

# Thermal Insulation Materials in Architecture: A Comparative Test Study with Aerogel and Rock Wool

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## Research Article

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## Abstract

Thermal insulation has great potential to reduce energy consumption in buildings. This study aims to provide a general perspective by addressing the thermal insulation materials used throughout the history of the construction industry and to understand the current situation with developing technology. The literature review was used as a method in the study. The insulation values of current thermal insulation products were investigated and compared. An energy loss and gain analysis were carried out on the Revit model to understand the difference between the widely used rock wool and a nanotechnology product, aerogel-added thermal insulation material. The results of the study show that thermal insulation materials produced with nanotechnology examined have lower thermal conductivity coefficients compared to other thermal insulation materials. According to the analysis carried out on the Revit model, the thermal insulation material with aerogel provides 8% savings in cooling loads compared to the use of rock wool. Developing competitive and sustainable materials is of the utmost importance. The literature review suggests that new composite insulators can be produced by combining suitable materials.

## Introduction

Thermal insulation gradually becomes more widespread in architecture for energy efficiency as humanity makes continuous progress in architecture, arising from the need for shelter and protection from weather conditions. Both customer demand and legal obligations motivate this progress. The increase in the supply and variety of thermal insulation materials in the construction sector brings along the requirement to choose the most suitable material.

Aiming to bring the energy efficiency in the final energy consumption sector in Turkey to the European Union standards, The Energy Efficiency Strategy was approved by the Ministry of Energy and Natural Resources in 2004. According to the data of the Directorate-General for Energy and Transport, the distribution of total energy use is 32% for transportation, 28% for industry, and 40% for buildings. Heating accounts for 85% of the energy used in buildings (Arslan and Aktas 2018). "TS 825 Thermal Insulation Requirements for Buildings", which was adopted in 1989 and became mandatory in 2000, is the first regulation for thermal insulation in Turkey. The 'Directive on the Thermal Insulation in Buildings' came into force in 2000, and the 'Directive on the Energy Performance of Buildings' came into force in 2008. With this legal regulation, it became obligatory to have an energy identity certificate for buildings (Ozer and Ozgunler 2019). According to The National Energy Efficiency Action Plan 2017-2023, final energy consumption in the building and service sector is gradually increasing in Turkey. Buildings have a share of 32.8% in final energy consumption. There is an increase in the building stock of more than 100,000 every year in Turkey (T.R. Official Gazette, December 29, 2017, No: 30289). Hence, energy efficiency applications in buildings will greatly contribute to this issue. Thermal insulation is one of these applications and has a high saving potential in energy efficiency.

Heat is a form of energy that flows between a system and its surroundings due to the temperature difference, and temperature is a value that can be measured from any point. In this context, there is a heat transfer from the warmer indoor environment to the outdoor environment in winter, and from the warmer outdoor environment to the indoor environment in summer. Thermal insulation is the process of minimizing the heat transfer between two environments at different temperatures through building components (Bayer 2006). In addition to reducing energy consumption, thermal insulation also creates more liable spaces with comfortable thermal conditions. In addition, considering the effects of moisture and humidity on human health, thermal insulation provides more favourable conditions. The service life of the building is extended, and the building becomes more protected against external factors.

Thermal insulation in buildings is generally applied on facades, roofs, terraces, unheated basements and entrances, partition walls, soil-contact floors, base slabs, and ceilings (Kocagül 2013).

The rapid depletion of energy resources has increased the tendency towards sustainability and ecological design in the construction industry. Thermal insulation comes to the fore in terms of efficient use of energy. With the developing insulation products, it is aimed to build long-lasting, economic, and sustainable structures by reducing energy loss and increasing comfort. It is crucial to use the most suitable thermal insulation materials in the building considering the structure and its location.

This study aims to provide a general perspective by addressing the thermal insulation materials used throughout the history of the construction industry and to understand the current situation with developing technology. A literature review was made on thermal insulation materials within the scope of the study. The insulation values of the subject insulation materials were compared. A Revit model was created and a heat loss and gain analysis were carried out on the model by using the data of thermal insulation materials containing rock wool and aerogel, a nanotechnology product, to make a comparison in the light of technological developments. The difference between the heating and cooling loads of the building insulated with two different materials was examined.

Developing competitive and sustainable materials is of the utmost importance. The literature review suggests that new composite insulators can be produced by combining suitable materials.

## Method

A literature review was made on thermal insulation materials within the scope of the study. The properties of thermal insulation materials and the insulation values, based on national standards, were examined. Materials are classified as commonly used thermal insulation materials, nanotechnology-product thermal insulation materials, and alternative thermal insulation materials.

Commonly used thermal insulation materials were limited to rock wool, glass wool, expanded polystyrene foam (EPS), extruded polystyrene foam (XPS). Aerogels and vacuum insulation panels were examined under the nanotechnology-product thermal insulation materials. A literature review was conducted on the use of natural materials including goat hair, wool, flax, straw, and hemp within the scope of alternative thermal insulation materials. The thermal insulation values of these thermal insulation materials were compared according to the literature review data.

Rock wool, one of the most widely used heat insulation materials in the construction industry, and a nanotechnology product with aerogel, which is not common in Turkey, were selected for comparison.

A building model was created to understand the difference between commonly used thermal insulation materials and nanotechnology-product thermal insulation materials. The model created using the Revit 2019 software was determined as a two-story office building. By keeping the data such as location, function, and building elements on the model, the thermal insulation material on the exterior wall and roof deck was changed. The thermal insulation layer thickness was kept the same in the model and the data of thermal insulation material with rock wool and aerogel additives were compared. Insulation values were obtained from the websites of the manufacturers. The heating and cooling loads were analyzed in the Revit model based on the insulation values of the materials.

Antalya, a city on a Mediterranean coast with a hot-humid climate, was selected as the test sample for the building model. In the city where the temperature data is very high in the summer months, cooling is one of the important problems in the buildings.

## Thermal Insulation Materials

Thermal insulation materials reduce heat transfer between two environments at different temperatures. There are concepts such as thermal conductivity, heat permeability resistance, and heat transmission coefficient in thermal insulation.

For example, when the temperature difference between two parallel surfaces of a homogeneous material with a thickness of 1 m is 1°C and this temperature remains constant, the amount of heat energy passed per unit time is called thermal conductivity ( $\lambda$ , W/mK) (Aydin 2010). The thermal conductivity resistance is the total value of how much heat is transmitted and depends on the thickness of the material (Çöl 2020). When the temperature difference between the two sides of a building element with 'd' thickness is 1°C under constant conditions, the amount of heat energy passing through the unit area per unit time is defined as the heat transmission coefficient and is denoted by 'u'; its unit is W/m<sup>2</sup>K (Aydin 2010). The most basic feature of thermal insulation materials is the heat transmission coefficient.

According to the International Standards Organization (ISO) and the European Standardization Committee (CEN), materials with a heat transmission coefficient less than 0.065 W/mK are defined as thermal insulation materials. Other materials are defined as building materials (TS 825).

The desired properties of thermal insulation materials include low thermal conductivity, low unit volume mass, fire resistance, vapor diffusion resistance, water absorption, sufficient compressive strength, resistance to chemical effects, incorruptibility, being parasite-free, economical, and processable (Ozer and Ozgunler 2019).

Traditionally, people used natural materials such as animal skins, fur, wool that were used for clothing in the nomadic living conditions of 7000 BC and before as thermal insulation materials in buildings. From the 1870s AD onwards, they built their houses using more durable materials such as soil, wood, bricks, and also used plant fibers such as straw, seaweed, and reeds. At the end of the 19th century, with the excessive increase in energy consumption as a result of the industrial revolution, and energy-saving awareness and heat loss calculations started in this period. Following these developments, industrial production of thermal insulation materials began. The use of plastics became widespread between 1950 and 2000, and after 2000, as a result of the environmental effects caused by plastic material production, a tendency to return to natural materials has arisen. With the developing technology, new materials such as aerogels and vacuum insulation panels have been produced (Bozasky 2010).

In this study, thermal insulation materials were divided into three groups to examine. Rock wool, glass wool, EPS, and XPS as commonly used thermal insulation materials were examined and aerogels which are thermal insulation materials with nanotechnology and vacuum insulation panels were discussed. The materials of vegetable and animal origin were limited to goat hair, wool, flax, straw, and hemp as alternative thermal insulation materials used in history within the scope of this study.

Rock wool is produced by turning stones such as dolomite, basalt, and diabase into the fiber at 1400-1600°C. By using binders such as starch, oil, and resins, they can be bonded together to obtain fiber. The fiber can be processed in the form of panels, rolls, mattresses, felts, pipes, and casts in different sizes and thicknesses depending on the place and purpose of use. It is widely used to provide fire safety behind the cladding and on ventilated facades, as it is resistant to heat and humidity, and generally non-flammable (Kirbiyik 2012). Rock wool and glass wool are similar in terms of their ecological properties, and rock wool can be recycled by manufacturers or disposed of in landfills (Woolley 2005).

Glass wool: a thermal insulation material produced at 1300-1450°C by mixing natural silica sand and usually recycled glass. Glass wool fibers are bonded by adding dust-preventing oil and phenolic resins (Arslan and Aktaş 2018). It is produced in different sizes and densities, in the form of plates, pipes, mattresses, and casts, depending on the place and purpose of use (Kirbiyik, 2012). It may change in size under external force. Energy usage is high as raw materials are melted at high temperatures. It may cause skin, larynx, and chest diseases due to dust and particles during production. It is potentially harmful to local soil quality due to limestone and silica extraction for raw material. As glass wool is thought to have a negative impact on air quality, it serves areas such as ground filling when recycled (Arslan and Aktas 2018).

EPS(expanded polystyrene foam): A petroleum-based, thermoplastic, closed-pore thermal insulation material in the form of foam. It is produced by inflating and fusing polystyrene particles by using pentane. 98% of EPS is still air. It can be processed in the form of blocks and cuttable sheets, depending on the place and purpose of use (Bayer 2006). Although it is chemically resistant to solvents, it may be affected by sunlight. It does not decay. Ecologically, there is a high energy use due to the use of petrochemicals, oil, and gas as raw materials. In addition, wastes such as heavy metals may occur during production. It may create a toxic effect by releasing carbon monoxide and carbon dioxide smoke and vapor in case of fire. EPS can be recycled by specialized organizations (Arslan and Aktas 2018).

XPS (extruded polystyrene foam): A thermal insulation material produced by extrusion machine by adding expansion gases and fire retardant to melted polystyrene. It can be sized and cut according to the place and purpose of use. It has low water absorption due to its closed porous structure. In this context, it is mostly used on pitched roofs and insulation of sandwich walls. It is also preferred in underground insulations and floors where high compressive strength is desired (Ozer and Ozgunler, 2019). Ecologically, although it has similar characteristics with EPS, it can be harmful to the environment due to the use of hydrofluorocarbon (HFC) and carbon dioxide (CO<sub>2</sub>) gas instead of pentane (Arslan and Aktas 2018).

Aerogels: It is a material discovered in the 1930s and primarily used in space applications. Since the 1980s, it has been a material of interest for use in building applications due to its high insulating properties and transparency (Buratti et al., 2021). Aerogels are the lightest additives in the literature. They are produced by combining a polymer with a solvent to form a gel, and then removing the liquid from the gel and replacing it with air. Aerogel contains nano-sized voids and has a porous structure in the range of 90-98%. Hence, it has a low unit volume mass. It can be produced from different materials such as silica, organic polymers, metal oxides, carbon, and metals (Yilmaz 2013). Although it is resistant to a temperature of approximately 1200°C, discoloration does not occur due to the long-term effect of sunlight. It is also resistant to moisture and mold formation. Aerogels are resistant and do not lose their properties in the long term (Ozer and Ozgunler 2019). The thermal insulation performance and optical transparency of aerogels allow their use in windowpanes and solar collector covers. Due to their low thermal conductivity and acoustic properties for noise reduction, aerogels can be used in buildings, as well as for indoor air quality, for photocatalysis in environmental cleaning, and in fire retardant sheets with non-flammability. (Riffat and Qiu 2013).

Vacuum insulation panels: Vacuum insulation panels (VIPs) are recognized as one of the high-performance thermal insulation solutions. They are made by utilizing the vacuum environment where heat conduction is low. The air in the insulation product is removed by vacuuming with nanotechnology. In this way, much thinner and low thermal conductivity panels are obtained (Baetens et al., 2010). These panels are usually produced by vacuuming different porous filling materials placed between aluminum-containing film, plastic, or stainless steel-covered protective barriers (Kumlutas and Yilmaz, 2008). Although they have a long service life, they may lose their thermal insulation properties when punctured. As custom products, they are also difficult to process. Since they are largely impermeable, condensation problems may occur (Arslan and Aktas 2018).

Goat hair: A natural material that has been used in Turkish culture throughout history. In the literature review, no specific heat insulation material produced with goat hair was found. However, cover materials made of goat hair and used in local tents are mentioned to have high thermal insulation performance in many sources.

Goat hair is environmentally friendly as it is a renewable natural raw material. They can be easily transported and used in building without any health hazards. It does not require any protective clothing, masks, or goggles for installation in the building. It has good thermal properties thanks to the proteins called keratin in its physical and chemical structure. It exhibits low thermal conductivity with its natural properties (Ahmed et al. 2019).

Wool: It has been used in clothing since ancient times, as it exhibits good thermal insulation performance. It shows a good acoustic performance thanks to its natural structure. Acoustic performance values increase depending on the thickness and density of wool fibers (Berardi and Iannace, 2015).

Flax: Flax fibers are produced from a plant that has been used since 5000 BC by the Egyptians. The flax contains about 70% cellulose. Flax fibers retain air and have high insulation properties. The elasticity of the fibers also allows them to be used as impact and sound insulators. Flax fibers are often mixed with polyester to increase mechanical resistance, and with additives such as boron salts to increase fire and moth resistance. Flax and hemp can be mixed to produce high-performance thermal insulation material. Flax is easy to grow in any soil without the need for fertilization or purification. When polyester fiber is not used in flax, its waste can be reused, recycled, and used for fertilizer production (Arslan and Aktas 2018).

Hemp: It is not subject to a standard as a heat insulation material.

Hemp fiber is produced from hemp and post-harvest parts of the plant. Hemp, as an insulation material, has a high tendency to retain moisture. As the moisture content increases, the heat transfer coefficient of the material increases. It must be protected from moisture, rodents, and insects. Due to its low compressive strength, it can be used between the wooden frame system, on the lower surfaces of the roof, walls, and for slabs, where it will not be under load (Ozer 2017). The fire risks of cellulose-containing materials such as hemp can be resolved when treated with fire retardant chemicals (Oldham et al., 2011).

Straw: It is known to be used in mud bricks dating to 8300 BC and in ancient Egyptian tombs. In Turkey, straw is a material that can be renewed annually and is abundant and easy to find at certain times. In areas where grain production is available, the stalks of crops such as wheat, oats, rice, and barley are considered waste and discarded, mostly by burning. However, shelters with high energy performance can be built with this material. Strawbale containing cellulose has good insulating properties. Grain-free straw is available every year and is a renewable resource. In a sustainable system, straw can be regrown in less than a year (Irkli Eryildiz and Baskaya 2000).

The properties of the thermal insulation materials examined within the scope of the study with literature review are summarized in Table 1. Considering the thermal conductivity values, aerogels show the lowest performance after vacuum insulation panels. The thermal conductivity values of commonly used thermal insulation materials are very close to each other. Thermal conductivity values of alternative thermal insulation materials are also very close to each other. Unit volume mass values differ in all materials. All groups except alternative thermal insulation materials have resistance to parasites and incorruptibility properties. Processability is possible almost in all materials, except it is difficult in vacuum insulation panels. Also, vacuum insulation panels have the highest vapor diffusion resistance. In literature, there is a lack of data in alternative thermal insulation materials compared to other materials.

Table 1  
Thermal Insulation Material Properties Summary Table (TS 825) (Ozer 2017) (Arslan and Aktas 2018) (Ahmed et. al. 2019)

MATERIAL PROPERTIES	COMMONLY USED THERMAL INSULATION MATERIALS				THERMAL INSULATION MATERIALS WITH NANOTECHNOLOGY		ALTERNATIVE THERMAL INSULATION MATERIALS				
	GLASS WOOL	ROCK WOOL	EPS	XPS	AEROGEL	VAC. INSULATION PANEL	GOAT HAIR	WOOL	FLAX	STRAW	HEMP
Thermal conductivity (W /m. oC)	0.035-0.050	0.035-0.050	0.035-0.040	0.030-0.040	0.013 - 0.024 *	≤0.0053	0.036-0.073**	0.038-0.054	0.038-0.075	0.058	0.040-0.050
Unit volume mass (kg/m3)	15-150	20-200	≥15	≥25	70- 150 *	210	214-269**	10-25*	20-100*	150	20- 68
Avg. Water Absorption	High	High	Low	Low	High	Low			High	High	High
Vapor diffusion resistance (μ)	1	1	20-100	80-250	5	∞			2,9*	3	1 2
Compressive strength (kPa)	15-80	15-80	60-200	150-700	>80	≥150					
Resistance to parasites	Good	Good	Good	Good	Good	Good	Bad	Bad	Bad	Bad	Bad
Indefectibility	Does not decay	Does not decay	Does not decay	Does not decay	Does not decay	Does not decay	May decay	May decay	May decay	May decay	May decay
Processability	easy	easy	easy	easy	easy	difficult	easy	easy	easy	easy	easy
(–): No data found											
(* Arslan and Aktas, 2018) (**Ahmed et.al, 2019)											

## Comparison Of Thermal Insulation Materials Over The Model

Two materials were selected within the scope of the study to evaluate how much benefit thermal insulation materials provide in energy loss gain with the developing technology. One of these materials was rock wool, which is in widespread use, and the other was a nanotechnology-product thermal insulation material with aerogel. The technical data of these materials were obtained from the websites of the manufacturers. We paid attention to choose the most widely used materials that could be considered new. While the material with aerogel is not used intensively, it has the potential to become widespread thanks to its advantages.

A building model was prepared with the Revit 2019 software to determine the difference between the performance values of the selected materials (Figure 1). The model was designed as a two-story office building (Figure 2). The building is 410 m<sup>2</sup> in total. Yalı Street, Antalya, Turkey was determined as the building location, and coordinates and climate data was used in the software accordingly.

In the office building, there is an open office area, stairwell, storage, and toilet areas on the ground floor and there are two terraces and an open office area on the first floor (Figure 3-4). The roof of the building is designed as a terrace.

Calculations have been made assuming that thermal insulation material will be used on the exterior walls, terrace, and roof slabs of the building. In addition, all the structural elements are kept constant to understand the difference between the materials. In the same way, the thickness of the rock wool and aerogel material was equal.

First, the layers to be used in the exterior wall, terrace and, roof slabs for insulation were determined and the U value was calculated. Accordingly, the U value of the roof slab was 0.324 W/m<sup>2</sup>K for rock wool and 0.138 W/m<sup>2</sup>K for aerogel. The u value of the terrace was 0.359 W/m<sup>2</sup>K for rock wool and 0.144 W/m<sup>2</sup>K for aerogel (Table 2 and Table 3).

It was assumed that the exterior walls were made of gas concrete blocks with 5 cm thick insulation material. Accordingly, the U value was calculated as 0.361 W/m<sup>2</sup>K for rock wool and as 0.206 W/m<sup>2</sup>K for aerogel (Table 4 and Table 5).

Table 2. The U value of the roof slab for rock wool

1	2	3	4	5	6
Heat Loss Surface	Construction Elements in the Building	Construction element thickness d (m)	Heat conduction coefficient calculation value (W/mK)	Thermal Conductivity Resistance R (m <sup>2</sup> K/W)	Thermal Permeability Coefficient U (W/m <sup>2</sup> K)
SLAB Terrace	Ri			0.130	
	Ceramic Tiles	0.008	2.3	0.003	
	Adhesive	0.004	1.4	0.003	
	Reinforced Concrete Screed	0.03	1.4	0.021	
	Reinforced Concrete	0.2	2.5	0.080	
	<u>Rock Wool Thermal Insulation</u>	<u>0.1</u>	<u>0.04</u>	<u>2.500</u>	
	PVC Membrane	0.001	0.23	0.004	
	Rd			0.040	
<b>Total</b>				<b>2.782</b>	<b>0.359</b>

Table 3. The U value of the roof slab with aerogel

1	2	3	4	5	6
Heat Loss Surface	Construction Elements in the Building	Construction element thickness d (m)	Heat conduction coefficient calculation value (W/mK)	Thermal Conductivity Resistance R (m <sup>2</sup> K/W)	Thermal Permeability Coefficient U (W/m <sup>2</sup> K)
SLAB Terrace	Ri			0.130	
	Ceramic Tiles	0.008	2.3	0.003	
	Adhesive	0.004	1.4	0.003	
	Reinforced Concrete Screed	0.03	1.4	0.021	
	Reinforced Concrete	0.2	2.5	0.080	
	<u>Thermal Insulation with Aerogel</u>	<u>0.1</u>	<u>0.015</u>	<u>6.667</u>	
	PVC Membrane	0.001	0.23	0.004	
	Rd			0.040	
<b>Total</b>				<b>6.949</b>	<b>0.144</b>

Table 4. The U value of the exterior wall with rock wool

1	2	3	4	5	6
Heat Loss Surface	Construction Elements in the Building	Construction element thickness d (m)	Heat conduction coefficient calculation value (W/mK)	Thermal Conductivity Resistance R (m <sup>2</sup> K/W)	Thermal Permeability Coefficient U (W/m <sup>2</sup> K)
EXTERIOR WALL	Ri			0.130	
	Screed	0.02	1.6	0.013	
	Gas Concrete Block Wall	0.2	0.15	1.333	
	<u>Rock Wool Thermal Insulation</u>	<u>0.05</u>	<u>0.04</u>	<u>1.250</u>	
	Screed	0.01	1.6	0.006	
	Rd			0.040	
<b>Total</b>				<b>2.772</b>	<b>0.361</b>

Table 5. The U value of the exterior wall with aerogel

1	2	3	4	5	6
Heat Loss Surface	Construction Elements in the Building	Construction element thickness d (m)	Heat conduction coefficient calculation value (W/mK)	Thermal Conductivity Resistance R (m <sup>2</sup> K/W)	Thermal Permeability Coefficient U (W/m <sup>2</sup> K)
EXTERIOR WALL	Ri			0.130	
	Screed	0.02	1.6	0.013	
	Gas Concrete Block Wall	0.2	0.15	1.333	
	<i>Thermal Insulation with Aerogel 0.05</i>		<i>0.015</i>	<i>3.333</i>	
	Screed	0.01	1.6	0.006	
	Rd			0.040	
Total				4.855	0.206

After finding the total heat transmission coefficient values of the building elements to be used as thermal insulation material, a comparison was made with the U values recommended for buildings in Antalya, which is located in the first region according to TS 825. It was concluded that the calculated values were below these values. Then, the heating and cooling loads were calculated on the Revit model. First, the main function of the building, its location, and the building service system were defined in the program. After this process, location type settings were adjusted for all spaces in the building. The following data was provided: There will be one user per 20m<sup>2</sup>, the offices will be illuminated between 6:00 and 23:00. In the model, the heating setpoint was determined as 20°C and the cooling setpoint as 24°C.

In line with the U value calculations made for the material with rock wool and aerogel, the U values closest to the calculated value were selected for the building elements for all spaces in the building. The U values of other structural elements were kept the same for both materials. A summary heating-cooling load analysis for each condition was carried out on the model.

As a result of the analysis, the warmest time was August, 02:00 pm. Accordingly, the total cooling load was 33985 W and the total heating load was 13375 W for rock wool. The total cooling load was 31251 W and the total heating load was 11852 W for aerogel. As is seen, the energy consumption of the building decreases with the use of materials with aerogel.

## Conclusion

This study aims to provide a perspective on insulation materials, considering their use throughout history. Measures to be taken on energy efficiency in the construction industry play a significant role in sustainability and environmental problems. One of these measures is thermal insulation. Environmental effects of thermal insulation materials throughout their entire life cycle should be taken into account. There is a tendency to use natural materials instead of petroleum-based products, and research continues in this context. It can be suggested that more environmentally friendly and rational thermal insulation materials can be created by combining animal-based and plant-based materials and advanced technology.

Within the scope of the study, an analysis was made on the Revit model to understand the difference between the materials produced with the developing technology and the materials used commonly. The difference in heating and cooling load calculations was compared for rock wool and aerogel. In the analysis, insulation material was used in the exterior walls, terrace, and roof slabs. In the comparison of rock wool and aerogel, material thicknesses were kept the same and other structural elements were kept constant. Using the nanotechnology-product aerogel provides a total of 8% savings in cooling load and 11% in heating load compared to rock wool. As the size, properties, and direction of the structural element in the analysis model change, the heating and cooling loads will also change. Likewise, load calculations may differ when the building function and the number of users change.

## Declarations

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## Author Contributions

Hacer Mutlu Danacı (HMD): supervisor, controller, literature researcher, synthesizing of the results, translate.

Neslihan Akin (NA): literature researcher, analyser of the existing relevant studies, collecting experimental data.

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## Ethics declarations and Ethical approval

Not applicable

## Consent to participate

The authors have consent to participate.

## Consent to publish

The authors have consent to publish.

## Competing interests

The authors declare that they have no competing interests.

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## Availability of data and materials

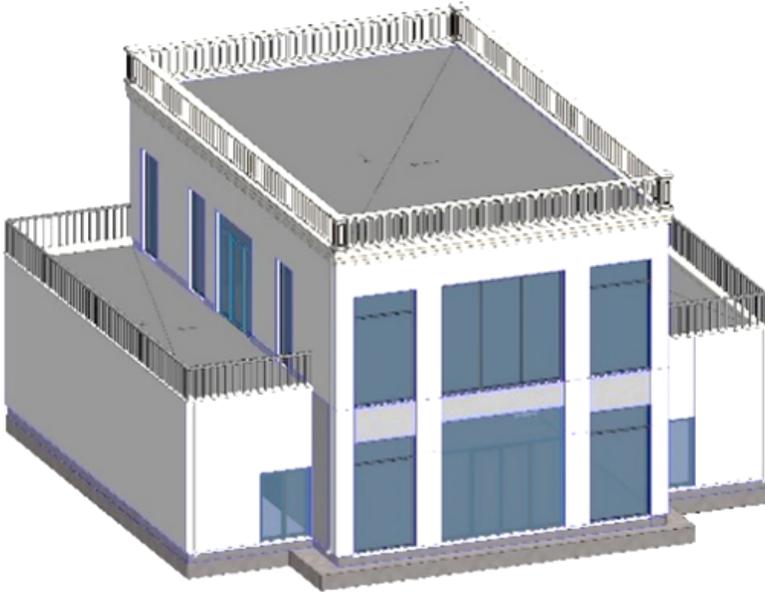
Not applicable

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## Figures



**Figure 1**

Model perspective



Figure 2

Building section

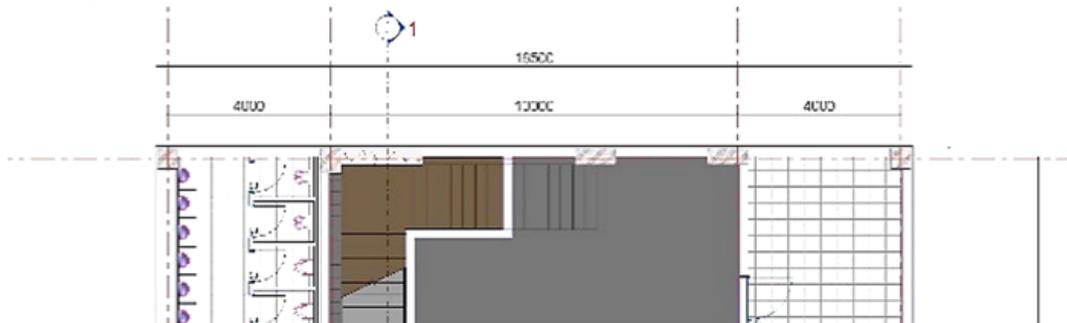


Figure 3

Ground floor plan

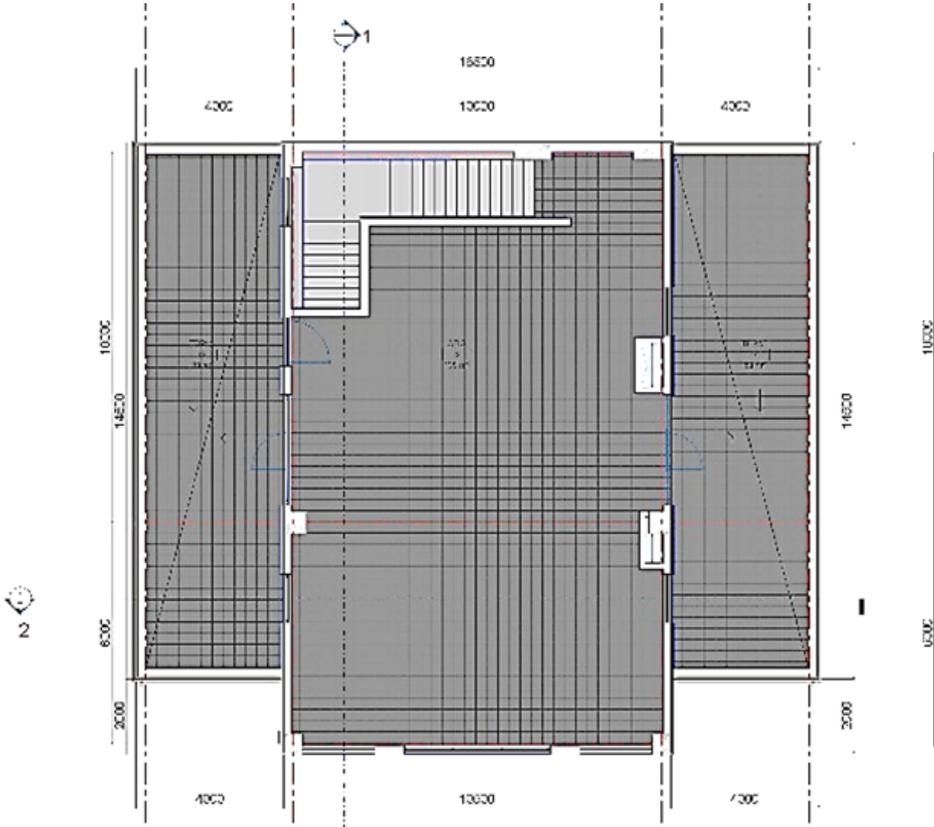


Figure 4

First-floor plan