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1   **MECHANICAL CHARACTERIZATION AND THERMAL CONDUCTIVITY MEASUREMENTS BY**

2   **MEANS OF A NEW 'SMALL HOT-BOX' APPARATUS: INNOVATIVE INSULATING**

3   **REINFORCED COATINGS ANALYSIS**

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14

15 **Abstract**

16 The insulation of the building envelope contributes to the reduction of annual energy

17 consumptions. The development of new materials, such as fibre reinforced insulating coatings,

18 could be useful in order to obtain an effective solution for the improvement of energy performance

19 and for reinforcement of the walls.

20 The evaluation of the thermal and mechanical characteristics of building coatings with good

21 thermal insulation properties and mechanical resistance is the aim of the present paper. A new

22 experimental apparatus, Small Hot-Box, built at the University of Perugia, was used for the

23 evaluation of the thermal conductivity of four different coatings (with and without a reinforced

24 structure). No European standards are available for this innovative facility, but it takes into account

25 some prescriptions of EN ISO 8990. The apparatus was calibrated with materials of known thermal

26 conductivity. The thermal conductivity can be calculated with both the thermal flux meter and the

27 Hot Box method. Good values of the thermal conductivity, in the range of 0.09-0.11 W/mK were

28 found for all the samples, except for one (0.21-0.24 W/mK).

29 Mechanical tests were also carried out in laboratory on all the samples and results were used to

30 evaluate the shear modulus and strength of the wall panels.

31

34

1.   Introduction

36   Energy consumption for buildings heating and air conditioning represents on average the 40

37 % of energy consumptions in Europe [1]. Furthermore a relevant part of the building heritage in

38 Europe is constituted by old buildings [2,3,4] with poor quality insulation materials. Therefore,

39 recent regulations, as for example the EU Directive 2010/31 [5] on energy efficiency in buildings,

40 aims at increasing target energy efficiency standards, considering both the single components and

41 the entire building. The building envelope plays a fundamental role in energy balance. The

42 evaluation of the building components thermal properties requires a high level of accuracy and

43 many experimental methods for the thermal characterization of materials have been performed

44 from research efforts all over the world. Several methods for measuring the thermal properties are

45 well known; the guarded hot plate is the most common method used for the evaluation of the

46 thermal conductivity of an homogeneous or multilayer material [6]. Many studies concerning the

47 characterization of thermal properties of materials are available; André et al. [7] presented an

48 experimental set-up based on the hot wire method for the thermal characterization of materials,

49 while a tiny hot plate method is proposed by Jannot et al. [8,9] for the thermal conductivity

50 measurement of heterogeneous materials [10].

51   Furthermore, for non-homogeneous structures, composed by different materials or

52 components (such as doors, windows or French windows), or when the heat transfer is two - or

53 three-dimensional, different techniques are used; the most common method for the thermal

54 transmittance evaluation is the calibrated Hot-Box [11,12]. Since Seventies the guidelines for Hot

Box design criteria are reported in EN ISO 8990 [13] and EN ISO 12567-1 [14]. In particular EN ISO 12567-1 specifies a method to measure the thermal transmittance of doors or windows, but also the thermal conductivity of homogeneous materials can be evaluated. The heat flux through the sample can be evaluated by means of thermal flux meters installed on the surface of the sample (Thermal Flux Meter Method, TFM). In this case the thermal conductivity of the panel will be calculated as the (thermal flux/surface temperature difference) ratio. The flux meter methodology is also considered in the UNI EN 1934:2000 [15]. At the University of Perugia (Department of Engineering), a Calibrated Hot Box was built in 2008, according to UNI EN ISO 8990 [13,16]. It is composed of two chambers (dimensions 2.5 x 1.2 x 3.2 m height), the cold and the hot one [16,17,18,19,20].

Considering homogeneous materials, other experimental apparatus could be used: the guarded hot plate or heat flow meter method (EN ISO 12667 and ASTM C518–10 [21,22]). The heat flow meter apparatus is a comparative device and requires a reference material with known thermal properties for calibration. The heat flow meter apparatus establishes steady state one-dimensional heat flux through a test specimen between two parallel plates at constant but different temperatures [23].

In this context, in the present study measurements with a new experimental apparatus, named Small Hot-Box, were carried out. The experimental system has been designed and built at the Laboratory of Thermal Science, University of Perugia. The apparatus allows the evaluation of the thermal conductivity of homogeneous materials, but the operating principle arises from the Hot-Box method. The advantage of the apparatus with respect to Hot-Box is the possibility of testing homogeneous materials with smaller samples (300 x 300 mm); with respect to the Hot Plate apparatus, it can provide a thermal transmittance value measured in conditions similar to the in-situ ones.

Fibre reinforced insulating coatings were characterized with the innovative apparatus. The mechanical properties of the same samples were also evaluated, in order to show the influence of the fibres on the mechanical resistance.

82   Retrofitting techniques for masonry constructions are extensively found in the existing

83   literature. FRP (Fibre-Reinforced Polymer) systems are increasingly used to strengthen masonry

84   structures: reinforcement is frequently bonded to the surface of existing walls, where it provides

85   tensile strength and prevents the opening of cracks [24,25,26,27].

86   The use of FRPs without epoxy adhesives is less well established [28,29]. Only recently the use of

87   non-organic matrixes has been the subject of research, and it could be a valid alternative to the

88   use of epoxy matrixes. Mechanical tests were conducted in laboratory on 1.2 x 1.2 x 0.24 m

89   brickwork panels. All wall panels were subjected to shear strength and test results were used to

90   evaluate the shear strength of the masonry before and after the application of the strengthening

91   made of a G-FRP (Glass Fibre-Reinforced Polymer) reinforced insulation coating applied on both

92   panel sides.

93   Insulation coatings can be used in many applications, such as refurbishment of old buildings,

94   on internal as well as external surfaces, and they should offer a non-invasive method for reinforce

95   historic buildings and saving energy without altering their forms. Fibre-Reinforced Polymers (FRP)

96   are composed of high-strength fibres (such as glass) embedded in a polymer resin (such as

97   polyester), durable (thanks to the resin), and lightweight. Glass fibre reinforced concrete is a

98   composite material made of components with different mechanical properties: cement mortar and

99   G-FRP in place of metal grids. Cement avoids buckling of glass fibres when compressing them,

100   glass fibres improve the tensile strength and ductility. This solution is very diffused in order to

101   improve the shearing strength of the walls [30,31]. Thermal insulation plasters, as the samples

102   investigated in the present study, consisting in innovative reinforced coatings made of mortar and

103   G-FRP, try to combine good mechanical and thermal properties for building refurbishment.

104   Innovative coating solutions are therefore in development, such as aerogel-based high

105   performance insulating plasters, but a limited number of studies exists in this field, probably due to

106   the high costs of the innovative system [32].

107

108   **2.   Materials and methods**

109   **2.1   Description of the samples**

110   Four mortars with different chemical compositions were investigated, each one with and

111   without G-FRP, for eight samples in total. The G-FRP grid is characterized by a 66 mm square

112   mesh inserted into the matrix. It is produced by Fibre Net (Udine, Italy) and is fabricated with an

113   AR (Alkali Resistant) fibre glass (Fig.1 and Tab.1).

114   Samples for thermal measurements were realized by using a layer of plasterboard as

115   support base. Nine square samples were therefore realized, (including the only plasterboard

116   (PL), 13 mm thickness), with external dimensions 30 × 30 cm (total area of 0.09 m^2), according

117   to the dimensions of the opening for the lodge of the samples. The thicknesses of the

118   specimens and the description of the coatings for thermal measurements are reported in Tab.2.

119   Cylindrical samples approximately 94 mm in diameter and approximately 180 mm in

120   height were realized for compression tests;10 square walls 1.2 m x 1.2 m were assembled in

121   laboratory for shear tests.

122

123   **2.2   Thermal characterization**

124   The new experimental apparatus was built at the Laboratory of Thermal Science - the

125   University of Perugia - for thermal conductivity measurements. A general view of the apparatus

126   is represented in Fig. 2. It is composed of one box (external dimensions 0.94 x 0.94 x 0.50 m)

127   that behaves as hot chamber: the outer walls of the chamber are made of very thick insulation

128   (200 mm of foam polyurethane + 20 mm of wood), in order to minimize the thermal losses and

129   the heat flux through the walls. The thermal conductivity λ of the expanded polyurethane is

130   0.0245 W/m K and the thermal transmittance of the walls is 0.114 W/m^{2}K. The second part of

131   the experimental system is the closure side of the box (dimensions 0.94 x 0.94 x 0.20 m thick):

132   it is a sandwich wall composed of two panels of wood (20 mm each) with a central layer of

133   expanded polyurethane (200 mm). In the central part of it there is an opening for the placement

134   of the sample, with 0.30 x 0.30 m dimensions. The contact zones between the support panel

135   and the sample are covered with insulation rubber in the perimeter joints, which are also sealed

136   with silicone during the test.

137   The cold side of the system is the laboratory room (internal dimensions 3.39 m x 4.22 m x

138   2.97 m high), completely insulated from the outside. The small Hot-Box is positioned inside this

139   room, where it is not possible to set the temperature but it was monitored during a long period

140   before the construction of the apparatus and it was observed that the daily temperatures are

141   very steady (maximum difference about 0.8°C). During the test, the temperatures inside the hot

142   room are maintained constant by means of a heating source made of a 3 m long (50 W) S-

143   shaped heating wire. In order to avoid direct radiation effects, a screen (baffle) made of poplar

144   wood (emissivity 0.90) is placed between the heating system and the support panel. The

145   heating wire is switch on and off automatically thanks to a PID (Proportional-Integral-Derivative)

146   control system. Inside the hot chamber, 9 thermoresistances are installed in order to control the

147   surface temperatures of the sample (4 probes), of the support panel (4 probes), and the air

148   temperature (1 probe). In the laboratory cold side, 8 probes are fixed to the surface of the

149   specimen and of the support panel, and one is placed in the room for air temperature

150   measurement. Finally a thermal flux meter is placed in the central area of the sample, in order

151   to measure the heat flux from the hot side to the cold one. The apparatus diagram with the

152   sensors' position are represented in Fig.3. All the monitored data are transferred to a PC: it is

153   possible to select the time step for the data acquisition, and it is also possible to visualize and

154   save the acquired data. In order to avoid the air stratification, two fans (each one with an electric

155   current equal to 0.11 A) were installed inside. A convective equilibrium was achieved thanks to

156   this ventilation system and a maximum difference of about 0.6°C on the hot face was achieved

157   after the fans' installation.

158   A switchboard was finally assembled: it is composed of a master switch, a PID controller,

159   an electrical energy meter, and a speed variator for the regulation of the fans' velocity.

160   Considering the evaluation of the heat flow supplied to the hot chamber in order to keep the

161   steady-state conditions, an ammeter was also installed in order to evaluate the current passing

162   through the hot wire. The heat power released by the resistance during a test could be

163   evaluated as the product of the hot wire thermal resistance (measured in Ohm) and the square

164   current through the hot wire (in ampere). On the contrary the electric energy meter measures

165 directly the energy entering the hot side, but it has a low accuracy and it was used only as a

166 control instrument.

167   The Hot Box method could be used for calculating the thermal conductivity of the

168 samples, by evaluating the heat flux through the sample as the difference between the input

169 power (P_i in W) in the hot chamber and the heat losses through the walls and the thermal

170 bridges (P_w in W). The incoming power P_i can be measured considering two contributes: the

171 heat flux released by the resistance during the test (P_r in W) and the contribute of the fans (P_f in

172 W). The contribution of the losses P_w is evaluated by means of calibration measurements and it

173 shall be plotted vs. the air temperature difference between the hot and the cold side.

$$P_s = P_i - P_w \quad [W] \tag{1}$$

175 where:

176   - P_s is the power coming out through the tested specimen (W);

177   - P_i is the entering power in the hot chamber, measured by a power meter (W);

178   - P_W is the power loss through the walls and the thermal bridges, evaluated by the

179   calibration curve equation (6) (W).

180   The thermal conductivity of the specimen is then calculated by dividing the product of the

181 power through the specimen (P_s in W) and its thickness by the area of the specimen A_s (m^2) and

182 the surface temperature difference between its two sides:

$$\lambda = \frac{P_s \cdot s}{A_s \cdot (T_{SH} - T_{SC})} \ [W/(m \cdot K)] \tag{2}$$

184   Specific calibration panels (foam polyurethane, expanded polystyrene, plasterboard, and

185 wood) were assembled for the calibration tests and many measurements were carried out by

186 considering different set-point temperatures of the hot chamber (the air temperature difference

187 between hot and cold side was maintained higher than 20°C for all the tests). Generally it was

188 observed that the mean error of the apparatus decreases by decreasing the set point

189 temperature of the hot side. A mean value of 50°C for the hot chamber was considered.

190   The thermal flux meter method is based on a thermal flux meter probe placed in the

191 central part of the sample, as shown in Fig. 3. The probe (model HP01 - Hukuseflux) is a

192 thermopile operating in the -2000 ÷ +2000 W/m^2 power range and in the -30 ÷ +70°C

193 temperature range. It measures the differential temperature across the ceramics-plastic

194 composite body and generates a small output voltage proportional to the local heat flux. In order

195 to calculate the thermal conductivity, 8 termoresistances are installed on the surface of the

196 sample, with four sensors each side (Fig. 3). The thermal resistance R_t could be calculated as

197 follows (Progressive Average Methodology) [33,34]:

198
$$R_t = \frac{\sum_{j=1}^{n}(T_{SHj}-T_{SCj})}{\sum_{j=1}^{n}q_j} \quad [(m^2 \cdot K)/W] \tag{3}$$

199 where the index j is related to each acquisition time, T_{sH} is the mean value of the panel

200 surface temperature of the Hot side, T_{sC} is the mean value of the panel surface temperature in

201 the Cold side, and q is the heat flux through the sample (W/m^2). The average values of the

202 temperatures of the four sensors installed in each side of the sample and the mean thermal

203 heat flux were used for the calculation.

204 The value of the thermal conductivity can be calculated by the mean value of the thermal

205 resistance R_t during the selected period (about 2 – 3 h) and the thickness of the specimen (s in

206 m):

207
$$\lambda = s/R_t \quad [W/(m \cdot K)] \tag{4}$$

208

209 **2.3 Mechanical characterization**

210 The strengthening technique is very similar of the traditional steel jacketing for masonry

211 wall panels. Both G-FRP and thermal insulating mortars underwent a mechanical

212 characterization. The mechanical properties of the mortars were evaluated by compression

213 tests in compliance with EN 12390-2 2009 [35]. Compressive strength of mortar at 30 days

214 after casting has been measured.

215 In order to study the shear behaviour of the wall panels reinforced with thermal insulating

216 plaster, 10 wall panels were tested in diagonal tension [36,37], as reported in Fig.4.

217 Using the Turnšek and Cacovic [38] formulation, the shear strength is:

218
$$\tau = \frac{f_t}{1.5} = \frac{p}{3 \cdot A_n} \tag{5}$$

219   in which *p* is the diagonal load and A_n is the cross-section area of the wall panel. For both

220   unreinforced and reinforced wall panels, brickwork pattern was made from all headers (*header*

221   *bond pattern*) on each course. Panels were assembled by using a lime-based mortar for

222   construction in laboratory.

223

224 **3.**   **Results**

225 **3.1**   **Thermal properties**

226   By applying the Hot-Box method data was calculated with a calibration curve based on

227   materials with a known thermal conductivity higher than 0.06 W/mK (for the calibration curve

228   construction a wood panel (λ = 0.12 W/mK), a plasterboard panel (λ = 0.20 W/mK) and an

229   insulating panel with wood fibres and cement (λ = 0.065 W/mK) were used). The following

230   calibration curve was used:

231
$$P_W = 0.2487 \cdot \Delta T_a + 1.4567 \ \ [W] \tag{6}$$

232   where:

233   - P_W is the power loss through the walls and the thermal bridges (W);

234   - ΔT_a is the air temperature difference between the hot and the cold side (°C).

235   By measuring P_i in eq. (1), P_s and λ of the sample could be calculated by applying

236   equations (1) and (2). λ of the coating should then be calculated knowing λ and s of the

237   plasterboard panel used as support base, by applying the following:

238
$$\lambda_{coating} = \frac{s_{coating}}{\frac{s_{total}}{\lambda_{total}} - \frac{s_{plasterboard}}{\lambda_{plasterboard}}} \ \ [W/(mK)] \tag{7}$$

239

240   Results are showed in Table 3.

241   It can be observed that the R-FRP and R2-FRP have the best thermal insulation

242   behaviour, the C type has the highest thermal conductivity (0.275 W/mK without G-FRP and

243   0.189 W/mK with G-FRP grid). The same data was obtained by using the thermal flux meter

244   methodology. The thermal conductivity of the plasterboard is 0.19 W/mK (with a difference of

245   only 5% in respect to the value declared from the company, equal to 0.2 W/mK).

246   Table 4 shows the thermal conductivity values obtained for the different specimens, with

247   and without reinforced grid system: the comparison between the results is represented in the

248   table considering both the methodologies.

249   All the coatings have good thermal properties, even if they were developed as structural

250   mortars; generally the thermal conductivities are lower than the ones of traditional coatings

251   (values in 0.5-1.0 W/mK range).

252   The thermal conductivity values of the samples with G-FRP vary between 0.089 and

253   0.210 W/mK. The best mortar is R2-FRP type, the worst is C-FRP (0.210 W/mK), but it is the

254   best coating considering the mechanical resistance of the samples (see paragraph 3.2). The

255   thermal conductivity of the samples with G-FRP decreases of about 11-15 % with respect to

256   samples without G-FRP, except for R: in this case it is possible to observe an increasing of

257   about 8% probably due to a flaw of the mortar grout during the laying of the samples (Fig.5); the

258   improvement in terms of reduction of the thermal conductivity (about 11-15%) is probably due to

259   air included in the mixture.

260   Furthermore it is important to observe that the thermal conductivities of the samples with

261   and without G-FRP are not so different from the error value of the apparatus (about 10%), and

262   therefore they are not so different in terms of thermal performance: minimum changes of the

263   final thermal conductivity values are attributed especially to differences in the laying of the

264   samples.

265   Considering the comparison between the two methodologies (Hot Box and Thermal Flux

266   Meter, see Tab.4) it can be observed that the differences vary in 9 - 23% range: the thermal

267   conductivities obtained with the Hot-Box Method are in general higher than the ones obtained

268   by the Thermal Flux Meter Method for almost all the samples. Nevertheless the Thermal Flux

269   Meter Method seems more reliable, because the considered calibration curve used for the Hot-

270   Box method is preliminary and much more materials with λ in 0.05 – 0.50 W/(mK) range should

271   be used for the improvement of that curve (6).

272

273   **3.2   Mechanical resistance**

274   The technical developments of the last years have enabled to produce new mortars with

275   specific properties, such as a low salt content and size of the aggregate in function of the

276   masonry characteristics in order to achieve the highest possible compatibility with existing

277   masonry. Sixteen 94 mm diameter cylindrical samples (four for each mortar type) have been

278   tested in compression. Mortar cylinders were approx. 180 mm in height. The average

279   compression strength of the cylindrical samples at 30 days after casting was 0.66, 0.72, 0.87,

280   and 2.70 MPa respectively for mortars D-, R-, R2-, and C-type (Tab.5). These values are

281   similar both in terms of compressive strength and Young's modulus with the mortar's

282   mechanical properties of historic stone multi-leaf masonry walls [39].

283

284   *Un-reinforced panels*

285   When subjected to shear tests in diagonal tension, all un-reinforced panels exhibited a

286   failure along the compressed panel diagonal. If the diagonal compression force is strong

287   enough to exceed the lateral strength capacity of the wall panel, diagonal cracking opened

288   slowly in the mortar joints and in the bricks starting from the central part of the wall panel and

289   producing a tensile failure of the walls and an abrupt loss of lateral stiffness (shear modulus).

290   Two unreinforced brickwork panels have been tested (test n. 5 and 6) and the average lateral

291   capacity and shear strength τ were respectively 201.1 kN and 0.230 MPa, while the shear

292   modulus G was 4078 MPa. Results are summarized in Table 6.

293

294   *Reinforced panels*

295   Eight reinforced masonry panels were subjected to the diagonal tension test and a single

296   test was performed on each wall panel. In-plane resistance of unreinforced masonry wall panels

297   is mainly based on the thermal insulating mortar strength. Table 6 gives the results in terms of

298   diagonal compression capacity, shear strength and modulus for each test.

299   For panels reinforced with D-type mortar, as expected, the wall panels reinforced with this

300   technique did not resulted very stiff (shear modulus G=4054 MPa). Lateral capacity was 247.5

301   kN. The stress-strain curve shows a quasi-elastic behaviour with a weak yield plateau. The

302	failure mode involved a sudden loss of collaboration between the reinforcement (lime mortar)

303	and the substrate (masonry), with some cracks along the compressed diagonal observed on

304	mortar surface.

305	The results of the shear tests did not show a significant high increases both in terms of

306	shear strength and stiffness when mortar type R has been applied. The lateral capacity and

307	stiffness (shear modulus) values became, respectively, 215.6 kN and 4829 MPa, with a limited

308	increment of 7 and 18.4% when compared to the values measured for the same panels before

309	reinforcement. The failure modes observed for these panels are characterized by a very similar

310	cracking pattern as those of the un-reinforced (Fig.6).

311	For wall panels reinforced using thermal insulating mortars R2 and C-type, a significant

312	enhancement of the shear strength was detected: an increase of 114.8 and 109.1% was

313	measured for R2 and C-type mortar, respectively.

314	From these test results, a clear tendency is evident: the reinforcing technique can cause

315	an increase of the shear stiffness only if a thermal insulating mortar with good mechanical

316	properties is used (type R2 or C). For reinforced panels shear stress versus angular strain

317	responses, such as those shown in Fig. 7, a two-stage behaviour has been detected: for small

318	values of the angular strain (approx. up 0.5‰) the behaviour is almost linear elastic while it

319	becomes highly inelastic for larger values of the deformation. The elastic phase of the

320	reinforced panels curves is characterized by a similar slope as those of the un-reinforced. Thus,

321	a first consequence of the reinforcement is the increase of the strength of the wall while leaving

322	unchanged the in-plane stiffness measured in the elastic phase.

323

324	**4.	Conclusions**

325	The present paper is focused on the importance of combining thermal and mechanical

326	properties in buildings refurbishment. The use of construction materials with good thermal

327	properties is in fact the first condition for greatly reducing the thermal heat losses of the final

328	products. The study is focused on glass fibre reinforced insulating mortars: they combine good

329	mechanical and thermal properties for building refurbishment.

The insulating behaviour of the coatings was investigated by an original experimental apparatus named Small Hot-Box. It is an effective alternative system used instead of the Hot-Plate apparatus for the experimental evaluation of the thermal resistance of homogeneous materials. The tested samples are installed in a support panel between the hot and the cold sides; an air temperature difference is maintained during the test. A heat flux pass through the sample during the test: the thermal conductivity can be evaluated by measuring the heat flux and the surface temperatures of the specimen. Two different methodologies are presented: the thermal flux meter method and the Hot-Box one. The first method takes into account the heat flux measured by the thermal flux meter installed on the sample, the second one evaluates the heat flux through the specimen as the difference between the input heat flux and the heat losses through the walls.

Considering the thermal flux meter method, all the coatings have good thermal properties (thermal conductivities variable in 0.09 – 0.23 W/(mK) range) and the best thermal behaviour can be attributed to R and R2 mortars. Also considering the Hot-Box method, the lowest thermal conductivities were found for R and R2 mortars. Even if both the results are aligned, considering the two methodologies, the thermal flux meter method results should be considered more reliable because the calibration curve used for the Hot-Box method is just preliminary and it should be improved. The best thermal performance were obtained for the samples D, R, and R2 (λ = 0.09 – 0.105 W/mK), while for C a value of 0.19 – 0.27 W/mK was found.

Generally, with the glass fibre reinforced grid the thermal conductivity of the samples decreases of about 11-15 % except for mortar type R but this behaviour is probably due to the small dimensions of the specimens; anyway it is expected that the thermal resistance of the mortars in situ would not significantly modified by the G-FRP insertion.

The externally applied G-FRP mesh to masonry panels resulted in a stronger system, as compared to the un-reinforced configuration. The addition of a G-FRP reinforced coating resulted in an increase in in-plane load capacity between 7 and 115%. However the reinforcement can produce an increase of the in-plane load-capacity only if a thermal insulating mortar with good mechanical properties is used; large increases in shear capacity were only found for wall panels reinforced with thermal mortars R2 and C: it demonstrates that the G-FRP grid upgrade with a

358   lime-based thermal insulating mortar is promising, but less effective compared to the reinforcement

359   with epoxy resins or concrete coatings. Mechanical shear tests have demonstrated that the

360   adhesion between the masonry panels and the coating used as a base for reinforcement (G-FRP

361   mesh) was the critical element in the reinforcing system. Failure of reinforced panels resulted from

362   the separation of the layer of thermal insulating mortar from the masonry panels and from the

363   opening of diagonal cracks along the compressed panel's diagonal.

364   Finally, by combining results of thermal and mechanical characterization, the samples with

365   the R2 mortar seem the more promising for building refurbishment, being the best compromise

366   between thermal and mechanical performance.

367

368   **Nomenclature**
369   A = panel surface (m^2)
370   e = error (%)
371   f_t = tensile strength (MPa)
372   G = shear modulus (MPa)
373   λ = thermal conductivity (W/mK)
374   P = power (W)
375   p = diagonal compression load (N)
376   q = heat flux (W/m^2)
377   R_t = thermal resistance (m^2K/W)
378   s = thickness (m)
379   T = temperature (°C)
380

381   **Subscirpts**
382   a = air
383   C = Cold side
384   f = fans
385   H = Hot side
386   HB = Hot Box method
387   i = input
388   m = mean
389   p = panel
390   r = resistance of the hot side
391   s= specimen

392   S = surface

393   *tfm* = thermal flux meter method

394   *w* = walls

395

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