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Research Article

Residential building thermal transmittance simulation-based analysis in Tehran city with an approach to assess wall insulation

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ABSTRACT

The article deals with the study related to thermal insulation of building walls in Tehran through energy consumption reduction, aiming to contribute to sustainability of the urban environment. In Iran, more than 40% of total energy consumption is related to the construction and housing sector, so optimization of the building thermal performance has a high relevance.

Insulation materials are increasingly being used in Tehran; however, there is still a lack of a comprehensive quantitative framework embracing local materials and building typology. In this regard, the equivalent of ten different insulation configurations has been simulated for thermal performance using Design Builder software in order to study their respective effects on energy efficiency. Each configuration includes variations in insulation types and thicknesses.

The results highlight that insulation materials, including polyurethane, fiberglass board, and mineral wool, are excellent thermal performance enhancers, while the high level is normally achieved by growing the heat balance. Besides, finding the optimal range of insulation thickness-2-6 cm-provides practically the maximum energy economy.

This quantitative framework will help architects and designers make informed choices about appropriate wall insulation materials in Tehran's buildings. The novelty of the present research is that, for the first time, such a study will focus on the specific climatic condition of Tehran and its local construction practice. These findings have broader implications for further research and urban planning, since this laid framework may be applied to the multiple Iranian cities with diverse climate zones, hence guiding sustainable building designs throughout the nation.

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INTRODUCTION

Thermal insulation of a building wall is crucial for reducing the loss of thermal energy in buildings. According to an investigation published in Case Studies in Thermal Engineering journal, Energy is one of the major challenge faced by mankind. Buildings consume approximately one-third of the total national energy in China, including energy consumption in transport, industries, appliances, buildings and so on, so the reduction of building energy consumption

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is paramount for sustainability [1, 2]. Building energy usage is a significant issue in numerous countries and cities. Tehran, Iran's capital, is encountering this issue in a comparable manner. As the investigation entitled" Thermal analysis model of a building equipped with a green roof and its energy optimization", The construction and housing sector uses more than 40% of energy in Iran [3]. Neglecting this issue in Tehran, the capital city of Iran, could lead to negative consequences for energy usage, ultimately resulting in significant heat loss in urban buildings.

Although Tehran uses thermal insulation to varying degrees, research on the types of insulation materials used indicates that there is no clear framework that illustrates the range of thermal insulation options for walls. In addition, the lack of a quantitative framework for wall insulation materials can negatively affect the architectural design of buildings in Tehran, and they do not have access to a suitable reference that specified insulation materials quantitatively. In accordance with this issue, there is a research gap in the field of quantitative study of these insulations and their effectiveness in Tehran. Architects and building designers have paid little attention to this issue throughout the design process because of their low efficiency and limited quantity.

To address this problem, future research should develop a quantitative framework for thermal insulation materials for building walls based on Tehran's building wall design typology and thermal insulation materials that are readily available in the Iranian market. The research findings and the quantitative framework that were developed would allow Tehran architects and building designers to carefully consider the type of wall thermal insulation materials when designing buildings. The research framework presents the innovative method of insulation materials quantitative analysis.

LITERATURE REVIEW

Building Thermal Transmittance

The assessment of energy efficiency of heating and wall layers is considered as important component to energy efficiency in the building context. This area has been considered in prior literature and included aspects of insulation thickness, thermal mass, and heat transfer coefficients. The literature review also provided a considerable body of literature on insulation layer thickness optimization in regard to evaluating indicators of thermal resistance [4]. This comprised published research on insulating layers alongside assessing the dynamically assessed heat-transfer properties of proposed insulating layer characteristics [5]. An optimization characterization of the thermal insulation-layer characteristics of the building envelope exterior-wall systems was also discussed to account for a life-cycle economic assessment [6]. Experimental research has been conducted to analyze the heat flows through ventilated wall systems with different types of heat-conductive connectors [7]. Using vacuum insulation panels (VIP) was investigated to reduce heat energy loss through walls by lowering the thermal transmittance of lightweight steel frame (LSF) wall systems [8]. Cardboard was also assessed as an environment-friendly wall thermal insulation for low-energy prefabricated buildings [9]. The External Thermal Insulation Composite System (ETICS) is a common passive strategy to obtain energy savings in existing buildings, and its thermal performance decay has been evaluated through laboratory tests [10]. Filling the empty air cavity between two layers of building materials with insulation can also reduce energy loss through opaque envelope surfaces [11]. The research entitled "Climate change and ideal thermal transmittance of residential buildings in Iran" aimed to determine the degree to which the thermo-physical parameters of building envelope materials must be altered in order to maintain their ideal thermal performance during climate change. In this regard, optimal thermal transmittances (U-values) of residential building envelopes for both present and future climate scenarios were calculated, and compared. As a result, the investigation concluded that future ideal U-values in the central and northern regions will be either higher or lower than current values. For areas of high cooling demand, future U-values are likely to be less than ideal U-values, and with the possibility of being the least possible [12]. In another investigation conducted in 2021, the objective of this research was to ascertain the thermal transmittance of external walls for single-family homes and to establish the optimal thickness of thermal insulation using energy simulation to maintain heating energy consumption under climate change conditions while complying with state regulations in the Los Ríos region of Chile. It was demonstrated that for each time period and in each geographical location of the region, the optimal U-value of the external walls is different [13].

Significance of Layer Optimization in Wall Construction

Building wall layer optimization attempts to determine the optimal combination of insulation thickness and position to enhance the thermal performance of building walls [14]. In an investigation, the wall layer optimization process aims to minimize the total cost while considering the insulation thickness, AC load, and energy consumption cost [15]. The best overall performance was achieved by a wall with three layers of insulation, each 26 mm thick, placed inside, middle, and outside, followed closely by a wall with two insulation layers, each 39 mm thick, placed in the middle and outside [6, 14]. In another study conducted in 2011, insulation layer optimization was analyzed in the Riyadh climate zone, and the researcher wanted to determine the effect of one, two, or three layers of insulation in various locations. The findings demonstrate that the ideal thickness of an insulating layer is independent of where it is placed within the wall and that, in the case of many layers, the total optimum thickness of those layers is equal to the optimum thickness of a single layer [14]. In another article, which was based on Iran's different climate zones, it was strongly advised to maximize the insulation thickness of the walls. The yearly heating and cooling loads of a modeled building in Iran's climate zones were computed using numerical analyses, with insulation materials of varying thermal conductivities and costs were used as external wall layers. According to the results, ranged from 0.79 to 11.39 cm, with glass wool identified as the best insulation for overall cost reduction [16]. The research entitled "Investigation of the wall's optimum insulation position from a maximum time lag and minimum decrement factor point of view" concentrated on the wall insulation layer position to maximize heat conduction time lag, and four-centimeter-thick insulation was placed in different positions on a 20-cm-thick wall. As part of the research conclusion, significant time lags and minimal decrement factors occur when half the insulation is placed on the outer surface of the wall and the other half in its mid-center plane [17].

Thermal Analysis through Simulation Models

Thermal simulation of building walls is a key aspect of building design and energy efficiency [18]. Several studies have been published related to modeling the thermal performance of a building wall, especially in the context of historical or multilayer wall for retrofit scenarios. While a study that investigated the heat transfer process has a similar aim in supporting building retrofits and decreasing energy consumption [19]. The worth of the data obtained through the study include its contribution of long-term data monitoring regarding long-term process and numeric simulations, and the insight of applying numerous wall materials and properties to model the thermal behavior of building walls [20].

As a standard process, the work of evaluating and interpreting monitoring data for building wall thermal simulation is made more robust by integrating long-term monitoring data with numerical simulations. Each of the following tasks are typical for long-term thermal assessment of building wall systems:

- **Long-term monitoring**: A monitoring system is implemented to perform long-term assessment of the thermal performance of the building wall.
- **Numerical Simulation**: Based on the established methodology, numerical modeling software is used to formulate a numerical model at the component level of the wall system. That is run simulations of material types that are identified in the in the database, and the simulation data is reviewed to select the most effective materials to minimize the differences between the simulated data and monitored data.
- **Optimization**: In this step, the materials that were selected are used to produce the first optimized simulation.
- **Assessment**: Assess reliability and robustness of the numerical simulations with a data comparison of the monitored data and numerical simulated data.
- **Interpretation**: Evaluate the simulations' results based on the monitored data to assess the thermal performance of the component wall system, to aid decision making for energy efficiency target calculations and comfort of use measures [20].

There are many simulation methods to assess the thermal transmittance of the walls of buildings. These methods include experimental, numerical, and analytical methods. Research that the present study has conducted included the following:

- Research presented a new and simple way to assess the wall thermal transmittance, focusing on assessing its feasibility. This study has used simulation and experimental methods [21].
- Research compared the thermal transmittances of lightweight steel-framed wall systems, using both experimental and numerical methods. This study compared thermal variances through the thermal conductivity of distinct components of lightweight steel-framed wall systems using a more complex geometric properties in its evaluation [22].
- Research conducted an overview and comparison of six analytical methods used to determine the thermal transmittance of lightweight steel-framed wall systems. The review consisted of careful analysis of the estimation methodology along with a comparison of the accuracy of each analytical method [23].

Literature Critical Analysis

To summarize the reviewed studies, in the first point, the impact of insulation layer placement on the dynamic heat transfer of building walls was investigated with an emphasis on the optimization of insulation thickness. Economic evaluations guided the consideration of thermal insulation properties, with a particular focus on vacuum insulation panels (VIPs) and external thermal insulation composite systems (ETICS) for limiting heat loss. Another option is to fill the air cavities with insulation. From another perspective, filling air cavities with insulation materials is also recognized as an effective strategy. Wall layer optimization involves determining the optimal combination of insulation thickness and layer placement while considering total cost and energy consumption. From another perspective, the performance of one, two, or three layers of insulation was analyzed. In Iran's climate zones, numerical investigations have determined ideal insulation thickness and material. One study focused on maximizing heat conduction time lag by positioning insulation layers and concluded that placing insulation outside and the mid-center of the wall resulted in significant time lags and minimal decrement factors.

Based on the reviewed investigations, there is a lack of specific focus on the Iranian context, particularly considering its unique climate conditions and building practices. The multi-climatic nature of Iran significantly influences the extent of thermal energy loss in buildings across different regions. While various regions require analysis, conducting this research for Tehran, the high-density capital, is particularly necessary. Second, economic evaluation of thermal insulation analysis relies on regional data, potentially overlooking localized factors that influence cost-effectiveness in Iran. Therefore, this research seeks to provide a quantitative framework based on the design typology of buildings in Tehran and the local thermal insulation materials as a tool for architects in Tehran enabling them to use this framework to design buildings based on numerical data and address the lack of such a practical tool.

MATERIALS AND METHODS

According to the research title, it is important to have a comprehensive method that covers all aspects of building wall thermal transmittance and heat consumption. Therefore, a simulation-based approach using Design Builder software is considered. This section describes the key steps of the methodology.

Design Builder was chosen as the simulation software for this study because of its capabilities control in assessing the thermal performance of building walls in different environments. In this investigation, Tehran's climatic conditions will be considered. The ability to conduct a detailed examination of different building insulation and layering configurations is unique. The selected versions - Design Builder version 6.10.006 and Energy Plus version 8.9 - formed the basis for modeling and energy simulation in this study. According to Design Builder website, easy-to-use tools allow for the comparison of different design options, identification of the best solutions and high-quality reports, and rendering of graphics to help communicate results to project stakeholders in an easily understandable way.

Methodology Steps Description

- **Building modeling**: the first phase involves two dimensions building modeling using the engineering drawing software Autodesk AutoCAD version 2020. After that, three-dimensional modeling was conducted using Design Builder. Figures 1-2 show a 2D model, and Figure 3 shows the 3D model. In the next part, each part of the plan was defined as a specific zone, as is apparent in Figure 1 coloring, and Table 1 expresses them separately. It is considerable that Zone 1 (Figs. 4 - 5) is considered the main part of the simulation process in this investigation.
- **Material property assignment**: According to the aforementioned case study, the simulation process is

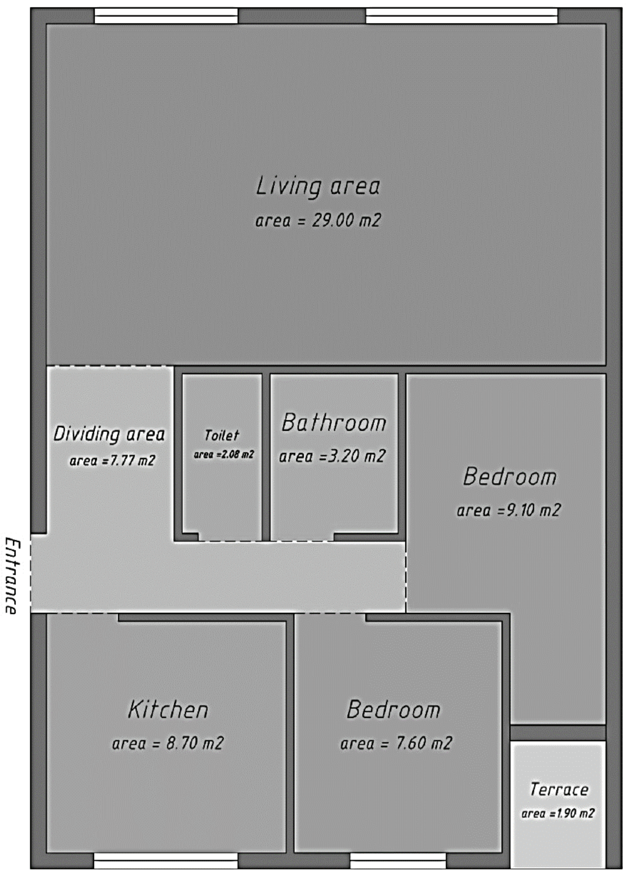


Figure 1. Building plan zoning.

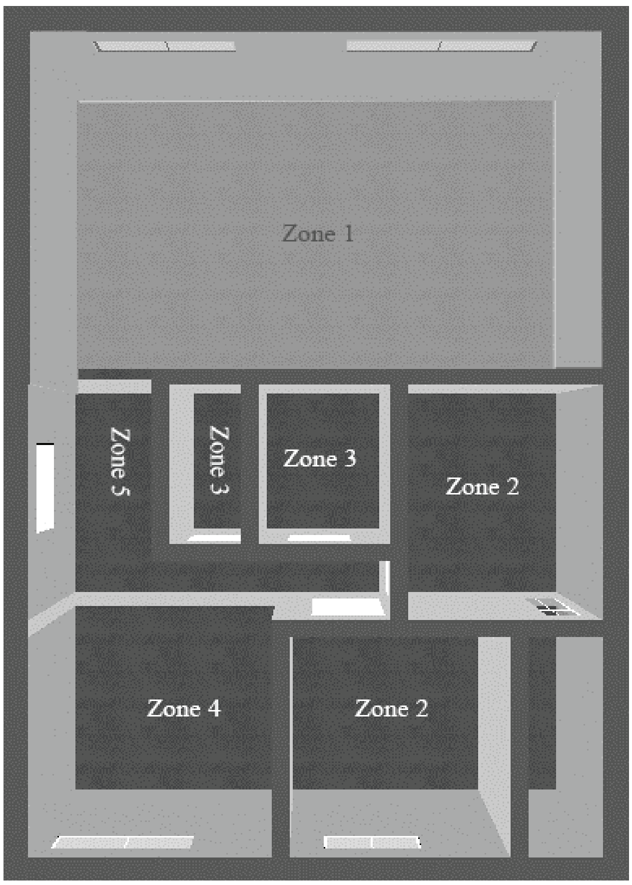


Figure 2. Building plan 2d model zoning.

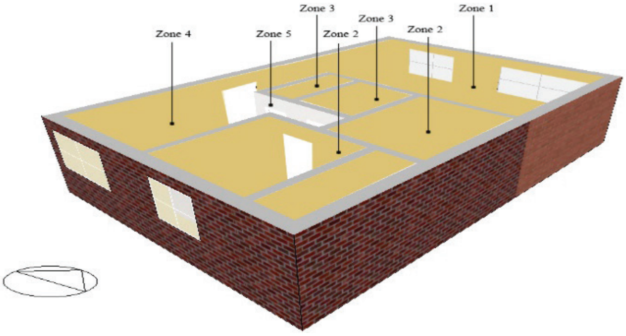


Figure 3. Building 3d model zoning.

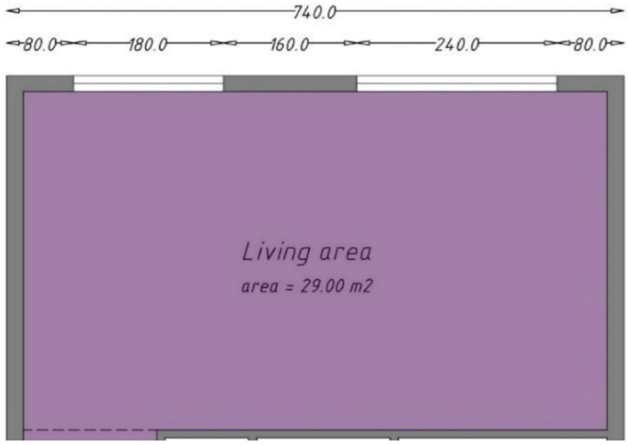


Figure 4. Zone 1 plan.

Table 1. Plan spaces zoning

Num.	Space in plan	Zone
1	Living area	1
2	Bedroom	2
3	Bathroom – Toilet	3
4	Kitchen	4
5	Dividing area	5

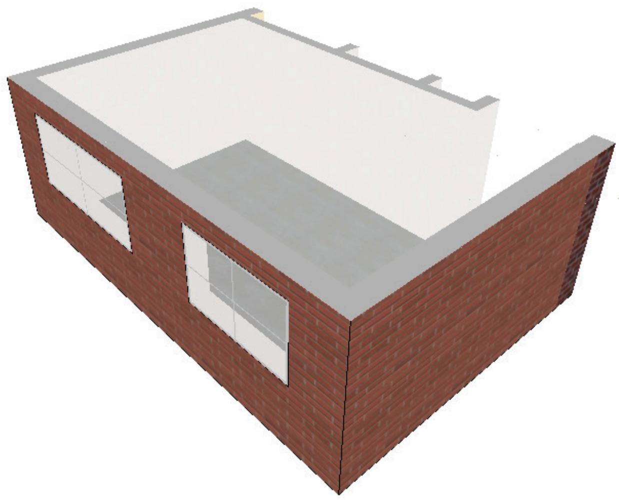


Figure 5. Zone 1 3d model.

conducted on ten types of building wall layer configurations in one of the most commonly used types of walls in Tehran construction, which the insulation layer and its thicknesses are changed. So they named ten types of walls (wall types 1-10) in accordance with the insulation changes. The specific category in this section (ten wall types) was determined based on the Tehran materials market. The layer thickness and specific thermal properties of materials, such as R-value and U-value, will be assigned based on standard values and manufacturer specifications for each wall type. It is considerable that the R-value and U-value are determined in Design Builder automatically in accordance with defined wall layering and Iran's national building regulations. Table 2 lists the properties of all the wall layers, that were simulated in this study. Figure 6 indicates the typical wall which is used in the simulation process.

- **Climate zone selection**: Simulations were conducted for Tehran's climatic situation, considering specific temperatures, humidity, and solar radiation. Table 3 and 4 present the aforementioned details, which are written based on the Design Builder software. In accordance with previous research, Tehran is located in the south of the Alborz Mountain Range and in the north of the Iran central dessert. Tehran (from 35° 35′ to 35° 55′ N, and from 51° 04′ to 51° 32′ E) is warm and dry in summer, and cold and humid in winter. The north and north-east of Tehran are surrounded by the Alborz Mountain Chain [25].
- **Insulation layer configuration**: Several simulations were conducted with different insulation layer configurations. This included variations of type, thickness, and placement of insulation materials in the wall construction. All of the insulation layers and thickness can be observed in Table 2.
- **Optimization process**: With the layer configuration (insulation layer) established and simulation reports available, an optimization process was initiated to · provide the most beneficial combination of insulation layer(s) to achieve the best thermal performance improvement.

RESULTS AND DISCUSSION

Optimized Wall Simulation: 2 cm Insulation

According to wall layer optimization, a simulation was conducted ten times based on the ten insulation layer optimizations in Figure 7. Figures 8 to 18 present the simulation results of the optimization. There are eight outputs and

Table 2. Wall Types Layering

	Material	Thickness (m)	R-Value (m^2-K/W)	U-Value (W/m^2-K)
Wall type 1	Façade brick	0.05	1.439	0.695
	Cement mortar	0.03		
	Cement wall block	0.15		
	Insulation – Polystyrene - HFC	0.02		
	Gypsum board	0.015		
Wall type 2	Façade brick	0.05	1.361	0.735
	Cement mortar	0.03		
	Cement wall block	0.15		
	Insulation - Polystyrene – CO2	0.02		
	Gypsum board	0.015		
Wall type 3	Façade brick	0.05	1.114	0.897
	Cement mortar	0.03		
	Cement wall block	0.15		
	Insulation – Polyvinyl Chloride	0.02		
	Gypsum board	0.015		
Wall type 4	Façade brick	0.05	1.237	0.808
	Cement mortar	0.03		
	Cement wall block	0.15		
	Insulation – Mineral Fiberglass	0.02		
	Gypsum board	0.015		
Wall type 5	Façade brick	0.05	1.344	0.744
	Cement mortar	0.03		
	Cement wall block	0.15		
	Insulation - Fiberglass	0.02		
	Gypsum board	0.015		
Wall type 6	Façade brick	0.05	1.378	0.726
	Cement mortar	0.03		
	Cement wall block	0.15		
	Insulation – Rock wool	0.02		
	Gypsum board	0.015		
Wall type 7	Façade brick	0.05	1.132	0.883
	Cement mortar	0.03		
	Cement wall block	0.15		
	Insulation - Silicon	0.02		
	Gypsum board	0.015		
Wall type 8	Façade brick	0.05	1.328	0.753
	Cement mortar	0.03		
	Cement wall block	0.15		
	Insulation – Fiberglass board	0.02		
	Gypsum board	0.015		
Wall type 9	Façade brick	0.05	1.248	0.801
	Cement mortar	0.03		
	Cement wall block	0.15		
	Insulation – Polyurethane foam	0.02		
	Gypsum board	0.015		
Wall type 10	Façade brick	0.05	1.028	0.972
	Cement mortar	0.03		
	Cement wall block	0.15		
	Insulation – Wood wool	0.02		
	Gypsum board	0.015		

Table 3. Activity, area, volume, and environmental properties

1. Activity Template	
Template	Domestic Lounge
Sector	Residential space
Zone type	Standard
Include zone in thermal calculation	+
Include zone in Radiance daylighting calculation	+
2. Floor Areas and Volumes	
Floor area (m^2)	25.63
Zone volume (m^3)	71.77
Inner surface mode	Deflation
3. Occupancy	
Occupancy density (people/m^2)	0.0188
Schedule	Dwell_DomLounge_Occ
3.1. Metabolic	
Activity	Eating/drinking
Factor (Men=1.00, Women=0.85, Children=0.75)	0.90
Co2 generation rate (m^3/s-W)	0.0000000382
3.2. Clothing	
Clothing schedule definition	3349
3.3. Comfort Radiant Temperature Weighting	
Calculation type	Zone average
4. Environmental Control	
4.1. Heating set point temperature	
Heating (°C)	21.00
Heating set back (°C)	12.00
4.2. Cooling set point temperature	
Cooling (°C)	25.00
Cooling set back (°C)	28.00
4.3. Humidity control	
RH Humidification set point (%)	10.00
RH Dehumidification set point (%)	90.00
4.4. Ventilation set point temperature	
Natural ventilation	
Indoor main temperature control	+
Min temperature definition	By value
Min temperature (°C)	24.00
Indoor max temperature control	-
4.5. Minimum fresh air	
Fresh air (l/s-person)	10.00
Mechanical ventilation per area (l/s-m^2)	0.00
4.6. Lighting	
Target Illuminance (lux)	150
Default display lighting density (W/m^2)	0.00
5. Computers	
On	-
6. Office equipment	
On	+
7. Miscellaneous	
On	-
8. Catering	
On	-
9. Process	
On	-

Table 4. Building construction properties

1.Construction template	
Template	Medium weight, moderate insulation
External wall	**Variable**
Below grade walls	Brick/brick wall (insulated to 1995 regs)
Flat roof	Flat roof U-value = 0.25 W/m^2K
Pitched roof (occupied)	Clay tiles (25mm) on air gap (20mm)
1.1. Semi-exposed	
Semi-exposed ceiling	Roofspace floor insulation 50mm
Semi-exposed floor	External floor-Energy code standard
1.2. Floors	
Ground floor	Ground floor slab
External floor	External floor
Internal floor	100mm concrete slab
1.3. Sub-surfaces	
Walls	100mm concrete slab
Internal	100mm concrete slab
Roof	100mm concrete slab
External door	Wooden door
1.4. Internal thermal mass	
Construction	100mm concrete slab
Exposed area (m^2)	0.00
1.5. Adjacency	
Adjacency	Auto
1.6. Surface convection	
Heating design	
Inside convection algorithm	6-TARP
Outside convection algorithm	6-DOE-2
Cooling design	
Inside convection algorithm	6-TARP
Outside convection algorithm	6-DOE-2
Simulation	
Inside convection algorithm	6-TARP
Outside convection algorithm	6-DOE-2
1.7. Linear thermal bridging at junctions	
Use Psi values	-

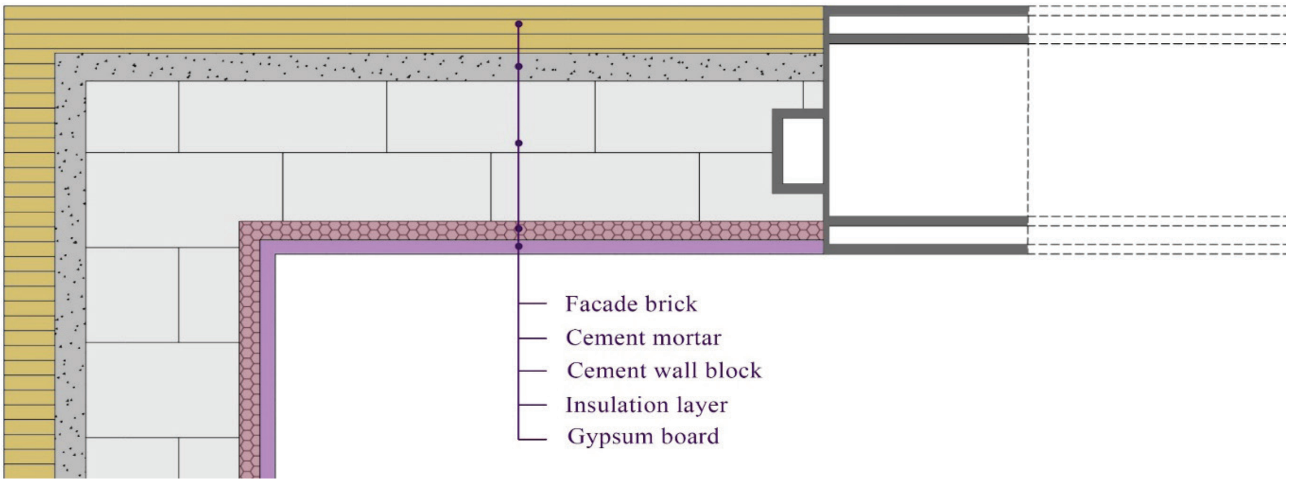


Figure 6. Typical wall detail.

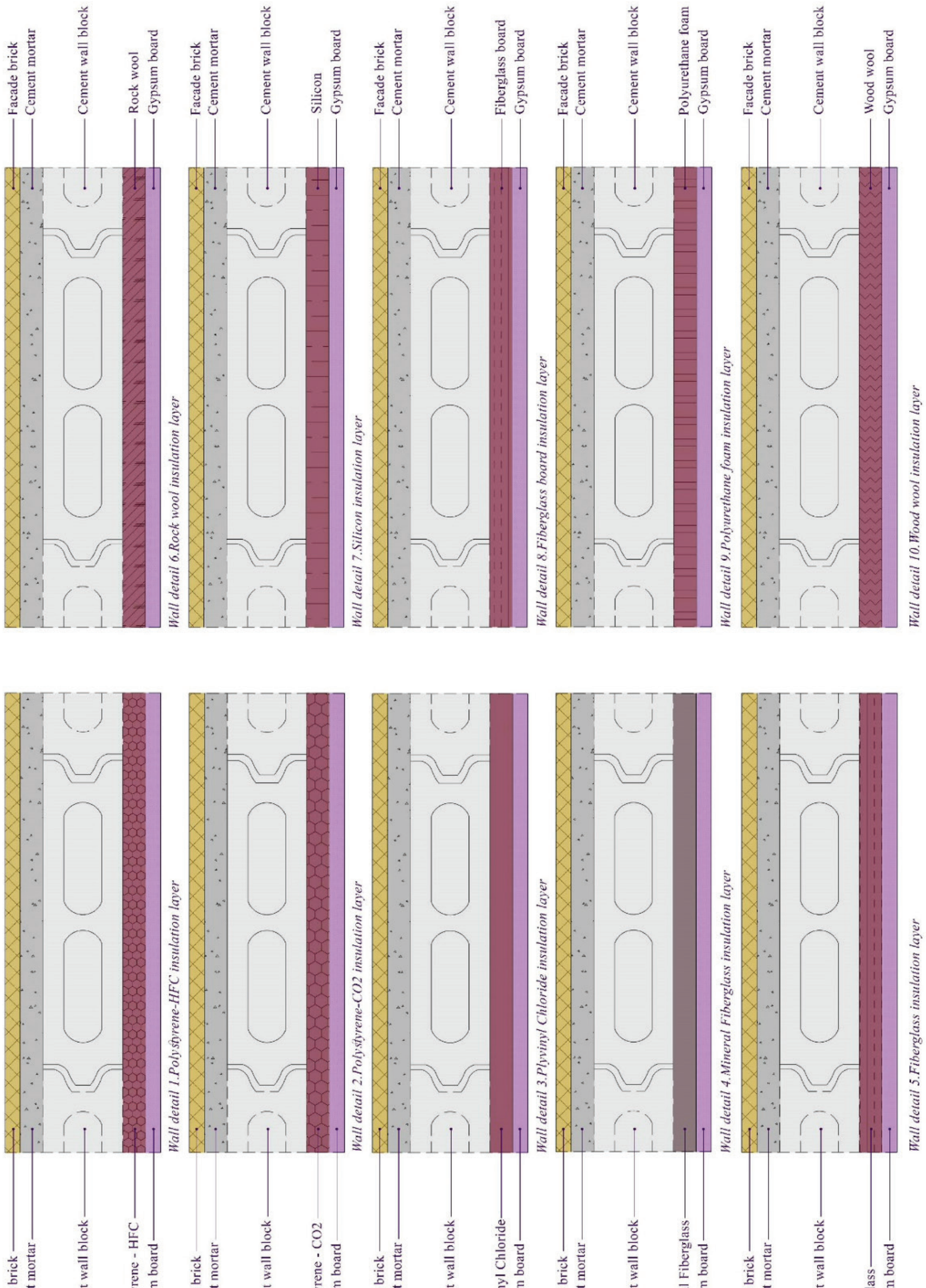


Figure 7. insulation wall layer optimization.

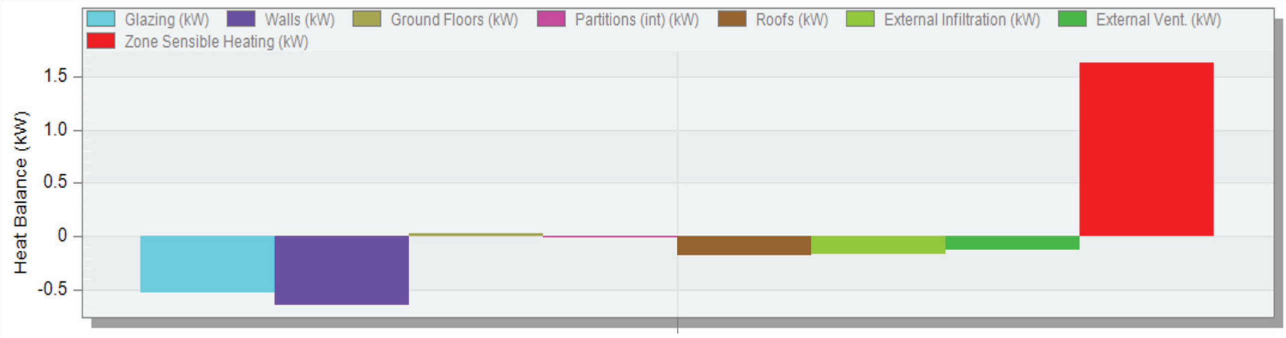


Figure 8. Wall 1 – polystyrene - HFC insulation simulation.

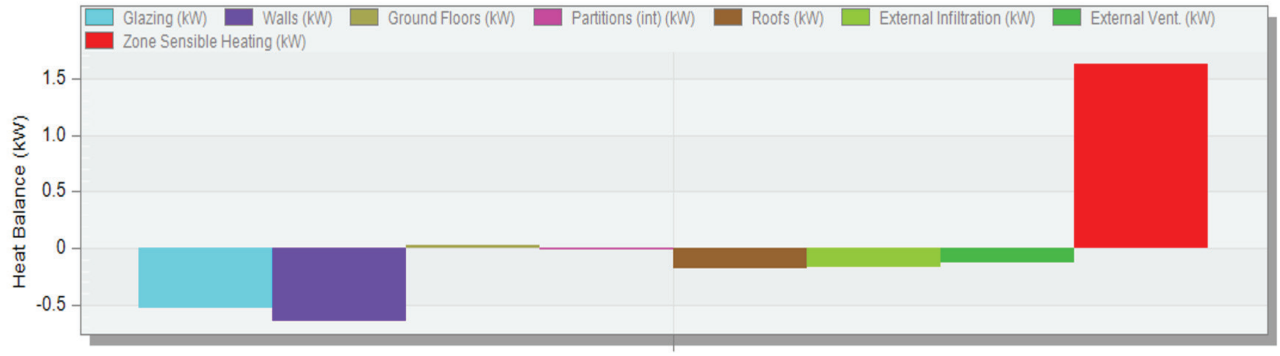


Figure 9. Wall 2 – polystyrene – CO2 insulation simulation.

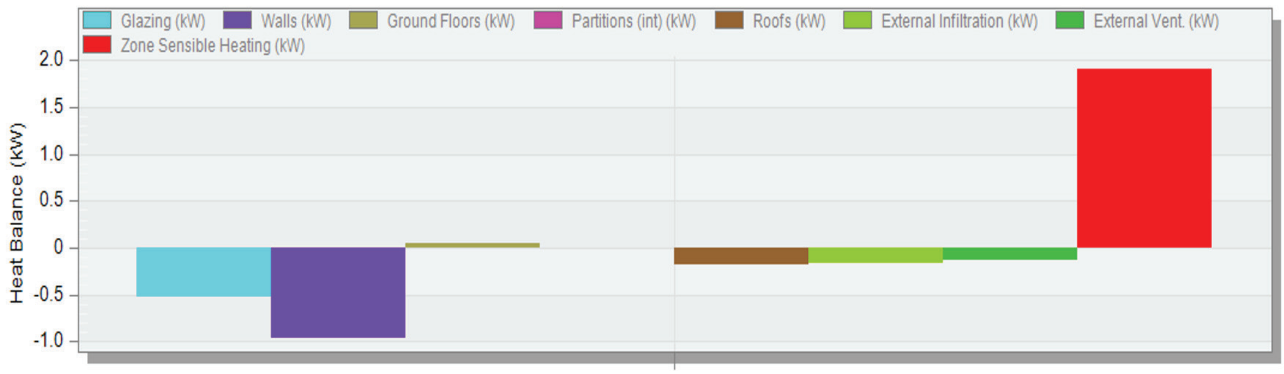


Figure 10. Wall 3 – poly vinyl chloride insulation simulation.

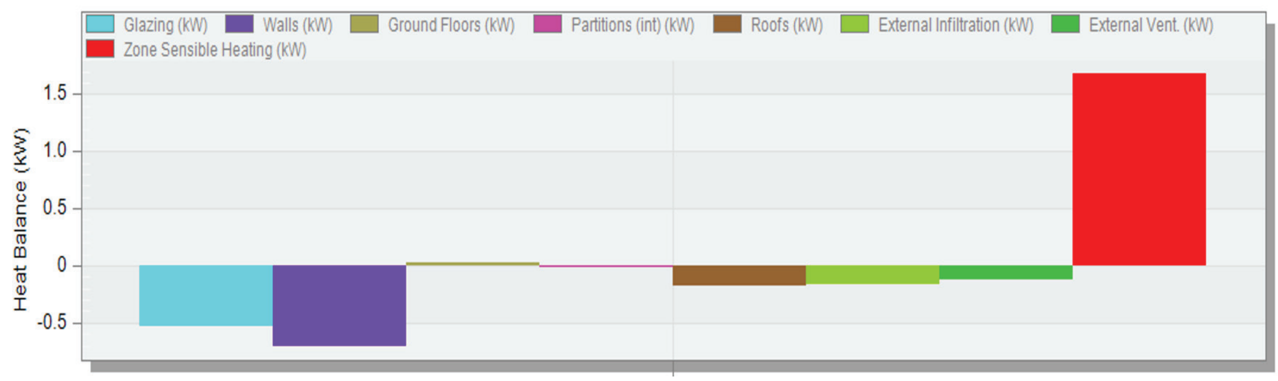


Figure 11. Wall 4 – mineral fiberglass insulation simulation.

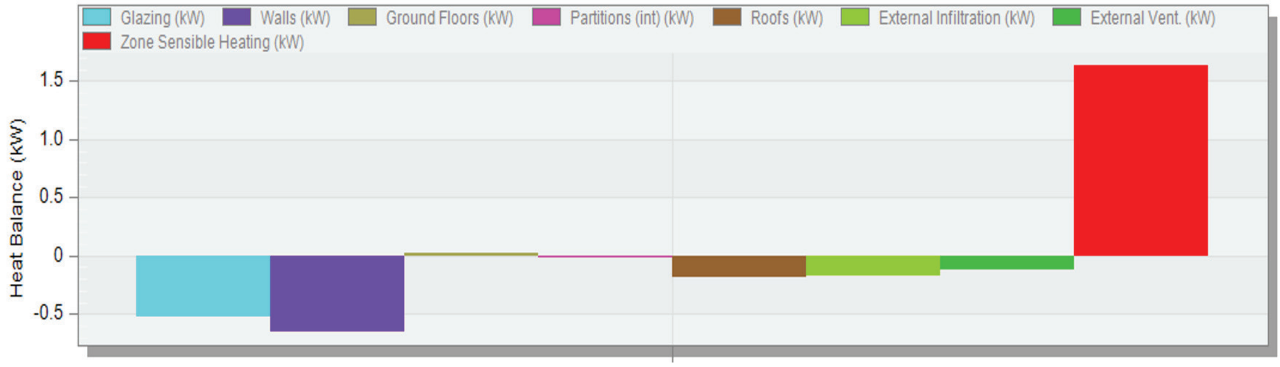


Figure 12. Wall 5 –fiberglass insulation simulation.

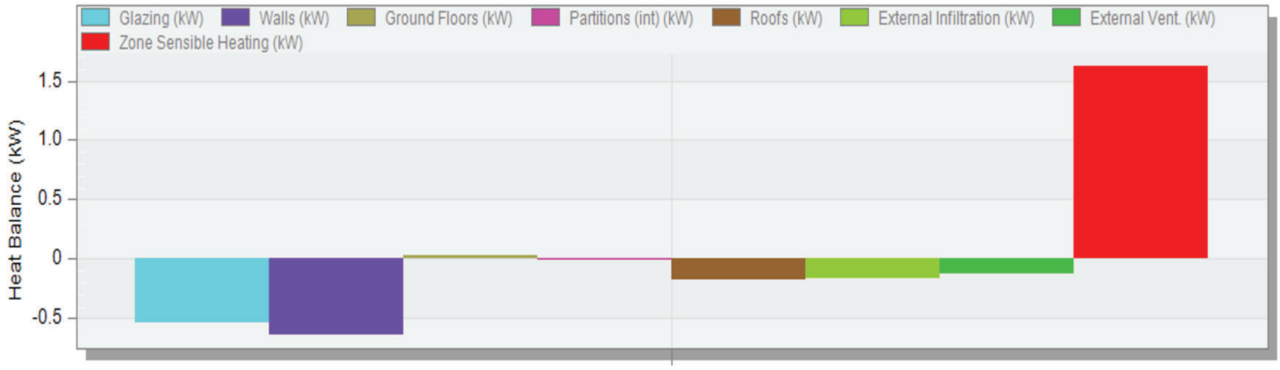


Figure 13. Wall 6 –rock wool insulation simulation.

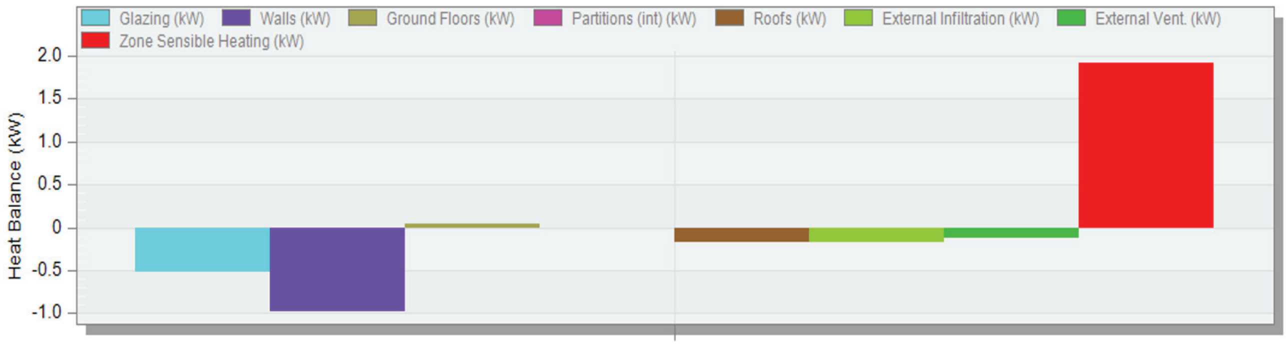


Figure 14. Wall 7 –silicon insulation simulation.

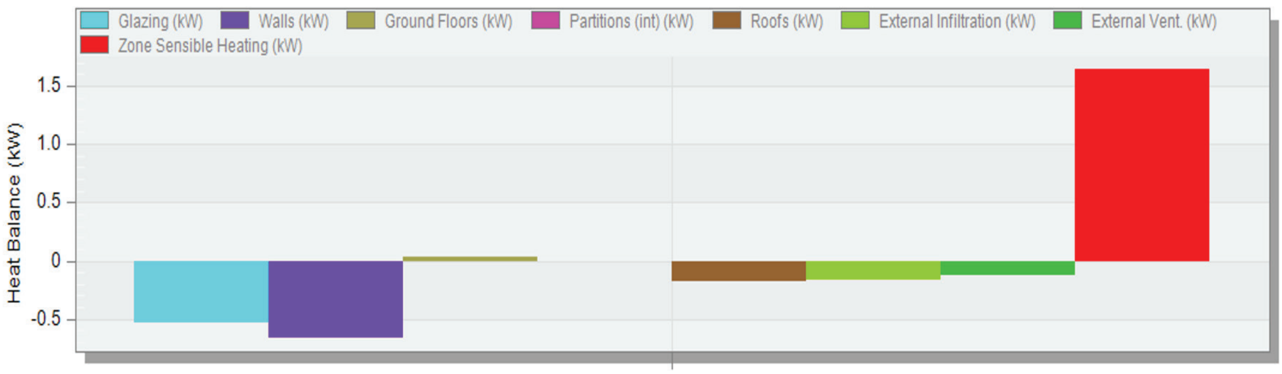


Figure 15. Wall 8 –fiberglass board insulation simulation.

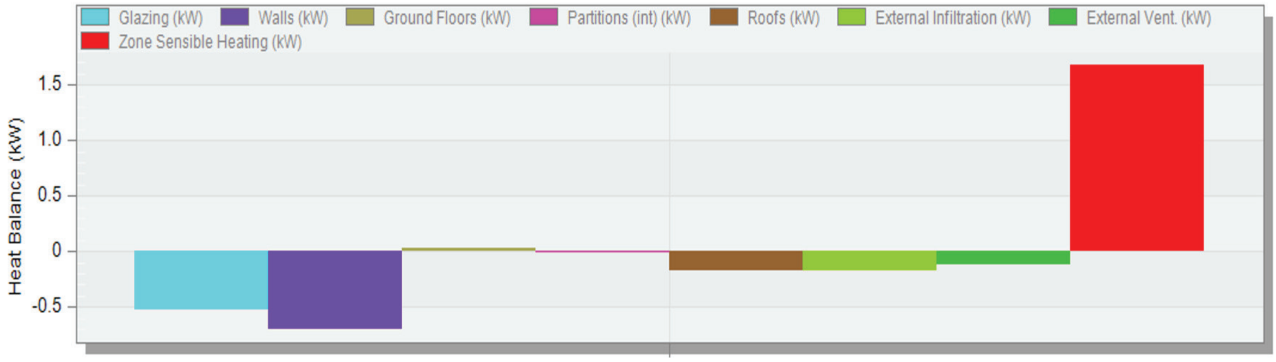


Figure 16. Wall 9 – Polyurethane insulation simulation.

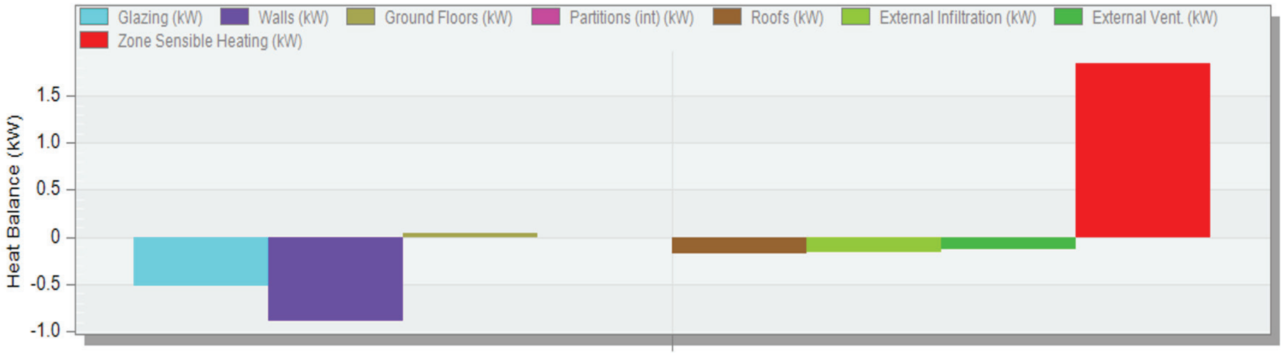


Figure 17. Wall 10 –wood wool insulation simulation.

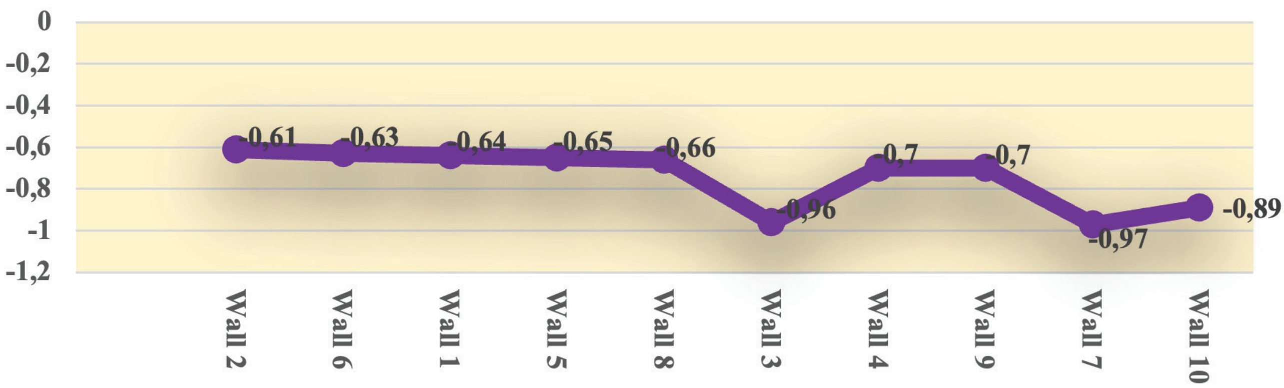


Figure 18. insulation wall layer optimization.

each Figure provides eight outputs: glazing, walls, ground floor, partitions, roofs, external infiltration, external ventilation, and zone sensible heating.

Figure 19 shows the wall heat balance of the simulation results. In accordance with the extracted quantity, the heat balance of wall 7 was the lowest among all wall layer optimizations. This indicates that fiberglass board is a weak insulation layer, as shown in Figure 16, with a heat balance of -0.97 kilowatts.

Wall 10 (Fig. 18). Insulated with wood wool. has a heat balance eight times better than that of a fiberglass board (-0.89 kilowatts).

Walls 3, 4, and 9 present the heat balance of polyvinyl chloride, mineral fiberglass, and polyurethane as insulation layers. As is obvious in Figures 11, 12, and 17, their heat balance quantities are the same (-0.70 kilowatts). Therefore, they conduct in a manner similar to thermal transmittance as wall insulation.

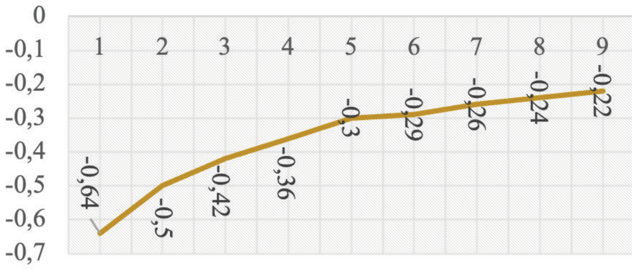


Figure 19. heat balance of polystyrene – HFC.

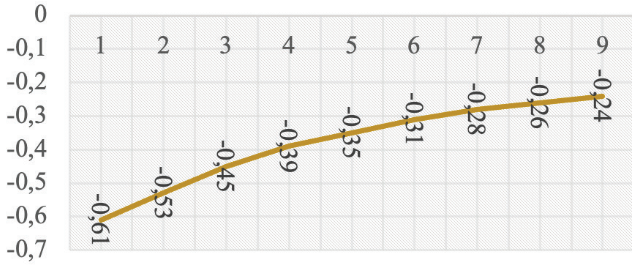


Figure 20. Heat balance of polystyrene – CO2.

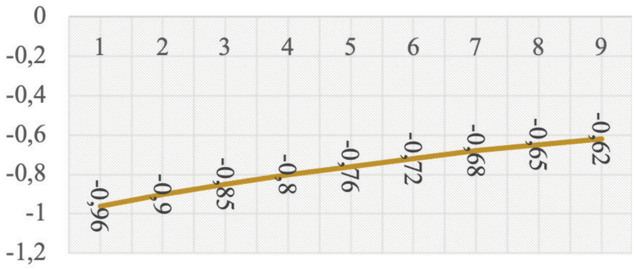


Figure 21. Heat balance of polyvinyl chloride.

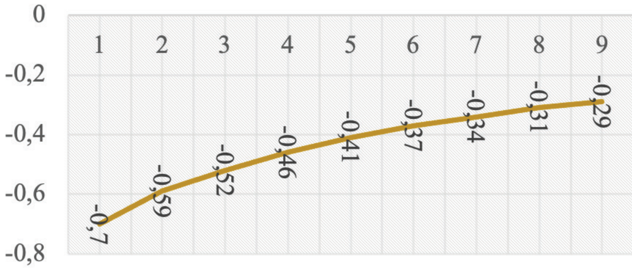


Figure 22. Heat balance of mineral fiberglass.

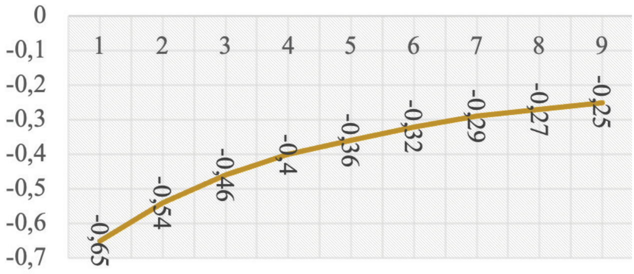


Figure 23. Heat balance of fiberglass.

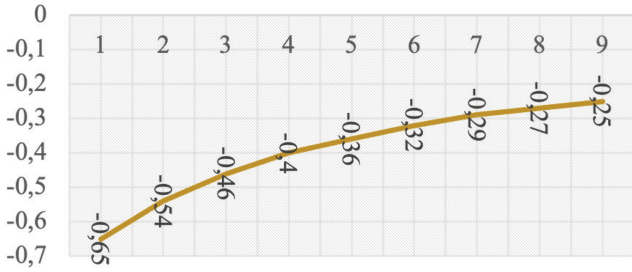


Figure 24. Heat balance of rock wool.

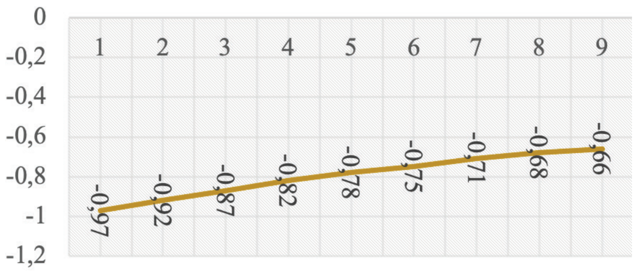


Figure 25. Heat balance of silicon.

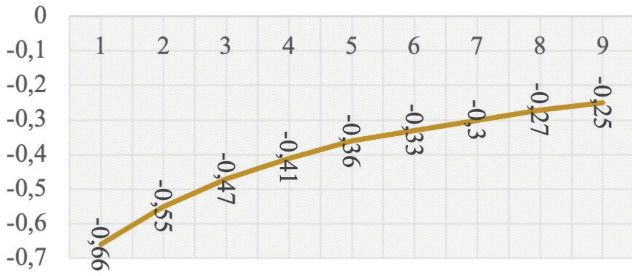


Figure 26. Heat balance of fiberglass board.

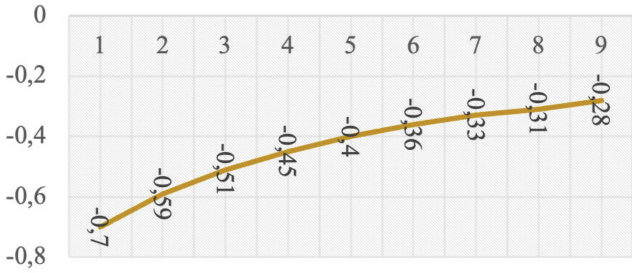


Figure 27. Heat balance of polyurethane foam.

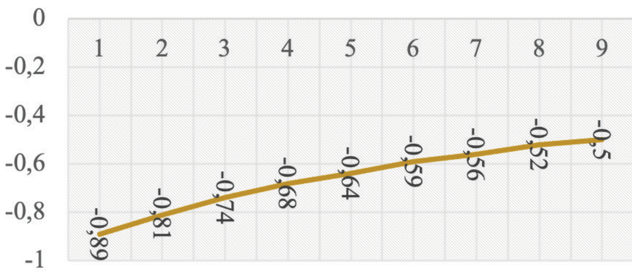


Figure 28. Heat balance of wood wool.

Walls 6, 1, 5, and 8 present the heat balance of rock wool, polystyrene, fiberglass, and fiberglass boards as insulation layers. The heat balance values are similar as shown in Figures 14, 9, 13, and 10.

Optimized Walls Simulation: Various Thickness Insulation

In this part, a change was made in the simulation condition. According to Figure 18, the result of the simulation using all ten types of thermal insulation indicated a negative heat balance.

According to Table 5, the simulation results of the selected wall type are specified for ten types of thermal insulation and three thicknesses. Thermal insulation with thicknesses of two, three, and four centimeters was investigated. The results regarding thermal insulation with a thickness of two centimeters are presented in Section 3.1, which are shown in Figures 9–18. In this section, the results of the wall simulation based on thermal insulation with thickness of three and four centimeters are specified. The key factor in the simulation results, expressed as heat balance, is detailed in Table 5 for each thermal insulation layer and its various thicknesses.

Wall heat balance factor

The meaning of heat balance involves the balance between incoming and outgoing heat to maintain a stable temperature and is explored in various contexts [24, 25]. This refers to the difference between the heat entering leaving a building's space.

According to the simulation result, walls are the intended output, which expresses the heat balance of the zone that has been analyzed (zone 1 of the case study). Wall heat balance quantity may express three concepts:

- If the wall heat balance is ≥ 0, the heat gains exceed the heat losses, indicating that the building receives more heat from sources like solar gain or internal heat generation than it loses through conduction, convection, and radiation.
- If the wall heat balance is 0, there is no heat loss or gain, indicating efficient thermal energy retention by the wall insulation.
- If the wall heat balance is less than or equal to zero, a negative heat balance indicates that the heat losses exceed the heat gains. More heat is lost than is gained in the building in this situation, which could lead to increased energy usage associated with heating and maintaining the temperature within a comfortable range.

According to Figures 9–18, The results of the simulation show that the heat balance in the specified wall of the space introduced in the case study is expressed as a negative value despite the use of various thermal insulations. It indicates that the quantity of heat transferred from the indoor to the outdoor is greater than the amount of heat transferred from the outdoor to the indoor. Therefore, the designed details and thermal insulation are not sufficient in the mentioned case. Since insulation layer thickness is a considerable factor in analyzing wall heat balance, the second part of the simulation was done with an approach to developing the heat balance value.

The optimal thickness of insulation layers in various applications, such as composite insulation for external walls and building construction, varies based on factors like climate, materials, and desired energy savings [26]. The research conducted in 2022, indicated that the optimal insulation thicknesses for various building materials across multiple thermal zones, ranged from 18.21 mm to 346.05 mm [27]. In this regard, changes in the thickness of the insulation layer were made in the simulation of the introduced model in order to achieve the optimal amount of thermal insulation. According to the way of implementing external walls in Tehran, the thickness of the thermal insulation layer was considered equal to 3 cm to 10 cm, and the simulation of the second series was conducted. Table 5 expresses the result of the simulation series. As is obvious, there are ten types of insulation in exterior wall types. In this table, the thermal balance factor has been determined for each of the walls.

The noteworthy point in these findings is the ratio between the thickness of the thermal insulation layer and the thermal balance value of each wall in the defined space. As it is obvious from Table 5, in the last column, there are bar diagrams that determine the relationship between increasing insulation layer thickness and heat balance in each wall type. For all ten wall types, the trend remains consistent. It means the heat balance value is expected to increase while the thickness of the insulation layer is being raised.

Comparison simulation analysis

As it is obvious in Figures 19–28, the heat balance quantity of ten wall insulation types is expressed based on the thickness. In regard to the increase in insulation layer thickness, heat balance quantity is developing. In another sense, the heat loss is reducing. The development value is different based on the type of insulation layer.

For instance, the change in heat balance in the wall with polyurethane foam as an insulation layer is 42 units (Fig. 28), which is the best insulation behavior. On the other hand, silicon is counted as a weak insulation layer as its change is 31 units (Fig. 26).

Rate of efficiency in insulation development

As is obvious, there is a direct relationship between an increase in insulation layer thickness and wall heat balance development. In another aspect, there is a considerable factor about the amount of heat balance based on the thickness increase. In another sense, the increase in heat balance is not equal to the thickness increase in any insulation layer.

For instance, in polystyrene (HFC), when the thickness increases from 2 cm to 10 cm, the heat balance value increases by 0.06, 0.08, 0.06, 0.06, 0.01, 0.03, 0.02, and 0.02. So it shows that the insulation thickness increase will

Table 5. Simulation report of heat balance in various thickness

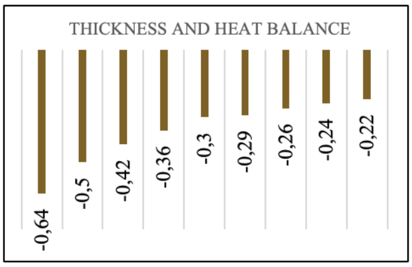
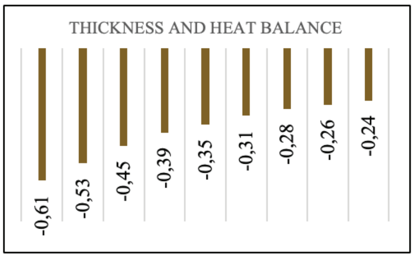
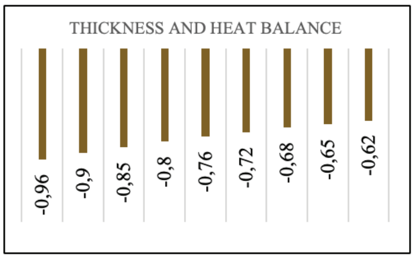
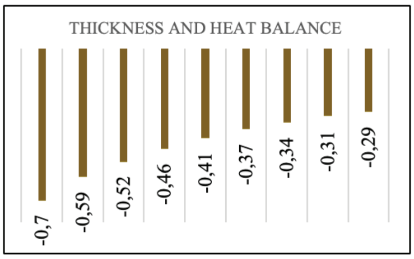
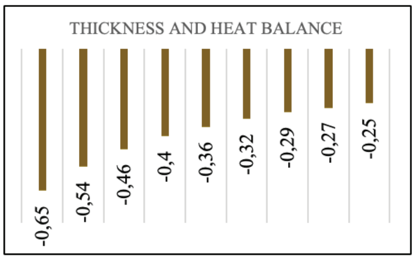
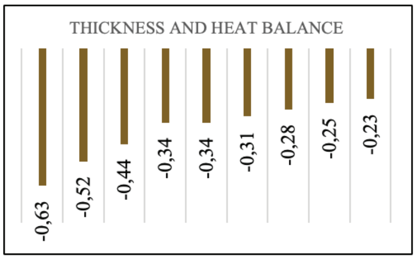
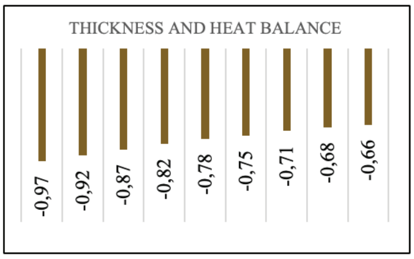
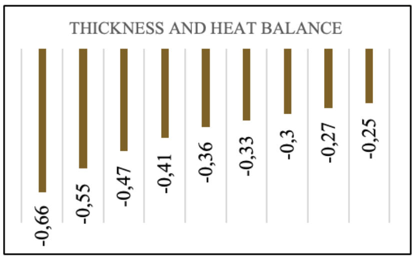
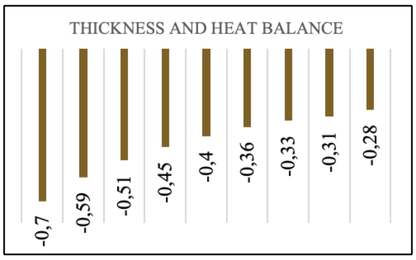
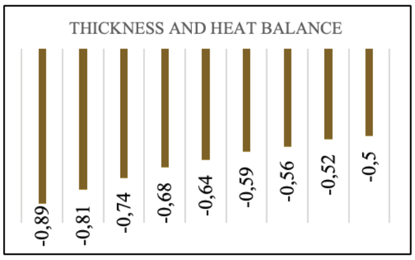
	Insulation	Thickness (m)	Heat balance (KW)	Change in Heat Balance (KW)	Thickness and Heat balance diagram
Wall type 1	Insulation – Polystyrene - HFC	0.02	-0.64		
		0.03	-0.50	+0.06	
		0.04	-0.42	+0.08	
		0.05	-0.36	+0.06	
		0.06	-0.30	+0.06	
		0.07	-0.29	+0.01	
		0.08	-0.26	+0.03	
		0.09	-0.24	+0.02	
		0.10	-0.22	+0.02	
Wall type 2	Insulation - Polystyrene – CO2	0.02	-0.61		
		0.03	-0.53	+0.08	
		0.04	-0.45	+0.08	
		0.05	-0.39	+0.06	
		0.06	-0.35	+0.04	
		0.07	-0.31	+0.04	
		0.08	-0.28	+0.03	
		0.09	-0.26	+0.02	
		0.10	-0.24	+0.02	
Wall type 3	Insulation – Polyvinyl Chloride	0.02	-0.96		
		0.03	-0.90	+0.06	
		0.04	-0.85	+0.05	
		0.05	-0.80	+0.05	
		0.06	-0.76	+0.04	
		0.07	-0.72	+0.04	
		0.08	-0.68	+0.04	
		0.09	-0.65	+0.03	
		0.10	-0.62	+0.03	
Wall type 4	Insulation – Mineral Fiberglass	0.02	-0.70		
		0.03	-0.59	+0.11	
		0.04	-0.52	+0.07	
		0.05	-0.46	+0.06	
		0.06	-0.41	+0.05	
		0.07	-0.37	+0.04	
		0.08	-0.34	+0.04	
		0.09	-0.31	+0.03	
		0.10	-0.29	+0.02	
Wall type 5	Insulation - Fiberglass	0.02	-0.65		
		0.03	-0.54	+0.11	
		0.04	-0.46	+0.08	
		0.05	-0.40	+0.06	
		0.06	-0.36	+0.04	
		0.07	-0.32	+0.04	
		0.08	-0.29	+0.03	
		0.09	-0.27	+0.02	
		0.10	-0.25	+0.02	

Table 5. Simulation report of heat balance in various thickness (counted)

	Insulation	Thickness (m)	Heat balance (KW)	Change in Heat Balance (KW)	Thickness and Heat balance diagram
Wall type 6	Insulation – Rock wool	0.02	-0.63		
		0.03	-0.52	+0.11	
		0.04	-0.44	+0.08	
		0.05	-0.34	+0.10	
		0.06	-0.34	+0.00	
		0.07	-0.31	+0.03	
		0.08	-0.28	+0.03	
		0.09	-0.25	+0.03	
		0.10	-0.23	+0.03	
Wall type 7	Insulation - Silicon	0.02	-0.97		
		0.03	-0.92	+0.05	
		0.04	-0.87	+0.05	
		0.05	-0.82	+0.05	
		0.06	-0.78	+0.04	
		0.07	-0.75	+0.03	
		0.08	-0.71	+0.04	
		0.09	-0.68	+0.03	
		0.10	-0.66	+0.02	
Wall type 8	Insulation – Fiberglass board	0.02	-0.66		
		0.03	-0.55	+0.11	
		0.04	-0.47	+0.08	
		0.05	-0.41	+0.06	
		0.06	-0.36	+0.05	
		0.07	-0.33	+0.03	
		0.08	-0.30	+0.03	
		0.09	-0.27	+0.03	
		0.10	-0.25	+0.02	
Wall type 9	Insulation – Polyurethane foam	0.02	-0.70		
		0.03	-0.59	+0.11	
		0.04	-0.51	+0.08	
		0.05	-0.45	+0.06	
		0.06	-0.40	+0.05	
		0.07	-0.36	+0.04	
		0.08	-0.33	+0.03	
		0.09	-0.31	+0.02	
		0.10	-0.28	+0.03	
Wall type 10	Insulation – Wood wool	0.02	-0.89		
		0.03	-0.81	+0.08	
		0.04	-0.74	+0.07	
		0.05	-0.68	+0.06	
		0.06	-0.64	+0.04	
		0.07	-0.59	+0.05	
		0.08	-0.56	+0.03	
		0.09	-0.52	+0.04	
		0.10	-0.50	+0.02	

be useful if it is defined within a limited range, and if the thickness increase happens outside of that range, it is not efficient. As it is clear, in Table 5, there is a column entitled "change in heat balance", and it expresses the numerical rate of heat balance development in relation to insulation layer thickness increase. In accordance with these numerical values, it would be possible to make a reasonable decision about the thickness of the insulation layer in the building wall to make efficiency achievable. As an economic aspect, it should be considered that the increase in insulation layer thickness is not reasonable except within specific limits.

Figures 29-38 express the improvement rate of the insulation value of each wall type, which is expressed in Table 5. In a general view, each Figure contains one matrix and a linear diagram. The matrix categorized insulation layer thickness and insulation layer improvement rate. The diagram presents the values of the matrix in two ranges. Range 1, which is colored purple, shows the suitable range of insulation improvement based on the layer thickness. In another sense, increasing the insulation layer thickness in range 1 is efficient. On the other hand, range 2, which is colored red, shows an unsuitable range of insulation improvement. In another sense, the increase in insulation layer thickness is not efficient in this range.

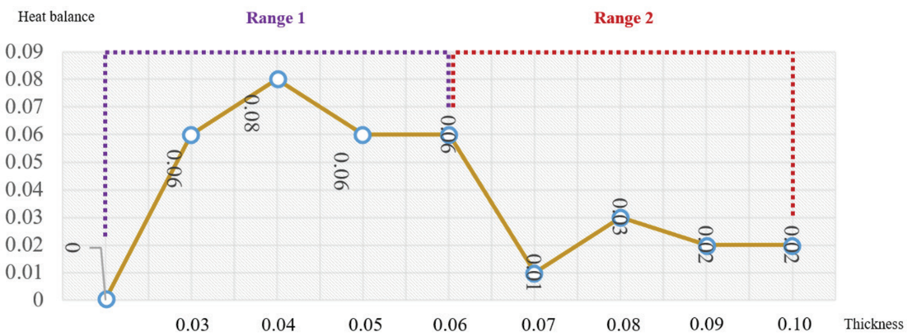


Figure 29. Polystyrene – HFC Figure ratio.

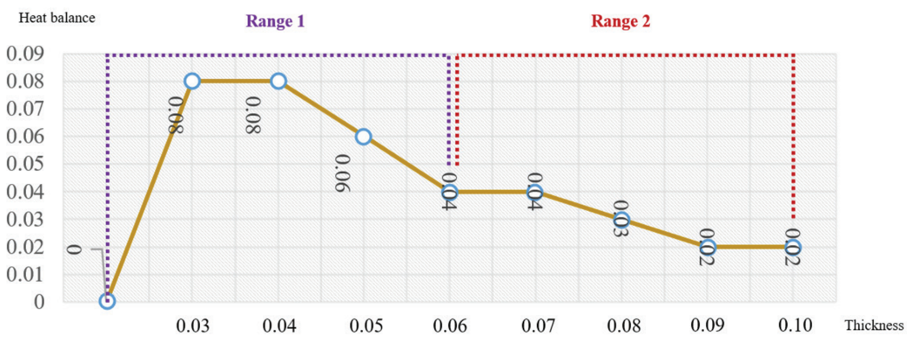


Figure 30. Polystyrene – CO2 Figure ratio.

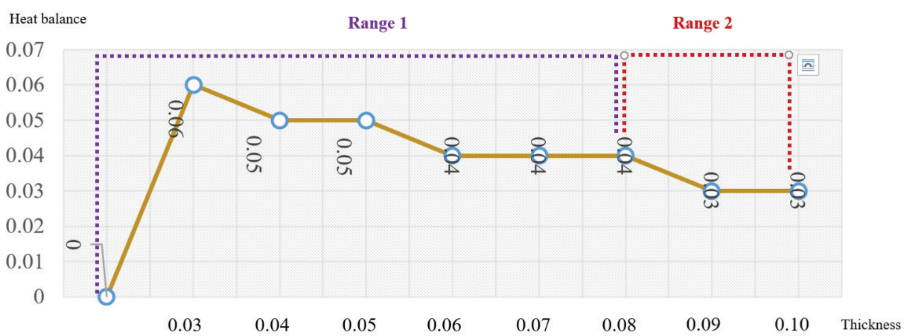


Figure 31. Polyvinyl Chloride Figure ratio.

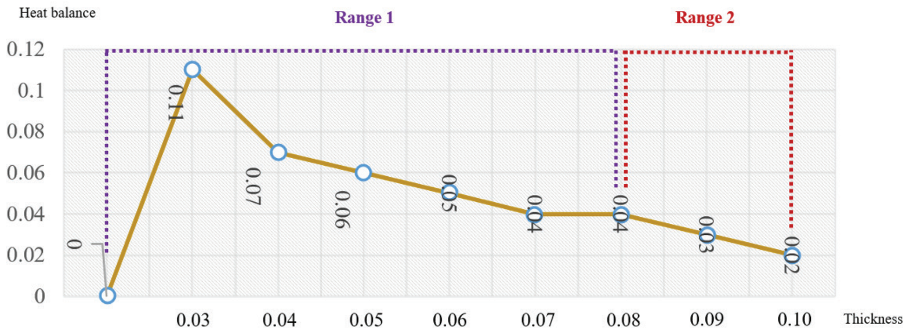


Figure 32. Mineral Fiberglass Figure ratio.

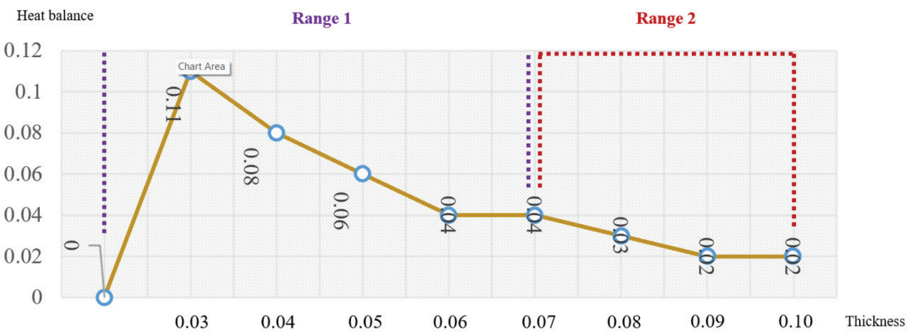


Figure 33. Fiberglass Figure ratio.

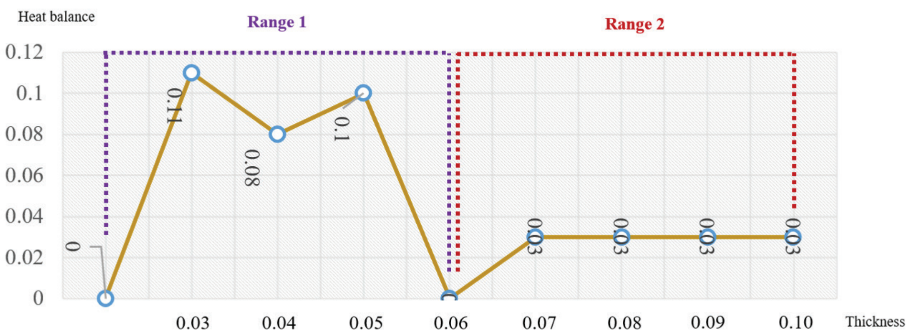


Figure 34. Rock wool Figure ratio.

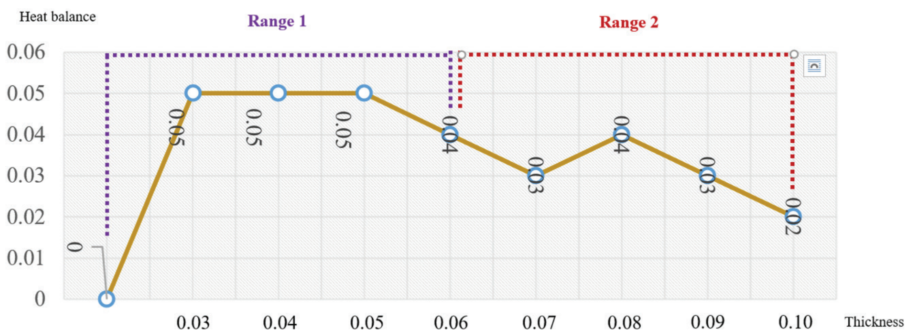


Figure 35. Silicon Figure ratio.

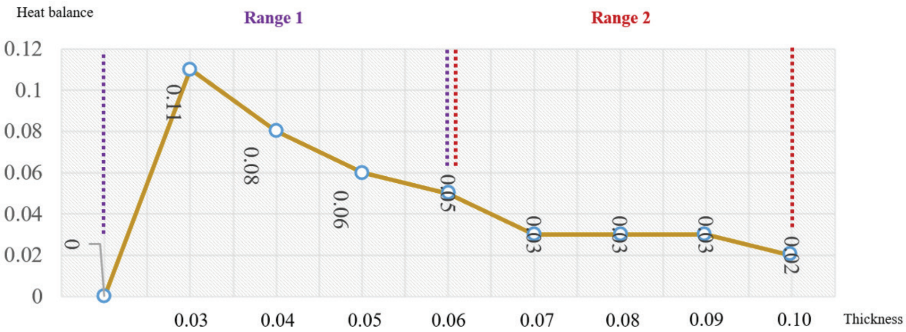


Figure 36. Fiberglass board Figure ratio.

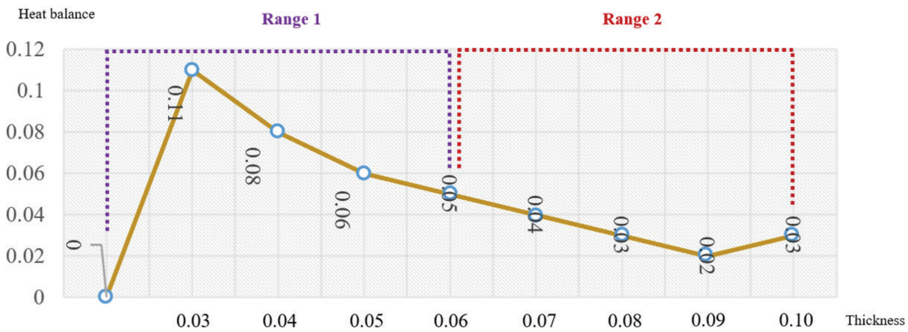


Figure 37. Polyurethane foam Figure ratio.

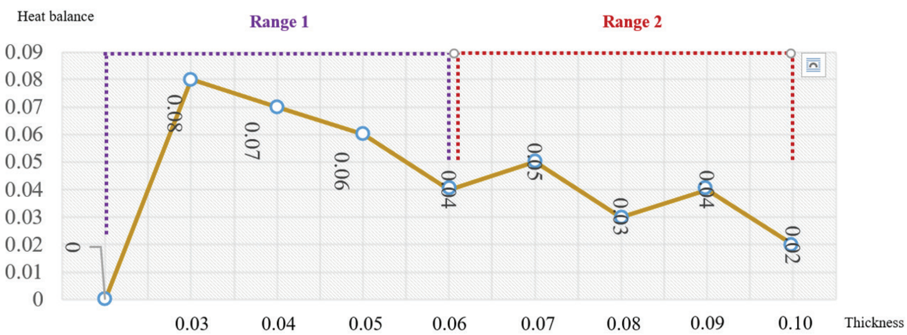


Figure 38. Wood wool Figure ratio.

$$\text{Polystyrene} - \text{HFC} = \begin{bmatrix} 0.02 & - \\ 0.03 & 0.06 \\ 0.04 & 0.08 \\ 0.05 & 0.06 \\ 0.06 & 0.06 \\ 0.07 & 0.01 \\ 0.08 & 0.03 \\ 0.09 & 0.02 \\ 0.10 & 0.02 \end{bmatrix}$$

As it is obvious in Figure 29, range 1 shows the increase of polystyrene (HFC) thickness from 2 cm to 6 cm, which would grow the wall heat balance between 0.06 and 0.08 units. On the other hand, in range 2, when the thickness increases from 7 cm to 10 cm, the heat balance would grow between 0.01 and 0.03 units. So, the increase in polystyrene (HFC) thickness is efficient between 2 cm and 6 cm, as range 1 is expressed in the diagram in Figure 29.

$$\text{Polystyrene} - \text{CO2} = \begin{bmatrix} 0.02 & - \\ 0.03 & 0.08 \\ 0.04 & 0.08 \\ 0.05 & 0.06 \\ 0.06 & 0.04 \\ 0.07 & 0.04 \\ 0.08 & 0.03 \\ 0.09 & 0.02 \\ 0.10 & 0.02 \end{bmatrix}$$

As it is obvious in Figure 30, range 1 shows the increase of polystyrene (CO2) thickness from 2 cm to 6 cm, which would grow the wall heat balance between 0.04 and 0.08 units. On the other hand, in range 2, when the thickness increases from 7 cm to 10 cm, the heat balance would grow between 0.02 and 0.04 units. So the increase in polystyrene (CO2) thickness is efficient between 2 cm and 6 cm, as range 1 is expressed in the diagram in Figure 30.

$$\text{Polyvinyl Chloride} = \begin{bmatrix} 0.02 & - \\ 0.03 & 0.06 \\ 0.04 & 0.05 \\ 0.05 & 0.05 \\ 0.06 & 0.04 \\ 0.07 & 0.04 \\ 0.08 & 0.04 \\ 0.09 & 0.03 \\ 0.10 & 0.03 \end{bmatrix}$$

As it is obvious in Figure 31, range 1 shows the increase of polyvinyl chloride thickness from 2 cm to 6 cm, which would grow the wall heat balance to 0.06 units. On the other hand, in range 2, when the thickness increases from 7 cm to 10 cm, the heat balance would grow to 0.04 units. So, the increase in polystyrene (CO2) thickness is efficient between 2 cm and 6 cm, as range 1 is expressed in the diagram in Figure 31.

$$\text{Mineral Fiberglass} = \begin{bmatrix} 0.02 & - \\ 0.03 & 0.11 \\ 0.04 & 0.07 \\ 0.05 & 0.06 \\ 0.06 & 0.05 \\ 0.07 & 0.04 \\ 0.08 & 0.04 \\ 0.09 & 0.03 \\ 0.10 & 0.02 \end{bmatrix}$$

As it is obvious in Figure 32, range 1 shows the increase of mineral fiberglass thickness from 2 cm to 6 cm, which would grow the wall heat balance to 0.11 units. On the other hand, in range 2, when the thickness increases from 7 cm to 10 cm, the heat balance would grow to 0.04 units. So, the increase in mineral fiberglass thickness is efficient between 2 cm and 6 cm, as range 1 is expressed in the diagram in Figure 32

$$\text{Fiberglass} = \begin{bmatrix} 0.02 & - \\ 0.03 & 0.11 \\ 0.04 & 0.08 \\ 0.05 & 0.06 \\ 0.06 & 0.04 \\ 0.07 & 0.04 \\ 0.08 & 0.03 \\ 0.09 & 0.02 \\ 0.10 & 0.02 \end{bmatrix}$$

As it is obvious in Figure 33, range 1 shows the increase of fiberglass thickness from 2 cm to 6 cm, which would grow the wall heat balance to 0.11 units. On the other hand, in range 2, when the thickness increases from 7 cm to 10 cm, the heat balance would grow to 0.04 units. So the increase in fiberglass thickness is efficient between 2 cm and 6 cm, as range 1 is expressed in the diagram in Figure 33.

$$\text{Rock wool} = \begin{bmatrix} 0.02 & - \\ 0.03 & 0.11 \\ 0.04 & 0.07 \\ 0.05 & 0.06 \\ 0.06 & 0.05 \\ 0.07 & 0.04 \\ 0.08 & 0.04 \\ 0.09 & 0.03 \\ 0.10 & 0.02 \end{bmatrix}$$

As it is obvious in Figure 34, range 1 shows the increase of rock wool thickness from 2 cm to 6 cm, which would grow the wall heat balance to 0.11 units. On the other hand, in range 2, when the thickness increases from 7 cm to 10 cm, the heat balance would grow to 0.04 units. So, the increase in rock wool thickness is efficient between 2 cm and 6 cm, as range 1 is expressed in the diagram in Figure 34.

$$\text{Silicon} = \begin{bmatrix} 0.02 & - \\ 0.03 & 0.05 \\ 0.04 & 0.05 \\ 0.05 & 0.05 \\ 0.06 & 0.04 \\ 0.07 & 0.03 \\ 0.08 & 0.04 \\ 0.09 & 0.03 \\ 0.10 & 0.02 \end{bmatrix}$$

As it is obvious in Figure 35, range 1 shows the increase of silicon thickness from 2 cm to 6 cm, which would grow the wall heat balance to 0.05 units. On the other hand, in range 2, when the thickness increases from 7 cm to 10 cm, the heat balance would grow to 0.04 units. So, the increase in silicon thickness is efficient between 2 cm and 6 cm, as range 1 is expressed in the diagram in Figure 35.

$$\text{Fiberglass board} = \begin{bmatrix} 0.02 & - \\ 0.03 & 0.11 \\ 0.04 & 0.08 \\ 0.05 & 0.06 \\ 0.06 & 0.05 \\ 0.07 & 0.03 \\ 0.08 & 0.03 \\ 0.09 & 0.03 \\ 0.10 & 0.02 \end{bmatrix}$$

As it is obvious in Figure 36, range 1 shows the increase in fiberglass board thickness from 2 cm to 6 cm, which would grow the wall heat balance to 0.11 units. On the other hand, in range 2, when the thickness increases from 7 cm to 10 cm, the heat balance would grow to 0.03 units. So, the increase in fiberglass board thickness is efficient between 2 cm and 6 cm, as range 1 is expressed in the diagram in Figure 36.

$$\text{Polyurethane foam} = \begin{bmatrix} 0.02 & - \\ 0.03 & 0.11 \\ 0.04 & 0.08 \\ 0.05 & 0.06 \\ 0.06 & 0.05 \\ 0.07 & 0.04 \\ 0.08 & 0.03 \\ 0.09 & 0.02 \\ 0.10 & 0.03 \end{bmatrix}$$

As it is obvious in Figure 37, range 1 shows the increase of polyurethane foam thickness from 2 cm to 6 cm, which would grow the wall heat balance to 0.11 units. On the other hand, in range 2, when the thickness increases from 7 cm to 10 cm, the heat balance would grow to 0.04 units. So, the increase of polyurethane foam board thickness is efficient between 2 cm and 6 cm, as range 1 is expressed in the diagram in Figure 37.

$$\text{Wood wool} = \begin{bmatrix} 0.02 & - \\ 0.03 & 0.11 \\ 0.04 & 0.08 \\ 0.05 & 0.06 \\ 0.06 & 0.05 \\ 0.07 & 0.04 \\ 0.08 & 0.03 \\ 0.09 & 0.02 \\ 0.10 & 0.03 \end{bmatrix}$$

As it is obvious in Figure 38, range 1 shows the increase of wood wool thickness from 2 cm to 6 cm, which would grow the wall heat balance to 0.11 units. On the other hand, in range 2, when the thickness increases from 7 cm to 10 cm, the heat balance would grow to 0.04 units. So, the increase in polyurethane foam board thickness is efficient between 2 cm, and 6 cm as range 1 is expressed in the diagram in Figure 38.

Efficient Impacts of Insulation Development

According to ten types of insulation layer simulation, each insulation type has its own efficient wall influence in a specific range, which is shown in Figures 29-38. These determined ranges introduce a framework that can be used as a tool by building designers and architects when they want to choose the suitable thermal insulation.

Table 6 shows the proportions of insulation layer thickness and heat balances as a framework. So in this way, building designers and architects can be able to choose the best possible insulation with regard to the project situation in Tehran and local insulation. In another sense, in a building project located in Tehran, a building designer who needed to design a wall detail would be able to make a decision about the wall insulation type and its thickness based on the information in Table 6 and the local insulation materials. A considerable point that makes the difference in this research is efficiency. It means that in addition to paying attention to the type and thickness of the thermal insulation, they can consider the efficiency of each material as an important economic factor.

As an example, if a building designer wanted to design the exterior wall detail of a building in Tehran and the local material was polystyrene and fiberglass, he would have five insulation types (polystyrene HFC, CO_2, fiberglass, mineral fiberglass, and fiberglass board). In this way, he would be able to make a clear decision about insulation to have the best thickness and reduce waste thermal energy. Also, in this method, with regard to the numerical information, it would be possible to find out about the designed building heat balance. In another positive aspect, building designers and architects can use the choices that have an efficient impact as insulation.

Previous research analysis and discussion

According to similar research in which the investigation analyzed the influence of wall insulation thickness in five cities in China, the heat transfer coefficient was expressed. Various thicknesses of polystyrene board, from 0 mm to 100 mm, were analyzed. The research had achieved a table framework that explained the relationship between the thickness of the insulation layer and the cost of energy per square meter [28]. While the mentioned research has conducted the study based on one type of insulation, this article has presented the methodology of the study by simulating a various number of insulation types that are used in the design of walls in Tehran, which is helpful for architects who work locally in Tehran.

Another study, which was conducted in 2023, made an analysis based on building envelope typology in Baghdad in accordance with two parameters that include window-to-wall ratio and envelope insulation. The research concluded that the annual thermal load can have a considerable reduction of about 49% when it uses an insulation like a stone wall with a thickness of 5 cm [29]. So despite the closeness of the research path to the current research, the use of insulation diversity in the presented research is significant.

In research published in the International Research Journal of Advanced Engineering and Science, the researcher analyzed the insulation thickness of a building wall to find out the most economical choice of insulation thickness. As a conclusion, the researcher found that the economic insulation thickness of the local insulation is 4.7 cm in accordance with heating, cooling, and the annual energy requirement [30]. So it is obvious that finding the most economic thickness is important to developing efficiency. While this point is made based on one insulation in the mentioned article, the current research categorizes the 10 insulations, so it presents the insulation's efficiency in a more precious method.

In key research that was done in 2021 in Turkey, researchers made an optimization analysis based on four different thermal insulation materials: glass wool, rock wool, extruded polystyrene, and expanded polystyrene. In the investigation, the researcher wanted to consider the heating degree-day method, energy saving costs, payback period, and CO_2 emissions, and as a result of the study,

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Table 6. Efficient range of insulation layer

	Insulation	Thickness (m)	Heat balance (KW)
Wall type 1	Polystyrene - HFC	0.02	-0.64
		0.03	-0.50
		0.04	-0.42
		0.05	-0.36
		0.06	-0.30
Wall type 2	Polystyrene – CO2	0.02	-0.61
		0.03	-0.53
		0.04	-0.45
		0.05	-0.39
		0.06	-0.35
Wall type 3	Polyvinyl Chloride	0.02	-0.96
		0.03	-0.90
		0.04	-0.85
		0.05	-0.80
		0.06	-0.76
Wall type 4	Mineral Fiberglass	0.02	-0.70
		0.03	-0.59
		0.04	-0.52
		0.05	-0.46
		0.06	-0.41
Wall type 5	Fiberglass	0.02	-0.65
		0.03	-0.54
		0.04	-0.46
		0.05	-0.40
		0.06	-0.36
Wall type 6	Rock wool	0.02	-0.63
		0.03	-0.52
		0.04	-0.44
		0.05	-0.34
		0.06	-0.34
Wall type 7	Silicon	0.02	-0.97
		0.03	-0.92
		0.04	-0.87
		0.05	-0.82
		0.06	-0.78
Wall type 8	Fiberglass board	0.02	-0.66
		0.03	-0.55
		0.04	-0.47
		0.05	-0.41
		0.06	-0.36
Wall type 9	Polyurethane foam	0.02	-0.70
		0.03	-0.59
		0.04	-0.51
		0.05	-0.45
		0.06	-0.40
Wall type 10	Wood wool	0.02	-0.89
		0.03	-0.81
		0.04	-0.74
		0.05	-0.68
		0.06	-0.64

a comparison was done to determine the worst and best insulation material and the best thickness variety of each insulation [31]. The mentioned research has taken a similar approach to the current investigation, and it expresses the importance of various insulation simulations to find out more detail about the local situation, so it shows the importance of the current research in the city of Tehran.

The perspective of the thickness of the wall insulation layer can be considered based on the cost of the building life cycle, as research was conducted in 2020, and the investigator objective was to determine the optimum insulation thickness of residential buildings in Turkey with an approach to knowing the relation between insulation thickness and building life cycle cost [32]. Therefore, the present research will be the first step on the path that will determine the possibility of investigating the relationship between the thickness of various types of thermal insulation layers in buildings used in Tehran, and so the life cycle costs of the buildings in this city could be expressed as a future key topic about the city of Tehran.

Another study, done in 2010, expressed an analysis of insulation layer efficiency thickness in four different climates in Turkey. The researcher concluded that the optimum insulation thickness at indoor temperatures of 18 and 22 °C was determined to be 0.0663 and 0.0816 meters, respectively [33]. So as a difference, although the mentioned research concentrated on the various climates, the current research concentrates on the variety of insulations in one region, and it is considerable that it could be the basis of future research on the same topic in another climate in Iran.

CONCLUSION

According to the consumption of thermal energy in buildings, considering related components of buildings could play an important role in reducing thermal loss. As a numerical point of view, this issue is more than 40% in Iran. Lack of enough numerical determination in Iran's big cities like Tehran could have a negative impact on the energy usage of this country, and this numerical perspective is counted as a research gap in related investigations.

Findings

Based on the mentioned issue, this research makes an attempt to establish a numerical framework in building walls—an important component of buildings—with an approach to assessing local insulation layers that are used in Tehran's building wall typology, and it aims to develop a quantitative framework that helps local architects and building designers choose the best insulation material in their design process in both energy loss prevention and economic efficiency material aspects. In another meaning, when there is a quantitative framework (Table 5-6 and Figs. 29-38), architects who design the building's first phase could use the details of insulation materials in various ranges (both type and thickness) in their design, and in this way they will be able to consider wall insulation properties in their project. In the investigation, the reviewed literature was categorized into three parts, including building thermal transmittance, the significance of layer optimization in wall construction, and the development of simulation models for thermal analysis. The methodology is a simulation-based method that uses the most common Tehran residential building wall typology as the specific case. The procedure of simulation shapes based on the ten types of local insulation that Figured the typological wall. Finally, the simulation is done with Design Builder software as the main tool, and the results are established.

The results are extracted and each wall configuration is assessed based on its insulation properties.

The key highlights of the research are:

- The most efficient insulation materials that develop the thermal efficiency of building walls are fiberglass, fiberglass board, mineral fiberglass, rock wool, polyurethane, and wood wool, which develop the change in heat balance of 0.11 kilowatts with a thickness of 3 centimeters. In accordance with the various choices, architects and building designers in Tehran could be able to choose the one with the best price and accessibility to the local area.
- The second group of thermal insulation materials is polystyrene (Co2), polystyrene (HFC), and polyvinyl chloride, whose change in change in heat balance equals 0.08 and 0.06 kilowatts with a thickness of 3 centimeters.
- The insulation material whose Figure rate's development is not efficient is silicon, whose development is 0.05 kilowatts with a thickness of 3 centimeters.

Research Novelty Points

According to the research process and the results, the novelty points of this research are expressed as following:

- **Region-spesific framewok**: It provides a quantitative framework with regard to climate and construction in Tehran; it thus furnishes real and appropriate guidelines for architects and designers locally.
- **Local material examination**: The simulation involves insulation materials available locally, so that the findings are applicable to the real situation in a building practice context in Tehran.
- **Detailed insulation efficiency analysis**: Measuring Insulation Effectiveness: This measures the association between insulation thickness and thermal performance.
- **Filling of research gap**: Evidence of Relevance: It addresses the need for numerical assessment of insulation materials in the Iranian context.

Study Potentials and Limitations

- The key potentials
- **Adaptation to other climate zones**: While this research focused on Tehran, the framework can be adapted to other Iranian cities with diverse climatic conditions. The findings could be used as a foundation for further research to assess the effectiveness of insulation

in varying climate zones across the country, offering tailored solutions to reduce energy consumption nationwide.

- **Various insulation materials:** Variety of insulations: In this analysis ten insulation materials were studied, and the variety of insulations could still be further developed from local materials in other Iranian cities.
- **Building typology constraints**: This analysis was limited to known building typologies in Tehran which may lessen the relevance to unknown or modern building typologies. Future studies would include a wider building typology in order to leverage a range of design conditions and increase the generalizability of the insulation framework.
- **Integration with renewable energy systems**: Systems such as renewable energy. Future studies could learn from this insulating framework in order to develop designs which are more sustainable (e.g. compatibility with renewable energy systems (solar energy). The combined synergies for thermal insulation in space, in addition to energy producing sources could lessen the combined impact for the environment in buildings.

Limitations

- **Experimental Examination**: According to the limitation of experimental services related to materials testing, do a reasonable comparison between theoretical findings and practical findings. This could be an effective point that impacts the credit of results.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article

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