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Analysis of Portuguese Residential Buildings' Needs and Proposed Solutions

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ABSTRACT: The Portuguese housing sector experienced a significant growth throughout the 20th century, particularly in the last quarter, after the democratic revolution in 1974. In fact, the number of buildings built between 1970 and 1990 is more than one third of the buildings actually existing in Portugal. Therefore most of them were built before the publication of the first regulation concerning the energy efficiency in buildings. Regarding this scenario, it would be expected that rehabilitation activities would represent most of the current construction activities. However, given some remaining barriers from old social policies, this situation is not observed; actually building retrofitting is the least significant sector, accentuating the degradation level of major part of the Portuguese housing stock. Several studies show that the main problems are found in the building's envelope elements, such as roofs and façades. Based on this context, the aim of this paper is to introduce some examples of building retrofitting systems that, adapted to the Portuguese main needs and requirements may represent sustainable solutions to overcome the identified needs of Portuguese buildings' envelope.

Key-words: Housing Envelopes, Energy Retrofitting, Portugal, Sustainable Retrofitting.

1 INTRODUCTION: OVERVIEW OF PORTUGUESE HOUSING MARKET

The Portuguese building stock grew almost 11 times between 1919 and 2001, being the highest rate between 1971 and 1990, as shown in Figure 1. According to the last available data (INE, 2011), in 2011 there were almost 1.48 residential units per family, from which 19.3% are seasonal residences and 12.5% are unoccupied. In last two decades, the Portuguese building sector was very active: 5.9% of the existing buildings have less than 10 years and, between 2001 and 2011, the average rhythm of construction reached 51 000 new buildings per year. However, between 2005 and 2011, due to the crisis in the construction market, this number slightly declined to 41 874 new buildings per year (INE, 2011).

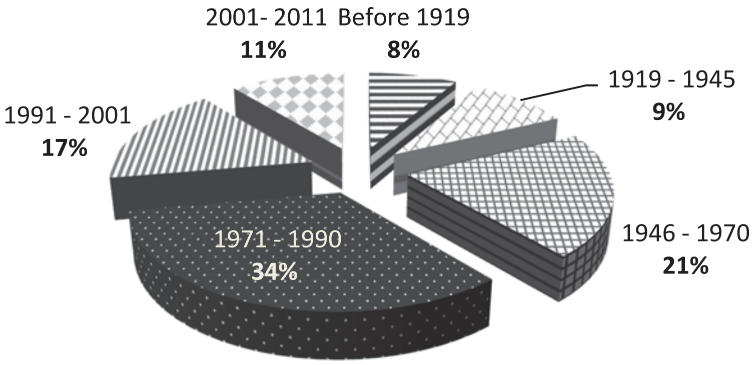


Figure 1. Existing buildings (INE, 2011)

Housing rent prices were frozen for long periods of time along the 20th century, mainly after the 1974 democratic revolution, what lead progressively to a huge lack on the renting market and significant decay of the housing stock. Although minimized within the 80's, this situation produced permanent distortion in the housing market. Although the total number of rented dwellings dropped about 21% after the 1980's, according to the IV General Housing Census (INE 2001) the percentage of dwellings occupied by owners and tenants remained almost the same. However ownership expenses can be twice as great as renting ones, it is noticeable the tendency of the Portuguese population in purchasing a house of their own instead of renting it. Beyond quality, the prices of dwelling depend mostly on the construction location. Portuguese government is making efforts in renewing the rental housing market, not only to promote the rehabilitation of existing buildings but also to promote people's mobility.

However, rehabilitation remains the less significant sector in the national market, as figure 2 shows. This low activity can be explained by the old rental policy, the inflation rates and lack of public incentives, which made economically unfeasible the execution of maintenance or retrofitting works by the owners. The small investment in building conservation and rehabilitation justifies the high degradation level not only of the façades but also of the other building elements.

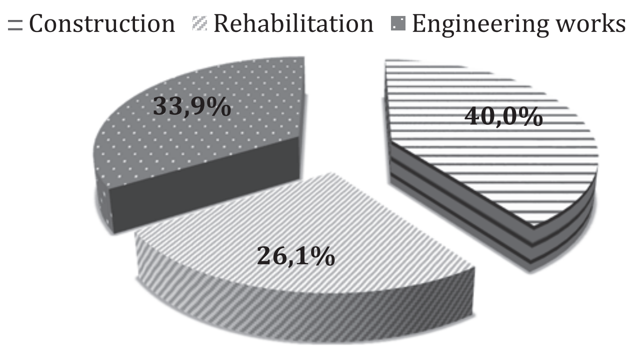


Figure 2. Investment in the Portuguese construction sector (INE, 2011)

According to data published in the 2011 Census, about 25% of the Portuguese buildings built after 1946 require some kind of reparation. The remaining 75% do not show reparation needs due recent maintenance interventions, provided by owners. Façades, including windows, represent about 30% of the buildings' needed interventions, having its deterioration factors closely related with the type of coating materials used. Regarding the needs at the level of indoor comfort, mainly thermal comfort, studies concluded that most building stock must be thermal retrofitted (INE & LNEC, 2013; Rodrigues & Freire, 2014; Brás et al, 2015).

Taking into account the characteristics of the Portuguese housing market and how they affect the quality of urban buildings, namely at the level of inhabitant's comfort, it is indispensable to study and implement new building retrofitting solutions. Given the importance of envelopes in the building's degradation process, the current work presents some refurbishing systems commonly adopted throughout European union. Nevertheless, before attempting to implement popular systems to the specific Portuguese market, it is necessary to properly characterize the requirements that the solutions have to fulfil. In this cense, this paper will start focusing the most common problems identified on multi-storey housing envelopes and the related Portuguese legislation.

2 MAIN NEEDS AND REQUIREMENTS IN PORTUGUESE BUILDING ENVELOPES

2.1 Structural Aspects

Reinforced concrete system is the most common building's structural solution in the second half of the 20th century. Critical situations on structural behaviour are not commonly reported in construction pathologies (INE, 2001), as the scarcity of occurrences may be related to the application of strong safety factors in the structural design. The main source of structural problems is the poor quality of foundation works and it affects mostly vertical envelop's elements, since the foundation's movements can cause cracks that compromise aesthetics, sealing and insulation properties. In façades and balconies, some problems could also be observed regarding insufficient protection of reinforcement steel bars. Upon long-term exposure the corrosive process developed on the bars can compromise the buildings' structural stability.

In Portugal, seismic activities are mostly observed in the South of mainland territory and Azores islands. Since Lisbon's great earthquake of 1755, seismic behaviour has been considered in the design of constructions, according to the seismic risks of each region. The first regulation on structural safety of constructions was published in 1958 (Decree-law n^{o} 41658, of May 31st, 1958) and considered, beyond static loads, dynamic loads of wind and seismic actions. The regulation was later updated towards its adaption to the general use of reinforced concrete structures (decree-law 47 723 of may 20th, 1967).

2.2 Building Physics Aspects

2.2.1 Thermal and Moisture Insulations

Before 1990, thermal insulation was a great issue in Portuguese buildings given the lack of regulations on the subject. Until then, the U value of building envelopes was very high because the use of insulation materials was not common.. Integration of different insulation materials and inappropriate insulation can lead, depending on the construction system, to the existence of thermal bridges, and therefore, to moisture condensation that effects inhabitant's health and promotes the degradation of building materials. Due to rainwater permeation, resulting from inappropriate sealing, moisture problems are also common in roofs and external walls, thus contributing for the prejudicial effects mentioned before. Another cause is related to deficient ventilation in compartments where high humidity levels are produced (bathrooms, kitchen and laundry areas).

RCCTE (Decree-Law 40/90 from the 6th February) was the first legal document concerning thermal performance and aimed the promotion of the general quality of the buildings, assuring better hygienic and comfort conditions and controlling the energy consumption for acclimatisation and hot water systems. In 1998 another regulation was published, concerning the building thermal performance envisaging over sized acclimatization systems and therefore the energy consumption. RSECE (Decree-Law 118/98 from the 7th May) was targeted to buildings with significant energy consumption for heating or cooling and was applicable mainly in buildings with over 25 kW installed.

Together, RCCTE and RSECE specifications intended to promote the improvement of the thermal quality of the buildings without increasing the energy demand and not rationalizing the consumption. The recommendations included passive cooling techniques, efficient solar collection practices and natural ventilation strategies to improve the indoor comfort. With the publication of directive 2010/31/UE, in 2013 the Portuguese regulations concerning thermal performance of buildings were updated, with the publication of a new decree-law (decree-law 118/2013, of August 20th) that extinguished the former regulations and resumed in a single document the Building Energy Certification System (SCE), the Regulation on energy performance for Residential Buildings (REH) and the regulation on energy performance for Commercial and Services Buildings (RECS).

As nearly 80% of the building stock was built before the publication of the first thermal regulation, the performance of thermal and moisture insulations are inadequate in the majority of cases. In spite of that, rehabilitation activities in view of the energy retrofitting are not yet common practices, what means that there is still a great effort to be done in the near future.

2.2.2 Noise Insulation

Providing adequate levels of acoustical comfort is a recurrent problem of Portuguese buildings. Major part of conventional constructions systems provide satisfactory insulation of vertical partition elements, thus the main complains are related to the interface between commercial and dwelling areas due to inadequate airborne sound insulation. For envelopes, in most causes, insulation issues are related with the quality of windows and other openings.

Until 2007 there was not a proper application of acoustic regulation codes. Since then, the approval of RGR (Decree-law nº 9/2007, from January 17th) enforced rigid requirements regarding the protection against sound and noise pollution, as shown in Figure 3.

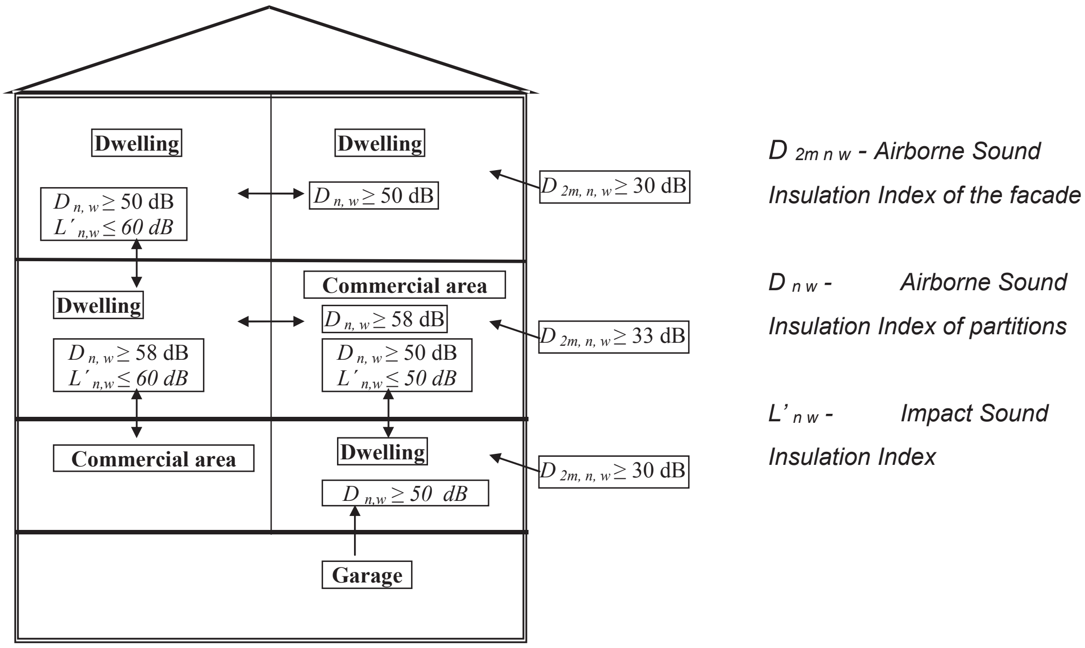


Figure 3. Sound insulation Requirements (Decree-law nº 9/2007, from January 17th).

2.3 Functional Aspects

According to Almeida *et al.* (2007), the functional quality of the majority of the multi-familiar dwellings is a significant short come of these buildings. Portuguese regulation on functional aspects is sufficient to maintain minimum conditions of inhabiting in living areas. Projects are developed in order to fulfil just the minimum acoustic and thermal comfort conditions, which is feasible due the mild climate and low noise pollution in the majority of the Portuguese territory (Bragança *et al.,* 2005).

Another general problem is that constructions usually don't consider future maintenance costs, which becomes a major concern of their inhabitants after 15 or even 10 years of use. This aspect is neglected even on projects promoted by governmental social housing policies. Ownership regime is the main determinant of the functional aspects of urban houses: housing owners are free to perform adaptations and modifications, cases in which greater involvement in maintenance and supervision are observed. In central and historical urban areas and in Social Housing, where tenants pay very small rents, owners do not have the necessary financial income to refurbish the dwellings. Tenants are sometimes the responsible for urgent refurbishments, but don't invest in significant reconstruction works, as they don't own the property. Changing the rent policy is one of the major concerns of the government after the occurrence of some accidents involving building ruining.

3 TECHNICAL SOLUTIONS TO IMPROVE THE PERFORMANCE OF PORTUGUESE BUILDINGS ENVELOPES

3.1 ETICS

ETICS stands for External Thermal Insulation Composite Systems and the first solutions were developed in the 1950s (Wetzel, 2007). The system is composed of rigid boards of insulation materials (polystyrene and concrete foams, mineral and wood fibres, etc.) attached to a supporting base through plastic adhesive, and externally covered with reinforced rendering (fig. 4). Some solutions also consider intermediary support bases, with rail mounting, whenever the base-surface does not have mechanical properties adequate for sustaining the system. An extensive variant of external cladding has been developed since the development of the first ETICS, including plasters (synthetic resins, cement, and plastic minerals) and tiles (ceramic, bricks, stones) finishing.

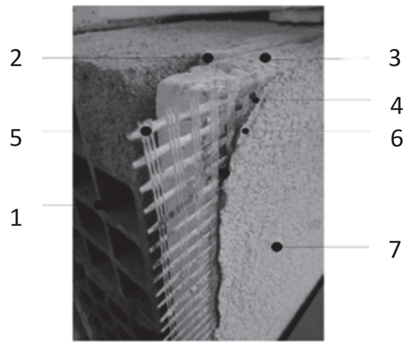


Figure 4. Components of a ETICS system: 1) base wall 2) Adhesive Layer 3) Insulation Board 4) Regularization layer 5) Rendering 6) Regularization Primer layer 7) External Coating (Plaster) (Perdigão, 2013).

As Wetzel (2007) concluded, ETICS has proven to increase the protection of external walls, improving considerably the thermal, moisture and noise insulation of the envelopes were they have been applied. For thermal insulation, the improvement of the U-value of a construction enveloped with ETICS is dependant on the thermal conductivity and thickness of the used insulation material (fig 5). The weather protection is particularly determined by the renderings, since most systems use water-repellent materials. Noise insulation properties are mainly related to characteristics of used elements (revetment, supporting system and type of fixation). Although external sound insulation is reportedly improved, the overall acoustic results are debatable. Users relate that, as the insulation improvement regarding external noises, the basic noise level is slightly reduced, what would enlarge the perception of disturbs from inside of the building (neighbouring dwellings).

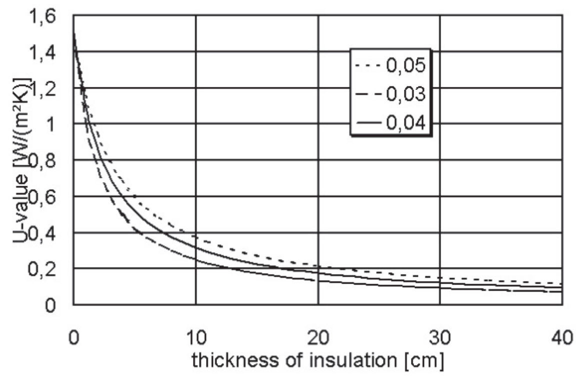


Figure 5. Variation of an external wall's U- value after fitting ETICS with different thermal conductivity insulation materials (Wetzel, 2007).

3.2 ETIDS

External Thermal Insulation Dry Systems (ETIDS) became popular in the end of the 1980's. It can be seen as a simplified version of ventilated coated façades. It is mostly used on refurbishments of three-layered external walls of large dimensions (Plewako *et al.*, 2007), and it's fixation is recommended on concrete elements .The system, applied directly on existing walls, consists of an internal insulation layer, bolted to the concrete base-wall, and an external layer, fastened on previously fixed bearing strips (fig.6). The external layer is commonly made of folded steel sheets, but fibre-cement boards are recurrent alternatives. Combinations with other external systems are also a possibility to attend aesthetic requirements. Top and bottom areas, edges and openings are covered with additional sheets or strips.

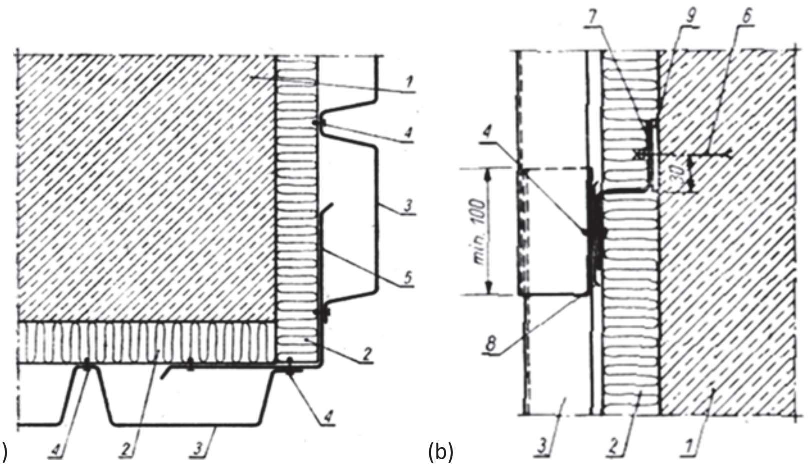


Figure 6. Layout of ETIDS components. (a) Corner top view. (b) Transversal section 1) base-wall 2) insulation board 3) coating (folded steel sheets) 4)fastener 5) corner strip 6)expansion bolt 7) Z profile 8)PVC washer 9) millboard washer (Plewako, 2007).

The insulation material and the inner air of vertical folds improve the envelope's thermal insulation, which is significantly reduced according to the thickness of insulation layer (fig. 7). Additional benefits on acoustic insulation are observed through the reflection of external noise by external steel sheets. Rainwater penetration is a potential threat to ETIDS systems as gaps on layers connections could initiate a corrosive process of steel components. However, proper fold's ventilation can protect internal layers from moisture penetration and condensation. The improvement of the building's overall thermal performance reflects on a corresponding reduction of energy consumption, as figure 8 illustrates.

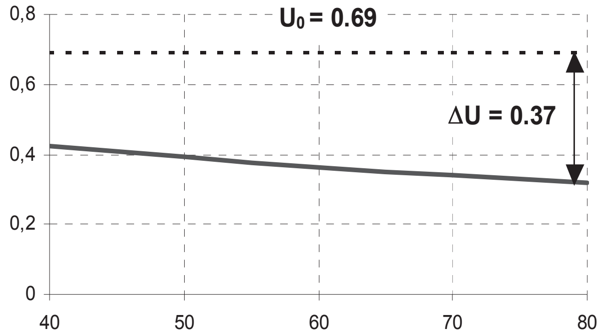


Figure 7. Variation f U-value according to the insulation thickness (Plewako, 2007)

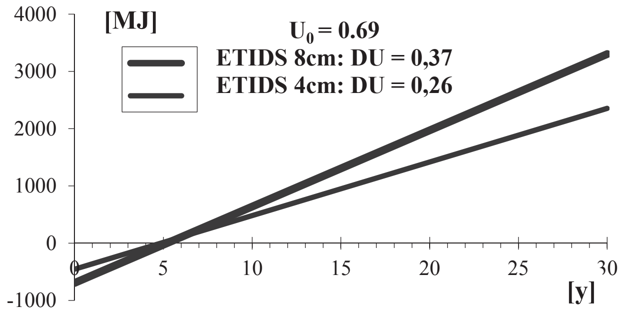


Figure 8. Approach of reduction on energy consumption for 1 m^2 (Plewako, 2007)

3.3 Ventilated Façades

As figure 9 presents, ventilated façades are composed of an insulation layer (polyurethane foam; expanded polystyrene or extruded polystyrene), fixed in the supporting wall, and a covering material separated 3 to 5 cm from the inner layer. This distance creates a cavity that allows the circulation of inner air by convection. The use of insulation boards is optional and helps to improve thermal properties of the system (Guimarães, 2013). The cladding layer provides protection from direct climate loads and (re)defines the building aesthetics. According to Bragança et al (2007), the most used covering materials are natural stone, man-made stone, ceramic, terracotta, plastic or metallic materials, oriented strand board (OSB), glass (transparent and opaque) and wood fibreboard with Portland cement. The cladding can be statically fixed into the supporting structure by anchoring devices or be supported by a steel frame structure. For both options, visible and non-visible solutions are available.

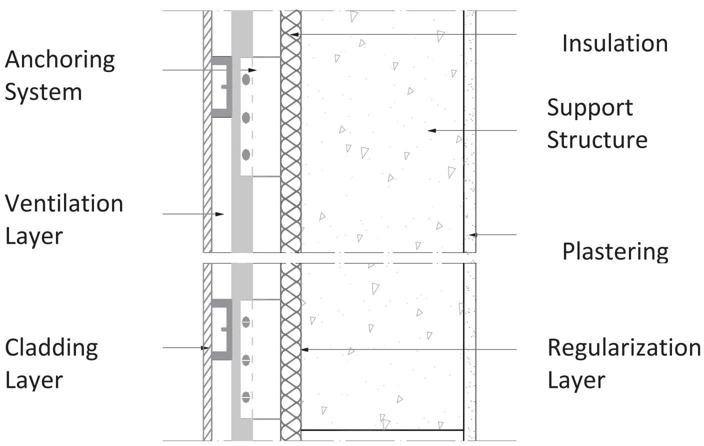


Figure 9. Transversal section of a typical ventilated façade (Mateus, 2004)

The system provides higher moisture control through the cavity, which protects the wall from rainwater and expels water vapour by convection, thus removing the moisture from both exterior and interior and preventing condensations. Also, the distance between cladding and inner layers reduces thermal bridges and improves the thermal inertia of the building, representing less heat gains (summer) and losses (winter), as figure 10 demonstrates.

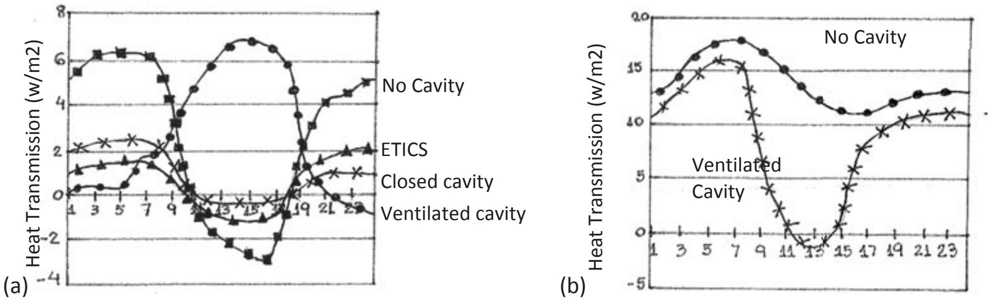
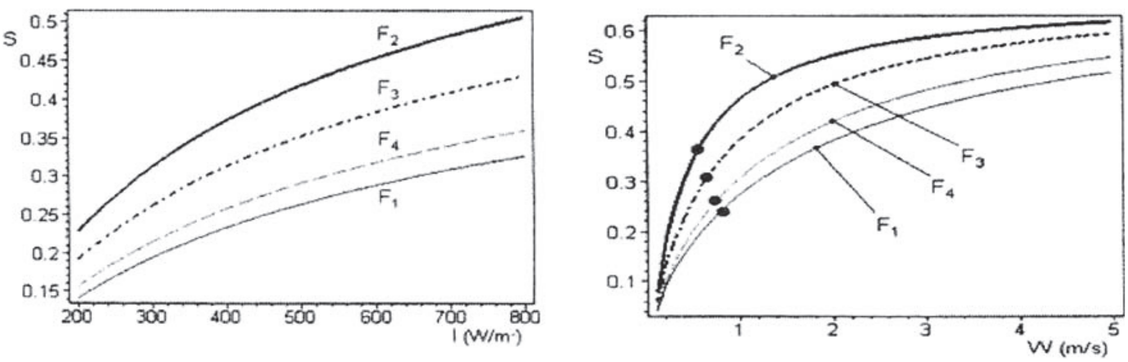


Figure 10. Heat Flux (W/m^2) from inside out along the daylight period for different envelope systems (a) summer (b) winter (Brunoro, 2007).

This characteristic reflects higher energy savings by reducing the needs for artificial acclimatization systems. In this context, it is also reported that the adopted cladding material influences the overall thermal performance. Figure 10 compares the energy efficiency performance of ventilated façades with different finishing: F1: aluminium panels F2: hollow brick tiles F3: concrete panels and F4: ceramic tiles



(a) (b)

Figure 11. Energy Saving (S) considering (a) solar radiation (I) (10cm thickness, 15 cm length) and (b) air flow speed (W) (15 cm length, solar radiation incidence of 400W/m^2) (Brunoro, 2007).

Compared to unventilated refurbishing solutions, the use of ventilated façades represents advantages regarding installation, as for the mechanical assembly of the finishing it is not necessary to use of adhesives and water-based plasters. In addition, it is a lower and easier maintenance system, where each layer can be individually handled and presents lower risks of cracking and/or detaching. Also, external cladding propitiates higher durability for the wall due to the protection against the weather.

4 CONCLUSIONS

Comparing to other construction activities, in Portugal the investment in rehabilitation is still very small and not adequate to the context, which causes the continuous degradation of the Portuguese building stock. Reality shows that few technical solutions are currently used to overcome this scenario and improve the quality and indoor environment performance of the Portuguese residential buildings. Regarding the conservation state of most building envelops and the contribution of these elements to urban and indoor environments quality, the current work presented three solutions for façade retrofitting commonly used among European countries. The first system, ETICS, is directly attached to the existing external wall. The second, ETIDS, is also applied externally on the existing façade and promotes ventilation due to the cladding characteristics. Lastly, the ventilated façades where the external cladding is separated from the existing wall by a cavity, are more complex and expensive retrofitting solutions but can improved considerably the overall performance of the façade.

The study showed that all presented solutions are suitable to improve the main needs of Portuguese building's external walls and that can be designed to satisfy regulation requirements, e.g. thermal, moisture and noise insulation. Since all of them are passive solutions to improve inhabitant's comfort, they can be understood as sustainable building rehabilitation practices. Considering the acknowledged potentialities and limitations, they have demonstrated to be viable answers to upgrade the functionality of the conventional building envelopes in Portugal. However, it is necessary to make experimental evaluations and further surveys to inhabitants to measure the real impact and performances of these technical solutions.

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