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Experimental and numerical comparison of internal insulation systems for building refurbishment

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Abstract

In order to increase the knowledge of both local builders and designers about the energy efficiency of internal insulation a test chamber has been realized at the Edilmaster site. The test system features two isothermal chambers separated by the specimen under test. The controlled temperatures guarantee a constant temperature difference in order to measure the heat flux with thermofluximeter techniques. In this paper the uninsulated system is a brick wall of about 50 cm thickness which represents a typical solution found in Trieste. Two internal insulation systems, with wooden and metallic studs, have been tested. The measurements highlighted the different thermal behavior between the area covered by the insulation material and the thermal bridges due to studs. The experimental results have been compared with solutions obtained with numerical and analytical methods.

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Keywords: wall insulation; energy savings; building refurbishment; thermofluximeter; numerical simulation.

1. Introduction

It is well known that buildings in industrialized countries are responsible of a large part of energy consumption and of dangerous emissions in atmosphere; a common figure for Italy is that about the 38% of national energy consumption is absorbed by building climatization [1]. For this reasons European and National regulations impose increasingly tight limits on energy consumption. The respect of these requirements is quite simple in new buildings where the building fabric and system plants can be accordingly designed, exploiting renewable energy resources. The problem is quite more difficult for existing buildings where the interventions can be limited by technical reasons and national regulations. In

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this case, the correct approach is to reduce the building losses by increasing building fabric insulation while assuring internal healthy conditions. The refurbishment of opaque facades in existing building can be done at the internal or external side; the two solutions are compared in [2] where it is highlighted that for identical insulated wall area internal insulation requires less investment cost than the external one. However the internal insulation can be the only solution for historical buildings, this the typical Italian situation especially in historical city centers.

A common mistake about the thermal losses computation in refurbished buildings with internal insulation is to evaluate the envelope thermal resistance omitting the effect of structural studs used to build the internal insulation structure, as described in [3] and [4] for light steel frame structures.

In order to increase the knowledge of both local builders and designers about the internal insulation, an agreement has been signed between the Università degli Studi di Trieste (Department of Engineering and Architecture, DIA) and Edilmaster of Trieste, a local construction school. The scope of this agreement is to test insulation methodologies applied to common structures used in Trieste.

Nomenclature

B	thickness [m]
C	thermal conductance [W/(m^2 K)]
c	specific heat [J/(kg K)]
H	height [m]
L	width [m]
Ra	Rayleigh number
Greek	
λ	thermal conductivity [W/(m K)]
ρ	density [kg/m^3]
θ	temperature [°C]
Subscripts	
ctr	center
std	stud
c	cold
h	hot
w	wall
eff	apparent in stud channel

2. Test chambers

For testing the insulation systems, a calibrated hot and cold chamber has been realized at Edilmaster facility. In the first phase, wall conductance has been measured using a thermoflux system [5]. In a second phase, the system will be updated in order to perform measures using a calibrated hot box method so in the design of the two chambers, we have followed the requirements of UNI EN ISO 8990:1999.

The system is composed by two insulated chambers with a length of 4.70 m, width 2.24 m and height 2.20 m, the two chambers are separated by the test wall with dimensions of 1.90 x 1.93 m and area equal to 3.67 m^2. Table 1 reports the composition of chamber walls:

Table 1. Chamber structures

walls		ceiling		floor	
material	Thickness [mm]	material	Thickness [mm]	Material	Thickness [mm]
plasterboard	12.5	Plasterboard	12.5	EPS	200
EPS	75	EPS	100	Wood board	25
Plasterboard	12.5	Mineral wool	50		
EPS	100				

The temperature in the cold chamber is kept constant by an air-conditioning unit; whereas, the hot chamber is kept at a higher temperature by means of two 100 W electrical resistances with a fan for air distribution. A thermostat maintains the hot chamber temperature at about a constant value of 26 °C by switching on or off one of the two resistances.

The cold chamber is maintained at a temperature of nearly 5 °C, value selected after some trials in order to increase the time between de-frosting cycles. The values have been selected in order to maintain a constant and sufficiently elevated temperature difference among rooms.

The measurement system, product by LSI, is composed by:

- Data acquisition system BABUC A
- Heat Flux Plate BSR240
- 4 RTD BST240 for the measure of the wall superficial temperature
- 2 RTD EST0338#s for the measure of chambers air temperature

The uniformity of the wall temperature in the zone of the measure is checked with an infrared camera FLIR E 60 bx .

3. Measured Walls

A typical wall traditionally used in historical buildings located in Trieste has been selected for the measurements. It is a supporting wall assembled with solid bricks of size 55x25x12 cm. Considering internal and external 1.25 cm thick plaster the overall thickness of the wall is 0.51 m. Before applying the insulation layers the thermal conductance of the base wall has been measured using the thermofluximeter equipment obtaining C_w=1.64 W/(m^2 K). Two intervention on the base wall have been considered by applying 3 cm EPS boards at the hot side of the wall separated by studs at a distance of 500 mm then covered by a 12.5 mm thick plasterboard as presented in Figure 1 a). The difference between the two systems is the type of vertical studs having the same size 60x30 mm; wooden studs in the former and C-shape metallic studs in the latter.

Figure 1 b) presents a picture of the test wall with metallic studs without the plasterboard cover layer. The same picture shows the bended metal ribbons used to fix the metal studs to the wall. It is worth noting that this disposition creates a thermal bridge between the cold wall and the internal warm plasterboard.

4. Results

Four measures have been carried for characterizing the insulation performance on the tested wall: the specific heat flux on the center of insulation panel and on the wooden and metal studs. Table 2 reports the measured values: cold and hot temperatures, averaged on the two thermoresistances positioned on the hot and cold sides of the specimen, and the resulting one dimensional thermal conductance.

We can observe that, as expected, the values of conductance measured at the centre of the EPS board coincide, while the conductance on the wood stud is equal to 64% of the one measured on the metallic stud.

The low performance of metal studs can be shown also In Figure 3 b) in which the effect of metallic studs is clearly visible.

Table 2 highlights the requirement to evaluate a "real" conductance and hence transmittance of the insulated wall taking into account the effect of the supporting studs too. In the following two techniques are presented in order to obtain the overall thermal performance of the wall.

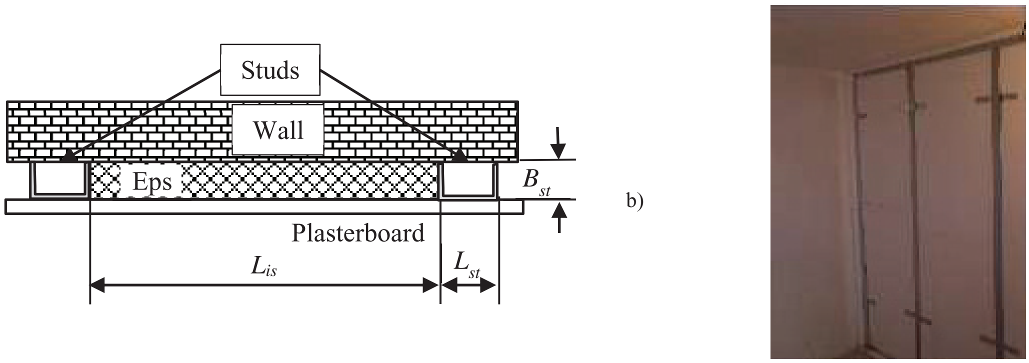
a) b)


Figure 1: internal insulation system with metallic studs a) , picture of the internal assembly b)

Table 2. Experimental Results

	Wooden		Metal	
	center	stud	center	stud
θ_c	6.2	-1.1	6.1	6.2
θ_h	24.7	23.2	24.3	22.9
ϕ''	11.3	22.0	11.1	23.5
C	0.61	0.90	0.61	1.41

4.1 Wall conductance

Based on the results presented in Table 2 the overall conductance of the insulated wall has been obtained. For this the methods of UNI EN ISO 6946:2008 has been used. The thermal characteristics of the non uniform layer composed by metal and wooden studs and insulation board, presented in Figure 1 a), has been obtained using the measured fluxes reported in Table 2 and a conductivity of 0.21 W/(m K) for the plasterboard layer. Table 3 reports the wall conductance along with the error between the adiabatic and isothermal approach of UNI EN ISO 6946:2008. It is worth comparing the results of Table 3 with the ones reported in Table 2. Considering also the studs the conductance is 6.6 % higher for wooden studs and 32.8% higher for metal studs respect the one obtained using EPS board center values only.

Table 3: Conductance of whole wall

	C_w	error
Wooden suds	0.65	0.7 %
Steel Studs	0.81	16.1 %

5. Numerical results

The results reported in Tables 2 and 3 clearly show that it is a mistake to disregard the effect of studs in for computing the conductance and therefore transmittance of a refurbished wall. Along with the experimental approach, two calculation methods are also presented.

5.1 Analytical calculus

The methods of UNI EN ISO 6946-2008 are used with material properties obtained in UNI EN ISO 10456:2008 , with reference to Figure 1 a) the problem is easy for the wooden studs, while the thermal resistance of metallic studs must be evaluated because of the convective flow inside the hollow narrow channel between studs and wall. To evaluate the thermal resistance of a metallic stud the following correlation is applied:

$$\frac{\lambda_{eff}}{\lambda} = 0.24 \left[6.25 - 1.25 \left(1 + \frac{L_{st}}{l}\right)^{-1.67}\right] Ra_l^{0.25}; \quad l = \sqrt{H_{st} \cdot B_{st}} \tag{1}$$

Where H_{st} is the camber height. The metallic stud value conductance is C_{st} = 1.38 W/(m^2 K), and takes into account using Eq. (1) the convective resistance only, while neglecting stud thin metal wall conductivity and radiation effects inside the narrow cavity. Table 4 reports the computed values and the percentage difference of the wall conductance with the experimental values of Table 3.

Table 4. results of analytical calculus

	C_{is}	C_{st}	C_w	Δ
Wood stud	0.66	1.09	0.78	+20%
Metallic stud	0.66	1.38	0.84	+3.8%

5.2 Numerical simulation

The simplified analytical method does not take into account the multidimensional heat transfer problem, furthermore the heat transfer through steel studs has to take into account also the effect of radiation inside the hollow chamber between the stud and the wall, furthermore, conduction in the metal studs cannot be neglected. In order to complete the analysis a three-dimensional simulation of the insulation system has been carried using the software Ansys Fluent 14.5. The structured grid features about 150 000 hexahedral cells, with 2nd order upwind discretization for flow and heat transfer inside stud and S2S model for radiative heat transfer computation. Table 5 reports the numerical results using the values for the whole wall, while Figure 2 presents the comparison of plasterboard surface temperature obtained with the numerical simulation and a thermographic picture. The inspection of Figure 2 shows how the metallic stud influences the surface temperature, for instance the effect of metallic brackets, which connect the stud to the wall, is clearly visible in both the numerical simulation and infrared picture.

6. Conclusions

An experimental and numerical approach has been performed in order to obtain the thermal performance of two internal insulation systems. The effect of wooden and metallic studs has been highlighted. The results show that the use of conductance values neglecting the studs effect leads to an overestimation of the insulation performance of refurbished walls. Overall conductance values have been obtained using experimental results and two computational methods. The numerical results give insulated wall conductance values that fall within a 10 % difference with the experimental results. However, the results show that for a real comparison between local heat flux values and the overall heat transfer through the insulated wall a hot box apparatus should be used, therefore such equipment will be implemented in the already existent test facility.

a) b)

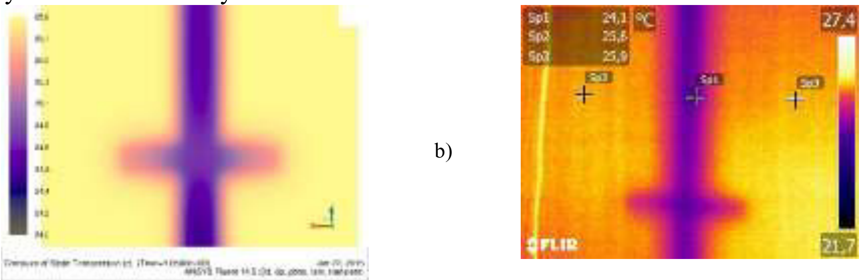


Figure 2: Comparison between simulated temperatures a) and thermographic picture b)

Table 5. Results of numerical computation

	C_{ctr}	C_{std}	C_w	Δ
Wooden stud	0.65	0.97	0.70	+7.1%
Metallic stud	0.65	1.21	0.73	-10.0 %

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Biography

Marco Manzan is Associate professor of Thermodynamics and Heat Transfer at the University of Trieste. Main research effort has been committed to the numerical analysis of heat transfer problems working on finite element solution of thermal problems, stability of numerical methods in convection problems and energy buildings performance simulation.