Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 82 (2015) 480 – 485

Energy Procedia

ATI 2015 - 70th Conference of the ATI Engineering Association

Thermal behaviour and energy saving evaluation of innovative reinforced coatings

Cinzia Buratti[1,]*, Elisa Belloni[1], Elisa Moretti[1], Domenico Palladino[1], Marco Vergoni[1]

[1] *Department of Engineering - University of Perugia, Via G. Duranti 63 – 06125 Perugia – Italy.*

Abstract

The use of fibre-reinforced interlayer structures as coatings is very spread in building refurbishment, but it is important to find effective solutions both for mechanical and thermal performance.

In the present paper the thermal behaviour of innovative fiber-reinforced coatings was investigated in order to find the best solutions in terms of mechanical strength and energy saving in buildings.

Four different coatings (with and without the internal reinforced structure) were considered and their thermal conductivities were preliminary investigated by using an innovative measurement apparatus (Small Hot Box).

A thermal analysis was carried out for the evaluation of the effects of the coatings on the building envelope, especially the thermal transmittance, calculated for different thickness. Preliminary results showed that 3-4 cm of coatings allowed to reduce thermal transmittance of building envelope by about 60-70%.

In order to evaluate the energy saving, one building was considered and simulated by means of Trnsys software: it was chosen for the evaluation of the refurbishment of the building by using the selected solutions. The simulation model was implemented in SketchUp and the energy demand with and without the innovative coatings was simulated; the simulation model was also used for the evaluation of energy saving in different climate conditions.

Results show that for two coatings an important reduction of the heat loss through of the building envelope can be obtained.

© 2015 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license
(http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the Scientific Committee of ATI 2015

*Keywords:*fibre-reinforced coatings, thermal measurement, dynamic simulations, buildings reurbishment, energy saving

Nomenclature

C-GFRP	mortar with cement, aggregates and other additives with high mechanical strength

---

* Corresponding author. Tel.: +39.075.5853993.
E-mail address: cinzia.buratti@unipg.it

1876-6102 © 2015 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license
(http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the Scientific Committee of ATI 2015

doi:10.1016/j.egypro.2015.11.848

D-GFRP	mortar with clay, cork and natural calk
EBW	existing load bearing wall
N-GFRP	mortar with natural calk, limestone sand, aggregates
PL	plasterboard sheet
R-GFRP	mortar with natural calk, limestone sand, aggregates

1. Introduction

Envelope building refurbishment is more and more necessary in order to improve both energy performance and mechanical resistance of the walls. In Italy at least 90% of buildings were constructed before 1991 and they are not in compliance with the current law regulations and sometimes the retrofitting of low quality historic masonry walls is mandatory. In particular the thermal insulation in buildings contributes not only to reducing the size of the heating and cooling system, but also the annual energy consumptions. In this context the development of new materials as fiber reinforced insulating coatings would be very useful in order to obtain an effective solution both for the improvement of the energy performance of the building and for the reinforcement of the walls.

In this paper the thermal properties of fiber reinforced insulating coatings were measured with an innovative apparatus and the energy saving due to their application was evaluated were studied.

2. State of art of reinforced insulating coatings

Fiber-Reinforced Polymer (FRP) is composed of high-strength fibers as glass embedded in a polymer resin (such as polyester). It is high strength, durable (thanks to the resin), and lightweight. Glass fibre reinforced concrete is a composite material made up of the union of two materials with different mechanical properties: cement mortar and glass FRP. Glass fibers improve the tensile strength and ductility, while cement avoids buckling of glass fibers when compressing them. This kind of solution is very diffused in order to improve the shearing strength of the walls[1]. Nevertheless the energy-thermal properties of the coatings are also important: insulation plasters can be used in many applications, including external and internal wall systems. Innovative coating solutions are therefore in development, such as aerogel-based high performance insulating plasters: a limited number of studies exists in this field, probably due to the high costs of the innovative system [2].

2.1. Description of the samples

Square samples were realized for thermal measurements. All the samples were assembled with external dimensions 300 × 300 mm, for a total area of 0.09 m^2, due to the dimensions of the experimental apparatus. At first a specimen composed by only plasterboard without coating was tested (specimen PL): it is the support panel of all the samples and the total thickness is 13 mm. Therefore four coatings were analyzed with different chemical compositions. All the samples have a Glass Fiber Reinforced Plastics grid characterized by square mesh with dimensions of 60 x 60 mm, inserted into the matrix. The description of the coatings and the total thicknesses of the specimens are reported in table 1.

Table 1. Description of the samples for thermal measurements.

Samples	Description	s plasterboard (mm)	s coating (mm)	s total (mm)
PL	plasterboard sheet	13	-	13
D-GFRP	mortar with clay, cork and natural calk	13	42	55
R-GFRP*	mortar with natural calk, limestone sand, aggregates	13	45	58
N-GFRP*	mortar with natural calk, limestone sand, aggregates	13	42	55
C-GFRP	mortar with cement, aggregates and other additives with high mechanical strength	13	44	57

*R-GFRP and N-GFRP have similar composition, but the sample N-GFRP was optimized in terms of mechanical resistance

3. Methodology

3.1. Thermal measurements

A new experimental apparatus was designed and built at the Laboratory of Thermal Science, University of Perugia, for the evaluation of the thermal conductivity of building homogeneous materials; it is named Small Hot-Box (Figure 1). It is composed of one box (external dimensions 0.94 x 0.94 x 0.50 m) that behaves as hot chamber: the outer walls of the chamber are made of very thick insulation, in order to minimize the heat flux through the walls [5]. The second part of the experimental system is the closure side of the box: it is a sandwich structure composed of two panels of wood with a middle layer of expanded polyurethane. In the central part an opening for the placement of the sample is present, with 0.30 x 0.30 m dimensions. The cold side of the system is the laboratory room completely insulated from the outside. The temperatures inside the hot room are kept constant thanks to a heating wire placed inside the room. The difference between the hot and the cold side temperatures is maintained at least equal to 20°C. The tests are carried out by considering the thermal flux meter methodology: a thermal flux meter was installed in the central part of the sample in order to evaluate the heat flux through the panel; 8 termoresistances were installed on the surface of the sample, with four sensors each side. Preliminary calibration measurements show that the error of the innovative apparatus is about 9%.

The value of the thermal conductivity can be calculated as follows (eq.(1)):

$$\lambda = \frac{q}{(T_{sH} - T_{sC}) \cdot s} (W/mK) \tag{1}$$

with:

- q: heat flux through the sample (W/m^2);
- T_{sH} and T_{sC}: mean surface temperature of the samples in the Hot and Cold sides during the test (°C);
- s: total thickness of the sample (m).

The total thermal resistance R of the sample is composed by two contributes: the coating contribute and the plasterboard one (see equation (2)). By using this equation it is possible to evaluate only the thermal conductivity of the coatings λ_c.

$$R = \frac{s_c}{\lambda_c} + \frac{s_p}{\lambda_p} (m^2 K/W) \tag{2}$$

Fig. 1. Small Hot-Box apparatus with a coating sample inserted.

3.2. Energy Simulations

The energy performance of the four fiber-reinforced coatings were evaluated by means of energy simulations [3,4]. The case study is a non-residential building and it consists in four floors of about 300 m^2 per floor. The building is characterized by load bearing wall of about 0.42 m thickness, with an estimated thermal transmittance of 1.574 W/m^2K and by double glazing (4/12/4) with a calculated thermal transmittance of 2.9 W/m^2K.This case study was chosen because it must be refurbished and the studied fiber-reinforced coatings can be an alternative option. In Figure 2 the simulation model implemented in TRNSYS is shown.

An infiltration class equal to 3 was assumed for all the semi-transparent surfaces (equal to 9 $m^3/(h\cdot m^2)$), while the other internal gains were fixed and set as input parameters, in compliance with Italian regulations. Considering office as intended use, Italian regulations provide:

- lighting load: 15 W/m^2;
- load due to people: 130-140 W per person;
- air changes: 2 vol/h.

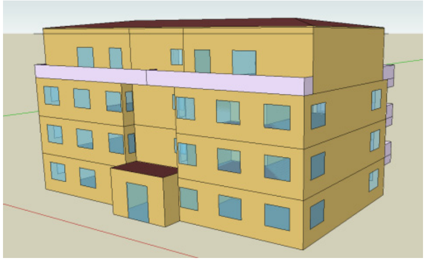

Fig. 2. 3-D model simulation implemented in TRNSYS software

Table 2. Period of the year, of the day and set point temperature considered for heating.

City	Climatic zone	Heating (set point temperature =20°C)	
		Yearly Period	Daily Period
Naples	C	15/11 - 31/03	8:00 a.m. - 7:00 p.m.
Rome	D	1/11-15/04	8:00 a.m. - 7:00 p.m.
Milan	E	15/10-15/04	8:00 a.m. - 7:00 p.m.

The “ideal energy” (energy needed to maintain a specific indoor temperature during the year) was considered as output for the simulations. In order to evaluate energy savings, different climate conditions were considered; in particular, three thermal zones in agreement with Italian regulations were chosen (C, D, E) and for each zone the most representative city was selected (Naples, Rome, Milan). The period of the year for heating and the respective air temperature of set point assumed for each thermal zone are reported in table 2.

4. Results and discussion

The measured thermal conductivity of the plasterboard is 0.19 W/mK (the value declared from the company is 0.2 W/mK). The thermal conductivity values of the other samples obtained by using the thermal flux meter methodology vary in 0.089 – 0.210 W/mK range. The errors vary in 3-5% range. The best mortar is N-GFRP type, the worst is C-GFRP (0.210 W/mK). Nevertheless this is the best coating considering the mechanical resistance of the samples [6]. Anyway all the coatings have a good thermal behavior considering that they are developed as structural mortars; the thermal conductivities are lower than traditional coatings (values in 0.5-1.0 W/mK range).

Table 3. Thermal transmittance of the existing load bearing wall and the ones calculated with fiber-reinforced coatings

Walls	Stratigraphy (m)	Thermal Transmittance (W/m^{2}K)	Reduction
EBW	Plaster (0.01)- load bearing wall (0.42)-Plaster (0.01)	1.574	-
EBW+D- GFRP	D-GFRP (0.05)- load bearing wall (0.42)- D-GFRP (0.05)	0.588	-62.6%
EBW+R- GFRP	R-GFRP (0.05)- load bearing wall (0.42)-R-GFRP (0.05)	0.604	-61.6%
EBW+N- GFRP	N-GFRP (0.05)- load bearing wall (0.42)-N-GFRP (0.05)	0.575	-63.5%
EBW+ C-GFRP	C-GFRP (0.05)- load bearing wall (0.42)-C-GFRP (0.05)	0.917	-41.7%

Table 4. Heating and Heat loss reduction considering different fibre-reinforced coatings.

	Refurbishment	Naples	Rome	Milan
Heating consumptions(kWh/m^{2}year)	EBW	1591.92	1864.25	3585.57
Heating (kWh/m^{2}year)	EBW - D-GFRP	42.17	46.03	96.9
	EBW - R-GFRP	42.44	46.34	96.94
	EBW - N-GFRP	43.56	47.54	99.61
	EBW - C-GFRP	21.94	23.9	53.7
Heat loss (%)	(EBW - D-GFRP)/EBW	-29.5%	-34.3%	-76.9%
	(EBW - R-GFRP)/EBW	-28.6%	-33.6%	-75.4%
	(EBW - N-GFRP)/EBW	-30.1%	-34.7%	-77.9%
	(EBW - C-GFRP)/EBW	-14.7%	-22.7%	-50.5%

The energy performance of the building was simulated by considering the different stratigraphy for the external wall. In table 3 the thermal transmittance of the existing load bearing wall (EBW) and the ones calculated with 5 cm of fibre-reinforced coatings on both sides of the wall are reported. 5 cm of fibre-reinforced coatings allow to obtain an important thermal transmittance reduction greater than 60%, for all the considered coatings, except for the C-GFRP, but it has a better mechanical resistance and a higher thermal conductivity than the other ones.

The heat loss from the external walls and the energy saving obtained are shown in table 4. The energy saving achieved during the heating period for Rome and Naples is very close to each other and about 45 kWh/m^{2}year for D-GFRP, R-GFRP and N-GFRP coatings, while a lower energy saving (about 20-25 kWh/m^{2}year) is achieved for the other fiber-reinforced coating (C-FB). A greater energy saving was found for Milan (about 100 kWh/m^{2}year for D-GFRP, R-GFRP, and N-GFRP, and about 50 kWh/m^{2}year for the C-FB).The calculated heat loss reduction for each considered city is also shown in table 4; D-GFRP, R-GFRP, and N-GFRP show an important heat loss reduction through load bearing walls, about 30% for both Naples and Rome and 75-80% for Milan. A lower heat loss reduction (of about 15-20% for Rome and Naples, and of about 50% for Milan) was assessed using the last fiber-reinforced coating due to the higher thermal conductivity of the same material.

5. Conclusions

In this paper the thermal performance and the energy saving reached by using innovative fiber-reinforced insulating coatings were studied. They have a very good mechanical resistance and a thermal conductivity measured by an innovative apparatus (small Hot Box); therefore they can be an useful and alternative material for the refurbishment of the buildings. The energy saving due to the application of these materials was also assessed in different climate conditions; during the heating period for D-GFRP, R-GFRP, and N-GFRP an energy saving of about 40 kWh/m^{2}year was reached for Rome and Naples and about 100 kWh/m^{2}year for Milan. An important heat loss reduction was reached, in particular about 30% for Naples and Rome and more than 70% for Milan. Instead, a lower energy saving (40-50 kWh/m^{2}year and about 100 kWh/m^{2}year) and heat loss reduction (-15%, -23%, -50%) was obtained considering the other fiber-reinforced coating (C-GFRP), which has a higher mechanical resistance than the other ones.

References

[1] EnfedaqueA, GálvezJC, SuárezF.Analysis of fracture tests of glass fibre reinforced cement (GRC) using digital image correlation. *Construction and Building Materials* 2015;**75**:472–487.

[2] Buratti C, Moretti E, Belloni E, Agosti F. Development of Innovative Aerogel Based Plasters: Preliminary Thermal and Acoustic Performance Evaluation. *Sustainability* 2014;**6**:5839-5852.

[3] Buratti C, Belloni E, Palladino. Evolutive Housing System: Refurbishment With New Technologies And Unsteady Simulations Of Energy Performance. *Energy and Buildings* 2014; **74**: 173-181.

[4] Tzikopoulos AF, Karatza MC, Paravantis JA. Modeling energy efficiency of bioclimatic buildings. *Energy and Buildings* 2005; **37**:529-544.

[5] Corradi ML, Borri A, Sisti R, Buratti C, Belloni E, Moretti E. Masonry Wall Panels Retrofitted with Thermal-Insulating GFRP-Reinforced Jacketing. Materials and Structures (in press).

[6] Borri A, Buratti C, Sisti R, Castori G, Belloni E, Palladino D, Corradi M. Rinforzo a taglio di pannelli murari con intonaci termoisolanti fibrorinforzati. IF CRASC 15, VI Convegno su Crolli, Affidabilità Strutturale, Consolidamento. Roma, 2015.

Cinzia Buratti - Biography

Born in Marsciano (PG, Italy) 1966; Civil Engineer 1990; Researcher since 1990, University of Perugia (Italy); PhD in Applied Physics 1995;Assistant professor 1997 – 2004;Associate professor since 2005; Scientific research in: building physics; Transparent Insulating Materials; biomass and bioenergy; thermal comfort; acoustics.