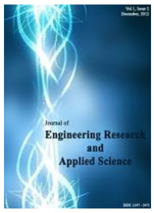
Journal of Engineering Research and Applied Science
Available at www.journaleras.com
Volume 9 (2), 2020, pp 1588-1596
ISSN 2147-3471 © 2020



Analysis of heat transfer properties and advantages of perlite-filled insulation bricks

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Accepted 1 November 2020

Abstract

Perlite has recently emerged as a material used especially in the construction industry. The light brick is obtained by using light materials such as cement, sand, water, and perlite in brick production. Especially recently, studies have been carried out to make the bricks lighter using mines such as perlite. The reason for doing all of these studies is not to add resistance to the brick, but to increase the insulation of the bricks. It is of great importance that the bricks used in the construction industry are both lightweight and good insulation material. In our study, the perlite-filled insulation bricks were examined and the effect of these bricks on insulation was examined and interpreted.

Keywords: brick, insulation, perlite, heat transfer analysis.

1. Introduction

Perlite is defined as an acidic volcanic glass. Perlite takes its name from the word Perle, which means pearl, because of the small pearl-luster spheres formed as a result of the breaking of some perlite types. Here, by heating up to the appropriate temperature, glass minerals are formed with the explosion of the heat shock and as a result of expansion, at this point, a foamy light-colored mass is formed [1]. When perlite is examined, it is seen that the mass formed after its expansion has a lightweight and porous structure. The most important feature of perlite; is seen as the water it contains as a compound of 2.5% in the hydrated glassy silica structure. The water contained in the perlite makes it stable.

The word perlite is used to describe expanded perlite and raw perlite. When the perlite rocks are examined, it is seen that their structures and colors are different from each other. Perlite appears to be very difficult to identify visually. It was determined that the raw perlite has different colors and tones from transparent open to bright black, and the perlite turns white as it begins to expand. The most important feature of perlite is seen as the water varying between 2% and 6%. It is revealed that the water in the perlite provides the stability of the perlite [2]. According to theories, it is seen that perlite is formed as a result of the absorption of magmatic water. For this reason, it has been determined that perlite contains a high amount of water. It was concluded that the expansion ability of the perlite depends on the chemical structure of the perlite and the water [3].

During the instantaneous heating of perlite (750-1200 °C), steam comes out of its body. With the release of this steam, an increase in the volume of perlite occurs. Perlite turns into a foam aggregate consisting of glassy grains. In this case, perlite can expand up to twenty times its initial volume. This product is called expanded perlite. Perlite is a non-fibric, acid-composition volcanic glass. Perlite does not contain organic matter, heavy metal, nitrate phosphorus, sulfate, and radioactive elements. Therefore, the chemical structure of perlite appears to be quite pure [5].

There are aluminum and siliceous compounds in raw perlite. Therefore, as a result of chemical reaction with the raw perlite calcium-based binders, it shows hydraulic activity. It is seen that perlite is used in the construction sector due to its hydro-activity feature. As a result of adding perlite into the cement, it was determined that the concrete gained durability. Raw perlite rock; It can also be used as aggregate by breaking and sieving or naturally. Turkey has perlite reserves in large fields used in the form of natural aggregate.

On the other hand, expanded perlite and pumice can

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be used in similar areas due to their low density and their sound and heat insulation. When the perlite reserves in the world are examined, there are 7.7 billion tons of perlite reserves in different countries. 1.8 million tons of perlite are produced in the world. -4% is used as agricultural material [4].

It is observed that there is a large perlite potential in Turkey with a different expansion rate of 5.7 billion tons. Perlite deposits in Turkey have been determined as follows. These are; Ankara-Çubuk, Kızılcahamam, Çankırı-Orta, Van-Erciş, Kars-Sarıkamış, Erzincan-Mollaköy, Erzurum-Pasinler, Bitlis-Tatvan, Cumaovası, Dikili and Foca, Izmir-Bergama, Nevşehir-Acıgöl-Derinkuyu and Malatya-Pötürge.

In Turkey, it was determined that concrete aggregates with perlite and pumice were used in first-class construction and Light building elements were used. It is seen that 17% of iron saving is achieved when the constructions using perlite are examined. It has been determined that perlite provides sound and heat insulation within this construction. The use of perlite in the construction sector should be increased, encouraged, and mandated [3].

Perlite is used in the construction industry, especially in walls, roofs, floors, ceilings, and partitions. These are used together with various methods in every area that requires heat and sound insulation. Perlite; When used in the form of heat insulation, it provides a great benefit to the country's economy and its owners.

Perlite is added to liquid mortars in buildings to provide sound and heat insulation. Thanks to perlite, it has been determined that cooling systems in buildings are provided more easily in summer and winter. Therefore, perlite in the construction industry in Turkey, wall, floor, wall panels are being used to manufacture density. Expanded perlite is mixed with materials such as cement, gypsum, lime, and water and used as insulation material, resulting in heat and sound insulation.

Perlite; It is seen as a material used in every region where heat and sound insulation is desired due to its thousands of air spaces. In the insulation of heat bricks, tanks, and various furnaces, thin perlite can be used to ensure that the liquefied gases are kept at the liquefaction temperature in double-walled tanks. The reason why thin perlite can be used in this way is; It has a very low thermal conductivity value. When the tank is examined, it can be freely filled into its double-wall under atmospheric pressure and vacuum. Perlite should be used with free filling to prevent heat loss in furnaces with a temperature up to 1050 °C. It is seen that perlite is used for lightness The usage of these perlites is listed as follows. These;

-60% concrete and plaster aggregate,

-23% filter material,

-8% insulating material production,

and insulation purposes in the production of bricks used in boilers, furnaces, annealing, forging, heat treatment, and melting furnaces up to 1050°C on the heated brick.

The usage areas of expanded perlite in the construction sector are listed as follows. These are;

- Shaped insulation material (to be used in roof and floor insulation),
- Perlite plasters,
- Lightweight insulation concrete with perlite aggregate (as gypsum and cement binder)
- Perlite aggregate lightweight construction elements,
- Pipe insulations,
- Ceiling tiles,
- Loose filling material,
- Surface flooring,
- Special purpose perlite concretes,
- Perlite filled bricks.

The production process stages of perlite are listed as follows. These are;

- Crushing process,
- Pre-grinding process,
- Drying process,
- The grinding process,
- Fine grinding process,
- Screening, classification, sizing process,
- It is the storage process.

The ground, sized raw perlite is preheated up to 400 °C . Afterward, it is seen that the perlite is heated at 700-1200 °C, after this heating process, the water vapor inside the perlite comes out, and then the explosion process takes place in a short time and its volume increases 4-30 times. In this way, a slightly glassy porous perlite formation is achieved [6].

Perlite is seen as a natural source of aluminosilicate. It has been determined that it has the potential to improve the properties of cement-based building materials due to this aluminosilicate [7]. As a result of the researches, it is seen that perlite powder has pozzolanic properties and that perlite powder is a good additive for concrete [8]. It has been determined that the differences in thermal conductivity and apparent density of concrete are caused by differences in perlite pores. In this study we have done, the insulation effect of perlite filled insulation brick has been examined and interpreted.

2. Insulation effect of perlite filled insulation brick

Perlite is made of volcanic glass, which has been inflated strongly as a result of a thermal process and has been used. The insulating capacity of perlite is in the lower middle area. Perlite can also be used in many areas for thermal insulation. Perlite can be used as cast and blown insulation. Perlite has excellent fire protection properties; besides it also serves as heat and sound protection.

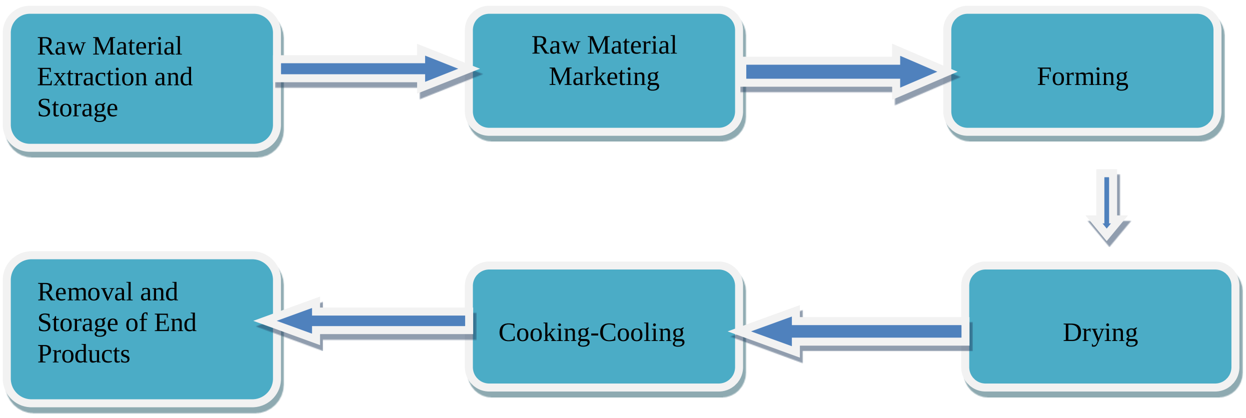
Table 2.1 Properties of Perlite

Thermal Conductivity	**0.04-0.07 W/mK**
Building Material Class	A1/A2 (non-flammable / containing a small amount of flammable material)
Minimum insulation thickness according to EnEV 2014	20 cm
Density	40-90 kg/m^3
Price per m^2	20-45 Euro
Price per m^3	100-170 Euro

The durability of a building and the ability to fulfill the health conditions are seen directly related to the materials that can be used in the production of the building. It is necessary to measure the resistance of the materials used here, especially against physical and chemical effects. As a result of this study, it is seen that the resistance here extends the life of the structure. The lightness of the material to be used in the building also reduces the amount of reinforcement that can be used in reinforced concrete. It turns out that this will reduce the cost of construction. The fact that the materials used here are good in sound and heat insulation is of great importance for the health and comfort of the people living in that environment.

Brick production was carried out from the first pages until the nineteenth century by shaping in wooden molds, drying, and finally cooking in traditional ovens. In Turkey, which is under the name of clay brick is seen that this technique is very common. From the beginning of the nineteenth century, brick and tile production ceased to be a handicraft and became an industry branch. As a result, it was determined that the conditions sought in the soils to be used in the production of brick-tile have changed. Today, brick-tile production is carried out using molding in machines, shaping in presses, cooking, and drying in modern ovens. Geological and technological studies of the soils to be used in brick and tile production should be carried out. Since the raw material used in brick and tile production cannot be used directly, various ore preparation methods must be applied. Nowadays, it is seen that it is impossible to produce various types of tiles and various bricks from the same raw material [9]. Brick; It is produced by mixing the ground clay with water and then shaping, drying, and firing. In the past, the shaping of bricks was done manually. After the invention of brick-making machines at the end of the nineteenth century, firstly, brick production was achieved in the United States as a result of the use of these modern machines. It has been determined that brick production processes take place in six stages. Implications related to this are shown in the flow chart Figure 2.1 [10].

Figure 2.1 Brick Production [10]



In the range of 700-1200 °C, it can expand 4-20 times as a result of the vapor pressure of the water in perlite. When the expansion occurs here, light and porous structures are formed. The content of perlite is generally listed as follows;

-70-75% SiO_2,

-12-20% Al_2O_3

- It contains small amounts of other minerals.

There are glassy systems in perlite. Unlike glassy crystalline structures, there is no melting point. These systems first soften with the effect of temperature and then become sticky and fluid. Perlite softens between 750-1000 °C and gains a plastic feature. It is seen that if the sudden heating process takes place up to this temperature, the water in it will evaporate suddenly. It has been determined that the first volumes of the perlite grains can expand up to 30 times with the pressure of the steam here [11].

It is seen that perlite's physical structure is porous, lightweight, and suitable for thermal insulation, so it is necessary to use it in brick production. When the porosity property of perlite is examined, it was determined that this porosity gives the perlite absorbency and surface cooling properties.

3. Speficitations of perlite filled insulation brick

It is seen that the unit volume weight of the clay used in the production of perlite-filled insulation brick is 2.69 g/cm^3 in the measurement made by pycnometer. It was determined that the plasticity limit of this clay used was 28.3% and the liquid limit was 78%. The clay used here must be mixed with water in order to gain plasticity. Before the clay is baked it is dirty yellow in color. The reason why clay turns yellow is metal oxides and organic substances. It was determined that the color turned from dirty yellow to dark red after the firing process of the clay. Soda solubilization process was carried out in order to make a chemical analysis of clay here. It is seen that the residual matter ratio and the amount of SiO_2 from the solution obtained as a result of the soda solubilization method were determined. Chemical analysis of the clay used as a result of the test is given in the table below. The chemical analysis of the perlite used here is shown in Table 2.3 below and the chemical analysis of the perlite used here is shown in Table 2.4 below

Table 2.2 Chemical Composition of Investigated Clay [12]

SiO_2	**%52,09**
Al_2O_3	%9,06
Fe_2O_3	%2,27
CaO	%2,44
MgO	%12,11
K_2O	%1,75
SO_4	%0,10
TiO_2	%0,27
Na_2O	%6,38
A.Z.	%13,68

Table 2.3 Chemical Analysis of Perlite [11]

SiO_2	**%71-75**
Al_2O_3	%12,5-18
Na_2O	%2,9-4
CaO	%0,5-2
MgO	%0,1-1,5
K_2O	%4-5
Fe_2O_3	%0,5-1,5
TiO_2	%0,03-0,2
MnO_2	%0,03-0,1
SO_3	%0-0,2
FeO	%0-0,1

Table 2.4 Prescription Percentages

PRESCRIPTION	Perlite (By Weight %)	Clay (By Weight %)
Standard Prescription	0	100
Prescription-1	5	95
Prescription-2	10	90
Prescription-3	15	85
Prescription-4	20	80
Prescription-5	25	75
Prescription-6	30	70
Prescription-7	35	65

It is observed that the proportion of water used in prepared samples is constant at 8%. By bushel weight of the mixture produced here 0,05-0,10-0,15-0,20-0,25-0,30-0,35 a recipe was created by adding expanded perlite aggregate. It was determined that the samples prepared here were subjected to cooking at 950 °C. It was observed that the results were examined by performing volume reduction, compressive strength, unit weight measurement, and thermal conductivity experiments on cooked samples.

According to the results of the study; The results obtained from the experiments were interpreted by examining the compositional properties relationships. While the firing shrinkage observed as a result of firing the perlite-free sample is 5.9%, it is seen that the firing shrinkage in the perlite sample varies from 6.7% to 11.36%. As the number of perlites increases, the reason for the increase in the firing amount was determined as the perlite being exposed to a greater volume reduction at 900 °C , especially than clay. It has been revealed that there is a directly proportional change between the increase in the perlite ratio and the increase in firing shrinkage.

As a result of the measurement made on the compressive strength in the study, it is seen that the compressive strength of the sample without pearlite is 5.6 N/mm^2. It is seen that the pressure value decreases as the perlite addition is made as prescribed. It was determined that when the perlite ratio reached the highest level, the compressive strength value reached 2.1 N/mm^2. When the slightly vertically perforated brick walls are examined in the literature, it is seen that the minimum compression strength value of these bricks is 2.4 N/mm^2. To produce a brick that complies with the standards, 30% perlite must be present in the recipe. As a result of the study, it was determined that the perlite addition increasing with the compressive strength value has an inversely proportional form.

When unit weight levels are examined; It is seen that the unit weight is 1293 gr/cm^3 for the sample without pearlite. As a result of adding perlite to the samples, a decrease in unit weight occurs. Building materials should appear as lightweight building materials by standards. Therefore, their weight must be less than 1000 gr/cm^3. When the samples were examined, it was concluded that a decrease in unit weight was observed with the addition of perlite.

In the study, a decrease in the thermal conductivity value is observed by adding perlite. Since perlite is subject to firing shrinkage at a higher rate than clay at 950 °C, it should be ensured that sintering work is carried out in such recipes at lower temperatures. For perlite to be used after being obtained from nature, it must be subjected to an expansion process. In this way, an increase in cost is observed. For this reason, to reduce the unit cost in perlite insulated brick production, it is necessary to investigate the possibilities of cheaper expansion of perlite.

4. Heat transfer analyses of perlite and air-filled bricks

4.1. Analysis of perlite-filled brick

The indoor air temperature of the model is 22 °C, the outdoor temperature is -10 °C, and the convection coefficient is 20 W/m^2K. Heat transfer occurred in the brick by conduction and in the environment by convection. The transmission coefficients for brick and perlite were entered as 0.4 W/mK and 0.04 W/mK, respectively. "Temperature" and "Total Heat Flux" options are sufficient for us for thermal analysis results.

Convection and conduction heat transfer equations are used for the numerical results of the perlite filled brick whose thermal analysis has been made. Surface temperatures were chosen approximately according to the analysis results. Figure 4.1 and 4.2 show the temperature and total heat flux analysis by adding perlite material to the brick gaps.

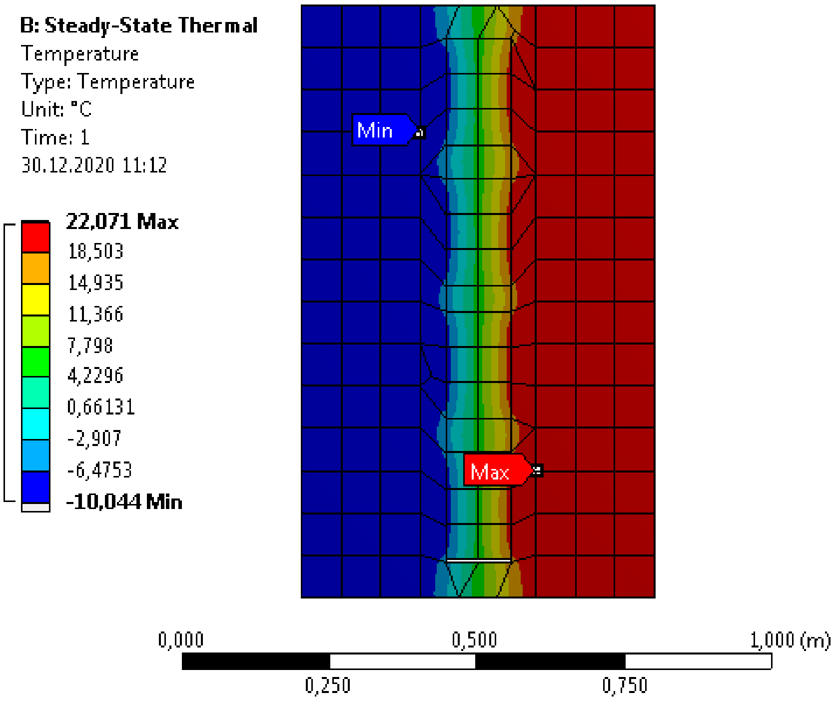


Figure 4.1 Temperature analysis of perlite filled brick

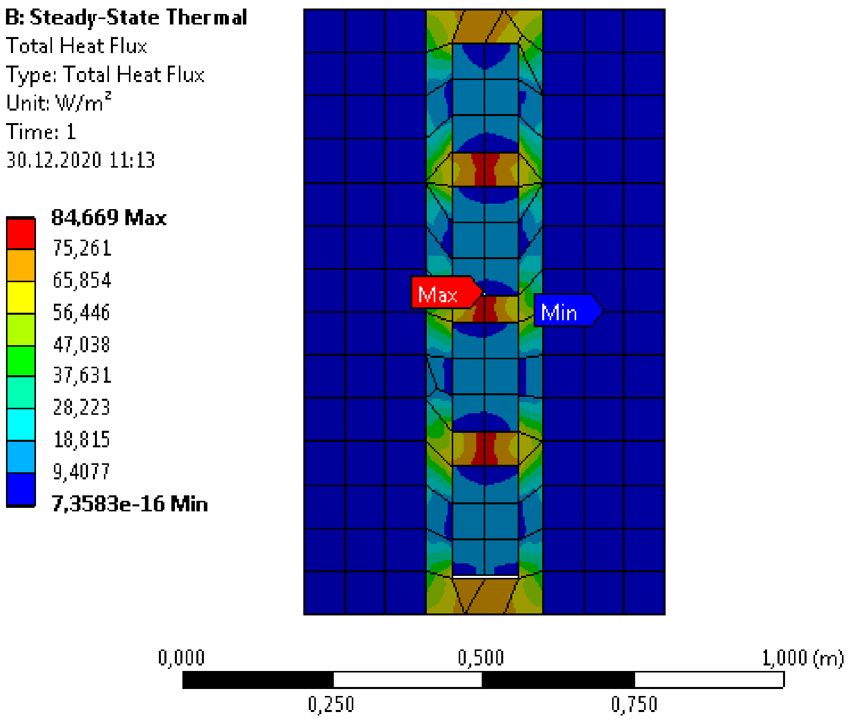


Figure 4.2 Thermal conductivity analysis of perlite filled brick

Convection heat loss calculation for indoor and outdoor environment:

$q_d = h \times (T_s - T_\infty)$
$q_d = 20 \times [(-8)-(-10)]$
$q_d = 40\ W/m^2$
$q_i = h \times (T_\infty - T_s)$
$q_i = 20 \times (22-19)$
$q_i = 60\ W/m^2$
Conduction heat loss calculation for brick:

$$q = U \times (T_i - T_d)$$

$$U = \frac{1}{RxA} = \frac{1}{\frac{1}{20} + \frac{0,4}{0,4} + \frac{1,2}{0,04} + \frac{0,4}{0,4} + \frac{1}{20}}$$

U = 0,031
q= 0,031 x [(22-(-10)]
$q = 0,996\ W/m^2$

Equivalent thermal circuit for mixed wall:

$$U = \frac{1}{RxA} = \frac{1}{\frac{1}{h_i} + \frac{L_a}{k_a} + \frac{L_b}{k_b} + \frac{L_c}{k_c} + \frac{1}{h_0}}$$

L_a = 0,4 cm, L_b = 1,2 cm, L_c = 0,4 cm

4.2. Analysis of air-filled brick

In figure 4.3 and figure 4.4, temperature and total heat flow analysis is made by adding cool air to the brick gaps.

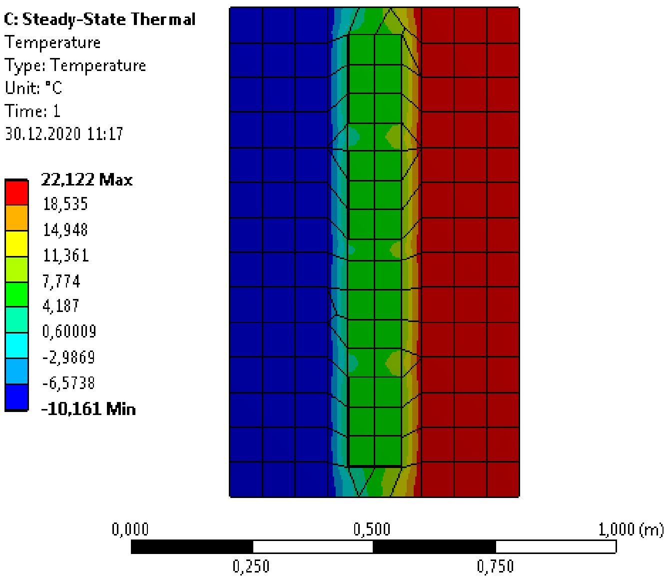


Figure 4.3 Temperature analysis of air filled brick

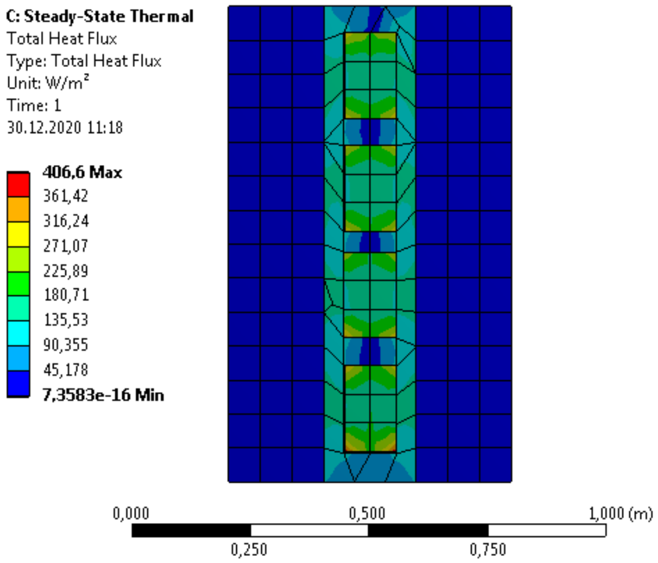


Figure 4.4 Thermal conductivity analysis of air filled brick

Convection heat loss calculation for indoor and outdoor environment:

$q_d = h \times (T_s - T_\infty)$

$q_d = 20 \times [3-(-10)]$

Conduction heat loss calculation for brick:

$$q = U \times (T_i - T_d)$$

Equivalent thermal circuit for mixed wall:

$$U = \frac{1}{RxA} = \frac{1}{\frac{1}{h_i} + \frac{L_a}{k_a} + \frac{L_b}{k_b} + \frac{L_c}{k_c} + \frac{1}{h_0}}$$

$L_a = 0{,}4$ cm, $L_b = 1{,}2$ cm, $L_c = 0{,}4$ cm

$q_d = 140$ W/m^2

$q_i = h \times (T_\infty - T_s)$

$q_i = 20 \times (22-16)$

$q_i = 120$ W/m^2

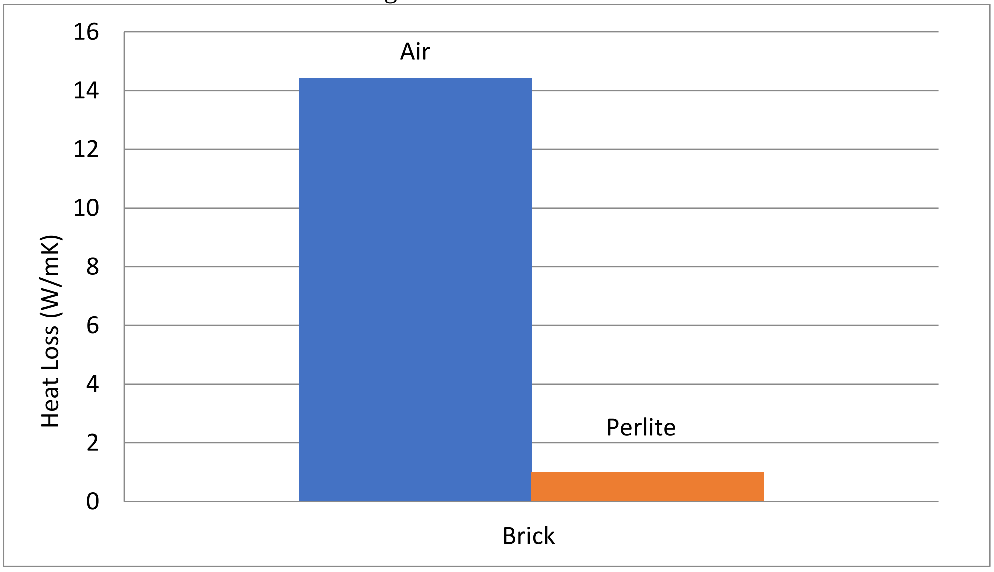
$$U = \frac{1}{RxA} = \frac{1}{\frac{1}{20} + \frac{0{,}4}{0{,}4} + \frac{1{,}2}{10} + \frac{0{,}4}{0{,}4} + \frac{1}{20}}$$

$U = 0{,}450$

$q = 0{,}450 \times [(22-(-10)]$

$q = 14{,}41$ W/m^2

Figure 4.5 Total heat loss



4. Conclusions

According to the thermal analysis and numerical results; Perlite was first added to the brick with the same size and number of voids. Later, it was accepted that there was still air in the brick gaps. The heat conduction coefficient of perlite (0.04 W / mK) is lower than the heat conduction coefficient of still air (10 W / mK). According to the results obtained according to the convection and conduction heat transfer equations, the heat loss of a perlite-filled brick is smaller than that of a still air-filled brick. There is an inverse proportion between heat transfer coefficient and heat loss. The heat loss experienced in a perlite filled brick is 93% less than in still air (figure 4.5). Increasing the use of perlite-filled insulation bricks on the exterior of our buildings is important in terms of reducing the heat loss experienced and the resulting energy need. It has been confirmed by the studies that the perlite filled insulation brick will create a more comfortable living space in our four-season residences. The rate of heat loss can be minimized by determining the rate of perlite addition depending on the brick thickness according to the regional conditions.

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