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Energy refurbishment in existing buildings: thermal bridge correction according to DM 26/06/2015 limit values.

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Abstract

The recent Italian decree 26.06.2015, concerning minimum requirements of new and renewed buildings, allows a 30% derogation on mean thermal transmittance limit values in case of insufflation with insulating materials in cavity walls in buildings object of refurbishment. The purpose of the present paper is to study the thermal bridges optimal correction in order to verify the respect of the mean thermal transmittance mandatory values. A typical repetitive module of a building façade with windows, sub windows and rolling shutter boxes is analysed. Thermal bridges due to pillars, beams, lintels, thresholds, jambs and thickness reductions of walls situated under windows are considered. The thermal bridges correction is obtained by means of high performance insulating material layers on the outer side of thermal bridges. A 2-D numerical model is used to determine the linear thermal transmittance of junctions. Calculations carried out by the authors show that the limit values of thermal transmittance provided by the decree are too severe to be respected, even in case of derogation.

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Keywords: Thermal bridges, insufflation technique, thermal transmittance, insulating materials, 2-D numerical simulation.

1. Introduction

Retrofitting of existing buildings plays a critical role to achieve sustainable development [1]. In fact, the building stock worldwide consumes approximately 40% of the total energy and emits one third of the total greenhouse gases emissions [2].

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Nomenclature

A	area (m^2)
d	aerogel panel thickness (m)
DD	degree days (d°C)
H	height (m)
ℓ	surplus length (m)
L	length (m)
L_{2D}	thermal coupling coefficient (W/mK)
R	thermal resistence (m^2K/W)
SR	surplus ratio (%)
U	thermal transmittance (W/m^2K)
λ	thermal conductivity (W/mK)
ψ	linear thermal transmittance (W/mK)

Subscripts

b	beam (see Fig. 2)
bc	beam-current wall thermal bridge (see Fig. 2)
c	current wall (see Fig. 2)
f	frame
g	glass
m	mean
p	pillar (see Fig. 2)
pc	pillar-current wall thermal bridge (see Fig. 2)
r	roller shutter box (see Fig. 2)
rbs	roller shutter box-beam-sub window thermal bridge (see Fig. 2)
rc	roller shutter box-current wall thermal bridge (see Fig. 2)
s	sub window (see Fig. 2)
sc	sub window-current wall thermal bridge (see Fig. 2)
w	window (see Fig. 2)
wc	window-current wall thermal bridge (see Fig. 2)

Several actions have been taken by the European Commission to reduce energy consumption through many revisions of Energy Performance Building Directives (EPBD): Directive 2002/91/EC, Directive 2010/31/EU, Directive 2012/27/EU [3,4,5].

In Italy, some mandatory laws have come into force to transpose European Directives [6]. The application of European Directive 2010/31/EU has been recently integrated with the publication of three mandatory decrees by the Ministry of Economic Development (decrees 26.06.2015) [7, 8, 9]. A great amount of attention has been addressed to reduce envelope energy need both in new and in existing buildings. This action can be considered as the essential start point to succeed in exploiting renewable sources and reducing primary fossil energy consumption.

In particular, decree 26.06.2015 concerning design minimum requirements allows a 30% derogation on limit values of thermal transmittance of existing buildings opaque walls in two cases: insulation of the inner part of building elements or insufflation with insulating materials in cavity walls. The latter case is very significant, since almost all Italian '45-'80 years residential buildings were built in reinforced concrete frame structure with beams and pillars completed by cavity wall technique. In an urban contest, an eventual coat insulation increases wall thickness and frequently is hardly achievable due to limited available distances among buildings and to property border reasons. Moreover, coat insulation of external walls frequently requires extra works, i.e. thresholds and lintels substitution, eventual new displacement of water and gas pipes, reposition of shutters and reconstruction of architectural and decorative elements.

Thus, instead of insulating the internal part of walls with a consequent reduction of net internal spaces [10,11] and probably risk of interstitial condensation, an useful insulation technique is to fill the air layer with granular insulating materials. The main problem related to this technology is the failure of thermal bridges correction with consequent higher energy needs and risk of mould growth. A study concerning buildings in Greece [12] has demonstrated that buildings heating need in case of insulated cavity walls without thermal bridges correction is by 50% higher than the one calculated for the more recent buildings with coat insulations and thermal bridges correction. Consequently, a low thickness insulation of pillars and beams with a high performance insulating material is necessary to reduce building envelope energy need.

In a previous paper [13], the authors demonstrated that the mean thermal transmittance limit values imposed by decree 26.06.2015 are impossible to comply without a correction of thermal bridges, even in the presence of derogation. A simple case study concerning an opaque vertical wall with thermal bridges due to beams and pillars has been investigated. In particular, it has been shown that a low thickness insulation applied on the outer side of pillars and beams is necessary to respect limit values.

The purpose of the present paper is to analyse a more complex case study, which is a façade with windows, sub windows and rolling shutter boxes. In addition to junctions due to beams and pillars, thermal bridges due to lintels, thresholds, jambs and thickness reductions of walls situated under the windows are considered.

The linear thermal transmittance of thermal bridges is calculated according to standard UNI EN ISO 10211 [14], by means of the 2D finite element simulator THERM [15]. The software has been validated according to UNI EN ISO 10211 prescriptions.

Thermal bridges correction in order to respect limit values is discussed, with particular attention to resolve junctions related to windows, sub windows and rolling shutter boxes. The insulation is achieved by an aerogel characterized by a very low declared thermal conductivity.

A parametric study is carried out by numerical simulations in order to determine thickness and width of insulation required to comply the decree.

2. The 26.06.2015 decree

The recent Decree 26.06.2015 concerning minimum energy targets in buildings, come into force on October 1st, 2015, fixes thermal transmittance limit values for vertical and horizontal opaque buildings elements outwards or towards not conditioned environments, to be respected in case of buildings energy refurbishment. The present research takes into account only vertical structures and the related limit values are reported in Table I as a function of the local climatic zone, according to heating degree days HDD (cumulated temperature differences, defined by UNI EN ISO 10349-3 [16] established by the Decree of President of the Republic 26.08.1993 no. 412 [17]. For each climatic zone, two limit values are provided, the first one, which is immediately operative, and the second one, which will come into force from January 1st, 2021 in conjunction with the requirement to realize NZEB buildings.

Limit values of thermal transmittance, reported in Table 1, include the effect of thermal bridges that compete to the building elements object of refurbishment.

Table 1. Limit U values for opaque vertical elements and derogated values (+30%) in case of internal insulation or insufflation.

Climatic zone	Degree days	U [W/m^{2}K] limit		U [W/m^{2}K] derogation	
		2015	2021	2015	2021
A	DD ≤ 600	0.45	0.40	0.59	0.52
B	600 < DD ≤ 900	0.45	0.40	0.59	0.52
C	900 < DD ≤ 1400	0.40	0.36	0.52	0.47
D	1400 < DD ≤ 2100	0.36	0.32	0.47	0.42
E	2100 < DD ≤ 3000	0.30	0.28	0.39	0.36
F	DD > 3000	0.28	0.26	0.36	0.34

The decree allows a 30% derogation on limit values in case of insulation on the internal part of the building elements or insufflation of insulating materials in cavity walls. The limit values provided by the derogation are reported in the last two columns of Table 1.

3. Case study

The proposed case study is very common in Italian constructions dating back to the '45-'80 years. During this period, the constructive technique was often characterized by frames with beams and pillars in reinforced concrete with completion masonry composed of cavity walls. A building façade with window, sub window and rolling shutter box is analysed. The repetitive module considered in calculations in order to verify the respect of limit values of thermal transmittance is depicted in Fig. 1. Thermal bridges due to pillars, beams, lintels, thresholds, jambs and walls thickness reductions situated under windows are considered. The module has a length of 5 m, including the width of pillars and a net height of 3 m.

Pillars sections vary according to the load and the height of the building; two types of pillar are considered in the present study: the first one 35 cm thick and 30 cm wide, typical of upper floors (Fig. 1a), the second one 70 cm thick and 40 cm wide, typical of lower floors (Fig. 1b). In the first case, net dimensions of current wall are 4.7×3 m, in the second one 4.6×3 m. A unique type of L-shaped border beam, 60 cm high and 15 cm thick, is also used.

Current cavity wall and sub window stratigraphies are reported in Tables 2 and 3 respectively; these are the only two surface opaque elements that constitute the repetitive module. Thermal conductivities of construction materials are provided by the standards UNI 10351, UNI EN ISO 10456 and UNI/TR 11552 [18,19,20]. Conventional surface resistances of UNI EN ISO 6946 [21] are used. Thermal transmittance, obtained by filling air layer with a traditional insulating material (λ = 0.037 W/mK), is shown in the last row of Table 2. The value is in the range allowed by the decree (Table 1), but it doesn't take into account the presence of the sub window (thinner sections) and thermal bridges.

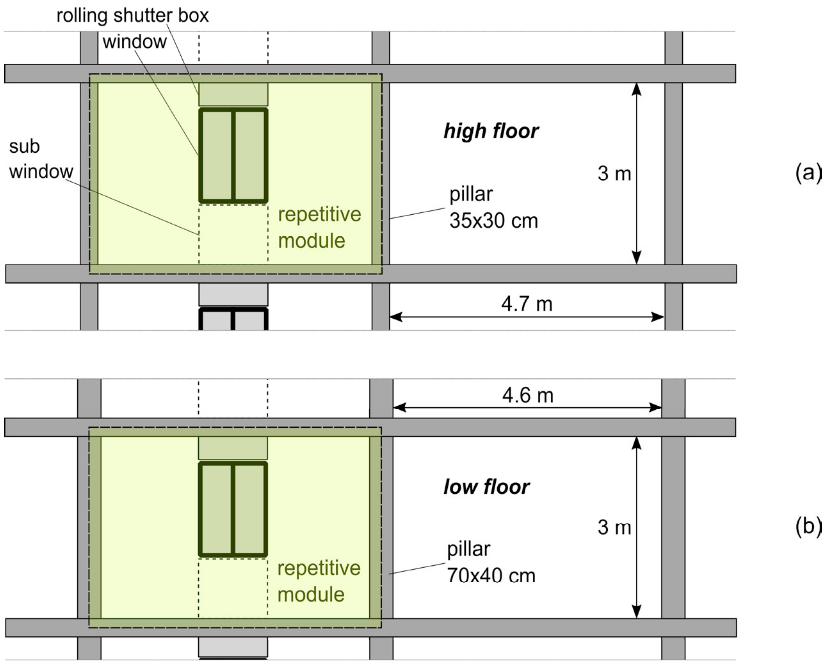

Fig. 1. Repetitive module: pillar 35×30 cm (a), pillar 70×40 cm (b).

Table 2. Non-insulated and insulated cavity wall stratigraphy.

	Layer	Thickness [cm]		λ [W/mK]	R [m²K/W]	
	Internal surface				0.130	
1	Internal plaster	1		0.700	0.014	
2	Air brick	8			0.200	
3	Air	12	15		0.180	
	Insulation			0.037	3.243	4.054
4	Air brick	12			0.310	
5	External plaster	4		0.900	0.044	
	External surface				0.040	
	Total thickness	*37*	*40*			
			Non-insulated cavity wall	*R [m²K/W]*	*0.919*	
				U [W/m²K]	*1.09*	
			Insulated cavity wall	*R [m²K/W]*	*3.982*	*4.793*
				U [W/m²K]	*0.25*	*0.21*

Table 3. Sub window stratigraphy.

	Layer	Thickness [cm]	λ [W/mK]	R [m²K/W]
	Internal surface			0.130
1	Internal plaster	1	0.700	0.014
4	Air brick	12		0.310
4	Air brick	12		0.310
5	External plaster	4	0.900	0.044
	External surface			0.040
	Total thickness	*29*		
			R [m²K/W]	*0.849*
			U [W/m²K]	*1.18*

In order to simulate heat transfer through the different thermal bridges of the repetitive module using a 2-D model, the stratigraphies of the two types of pillar (Table 4) and floor (Table 5) are requested.

Table 4. Pillar stratigraphy.

	Layer	Thickness [cm]		λ [W/mK]	R [m²K/W]	
	Internal surface				0.130	
1	Internal plaster	1		0.700	0.014	
6	Pillar	35	70	1.910	0.183	0.367
5	External plaster	4		0.900	0.044	
	External surface				0.040	
	Total thickness	*40*	*75*			
			Pillar	*R [m²K/W]*	*0.412*	*0.595*
				U [W/m²K]	*2.43*	*1.68*

Table 5. Floor stratigraphy.

	Layer	Thickness [cm]	λ [W/mK]	R [m²K/W]
	Bottom surface			0.100
1	Internal plaster	1	0.700	0.014
7	Slab and masonry	22		0.330
8	Concrete screed	4	1.060	0.038
9	Cement mortar	1.5	1.400	0.011
10	Stoneware tiles	1.5	1.470	0.010
	Upper surface			0.170
	Total thickness	*30*		
		Floor	*R [m²K/W]*	*0.673*
			U [W/m²K]	*1.49*

It is also necessary to know window and roller shutter box geometrical, constructive and thermal characteristics.

In the present study, a window constituted by a 6 cm thick PVC frame section ($U_f = 2.12$ W/m²K) and double glazed (4-12-4 mm) with air cavity ($U_g = 1.88$ W/m²K) and common spacer ($\psi_g = 0.07$ W/mK) is considered. Thermal transmittances of the frame, glass and spacer are calculated according to UNI EN ISO 10077-2 [22].

A non-insulated soft wood ($\lambda = 0.13$ W/mK) 5 mm thick roller shutter box is assumed, with thermal characteristics and geometry according to UNI EN ISO 10077-2. The depth of the rolling shutter box is about 30 cm, with a thermal transmittance of 5.19 W/m²K. When insufflation is considered in current wall, a 2 cm thick layer of insulating material ($\lambda = 0.037$ W/mK) is applied to the roller shutter box, reaching a thermal transmittance of 1.83 W/m²K.

Fig. 2 contains buildings elements and relative thermal bridges of the repetitive module considered in the present study. A list with subscripts identification is present in legend.

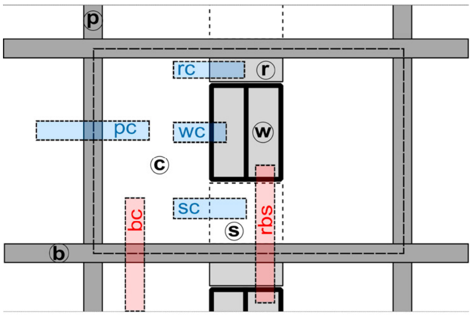

Fig. 2. Building elements and thermal bridges of the repetitive module.

Fig. 3-6 sketches thermal bridges constructive details. They correspond to THERM models. In particular, light green lines represent boundary conditions. Numbers are referred to stratigraphies reported in Tables 2-5.

For the L-shaped beam (identified by number 11 in Fig. 4 and Fig. 6) the same thermal conductivity of pillars ($\lambda = 1.91$ W/mK) is assumed. The marble slab of the window threshold (identified by number 12 in Fig. 6) is 15 mm thick with thermal conductivity $\lambda = 3$ W/mK. The insulation layer of the roller shutter box is identified by the number 13 in Fig. 6.

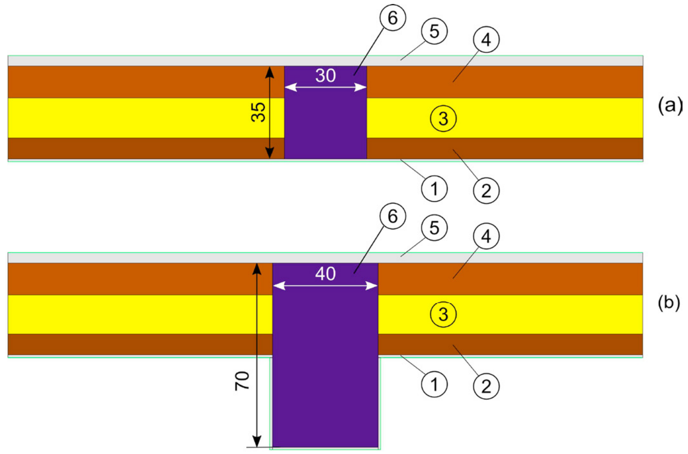

Fig. 3. Pillar-current wall thermal bridge (pc): pillar 35×30 cm (a), pillar 70×40 cm (b). Numbers are referred to Tables 2 and 4 (sizes are in cm).

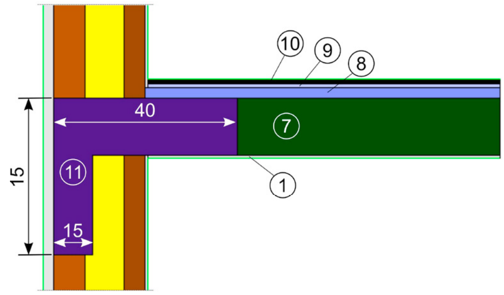

Fig. 4. Beam-current wall thermal bridge (bc). Numbers are referred to Table 5 (sizes are in cm).

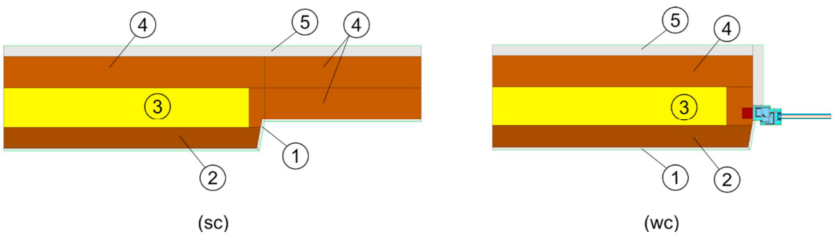

Fig. 5. Sub window-current wall thermal bridge (sc) and window-current wall thermal bridge (wc). Numbers are referred to Tables 2 and 3.

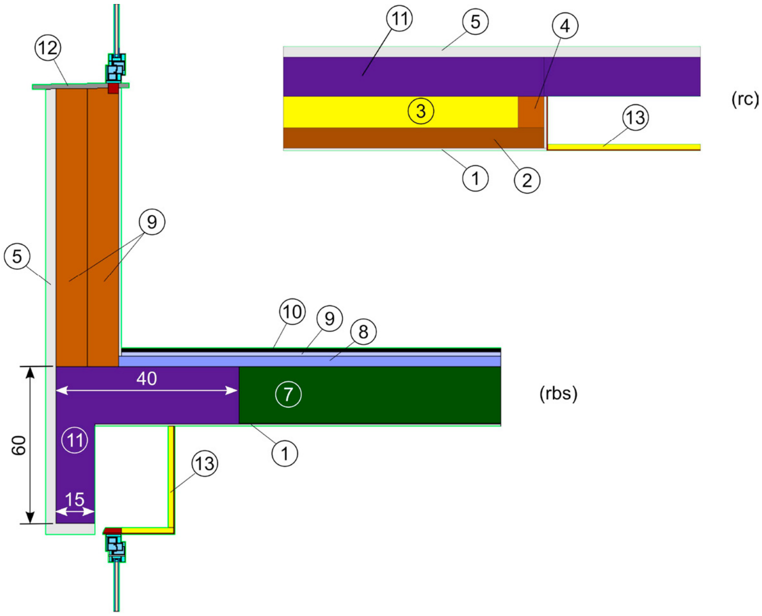

Fig. 6. Roller shutter box-beam-sub window thermal bridge (rbs) and roller shutter box-current wall thermal bridge (rc). Numbers are referred to Tables 2, 3 and 5 (sizes are in cm).

4. Results and discussion

The following relation calculates the mean thermal transmittance value of the repetitive module U_m, to be compared with Table I limit values:

$$U_m = \frac{U_c A_c + U_s A_s + \sum_i \psi_i L_i}{A_c + A_s} \tag{1}$$

where U_c is the thermal transmittance of the current wall of area A_c, U_s is the thermal transmittance of the sub window of area A_s and $\Sigma_i \psi_i L_i$ is the contribution of all thermal bridges that compete to the repetitive module (Fig. 7):

$$\sum_i \psi_i L_i = \psi_{pc} H_p + \psi_{bc}(L_b - L_w) + \psi_{rbs} L_w + 2\psi_{sc} H_s + 2\psi_{wc} H_w + 2\psi_{rc} H_r \tag{2}$$

ψ_{pc} = pillar-current wall thermal bridge of length H_p linear thermal transmittance (see Fig. 3)
ψ_{bc} = beam-current wall thermal bridge of length (L_b-L_w) linear thermal transmittance (see Fig. 4)
ψ_{rbs} = roller shutter box-beam-sub window thermal bridge of length L_w linear thermal transmittance (see Fig. 6)
ψ_{sc} = sub window-current wall thermal bridge of length H_s linear thermal transmittance (see Fig. 5)
ψ_{wc} = window-current wall thermal bridge of length H_w linear thermal transmittance (see Fig. 5)
ψ_{rc} = roller shutter box-current wall thermal bridge of length H_r linear thermal transmittance (see Fig. 6)

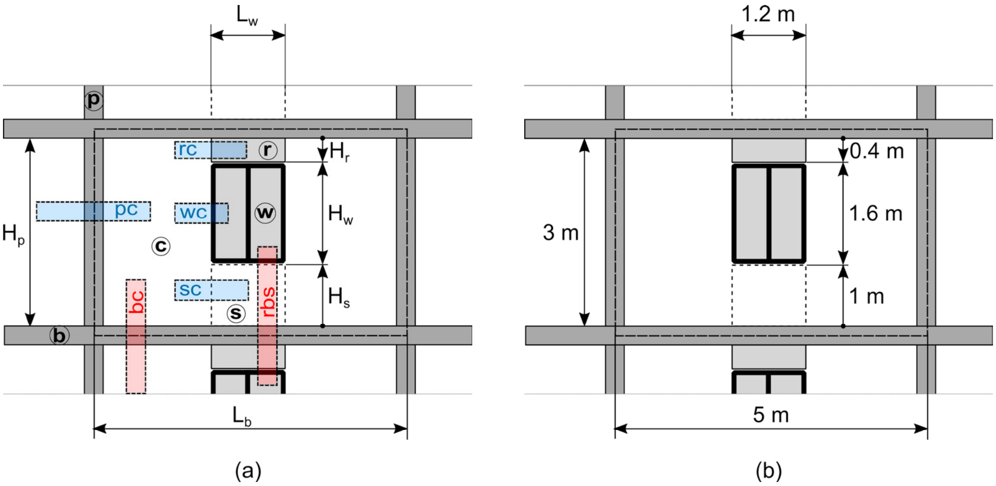

Fig. 7. Building elements and thermal bridges of the repetitive module: nomenclature (a), dimensions (b).

Linear thermal transmittances of above mentioned thermal bridges have been obtained by a finite element 2-D model, according to UNI EN ISO 10211. Calculations have been carried out by THERM, a finite-element simulator developed at Lawrence Berkeley National Laboratory (LBNL). In general:

$$\psi = L_{2D} - \sum_i L_i U_i \tag{3}$$

where L_{2D} is the thermal coupling coefficient obtained from the 2-D calculation of the component separating the two environments being considered, U_i is the thermal transmittance of the 1-D i-th component, separating the two environments being considered, L_i is the length over which the value U_i applies.

The calculation method has been previously tested and validated in accordance to case-studies A.1 and A.2 of Annex A of UNI EN ISO 10211. The values of ψ_b and ψ_{rbs} have been estimated referring calculations to internal measures, according to UNI EN ISO 14683 [23]. A first set of calculation was carried out in order to compute mean thermal transmittance U_m of the repetitive module for both 35×30 cm and 70×40 pillars and for both non-insulated and insulated cavity. Results are shown in Table 6, for two different thicknesses of the cavity: 12 cm and 15 cm. Examination of Table 6 reveals that the calculated mean transmittance U_m does not respect the values imposed by the decree anyhow, even in case of derogation.

Table 6. Mean thermal transmittance of not-insulated and insulated cavity wall [W/m^{2}K].

		U_s [W/m^{2}K]	
		U_m [W/m^{2}K] Cavity thickness	
Cavity wall	Pillar	12 cm	15 cm
Not insulated	35×30 cm	1.66	1.58
	70×40 cm	1.69	1.61
Insulated	35×30 cm	0.94	0.88
	70×40 cm	0.99	0.93

It is therefore necessary thermal bridges correction. Owing to the small thickness of external plaster used in buildings of '45-'80 years, according to authors' experience, no more than 2÷3 cm of useful thickness are available in order to insulate thermal bridges from outside and to maintain the original vertical shape of the façade. In fact, a thicker insulation might cause a building outer side thickening, with consequent executive problems related to the presence of complementary or decorative elements such as lintels, thresholds, blinds, balconies and pluvial down and gas pipes. Furthermore, string courses, decorative pilasters and dripstones are generally about 10 cm thick: increasing the façade thickness causes they are less pronounced or even hidden. Finally, the application of a thick insulation layer might not be compatible with the respect of the boundaries and the ownership limit of the building itself toward its neighbours. This problem is very common in high housing density urban areas.

These problems can be overcome with the adoption of a new generation insulating materials, made with nano-technologies and characterized by a very low declared thermal conductivity (until 0.015 W/mK). The use of these materials for the complete external coating could be too expensive; actually the cheapest way is to fill the cavity with traditional insulating material, limiting the use of high-performance insulating products only to correct thermal bridges. In the present study aerogel panels, with declared thermal conductivity equal to 0.018 W/mK, are used for sub window insulation and thermal bridges correction. An aerogel sheet is attached to the outside of the sub-window, reducing his thermal transmittance as shown in Table 7.

Table 7. Sub window thermal transmittance [W/m^{2}K].

		U_s [W/m^{2}K]
Not insulated		1.18
Aerogel thickness	1 cm	0.72
	2 cm	0.52
	3 cm	0.40

The correction of the pillar and beam thermal bridges, respectively (pc) and (bc), is represented in Fig. 8: L is the thermal bridge width, ℓ stands for the aerogel length that exceeds L dimension and d represents the aerogel thickness. In order to take into account the influence of ℓ parameter (i.e. as the correction should be extended compared to the width of the thermal bridge of pillars and beams), the percentage surplus ratio SR is defined:

$$SR = \frac{\ell}{L} \cdot 100 \tag{4}$$

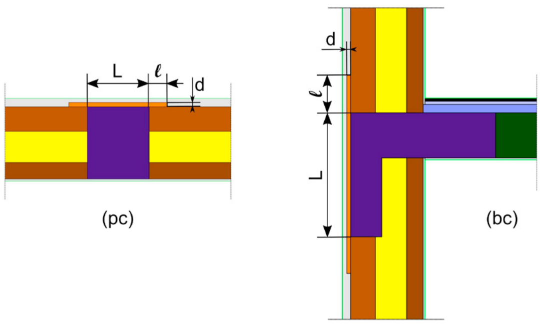

Fig. 8. Correction of thermal bridges (pc) and (bc).

Fig. 9 and Fig. 10 show the correction of other thermal bridges present in the repetitive module and adopted in all simulations. Rolling shutter box is fully covered by the aerogel sheet, in continuity with the beam insulation. A 30 cm surplus of aerogel coat is assumed for the sub window-current wall and window-current wall thermal bridges, as shown in Fig. 10.

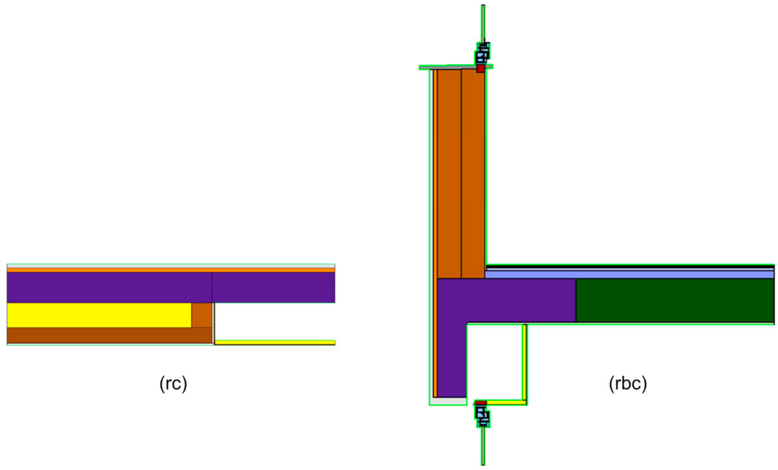

Fig. 9. Correction of thermal bridges (rc) and (rbc).

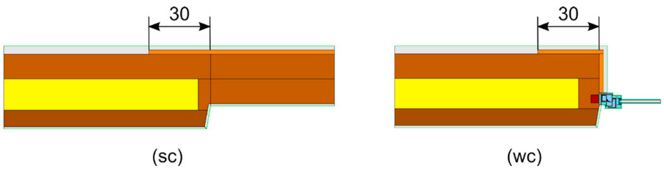

Fig. 10. Correction of thermal bridges (sc) and (wc); sizes are in cm.

Several simulations were carried out to determine the thermal bridge optimal correction and to verify the respect of the mandatory limits.

The influence of ℓ parameter is shown in Fig. 11, where the mean thermal transmittance U_m of the façade is reported as a function of the surplus ratio SR for three different thicknesses of aerogel panel, d = 1 cm, d = 2 cm and d = 3 cm and for two different thicknesses of the insulated air cavity, 12 and 15 cm in the case of 70×40 cm pillar.

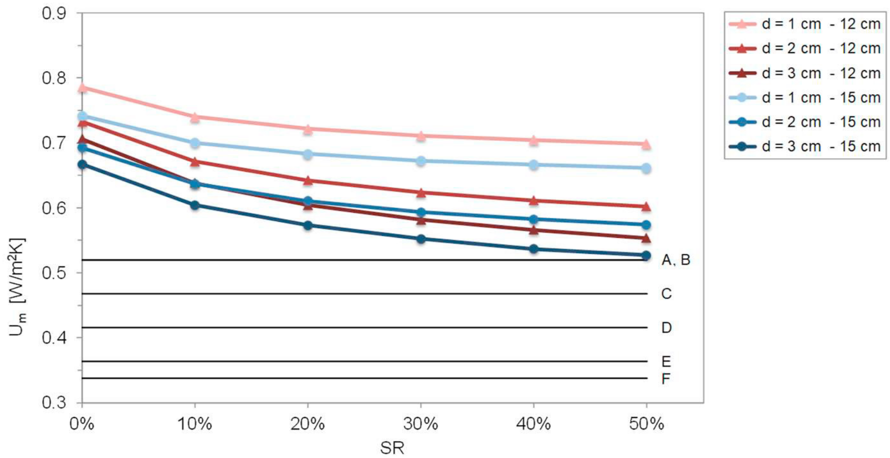

Fig. 11. Mean thermal transmittance U_m versus SR (70×40 cm pillar).

Fig. 11 reveals that, as SR ratio increases, mean transmittance decreases. However, a saturation effect ensues, i.e. to increase excessively the length of the thermal bridge correction on pillars and beams does not lead to improvements in the performance of the wall. A useful value for the defined surplus ratio SR is around 50%. The limit thermal transmittances are also reported in Fig. 11, considering the derogation provided by the decree 26.06.15. Fig. 11 shows that the compliance with the limit values cannot be reached, even if the air gap is 15 cm thick.

The respect of the limit values for U_m is also investigated in Fig. 12, where U_m versus SR is carried out for two different types of pillars 35×30 cm and 70×40 cm and for three different thicknesses of aerogel panel (d = 1, 2, 3 cm) in the case of 15 cm insulated cavity wall. Inspection of the Fig. reveals that the influence of pillar dimensions are negligible and, under no circumstances, it is possible to respect the limit values.

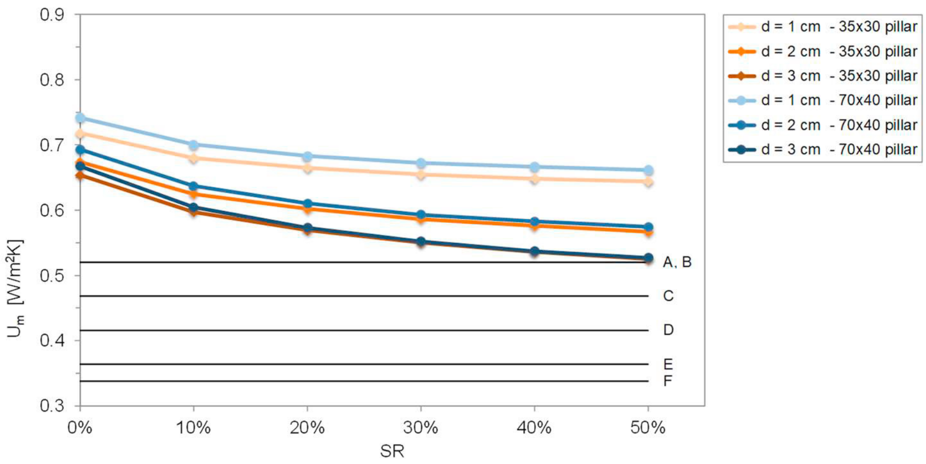

Fig. 12. Mean thermal transmittance U_m versus SR (15 cm air layer).

Finally, the influence of thermal bridges related to windows, sub windows and roller shutter boxes is depicted in Fig. 13.

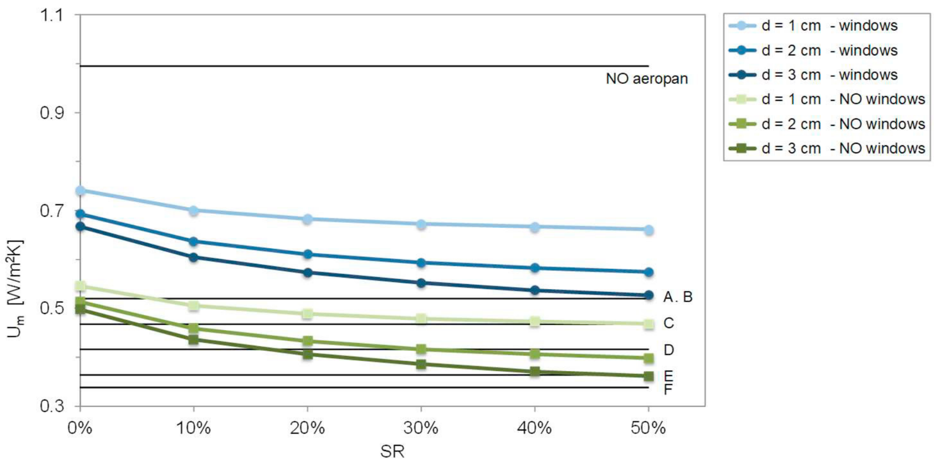

Fig. 13. Mean thermal transmittance U_m versus SR in presence and in absence of window (70×40 pillar, 15 cm air layer).

Fig. 13 shows that in absence of the window (i.e. absence of the window, sub window and roller shutter box in the repetitive module, only thermal bridges of beams and pillars are considered), it is possible to comply the decree

26.06.2015: 1 cm of aerogel allows the respect of the limits values in climatic zones A, B, C, 2 cm in zone D and 3 cm in zone E, while it is impossible to comply with the limit in zone F.

5. Conclusions

In the present paper, the energy improvement of cavity walls of '45-'80 years buildings by means of insufflation and thermal bridge correction has been investigated, taking into account limit values on thermal transmittance provided by DM 26.06.2015 Italian mandatory decree for refurbishing design. A common existing repetitive module containing window, sub window and roller shutter boxes has been considered. The following conclusions can be drawn:

- an useful value for the defined surplus ratio SR is around 50%. Curves of thermal transmittance U_m versus SR tend to become horizontal over this limit value, so that, if SR is greater than 50%, no significant increase in mean thermal transmittance is achieved;
- in presence of windows, sub windows and roller shutter boxes it is impossible to respect limit values provided by 26.06.2015 decree, even in case of derogation and independently from Climatic Zone;
- curves asymptotic behaviour can suggest new proper limits that can be really reached.

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