

## Digital Modeling for Selecting the Optimal Combination of Building and Thermal Insulation Materials

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### Abstract:

The climate of Iraq is considered continental, as it is very hot in summer and very cold in winter. Therefore, achieving thermal comfort inside the building requires high energy consumption for air conditioning purposes, which significantly increases costs during the operation and maintenance stage of the building's life cycle. The research aims to provide an organizational and technological solution by developing a digital model to select the optimal combination of building and thermal insulation materials to reduce energy consumption in buildings. The research methodology uses thermodynamic relationships and equations in programming commands and instructions. The Python language was used to develop the program, and the study's results included the creation of a simplified interface for selecting the optimal combination of building materials and thermal insulation. The thickness of the thermal insulation material determines the results produced by the program. For a thickness  $\leq$  (0.05 m), (Thermiston) was the optimum building material. While using a thickness  $>$  (0.05 m), the program specified a different group of building materials to form the optimal combination of building materials and thermal insulation materials.

### Keywords:

Building envelope; Objective function; Optimal combination; Python language; Thickness of thermal insulation material.

### Highlights:

- Digital model optimizes building and insulation material combinations.
- Python-based tool calculates thermal performance and cost-effectiveness.
- Study identifies ideal insulation thickness for energy saving in Iraq.
- Comparison of expanded polystyrene and cork for building envelope efficiency.
- Numerical approach reduces energy consumption and thermal conductivity.

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## 1. INTRODUCTION

The highest electrical energy consumption in summer in Iraq is for air conditioning, which places significant pressure on the electrical system and increases operating costs during the building's life cycle. Therefore, there is a need to find practical solutions to reduce energy demand [1]. One effective solution to reduce energy demand in buildings is to reduce heat gain in summer, which occurs through the building envelope due to its low resistance to the transfer of thermal load from outside the building into the building [2]. Increasing the thickness of the thermal insulation material effectively contributes to reducing the building's heat gain, but at the same time, increasing the thickness of the thermal insulation material will increase the cost of construction, so it is necessary to have a balance between increasing the ability of the thermal insulation material to resist heat transfer and the cost of the thermal insulation material, which is called the optimal thickness of the thermal insulation material [3]. Improving the properties of the building envelope will significantly reduce energy consumption in buildings. One of the most important components of the building envelope is the external walls, through which about 25-30% of the heat is transferred from outside to inside in the summer and vice versa in the winter [4]. The selection of the optimal combination of building materials and thermal insulation materials depends on several factors, including thermal resistance, moisture resistance, fire resistance, material cost, and material weight. In addition, selecting the optimal combination of building envelope components can be approached in multiple ways [5]. The primary objective of this research is to enhance the method for selecting the optimal combination of building materials and thermal insulation by developing a digital framework. This framework aims to provide a systematic approach that supports more informed and efficient decision-making when choosing materials for building envelopes. The theoretical background of the research drew on prior literature on improving the properties of the building envelope. The scope of this study is that the program's application is specific to the climate of Iraq, as the values of both  $R_{si}$  and  $R_{se}$  entered in the program interface are tailored to Iraqi weather and climate conditions. The methodology followed in this research relied mainly on thermodynamic equations, using thermal insulation coefficients for building materials and thermal insulation materials, as well as the different thicknesses of thermal insulation materials, to program commands and instructions within the program. This information was programmed by adopting the programming language (Python), which is characterized by its flexible ability to translate

data and equations into digital language. The results of this research will contribute significantly to the development of methods for selecting optimal materials for building envelopes, thereby enhancing the reliability of design decisions during the building's design stage.

## 2. COMPUTER PROGRAM TO SELECT THE OPTIMAL COMBINATION

After identifying the vital role played by the building envelope (especially the external walls) in the heat exchange process between the building and its external surroundings, the research seeks to develop a digital prediction technology to choose the optimal combination of external wall building materials with the thermal insulation materials, through developing a computer program for the purpose carrying out the selection process based on the data that is included in the program database. This data mainly consists of the most widely used building materials in Iraq, a set of thermal insulation materials commonly used in construction projects, and their thermal conductivity coefficients. The programming process relies on mathematical relationships derived from the wall layers' thermal-resistance equations, which are then translated into digital symbols and Python code.

## 3. PYTHON PROGRAMMING LANGUAGE

The Python language was developed by developer Guido van Rossum in 1991. The developer chose the name Python for this programming language, in reference to the book (Monty Python's Flying), a series produced by the British Broadcasting Corporation, to give it a short, distinctive name. Python is an interpreted, interactive, object-oriented programming language. It also provides high-level data structures, including associative arrays (also called dictionaries), lists, sets, rows, modules, and automatic memory management. The Python language is characterized by a relatively simple interface and programming commands that are easy to formulate, as well as the diversity of its libraries, which help reduce code by a third. As a result of these advantages, the Python language has become one of the most widely used programming languages today [6].

## 4. METHODOLOGY FOR CREATING THE PROGRAM

It was previously mentioned that the thickness of the thermal insulation material is extremely important in increasing the efficiency of the thermal insulation process in the building. Therefore, the thickness of the thermal insulation material will be the primary focus in developing a program to select the optimal combination. The programming process is carried out by including (10) building materials commonly used in Iraq with (12) thermal

insulation materials in the program database (a small set of building materials and thermal insulation materials has been included because the program is currently intended for scientific purposes only and as a kind of trial run for the program, and it is possible in the future to develop the program to include most building

materials and thermal insulation materials. The fixed parameters that are entered into the program database are the name of the building material, its thickness, and its thermal conductivity, as well as the name of the thermal insulation material and its thermal conductivity, as shown in Table 1.

**Table 1** Building Materials, Thermal Insulation Materials, and Their Thermal Conductivity Coefficients [7, 8].

Building material	Thickness of building material	Thermal conductivity coefficient K (W/m. Kelvin)	Thermal insulation material	Thermal conductivity coefficient K (W/m. Kelvin)
Reinforced concrete 1:2:4	20 cm	1.49	Expanded Ebonite	0.160
Limestone bricks	25 cm	1.23	Expanded Cork	0.043
Perforated clay bricks	24 cm	1.37	Raw Cork	0.0455
Solid clay bricks	24 cm	0.54	Wood fibres	0.150
Thermiston	20 cm	0.21	Rockwool	0.049
Hollow concrete blocks	20 cm	1.4	Expanded polystyrene	0.04
Heritage Building Bricks	20 cm	0.49	Extruded polystyrene	0.029
Building stone	30 cm	1.4	Styrofoam	0.037
Thick red bricks	24 cm	0.67	Glass wool	0.045
Gypsum boards	16 cm	0.41	Synthetic rubber	0.055
			Perlite	0.050
			PVC	0.190

Another fixed parameter that is included in the program database is the fixed thickness of the thermal insulation material, which was assumed in this study (0.05 m). The variables that are also entered into the program, but through the main interface of the program and not in the program's database, are both the resistance value of the internal surfaces of the wall ( $R_{si}$ ) and the resistance value of the external surfaces of the wall ( $R_{se}$ ), in addition to the variable thickness of the thermal insulation material. According to the Iraqi Code for Thermal Insulation, the total thermal resistance of the building wall layer is calculated using Eq. (1).

$$RT = R_{si} + R_1 + R_2 + \dots + R_n + R_{se} \quad (1)$$

where:

$RT$ : Total thermal resistance.

$R_{si}$ : Inner surface thermal resistance.

$R_{se}$ : External surface thermal resistance.

$R_1, R_2$ : The thermal resistance of each material of the wall layer.

The values of  $R_{si}$  and  $R_{se}$  vary by country, depending on prevailing climatic conditions, and are calculated using fixed criteria. For Iraq, the values of  $R_{si}$  and  $R_{se}$  according to the Iraqi code for thermal insulation [7] are:

$$R_{si} = 0.13 \text{ m}^2 \text{ K/watt}$$

$$R_{se} = 0.04 \text{ m}^2 \text{ K/watt}$$

The thermal resistance of each wall layer or of the thermal insulation material is calculated according to Eq. (2).

$$R = \frac{d}{k} \quad (2)$$

where:

$d$ : Thickness of each wall layer material.

$k$ : The thermal conductivity coefficient for each material of the wall layer or the thermal conductivity coefficient for the thermal

insulation material. (W/m. Kelvin) For the selection program, the steps were programmed so that the objective function (N), which represents the total resistance of the wall layers, was always at its maximum, ensuring the highest thermal resistance of the wall was achieved. Eq. (3) represents the objective function in the program for selecting the optimal combination of building materials and thermal insulation materials.

$$N = R_{si} + R_w + R_{se} = \text{Max} \quad (3)$$

where:

$N = RT$ : Total thermal resistance (or objective function).

$$R_w = R_m + R_i \quad (4)$$

where:

$R_m$ : Thermal resistance of building materials ( $R_m = d_m/k_m$ ).

$R_i$ : Thermal resistance of thermal insulation materials ( $R_i = d_i/k_i$ ).

$d_m$ : The thickness of the building material.

$k_m$ : Coefficient of thermal conductivity of the building material (W/m. Kelvin).

$d_i$ : The thickness of the thermal insulation material.

$k_i$ : Coefficient of thermal conductivity of thermal insulation materials (W/m. Kelvin).

The next step in programming is carried out by conducting comparison operations in the program's database for the thermal conductivity coefficients of building materials, so that the fixed thickness of the thermal insulation material, whose value is (0.05 m), which is symbolized by ( $d_x$ ), is adopted if the thermal conductivity coefficient of the building material ( $k_m$ ) is less or equal to (0.5 W/m. Kelvin), but if the thermal conductivity coefficient of building materials ( $k_m$ ) is greater than (0.5 W / m. Kelvin), in this case the

variable thickness of the thermal insulation materials, which is symbolized by the symbol ( $d_y$ ), is adopted in the objective function calculations. By applying Eq. (2), the thermal

resistance of each building material and each heat-insulating material is calculated as follows. In the first case, when ( $k_m$ )  $\leq$  (0.5 W/m. Kelvin)

$$R \text{ (for thermal insulation materials)} = [d_x/k_1, d_x/k_2, d_x/k_3, \dots, d_x/k_n] \\ = [R_{x1}, R_{x2}, R_{x3}, \dots, R_{xn}] \\ R \text{ (for building materials)} = [d_1/k_1, d_2/k_2, d_3/k_3, \dots, d_n/k_n] \\ = [R_1, R_2, R_3, \dots, R_n]$$

where:

$R_{C1}$ : Thermal resistance of the wall layers in the first case.

$$R_{C1} = \begin{pmatrix} R_{x1} + R_1, R_{x1} + R_2, R_{x1} + R_3, \dots, R_{x1} + R_n \\ R_{x2} + R_1, R_{x2} + R_2, R_{x2} + R_3, \dots, R_{x2} + R_n \\ R_{x3} + R_1, R_{x3} + R_2, R_{x3} + R_3, \dots, R_{x3} + R_n \\ \vdots \\ R_{xn} + R_1, R_{xn} + R_2, R_{xn} + R_3, \dots, R_{xn} + R_n \end{pmatrix}$$

The processes that the program performs later are to collect the thermal resistance of each thermal insulating material and each building material, and to obtain the total thermal resistance of the wall layer. Then the program compares all combinations shown in the matrix, and the three best combinations of building materials and thermal insulation

materials are selected, which achieve the three highest thermal resistance values for the wall layer.

$$R_{C1} = \begin{pmatrix} Max1 \\ Max1 \\ Max1 \end{pmatrix}$$

In the second case, when ( $k_m$ )  $>$  (0.5 w / m. Kelvin).

$$R \text{ (for thermal insulation materials)} = \{d_y/k_1, d_y/k_2, d_y/k_3, \dots, d_y/k_n\} \\ = [R_{y1}, R_{y2}, R_{y3}, \dots, R_{yn}] \\ R \text{ (for building materials)} = [d_1/k_1, d_2/k_2, d_3/k_3, \dots, d_n/k_n] \\ = [R_1, R_2, R_3, \dots, R_n]$$

where:

$R_{C2}$ : Thermal resistance of the wall layers in the second case

$$R_{C2} = \begin{pmatrix} R_{y1} + R_1, R_{y1} + R_2, R_{y1} + R_3, \dots, R_{y1} + R_n \\ R_{y2} + R_1, R_{y2} + R_2, R_{y2} + R_3, \dots, R_{y2} + R_n \\ R_{y3} + R_1, R_{y3} + R_2, R_{y3} + R_3, \dots, R_{y3} + R_n \\ \vdots \\ R_{yn} + R_1, R_{yn} + R_2, R_{yn} + R_3, \dots, R_{yn} + R_n \end{pmatrix} \\ R_{C2} = \begin{pmatrix} Max2 \\ Max2 \\ Max2 \end{pmatrix}$$

The software processes later compare the three highest values resulting from the first set ( $R_{C1}$ ) with the three highest values resulting from the second set ( $R_{C2}$ ), so that the program chooses

the three highest values resulting from the two sets, which will be the three highest values for ( $R_w$ ) for later use in Eq. (3).

$$R_w = \begin{pmatrix} Max1 \\ Max1 \\ Max1 \end{pmatrix} \text{ Comparison Process } \begin{pmatrix} Max2 \\ Max2 \\ Max2 \end{pmatrix} = \begin{pmatrix} Max1,2 \\ Max1,2 \\ Max1,2 \end{pmatrix} \\ N = R_{si} + \begin{pmatrix} Max1,2 \\ Max1,2 \\ Max1,2 \end{pmatrix} + R_{se}$$

It is possible to summarize and explain the methodology used to create the program (Selecting the optimal combination of building

materials and thermal insulation materials) as shown in Fig. 1.

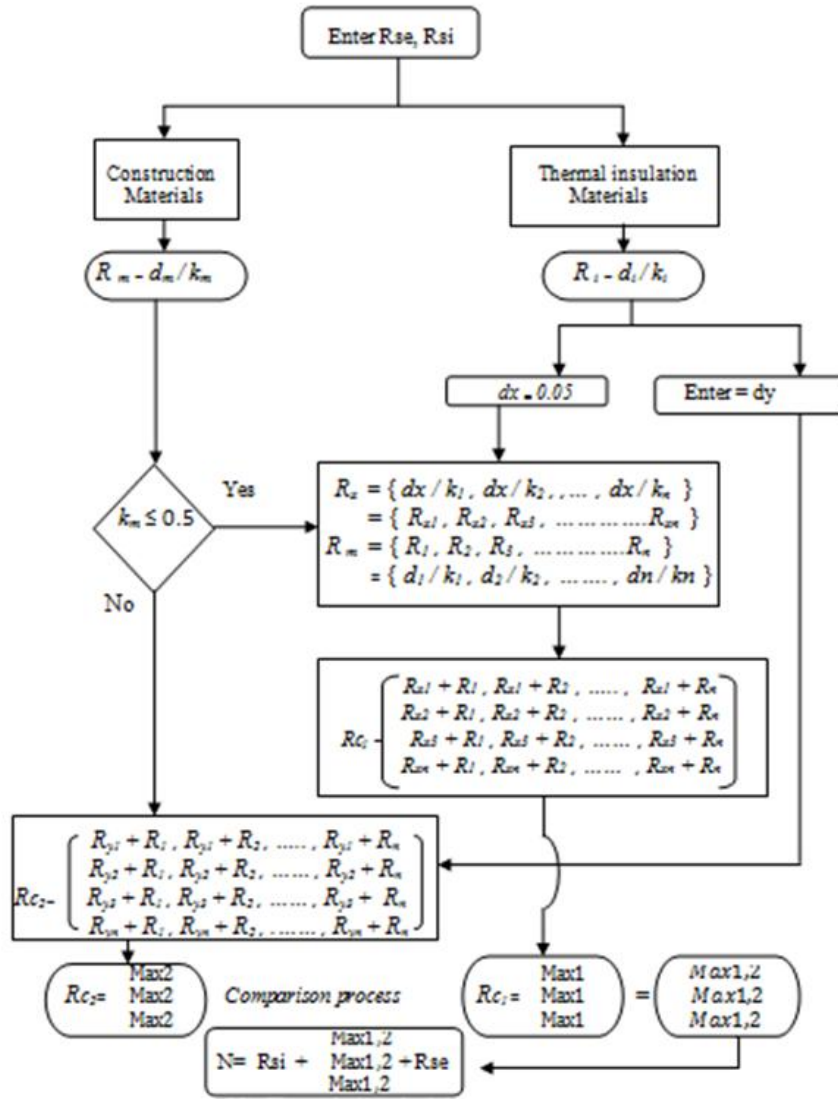


Fig. 1 Methodology for Creating the Program.

### 5.RESULTS AND DISCUSSION

The program (Selecting the optimal combination of building materials and thermal insulation materials) consists of two main

parts. The first part is the program library, which contains the program database and program codes, as shown in Fig. 2 and Fig. 3, respectively.

```

2 # coding: utf-8
3
4 # In[4]:
5
6
7 import tkinter as tk
8 from tkinter import font
9 from tkinter import ttk
10
11 # dictionaries of keys and values
12 k1 = {'Reinforced concrete 1:2:4': 1.49, 'Limestone bricks': 1.23, 'Perforated clay bricks': 1.37,
13       'Solid clay bricks': 0.54, 'Thermiston': 0.21, 'Hollow concrete blocks': 1.4,
14       'Heritage Building Bricks': 0.49, 'Building stone': 1.4, 'Thick red bricks': 0.67, 'Gypsum board':0.41}
15
16 k11 = {'Reinforced concrete 1:2:4': 0.2, 'Limestone bricks': 0.25, 'Perforated clay bricks': 0.24,
17        'Solid clay bricks': 0.24, 'Thermiston': 0.20, 'Hollow concrete blocks': 0.20,
18        'Heritage Building Bricks': 0.20, 'Building stone': 0.30, 'Thick red bricks': 0.24, 'Gypsum board':0.16}
19
20
21 k2 = {'Expanded Ebonite': 0.160, 'Expanded Cork': 0.043, 'Raw Cork': 0.0455,
22       'Wood fibres': 0.150, 'Rockwool': 0.049, 'Expanded polystyrene': 0.04,
23       'Extruded polystyrene': 0.029, 'Styrofoam': 0.037, 'Glass wool': 0.045,
24       'Synthetic rubber': 0.055, 'Perlite': 0.050, 'PVC': 0.190}
25
26
    
```

Fig. 2 Program Database.

```

50 list1=[]
51 list1names=[]
52
53
54 for key1 in k1:
55     if k1[key1]<0.5:
56         for key2 in k2:
57             t1=0.05/k2[key2]
58             list1.append(t1)
59             list1names.append(key2)
60
61 d3=(x::float(k11[x])/k1[x] for x in k1 if k1[x] <0.5)
62
63
64 d4=(x::float(k11[x])/k1[x] for x in k1 if k1[x] >0.5)
65
66
67
68
69 list2=[]
70 list2names=[]
71 d1=0.5
72 for key1 in k1:
73     if k1[key1]>0.5:
74         for key2 in k2:
75             t2=d1/k2[key2]
76             list2.append(t2)
77             list2names.append(key2)
78
79
80 T1=[]
81 T1names=[]
82 zip1names=[]
83 for key in d3:
84     for element in list1:
85         t1=d3[key]+element
86         T1.append(t1)
87         T1names.append(key)

```

**Fig. 3** Program Codes and Commands.

The second part of the program is the main interface of the program, which is a simplified interface through which the values of  $R_{si}$  and

$R_{se}$  are entered, in addition to the variable thickness of the thermal insulation material, as shown in Fig. 4.

**Fig. 4** Main Interface of the Program.

Through the main interface of the program, the values  $R_{si}$  and  $R_{se}$  were entered, which according to the Iraqi thermal Insulation Code are (0.13) and (0.04) respectively [7]. The variable thickness of the thermal insulation material is also entered. In the first case, a variable thickness of the thermal insulation material was chosen, with a value less than 0.05 m, representing the fixed (assumed) thickness. The comparison results for the three greatest values of the objective function were as follows:

- 1) In the first ranking came the combination of building material (Thermiston) with thermal insulation material (Extruded polystyrene).
- 2) In second ranking was the combination of (Thermiston) and (Styrofoam).
- 3) In the third ranking was the combination of (Thermiston) and (Expanded polystyrene) as shown in Fig. 5.

Ranking	Construction Materials	Thermal insulation materials	target function
1	Thermiston	Extruded polystyrene	2.846518883415435
2	Thermiston	Styrofoam	2.473732303732304
3	Thermiston	Expanded polystyrene	2.3723809523809525

**Fig. 5** Program Results for Variable Thickness Less than (0.05 m).

In the second case, a variable thickness of the thermal insulation material greater than 0.05 m was chosen. The comparison results for the three greatest values of the objective function were as follows:

1) In the first ranking came the combination of building material (solid clay bricks) with thermal insulation material (extruded polystyrene).

2) In the second ranking was the combination of (thick red bricks) with (extruded polystyrene).

3) In the third ranking came the combination of (building stone) with (extruded polystyrene) as shown in Fig. 6.

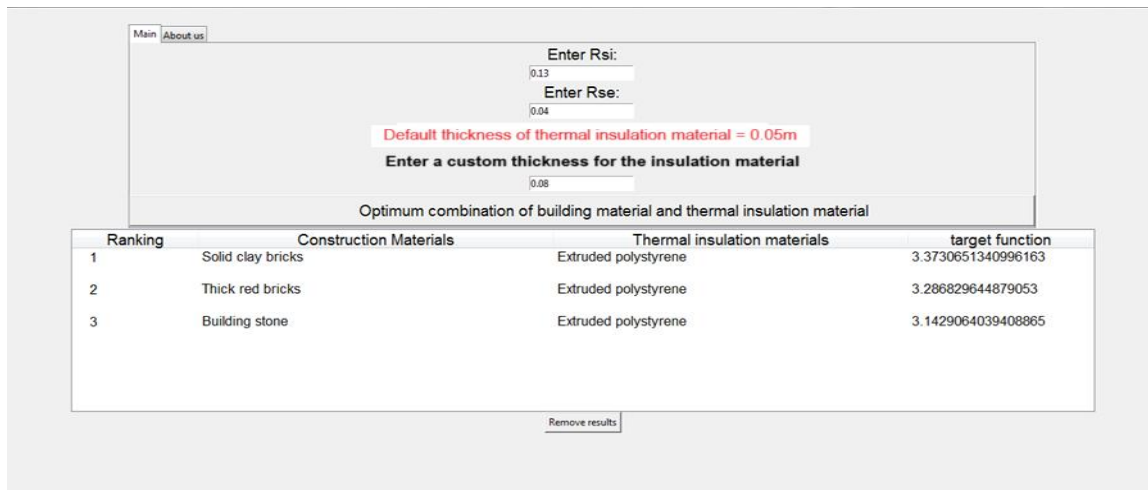


Fig. 6 Program Results for Variable Thicknesses Greater than (0.05 m).

### 5.1. Program Characteristics

- 1) The program is considered the first version in the world in the field of selecting the optimal combination of building materials and thermal insulation materials.
- 2) Easy to use.
- 3) It does not require courses or classes to learn how to use it.
- 4) It does not require a specialist to operate it.
- 5) The program has a simple user interface.
- 6) To obtain different results, the program only needs to change one parameter in the program interface.
- 7) The program can be developed and updated.
- 8) The program has a database that can be updated in all languages of the world.
- 9) It does not require a large memory space when installed on smart phones or computers.
- 10) It is considered one of the results of organizational and technological modeling in the field of choosing the opaque parts of the building envelope.

### 5.2. Importance of the Program

- 1) The program supports engineers and builders in the decision-making process regarding choosing the optimal combination of building materials and thermal insulation materials.
- 2) The program provides the three optimal options for the opaque parts of the building envelope.
- 3) The program saves a lot of time needed to choose the optimal combination of

building materials and thermal insulation materials.

- 4) The program saves the effort spent on manual calculations to choose the opaque parts of the building envelope.
- 5) Reduces the human mistakes in the selection process.
- 6) It reduces the cost of thermal insulation materials by determining the optimal thickness that provides the best thermal insulation at the lowest cost.
- 7) The program is considered a reliable scientific base for researchers and graduate students in the field of comparing and choosing the optimal combination of building materials and thermal insulation materials.
- 8) Digital application of thermodynamic equations for calculating the thermal resistance of wall layers.

### 6. CONCLUSION

Using thermodynamic equations and thermal insulation coefficients for building materials and thermal insulation, a digital method was developed to select the optimal combination of building envelope materials. The data and equations were translated into Python commands and instructions. The research results were presented by creating a computer program (which can be considered the first of its kind) capable of deducing the three optimal combinations of building materials and thermal insulation materials for different thermal insulation thicknesses. The program interface contains two types of thermal insulation material thickness, one of which is fixed (0.05 m), which is considered the minimum thickness

used for the thermal insulation material. This thickness was adopted for comparison with the variable thickness of the thermal insulation material (greater than 0.05 m), which is determined each time the optimal combination is sought. Another result of the program is that the objective function will attain its three highest values in all cases. This digital method can facilitate selecting the optimal combination of building and thermal insulation materials based on their thermal coefficients.

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