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What is This?

A contribution for the improvement in thermal insulation of *tabique* walls coated with metal corrugated sheets

Sandra Cunha^{1,2}, Jorge Pinto^{1,2}, Anabela Paiva^{1,2}, Ana Briga-Sá^{1,2}, Nuno Soares¹, Humberto Varum³ and Débora Ferreira^{4,5}

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Abstract

Tabique is a traditional Portuguese building technique using timber and earth and was intensively applied until the 20th century. There is an impressive *tabique* heritage that requires maintenance and rehabilitation interventions. Taking into account the facts that technical and scientific publications related to this particular technique are lacking and that the technique is also applied worldwide, this research work is a very relevant one. This study aims at studying the thermal insulation behaviour of *tabique* walls and in particular, *tabique* walls coated using metal corrugated sheets and thermally reinforced with an insulation material. This type of building component is initially characterized and some building details concerning the metal corrugated sheet coating are described. An experimental work was conducted to determine the thermal transmission coefficient of the *tabique* wall samples. It was concluded that providing the *tabique* wall coated with metal corrugated sheets with a 3 cm extruded polystyrene board results in a thermal insulation improvement of 61%. These results revealed that the thermal insulation reinforcement of *tabique* walls is possible and it may be a straightforward building procedure because it can be achieved using the thermal insulation building materials that are currently being used. Therefore, the thermal insulation reinforcement of *tabique* walls seems feasible. Furthermore, the thermal insulation parameters obtained in this study are similar to the ones obtained for currently applied walls solutions in new buildings. This technical fact may provide guidance for the possibility of using solutions used in old buildings to meet the thermal comfort requirements expected in today's times. The knowledge gained will also be useful to support future proposals of energy rehabilitation solutions.

Practical implications: In this article, *tabique* construction and its relevance worldwide are discussed. This article highlights the building details concerning the use of metal corrugated sheet coating on *tabique* walls and evaluates the thermal insulation behaviour of this wall system. The outcomes indicate that it

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is possible to improve the thermal insulation of a *tabique* wall. The data obtained in this study may be valuable for repairing *tabique* walls and may also inspire innovative building solutions in modern industrial practice.

Keywords

Tabique construction, metal corrugated sheets, thermal insulation, traditional building techniques, rehabilitation, sustainability

Introduction

Currently, high energy consumption in buildings is a worldwide problem. Therefore, it is important that strategies be defined to improve the energy performance of new and existing buildings. Part of the existing buildings are old constructions that were built using techniques that currently have fallen in disuse due to the technological evolution in the construction sector, but whose potential should be analysed, particularly their structural and thermal properties. These studies are extremely important to improve the energy efficiency of old buildings, particularly through rehabilitation interventions. Timber and earth are materials that can be found under different climatic conditions in ancient buildings all over the world. However, the knowledge about these old techniques needs further enhancement, although some scientific research has been conducted related with the energy use and thermal comfort of rammed earth.¹⁻³ Earth is also used in other building techniques such as *tabique*, where it is combined with timber.

Tabique is a traditional Portuguese building technique that was extremely relevant until the beginning of the 20th century and before the introduction of the reinforcement concrete technique. Therefore, there is an impressive Portuguese *tabique* heritage.¹⁻³ Some research studies have highlighted the alarming degradation level of this type of construction and the need for restorative actions.⁴

There continue to be few scientific publications on this subject and technical building aspects related to the *tabique* construction need

to be registered in order to be available to the technical community.

The *tabique* building technique consists of using natural, non-processed building materials and simple procedures. It does not require highly advanced technological processes, sophisticated equipments or facilities. In fact, timber and earth are the main building materials used. In general, both materials are naturally occurring, locally available in abundance, can be recycled and consequently are more sustainable. Taking into account that there is no excessive amount of energy or water consumption or CO₂ emissions associated with the construction process of a *tabique* component, a sustainable relevance of this technique may be implied. Furthermore, this solution features a large number of ancient buildings and therefore knowledge of its thermal behaviour is crucial for rehabilitation interventions and for maintaining and compatibilizing *tabique* components with actual thermal reinforcement techniques.

In the rehabilitation process of a *tabique* building, the thermal behaviour assessment of the building is crucial to propose adequate thermal insulation reinforcement solutions in response to the expected comfort and energy efficiency requirements. In this context, the study of the thermal performance of *tabique* walls is extremely important considering the important role of those elements on the envelope and consequently on the thermal behaviour of the building. This is the main goal of this research work, which focusses on assessing the thermal insulation behaviour of *tabique* walls, *tabique* walls coated with metal corrugated sheets and their

performance when a usual thermal insulation material is included as a system component.

This information may be helpful in future thermal rehabilitation processes of *tabique* construction or in other similar building techniques. In fact, there are similar building techniques worldwide, namely *pau a pique*, *taipa de mão* and *taipa de sebe* in Brazil; *quincha* in Chile and Peru and wattle and daub in Anglo-Saxon countries. Therefore, this article may contribute to the maintenance of heritage related to *tabique*.

For this purpose, an experimental work was performed in laboratory in which three *tabique* wall samples were specifically prepared and thermally tested. In this analysis, the following samples were considered: a *tabique* wall, a *tabique* wall coated with metal corrugated sheets and a *tabique* wall coated with metal corrugated sheets and thermally reinforced. The *tabique* wall sample works as the reference. The *tabique* wall coated with metal corrugated sheets represents a traditional building option for coating of *tabique* walls. The thermal transmission coefficient of each solution was quantified and is discussed in this article.

This article is structured as follows: first, the *tabique* construction is discussed, in which the most traditional types of finishing of the exterior *tabique* walls are presented; second, some building details of the metal corrugated sheet coating solution are introduced and described; third, the adopted methodology and experimental setup are shown, in which the identification of the main equipment and a detailed description of the used *tabique* wall samples are included; fourth, the main experimental results are shown and discussed, in particular, the thermal transmission coefficient estimated for the three different building solutions of *tabique* wall tested and finally, the main conclusions of this research work are drawn.

Tabique construction characterization

Construction details

Tabique is a Portuguese traditional building technique that was highly applied until the

beginning of the 20th century. There is a rich *tabique* heritage throughout Portugal. This reality is even more impressive in the northern part of the country, where the old city centres are very likely to be built up with *tabique* buildings. In this part of the country, the rural old buildings are also relevant in terms of *tabique* heritage. The uniqueness of using earth as a building material is also observed in two other important Portuguese traditional building techniques, which are the adobe and the rammed earth. However, in these two cases, a building component is essentially built with earth rather than a timber structure and, therefore, earth plays a fundamental role in terms of the component's structural behaviour.

A *tabique* component, such as a wall (Figure 1), is formed by a regular timber frame covered on both sides by an earth render. The timber elements of the frame are nailed to each other and the most common timber frame solution is formed by vertical boards linked to each other by other horizontal timber elements.

Vertical and horizontal boards are displayed regularly. Usually, vertical boards are stiffer than horizontal boards. The horizontal boards are applied on both surfaces of the vertical boards. There is the possibility of the timber system solution being structurally reinforced by the inclusion of timber boards displayed diagonally. Autochthonous wood species are supposed to be applied in the timber structure. In the study by Pinto et al.,⁵ four wood species have been identified so far. They are, in order of relevance, the *Pinus pinaster*, 65% incidence; the *Castanea sativa* Mill., 25% incidence; the *Populus* sp., 7% incidence and the *Tilia cordata*, 3% incidence. *P. pinaster* is clearly the most used wood in this context. These species are autochthonous of the north of Portugal. Other wood species are likely to be found in other parts of Portugal.

The earth render used as a filling for the timber structure may have a residual structural contribution but it plays a fundamental role in the preservation of the timber structure, as an infill of the existing gaps in between timber

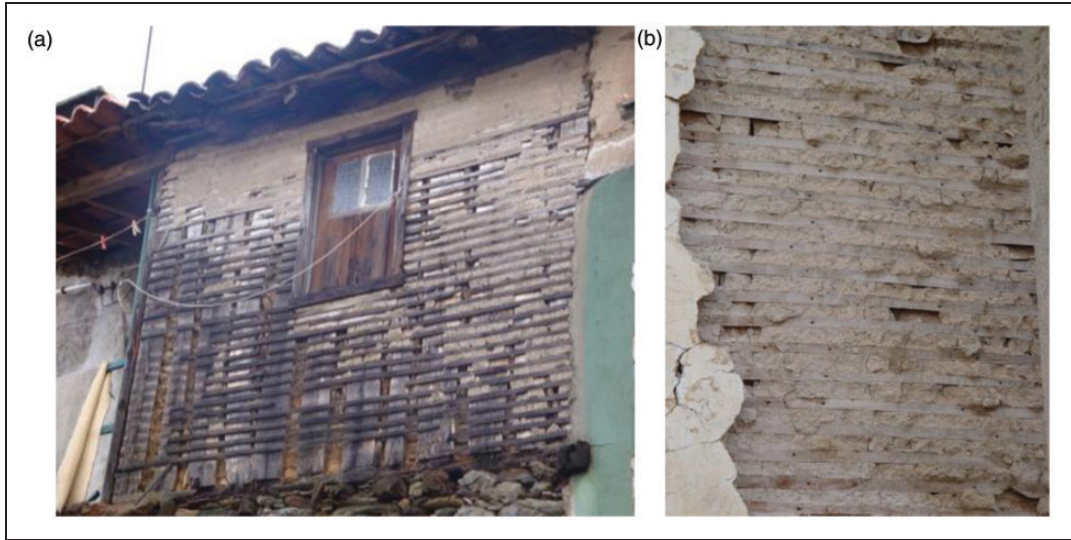


Figure 1. Components of a *tabique* wall: (a) timber frame with vertical and horizontal boards and (b) timber frame covered with earth render.

elements. For instance, it protects the timber structure from insect attacks and fire. The earth render may include lime in its constitution or it may be exclusively local earth. A dimensional pattern was not found for exterior and interior *tabique* walls.^{4,6,7} This variability added to the fact that different wood species and local earth may be used, justifying the heterogeneity associated with the *tabique* building components. Plus, the fact that these components may present different levels of degradation increases that heterogeneity. Consequently, it also increases the complexity of studying its behaviour, in particular, the thermal insulation behaviour.

In Portugal, a *tabique* building is very likely to be a two-floor dwelling. However, there are many more alternative building scenarios.^{4,6,7} These types of buildings may have high value in terms of technical quality. Taking into account the fact that the earth render applied on the facade of the exterior *tabique* walls may be susceptible to rain because of which there may be an unexpected early deterioration, there are alternative building technique solutions to reduce this technical vulnerability.⁸

The most traditional solution to make a building waterproof consists of adopting as a type of finishing wash painting (Figure 2(a)), metal (steel or zinc) corrugated sheets (Figure 2(b)), slate boards (Figure 3a) or ceramic tiles (Figure 3(b)). The exterior covering may be used on all the facades or only on the ones that are more exposed to rain.

Metal corrugated sheet covering solutions

Apart from making the building waterproof, a traditional coating may also improve the thermal insulation behaviour of an external *tabique* wall. To study the influence of a coating material in the thermal performance of *tabique* walls, the previous knowledge of the constructive details related to the adopted coating is required. In the context of the metal corrugated sheets coating solution, the junction of two external walls (Figure 4(a)), the roof abutment (Figure 4(b)), the window and door abutments (Figure (5)), the connection of sheets and the fastening process are some of these building details that may influence the waterproofing and the thermal insulation ability of the coating. A traditional

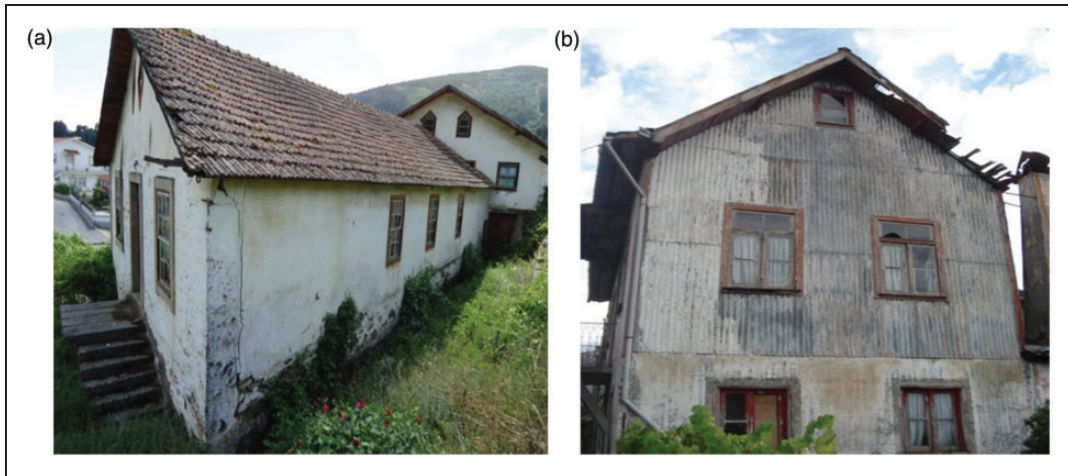


Figure 2. (a) Whitewash painting and (b) metal (steel or zinc) corrugated sheets as exterior types of finishing of Portuguese *tabique* dwellings.



Figure 3. (a) Slate boards and (b) ceramic tiles as exterior types of finishing of Portuguese *tabique* dwellings.

building solution of junction of two orthogonal external *tabique* walls covered by metal corrugated sheets consists of applying two timber boards, as detail I in Figure 4(a) indicates. They

are applied on the metal sheets and nailed to the main timber structure of the wall (III, Figure 4(a)). Figure 4(a) shows the nailed fastening process of the metal sheets (II, Figure 4(a)) to the



Figure 4. (a) Junction of walls and (b) roof abutment building details of the metal corrugated sheet coating. I: junction of *tabique* walls; II: metal corrugated sheets; III: timber frame; IV: granite masonry wall; V: nail; VI: connection of sheets; VII: roof abutment.

main timber structure of the wall (V, Figure 4(a)) and also presents a detailed example of the connection of metal sheets by overlapping (VI, Figure 4(a)). In addition, the typical Portuguese *tabique* building solution of having a granite masonry (IV, Figure 4(a)) on the ground floor and *tabique* walls placed on the upper floors is also highlighted in Figure 4(a). Figure 4(b) and Figure 5 show that additional timber elements are also usually applied to perform the required abutment of metal sheets in the constructive details of the roof, window and door.

The nailed fastening system of the metal corrugated sheet to the main timber structure of the *tabique* wall is also an important building detail because it guarantees the stability of the coating. The inherent weight of the metal corrugated sheets, the wind pressure and the thermal variation are some of the loads that may be applied on the sheets. The nailed fastening system has to be adequate in order to allow transferring of these loads to the main timber structure of the wall. In this context, Figure 6(a) shows a traditional reinforcement solution of a nail fastening

by including an additional metal sheet (details in Figure 6(a)). With this solution, the intention is to increase the robustness of the structure under the dynamic wind effect on the metal corrugated sheet coating. On the other hand, Figure 6(b) shows the inner face of a metal corrugated sheet used as exterior coating of a *tabique* wall and its respective nailed fastening system. The type, the size and the lining up of the nails used, which are regularly applied as the fastening system, are technical aspects shown in this figure.

In addition, Figure 7 presents the facade of another *tabique* building in which its exterior *tabique* wall, on the first floor, also has a metal corrugated sheet coating type applied. A comprehensive perspective of the above-identified building details can be obtained by seeing this figure, in particular, in terms of building details concerning the connection of sheets. It is clear that horizontal (d, Figure 7) and vertical (e, Figure 7) overlapping between adjacent sheets is required in order to build an adequate coating in terms of waterproof and thermal insulation behaviours. Meanwhile, an alternative



Figure 5. (a) Window and (b) door abutment building details of metal corrugated sheet coating.

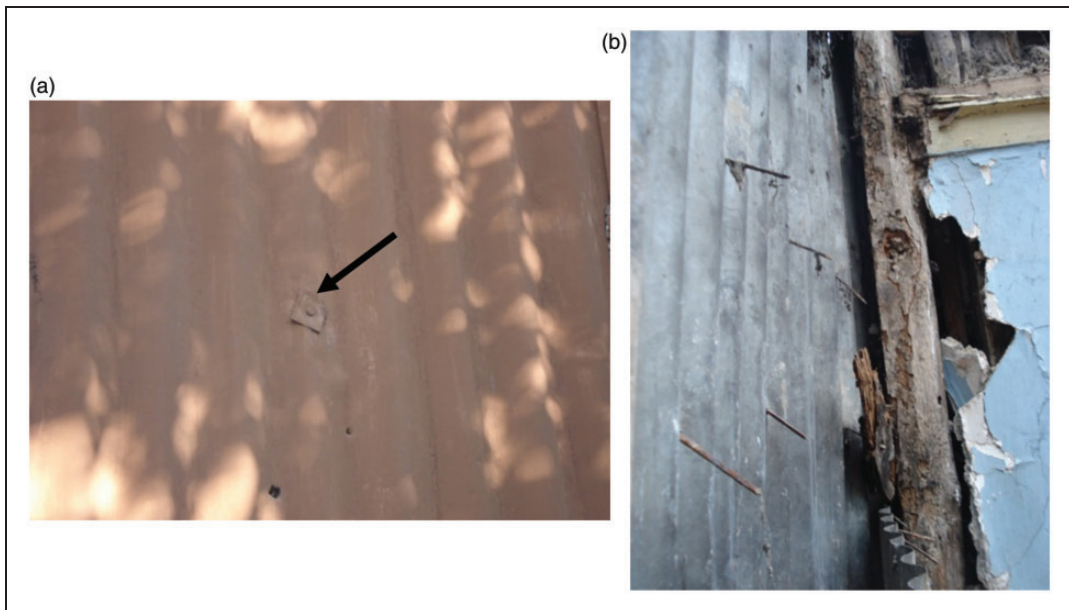


Figure 6. Nailed fastening details of metal corrugated sheet coating: (a) reinforcement and (b) inner face.

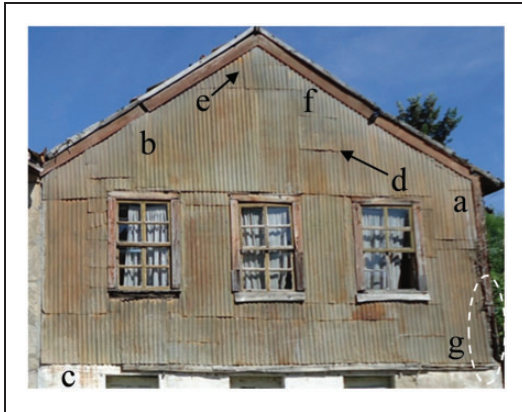


Figure 7. Complementary information concerning building details of the metal corrugated sheet coating of *tabique* walls.

a: junction of *tabique* walls; b: metal corrugated sheet; c: granite masonry wall; d: horizontal overlapping; e: vertical overlapping; f: roof abutment; and g: pathology.

roof abutment solution of the metal corrugated sheet coating shown in Figure 4(b) is also presented in Figure 7. In this case, a timber board is nailed on the sheets in the junction of the coating and the roof (f, Figure 7). Furthermore, similar junction of *tabique* walls and window abutment solutions shown in Figures 4(a) and 5(a), respectively, are also applied in Figure 7. A typical pathology of this kind of building system (g, Figure 7) related to the degradation of the bottom of the timber boards that appear in the junction of the *tabique* walls is also featured in Figure 7. This type of pathology is also highlighted in Figure 4(a).

The knowledge of the construction details referred above is extremely important to define solutions for repairing anomalies and to improve the mechanical, physical and thermal behaviours of *tabique* components. Regarding the thermal performance of such building solutions, different aspects should be considered. The thermal conductivity and the thickness of the different materials that make up the system are key factors for determining its thermal inertia and its ability to store and release heat to the interior of the building. Considering that a *tabique* component is a heterogeneous element comprising a timber

frame filled with earth, the complexity of studying the thermal behaviour of the element increases. For instance, the calculation of the heat transfer coefficient using the analytical formulation is not a straightforward task. In the case of homogeneous building elements this value can be achieved more easily. In this case, the different thermal parameters, such as the thermal conductivity, the thermal resistance and the thermal transmission coefficient, have been assessed in several of technical reports. In the case of *tabique*, these data are still not available, as they have not been intensively researched before. Therefore, the experimental study of such solutions is essential.

Materials and methods

Experimental setup

The experimental work was performed in the laboratory of civil engineering of the University of Trás-os-Montes e Alto Douro in the city of Vila Real. A thermal test room was used as an alternative solution to a thermal test cell. The dimension of the thermal test room is 4.00 m × 3.00 m × 2.54 m (length × width × height) and it is thermally controlled. This experimental procedure has been successfully applied in previous research works.^{8–12} An approximately constant interior temperature of the thermal test room was ensured by using a domestic heater in the room, which was continuously switched on during the test performance. The interior temperature should be always higher than the exterior temperature in order to ensure that the heat flux occurs from the interior to the exterior of the test room. In this case, the interior temperature varied between 30°C and 35°C.

A 0.75 m × 0.65 m (width × height) sample of a *tabique* wall was built in this research work, case I, in order to be thermally tested. Then, this *tabique* wall sample was coated with a metal corrugated sheet and also tested, case II. Finally, a thermal reinforcement solution of this traditional building component was proposed and also tested, case III. Adding a

0.03 m thick extruded polystyrene (XPS) board into the building system of the wall was the common thermal reinforcement solution considered at this stage. XPS has been widely applied as an insulation material simultaneously in new buildings and in rehabilitation of heritage processes. A 0.03 m thick board XPS was used assuming that this thickness is sufficient to improve the thermal behaviour of the tested *tabique* solution. Figure 8(a) and Figure 8(b) present the building system of the *tabique* wall coated with metal corrugated sheets (case II) and of the thermal reinforcement solution (case III) studied in this research work, respectively. The *tabique* wall sample of case I is similar to the wall sample of case II but devoid of metal corrugated sheet coating. The XPS board was placed from the outer face, between the metal

corrugated sheet and the earth render, as shown in Figure 9(b).

In this specific case, the timber structure of the sample (Figure 9(a)) was obtained from a real timber structure of a *tabique* wall of a Portuguese dwelling. The applied metal corrugated sheet on the outer face of the sample of the wall (IV, Figure 10) was also a portion of a real traditional metal corrugated sheet. On the other hand, it was not possible to maintain the real earth render of the wall because it had been removed as a result of the demolition process of the dwelling and also due to the transportation of the wall from the building site to the laboratory. This fact implied that an additional experimental work had to be done in order to find out an adequate earth render (i.e. similar to the real one) to apply in the *tabique* wall sample.

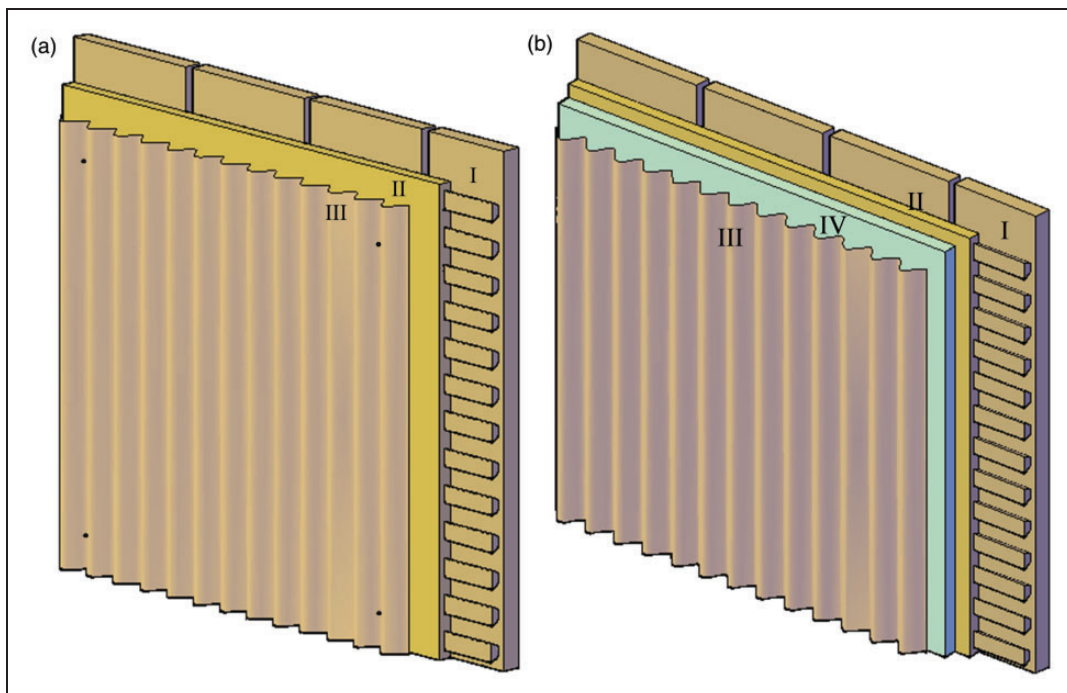


Figure 8. Samples of a *tabique* wall coated with metal corrugated sheets: (a) building system (case II) and (b) adopted thermal reinforcement solution (case III).

I: timber structure; II: earth render; III: metal corrugated sheet; IV: XPS board.
XPS: extruded polystyrene.

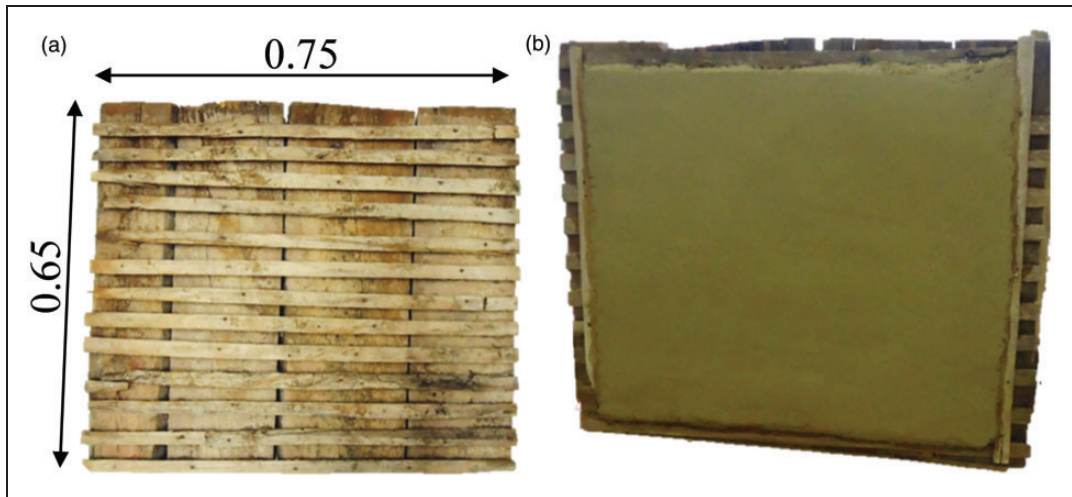


Figure 9. Preparation of the *tabique* wall sample (case I): (a) the timber structure (m) and (b) earth render application.

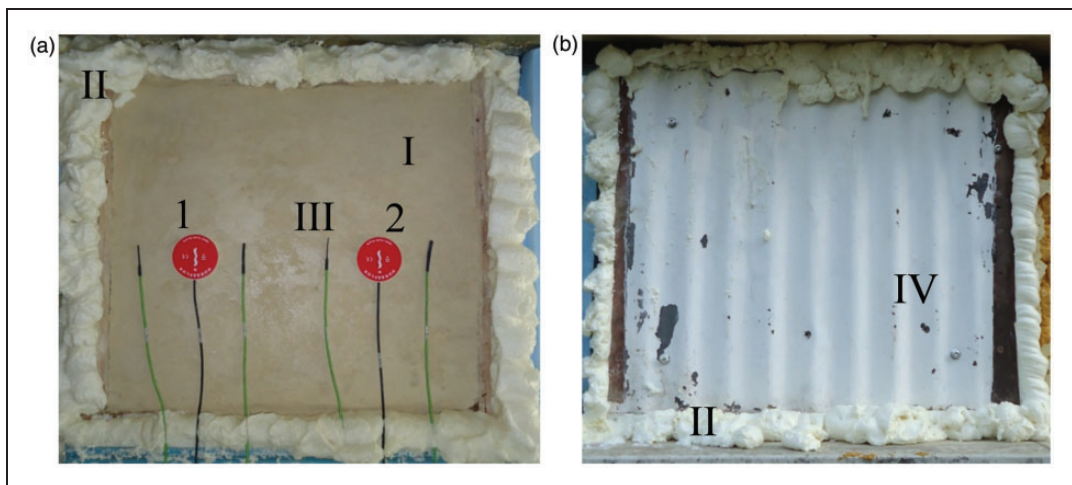


Figure 10. Thermal insulation test performance of the *tabique* wall sample coated with metal corrugated sheets: (a) inner face and (b) outer face.
I: inner face of the wall sample, earth render finishing; II: polyurethane foam; III: temperature sensors; IV: metal corrugated sheet; and I and 2: heat flowmeters.

P. pinaster was the identified species of wood for the timber elements of the wall. The timber structural system of the wall is compound by vertical timber boards connected to each other by horizontal timber boards, which are nailed on the vertical boards on both sides

(Figure 9(a)). In terms of medium values, the vertical boards presented a width of 0.164 m, a thickness of 0.025 m and a gap between them of 0.003 m. Meanwhile, the horizontal boards had the following average dimensions, width of 0.026 m and thickness of 0.018 m, and they

were separated from each other by 0.021 m. The earth render was applied on the timber structure, on both sides, and in order to completely cover the timber elements (Figure 8(b)). A 0.01 m thickness layer of an earth render was guaranteed. After the application of the earth render on the timber structure, the *tabique* wall sample was dried for 30 days under controlled thermal-hygrometric conditions of the laboratory. The thickness of the applied metal corrugated sheet was 0.007 m.

Based on these technical specifications, it is clear that a *tabique* wall covered with metal corrugated sheets is a heterogenic building element. This uniqueness is even more evident taking into account the fact that earth and wood are natural building materials, whose properties may vary widely. For instance, previous research studies^{4,6,7} that focused on characterising the *tabique* construction in the northern part of Portugal concluded that the building scenario of having a timber structure of autochthonous wood species and a render based on local earth is very likely to occur. It was observed that there is a significant variation in the dimensions of the constituents of *tabique* elements and also that this type of building elements may have different levels of conservation, which increase the referred heterogeneity. Therefore, this variability may cause entropy in the process of accessing the thermal insulation abilities of these types of traditional building elements, analytically, numerically or experimentally, and also it may make the process of delivering generalized thermal parameters difficult.

After the drying process, the sample of the *tabique* wall coated with metal corrugated sheet replaced an existing window in the north-east facade of the test room (Figure 10). The sample was carefully fixed to the wall of the test room using polyurethane foam (II, Figure 10). This solution for fixing the sample also avoided undesirable insulation voids, thermal bridges, non-insulated headers and other defects that may compromise the feasibility of the final thermal results. In

practice, the polyurethane foam will work as one of the abutment building details of the metal corrugated sheet coating presented earlier.

According to ISO 9869:1994¹³ and the research of other authors, the recommended equipment comprises two heat flow meters (1 and 2, Figure 10(a)), four surface temperature sensors (III, Figure 10(b)), two ambient temperature sensors, a data logger and a computer. Both heat flow meters and surface temperature sensors were fixed in the middle of the inner face of the wall (Figure 10(a)). Meanwhile, the interior and the exterior temperatures ($Ti(n)$ and $Te(n)$) were measured using thermohygrometric equipment kept indoors and outdoors, respectively. Based on the standard,¹³ the accuracy of heat flow meters and temperature sensors is about 5% when these instruments are calibrated. According to the experimental methodology adopted in this research work, the conditions in which the tests were performed and the type of element tested, an uncertainty of the results varying from 14% to 28% is expected. Therefore, this aspect has to be considered in case of extrapolating the results obtained in this article.

Methodology

The methodology used to analyse the thermal insulation performance of *tabique* walls coated externally with metal corrugated sheets was based on an experimental work done according to ISO 9869:1994 entitled “Thermal insulation: building elements – in situ measurement of thermal resistance and thermal transmittance.”¹³

According to the international standard,¹³ the thermal transmission coefficient (U) of a material or a building system can be quantified by applying equation (1)

$$U(ntotal) = \frac{\sum_{n=1}^{ntotal} q(n)}{\sum_{n=1}^{ntotal} (Ti(n) - Te(n))} \quad (1)$$

where $q(n)$ is the heat flow across the wall sample in the moment n ; $Ti(n)$ and $Te(n)$ are the interior and the exterior temperatures in the moment n ,

respectively, and $ntotal$ is the total number of moments in which the data were collected.

Taking into account the fact that two heat flow meters were used corresponding to $q1(n)$ and $q2(n)$, it is possible to estimate two thermal transmission coefficients, $U1(ntotal)$ and $U2(ntotal)$, which are the thermal transmission coefficients related to the data registered by the heat flow meters 1 and 2, respectively, by applying equation (1). Thus, the thermal transmission coefficient of the wall model ($U'(ntotal)$) is the average value of $U1(ntotal)$ and $U2(ntotal)$ according to equation (2)

$$U'(ntotal) = \frac{U1(ntotal) + U2(ntotal)}{2} \quad (2)$$

According to the standard,¹³ a minimum test duration of 3 days is required if the temperature is stable around the heat flow meters. Otherwise, this duration may be more than 7 days as a precaution and depending on the thermal inertia of the building component. Based on the above-described constituency system of a *tabique* wall, the respective thermal inertia of this type

of traditional building element may be considered low and, consequently, a minimum test duration of 3 days is acceptable.¹³

Experimental results and discussion

The temperatures ($Ti(n)$ and $Te(n)$) and the heat flow across the wall model ($q1(n)$ and $q2(n)$) were measured continuously (in between 10 min intervals (n)). The heat flow meters 1 and 2 (Figure 10) measured the heat flow that occurred across the wall sample $q1(n)$ and $q2(n)$, respectively. The thermal behaviour test of the sample related to case I was performed in April 2012 and May 2012, with the duration being 14 days (Figure 11). On the other hand, the thermal behaviour test of the sample related to case II was performed in October 2012 and November 2012, the duration being 7 days (Figure 12). Meanwhile, the test of the sample of the *tabique* wall coated with metal corrugated sheet reinforced with the XPS board (case III) took place in September 2012 and October 2012, over a period of approximately 10 days (Figure 13). This testing schedule was

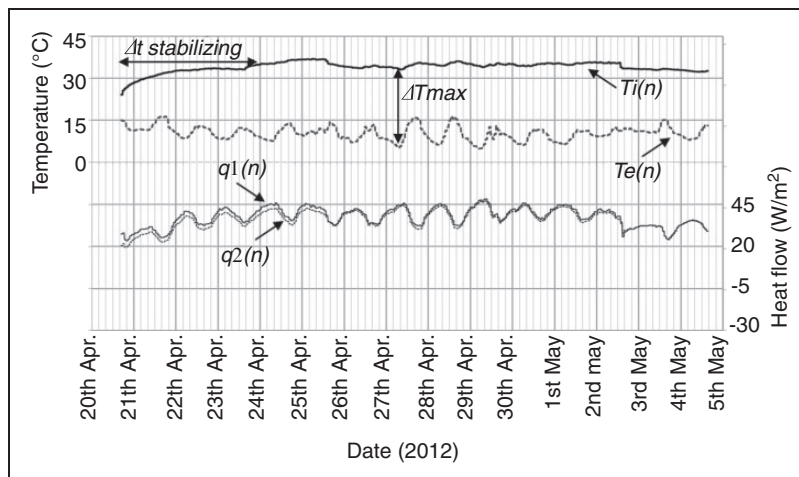


Figure 11. Collected data of the thermal insulation test of the sample of the *tabique* wall (case I). $Ti(n)$: interior temperature; $Te(n)$: exterior temperature; $q1(n)$ and $q2(n)$: heat flow measured by the heat flow meters 1 and 2, respectively; $\Delta Tmax$: maximum thermal gradient; Δt stabilizing: required time to stabilize the interior temperature of the test room.

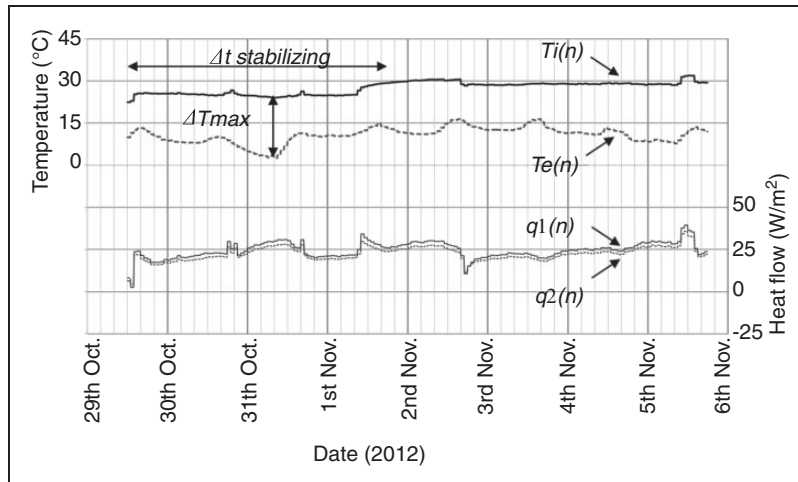


Figure 12. Collected data of the thermal insulation test of the sample of the *tabique* wall coated with metal corrugated sheets (case II).

$T_i(n)$: interior temperature; $T_e(n)$: exterior temperature; $q_1(n)$ and $q_2(n)$: heat flow measured by the heat flow meters 1 and 2, respectively; ΔT_{max} : maximum thermal gradient; $\Delta t_{stabilizing}$: required time to stabilize the interior temperature of the test room.

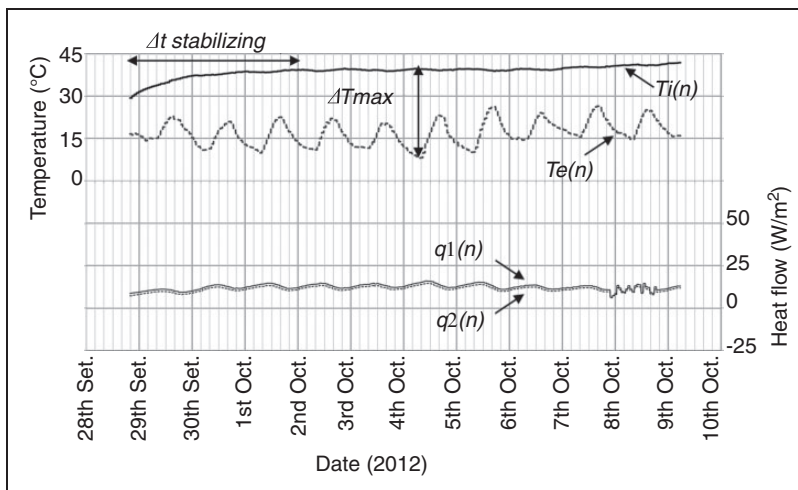


Figure 13. Collected data of the studied reinforcement thermal insulation solution (case III).

$T_i(n)$: interior temperature; $T_e(n)$: exterior temperature; $q_1(n)$ and $q_2(n)$: heat flow measured by the heat flow meters 1 and 2, respectively; ΔT_{max} : maximum thermal gradient; $\Delta t_{stabilizing}$: required time to stabilize the interior temperature of the test room.

based on the logistic aspects related to this specific research and climate restrictions. The fact that the tests were performed during different periods of the year, with different thermal

conditions, should not influence the results. In fact, the adopted methodology allows calculating the thermal transmission coefficient based on the temperature differential that occurred

between the interior and exterior of the test room and, consequently, based on the heat flux verified through the sample. Taking into account that the thermal transmission coefficient is the heat transferred through an element having an area of 1 m^2 and when it is submitted to a differential of temperature of 1°C , its value can be obtained and compared for different periods of the year. However, further experimental work should be carried out in order to test different samples and to verify this assumption. Therefore, the recommended minimum test duration of 3 days was guaranteed in both cases. In fact, in both situations, 3 days was approximately the required time to stabilize the interior temperature (Δt stabilizing) in all the tested cases. As it was stated earlier, this thermal condition was achieved by using a domestic heater in the test room, which was consecutively switched on during the test. It was possible to stabilize the interior temperature of the test room at the approximate value of 33°C , 30°C and 39°C for the testing cases I, II and III, respectively. In terms of exterior temperature, in all the cases, the collected data are in accordance with the expected temperature in the northeastern parts of Portugal and for the respective period of time of the year. This region has a continental climate, which is characterized by hot summers and cold winters and a high temperature range during 1 year time. For instance, in Vila Real city, during winter, the average temperatures may range from -5°C to 25°C and during the summer time, this range may vary from 5°C to 39°C . These are figures registered between 1981 and 2010, according to the Portuguese Institute of Sea and Atmosphere.¹⁴ For these conditions (region and time of the year), the data concerning the exterior temperature also express clearly the natural variation of temperature during the daytime (day and night periods) (Figures 11–13). In the three cases, the interior temperature is more stable and higher than the exterior temperature. Therefore, the thermal gradient between interior and exterior temperatures (ΔT) achieved during the tests is adequate to

apply the methodology already presented. These thermal conditions were conducive for the desirable continuous heat flow across the wall sample from the inside to the outside. The establishment of this thermal peculiarity is important in order to evaluate the thermal insulation performance of the analysed building systems. In all the cases, the values of the heat flow, $q1(n)$ and $q2(n)$, are approximately the same, which allows one to obtain values of the thermal transmission coefficient (U) that are more reliable. Therefore, the thermal transmission coefficient of the wall sample related to cases I, II and III can be quantified by applying the data of the graphs shown in Figures 11, 12 and 13, respectively, in equation (1), followed by equation (2). The obtained results are presented in Table 1.

According to the obtained results (Table 1), the thermal transmission coefficient of the *tabique* wall (case I), the *tabique* wall coated with metal corrugated sheets (case II) and the *tabique* wall coated with metal corrugated sheet and reinforced with an XPS board (case III) is 1.59 , 1.45 and $0.56 \text{ W/m}^2\text{C}$, respectively. There is a slight improvement in thermal insulation observed by coating the *tabique* wall with metal corrugated sheets, which corresponds to a reduction of $0.14 \text{ W/m}^2\text{C}$ in terms of thermal transmission coefficient (8.8%). On the other hand, providing the *tabique* wall coated with metal corrugated sheets with an XPS board (thickness of 0.03 m and placed underneath the metal corrugate sheet) results in a significant improvement in thermal insulation because the respective thermal transmission coefficient decreases by $0.89 \text{ W/m}^2\text{C}$, which

Table 1. Thermal transmission coefficient of the tested cases (U').

	Tested cases		
	Case I	Case II	Case III
U' -value ($\text{W/m}^2\text{C}$)	1.59	1.45	0.56

corresponds to a 61% insulation gain (Table 1). Therefore, the thermal insulation reinforcement of *tabique* walls seems to be feasible. Furthermore, the thermal insulation parameters obtained in this study are similar to the ones obtained for currently applied walls solutions in new buildings, particularly those built with brick masonry, revealing the possibility of using solutions used in old building to meet the thermal comfort requirements expected in today's times.

Conclusions

The application of metal corrugated sheets is a common type of finishing of the exterior of *tabique* walls. This traditional building solution intends to increase the durability of a building by enhancing the water-resistance ability of the *tabique* walls. In fact, the earth render that characterizes this type of building component may be vulnerable to water. Therefore, the metal sheets have to be applied on the wall efficiently in order to ensure this important functionality. Some examples of traditional solutions of metal corrugated sheet coating such as junction of *tabique* walls, abutments, overlapping of the metal sheets and nail fastening are discussed in this article. In general, timber boards are used for the abutments of the metal sheets, which are fixed using nails. Adequate horizontal and vertical overlapping of the metal sheets is necessary to guaranty good tightness. A thermal insulation test allowed the understanding that the application of metal corrugated sheet does not have an expressive thermal insulation impact because there is only an 8.8% reduction in the thermal transmission coefficient. In contrast, the application of an XPS board that is 0.03m thick between the metal corrugated sheet and the *tabique* wall leads to a 61% decrease in the thermal transmission coefficient. XPS is a currently applied building material used in the improvement of the energy performance of walls. These technical facts indicate that the improvement of the thermal insulation behaviour of *tabique* heritage is possible by adopting currently applied

thermal insulation reinforcement techniques. Currently applied thermal insulation building materials such as expanded polystyrene or mineral wool should also be considered in future research. On the other hand, the incorporation of raw materials as thermal insulation materials may be an interesting building option to keep the sustainable characteristics related to *tabique*. At the same time, performing thermal insulation tests in situ and using a more representative *tabique* wall sample are two additional aspects that need to be taken into account in further research concerning the thermal behaviour study of *tabique* heritage. Considering a vapour barrier membrane in insulated *tabique* solutions and the embodied energy are other technical aspects that need to be researched in this context. The outcomes of this research study may be helpful in the rehabilitation interventions of *tabique* buildings.

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Conflict of interest

None declared.

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