Simulation of energy-efficient building prototype using different insulating materials

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Abstract. The objective of this work is to analyze the energetic efficiency of an individual building including an area of 130 m² multi-zone, located in the region of FEZ which is characterized by a very hot and dry climate in summer and a quite cold one in winter, by incorporating insulating materials. This study was performed using TRNSYS simulation software during a typical year of the FEZ region. Our simulation consists in developing a comparative study of two types of polystyrene and silica-aerogel insulation materials, in order to determine the best thermal performance. The results show that the thermal insulation of the building envelope is among the most effective solutions that give a significant reduction in energy requirements. Similarly, the use of silica-aerogels gives a good thermal performance, and therefore a good energy gain.

1. Introduction

The Moroccan Government aims to achieve a primary energy saving of about 12% on the 2020 horizon in the various economic sectors. Indeed, the building sector is one of the most energy-consuming in Morocco and rises up to 35% of the total power consumed by the country. This makes this sector a priority for the application of energy savings. The thermal insulation plays a main role in the reduction of energy consumption and also in the creation of a healthy and more comfortable space of life. That is why, a lot of research and studies are developed in order to improve the thermal insulation of buildings.

Among these studies, M. S. Mohsen et al. [1] focused on energy savings by building insulation using different materials such as polystyrene, rock wool and air gap. The results obtained showed that the use of polystyrene in wall and roof insulation could reach 77% energy savings, whereas rock wool cannot exceed 73%.

M. Ozel et al [2] studied the influence of the solar absorption of the external surface facing south, on the annual transmission loads of cooling and heating. The solar absorption coefficient of the outer surface has been varied from 0 to 1, with increments of 0.2, and extruded polystyrene was selected as insulating material. The results show that for insulated and non-insulated walls, the solar absorption coefficient influences very little the optimum thickness of the insulator, but has a greater effect on energy savings.
M. Ibrahim et al [3] has experimentally and analytically studied the thermal performance of exterior walls protected by an insulation layer based on «silica- aerogels ". The objective is to optimize the composition of the outer wall layers for the following cases: continuous heating, intermittent heating and no heating. For this purpose, six wall configurations were examined: insulation on the outside, insulation on the inside, insulation on the inside and outside, insulation in the middle, insulation in the middle and on the outside, insulation in the middle and on the inside. The results showed that the coating gives a better result than the traditional insulators.

Diagnosing the energy performance of a building provides information on the energy performance of a dwelling or building by evaluating the amount of energy actually consumed or estimated and its impact on greenhouse gas emissions. It describes the building or housing and its equipment for heating, air conditioning, for the production of sanitary hot water, cooling, ventilation, as well as the conditions of their use related to thermal comfort. It indicates, as the case may be, the amount of energy actually consumed (on the basis of the invoices), or the estimated energy consumption for a standardized use of the building or housing (with a method of calculation).

This is done initially by calculating the annual heating and cooling requirements per square-meter of the tested building, depending on the thermo-physical properties of its enclosure, the climatic zone, the rate of the glazed bays of the heated and/ or cooled spaces as well as their distribution on the various directions.

The chosen example is the diagnosis of energy efficiency (using the simulation software TRNSYS [4]), of an individual building having an area of 130 m². The local is located in the region of Fez. Insulating materials are tested in order to determine their impact on the energy consumption. In this simulation, we examined the improvement brought by insulation of the roofs and the exterior walls by two types of polystyrene insulation materials and a silica-aerogels-based coating.

2. Description of the building

The project considers an individual house with an area of 130 m² including a bedroom, two living rooms, a kitchen, a restroom, a bathroom and a hall. It is located in the region of Fez, which is characterized by a very hot and dry climate in summer and a quite cold one in winter. The composition of the walls constituting the building is described in the Table-1:

![Figure 1. Scheme of the tested building](image)
Table 1. Composition of the walls

| Wall    | Constitution (inside to outside)                                                                 | U (W/m².K) |
|---------|-------------------------------------------------------------------------------------------------|-------------|
| Outside wall | Coating (1,2 cm) + Brick (15 cm) + air layer (5 cm) + Brick (15 cm) + Coating (1,2 cm)        | 0,525       |
| Roof    | Mortar (2 cm) + Slabs 05_4 (15 cm) + Slabs 12_Concrete (10 cm) + Mortar (2 cm)                | 0,813       |
| Floor   | Tile (3 cm) + Mortar (3 cm) + Concrete _c600 (20 cm)                                           | 0,893       |
| Window  | Double Glazing                                                                                  | 2,95        |

3. Modeling

The dynamic behavior of the building is simulated through a multi-zone transient modeling by TRNSYS with a time step of 1h. We have divided the building into seven thermal zones. The simulation consists of calculating the cooling and heating requirements according to the standards applied in Morocco, the temperature of thermal comfort for heating is 20 °C and for air conditioning of 26 °C. The climatic data of the Fez region, taken from the METEONORM [7] software, have been integrated into the TMY2 form. The figure below presents the modeling of the building studied in the software "TRNSYS simulation Studio".

![Diagram of the building model](image)

The study is made according to the basic model of ordinary construction in Morocco, without any improvement in the energy efficiency of the building. The graph below illustrates the heating and cooling requirements of the building.
Figure 3. Monthly evolution of the building energy requirements

It is noted in Figure 3 that the heating period extends from November to March, while that of refreshment starts in May and ends in October. It may also be observed that the heating and cooling peaks correspond respectively to the months January and July. By calculating the annual energy requirements, the results mentioned in Table 2, are obtained.

Table 2. Calculation of building energy requirements

|                      | Annual Heating requirements (KWh/year) | Annual Air Conditioning requirements (KWh/year) | Energy Performance (KWh/m².year) |
|----------------------|----------------------------------------|-------------------------------------------------|---------------------------------|
| Tested building      | 4299                                   | 5912                                           | 78,54                           |

4. Proposed improvements

4.1 The impact of insulation

In this simulation, we were able to study the effect of insulation on energy efficiency using extruded polystyrene. The insulation was used by varying its thickness between 1 cm and 6 cm, for the exterior walls, the roof and the floor, in order to determine the part which must be isolated as a priority.
Figure 4. Energy consumption and performance according to the thickness of the insulator

In view of these results, it can be observed that the insulation of the roof and the outside walls is accompanied by a considerable decrease of energy requirement in heating and air conditioning when the thickness of the insulation increases. This need seems to stabilize from a thickness of 6 cm insulation. The insulation of the outside walls can thus bring an energy gain in the order of 7.80%, and that of the roof, contributes to a gain of 20.45%, thus much more important than the external walls. Whereas, floor insulation has no influence on energy consumption and performance. Since there is non-heat exchange.

4.2 Comparative Study: choice of insulating materials

Then the simulation is centered on the suitability of the choice of insulating materials. Thus, we choose for the outside walls and the roof two types of insulation: the polystyrene and a silica-aerogel-based coating.

Silica-aerogel are lightweight and have exceptional thermal properties (high porosity, low density and low thermal conductivity). The technique used is based on the application of such an insulating and innovative coating based on the aerogels of silica for the outside surface of the building in order to make a thermal insulating coating.

The characteristics of the materials are described in the following table:

Table 3. Characteristics of the insulating materials used

| Materials           | Thickness (cm) | Thermal conductivity (W/m.K) | Density (Kg/m³) | Specific heat (J/Kg.K) |
|---------------------|----------------|------------------------------|-----------------|------------------------|
| Polystyrene         | 6              | 0.030                        | 35              | 1180                   |
| Silica-aerogel-based coating | 6              | 0.027                        | 200             | 1100                   |
Figure 5. Calculation of the building's annual energy requirements according to the insulation material

The results of the calculation show a clear improvement in terms of energy requirements when using innovative insulating materials, since energy gain can reach 29% using silica-aerogel-based coating and 28% using polystyrene

4.3 Effect of the external surface temperature on the transmission loads

Mathematical model

Considering an external wall subjected to several variations of parameters, ambient temperature, solar radiation, convection and radiation, as shown in the diagram below:

\[
\begin{align*}
-\lambda \frac{\partial T}{\partial x} \bigg|_{x=v_p} &= h_{e,\rho} (T_{amb} - T_p) + \alpha I_s + q_{r,\rho} \\
\end{align*}
\]

(1)

The radiation exchange \(q_{r,\rho}\) is given by [5]:

\[
q_{r,\rho} = \varepsilon_0 \sigma (T_{sky}^4 - T_p^4)
\]

(2)

Where \(\varepsilon_0\) is the surface emissivity appropriate to materials, and the sky temperature can be calculated as follows [6].
\[ T_{\text{sky}} = 0.0552 T_{\text{amb}}^{1.5} \]  
(3)

The convective heat transfer coefficient has been estimated according to [6]:

\[ h_{c,o} = 2.8 + 3.3V \]  
(4)

Where:

- \( q_{s,a} \): Radiation density of heat flux;
- \( h_{c,o} \): Convection thermal transmission coefficient;
- \( V \): Wind speed;
- \( \varepsilon_{p} \): Emissivity of the material;
- \( \sigma \): Stefan-Boltzmann constant;
- \( \alpha \): Absorption coefficient;
- \( T_{\text{amb}} \): Ambient temperature;
- \( T_{\text{sky}} \): Sky temperature;
- \( T_{p} \): Outside surface temperature;

Discrete equation:

\[ -\lambda \frac{(T_i - T_{i-1})}{\Delta x} = h_{c,o}(T_{\text{amb}} - T_{p}) + \alpha I_s + q_{r,o} \]  
(5)

With:

- \( T_i = T_{p} \)
- \( T_{i-1} = T_{\text{amb}} \)
- \( \Delta x = \) The mesh step

We can also determine the outside surface temperature of the roof:

\[ \alpha I_s + \varepsilon_{p} \sigma (T_{\text{sky}}^4 - T_{p}^4) + h_{c,o}(T_{\text{amb}} - T_{p}) + \frac{\lambda}{\Delta x}(T_{p} - T_{\text{amb}}) = 0 \]  
(6)
For solving this equation, we use the Newton-Raphson method that is generally used in non-linear one-dimensional problems. Thus, the temperature profiles of the external face are represented in Figure 6.

It can be observed that the outside surface temperature follows the same trend as in the case of a coating with the silica-aerogel-based material. However, this temperature remains slightly higher in the case of coating (with a relative difference of 5%). This is probably due to the large amount of heat transformed from the absorbed solar radiation producing a temperature rise of the outside surface, therefore the internal temperature will also be relatively higher. We can therefore conclude that the outside surface temperature has a significant effect on the annual heating and cooling transmission loads.

5. Conclusion

This work has been devoted to the study of the conformity of the energy performance of a multi-zone building located in the region of Fez. The heating and cooling energy requirements of this building were calculated on the basis of the thermo-physical properties of the enclosure and their distribution in the various orientations. The conclusions are:

- The insulation of the roof and the external walls leads to an energetic decrease in heating and air conditioning. Similarly, the insulation of the roof seems to be more important compared to the insulation of the external walls.
- The energy gain can reach 29% using the silica-aerogels base coating and 28% using polystyrene.
- The temperature of the outside face has a great effect on the annual heating and cooling transmission loads.
- In the event that the house is heated and air-conditioned by a stationary electric source produced from fossil fuel, the insulation of the roof and exterior walls leads to a reduction of greenhouse gas emissions in the range of 1900 Kg CO2 eq per year. According to the same hypothesis, the generalization of this isolation alternative to all residences of the city of Fez would be a real opportunity to decrease energy consumption up to 200 000 T-CO2 eq per year. This type of initiative supports government action, enhances the efforts of the kingdom's territories in favor of the climate, and respects Morocco's commitments of reducing its greenhouse gas emissions by 42% on the 2030 horizon.
6. References

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