Thermo-Physical Performance and Energy Aspects of Vertical Walls Opaque to the Retrofitting Of Buildings through a Simulation under Non-Stationary Conditions

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Abstract—The building envelope of a building constructed in the past usually presents design characteristics which are not suitable to avoid the thermal exchanges between inside and outside. The previous use of inefficient building systems, often directed to saving of materials, has created inadequate walls to energy saving. Opaque components of reduced thickness and often in a single layer, except for the plaster with low thermal insulation characteristics, have high thermal transmittance values. This is a characteristic parameter for evaluating energy in steady and winter state, as well as inadequate values of phase shift of the heat wave, characteristic parameter of the behavior under dynamic and summer state. In this work we report a summary of a comparative study of thermal characteristics, in steady and unsteady state, of the external opaque vertical surfaces exposed to energy retrofitting with different techniques. The horizontal walls, the perimeter walls of closure or the horizontal and inclined surfaces, such as roofs, largely influence the energy efficiency and the resulting performance of a building. We started our study considering the energy performance of a generic 200 mm calcareous tuff wall, commonly used in old buildings in Southern Italy. We varied the thickness, by simulating the behavior, through retrofitting techniques such as exterior insulation and finishing system, the insertion of a ventilated cavity or interstitial insulation, or an internal insulation.

Index Terms — building systems, energy saving, insulation, transmittance

I. METHODOLOGY

The simulations were carried out under dynamic condition, obtaining a very realistic and complete analysis, assessing in detail the reaction of the building exposed to various external factors, such as the periodic variation of the temperature [1].

The first step was to define the weather condition limits for the thermo-physical analysis of the opaque vertical element, made up of only calcareous tuff with 2300 kg/m³ density, largely used as a closure element for buildings in the Mediterranean area [2]

The climate zone chosen, according to the Italian classification, is the "C" area with 974 day degree, minimum project temperature Winter \( T_{\text{MIN}} = 3.0 \, ^\circ \text{C} \), and for summer, July is the month of maximum solar radiation \( T_{\text{MAX}} = 33 \, ^\circ \text{C} \), with Temperature monthly with: \( T_{\text{MEAN}} = 26.9 \, ^\circ \text{C} \) [3].

Fig.1 and Fig.2 show the climatic profiles, containing the daily average monthly temperatures [°C], and the monthly average daily solar radiation on vertical south facing surface [MJ/m²] [4].
The main characteristics of the material are shown in Table I, while Fig. 3 shows a dynamic simulation of the thermal lag of the south facing wall in the day of maximum solar irradiation [5].

On the basis of this analysis, we simulated the behaviors for different wall thickness, assuming the configuration of 200 mm as a baseline, and calculating the parameters of mass surface, thermal lag wave (hour), internal admittance, transmittance U [W/m² K], decrement factor [6], [7].

Internal admittance remains almost unchanged, so it is not reported in the graph of this phase. It is to be remembered, in reading the graph that the parameters for surface mass and the wave of thermal lag are to be considered the best results of percentage increase, while the remaining ones are to be considered the most efficient results of percentage decrease.

**Table I. Thermo-physical properties of the material tuff calcarenitic**

<table>
<thead>
<tr>
<th>Conductivity $\lambda$</th>
<th>Thermal Resistance</th>
<th>Density $\rho$</th>
<th>Thermal capacity $C$</th>
<th>Factor $\mu_a$</th>
<th>Factor $\mu$</th>
</tr>
</thead>
</table>

Fig. 1 - Monthly daily average outdoor temperatures

Fig. 2 - Monthly average daily solar radiation on vertical surface facing south
II. RESULTS

In the first phase of the thermo-physical analysis, it is evident that the variation of the mass surface positively influences the dynamic characteristics of the external walls much more than the ones at the steady state. In fact, according to a decrease of the thermal transmittance, proportionally related to the increase of the mass surface, the phase shift of the thermal wave is definable almost proportional to the increase of the surface mass. Although the phase shift variation of the thermal wave increases with the increase of the mass. Even the decrement factor decreases significantly: a decrease of a factor equal to about 10 corresponds to the doubling of the surface mass of the component. The next phase of the performance comparison of the wall presented below, has provided the simulation of heat transfer in steady and dynamic state in the element in a function of the stratigraphy for various
techniques used for energy retrofitting of walls starting from monolayer configuration shown in the previous section.

Fig. 5. Percentage change in thermo-physical parameters with respect to the wall is not insulated (Baseline).

Fig. 5 shows the percentage changes of the parameters of heat transfer in steady and dynamic state according to the stratigraphy, the design solution for the energy retrofitting of the closure opaque element described before. The baseline reference is the not isolated element. It was subsequently evaluated, on the same thermo-physical parameters, also the variation of stratigraphy and the choice of the thermal insulation on the energy performance.

Table II - Main thermo-physical properties of the materials used in the simulation of retrofitting

<table>
<thead>
<tr>
<th></th>
<th>Conductivity $\lambda$ [W/(m K)]</th>
<th>Thermal Resistance $R$ [(m$^2$K)/W]</th>
<th>Density $\rho$ [Kg/m$^3$]</th>
<th>Thermal capacity $C$ [kJ/(kg K)]</th>
<th>Factor $\mu_a$</th>
<th>Factor $\mu_u$</th>
</tr>
</thead>
<tbody>
<tr>
<td>XPS (Baseline)</td>
<td>0,036</td>
<td>1,250</td>
<td>35</td>
<td>1,45</td>
<td>200,00</td>
<td>200,00</td>
</tr>
<tr>
<td>Fiberglass</td>
<td>0,042</td>
<td>1,087</td>
<td>16</td>
<td>0,67</td>
<td>1,33</td>
<td>1,33</td>
</tr>
<tr>
<td>Cork</td>
<td>0,041</td>
<td>1,111</td>
<td>130</td>
<td>2</td>
<td>4,00</td>
<td>9,52</td>
</tr>
<tr>
<td>Mineralized wood-wool</td>
<td>0,040</td>
<td>1,042</td>
<td>160</td>
<td>2,1</td>
<td>5,00</td>
<td>5,00</td>
</tr>
<tr>
<td>Insulating plaster</td>
<td>0,300</td>
<td>0,152</td>
<td>1300</td>
<td>0,84</td>
<td>32,00</td>
<td>32,00</td>
</tr>
</tbody>
</table>

A summary of the thermo-physical characteristics of the materials used in the comparison is shown in Table II. Fig. 6 shows the percentage changes of the thermo-physical performance relative to the isolation in XPS considered as baseline. With reference to the benefits in terms of energy consumption, the wall was simulated using software for energy audit of buildings, and placed in a generic position of the building to redevelop. The exterior 4 walls were replaced with the solutions of retrofitting compared in this study, while the other components, including the floor ceiling (roof) and lower (floor), considered adiabatic, were left unmodified [8],[9].
Fig. 6 - Percentage change in thermo-physical parameters of the wall relative to the configuration with the XPS insulation (Baseline).

Fig. 7 - Energy demand per month for the various configurations of opaque surfaces vertical

Fig. 7 shows the monthly energy consumptions [MJ], referred to different examples of renovation of the wall, with insulating materials. Fig. 8 shows the cumulative energy consumption for the winter and summer seasons. The same dynamic simulation of the energy consumption of the building envelope has been repeated with various insulating materials, referring to the thermo-physical values of a wall insulated with 500 mm of XPS (case Base) [6]. Fig. 9 shows the energy consumption on a monthly basis [MJ] referred to the set of materials for the energy retrofitting of the opaque part of a building envelope, while in Fig. 10, as well as for the previous simulation, shows the cumulative energy consumption for the winter and summer seasons [10].
Fig. 8 - Energy demand and seasonal total for the various configurations of opaque surfaces vertical.

Fig. 9 - Energy demand per month for the various materials for retrofitting of opaque surfaces vertical.

Fig. 10 - Energy demand and seasonal total for the various materials for retrofitting of opaque surfaces vertical.
The thermal simulations of the thermo-element for the various configurations of retrofitting have showed a more significant change with regard to the behavior in winter conditions, configuration most influenced by the transmittance of the element. The study shows how the values of transmittance and surface mass, parameters attributable to the steady-state heat transfer, are not affected by the provision of thermal insulation, while vary significantly the parameters attributable to the dynamic behavior of the element. In particular, the decrement factor and the phase shift of the thermal wave does not undergo significant changes. This, in fact, undergoes increases in the systems that provide for a shift of the insulation towards the inner part of the wall. Another factor in which it is possible to observe a change in internal admittance, which remains roughly constant for all configuration that provide for the accumulation of thermal mass in contact with the internal environment. This parameter is also used to quantify the ability of a wall to accumulate or release heat to the environment if subjected to changes in internal temperature. Among the various configurations, obviously with different specifications between the two seasons, the ventilated wall configuration has obtained the best performance in winter, with -65% of energy consumption compared to the baseline configuration, while the best behavior in summer conditions has been achieved by the configuration skim coat, with -31%. Together, these two configurations have demonstrated the best overall performance with 50.7%. To skim coat and 49.1% for ventilated wall. For all other configurations, the results are to be considered for improvement but to a lesser extent with the following percentages of cumulative energy savings for the two seasons: Isolated cavity = -42% and -36.6% = internally insulated.

Between the different configurations of the materials used for the upgrading the energy efficiency of the standards walls for the two seasons, the XPS material in the simulations is widely used in the renovation, the best result in winter conditions is achieved with by mineralized wood -wool, with a -5% reduction in consumption, while the same material has the best result in the behavior of summer season with a reduction in consumption of 40%. This result is given by the improvement in the value of superficial mass and its thermal wave lag and decrement factor. The value of cumulative of the energy demand for both seasons is improved by 20.5%. All other materials have shown the energy performance in winter conditions worse than the XPS, while in summer conditions, are to be considered improvements with cork = -10% and -23% insulating plaster, fiberglass is considered pejorative + 10%. In terms of overall energy demand results are reported for the remaining materials the following changes for the worse compared to the Baseline configuration of XPS:

Fiberglass = +12%  Cork = +7%  While the Insulating Plaster has shown a slightly improve = -4.6%

The calculation, in not stationary regime, has showed the incidence of the behavior of an opaque material during the summer season, not evaluated at steady state. Finally, it serves to highlight how the thermo-physical simple analysis of the construction element, in particular of the surface mass, it is possible to predict the energy behavior in operating conditions of operation.

REFERENCES


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