BALCONIES AND THERMAL BRIDGES: A CASE STUDY AND A METHOD IN BUILDING REFURBISHMENT.

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ABSTRACT: During the refurbishment design of a building, we started to think how to answer a simple question: «once we have “reasonably” increased the insulation of walls, roofs and windows, how do we deal with balconies?» To reduce their thermal bridge is possible, but how much does it cost the energy we are going to save? The economic and technical feasibility of different retrofitting strategies has been studied, assessing their construction costs, the reduction of thermal losses (through the envelope) and the energy and economic savings. The main strategies analyzed are: 1) Balconies without any thermal insulation; 2) Lower side thermal insulation of balconies; 3) Thermal insulation of both surfaces of balconies; 4) Demolition and reconstruction of new balconies; 5) Realization of sunspaces. The work that is being done allowed us to assess a model to evaluate the convenience of different retrofit operations on the balconies of residential buildings, during the design phase. At current costs, demolition and reconstruction of balconies seems to be not advantageous (if balconies are not damaged from the structural point of view), while the transformation of existing balconies into sunspaces seems to be (if well designed) a good solution to save energy, with very variable costs for realization.

Keywords – retrofit, thermal bridges, balconies, sunspaces, economic analysis.

1. INTRODUCTION

Since multi-storey flat have been arisen, balconies have been a feature of this kind of building and they are becoming a more common sight in new high rise developments. This is essentially due to the desire for immediate access to outdoor space, that has been addressed by designers adding balconies. The easiest solution is to create use a direct extension of the floor slab, using reinforced concrete.

Together with energy issues, there are many other aspects that have to be considered: the durability, the condensation risk and the structural decay. Retrofit interventions on the building envelope require to careful evaluate construction details for architectural, constructive, energy, maintenance and durability issues. The focus of this work is the correction of balcony thermal bridging in a refurbishment intervention. Energy consumptions of buildings are influenced by the presence of thermal bridges. This is even truer when we are considering refurbished buildings, where through the application of extra insulation is possible to decrease thermal losses in the current section. One of the most critical details to address, especially in the refurbishment of a building, is how to solve the thermal bridge due to balcony slabs. The impact of such thermal bridge (for concrete balcony slabs) for a typical multi-unit residential building in Toronto has been evaluated by [2-3]. The results show that reducing the heat transfer through balcony slabs (inserting a balcony separator) could lead to a reduction of the peak heating load by 6–16% and to a reduction on annual space heating energy consumption of 5–11%, while the reduction for the annual space cooling energy consumption is (obviously) negligible.

Many solutions could be considered in order to reduce the thermal bridge of balconies, once designers have “reasonably” increased the insulation of walls, roofs, slab and windows.

One of the easiest solutions, when an extra insulation from the exterior of the wall is applied, is to insulate the lower side of the balconies. Another option is also to insulate the upper side, when it’s possible considering the difference of thickness between the interior and balcony slabs.

A more important option is to demolish and to rebuild a new balcony. Different demolitions techniques and different new balcony structures are possible. Of course this option is very expensive and has to be evaluated in a wider range (damaged existing balconies, environmental issues, the need of wider spaces, etc…).

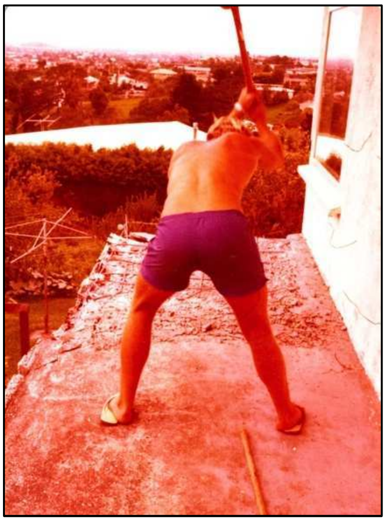



Figure 1. Example of demolition techniques by pneumatic drill and circular saw.

Among the different demolition alternatives, the pneumatic drill and the circular saw cut techniques have been considered. For the reconstruction, we considered a metallic (steel) structure, fixed by chemical bolts to the existing concrete structure. External prefabricated structures could be used to realize new balconies.


Figure 2. A stand-alone balcony (on the left) and a steel structure (on the right). Source [werzalit.com and schoeck.it]

In new buildings is possible use load-bearing thermal insulation elements which form a thermal break between the balcony and the internal floor. These elements are made specifically to transfer load and maintain full structural integrity. An insulation material (usually, polystyrene hard foam) is used for the thermal break, while stainless steel is used to maintain structural integrity. There are different manufacturers of structural Thermal Break Assemblies and Systems, which offer similar products and solutions.

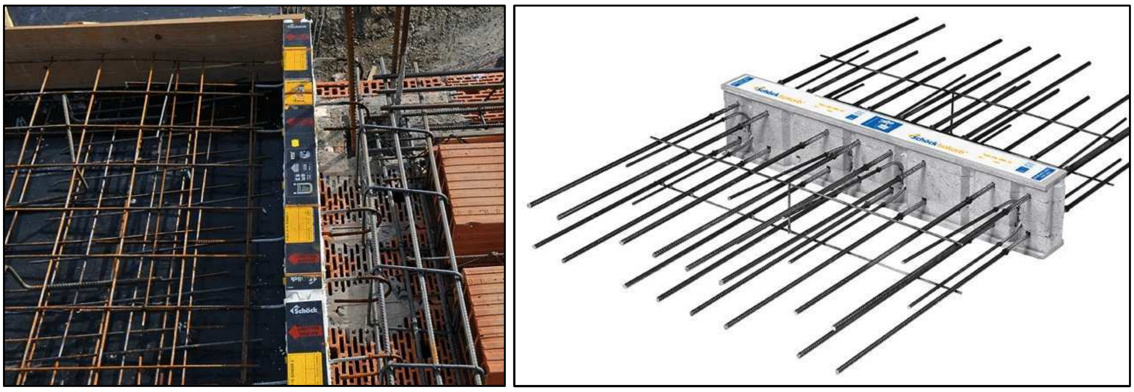


Figure 3. Example of a structural thermal systems. Source [www.shoeck.it]

Lastly, closing the existing balcony it's possible to realize a sunspace, with benefits in the winter season due to the reduction of thermal losses and to solar heat gains growth. This effect could be evaluated with different method: the quasi-steady state calculation (according to EN ISO 13790) and dynamic modeling. Several Authors dealt with this topic. Asdrubali [1] evaluated the effect of solar greenhouses in the energy balance of a building, using two different stationary procedures (Method 5000 and UNI/TS 11300), together with a dynamic simulation tool (TRNSYS), comparing the simulated data with real energy consumptions for a case study. The results show that the average reduction of the winter energy demand due to the greenhouse is about 20%, and that all methodologies are in good agreement with real energy consumptions data. Among the various methods, the Method 5000 seems to slightly overestimate the contribution of the sunspace. O'Brien [5] investigated on thermal zoning and interzonal airflow in the design and simulation of solar houses. Results show that passive solar buildings, in particular, can benefit from increased air circulation with a forced air system because it allows solar gains to be redistributed and thus reduces direct gain zone overheating and total energy consumption. These benefits have to be balanced with increasing fan energy consumption. For performance modeling of passive solar houses, the building should be divided into at least two zones: direct gain and non-direct gain. The use of multiple zones, despite is more time-consuming, allows the potential for overheating to be better characterized and to better estimate the energy consumption (that would be otherwise underestimate with the common simplification of using a single zone to represent a building).

Passerini [6] in his work proposed some improvements to the quasi-steady-state methods, in order to answer to some lacks of the calculation procedure. The proposals regard shading factors (the technical standard considers a unique value for all the internal surfaces), formulation of the indirect gain, heat dispersion of the solar gain through the ground and air ventilation passing through the sunspace. Passerini [6] collected some useful data from two experimental sunspaces scale models, through measurements and calculations of the physical quantities involved in sunspace functioning, and from a real refurbishment case of an apartment, where the veranda was closed with windows and a mechanical air extraction system was installed in order to preheat the air in the veranda, also through a solar air collector.

Figure 4. Example of sunspaces. Source [Pictures by Authors]

The objective of this paper is to investigate the significance of thermal bridges, particularly balcony slabs on the energy performance of residential buildings (both multi-unit and single family house) and evaluate the potential improvement of different alternatives on energy savings, evaluating how much does it cost the energy we are going to save.

2. Methodology

The heat losses through the balconies give a low contribution on the total losses because the total length of the balconies L_{balc} is low in comparison with the total opaque wall surface S_{wall}. This concept could be expressed by a simple ratio between the two contributes (L/S). This parameter allows to compare different façade with balconies solutions. As a first evaluation it is possible to consider only the building façade without calculating the whole energy balance (gains and gains utilization factor) to evaluate the energy and economic saving due to the possible different solution of balconies thermal bridges corrections.

Results reported in § 2.1 are calculated according to this approach, considering two class of intervention on the exterior wall (corresponding to an extra insulation of 8 and 16 cm, λ_{INS} 0.040 W/(mK)) that lead to the achievement of energy Class B (EP_h < 58 kWh/m^2/y) and A (EP_h < 29 kWh/m^2/y), according to national legislation.

From the façade we therefore moved to the whole building, so that was possible to evaluate the energy efficiency on a real object, considering all elements that influence results (surface to volume ratio, solar gains, gain utilization factor, etc.). It has to be pointed out that when we refer to energy consumptions (kWh) it has to be considered a “reduction coefficient” that represents the real energy consumptions (from bills) to the calculated ones ratio.

Thermal bridges have been calculated by the use of a finite element software (THERM), according to ISO 10211:2007.

Two different case studies have been analyzed, both of them built in the sixties before energy saving standards applications and located in Brescia (northern Italy). The apartment block (social housing) building has a regular rectangular plan (Fig. 6), with a projected size of about 40.0x11.0 m; it has six heated floors over an open ground floor and under an unheated not accessible attic, for 24 apartments of different sizes (average A_C 85.0 m^2). A district heating system, with a nominal conversion factor f_P=0.85, serves the building, except for Domestic Hot Water (DHW) that is still provided by individual electrical boiler.

The single-family house has a porch at the ground level and is characterized by a great Surface to Volume ratio. The heating supply system is a gas non-condensing boiler (f_P=1), with a poor efficiency. The DHW is provided by a gas-fired non condensing boiler. For both buildings, the DHW consumption is not considered in the analyses.

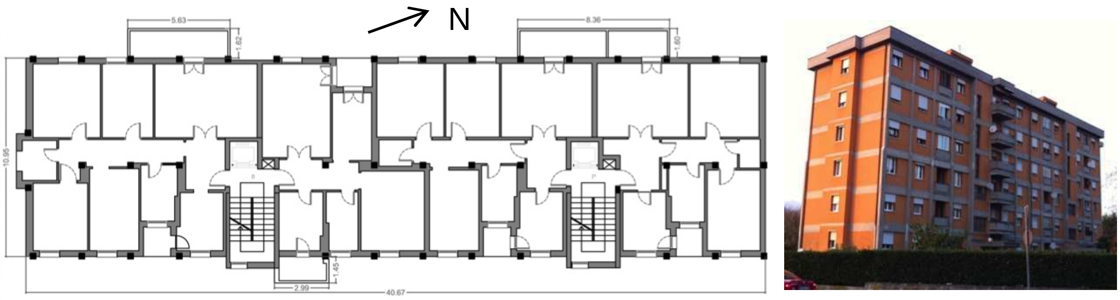


Figure 6. Typical plan of the apartment block building.

Figure 7. Ground and first floor of the single family house building.

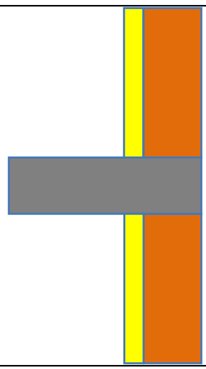
Table 1. Geometrical and main energy features of the building.	APART. BLOCK	SINGLE FAMILY	
Conditioned Area (internal dimensions)	2'046	105	[m^2]
Conditioned volume (external dimensions)	7'984	435	[m^3]
Compactness ratio (Thermal Envelope area/Conditioned vol.)	0.46	1.00	[m^{-1}]
Thermal envelope area (opaque)	3'335	422	[m^2]
Windows surface area:	351	14	[m^2]
Average U-value (of whole building envelope). Existing	1.46	0.90	[$W/(m^2K)$]
Average U-value (of whole building envelope). Class B	0.53	0.37	[$W/(m^2K)$]
Average U-value (of whole building envelope). Class A	0.40	0.29	[$W/(m^2K)$]
L/S	0.06	0.04	[1/m]
EP_h (initial)	169	287	$kWh/m^2/y$
EP_h (class B)	53	99	$kWh/m^2/y$
EP_h (class A)	29	68	$kWh/m^2/y$
Reduction coefficient	0.70	0.58	[-]

2.1. Interventions

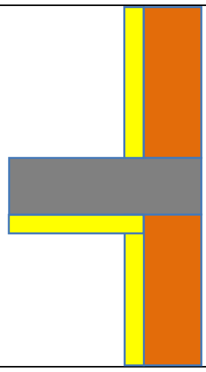
The following list of interventions on balconies are referred to the apartment block building, considering a total length of balconies of 100 m and a opaque wall surface of 1’800 m^2. The thickness of the balcony is equal to 25 cm.

Costs of the analyzed retrofit solution on balconies include materials, machinery and manpower, overhead costs for safety and site and contractor’s profit and they have been collected and validated from manufacturers and construction companies. The total costs reported in the tables include both the realization cost of extra insulation on walls (equal to 70 €/m^2 for 8 cm and 80 €/m^2 for 16 cm) and the one of retrofit interventions on balconies. Costs of the scaffolding are already included in the cost of the wall insulation. The thermal bridge contribution represents the percentage of heat losses through the (thermal bridge of) balconies compared to the overall heat losses over the whole opaque façade.

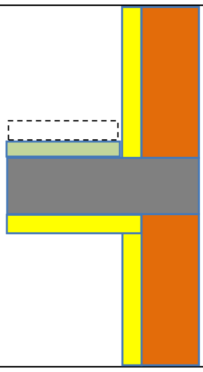
CASE [b]: Balconies are insulated with 4 cm of EPS on the lower side. (λ_{INSUL} = 0.04 W/(mK)). Thicker insulations would not lead to significant energy savings. The cost of insulating layer has been considered 50 €/m^2 of balcony surface.
CASE [c]: Balconies are insulated with 4 cm of EPS on the lower side and 3 cm on the upper side (λ_{INSUL} = 0.04 W/(mK)), previously removing (10 €/m^2) and then rebuilding the slab (20 €/m^2), waterproofing membrane and floor surface. The cost of upper insulation is 20 €/m^2. This intervention is only possible when the thickness of slab is higher than 10 cm to maintain the correct slope.
CASE [d1]: *Demolition* could be made by cutting technique (circular saw) or by hammer drills. The first option is more expansive and requires specialized operations, together with a crane. The *reconstruction* is made by external steel structures fixed by chemical bolts. To realize concrete parapets is more expensive than to realize steel railings.
Costs of intervention [k€]: 20 (demolition by hammer drill) + 76 (reconstruction)
CASE [d2]: The *reconstruction* is made by structural light-weight concrete and steel reinforcing bars fixed to existing concrete beam with chemical bolts.
Costs of intervention [k€]: 20 (demolition by hammer drill) + 70 (reconstruction)
CASE [e]: For this example (referred to the same building façade, as it would be a new realization), it has been chosen a ttermal break with a thickness of 8 cm and an equivalent λ-value of 0.095 W/(mK), as declared by manufacturer. The comparison has been made with the case without thermal bridge correction.



CASE [a]: No insulation of balconies		
	s_{INSUL} = 0.08 m	s_{INSUL} = 0.16 m
U_{WALL} [W/(m^2K)]	0.34	0.20
Ψ [W/(mK)]	0.65	0.63
$Q_{T,0}$ [kWh/(m^2y)]	19.34	11.56
Thermal bridge contribution	9.6%	15.0%
Costs of wall insulation [k€]	138	173

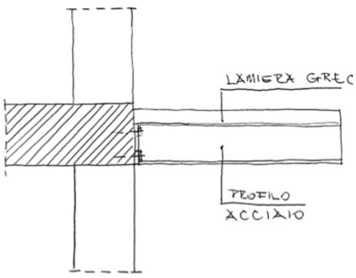


CASE [b]: Lower side thermal insulation		
	s_{INSUL} = 0.08 m	s_{INSUL} = 0.16 m
U_{WALL} [W/(m^{2}K)]	0.34	0.20
Ψ [W/(mK)]	0.54	0.54
$Q_{T,0}$ [kWh/(m^{2}y)]	- 0.30	- 0.30
Thermal bridge contribution	8.2%	13%
Costs [k€]	146	180

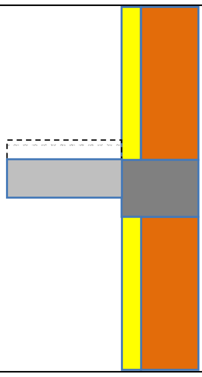


CASE [c]: Lower and upper side thermal insulation		
	s_{INSUL} = 0.08 m	s_{INSUL} = 0.16 m
U_{WALL} [W/(m^{2}K)]	0.34	0.20
Ψ [W/(mK)]	0.40	0.42
$Q_{T,0}$ [kWh/(m^{2}y)]	- 0.72	- 0.60
Thermal bridge contribution	6%	10%
Costs [k€]	161	195

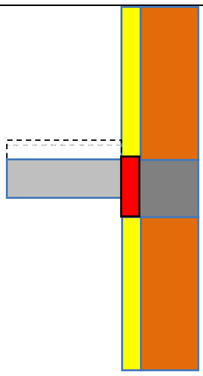
CASE [d1]:



Demolition and reconstruction of balconies		
	s_{INSUL}=0.08 m	s_{INSUL}=0.16 m
U_{WALL} [W/(m^{2}K)]	0.34	0.20
Ψ [W/(mK)]	0	0
$Q_{T,0}$ [kWh/(m^{2}y)]	- 1.86	- 1.70
Thermal bridge contribution	-%	-%
Total Costs [k€]	234	268



CASE [d2]:Demolition and reconstruction of balconies		
	s_{INSUL} = 0.08 m	s_{INSUL} = 0.16 m
U_{WALL} [W/(m^{2}K)]	0.34	0.20
Ψ [W/(mK)]	0.316	0.326
$Q_{T,0}$ [kWh/(m^{2}y)]	- 1.17	- 0.96
Thermal bridge contribution	5%	8.3%
Costs [k€]	229	263



CASE [e]: New balconies in new buildings		
	s_{INSUL} = 0.08 m	s_{INSUL} = 0.16 m
U_{WALL} [W/(m^{2}K)]	0.27	0.18
Ψ [W/(mK)]	0.178	0.180
$Q_{T,0}$ [kWh/(m^{2}y)]	-1.67	-1.43
Thermal bridge contribution	3.5%	5.5%
Costs of thermal break [k€]	11.5	

2.2 Sunspaces

In addition to the presented interventions on balconies, the realization of sunspaces adjacent to the conditioned space closing the balconies space has been considered. Sunspaces give energy advantages because of the solar gains growth and the transmission and ventilation losses became lower than before. These issues have been calculated by means of the quasi-steady state calculation method of the standard ISO 13790 [4], as corrected by Passerini [6], to take into account the shadings on the internal windows and partition from horizons, overhangs and fins, and the shadings from overhangs on the floor of the sunspace. The solar heat gain Q_{SS} entering the sunspace is the sum of the direct heat solar heat gains Q_{Sd} through the partition wall between the unheated sunspace and the conditioned space and the indirect solar heat gains Q_{Si} absorbed by the opaque surfaces in the sunspace (partition wall and floor; ceiling and parapet are excluded).

$$Q_{SS} = Q_{Sd} + Q_{Si} \tag{1}$$

$$Q_{Sd} = \left(1 - F_{F,e}\right) \cdot g_e \cdot \left[\left(1 - F_{F,w}\right) \cdot g_w \cdot A_w \cdot F_{sh,w} + F_{sh,p} \cdot \alpha_p \cdot A_p \cdot \frac{H_{p,tot}}{H_{p,e}}\right] \cdot I_p \cdot t \tag{2}$$

$$Q_{Si} = N \cdot \left(1 - b_{tr}\right) \cdot F_{sh,f} \cdot \left(1 - F_{F,e}\right) \cdot g_e \cdot \sum_j I_j \cdot \alpha_j \cdot A_j \tag{3}$$

The presence of the sunspace reduces the transmission and ventilation heat losses between the conditioned zone and the adjacent unconditioned space using the correction factor b_{tr}.

$$Q_T = 0.024 \cdot N \cdot \left(H_{T,p} + H_{T,w}\right) \cdot b_{tr} \cdot \left(\theta_{\text{int}} - \theta_e\right) \tag{4}$$

$$Q_V = 0.34 \cdot HDD \cdot \left(1 - b_{tr}\right) \cdot n \cdot V \tag{5}$$

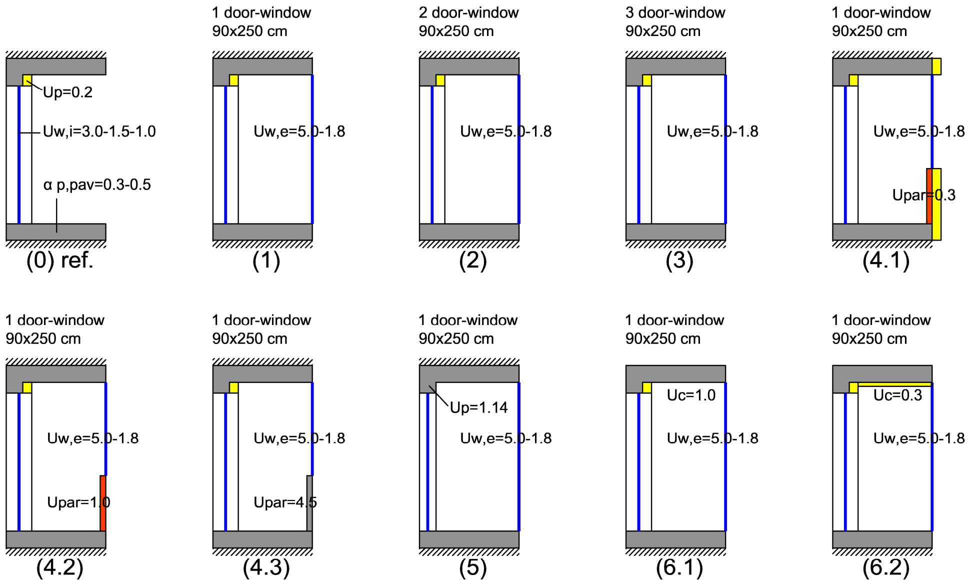


Figure 8. Sunspaces schemes used for sensitivity analysis.

Results are influenced by many parameters: the thermal transmittance of the wall (the U-value has been chosen equal to 0.2 as a typical Class A energy label), thermal and solar transmittance of internal and external glazing, the presence and the insulation rate of parapet, the upper and lower boundaries of sunspace, the absorption coefficients (depending by color and roughness of surfaces) of wall and balcony slab (considered equal each other). Other parameters (such as exposure, location, dimensions of the façade, the depth of the balcony) have been kept constant, since they are related to some constraints, but they could be investigated for a wider study. A sensitivity analysis has been made, considering a 5.3x1.8 m size balcony, with a window of 1.2x2.5 m, for a total of 108 simulations cases (12 for each scheme in Figure 8).

Results have been represented considering the net value (Q_{net}, kWh) between all cases *i* with the sunspace (ranging from (1) to (6.2)) and the reference case (0), without any sunspace, for the heating season (from October to April, in the North of Italy), according to the following formula, where Q_S are the solar gains and Q_L the losses. Q_{net} is here a balance in terms of energy need, which will be converted in primary energy once the analysis is made for the all building and heating system.

$$Q_{net} = \left(Q_{S,i} - Q_{L,i}\right) - \left(Q_{S,0} - Q_{L,0}\right) \qquad (6)$$

From graphs of Figure 9 it is possible to assert the more the external sunspace surfaces are insulated, the more sunspaces lead to benefits in terms of energy saving; it is clear the influence of the absorption coefficients and the influence of the transparent part of the façade (lower is the transparent area, greater are benefits). It has to be pointed out that other issues are related to the transparent area, such as lighting requirements (a minimum transparent surface is required, for healthy and lighting comfort) and usability of the sunspace.

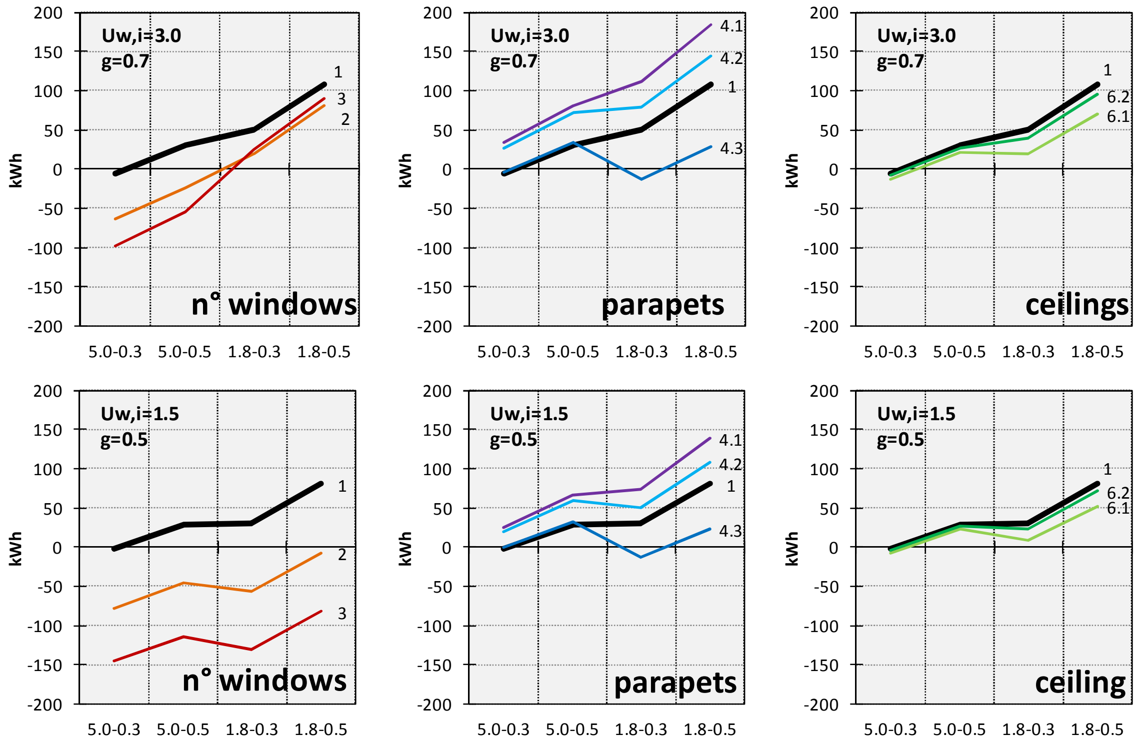


Figure 9. Sensitivity analysis results for a sunspace of 5.6 m length and different configurations, according to Figure 8. On the x-axis there are the U-value for the exterior glass and the α coefficient for wall and floor.

The presence of a parapet, if insulated, can improve the energy saving through the sunspace; it is also important to insulate the ceiling and the floor of the sunspace.

For the interior glazing, worse are the performances of the existing glass (greater U-value and lower g-value) better are benefits due to the realization of the sunspace. The same applies for the u-value of the interior wall. It has been found that, once the sunspace is chosen, it is better to have a better glass (low U-value, greater g-value) and a better wall (low U-value).

Case (5) (here not represented in the graph) represents a sunspace with a non-insulated partition wall. Sunspaces realized on a not-insulated wall lead to a great energy saving. Considering a non-insulated wall and the best sunspace configuration (that is with a U-value for the external glazing equal to 1.8 $Wm^{-2}K^{-1}$), this is equivalent to an exterior wall (with no sunspace) insulated with an external insulation of 14 cm.

Comparing a sunspace with an insulated partition wall and a sunspace with a not-insulated one, the greater energy saving is reached in the first case.

3. RESULTS

Applying this method on the façade of the building it is necessary to consider the dimension of balconies and the orientation. On the west face there are the most of the balconies (5.6 and 8.4 m of length for each floor) while on the east face there is only a balcony with 2.75 m of length, that has not been refurbished in a sunspace in order to contain costs of realization. For the apartment block building, all interventions are reported in the graph of figure 11, where the primary energy consumption is reported on the x-axis. On the y-axis is the cost of intervention (starting from the case 1), expressed in € over square meter of conditioned floor area. Efficiencies are showed in figure 12 (for the single family house), where real energy consumptions are reported on the x-axis. The efficiency of the intervention is defined as the value of the gradient that represents the cost of intervention per saved energy, €/kWh. The efficiencies of such interventions (referring to real energy needs) are lower compared to the ones of previous intervention of refurbishment (wall insulation, windows replacement, etc.). As previously stated, in Figure 10 has been represented the path we went through in order to reach reference points for energy class B and A, from which following analyses start.

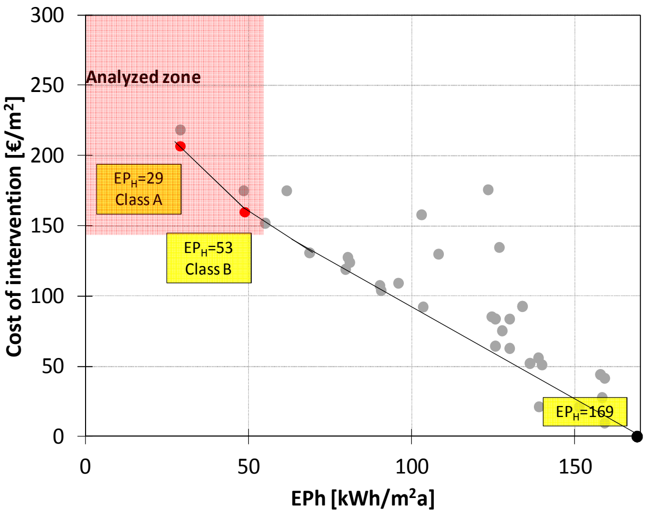


Figure 10. Path of refurbishment interventions from the existing building.

Graphs of figures 11 and 12 report cases of sunspaces, for Class B and Class A scenarios, characterized by either an external double glazing (U=1.8

$Wm^{-2}K^{-1}$, g=0.6, case [e2]) or a single one (U=5.0 $Wm^{-2}K^{-1}$, g=0.8, case [e1]), with an insulated parapet (U=0.3 $Wm^{-2}K^{-1}$), a double internal glazing (U=1.5 $Wm^{-2}K^{-1}$, g=0.5) and absorption coefficient for wall and floor equal to 0.5, applied to the apartment block building. Looking at graph of figure 11, there is evidence that sunspaces could lead to some benefits, but it strongly depending on costs of realization. This benefit (valuable in the range 6-8%) is slightly higher for class A intervention, compared to Class B. Considering the gain utilization factor in the whole analysis of the building leads to similar results to the ones obtained using the simplified method (façade energy balance).

Despite a wide range of costs has been considered (due to variable quotations, related to architectural, aesthetic and technological choices), there is still a chance to decrease costs of realization, in order to improve the efficiency. Even if efficiencies are not directly reported in the graph, it is clear that sunspaces could have a higher efficiency compared to other cases (the gradient of extra cost over energy saved is lower). Efficiencies are higher for the flat building compared with the single-family house (lower €/kWh).

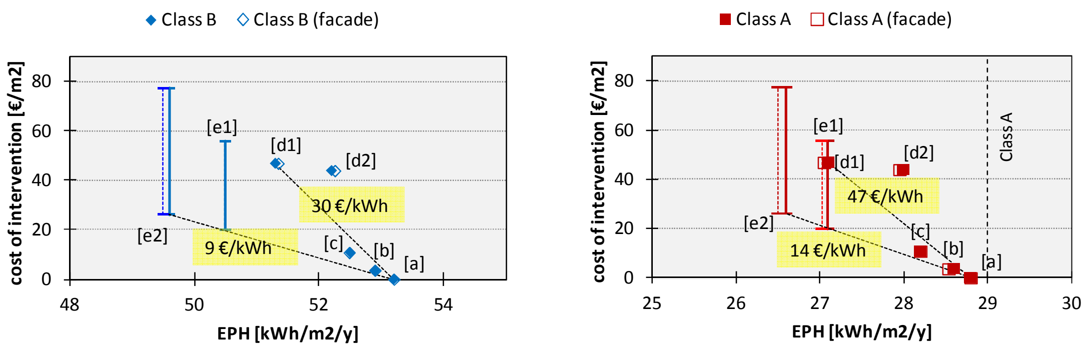


Figure 11. Results for class B (left) and class A (right) intervention on balconies comparing the application on the façade and the whole building. Apartment block building.

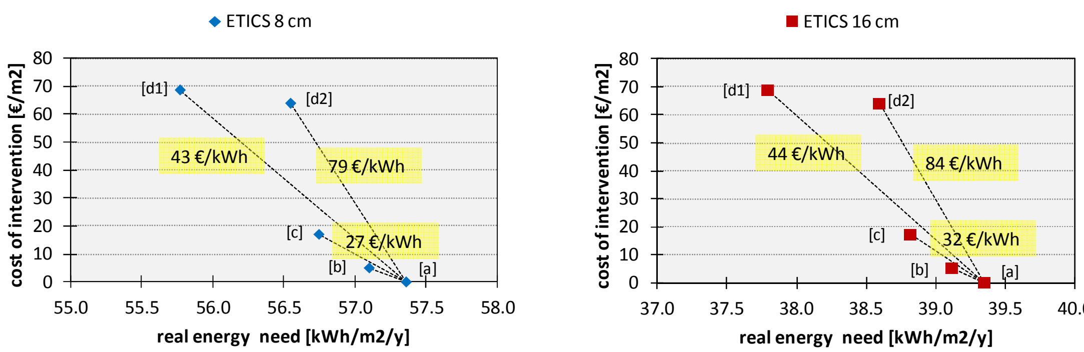


Figure 12. Energy saving and cost of intervention for balconies, comparing two different insulation levels. Single-family house. On the x-axis is the real energy need.

Considering the buildings as new, the use of thermal break systems brings to EP_H savings between 3% and 5% (for single family and apartment block buildings, respectively) with an additional cost of about 120 €/m of length.

Considering a higher extension of balconies (the length of balconies has be considered the double) the efficiency increases. It has to be pointed out that energy saving is greater than the case with lower length of balconies. For instance, in the case of realization of sunspaces, an energy saving in the range 10–15% has been achieved. This is essentially due to a greater influence of thermal bridges over the energy consumptions, compared to a double of costs (in a simple evaluation). For particular cases in which balconies are a key feature of the building envelope, thermal bridges would be potentially greater, and costs should be evaluated on a different scale.

As an extreme (bad) approach, it would be even possible to increase the insulation of the wall, neglecting thermal bridge corrections and other issues (quality, durability, mould growing, etc.). By an energy balance evaluation, it has been found that for a well insulated envelope (class A), the efficiency of this intervention is comparable with some of the balcony corrections, in particular with the best sunspace configuration.

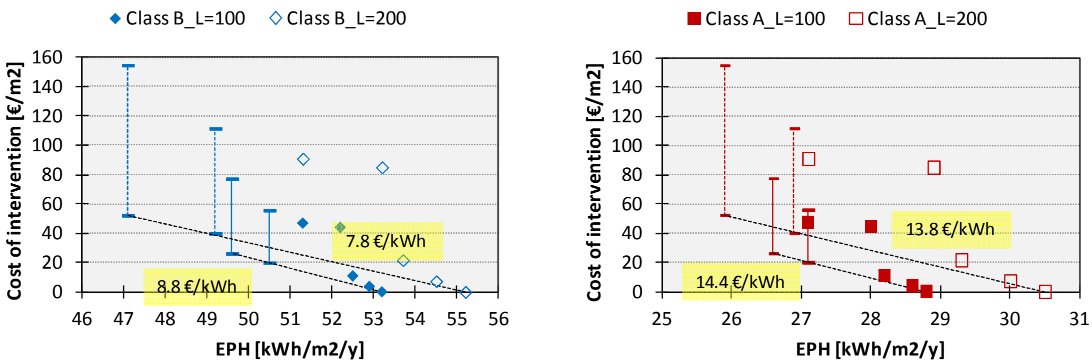


Figure 13. Results for class A and class B intervention on balconies comparing two lengths of balconies. Apartment block building. Points are referred to the whole building

4. CONCLUSIONS

In this work, we assessed a method to evaluate the influence of different interventions of balcony thermal bridging correction for residential buildings. Two different buildings have been analyzed, and a method on the façade has been presented. Results show that sunspaces seem to be a valid alternative in order to achieve energy savings. This option has to be carefully designed in order to assure both comfort and an architectural value to the added space. Technological and economic analyses play a fundamental role in the design and realization phase, together with the need to develop more accurate simulation tools in order to better understand a complex phenomena.

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