Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 101 (2016) 1050 – 1057

Energy Procedia

71st Conference of the Italian Thermal Machines Engineering Association, ATI2016, 14-16 September 2016, Turin, Italy

Ageing effects on the thermal performance of two different well-insulated buildings

Iole Nardi[a,*], Tullio de Rubeis [a], Stefano Perilli [a]

[a]*Department of Industrial and Information Engineering and Economics, University of L'Aquila, P.le Pontieri 1, L'Aquila 67100, Italy*

Abstract

To guarantee a comfortable accommodation to those who had their house destroyed or unfit due to the earthquake that in 2009 hit the city of L'Aquila, the "C.A.S.E. Project" (italian acronym for Complessi Antisismici Sostenibili ed Ecocompatibili – anti-seismic sustainable and environment -friendly complexes) was foreseen and realized: it entailed the realization of complexes of buildings, built according to italian seismic and energy-efficiency requirements.
After 7 years, the ageing effects on the thermal performance of the opaque envelope have been investigated out with thermographic surveys and heat flow meter measurements, on two buildings realized with different typologies, both belonging to C.A.S.E. Project.

Peer-review under responsibility of the Scientific Committee of ATI 2016.
Keywords: opaque envelope; well insulated walls; C.A.S.E Project; ageing effects.

1. Introduction

After the earthquake that hit the city of L'Aquila, the country seat of the Abruzzo region, in the middle of Italy, and its neighborhoods, a multiplicity of emergencies arise.

To complicate matters, this City was an important historical centre, having a rich cultural heritage, that required complex procedures and long times for buildings' architectural and functional restoration.

* Corresponding author. Tel.: +39 0862 434363.
E-mail address: iole.nardi@graduate.univaq.it

1876-6102
Peer-review under responsibility of the Scientific Committee of ATI 2016.
doi:10.1016/j.egypro.2016.11.133

Therefore, high priority was given to the construction of new houses for those who had their destroyed. To rapidly face this kind of emergency, new houses have been built, with specific action plans that involved the National Service of the Civil Protection and the local administration [1].

The main aims pursued were the realization of residential buildings in few months, and possibly before the onset of the winter season which could be very cold in this city, maximum anti-seismic safety, high quality homes, with standards comparable to the current housing [2].

Beyond the first two goals on the realization timing, which were undeniable, the quality of housing standards and utilities sided other goals, like high technological level, oriented to the energy self-sufficiency through accurate plant design, environmental sustainability of interventions, and natural diversification of public and private spaces.

These purposes were clearly identified even by the italian Law Decree 28 April 2009 n.39 [3], where it is stated that, beyond the seismic safety requirements, high attention is given to energy efficiency aspects and sustainability that characterize the whole project, not only for what concerns buildings insulation or heating systems, but for every aspect that concerns the use of renewable energy: processes, buildings materials, water usage, photovoltaic panels, solar-heating plant.

These requirements were satisfied by the realization of the "C.A.S.E. Project", acronym for Complessi Antisismici Sostenibili ed Ecocompatibili – anti-seismic sustainable and eco-compatible complexes. The C.A.S.E. Project consisted in the realization of 185 structures on concrete platforms, equipped with 40 seismic isolators with steel columns, 19 construction sites, hosting 4˙449 accommodations, needed for the almost 15˙000 evacuees [4], 330˙000 m^2 of living surface, 220˙000 m^2 addressed to parking [5]. Several building typologies have been employed, all of them using solution mainly based on dry construction approach, such as structural timber, prefabricated structural concrete and structural steel [5]. These complexes that should be transitional, are quite huge and structured, that seem to have to last for decays.

The great attention to energy and environmental aspects and impacts lead, in turn, to a list of minimum requirements that buildings had to satisfy and imposed in the tender bid for the realization assignment. For instance:

- all the accommodations need to have their own heat meter, to properly ascribe energy consumption;
- the tender project includes the providing and installation of solar heating collectors, able to satisfy the 50% of the needs, according to the Italian legislative decree DLgs 311/2006 et s.m. [6];
- the needed PV systems for electric power supply should be possibly integrated with the building architecture, favoring rooftop installation;
- the thermal transmittance of each building element has to comply the values imposed by Legislative Law Decree DL 192/2005 [7] modified by Legislative Law Decree DLgs 311/2006 [6]:
    - Opaque vertical elements: U=0.37 W/m^2K;
    - Opaque horizontal or sloped rooftop elements: U=0.32 W/m^2K;
    - Opaque pavement elements towards unheated spaces or outdoor: U=0.38 W/m^2K;
    - Transparent element, frame included: U=2.4 W/m^2K;
    - Glazing transmittance: U=1.9 W/m^2K;
- The project needs to be scalable, so it has to provide for modular configurations able to guarantee structural and thermal capabilities, and to allow the dismantling reuse or recycle of components;
- The project has to include system minimizing water consumption (i.e. dual flush button, aerator on faucet, etc).

Moreover, in the tender bid, all the interventions capable of minimizing resources, environmental loads, direct solar radiation (by the use of shading systems, passive solar systems or other technological solutions), and capable of enhancing indoor quality in terms of thermo-hygrometric parameters and acoustic comfort are valorized.

That's why the 60% of buildings has been ranked as A or A+ class (according to the energy classification in effect at that time [8]), with 7˙000 m^2 of solar water heating system have been installed (almost 4 kWt per accommodation), together with 35˙000 m^2 of PV system mounted on roof or park shelter (almost 1kW per accommodation), and 62 hectares are addressed to public green areas (including parks and gardens) and 30 playing fields [4].

Table 1. C.A.S.E Project infrastructures and facilities.

19	sites
185	structures con concrete platforms
40	seismic isolators per platform
4˙449	accommodations
15˙000	evacuees
330˙000 m^2	living surface
220˙000 m^2	parking area
7˙000 m^2	solar water heating system area
35˙000 m^2	PV system area

After 7 years from their realization, degeneration, weathering and ageing effect processes affect these buildings. Although the aforementioned technological solutions allowed to have accommodation with great indoor comfort, some inconveniences are arising due to ageing and lack of maintenance on the envelopes and plants. For instance, last year a few balconies fell down due to the wood rotting, caused by water seepage.

The ageing processes can depend on several factors, as outdoor or indoor environmental conditions, employed materials and their vulnerability to the environmental, frequency and quality of the maintenance. For technological plants, maintenance programs needed for managing or preserving their efficiency can be easily planned and performed. On the other hand, such programs are rarely foreseen and applied to building envelopes, as they would have less importance.

On the contrary, degradation processes on the envelope materials can deteriorate their thermal properties and, therefore, the thermal performance of the envelope, thus affecting the total energy consumption and indoor comfort.

In this work, the ageing effects on the envelope thermal transmittance of two different buildings, both belonging to the C.A.S.E. Project, are studied by using the heat flow meter method, after a previous qualitative inspection via infrared camera, to understand the behavior of these two structures.

2. Cases studies

The two analyzed buildings, marked with a dotted line, stand in different areas, namely Coppito 3 and Roio, shown in Fig. 1 a) and b).

The room layouts depicted in Fig. 1 c) and d) are different, according to the various technical solutions realized.

The first building typology (B1), depicted on the left side of Fig. 1, is a wood platform-frame building, also awarded with the Class A of CasaClima [9] energy certification. The second building typology (B2) is a prefabricated structure in reinforced concrete.

Standing on the different building typologies adopted, different solutions for the opaque envelope were studied and realized. Particularly, the two different wall assemblies, whose materials and thicknesses "s" are sketched in Fig. 1 c) and d) were adopted, both made by dry solution [2].

Building B1, in fact, is realized by a wooden bearing structure hosting a thick insulating layer, sandwiched between two wood panels made of masonite, externally covered by an insulating layer.

Building B2 is realized by assembling two concrete slabs on a thick rockwool panel, a plasterboard layer, two adjacent insulating layers and then two plasterboards panels as finishing surface.

Although these wall assemblies guarantee a good insulation due to the presence of thick insulating layers, there could be local thermal anomalies due, for instance, to the presence of bearing structures.

Therefore, as the current practice suggests, a preliminary qualitative thermographic inspection has been performed, in order to assess the presence of thermal discontinuities and, in such case, to avoid a wrong positioning of heat flow meter (HFM) probes.

Images in the infrared spectrum are those of Fig. 2, showing an even thermal field. Basing on this, the places for locating the flux plate and the temperature probes were chosen, also following a manageability criteria. In fact, north exposed walls were chosen to avoid direct solar irradiation of probes; this choice implied, as a drawback, the need to install them on surfaces that hadn't balconies but only windows, which could be quite difficult of course. These places are indicated by a red dot in Fig. 1e) and f).

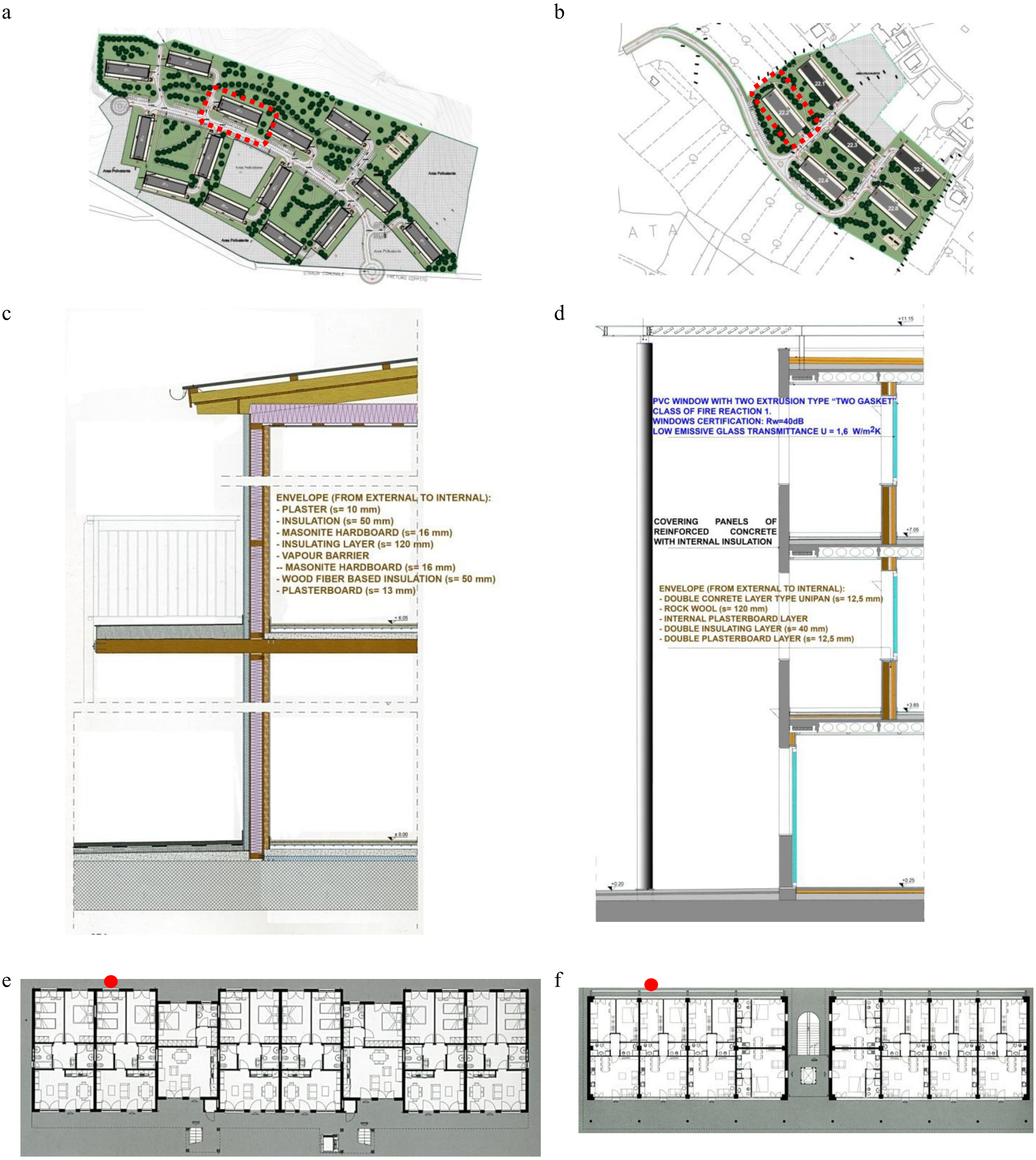

Fig.1. Construction site, wall assembly and rooms layout for B1 (left side: (a), (c), (e)) and B2 (right side: (b), (d), (f)), redrawn from [2].

It’s worth noting that an extensive qualitative thermographic campaign on many of the structures realized with the C.A.S.E Project has been performed, few years ago, by Legambiente, a civic association spread at national and international level, devoted to the safeguard and valorization of the of nature and environment [10]. The work highlights some critical situation on these buildings, proposing and discussing a series of IR images taken on buildings belonging to the C.A.S.E Project.

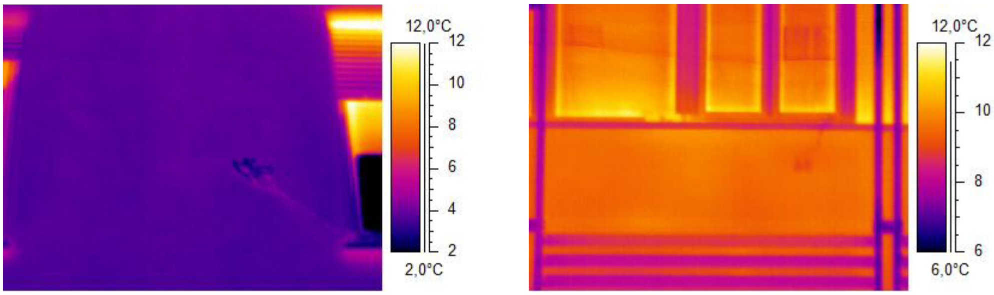

Fig. 2. IR images of: a) building B1; b) building B2.

3. Results and discussion

Measurements with the heat flow meter, lasting 4 days, were carried out according to standard [11], particularly they were performed during the winter season in the heating period of the city (15th October – 15 th April); data regarding heat flux, superficial temperature on the hot and cold side, acquired every 10 minutes, have been processed with the progressive average method. Mean progressive values are plotted in Fig. 3, together with the thermal conductance.

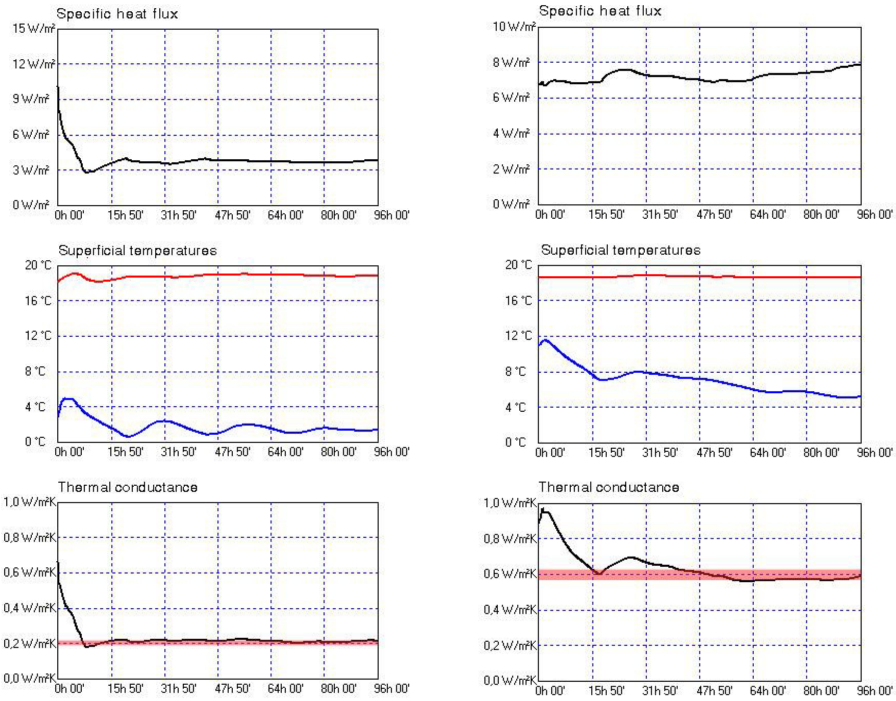

Fig. 3. Averaged values of heat flux, superficial temperatures and thermal conductance of: a) building B1; b) building B2.

Within the progressive average method, the thermal conductance C is calculated according to equation 1, as the ratio between the summation of all the ith heat fluxes, and the summation of the inside and outside wall temperature difference (respectively $T_{s,in}$ and T_s), calculated on the n records.

$$C = \frac{\sum_{i=1}^{n} q_i}{\sum_{i=1}^{n}(T_{s,in,i} - T_{s,i})} \tag{1}$$

Then, the thermal transmittance U is obtained by taking into account the convective phenomena that occur in proximity of the wall, i.e. by considering the internal and external liminar resistances h_{in} and h_{out}, that, in this case, can be retrieved from standard ISO 6946 [12]. Equation 2 expresses the formula for the thermal transmittance calculation.

$$U = \frac{1}{\frac{1}{h_{in}} + \frac{1}{C} + \frac{1}{h_{out}}} \tag{2}$$

The lower graphs of Fig. 3 show that the average values of the thermal conductance reach an asymptotic trend, and oscillation are within the 5% of the final value (pink stripe); particularly, basing on these results, the thermal conductance of building B1 and B2 are respectively 0.22 and 0.59 W/m^2·K, whilst the thermal transmittances, calculated by imposing internal and external convective coefficients as per standard UNI 6946 [12], are respectively 0.21 and 0.53 W/m^2·K.

These values are quite different from the maximum U value that building had to satisfy (which is 0.37 $W/m^2 \cdot K$), according to the competitive tender and to the national regulation in effect on 2009.

For building B1, the thermal transmittance is lower than the maximum allowed, for building B2 is 59% higher.

Comparing the result of B1 with the value declared by the builder (0.18 $W/m^2 \cdot K$), it seems that the envelope thermal performance didn't vary significantly after several years.

On the contrary, the thermal transmittance of the B2 enclosure is far from the maximum allowed. This induced to further investigate the thermal transmittance of this kind of wall assembly. Particularly, it has been decided to calculate the thermal transmittance basing on standard ISO 6946 [12]. The thermal conductivity values adopted for the calculus have been gathered from standard UNI 10351 [13], since specific values were not available. In detail, to guarantee a precautionary analysis, the maximum thermal conductivity value of each material has been chosen, in order to perform the evaluations in the worst possible case. Moreover, since the type of double insulating layer interposed was not specified in the reference [2], two different evaluations, with and without internal insulation, have been performed. Starting from these assumptions, the design U-value of the wall assembly of B2 equals respectively 0.35 $W/m^2 \cdot K$ and 0.24 $W/m^2 \cdot K$ (considering a layer of expanded polystyrene – thickness 40 mm). These values comply the requirement of the tender bid, but they are still far from the measured one. The discrepancy between these values allows to hypothesize that this kind of structure has been affected from ageing and/or weathering. This degradation process could be evaluated by monitoring the real space heating energy consumption and further investigated by considering and measuring the thermal transmittance of other structures built with the same technical solution.

4. Conclusions

Considerations on the ageing effect on materials, technologies and technical solution adopted in emergency housing are quite important, especially in Italy: the Country, in fact, often has to face natural disasters, like floods, earthquakes and landslides, and to face the sudden need for houses. Among the years, different housing solutions have been implemented; however, the challenge for the National Service of the Civil Protection is to provide, as soon as required, within the shortest possible time, comfortable housing for evacuees, exploiting the best available technologies for plants and buildings, also guaranteeing the quality of living. Therefore, the C.A.S.E Project, which has been defined "the biggest construction site in Europe", has been an important field test in this sense, and a study like this could be important for future construction approaches choices.

From the in situ measurement campaigns for the assessment of the thermal transmittance of the opaque envelope, performed according to the current and best technical practice (i.e. on the north exposed walls, during the winter season, lasting multiple of 24 hs, avoiding thermal anomalies), results are surprising.

In one case (B1), the thermal performances, although slightly worsened, are still good; in the second case (B2) the thermal transmittance got worse, affecting the total heat losses, and, therefore, the expense for heating consumption paid by occupants.

Results proposed in this study could help to guide the choices of technicians in case of future realization of emergency housing.

References

[1] Alexander DE. The L'Aquila Earthquake of 6 April 2009 and Italian Government Policy on Disaster Response. *J Nat Resour Pol Res* 2010; 2:4, 325-42.

[2] L'Aquila: il Progetto C.A.S.E. Costruttori for C.A.S.E., IUSS Press, 2010, ISBN: 978-88-6198-052-5.

[3] Law Decree 28 April 2009, n. 39 Interventi urgenti in favore delle popolazioni colpite dagli eventi sismici nella regione Abruzzo nel mese di aprile 2009 e ulteriori interventi urgenti di protezione civile (in italian).

[4] http://www.protezionecivile.gov.it/jcms/it/view_dossier.wp?contentId=DOS302 .

[5] Tosone A, Bellicoso A. L'Aquila City-land. Post-Earthquake Emergency Housing: the CASE Project. Proceedings of the XXXVIII IAHS World Congress, 16-19 April 2012 Istanbul, Turkey.

[6] Legislative Law Decree 29 December 2006, n.311 Disposizioni correttive ed integrative al decreto legislativo 19 agosto 2005, n. 192, recante attuazione della direttiva 2002/91/CE, relativa al rendimento energetico nell'edilizia (in italian).
[7] Legislative Law Decree 19 August 2005, n. 192 Attuazione della direttiva 2002/91/CE relativa al rendimento energetico nell'edilizia (in italian).
[8] Ministerial Decree 26 June 2009 Linee guida nazionali per la certificazione energetica degli edifici (in italian).
[9] http://www.agenziacasaclima.it/it/certificazione/3-0.html.
[10] http://www.legambiente.it/contenuti/dossier/tutti-classe-A .
[11] International Standard ISO 9869, Thermal insulation. Building elements. In-situ measurement of thermal resistance and thermal transmittance, 1994.
[12] International Standard ISO 6946, Building components and building elements – Thermal resistance and thermal transmittance – Calculation method, 2007.
[13] Interntional Standard ISO 10351, Materiali da costruzione. Conduttività termica e permeabilità al vapore, 1994.