

PAPER • OPEN ACCESS

Investigating the effectiveness of insulation for walls of buildings in Vietnamese climatic condition

To cite this article: Thi-My-Dung Do *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **869** 032008

View the [article online](#) for updates and enhancements.

Investigating the effectiveness of insulation for walls of buildings in Vietnamese climatic condition

Thi-My-Dung DO¹, Trong-Chuc NGUYEN^{2*} and Thanh-Quang-Khai LAM¹

¹Faculty of Civil Engineering, Mien Tay Construction University, Vinh Long, Vietnam

²Institute of Special Construction Engineering, Le Quy Don Technical University, Hanoi, Vietnam

E-mail: ntchuc.mta198@gmail.com

Abstract. Buildings are large heat consumers in all countries. In regions like Vietnam's climatic conditions, air temperature, and solar radiation, there is a complex relationship with the energy required for cooling in the summer and heating in the winter of residential buildings. Especially, the air temperature is always changing seasonally and affecting the living space temperature in buildings through the process of heat transfer through walls, roofs, ceilings, etc. This paper presents some common insulation materials and evaluates the effectiveness of using insulation for walls of buildings. The calculations are performed on the brick wall covered with insulating layer thickness varies in the range of from 0 cm to 10 cm. The results obtained are the basis for the design of the wall using insulation and the choice of cooling or heating equipment reasonably.

1. Introduction

In the climatic conditions of Vietnam, in the summer, the outdoor temperature is often high, while the indoor temperature is cooled by an air-conditioning system. Besides that, in the winter in the North of Vietnam, outdoor temperatures often drop and are lower than the inside temperatures of buildings (because inside the building is used air heating system). This leads to the temperature difference between inside and outside the building [1-3]. Then, the temperature difference formed the process of heat transfer through walls, roof, ceiling, floor, and glass, etc of the building. The heat transfer through a wall can exist in many ways such as contact, convection or radiation and is shown in Figure 1 [4, 5].

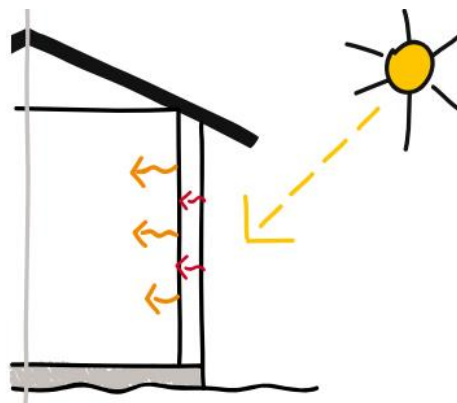


Figure 1. The process of heat transfer through a wall of the building



Currently, in the world as well as in Vietnam, insulation materials for buildings are widely used and popular. Insulation material works by slowing the transfer of heat through a wall, reducing heat exchanged between the inside and outside of the wall [6, 7].

Currently, there are many types of insulating materials be used in the construction process. These include Rockwool mineral wool, glass wool, ceramic wool, extruded polystyrene (XPS) foam, PE foam sponge, EPS (expanded polystyrene), airbag, etc and shown in Figure 2 [8]. Each insulation material has different properties and advantages and disadvantages. Therefore, the choice of insulation materials depends on the economy and the purpose of use. The basic components of some typical buildings using insulation materials are shown in Figure 3 [8].

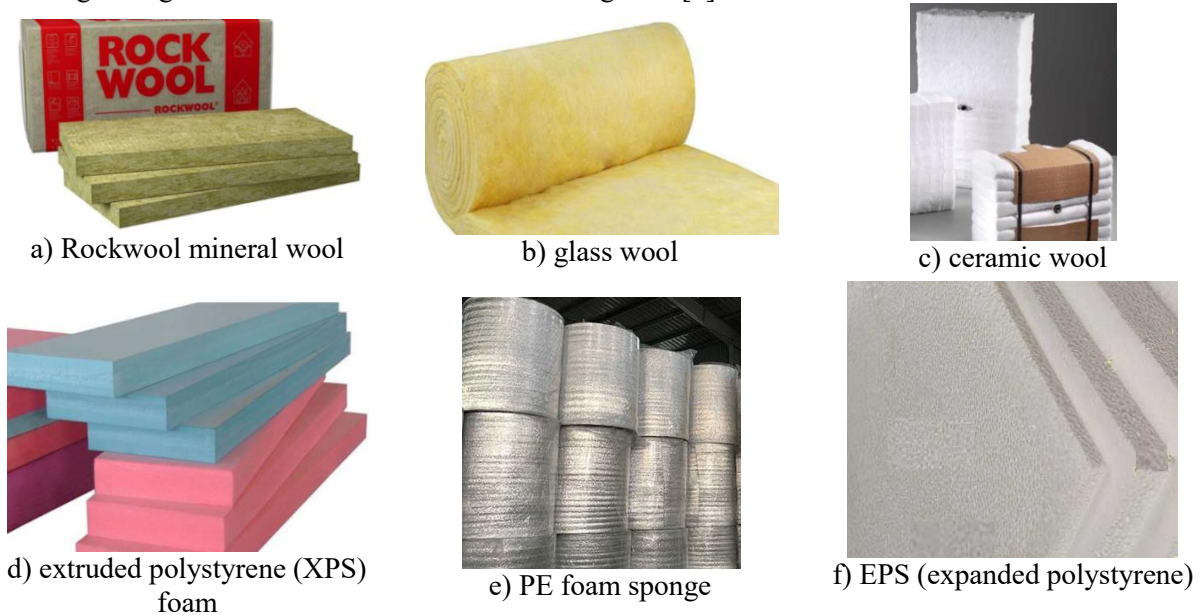


Figure 2. Some insulating materials for buildings



Figure 3. Some applications of insulation

Most of the above insulation materials are light porous because they contain large volumes of air chambers. Due to the porosity and containment of internal air cavities of the insulating element, their thermal conductivity is significantly reduced compared to solid [9-11].

To evaluate the insulation efficiency of materials based on various criteria. The criteria commonly used to evaluate the effectiveness of insulation materials: coefficient R is the thermal conductivity, $m^2 \cdot ^\circ C/W$ and heat transfer density q , W/m^2 .

Currently, the strong development of science and technology has created different types of insulation. And these types of insulation materials have been recommended and used by manufacturers. However, a detailed assessment of the effect and effectiveness of insulation thickness is still a matter of concern and research.

In this study, the authors studied the effect of insulation in buildings with their thickness changes. At the same time, the insulation material chosen for research is Rockwool mineral wool with many advantages, such as fireproof, heat and sound insulating. Rockwool mineral wool material is also produced and widely used in the Russian Federation [12].

2. Materials and methods

2.1. The basic differential equation of heat transfer

The temperature distribution in an object depends on space and time, which is determined by solving the differential equation (1) [13-15]:

$$\frac{\partial}{\partial x} \left(k_x \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left(k_y \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left(k_z \frac{\partial T}{\partial z} \right) + q_v = \rho c \frac{\partial T}{\partial t}, \quad (1)$$

where: T - temperature function depends on space and time, °C; k - heat diffusion coefficient, m^2/s ; c - specific heat capacity of the material, $\text{kJ}/\text{kg} \cdot \text{°C}$; ρ - density, kg/m^3 ; q_v - heat generated per 1 volume unit kJ/m^3 ; t - time, day.

The heat transfer is considered without an inner source ($q_v = 0$) and is given in equation (2):

$$\frac{\partial}{\partial x} \left(k_x \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left(k_y \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left(k_z \frac{\partial T}{\partial z} \right) = \rho c \frac{\partial T}{\partial t} \quad (2)$$

For homogeneous, isotropic materials ($k_x = k_y = k_z$) and stable heat transfer ($\partial T / \partial t = 0$), the differential equation (2) is written in the form of equation (3):

$$k \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) = 0 \quad (3)$$

To solve the equations (1), (2) and (3), it is necessary to use the boundary conditions of the thermal problem such as boundary condition type 1 (the law of heat distribution on an object's surface); boundary condition type 2 (the density of heat flow at the object's surface); boundary condition type 3 (convection heat transfer); boundary condition type 4 (the heat flow through the contact surface between two objects is preserved). Depending on the conditions of the problem, we use the boundary conditions accordingly [16-18].

The problem of heat transfer through a building's wall is a three-dimensional problem. However, because the width and height of each wall are much larger than the thickness of the wall. So, we consider the problem of heat transfer as one-dimensional and steady-state heat transfer. The differential equation (3) can be written as simply as equation (4):

$$k \frac{\partial^2 T}{\partial x^2} = 0 \quad (4)$$

The diagram of heat transfer through a single-wall with thickness l is shown in Figure 4.

The direction of heat transfer

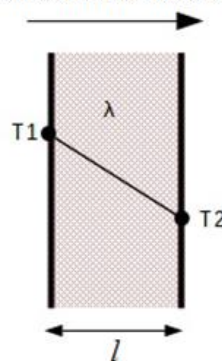


Figure 4. The amount of heat transferred through a flat wall

Using the boundary conditions of type 1 in order to solve the quadratic differential equation (4), we obtain the solution as follows (temperature distributed in the wall) and given by equation (5) [19, 20]:

$$T(x) = T_1 - \frac{T_1 - T_2}{l} x \quad (5)$$

The heat flux q (W/m^2) is determined by formula (6):

$$q = -\lambda \frac{dT}{dx} = \frac{T_1 - T_2}{\frac{l}{\lambda}} = \frac{T_1 - T_2}{R} \quad (6)$$

where: $R = l/\lambda$ - heat transfer resistance in $\text{m}^2 \cdot ^\circ\text{C}/\text{W}$.

The heat transferred Q (J) through the area F , for a time period t determined by the formula (7) [19, 20]:

$$Q = q \times F \times t \quad (7)$$

Diagram of heat transfer through multi-layer wall is shown in Figure 5. In many cases, especially with insulated walls, the heat transfer process goes through several layers of materials having different properties. This wall may be called a "composite wall".

Considering a wall made of n layers of l_i thickness and conductivity λ_i , the total resistance of composite walls is determined by equation (8) [16-18]:

The direction of heat transfer

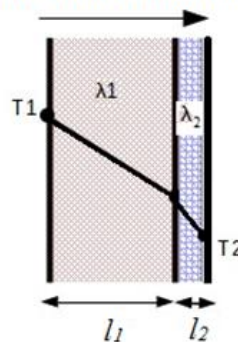


Figure 5. Heat flux through a composite wall made of a layer of insulating material

$$R_{total} = \frac{l_1}{\lambda_1} + \frac{l_2}{\lambda_2} + \dots + \frac{l_n}{\lambda_n} = \sum_{i=1}^n \frac{l_i}{\lambda_i} \quad (8)$$

where: R_{total} – heat transfer resistance of composite wall, $\text{m}^2 \cdot ^\circ\text{C}/\text{W}$; l_i – i th layer of material thickness, m ; λ_i – thermal conductivity coefficient of the i th material layer, $\text{W}/\text{m} \cdot ^\circ\text{C}$.

Because the shape of the wall is flat and simple - the layers of materials are parallel to each other, the equations (the heat flux q , the heat transferred Q) of the heat transfer process for a single-layer wall is still applied correctly for composite walls.

2.2. The working principle of insulation for walls of buildings

All thermal insulation materials work is to prevent heat energy from outside from flowing into the interior of the house (in summer) and reducing the heat loss from inside to outside (in winter).

3. Results and Discussion

Consider a brick wall with a thickness of 0.1m, length 6m, and height 3m. Assuming the temperature on the outside surface of the wall at the hottest part of the day in summer is 36°C . The temperature inside the wall (indoors) is 22°C . The brick has a coefficient of thermal conductivity $\lambda_1 = 0,8\text{W}/\text{m} \cdot ^\circ\text{C}$; Rockwool mineral wool sheet is used as insulation for walls with thermal conductivity $\lambda_2 = 0,036\text{W}/\text{m} \cdot ^\circ\text{C}$. In this study, to evaluate the effect of insulation thickness on the heat energy transfer through the wall in 1 hour.

Using the formulas (6) and (7) above, we obtain the result of the heat flux q over the wall without and using the insulation as shown in Table 1.

Table 1. Effect of insulation thickness on the heat flux q over the wall

#	Rockwool mineral wool insulation thickness, cm										
	0	1	2	3	4	5	6	7	8	9	10
The heat flux q , W/m ²	112	34.8	20.6	14.6	11.3	9.2	7.8	6.8	6.0	5.3	4.8
Heat insulation performance, %	0	37.86	63.21	73.93	79.82	83.57	86.07	87.85	89.29	90.54	91.42

The influence of insulation layer thickness on the heat flux through the wall and their insulation performance are shown in Figure 6.

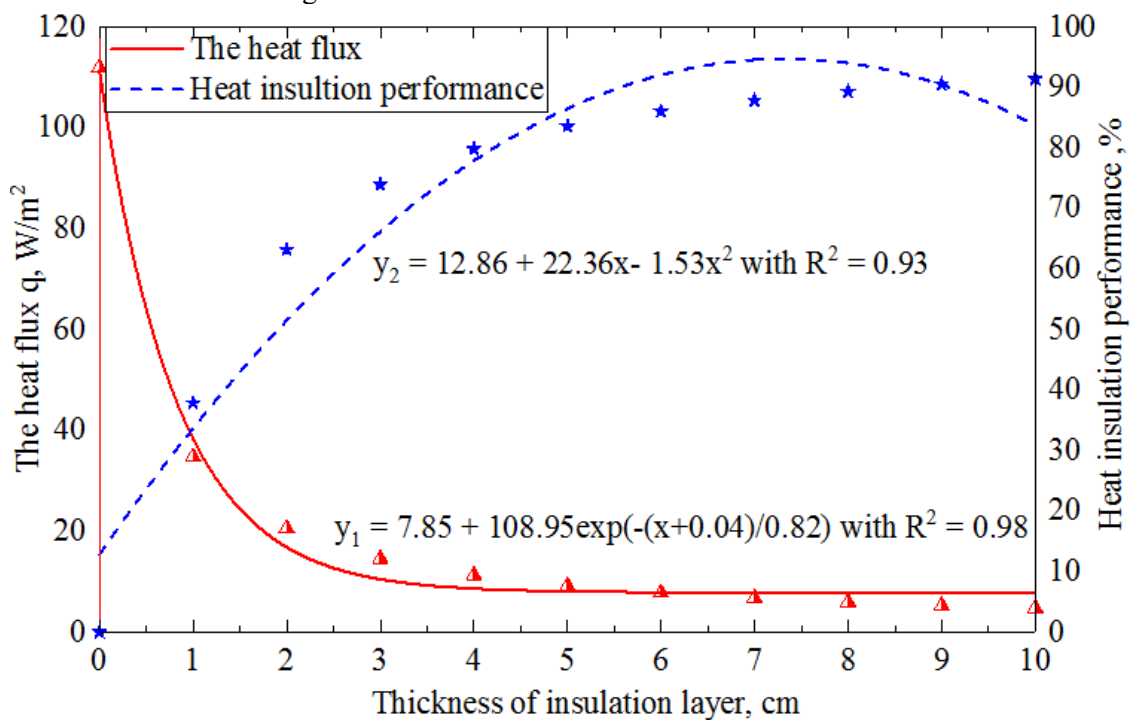


Figure 6. Relationship between insulation thickness to the heat flux through the wall and their insulation performance

From Figure 6 we can make the following remarks: The thickness of the insulation significantly affects the heat flux through the wall. In the summer when the wall without the insulation material, the heat flux through from the outside to the inside of the house through a wall is 112 W/m². To improve and reduce heat transfer through the wall, insulation material was used. It is easy to see that when the thickness of insulation changes from 0 to 4 cm, the heat flux through the wall decreases sharply from 112 W/m² to 11.3 W/m². Besides, data from Figure 6 also suggests that when increasing the thickness of the insulation layer from 4 cm to 10 cm, the degree of reducing the heat flux through the wall is negligible (from 11.3 W/m² to 4.8 W/m²). The relationship between the thickness of the insulation layer (x) and the heat flux (y_1) through a wall is given by a curve with equation (9):

$$y_1 = 7.85 + 108.95 \exp(-(x+0.04)/0.82) \text{ with } R^2 = 0.98 \tag{9}$$

The degree of the positive impact of the insulation material on the prevention of heat transfer from the outside to the inside of the building is assessed by heat insulation performance. The relationship

between the thickness of the insulation material and their insulation performance is given by the quadratic equation (10):

$$y_2 = 12.86 + 22.36x - 1.53x^2 \text{ with } R^2 = 0.93 \quad (10)$$

where: x - insulation thickness, cm

Based on the performance of the insulation layer, the process of designing buildings is necessary to select the optimal thickness of the insulation layer in order to achieve economic efficiency, space use, and aesthetics.

The heat energy transmitted through the wall in a unit of time (1 hour) is determined by the formula (7), where $F = 6 \times 3 = 18\text{m}^2$ is the area of the wall.

Table 2. The heat energy transmitted (Q) through the wall

#	Rockwool mineral wool insulation thickness, cm										
	0	1	2	3	4	5	6	7	8	9	10
Q, KJ	7257.6	2255.0	1334.9	946.1	732.2	596.2	505.4	440.6	388.8	343.4	311.0

Table 2 shows the heat energy transmitted through the wall for 1 hour with different insulation thickness. The results clearly reflect the effectiveness of the insulation for the walls of the building in Vietnamese climatic conditions.

4. Conclusions

Based on the results of the study, the following main conclusions can be drawn:

(1) The use of insulating materials for the walls of a building significantly reduces heat transfer through the wall. That means reducing heat loss when using cooling equipment (air conditioners and heaters).

(2) When the thickness of the insulation increases, the heat flux transmitted through the walls decreases. To achieve economic efficiency when using Rockwool mineral wool, we should choose a thickness of 5 cm (efficiency of heat loss reduction greater than 80%).

(3) Future research direction: It is necessary to expand the study of the effect of the insulation layer on sound insulation, fire resistance as well as waterproofing for ceilings of buildings.

References

- [1] Nguyen Son Lam, Pham Duc Hanh 2015 *Journal of construction science and technology* **43**6-41.
- [2] Jennifer L. Nguyen, Joel Schwartz, Douglas W. Dockery 2014 *Indoor Air* **24**(1) 103-112. doi: [10.1111/ina.12052](https://doi.org/10.1111/ina.12052)
- [3] Irsyad M, Pasek A D, Indartono Y S, Pratomo A W 2017 *IOP Conf. Series: Earth and Environmental Science* **60** 7p. doi: [10.1088/1755-1315/60/1/012028](https://doi.org/10.1088/1755-1315/60/1/012028)
- [4] Schiavoni S, D'Alessandro F, Bianchi F, Asdrubal F 2016 *Renewable and Sustainable Energy Reviews* **62** 988-1011. <https://doi.org/10.1016/j.rser.2016.05.045>
- [5] Sami A. Al-Sanea, Zedan M F, Al-Hussain S N 2012 *Applied Energy* **89**(1) 430-442. <https://doi.org/10.1016/j.apenergy.2011.08.009>
- [6] Jorge Lucero-Álvarez, Rodríguez-Muñoz N A, Martín-Domínguez I R 2016 *Sustainability* **8**(7) 19p. <https://doi.org/10.3390/su8070590>
- [7] Mohammed J. Al-Khawaja 2004 *Applied Thermal Engineering* **24** 2601-2610. <https://doi.org/10.1016/j.applthermaleng.2004.03.019>
- [8] Mohammad S. Al-Homoud 2005 *Building and Environment* **40**(3) 353-366. <https://doi.org/10.1016/j.buildenv.2004.05.013>
- [9] Zihlif A M, Ragosta G 2003 *Journal of Thermoplastic Composite Materials* **16**(3) 273-283.
- [10] Karamanos A, Hadjarakou S, Papadopoulos A M 2008 *Energy and Buildings* **40**(8) 1402-1411. <https://doi.org/10.1016/j.enbuild.2008.01.004>

- [11] Adel A. Abdou, Ismail M. Budaiwi 2005 *Journal of Building Physics* **29**(2) 171-184.[DOI: 10.1177/1744259105056291](https://doi.org/10.1177/1744259105056291)
- [12] Rakhimov R Z, Shelikhov N S, Konovaltseva T V 2018 *Stone wool thermal insulation. Moscow* 335p.
- [13] Trinh Van Quang 2007 *Thermal engineering for engineering students. Hanoi* 177p.
- [14] Roland W Lewis, Perumal Nithiarasu, Kankanhalli N S 2004 *Fundamentals of the finite element method for heat and fluid flow. John Wiley & Sons, Ltd* 356p.
- [15] Chuc N T, Bach L X 2019 *Magazine of Civil Engineering* **4**(88) 70-79.[DOI: 10.18720/MCE.88.7](https://doi.org/10.18720/MCE.88.7)
- [16] Chuc N T, Chinh M V, Bach L X 2019 *E3S Web of Conferences* **91** 8p.<https://doi.org/10.1051/e3sconf/20199102010>
- [17] Mahli T M I, Taufiq B N, Ismail, Masjuki H H 2007 *Energy and Buildings* **39**(2) 182-187.<https://doi.org/10.1016/j.enbuild.2006.06.002>
- [18] Meral Ozel 2014 *Energy and Buildings* **72** 288-295.<https://doi.org/10.1016/j.enbuild.2013.11.015>
- [19] Hou-Cheng Huang, Asif S. Usmani 1994 *Finite Element Analysis for Heat Transfer: Theory and Software. London* 197p.
- [20] Harry Suehrcke, Eric L. Peterson, Neville Selby 2008 *Energy and Buildings* **40**(12) 2224-2235.<https://doi.org/10.1016/j.enbuild.2008.06.015>