

Analysis of the effectiveness of thermal insulation of a multi-layer reinforced concrete slab using layer of concrete with low thermal conductivity under the climatic conditions of Vietnam

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Abstract. Multi-layer reinforced concrete slabs with thermal insulation materials are widely used in practice all over the world. In Vietnam, in order to apply modern construction of multi-layer structures with an inner layer of low thermal conductivity concrete into practice, it is necessary to conduct numerical researches on the peculiarities of the country climatic conditions country. In this paper, the authors analyze the heat transfer in multilayer reinforced concrete slabs' roof under the climatic conditions of Hanoi (Vietnam) using finite element method with computer simulation. The object of the study is the insulating capacity of multilayer reinforced concrete roofs under the influence of changes in the temperature of the outer surface of the structure of the buildings' roof. The research methods are based on the numerical simulation of heat transfer from the outer to the inner surface of the building roof. From the results obtained, compared to the traditional design solution, multilayer reinforced concrete slab appears to have more advantages, and these advantages are available with the use of heat-insulating material made of polystyrene concrete. These scientific researches enable to choose the rational roof design in Vietnam, which satisfies the demand to reduce influence of temperature.

1 Introduction

Vietnam is located in the sub-Equatorial monsoon climate. Winter in the North of Vietnam is cold, the air temperature sometimes drops to 1°C. In the Summer in the North of Vietnam, the highest temperature can reach up to 50°C, taking into account the influence of solar radiation. Therefore, the structure of the building roof must provide the required heat transfer resistance for the operating conditions of the buildings with internal temperature between (20-25)°C for the climatic conditions of Hanoi (Vietnam) to guarantee the coolness in summer and warmth in winter [1].

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Table 1. The characteristics of the materials used

No.	The material within layers	Material characteristic of the layers
1	Ceramic tile	$\lambda=0,81 \text{ W/(m.K)}$; $C=0,81 \text{ kJ/kg}^{\circ}\text{K}$; $\gamma = 1800 \text{ kg/m}^3$
2	Mortar layer	$\lambda=0,93 \text{ W/(m.K)}$; $C=0,84 \text{ kJ/kg}^{\circ}\text{K}$; $\gamma= 1800 \text{ kg/m}^3$
3	Porous bricks with rectangular holes 120x200mm	$\lambda=0,81 \text{ W/(m.K)}$; $C=0,88 \text{ kJ/kg}^{\circ}\text{K}$; $\gamma= 1800 \text{ kg/m}^3$
4	Slag concrete	$\lambda=0,41 \text{ W/(m.K)}$; $C=0,75 \text{ kJ/kg}^{\circ}\text{K}$; $\gamma= 1000 \text{ kg/m}^3$
5	Waterproof cement	$\lambda=0,93 \text{ W/(m.K)}$; $C=0,84 \text{ kJ/kg}^{\circ}\text{K}$; $\gamma= 1900 \text{ kg/m}^3$
6	Concrete Slab_ B12,5	$\lambda=1,55 \text{ W/(m.K)}$; $C=0,84 \text{ kJ/kg}^{\circ}\text{K}$; $\gamma = 2400 \text{ kg/m}^3$
7	Polystyrene concrete B1,5 (D350)	$\lambda=0,095 \text{ W/(m.K)}$; $C=0,88 \text{ kJ/kg}^{\circ}\text{K}$; $\gamma = 350 \text{ kg/m}^3$
8	Polystyrene	$\lambda=0,04 \text{ W/(m.K)}$; $C=1,38 \text{ kJ/kg}^{\circ}\text{K}$; $\gamma = 38 \text{ kg/m}^3$

Under the climatic conditions of Hanoi, the required heat transfer resistance (R_{0yc}) is determined by the formula (17) and (23) standard TCVN 4605-1988 [9] “Heating techniques - insulating component - Designs standard” и QCVN 09-2013 [10] “National technical regulation on Energy efficiency building” $R_{0yc} \geq 1,00 \text{ (m}^2 \cdot \text{K/W)}$ is obtained ; the calculated temperature of the interior air $t_i=20^{\circ}\text{C}$; Calculated temperature of the outside air $t_n=5^{\circ}\text{C}$ in winter & $t_n=30,3^{\circ}\text{C}$ in the summer, when considering solar radiation factors and other conditions, the estimated outdoor temperature is determined by: $t_{ig} \cdot t_b = t_n + \varphi \cdot I_{tb} / \alpha_n = 49,64^{\circ}\text{C} \approx 50^{\circ}\text{C}$; the heat transfer coefficient of the inner surface of the enclosing structure, for smooth ceilings is $\alpha_i=5,9 \text{ W/m}^2 \cdot \text{K}$ – (table 3 - TCVN 4605-1988); heat transfer coefficient (for winter conditions) of the outer surface of the enclosing structure, for roofs equal to Hanoi, $\alpha_n=25 \text{ (W/m}^2 \cdot \text{K)}$ – (table 4* TCVN 4605-1988).

In this article, the authors use three-layer slabs, which have an external layer of concrete class B12, 5, the thickness of the external layers of 40 mm and the inner layer of concrete with low thermal conductivity, with a compression resistance of the order of 1.5 MPa (D350) [2, 3, 11, 12]. The thickness of the inner layer x (mm) is determined from the required heat transfer resistance in Vietnam.

Heat transfer resistance R_0 , ($\text{m}^2 \cdot \text{K/W}$), we find the formula (1) TCVN 4605-1988 [9] “ Heating techniques-insulating component-Designs standard ”

$$R_0 = \frac{1}{\alpha_i} + R_{kc} + \frac{1}{\alpha_n} \tag{1}$$

R_{kc} - thermal resistance of the enclosing structure with successive homogeneous layers, defined as the sum of the thermal resistances of the individual layers.

Under the climatic conditions of Hanoi, by substituting in the original formula (1), numerical values are found.

$$R_0 = \frac{1}{5,9} + \frac{0,04}{1,55} + \frac{x}{0,095} + \frac{0,04}{1,55} + \frac{1}{25} \geq R_{0yc} = 1(\text{m}^2 \cdot \text{K} / \text{W}) \Rightarrow x \geq 0,07\text{m}$$

The thickness of the inner layer $x= 0,12 \text{ m}$. Three-layer plate heat transfer resistance $R_0=1,54 \text{ (m}^2 \cdot \text{K/W)}$, and plate thickness $h= 0,04+0,12+0,04 = 0,2(\text{m})$.

The size of the sandwich plate 1500x6000x200 mm (figure 5).

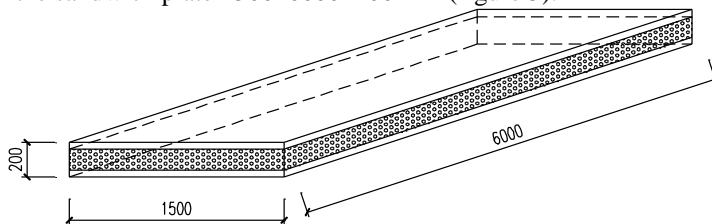


Fig. 5. The size of the sandwich plate 1500x6000x200 mm

To assess the possibility of using three-layer panels to improve the required heat transfer for the roof, the authors will solve following problems:

- Comparison of the possibility of insulation of three-layer plates (TN-1-in table.2) with thermal insulation of several thermal insulation roof designs, which are commonly used in Vietnam (TN-2, TN-3 and TN-4 in table.2).

- Comparison of the possibility of insulation of three-layer plates (TN-1-in table.2) with thermal insulation of two solutions of thermal insulation roof designs offered in Vietnam standard (TN-5 and TN-6 in table.3).

Table 2. Some thermal insulation for roof design solutions, plate thickness 200mm

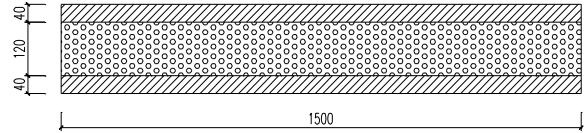
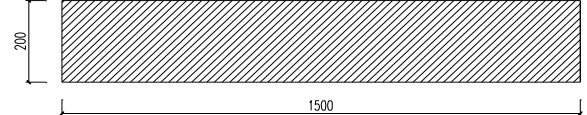
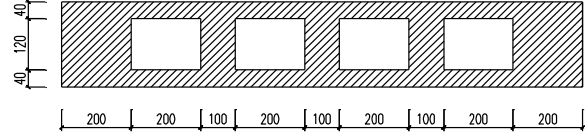
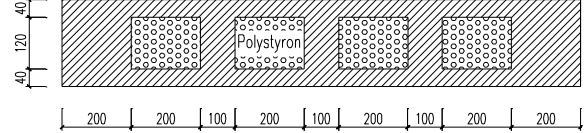
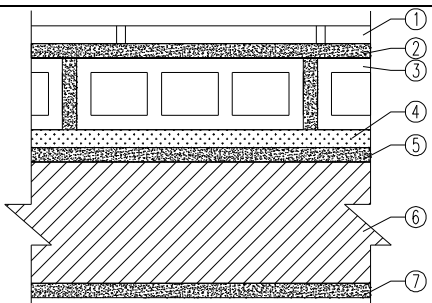
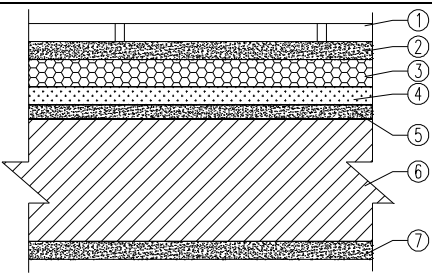
No.	Section of the roof slabs	Details of the layers
TN-1		- External layer: concrete B12,5, thickness 50mm. - Interior layer: Polystyrene concrete B1,5 (D350), thickness 120mm.
TN-2		- Reinforced concrete structure B12,5, thickness 200mm.
TN-3		- Reinforced concrete structure (B12,5), thickness 200mm with hole 120x200mm.
TN-4		- Reinforced concrete structure (B12,5), thickness 200mm, with foam block 120x200mm

Table 3. Two solutions of thermal insulation roof structures offered in standard Vietnam (QCVN 09-2013) [10]

No.	Section of the floor	Details of the layers
TN-5		1. Ceramic tile: thickness $\delta_1=0,015m$; size 200x200x15mm 2. Mortar layer: thickness $\delta_2=0,02m$; 3. Porous bricks: thickness $\delta_3=0,105m$; размер 200x200x105mm 4. Slag concrete: thickness $\delta_4=0,02m$; 5. Waterproof cement: thickness $\delta_5=0,02m$; 6. Concrete slab: thickness $\delta_6=0,12m$; 7. Mortar layer: thickness $\delta_7=0,02m$; Sum thickness of the floor: 0, 33m Heat transfer resistance: $R_0=1,006 m^2.K/W$
TN-6		1. Ceramic tile : thickness $\delta_1=0,015m$; размер 200x200x15mm 2. Mortar layer : thickness $\delta_2=0,02m$; 3. Polystyrene : thickness $\delta_6=0,05m$; 4. Mortar layer : thickness $\delta_2=0,02m$; 5. Waterproof cement : thickness $\delta_5=0,02m$; 6. Concrete slab : thickness $\delta_6=0,12m$; 7. Mortar layer : thickness $\delta_7=0,02m$; Sum thickness of the floor: 0, 265m Heat transfer resistance: $R_0 =1,545 m^2.K/W$

The authors analyze the heat transfer in a multi-layer reinforced concrete slab with the help of a complex computer program ANSYS, which is one of the modern programs, allowing users to put in necessary data, for example: thickness, physical and mechanical characteristics, etc. So that the results are approximate to the empirical results.

The heat transfer equation in multilayer reinforced concrete slab [8]:

$$\frac{\partial}{\partial x} \left(\lambda_x \frac{\partial t}{\partial x} \right) + \frac{\partial}{\partial y} \left(\lambda_y \frac{\partial t}{\partial y} \right) + \frac{\partial}{\partial z} \left(\lambda_z \frac{\partial t}{\partial z} \right) = \rho c \frac{\partial t}{\partial \tau} \quad (3)$$

With: $t(x,y,z,t)$ – temperature in coordinates (x, y, z) at time t ($^{\circ}\text{C}$);

$\lambda_x, \lambda_y, \lambda_z$ – thermal conductivity coefficients of concrete along the x,y,z axes $\text{W}/(\text{m}\cdot^{\circ}\text{K})$;

c - specific heat ($\text{kJ}/\text{kg}\cdot^{\circ}\text{K}$);

ρ - density ($\text{kJ}/\text{kg}\cdot^{\circ}\text{K}$).

3 Results and discussion

3.1 Comparison of the possibility of insulation of three-layer plates (TN-1 in table.2) with thermal insulation of several thermal insulation roof designs, which are commonly used in Vietnam (TN-2, TN-3 and TN-4 in table.2)

Using software ANSYS 18.0, the authors analyze heat transfer through roof structures (TN-1, TN-2, TN- 3 and TN- 4 in table 2) with material parameters in table 1 and climatic conditions in Hanoi, Vietnam. In summer, the calculated air temperature of the outer surface of the enclosing structure $t_n = 50^{\circ}\text{C}$ and the air temperature of the inner surface of the enclosing structure $t_i=20^{\circ}\text{C}$. The results are shown in figures 6, 7, 8, 9 and 10.

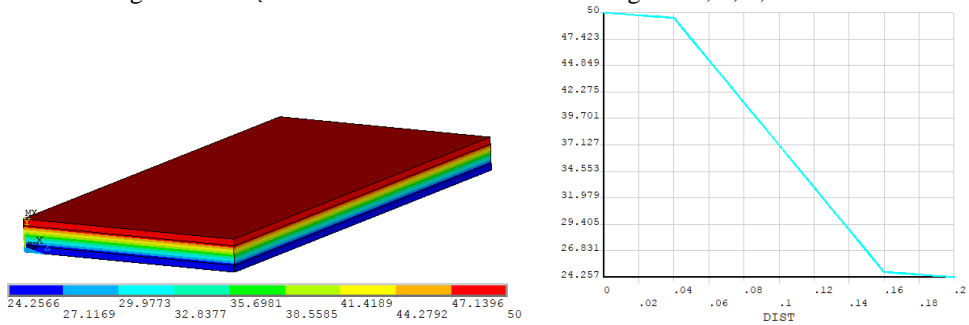


Fig. 6. Temperature distribution over the thickness of a multilayer reinforced concrete slab (TN-1)

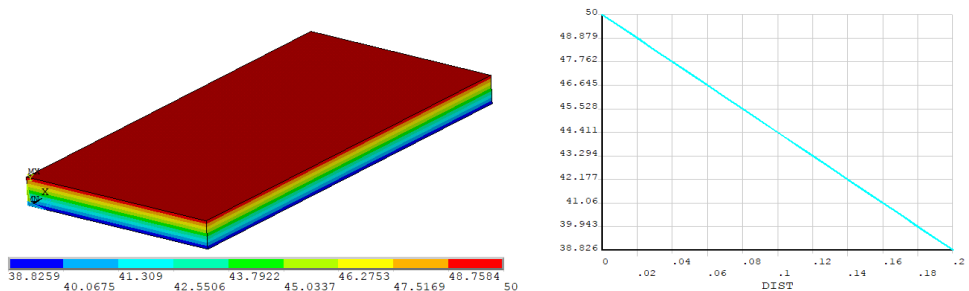


Fig. 7. Temperature distribution over the thickness of reinforced concrete slab (TN-2)

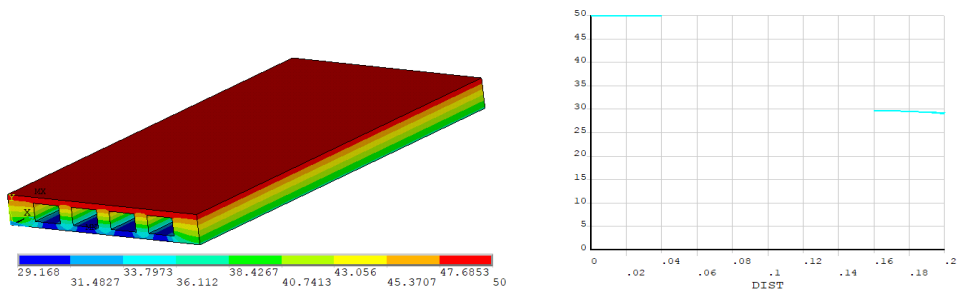


Fig. 8. Temperature distribution over the thickness of the hollow reinforced concrete slab (TN-3)

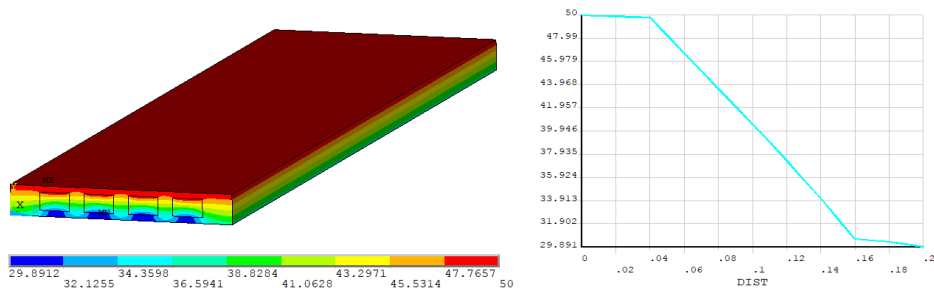


Fig. 9. Temperature distribution in reinforced concrete slab (using polystyrene block) TN-4

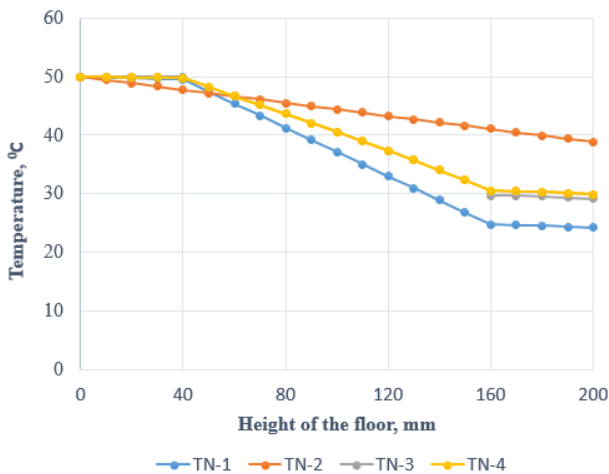


Fig.10. Comparison chart of heat distribution over thickness of slabs (TN-1, TN-2, TN-3 и TN-4)

The results of the analysis illustrate that at the same thickness of 200 mm, a three-layer plate with an interior layer of low thermal conductivity concrete has more possibility of thermal insulation (compared to other types of structures) than other types of structures mentioned. The temperature of the inner surface of three-layer structure of the roof will increase 4,26°C; solid concrete slab will increase 18,83°C; hollow concrete slab (porosity 32%) will increase 9,168° C and reinforced concrete slab (polystyrene blocks inserted, 32% of the area of the plane) will increase 9,891° C.

3.2 Comparison of the possibility of insulation of three-layer plates (TN-1-in table.2) with thermal insulation of two solutions of thermal insulation roof designs (TN-5 and TN-6 in table.3) offered in standard of Vietnam [10]

As in sections (a), the authors consider that the temperatures of the internal and external surfaces of the roof structure are $t_n = 50^{\circ}\text{C}$ and $t_t = 20^{\circ}\text{C}$ for the analysis of heat transfer processes through the roof structures (in table 3) on ANSYS programs. The results are shown in figures 11 and 12.

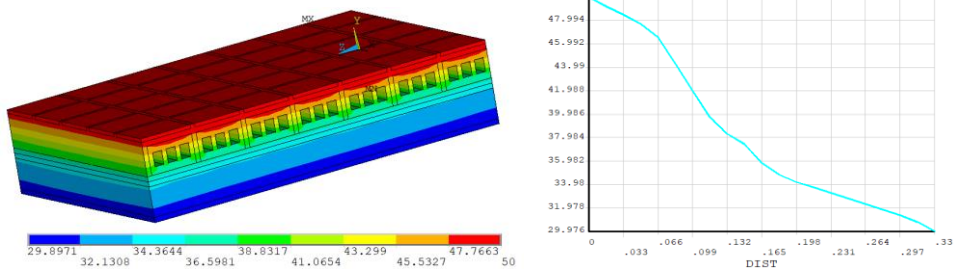


Fig.11. The temperature distribution over the thickness of the plate TN-5

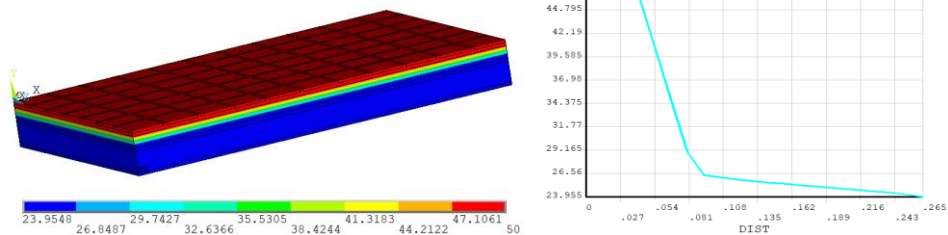


Fig.12. The temperature distribution over the thickness of the plate TN-6

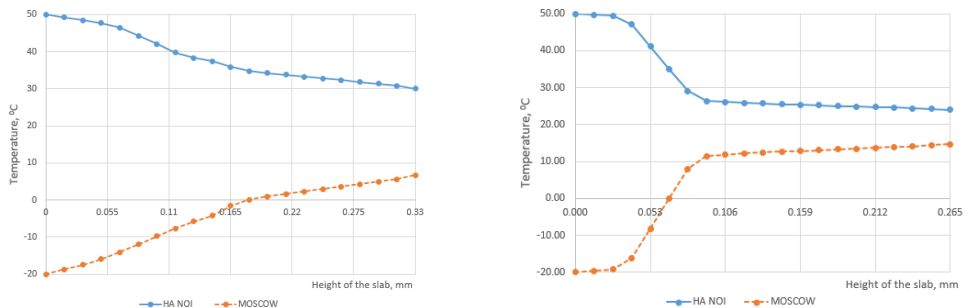


Fig.13. The temperature distribution over the thickness of the roof structure TN-5 (a) & TN-6 (b)

Similarly, analyze of heat transfer through the roof structure TN-5 and TN-6, when the external temperature of roof structure is $t_n = -20^{\circ}\text{C}$, the internal temperature is $t_t = 20^{\circ}\text{C}$ (corresponding to temperature in Moscow). The results of analysis of heat transfer through the structure with the conditions weather in Hanoi and Moscow are then compared. The results are shown in figures 13a and 13b.

The results of the analysis of heat transfer on some types of structures demonstrate that the three-layer reinforced concrete structure has a smaller thickness than other structural solutions with a thermal insulation layer of polystyrene.

In Vietnam, the biggest problem is eliminating the thermal insulation from outside into the buildings, which is opposite in countries with cold winter period (exp: Russia).

Therefore, this study considering the potential and appropriate aspects of the three-layer reinforced concrete structure under the climatic conditions of Vietnam has great practical meaning.

4 Conclusions

1. Three-layer reinforced concrete roof with an inner layer of concrete with low thermal conductivity is a rational, technological constructing solution under the climatic conditions of Vietnam, which allows to provide the required parameters of the microclimate, creating a comfortable mode for indoor-life.

2. The advantages of the investigated three-layer design compared to traditional solutions are: increasing thermal uniformity due to the reduction of heat-conducting inclusions and increasing manufacturability by reducing the duration and complexity of work.

3. The use of lightweight concretes with low thermal conductivity as a thermal insulation layer of three-layer reinforced concrete roof structures can increase the structural strength of the insulation, along with the overall durability and reliability of the structure.

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