ 3} + R_{Layer\ 4} + R_{Layer\ 5} + R_{Layer\ 6}$$

Formula (A)

Or

$$R_{Total} = \sum R_{Layers}$$

According to Table 1 and Table 3, total thermal resistance calculation process is being done by (Eq. E).

$$R_{Total} = 0.03 + 1.10 + 0.15 + 0.30 + 0.01 = 1.59\ (m^2.\ K / W)$$

Equation (E)

So the thermal resistance rate of the selected wall type is calculated based on the sample wall layers which is presented in (Tab. 1) separately, and it equals 1.59 m^2. K/W. After that, thermal transmittance rate of the mentioned wall is needed. In accordance with the referenced formula, to calculate the U-value, it would need to reverse the quantity of the R-value. So (Eq. F) shows the reverse process:

$$R_{Total} = \frac{1}{U.Total}$$

Equation (F)

$$U_{Total} = \frac{1}{R.Total}$$

Equation (G)

$$U_{Total} = \frac{1}{1.59} = 0.62 (W / m^2.K)$$

So the thermal transmittance rate of the selected wall type is calculated based on the sample wall thermal resistance rate, and it equals 0.62 m^2. K/W.

There is a considerable factor in the calculation process of 5.1, and it is the effect of thermal insulation materials in the wall thermal properties calculation. In another meaning, in the mentioned calculation, the sample wall layers' thermal properties were considered effective, and there is not the influence of any thermal insulation materials in them. So in this part, it would be needed to add the effect of each insulation materials properties to the walls.

According to (Fig. 2-6), the third layers are the insulation materials and they are changed in five types which are presented in (Tab. 3). (Tab. 2) expresses the R-value and U-value of the thermal insulation materials that are used in the wall models (Fig. 2 - 6). Therefore, in this step, the thermal properties (U-value and R-value) should be calculated considering the insulation materials. Sentences 1-5 show the process of the U-value calculations in each wall. It is considerable that the calculation procedure is being conducted based on the Formula (A), Eq. (F) and (G).

Sentence 1. Typical Building wall with Polystyrene insulation

$R_{Total\ (Typical\ wall\ without\ insulation)} = 0.62\left(m^2.K/W\right), R_{Polystyrene} = 1.17$

So $R_{Total\ (Typical\ wall\ with\ polystyrene)} = 1.79\ \left(m^2.\ K\ /\ W\right)$

$U_{Total\ (Typical\ wall\ with\ polystyrene)} =\ 0.55\ \left(W\ /\ m^2.\ K\right)$

Sentence 2. Typical Building wall with Fiberglass insulation

$R_{Total\ (Typical\ wall\ without\ insulation)} = 0.62\left(m^2.K/W\right), R_{fiberglass} = 0.11$

So $R_{Total\ (Typical\ wall\ with\ fiberglass)} = 0.73\ \left(m^2.\ K\ /\ W\right)$

$U_{Total\ (Typical\ wall\ with\ fiberglass)} =\ 1.36\ \left(W\ /\ m^2.\ K\right)$

Sentence 3. Typical Building wall with Rockwool insulation

$R_{Total\ (Typical\ wall\ without\ insulation)} = 0.62\left(m^2.K/W\right), R_{rockwool} = 1.14$

So $R_{Total\ (Typical\ wall\ with\ rockwool)} = 1.76\ \left(m^2.\ K\ /\ W\right)$

$U_{Total\ (Typical\ wall\ with\ fiberglass)} =\ 0.56\ \left(W\ /\ m^2.\ K\right)$

Sentence 4. Typical Building wall with Calcium Silicate insulation

$R_{Total\ (Typical\ wall\ without\ insulation)} = 0.62\left(m^2.K/W\right), R_{calcium\ silicate} = 0.47$

So $R_{Total\ (Typical\ wall\ with\ calcium\ silicate)} = 1.09\ \left(m^2.\ K\ /\ W\right)$

$U_{Total\ (Typical\ wall\ with\ fiberglass)} =\ 0.91\ \left(W\ /\ m^2.\ K\right)$

Sentence 5. Typical Building wall with Polyethylene insulation

$R_{Total\ (Typical\ wall\ without\ insulation)} = 0.62\left(m^2.K/W\right), R_{polyethylene} = 0.10$

So $R_{Total\ (Typical\ wall\ with\ polyethylene)} = 0.72\ \left(m^2.\ K\ /\ W\right)$

$U_{Total\ (Typical\ wall\ with\ fiberglass)} =\ 1.38\ \left(W\ /\ m^2.\ K\right)$

Thermal Transfer Energy Calculation

As shown in (Tab. 3), all five wall models were collected based on the technical details of the wall layers, thermal resistance, and thermal transmittance factors. From another perspective, walls are categorized on the basis of the U-value, which directly affects thermal transmittance. As a summary of the wall models, insulation layer, and U-value, (Tab. 4) is presented, and based on that, Diagram 1 presents the U-value rating in relation to the insulation layers. So, based on the thermal properties and the energy transmittance formula, the calculation of heat transfer in the wall types is being conducted.

$Q\ =\ k.A.\ \left(T\ Hot\quad T\ Cold\right).\ t\ /\ d$ Formula (B)

The position of (d) inside the formula is changed and the value of (k) is divided into it, and it is written in Eq. (H):

$Q\ =\ k\ /\ \left(d\right).\ A.\ \left(T_2 - T_1\right).t\ /\ 1000$ Equation (H)

Instead of k/(d) the expression (U) is placed (Eq. (I))

$k\ /\ \left(d\right)\ =\ U$ Equation (I)

and Formula (B) is rewritten in Formula (C)

$Q=\ U.\ A.\ \left(T\ Inside\quad T\ Outside\right).t\ /\ 1000$

Formula (C)

In this section, on the basis of the abovementioned Formulas, the thermal transfer quantity of each wall is being calculated. Table number 2 expresses the factors for the calculation are required to be performed by Formula (C).

U-values = mentioned in Table 5

Wall net area is calculated in Equation (D)

$T_{Inside}\ =\ 20$

$T_{Outside}\ =\ 10$

$t\ =\ 1\ hour\ \left(3600\ s\right)$

In the next step, the thermal transmittance energy is calculated. Equations (J) to (N) present the calculation process in 4.2.

Thermal Transfer Energy Equations

Based on the calculation was conducted and the current research topic, the determination of the relationship between the surface of each wall (based on type of thermal insulation) and the quantity of energy transferred is being conducted. The calculation process of this part is based on the Formula (C), and the algebra process of this formulation.

Wall Type 1

$Q\ =\ U.\ A.\ \left(T\ Inside\quad T\ Outside\right).t\ /\ 1000$

Formula (C)

(Eq. J) is changed and the area (A) quantity is considered empty as it is shown in (Eq. O-1):

$348.48\ KW\ =\ 0.55\ *\ A\ *\ \left(10\right)\ *\ 3600\ /\ 1000$

Equation (O-1)

The sides of the tie are calculated, and it is presented in (Eq. P-1):

$$348.48\ KW = 19.8 * A$$ Equation (P-1)

348.48 KW is replaced with Q and the relationship between Q and A is being showed. (Eq. Q-1) shows:

$$Q = 19.8 * A$$ Equation (Q-1)

Wall Type 2

$$Q = U.A.\left(T\ Inside \quad T\ Outside\right).t\ /\ 1000$$

Formula (C)

(Eq. K) is changed and the area (A) quantity is considered empty as it is shown in (Eq. O-2):

$$354.81\ KW = 0.56 * A * (10) * 3600\ /\ 1000$$

Equation (O-2)

The sides of the tie are calculated, and it is presented in (Eq. P-2):

$$354.81\ KW = 20.16 * A$$ Equation (P-2)

354.81 KW is replaced with Q and the relationship between Q and A is being showed. (Eq. Q-2) shows:

$$Q = 20.16 * A$$ Equation (Q-2)

Wall Type 3

$$Q = U.A.\left(T\ Inside \quad T\ Outside\right).t\ /\ 1000$$

Formula (C)

(Eq. L) is changed and the area (A) quantity is considered empty as it is shown in (Eq. O-3):

$$576.57\ KW = 0.91 * A * (10) * 3600\ /\ 1000$$

Equation (O-3)

The sides of the tie are calculated, and it is presented in (Eq. P-3):

$$576.57\ KW = 32.76 * A$$ Equation (P-3)

576.57 KW is replaced with Q and the relationship between Q and A is being showed. (Eq. Q-3) shows:

$$Q = 32.76 * A$$ Equation (Q-3)

Wall Type 4

$$Q = U.A.\left(T\ Inside \quad T\ Outside\right).t\ /\ 1000$$

Formula (C)

(Eq. M) is changed and the area (A) quantity is considered empty as it is shown in (Eq. O-4):

$$861.69\ KW = 1.36 * A * (10) * 3600\ /\ 1000$$

Equation (O-4)

The sides of the tie are calculated, and it is presented in (Eq. P-4):

$$861.69\ KW = 48.96 * A$$ Equation (P-4)

861.69 KW is replaced with Q and the relationship between Q and A is being showed. (Eq. Q-4) shows:

$$Q = 48.96 * A$$

Equation (Q-4)

Wall Type 5

$$Q = U.A.\left(T\ Inside \quad T\ Outside\right).t\ /\ 1000$$

Formula (C)

(Eq. N) is changed and the area (A) quantity is considered empty as it is shown in (Eq. O-5):

$$874.36\ KW = 1.38 * A * (10) * 3600\ /\ 1000$$

Equation (O-5)

The sides of the tie are calculated, and it is presented in (Eq. P-5):

$$874.36\ KW = 49.68 * A$$ Equation (P-5)

874.36 KW is replaced with Q and the relationship between Q and A is being showed. (Eq. Q-5) shows:

$$Q = 49.68 * A$$ Equation (Q-5)

DISCUSSION AND FINDINGS

Wall types thermal properties calculation

According to what (Tab. 1 and 3) have mentioned regarding the thermal characteristics of the materials (wall layering and also thermal insulation) and also according to the formulas A-C, the calculation of the thermal resistance coefficient (R-value) and the coefficient of thermal conductivity (U-value) of the wall types are calculated based on the mentioned process in the discussion section. (Tab. 4) shows the mentioned results. (Tab. 5) summarizes the wall types and U-values based on the thermal insulation layers.

In accordance with the presented results of Table 4, and its categorization in (Tab. 5), (Fig. 7) presents the Thermal transmittance rate (U-value) of each wall types. It is obvious that the U-value of Polyethylene is 1.38 W/m2. K, and it is the highest one in comparison with the other thermal insulation. It means that the quantity of thermal transmittance of in Polyethylene is higher than other insulation material.

Table 4: Wall types layers and thermal properties

	Wall Type	R-Value (m2.K/W)	U-Value (W/m2.K)
1	• Wall type 01 1. Gypsum Panel 2. Gypsum and Soil 3. Thermal Insulation (Polystyrene) 4. Cement block 5. Cement Plaster 6. Façade Stone (Granite)	1.79	0.55
2	• Wall type 02 7. Gypsum Panel 8. Gypsum and Soil 9. Thermal Insulation (Rockwool) 10. Cement block 11. Cement Plaster - Façade Stone (Granite)	1.76	0.56
3	• Wall type 03 12. Gypsum Panel 13. Gypsum and Soil 14. Thermal Insulation (Calcium Silicate) 15. Cement block 16. Cement Plaster - Façade Stone (Granite)	1.09	0.91
4	• Wall type 04 17. Gypsum Panel 18. Gypsum and Soil 19. Thermal Insulation (Fiberglass) 20. Cement block 21. Cement Plaster - Façade Stone (Granite)	0.73	1.36
5	• Wall type 05 22. Gypsum Panel 23. Gypsum and Soil 24. Thermal Insulation (Polyethylene) 25. Cement block 26. Cement Plaster - Façade Stone (Granite)	0.72	1.38

Table 5: Wall types insulation layer and U-Value

	Wall Type	U-Value (W/m2.K)
1	Wall type 01 - Thermal Insulation (Polystyrene)	0.55
2	Wall type 02 - Thermal Insulation (Rockwool)	0.56
3	Wall type 03 - Thermal Insulation (Calcium Silicate)	0.91
4	Wall type 04 - Thermal Insulation (Fiberglass)	1.36
5	Wall type 05 - Thermal Insulation (Polyethylene)	1.38

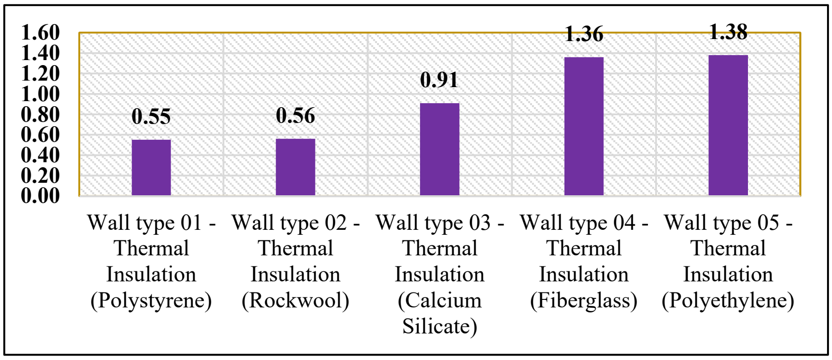


Figure 7: Wall types insulation layer U-Value

On the other hand, the quantity of thermal transmittance rate (U-value) of Polystyrene is 0.55 W/m2. K, and it counts the lowest thermal transmittance rate. So it shows the high efficiency of Polystyrene, as a thermal insulation material.

Based on the mentioned U-values and R-values of various wall types which present in (Tab. 4) and the U-value of walls which layered with Polystyrene and Polyethylene, the efficiency is a considerable factor. The comparison between the mentioned insulation materials (Fig. 8) and (Fig. 9), show the efficiency rates of these materials. (Fig. 8) determines the thermal transmittance rate (U-Value) of mentioned insulation materials, and (Fig. 9) shows the thermal resistance rate (R-value) of the insulations. In accordance with the Figures, Polystyrene provides more efficient insulation material.

Thermal transfer energy calculation

Upon performing the calculation of transferred energy using Formula (C) and the values of the variables listed in (Tab. 2), the resulting value is determined in kilowatts in the discussion section.

(Eq.J)to(Eq.N)present the calculation process.

$$Q_{Wall\ type\ 01} = (0.55 * 17.60 * 10 * 3600) / 1000 = 348.48\ KW$$

Equation (J)

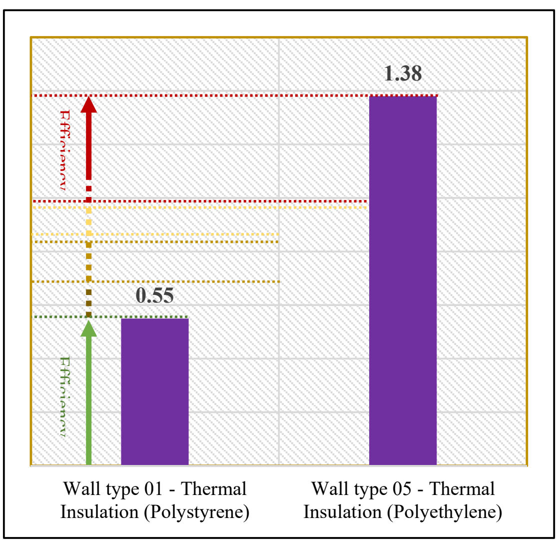


Figure 8: Polystyrene and Polyethylene U-Value

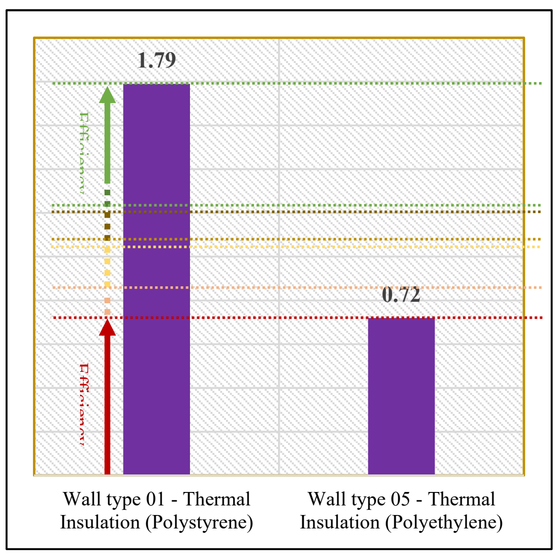


Figure 9: Polystyrene and Polyethylene R-Value

$$Q_{Wall\ type\ 02} = (0.56 * 17.60 * 10 * 3600) / 1000 = 354.81\ KW$$
Equation (K)

$$Q_{Wall\ type\ 03} = (0.91 * 17.60 * 10 * 3600) / 1000 = 576.57\ KW$$
Equation (L)

$$Q_{Wall\ type\ 04} = (1.36 * 17.60 * 10 * 3600) / 1000 = 861.69\ KW$$
Equation (M)

$$Q_{Wall\ type\ 05} = (1.38 * 17.60 * 10 * 3600) / 1000 = 874.36\ KW$$
Equation (N)

All in all, there collection of thermal transmittance (Eq. a-e), is presented in (Tab. 6) which determine five main categories.

Table 6: Wall types thermal transfer energy calculation

	Wall type	U-Value (W/m².K)	Q (KW)
1	Wall type 01	0.55	348.48
2	Wall type 02	0.56	354.81
3	Wall type 03	0.91	576.57
4	Wall type 04	1.36	861.69
5	Wall type 05	1.38	874.36

$$Q_{Wall\ type\ polystyrene} = 19.80\ A$$ Equation (Q-1)

$$Q_{Wall\ type\ rock\ wool} = 20.16\ A$$ Equation (Q-2)

$$Q_{Wall\ type\ Calcium\ Silicate} = 32.76\ A$$ Equation (Q-3)

$$Q_{Wall\ type\ Fiberglass} = 48.96\ A$$ Equation (Q-4)

$$Q_{Wall\ type\ Polyethylene} = 49.68\ A$$ Equation (Q-5)

Thermal transfer energy and area relationship

As it is presented in Table 6 and Figure 10, and based on the mentioned condition (Tab. 2) and the calculation (Formula C), the quantity of thermal energy transmittance of wall type 01 is the lowest amount of transmittance which equals 348.48 KW. On the other hand, the mentioned quantity for wall type 05 is the highest that equals 874.36 KW. So it shows the influence of the thermal insulation layers. As it is pointed out in (Fig. 8) and (Fig. 9) the difference of insulation material s properties (U-value and R-value) has effects in the heat energy transmittance. In another meaning, the more efficient insulation material (Polystyrene) prevents thermal transmittance against with non-efficient insulation material (Polyethylene).

Thermal transfer energy equations

the aforementioned variables and, the subject of the current research, determination of the relationship between the surface of each wall (based on type of thermal insulation) and the quantity of energy transferred is calculated. The calculation process of this part is based on the Formula (C), and the algebra process of this formulation is discussed in discussion section. The results of this procedure are presented in (Eq. F-J).

As (Eq. F) to (Eq. J) are presented, the new relation between thermal transmittance quantity (Q) and wall area (A) is extracted. These questions can be analyzed in two aspects. Firstly, is

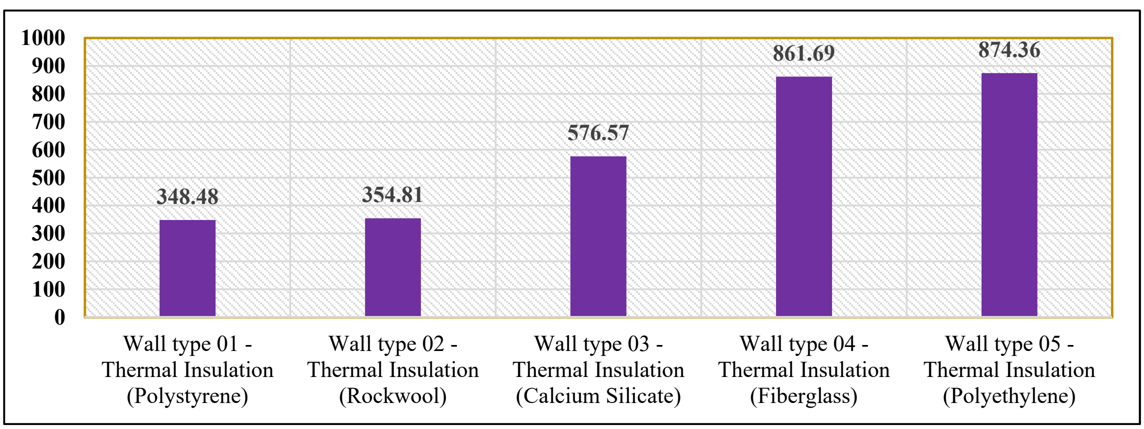


Figure 10: Wall types Thermal Transmittance Energy

about the quantity of the coefficient multiplied to A. It depends on the calculated thermal property (U-value). It means that by increasing the thermal conductivity of insulation materials, the coefficient factor is being increased. As it is obvious in (Eq. F-J), the coefficient in Polyethylene equation is more than coefficient of (Eq. F), which related to Polystyrene. On the second perspective, the achieved equation can be able to help architects and building designers to have an estimation about the thermal energy transmittance based on the designed walls in building and the selected insulation material for them. The main advantage of this process is that architects can check the estimation results and also they can change insulation material type as an effective factor to achieve the best thermal transmittance result in their project.

Comparison with the previous researches

The current study enhances the previous research on insulation in Iranian buildings over various climates with a specific emphasis on mathematical formulation, rather than software simulations. (eskandari, Maddahi, & Khosrozad, 2017) considered the cost-impacting insulation for energy consumption in Yazd, Tehran, and Tabriz by Energy Plus simulation, but in the current study, a mathematical approach has been used to investigate the effect of insulation on the thermal transmittance in Tehran. (Rosti, Omidvar, & Monghasemi, 2020) investigated ideal insulation thickness, energy savings, and payback periods for various modern wall types across eight Iranian cities. In contrast, this study uniquely establishes a quantitative relationship between thermal transmittance and wall area, enabling architects and designers to perform independent calculations and apply energy-saving strategies tailored to specific building requirements.

Other studies have been conducted on other aspects of insulation and wall types. (Mohammad & Shea, 2013) for example, compared modern wall materials to the traditional clay and brick in Tehran with the view of coming up with energy-efficient wall types. The study is unlike this since it focuses directly on thermal insulation material which has been used to give guidelines on the selection of appropriate insulation in order to enhance building energy efficiency. Similarly, (Ramin, Hanafizadeh, & Behabadi, 2015) analyzed optimum insulation thickness and positioning in wall layers. The research focus was on conventional materials like concrete and brick. This research fixes insulation positioning and varies insulation materials to analyze thermal performance. Other related works include (Rosti, Omidvar, & Monghasemi, 2019), who analyzed insulation layer positioning in the walls conditioned with earth-air heat exchangers, focusing on time lag and heat transfer rate. (Zerroug & Dzelzitis, 2019) analyzed insulation thickness by using the eQUEST tool, showing that beyond a certain insulation thickness, energy savings started to diminish. While these studies focus on thickness and positioning, this one focuses on how wall area affects energy consumption when combined with different insulation materials. The study quantifies the relation between wall area and thermal transmittance; it also gives a tool that can be used practically by designers to study optimization regarding energy performance in early phases of the project. In Iranian climates, this further advances insulation material selection beyond basic thickness and configuration considerations.

RESULT AND CONCLUSION

The article assesses the thermal transmittance of typical Tehran building walls and the optimization of insulation materials in terms of increased energy efficiency and comfort. In general, this work evidences that different insulation types are reflected in thermal transmittance and wall resistance, providing useful information for energy audits and renovation planning oriented toward the reduction of energy consumption in buildings.

This research methodology selected some of the most common Tehran building wall types, calculated their thermal properties, and evaluated a number of insulation materials. It follows from the results that there are significant U-value differences among these insulation materials: from a high efficiency of 0.55 W/m².K for polystyrene insulation to a low one of 1.38 W/m².K for polyethylene. This shows the importance of proper insulation selection for wall thermal performance improvement.

The thermal formula was used in calculating the heat transfer through walls; it was noted that polystyrene insulation had the least energy transferred, approximately 348.48 KW, and polyethylene had the highest, approximately 874.36 KW. This indicated that appropriate insulation is crucial in minimizing energy consumption while maximizing comfort. Though various studies have used simulation methods for this kind of study, this study employed a mathematical model approach specific to the climatic characteristics of Tehran, which relates wall area to thermal transmittance. This methodology supports designers and architects in the initial phases of a project to estimate energy performance and choose efficient locally available insulation for building walls.

To conclude, this research fills a crucial gap in the quantitative analysis of the wall thermal transmittance in Tehran's building, which emphasizes the need for effective insulation materials to approach the goal of energy efficiency in Tehran. efficiency, which contributes to sustainable building practices and environmental impact reduction. The findings provide a valuable resource for stakeholders involved in building design and construction in Tehran, the main city of Iran. As for the specific points, the conclusion includes:

- First, architects who want to design an architectural residential plan in Tehran can determine the best exterior wall detail according to the available materials. In another sense, they can use the relationships and formulas of this research to determine wall thermal transmittance quantities based on locally available insulation materials, so they can make the best decision in this case.
- Second, researchers who want to investigate building wall thermal transmittance in Tehran can develop acquired relations and formulas for different variables, like indoor and outdoor temperature differences, for other cities in Iran.
- The third advantage of the obtained relationships is the software simulation of buildings in terms of thermal transmittance. This means that investigators who want to conduct research on building thermal factors can determine the quantity of wall thermal transmittance in the five materials based on the wall area.

REFERENCES

Abhishek Bhardwaj , M. R., Keshav Pareek , et al. (2021). Heat transfer through brick walls for designing the building fabric. TechRxiv, 12. doi: 10.36227/ techrxiv. 16926439.v1

Aghakhani, S., Ghaffarkhah, A., Arjmand, M., Karimi, N., & Afrand, M. (2022). Phase change materials: Agents towards energy performance improvement in inclined, vertical, and horizontal walls of residential buildings. Journal of Building Engineering, 56, 104656. doi:https://doi.org/10.1016/j.jobe.2022.104656

Alfarawi, S., Omar, H., El-Sawi, A., & Al Jubori, A. (2022). Thermal Performance Assessment of External Wall Construction for Energy-Efficient Buildings. European Journal of Sustainable Development Research, 6, em0189. doi:10.21601/ejosdr/12039

Alkhalidi, A., Kiwan, S., & Hamasha, H. (2021). A Comparative Study between Jordanian Overall Heat Transfer Coefficient (U-Value) and International Building Codes, With Thermal Bridges Effect Investigation. Sustainable Development Research, 3, p10. doi:10.30560/sdr.v3n1p10

Ayed, R., Baddadi, S., Dellagi, A., Bouadila, S., & Lazâar, M. (2022). Thermal behavior improvement of building materials using expanded polystyrene.

Bienvenido-Huertas, D., Moyano, J., Rodríguez - Jiménez, C. E., & Marín, D. (2019). Applying an artificial neural network to assess thermal transmittance in walls by means of the thermometric method. Applied Energy, 233-234, 1-14. doi:https://doi.org/10.1016/j.apenergy.2018.10.052

Bienvenido-Huertas, D., Rubio-Bellido, C., Pérez-Ordóñez, J. L., & Moyano, J. (2019). Optimizing the evaluation of thermal transmittance with the thermometric method using multilayer perceptrons. Energy and Buildings, 198, 395-411. doi:https://doi.org/10.1016/j.enbuild.2019.06.040

Bond, D. E. M., Clark, W. W., & Kimber, M. (2013). Configuring wall layers for improved insulation performance. Applied Energy, 112, 235-245. doi:https://doi.org/10.1016/j.apenergy.2013.06.024

De Angelis, E., & Serra, E. (2013). Light Steel-frame Walls: Thermal Insulation Performances and Thermal Bridges (Vol. 45).

del Coz-Díaz, J. J., Álvarez-Rabanal, F. P., Alonso-Martínez, M., & Martínez-Martínez, J. E. (2021). Thermal Inertia Characterization of Multilayer Lightweight Walls: Numerical Analysis and Experimental Validation. Applied Sciences, 11(11). doi:10.3390/app11115008

eskandari, H., Maddahi, M. H., & Khosrozad, B. (2017). Impacts of Building Insulation on Energy Consumption in Different Climates of Iran: A Cost Analysis. Iranian Journal of Energy, 20(3), 5-18. Retrieved from http://necjournals.ir/article-1-1069-en.html

Evangelisti, L., Scorza, A., De Lieto Vollaro, R., & Sciuto, S. (2022). Comparison between Heat Flow Meter (HFM) and Thermometric (THM) Method for Building Wall Thermal Characterization: Latest Advances and Critical Review. Sustainability, 14, 693. doi:10.3390/su14020693

Evola, G., Marletta, L., Marino, C., Nucara, A., Panzera, M., Pietrafesa, M., . . . Tronchin, L. (2020). Experimental measurement of thermal transmittance in reinforced concrete buildings.

Hosseini Rostami, S., Baharestani, S. H., Sheikhi, S., & Malekafzali, A. A. (2019). Study of Zero Carbon Buildings and Policy Principles in Residential Environment for Sustainable Development. International Journal of Urban Management and Energy Sustainability, 1(2), 81-88. doi:10.22034/ijumes.2017.18.12.024

Jamal, B., Boukendil, M., Abdelbaki, A., & Zrikem, Z. (2020). Numerical simulation of coupled heat transfer through double solid walls separated by an air layer. International Journal of Thermal Sciences, 156, 106461. doi:https://doi.org/10.1016/j.ijthermalsci.2020.106461

Kishore, R. A., Bianchi, M. V. A., Booten, C., Vidal, J., & Jackson, R. (2021). Enhancing building energy performance by effectively using phase change material and dynamic insulation in walls. Applied Energy, 283, 116306. doi:https://doi.org/10.1016/j.apenergy.2020.116306

Kumar, D., Alam, M., Zou, P. X. W., Sanjayan, J. G., & Memon, R. A. (2020). Comparative analysis of building insulation material properties and performance. Renewable and sustainable energy reviews, 131, 110038. doi:https://doi.org/10.1016/j.rser.2020.110038

Long, L., & Ye, H. (2016). The roles of thermal insulation and heat storage in the energy performance of the wall materials: A simulation study. Scientific Reports, 6. doi:10.1038/srep24181

Marushchak, U., & Pozniak, O. (2022). ANALYSIS OF WALL MATERIALS ACCORDING TO THERMAL PARAMETERS. Theory and Building Practice, 2022, 63-70. doi:10.23939/jtbp2022.01.063

Mikulica, K., & Labaj, M. (2016). Foam Concrete Gravity Wedges as a Thermal Insulation of Flat Roofs. Key Engineering Materials, 722, 331-336. doi:10.4028/www.scientific.net/KEM.722.331

*Karimi, M., Heidari, S., & Mofidi Shemirani, S. (2023). Investigating the Impact of Exterior Window Shutters on Indoor Climate Conditions in Humid and Temperate Climate. International Journal of Architecture and Urban Development, 13(3), 41-58. https://*doi.org/10.30495/ijaud.2023.22569

Mohammad, S., & Shea, A. (2013). Performance Evaluation of Modern Building Thermal Envelope Designs in the Semi-Arid Continental Climate of Tehran. Buildings, 3(4), 674-688. doi:10.3390/buildings3040674

Ramin, H., Hanafizadeh, P., & Behabadi, M. (2015). Determination of optimum insulation thickness in different wall orientations and location in Iran. Advances in Building Energy Research. doi:10.1080/17512549.2015.1079239

Rosti, B., Omidvar, A., & Monghasemi, N. (2019). Optimum position and distribution of insulation *layers for exterior walls of a building conditioned by earth-air heat exchanger. Applied Thermal Engineering, 163, 114362.* doi:https://doi.org/10.1016/j.applthermaleng.2019.114362

Rosti, B., Omidvar, A., & Monghasemi, N. (2020). Optimal insulation thickness of common classic and modern exterior walls in different climate zones of Iran. Journal of Building Engineering, 27, 100954. doi:https://doi.org/10.1016/j.jobe.2019.100954

Schiavoni, S., D'Alessandro, F., Bianchi, F., & Asdrubali, F. (2016). Insulation materials for the building sector: A review and comparative analysis. Renewable and sustainable energy reviews, 62, 988-1011. doi:https://doi.org/10.1016/j.rser.2016.05.045

Soares, N., Martins, C., Gonçalves, M., Santos, P., da Silva, L. S., & Costa, J. J. (2019). Laboratory and in-situ non-destructive methods to evaluate the thermal transmittance and behavior of walls, windows, and construction elements with innovative materials: A review. Energy and Buildings, 182, 88-110. doi:https://doi.org/10.1016/j.enbuild.2018.10.021

Suvalov, M., Lomp, S., & Kalamees, T. (2023). Basic solutions for the renovation of lightweight brick walls of Estonian detached houses.

Teni, M., Krstić, H., & Kosiński, P. (2019). Review and comparison of current experimental approaches for in-situ measurements of building walls thermal transmittance. Energy and Buildings, 203, 109417. doi:https://doi.org/10.1016/j.enbuild.2019.109417

Yuan, J. (2018). Impact of Insulation Type and Thickness on the Dynamic Thermal Characteristics of an External Wall Structure. Sustainability, 10, 2835. doi:10.3390/su10082835

Zerroug, A., & Dzelzitis, E. (2019). Analysis of different building exterior walls insulations using eQUEST. E3S Web of Conferences, 111, 06032. doi:10.1051/e3sconf/201911106032

HOW TO CITE THIS ARTICLE

Hassani, A., & Khoshbakht Bahramani, S. (2024). Optimizing Building Wall Heat Transfer in Tehran Local Buildings with an Approach to Thermal Transmittance Quantity Calculation. International Journal of Urban Management and Energy Sustainability, (), -.

DOI: 10.22034/ijumes.2024.2035333.1233