Comparison of Energy-Saving Restoration Costs Based on Spain's Initial Constraints [Single-Family Zone B4]

Comparativa de Costes de Rehabilitación Energética en Función de las Restricciones Españolas de Partida [Unifamiliares-Zona B4]

Alexis Pérez Fargallo (Main Author) (Contact Autor)

Universidad del Bío-Bío/Centro de Investigación en Tecnologías de la Construcción y Depto. Arquitectura Construcción y Diseño/Teoría y Diseño de la Arquitectura, Chile.

Av. Collao 1202, Casilla 5-C, Edificio CITEC

CP 4051381, Concepción

(+56) 4131111781 - 0034 954556691

aperezf@ubiobio.cl

Vicente Flores Alés

Universidad de Sevilla/ETSIE/Depto. Construcciones Arquitectónicas II, Spain.

vflores@us.es

José María Calama Rodríguez

Universidad de Sevilla/ETSIE/Depto. Construcciones Arquitectónicas II, Spain.

jmcalama@us.es

Abstract

Energy efficiency in the residential sector is one of the priorities of the European Union. It is estimated to achieve an energy saving of 27% in the group of buildings in the residential sector in the EU countries by 2020 through the directives issued by the European Commission. The housing stock of Spain are among the least energy efficient in Europe as a result, try to introduce governmental aid to encourage thermal refurbishment of residential buildings. Currently programs energy rating in Spain focus on the evaluation of annual CO_2 emissions, however indicators annual primary energy consumption or investment cost improvement measures are not taken into account (Rua & López-Mesa, 2012). The target is investigates the economic aspects of investment and savings in energy efficiency improvements to houses, making a comparison between alternatives and starting situations that may appear at the time to evaluate the response of a building with order to deepen another valid indicator for EE actions on existing buildings (Ahern, Griffiths & O'Flaherty, 2013).

Keywords: Energy-Saving Restoration; Energy Efficiency; Energy Savings; Costs; Economic Feasibility.

Resumen

La eficiencia energética en el sector residencial es uno de los objetivos prioritarios de la Unión Europea. Se ha estimado alcanzar un ahorro energético del 27% en el conjunto de los edificios del sector residencial de los países comunitarios para el año 2020 a través de las Directivas promulgadas por la Comisión Europea. El stock de viviendas de España se encuentran entre las menos eficientes energéticamente en de Europa en consecuencia, se intentan introducir ayudas gubernamentales para incentivar el reacondicionamiento térmico de edificios residenciales. Actualmente los programas de calificación energética en España se centran en la evaluación a de las emisiones anuales de CO_2, sin embargo indicadores consumo anual de energía primaria o el coste de inversión en medidas de mejoramiento no son tenidos en cuenta (Ruá & López-Mesa, 2012). El objetivo es investigar los aspectos económicos relacionados con la inversión y el ahorro en mejoramientos de eficiencia energética para viviendas unifamiliares, realizando una comparativa entre las posibles alternativas y situaciones de partida que pueden aparecer a la en el momento de evaluar la intervención de un edificio, con la finalidad profundizar en otro indicador valido para actuaciones de EE en edificaciones existentes (Ahern, Griffiths & O´Flaherty, 2013).

Palabras Claves: Rehabilitación Energética, Eficiencia Energética, Ahorro Energético, Costes,Viabilidad Económica.

Introduction

The restoration of housing is emerging as a potentially key area for the reduction of energy consumption in most countries. Improving energy efficiency in this sector by studying the relationship between the energy savings and economic benefits obtained with such work is crucial in order to provide social impetus to drive that paradigm shift (Clinch & Healy, 2003).

Energy savings may be achieved through technical or non-technical measures. In all cases, the aim is to reduce energy consumption without undermining productivity, quality, etc. and obviously ensuring that the environmental impact caused is not greater than the initial impact of such construction work (Sartori & Hestnes, 2007).

The public authorities in Spain programme actions to promote and encourage measures to improve existing buildings and installations but the relationship between the final energy savings obtained after upgrading and the work necessary to achieve these savings is being ignored (Charlot-Valdieu & Outregui, 2011). These data are unknown to most of society, hence the need to create resources to allow decisions to be taken with a view to reducing energy consumption in existing housing stock.

In Spain, the Basic Documents of the Technical Building Code establish the minimum quality standards for the construction of housing. However, the direct application of these documents may entail substantial investments in restoration work, and may even make such work infeasible due to its economic and social impact (Vega, 2010). The aim of restoration work is to improve the conditions of buildings, consistent - if possible - with available financial means, the characteristics of the buildings in question and potential obstacles to the performance of such work (Trebilcock, 2011), and these characteristics may not coincide with the requirements that will be met by a new building.

In principle, it seems clear that solutions will be dependant upon the case studies identified. For this reason, specific cases incorporating realistic solutions need to be studied, selecting a sufficiently large number of systems to obtain a package that may serve as a model for establishing general criteria and incorporating economic criteria.

In Spain a number of recognised documents have been created. These are non-regulatory technical documents recognised by competent authorities, namely the Ministry of Industry, Tourism and Trade and the Ministry of Housing of Spain, in order to facilitate application and studies. Recognized documents may include the following: computer benefit-driven energy efficiency rating applications, technical specifications and guides or observations on the technical and administrative implementation of prescriptive energy efficiency certification

and/or any document that facilitates the application of the procedure, provided they are not related to the use of a specific product or system.

These documents are mainly based on the evaluation of annual CO2 emissions. However, annual primary energy consumption indicators or investment cost improvement measures are not taken into account (Rúa & López-Mesa, 2012), even though this information is extremely important for determining the possibilities of improving the thermal performance of existing buildings and also encouraging different actions.

Objectives

This research proposal aimed to link different perspectives of a common element: energy-saving restoration. The overall objective consisted in the performance of an energy and economic study to improve the thermal enclosure of houses in the south of Spain, analysing improvements to walls, ceilings, floors and openings from a technical, energy and economic standpoint. The aim of this study was to generate valid economic indicators for assessing improvements in existing buildings based on different factors such as the type of improvement (exterior or interior), housing regulations pursuant to which the homes were built or their relationship with other buildings (detached, semi-detached or terraced [between party walls] housing).

The purpose was to obtain financial ratios for the execution of energy improvements applied to the different buildings and their analysis in energy saving terms compared to the estimated cost of restoration. It is important to bear in mind that a simulation may differ from a real building due to multiple factors such as the similarity of the real climate to official climate models, set-point temperature values, differences between actual thermal enclosure and the energy model, the existence of uncontrolled entries of air, the difference between the theoretical and real efficiency of HVAC equipment, manual ventilation systems, inappropriate choice of air conditioning equipment, occupancy and user habits. For all these reasons, the values obtained in this research are purely cost estimates (León et al., 2010).

Methodology

The first step was to select a series of suitable buildings on which to perform energy-saving restoration work on openings, façades and roofs. These buildings were chosen based on the ease, speed and quality of construction and the materials used. Once the buildings had been selected, calculations were performed to determine the costs of implementing improvements to interior and exterior thermal insulation. The price obtained was a functional unit price, corresponding to the cost per unit of a construction element and representing the sum of basic, auxiliary and unitary elements of an entire building with a complex function within the construction (Ramirez de Arellano, 2004).

The initial construction systems used in the buildings were determined according to the claimed age of the houses to be restored and were divided into three groups: those built prior to the entry into force of Royal Decree 2429/1979, of July 6, on the Basic Building Regulations governing the Thermal Conditions of Buildings (CT-79) with brick structures, those built prior to CT-79 with concrete structures and those built after CT-79 with concrete structures (see Figure 1).

In order to obtain quantifiable parameters based on the age, type of construction, the characteristics and type of construction, a model building located in Seville (Spain) was selected, simulated based on different systems and built in accordance with different construction regulations and/ or construction systems, resulting in the creation of nine (9) models (see Figure 1). Common characteristics were established, such as the climate zone, use, orientation, etc., in order to identify differences and similarities between the restoration works performed on buildings constructed with different energy criteria, typologies and structural systems. In terms of the type of restoration work, consideration was given to whether the improvements were interior or exterior. As a result, the number of models increased from 9 in Figure 1 to 18. The building had a ground and first floor, a pitched roof and terraces, facing in a N-S direction, with a net floor area of 103.90 m². Table 1 shows the surface areas corresponding to openings (doors and windows) on each façade of the model studied.

Figure 1. Types of housing studied. Source: Self Elaboration, 2013.
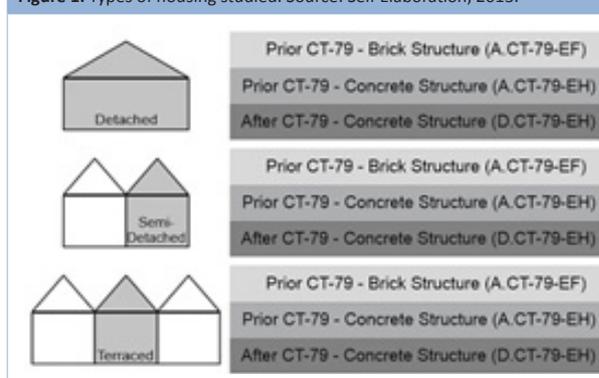
*CT-79 Royal Decree 2429/1979, of July 6. Basic Building Regulations governing the Thermal Conditions of Buildings.

Table 1. Surface area of openings (doors and windows) on each façade of the model studied. Source: Self Elaboration , 2013.

Orientation	Total surface area (m²)	Surface area of openings (m²)
North	43.21	11.99
East	55.34	0.00
West	55.34	4.20
South	40.21	4.95

These models were used to evaluate the reduction in energy demand of the homes for each of the proposed improvements and the economic costs for the execution of the improvement to the enclosure were analysed. The costs of the improvements to the enclosure were calculated per square metre of building. This analysis yielded economic ratios that we hope will facilitate decisions relating to the estimated cost of energy-saving restoration work on buildings taking into account the year and type of construction and the type of improvement.

The insulation selected for the restoration of the different parts of the enclosure was extruded polystyrene (XPS), due to its the great versatility when used in different construction systems. This material was to be used in walls, floors and roofs so that the data obtained in the analysis for the restoration of each element could be compared. The thickness of the insulation is dependant upon compliance with the maximum transmittance values established in the Technical Building Code.

Two types of finishing were selected for the restoration of façades, according to the type of work to be performed: exterior restoration work, consisting of cement rendering with mesh and white paint; or interior work, consisting of plaster with mesh and white paint.

For the restoration of floors, as with the façades, two types of intervention were chosen, but in the case of the floors resting directly on natural soil, only indoor restoration work was considered since exterior work was not feasible. The types of intervention selected, based on the type of work to be performed, were as follows: exterior restoration work, consisting of the replacement of existing material on the type of enclosure selected prior to intervention (mortar rendering or false plaster ceiling); or interior restoration work, consisting of the replacement of existing material (in floors, ceramic flooring laid on mortar was considered).

For restoration work on roofs, consideration was given to the type of roofing (flat or sloping). Depending on the type of intervention, the following restoration work was considered: for exteriors, in the case of flat roofs, replacement on the existing roof (Catalan tiles), and in the case of pitched roofs, demolition with recovery of the material and replacement of the gable roof (ceramic tiled roof); and for interior work, replacement of existing material used in walls selected prior to intervention (in the case of suspended ceilings, replacement with false plaster or plastered ceiling).

The joinery restoration systems were selected based on the initial joinery considered for the study models. In the case of houses with brick structures prior to CT-79 and initial joinery made from wood, the openings in these structures were restored with wood and glass joinery in 6/8/5 frames. The same type of glass was used in the other models, replacing the joinery according to the orientation of the building; aluminium frames were used in south and west-facing buildings, and aluminium frames with thermal break in north-facing homes due to the greater limitation of transmittances for homes facing in this direction.

All the above data were integrated in a calculation tool that evaluated each of the factors described above. This tool was used to simplify the procedure. For predimensioning air conditioning and heating in this tool, the monthly calculation method established in standard ISO 13790:2008 was used, based on the balance of useful losses and gains in winter and summer.

Results

Analysis of results according to the type of restoration work (interior - exterior).

The first analysis of the results obtained focused on the differences between exterior and interior thermal insulation restoration work. The data in Graph 1 show no substantial differences were recorded in energy savings and reductions in CO2 between the two types of restoration work. Any differences that were observed may have stemmed from the work performed on the sloping roof, since its transmittance value differed according to the position of the insulation material with respect to the roof.

As regards the restoration of walls, it is important to note that the cost of exterior and interior insulation and finishing is very similar, the cost of insulation accounting for between 50-52% of the investment and finishing between 48-50%. However, exterior insulation and finishing was 61% more expensive

than the same work on the interior. This was not the case with floors, where interior restoration was almost 22.72% more expensive. This was due to the type of insulation with bearing capacity necessary for intervention on the interior. The finishes on floors in both types of interventions were very similar, in contrast to the cost of insulation.

On the roofs of houses analysed here, interior and exterior finishing accounted for approximately 70% of the investment. Similarly, interior finishing was the most economical solution, since it was 29% less expensive than exterior finishing. The restoration of openings was not directly related to the type of restoration work since the investment was similar in both cases.

Graph 1. Estimated data for the energy-saving restoration of a terraced house [between party walls] prior to CT-79 with brick structure by type of restoration work performed. Source: Self Elaboration, 2013.
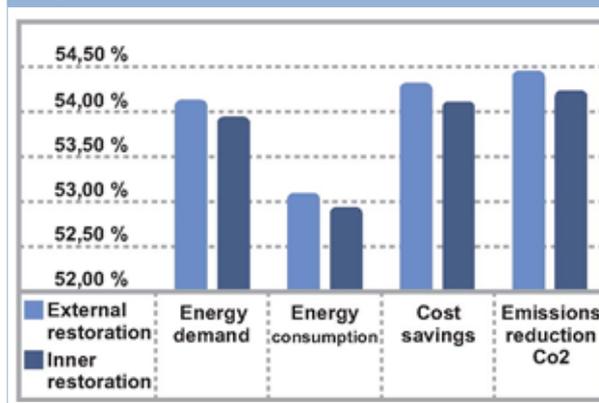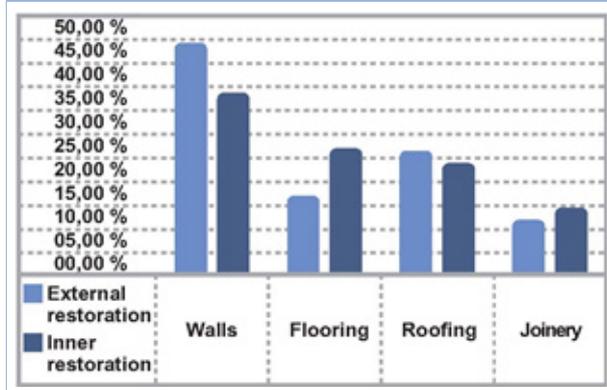
Table 2. Energy-saving restoration costs for a terraced house built prior to CT-79 with brick structure by type of restoration work. Source: Self Elaboration, 2013.

Estimated wall restoration costs			
	Insulation	Finishing	TOTAL
Exterior restoration	32.13 €/m²	29.56 €/m²	**61.69 €/m²**
Interior restoration	19.22 €/m²	19.13 €/m²	**38.34 €/m²**
Estimated floor restoration costs			
External restoration	6.64 €/m²	13.99 €/m²	**20.63 €/m²**
Interior restoration	12.79 €/m²	13.91 €/m²	**26.70 €/m²**
Estimated roof restoration costs			
External restoration	9.26 €/m²	23.75 €/m²	**33.01 €/m²**
Interior restoration	6.60 €/m²	16.91 €/m²	**23.51 €/m²**
Estimated joinery restoration costs			
Exterior restoration/Interior restoration			**70.85 €/m²**

| Overall costs and payback.		
	External restoration	Interior restoration
Walls	61.69 €/m	38.34 €/m²
Flooring	20.63 €/m²	26.70 €/m²
Roofing	33.01 €/m²	23.51 €/m²
Joinery	14.42 €/m²	14.42 €/m²
Total	129.74 €/m²	102.97 €/m²
Pay-back	12.70 years	10.12 years

An analysis of the aggregate costs (see Table 2 and Graph 2) revealed that the largest investments in these types of houses were made in walls, roofs and floors, with a relatively small percentage of the budget corresponding to openings. In the

type of housing analysed here, not all their openings were restored since this was not necessary in order to comply with DB-HE1. The overall cost of the interior restoration work was 20.50% more economical than exterior restoration work and had a 20.30% lower pay-back.

Graph 2. Percentage of overall costs for energy-saving restoration of a terraced house built before CT-79 with brick structure by type of restoration work. Source: Self Elaboration, 2013.

Graph 3. Percentage reduction in losses per element with respect to the total reduction for a terraced house built before CT-79 with brick structure by type of restoration work. Source: Self Elaboration, 2013.
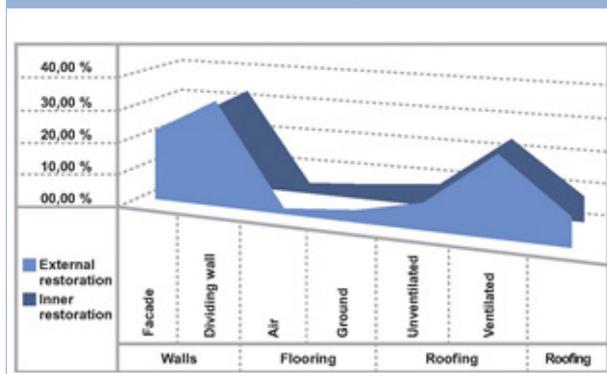
Another important aspect in energy-saving restoration work is the reduction of heat loss achieved through improvements in each building system. Graph 3 shows the data relating to the reduction of losses per element for the single-family home analysed.

The largest reductions in losses for the house studied were observed in walls and roofs, respectively. Restoration work on these enclosures would therefore be a priority; the fact that the restoration work was performed on the interior or exterior is not a determining factor. As shown in Graph 3, the data corresponding to reductions were very similar for both types of restoration work, with the exception of ventilated roofs where exterior restoration was only slightly more beneficial.

The choice of interior or exterior intervention is not only dependant upon economic or energy costs; other factors not mentioned thus far must also be considered, such as heritage factors, the reduction of net floor area, interference with occupants, etc. Moreover, the selection of elements to be restored must be prioritised according to the highest percentage reduction in losses, which will yield a lower pay-back or return on investment. If, in contrast, elements are restored but such improvements only achieve a slight reduction in their losses in percentage terms, the pay-back will

also increase, as will occur in the case of the selection of very high construction costs.

Analysis of results based on the type of building system or regulation.

In the following comparison of results, the same model was selected applying different construction systems depending on whether or not they were executed in accordance with CT-79 and different types of structures. Differences were observed in costs or energy savings associated with these characteristics; single-family detached homes with exterior intervention were selected for the purposes of this evaluation.

Graph 4 shows that the percentage savings or reductions in CO_2 emissions after theoretical intervention differed enormously depending on the baseline characteristics. The difference was around 10%; the house with brick walls was somewhere in the middle between the houses built after CT-79 and the property built before CT-79 with reinforced concrete structure.

The economic data obtained in the study of the restoration of walls and floors were very similar (see Table 3). In this respect, it is important to highlight that in the house after CT-79 energy-saving restoration work would initially only be necessary on the north façade. However, for calculation purposes, the integral restoration of the façades had to been considered, which, in turn, resulted in better thermal performance and greater energy savings.

In terms of the economic comparability of the restoration work on the floors of houses A.CT-79-EH and D.CT-79-EH, this was mainly due to the similarity of the building systems used in both homes since no type of insulation had been envisaged for the floors of houses with the characteristics defined after the introduction of CT-79.

Differences were observed in the energy-saving restoration of roofs but these are not sufficiently substantial to be relevant. The differences in costs between the study models ranged from 3-9%. However, substantial differences were observed in the restoration of openings. This difference was due to the improved thermal performance of the joinery, which was considered in the homes with brick structures, and where only the doors and windows on the north façade would have to be replaced since they do not comply with the limits stipulated in current legislation.

Graph 4. Energy data for detached single-family homes by construction system or energy regulation, exterior intervention. Source: Self Elaboration, 2013.
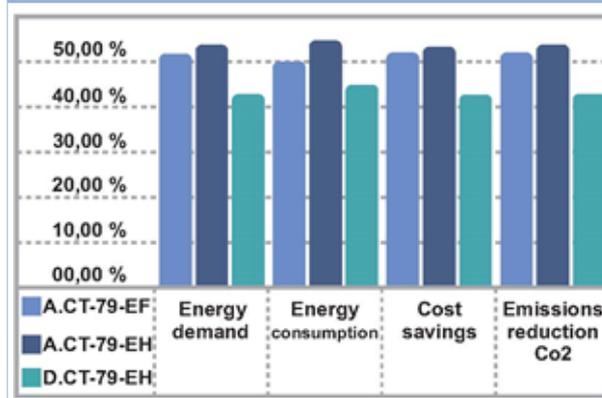
If the overall costs and their return are analysed (see Table 3), it can be seen that the costs are substantially similar, but the same cannot be said of the returns on investment. The difference is mainly in the lower initial energy consumption of the house built according to CT-79 criteria. As a result, the return-on-investment in houses built prior to CT-79 is around 45% lower than in houses that presented better initial performance (D.CT-79-EH).

Graphs 5 and 6 show that even though the investments are very similar, the percentage reduction in losses of restored elements in the models is substantially different.

Table 3. Energy-saving restoration costs for detached single-family homes by construction system or energy regulation, exterior intervention. Source: Self Elaboration, 2013.

Estimated wall restoration costs			
	Insulation	Finishing	TOTAL
A.CT-79-EF	30.63 €/m²	35.11 €/m²	65.74 €/m²
79-EH-A.CT	30.63 €/m²	35.11 €/m²	65.74 €/m²
79-EH-D.CT	30.63 €/m²	35.11 €/m²	65.74 €/m²
Estimated floor restoration costs			
A.CT-79-EF	6.64 €/m²	13.99 €/m²	20.63 €/m²
79-EH-A.CT	6.67 €/m²	12.97 €/m²	19.64 €/m²
79-EH-D.CT	6.67 €/m²	12.97 €/m²	19.64 €/m²
Estimated roof restoration costs			
A.CT-79-EF	9.26 €/m²	23.75 €/m²	33.01 €/m²
79-EH-A.CT	8.24 €/m²	23.75 €/m²	31.99 €/m²
79-EH-D.CT	6.26 €/m²	23.75 €/m²	30.01 €/m²
Estimated joinery restoration costs			
A.CT-79-EF			70.85 €/m²
79-EH-A.CT			160.22 €/m²
79-EH-D.CT			163.21 €/m²
Overall costs and payback.			
	A.CT-79-EF	79-EH-A.CT	79-EH-D.CT
Walls	65.74 €/m²	65.74 €/m²	65.74 €/m²
Flooring	20.63 €/m²	19.64 €/m²	19.64 €/m²
Roofing	33.01 €/m²	31.99 €/m²	30.01 €/m²
Joinery	14.42 €/m²	32.60 €/m²	33.21 €/m²
Total	133.80 €/m²	149.97 €/m²	148.60 €/m²
Pay-back	13.23 years	13.72 years	24.10 years

Graph 5. Percentage of overall energy-saving restoration costs for detached single-family homes by construction system or energy regulation, exterior intervention. Source: Self Elaboration, 2013.
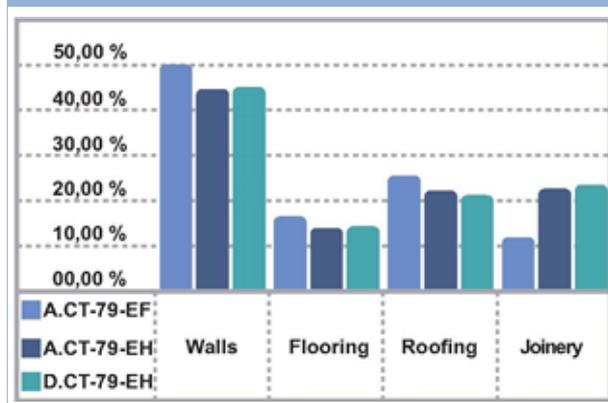
Graph 6. Percentage reduction in losses per element with respect to the total reduction in losses of detached single-family homes by construction system or energy regulation, exterior intervention. Source: Self Elaboration, 2013.
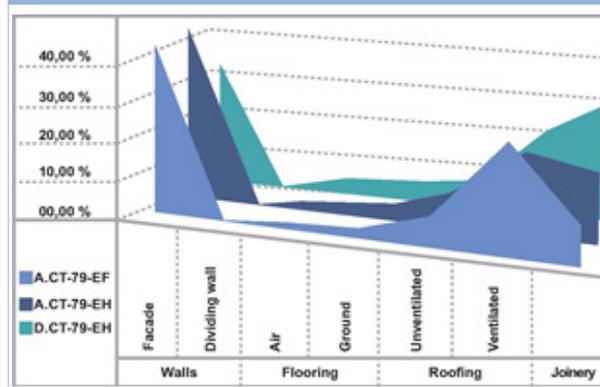
Analysis of results by type of construction.

Single-family homes may have different boundaries depending on their association with other dwellings. The analysis of both energy and economic differences based on this parameter revealed the type of housing that performed better after restoration.

For this analysis, a simulation was performed of houses built prior to the entry into force of CT-79 with exterior restoration work. In order to restore walls in semi-detached and terraced houses, consideration was given to the interior restoration costs of walls that, due to their location, cannot be improved from the exterior (partition walls).

Graph 7 shows the results for energy savings, cost savings and reductions in CO2 emissions by type of property. These show that the more thermal insulation is in contact with the exterior, the lower the energy savings obtained with similar restoration work. The difference ranges between approximately 2.5% and 4.0%, the biggest savings being observed in terraced houses and the minimum saving and the minimum emissions reduction in detached housing. It is important to highlight that this variation is due to solar factors and the worse initial characteristics of partition walls than façades.

Although it may seem logical, the difference in cost between the three types of restoration work is only dependant on the types of walls, which may be façades or partition walls, respectively, depending on the type of housing analysed (see Table 4). In contrast, the other enclosures are not linked to the type of housing and are therefore similar.

Graph 7. Estimated energy data after the evaluation for homes built prior to CT-79 with brick structures according to their boundary conditions (detached, semi-detached, terraced). Source: Self Elaboration, 2013.
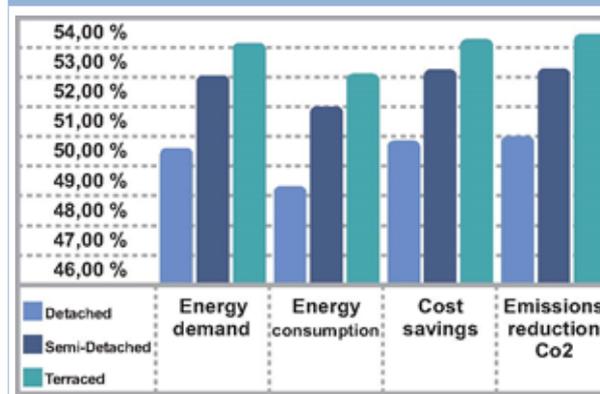
Although terraced houses have higher insulation costs, this increase is undermined by the economic difference in finishing, making the latter less economical in exterior restorations, with restoration work on semi-detached and terraced houses being between 2 and 3% more economical than the restoration of detached houses. However, the differences in pay-back ranges from 3.5 to 4%.

Table 4. Energy-saving restoration costs for houses built prior to CT-79 with brick structures by boundary conditions. Source: Self Elaboration, 2013.

Estimated wall restoration costs			
	Insulation	Finishing	TOTAL
Detached	30.63 €/m²	35.10 €/m²	65.74 €/m²
Semi-detached	31.70 €/m²	31.13 €/m²	62.83 €/m²
Terraced	32.13 €/m	29.56 €/m²	61.69 €/m²
Estimated floor restoration costs			
Detached Semi-detached Terraced	6.64 €/m²	13.99 €/m²	20.63 €/m²
Estimated roof restoration costs			
Detached Semi-detached Terraced	9.26 €/m²	23,75 € /m²	33.01 €/m²
Estimated joinery restoration costs			
Detached Semi-detached Terraced			70.85 €/m²
Overall costs and payback (Table 8)			
	Detached	Semi-detached	Terraced
Walls	65.74 €/m²	62.83 €/m²	61.69 €/m²
Flooring	20.63 €/m²	20.63 €/m²	20.63 €/m²
Roofing	33.01 €/m²	33.01 €/m²	33.01 €/m²
Joinery	14.42 €/m²	14.42 €/m²	14.42 €/m²
Total	133.79 €/m²	130.89 €/m²	129.74 €/m²
Pay-back	13.23 years	12.75 years	12.70 years

Graph 8. Percentage of estimated overall costs of exterior energy-saving restoration work on houses built prior to CT-79 with brick structures by boundary conditions (detached, semi-detached, terraced). Source: Self Elaboration, 2013.
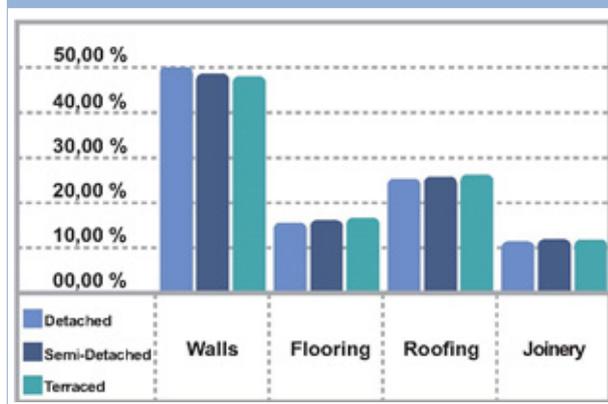
Graph 9. Percentage reduction in losses per element with respect to the total reduction in losses of houses built prior to CT-79 with brick structures according to their boundary conditions (detached, semi-detached, terraced). Source: Self Elaboration, 2013.
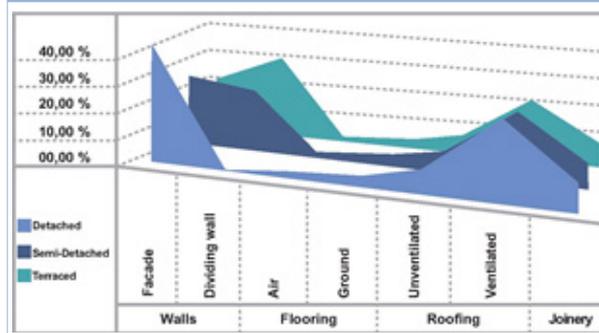
The differences in energy loss reductions ranged from 3.5 to 5%. This difference is due, as with the economic valuations, to the existence of party walls, which have worse initial thermal performance. Graph 9 shows that the reduction in losses with respect to the total loss of the walls ranged from 45.47% to 55.37% in the case of terraced housing, thus making restoration work in terraced houses more profitable than in detached homes.

Summary of economic results.

Table 5 shows the economic ratios per square meter of surface area for the restoration of houses by type of energy-saving restoration work.

Table 5. Estimated economic ratios per square meter of surface area for the restoration of houses by type of energy-saving restoration work, type of construction, building regulations and type of structure. Source: Self Elaboration, 2013.

Typology	Regulations/ Structure	Restoration work	Cost
Detached	A.CT-79-EF	Exterior	133.78 €/m²
		Interior	103.98 €/m²
	A.CT-79-EH	Exterior	149.95 €/m²
		Interior	116.60 €/m²
	D.CT-79-EH	Exterior	148.58 €/m²
		Interior	111.30 €/m²
Semi-detached	A.CT-79-EF	Exterior	130.88 €/m²
		Interior	105.05 €/m²
	A.CT-79-EH	Exterior	145.98 €/m²
		Interior	116.60 €/m²
	D.CT-79-EH	Exterior	129.26 €/m²
		Interior	100.60 €/m²
Terraced	A.CT-79-EF	Exterior	129.73 €/m²
		Interior	102.96 €/m²
	A.CT-79-EH	Exterior	144.41 €/m²
		Interior	116.60 €/m²
	D.CT-79-EH	Exterior	130.54 €/m²
		Interior	96.38 €/m²

Conclusions

Many different factors must be taken into account when undertaking energy-saving restoration work on a home. Thus, a single formula for such work cannot be determined, although certain general criteria may be established.

Exterior restoration work may yield better results in terms of the repair of thermal bridges but such work should not be performed in case of protected buildings and can be used for aesthetic or maintenance purposes. Interior restoration work is more economical than exterior work, hence the pay-back on such work is lower. The difference presents very significant values since it is approximately 20% in terms of both the total cost and the return. There are no substantial differences in the study models in energy savings and reductions in CO2 emissions between exterior or interior restoration work.

Such work must focus primarily on walls, roofs and openings. In the case of homes with wooden joinery, this can be limited to walls and roofs. In terms of walls, the characteristics of partition walls must be studied in detail. Roofs where greater reductions in losses can be achieved are those that are in contact with ventilated or slightly ventilated spaces. The order of restoration will be prioritized according to the percentage reduction in losses offered by the elements of the enclosure from the highest to the lowest. Economic investments to improve the thermal performance of floors are virtually unnecessary.

Energy savings for identical energy-saving restoration work depend on the time of construction of the houses and the surface area of the thermal enclosure in contact with the exterior; the larger the amount, the lower the energy savings after restoration, the greatest savings being achieved in terraced housing, albeit with less significant differences because, as has been determined, this ranges between 3 and 4%.

Acknowledgements

References

Ahern,C., Griffiths, P. & O'Flaherty, M. (2013) State of the Irish housing stock - Modelling the heat losses of Ireland's existing detached rural housing stock & estimating the benefit of thermal retrofit measures on this stock. Energy Policy 55, 139–151.

Clinch, J.P. & Healy, J.D. (2003). Valuing improvements in comfort from domestic energy-efficiency retrofits using a trade-off simulation model. Energy Economics, 25, 565–583.

León, A., Muñoz, S., León, J. & Bustamante, P. (2010). Monitorización de variables medioambientales y energéticas en la construcción de viviendas protegidas: Edificio Cros-Pirotecnia en Sevilla. Informes de la Construcción, 62(519), 67-82. doi: 10.3989/ic.09.045.

Ramírez de Arellano, A. (2004). Presupuestación de obras (3rd edition). Sevilla: Universidad de Sevilla.

Ruá, M. & López-Mesa, B. (2012). Certificación energética de edificios en España y sus implicaciones económicas. Informes de la Construcción, 64(527): 307-318. doi: 10.3989/ic.11.028.

Sartori, I. & Hestnes, A.G. (2007). Energy use in the life cycle of conventional and low-energy buildings: a review article. Energy and Buildings, 39, 249–257.

Trebilcock, M. (2011). Percepción de barreras a la incorporación de criterios de eficiencia energética en las edificaciones. Revista de la construcción, 10(1), 4-14.

Vega Catalán, L. (2010) La rehabilitación en el Código Técnico de la Rehabilitación. Congreso Internacional, Rehabilitación y Sostenibilidad en España. Barcelona.