Thermal performance of historical masonry structures: experimental data and numerical modeling

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The Italian building stock includes about 12 million buildings of which 15% were built before 1918 and about 65% were built before 1976, when the first Italian law that introduced the concept of energy saving came into force. A significant part of these buildings belongs to the listed built heritage. However, its preservation requires an adaptation of the original function and therefore an update of both the comfort conditions and the energetic behaviour to the today standards. To promote more conscious reuse actions, it is then necessary to deeply understand the thermal performance of historical built heritage, which is often characterized by masonry beam system.

This study aims at assessing, through experimental measurements and numerical simulations, the thermal performance of the exterior walls for a building belonging to the historical heritage in Catania, Southern Italy. San Giuliano Palace, whose main front is reported in Figure 1, was built in the XVIII century as the residence of a very notable family, and currently hosts the administrative offices of the local University.

As for many other buildings dating back to XVIII century in Catania, the exterior walls of San Giuliano Palace are made of roughly levelled basalt stones mixed with lime mortar and other loose stones. According to the visual analysis of the walls in other coeval buildings, the following average volumetric composition can be supposed: 67% basalt stones, 17% lime mortar, 16% mixed stones. The exterior walls have variable thickness, from 160 cm at the ground floor to 75 cm at the top floor. The main fronts are then finished by a 3-cm layer of lime mortar.

Now, the difficulty of knowing the exact distribution and quantity of the different materials in the exterior walls, as well as of the stones shape and size, make a reliable calculation of the U-value almost impossible. In such a case, experimental measurements through a heat-flux meter can be helpful.

In this study, continuous measurements through the heat-flux meter shown in Figure 2 were performed during 72 hours in January 2019 according to the international standard ISO 9869-1:2014. The wall selected for the campaign belongs to the room indicated in Figure 1 by a dotted box, and it is north exposed in order not to receive any direct solar radiation. Its thickness is 100 cm. The results of the campaign (Figure 2) suggest that the measured U-value for this wall is U = 0.67 W/(m^{2}K), i.e. it is comparable with modern scarcely-insulated walls made with hollow bricks. This was quite an unexpected result: indeed, it is common opinion that historical stone-made walls have high thermal conductance, since stones and lime mortar show a very high thermal conductivity. In the literature, the calculated U-values for similar walls (based on suitable hypotheses regarding the amount of materials and their properties) range between 1.3 and 1.5 W/(m^{2}K). In the authors' opinion, this difference between expected and measured U-values can be attributed to the presence of numerous small air cavities amongst the stones, which contribute to increase the thermal resistance.

Another topic addressed in this study is the assessment of the linear thermal transmittance (Ψ) for the main thermal bridges identified in San Giuliano Palace. In this case, the analysis is based on bi-dimensional steady-state numerical simulations performed with the software tool Therm 7.7, where the walls are represented through a single layer of a homogenous material with suitable equivalent thermal conductivity (i.e. providing the measured U-value for the given wall thickness) .

The resulting Ψ-values, referred to the internal side, range from 0.4 ÷ 0.5 W/(m·K) for corners to 0.8 ÷ 0.9 W/(m·K) for balconies. The thermal bridges associated with the installation of wooden window frames on the exterior walls have Ψ = 0.6 ÷ 0.7 W/(m·K). Overall, thermal bridges are responsible for 13.5% of the heat losses in the entire second floor.

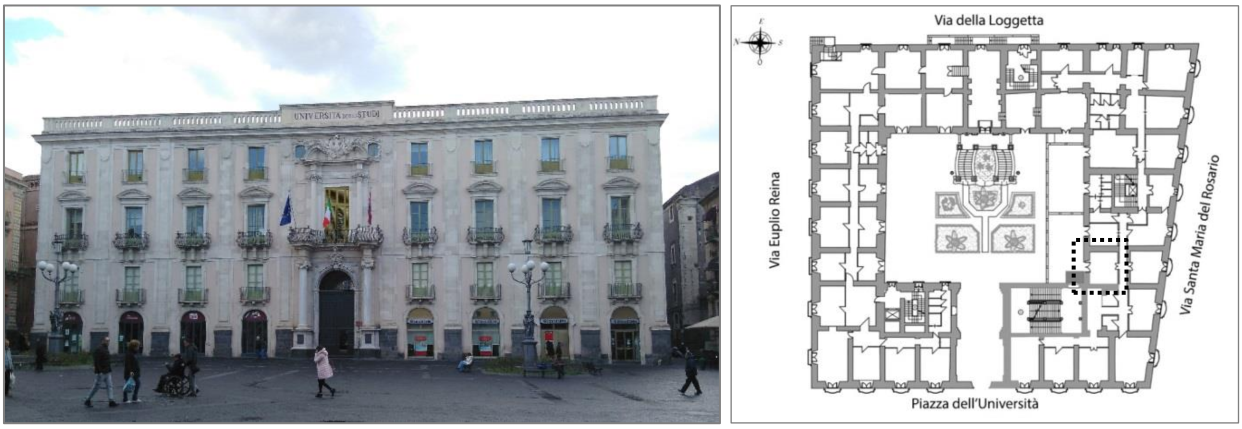

Figure 1 – San Giuliano Palace: main front (on the left) and plan of the second floor (on the right). The investigated wall is indicated by a dotted box.

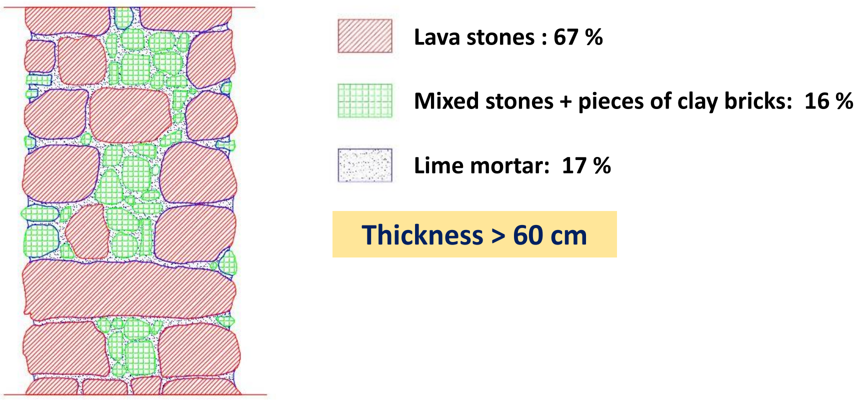

Figure 2 – Typical composition of exterior walls in historical buildings from the 1700s in Catania

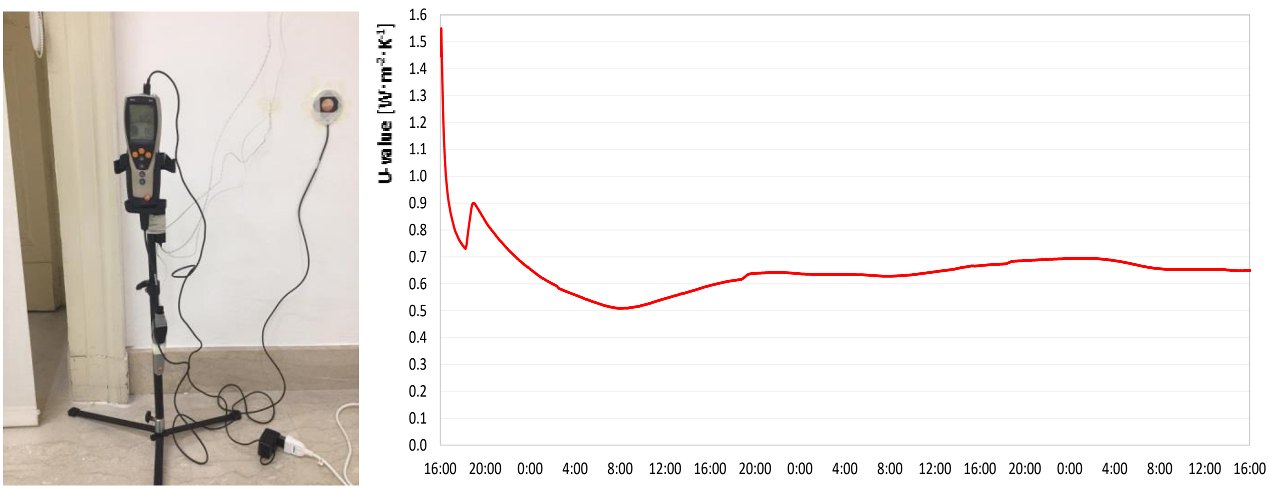

Figure 3 – The heat-flux meter (on the left) and the results of the measurement campaign (on the right)