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BEHAVIOUR OF A LIGHTWEIGHT EXTERNAL WALL UNDER MEDITERRANEAN CLIMATIC CONDITIONS

Luigi A. Besalduch* Roberto Ricciu* Andrea Manuello Bertetto**

* Department of Civil and Environmental Engineering and Architecture
University of Cagliari - Italy

** Department of Mechanical Engineering, Chemical and Materials
University of Cagliari - Italy

ABSTRACT

The increasing development and use of new lightweight building technologies makes more urgent the evaluation of their energy performance. It is even more necessary in climatic contexts, like the Mediterranean basin, in which the effect of the solar radiation during the summer period should be lessened by high thermal masses. The study here presented deals with the assessment of thermal performance of an opaque envelope designed and built in Sardinia in 2013. The study is focused on the measurement the dynamic parameters of prebuilt wall, made of OSB panels and cellulose. The measurement is compared with the minimum requirements of Italian national standards. The analysis was carried out using a climatic chamber settled in the laboratories of the University of Cagliari. The chamber consists of two shells that create on both faces of a full-scale wall different hygro-thermal conditions. One of the shell simulates the external conditions while the other ones. The data were acquired to measure the heat storage capacity of the specimen, and then the dynamic parameters were calculated according to the EN ISO 13786:2008.

Keywords: lightweight walls, specific heat capacity, thermal transmittance, cellulose loose-fill, thermal dynamic parameters

1 INTRODUCTION

Lightweight materials are an interesting technology for building envelope. If prebuilt they can solve constructive problems and can help to reduce the use of heavy and energy consuming materials for the building bearing elements [1]. However their performances in mild climate, like the Mediterranean one [2], are far to be completely established. Italian legislation sets minimum requirements for periodic thermal transmittance and give a classification for thermal decrement and time lag. These values generally are calculated according to international standards as the EN ISO 13786.

Input data do not limit only to thermal conductivity, but also specific heat and density have to be correctly assessed. As shown in the following, especially the first one, requires complex measurements and the literature data, even for the same material, are not coincident.

In this paper, the measurements of thermal conductivity and specific heat of a wood based envelope are described. They have been carried out through the use of a dedicated climatic chamber. The results are then discussed and compared with Italian legislation requirements [3].

2 METHODOLOGY

2.1 CASE STUDY

The sample analyzed is representative of an opaque envelope of a newly constructed wall. In particular the case study corresponds to the construction technology of a residential building, located in northern Sardinia. The building is surrounded by a ventilated woodlands at an altitude of approximately 200 m above sea level. The site is classified in climatic zone C with 1142 DD and an

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Contact author: Roberto Ricciu[1]

[1] Email: ricciu@unica.it.

horizontal solar radiation, during the worst month of the year, I_r=326 W/m^2. The construction consist of platform frame with a steel framework and two OSB plastered panels filled of insufflated cellulose fibers. This is a dry construction method increasingly used, because it permits a fast construction and maximizes steady state thermal properties. The value of thermal transmittance equal to 0,14W/m^{2}K, reached by the envelope for its opaque vertical components, is a high performance level both for a new construction – in a Mediterranean climate – and for an existing building in similar climatic conditions. Considering this value, the technical solution used allows a suitable level of indoor comfort, with a correct balance between the building-enclosure and building-system appliances during wintertime. The relevant question is whether so low thermal transmittance values, accomplishing the limits prescribed by the current legislation, will allow is possible to obtain the same results in the summertime. The envelope is characterized by an areal density M_s=50,7kg/m^2, does not comply with legislative prescriptions regarding surface thermal mass for vertical structural components, but could give a value of periodic thermal transmittance that meets the prescriptions (Y_{ie}=0,12W/m^{2}K).

The inertial behaviour of the thermal envelope is extremely important, in relation to the climatic context, to guarantee the indoor comfort, without needing to overestimate the power of the cooling systems. For this reason, due to the crucial role of the dynamic parameters of the cellulose fiber, a study on this material was carried out.

Determining the actual value of specific heat is not a simple task for the specimen in question. This because cellulose fiber is an extremely porous material, characterized by a low conductivity, and, because of its low density, a low thermal capacity. Cellulose fibers, together with other natural fibers such as wood wool, have already been objects of studies mainly focusing on their fire resistance class.

To determine the specific heat capacity a large number of methods are applied, some of them use very small specimens (i.e. calorimetric methods [4]), that are not representative of real walls. Other are based on the differential thermal analysis (DTA) technique [5] or need an elaborate theoretical analysis of the measured data with idealized boundary conditions [6, 7] Other techniques are the photothermal or photoacoustic ones [8], or transient method using an heat flow meter apparatus (HFM) [9]. In this paper is present a novel easier method to determine the specific heat capacity of real walls, through heat flux meters.

3 EXPERIMENTS

3.1 EXPERIMENTAL SET-UP

The climatic simulation chamber (Fig. 1) used for these analyses, allows testing the full-scaled walls with imposed inner and outer wall climatic conditions [10] and it is designed according to the EN 1934:2000 [11], ISO 9869:1994 [12] and EN 12494:1996 [13] standards.

The apparatus consists of two chambers that fully control the temperature, relative humidity and air velocity and a frame that hosts the specimen.

3.2 TEST SPECIMEN

The test specimen is made by a cellulose based material confined with two OBS panels, 2240 mm high, 1250 mm wide and 395 mm thick (Fig. 2). The cellulose between the two panels was blown until reaching a density of 60 kg/m³. The declared values for the thermal conductivity and the specific heat capacity of this material are respectively 0,038 W/mK and 2544 J/kgK. While instead for the OSB are respectively 0,13 W/mK and 1700 J/kgK, the density is 600 kg/m³.

The specimen was inserted into a frame of XPS having the same depth to minimize the lateral heat dispersion.

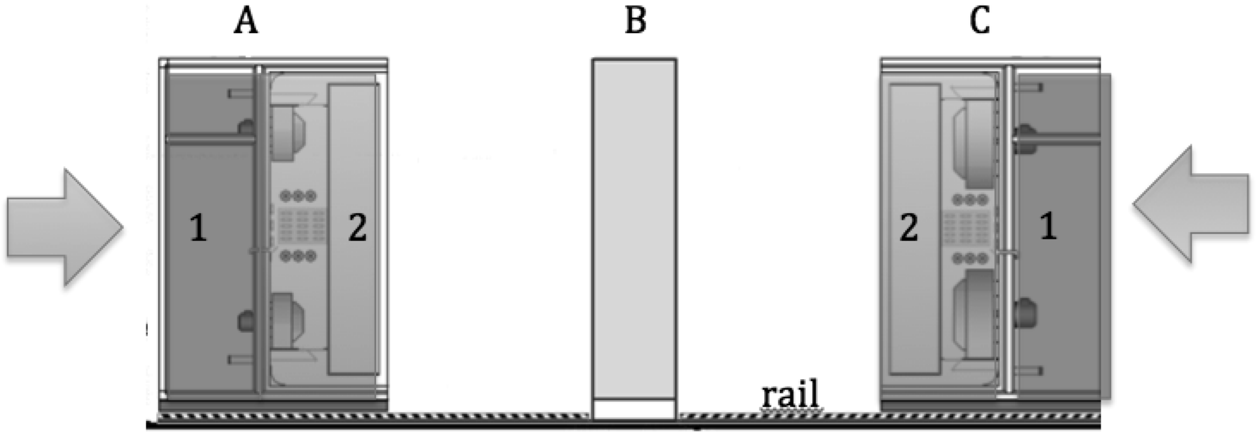

Figure 1 Climatic chamber, vertical section. (A) Indoor chamber, (C) Outdoor Chamber. The specimen is contained in a frame (B) between the two chamber.1 is the compartment electrical control system, 2 is the air handling compartment. The arrows indicate that the chamber A and C move on rails (dashed yellow line at the base of the chamber).

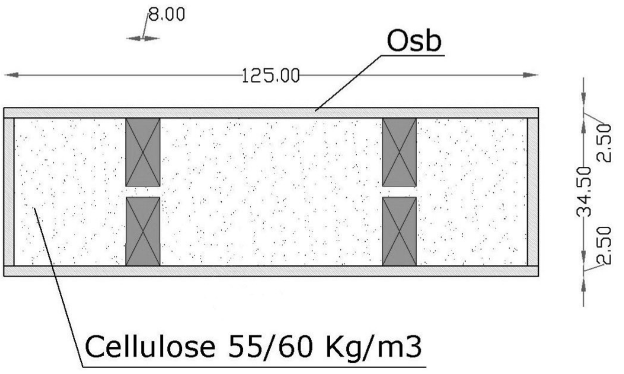

Figure 2 Test specimen (dimensions in cm).

3.3 EXPERIMENTAL METHOD

The test wall is instrumented by means of RTD (resistive temperature detector) sensors for the surface temperature measurement, NTC (negative temperature coefficient) thermistors for the air temperature and heat-flux sensors to measure the surface temperature and heat-flux.

The heat flux sensor is the FE01-3B model. The primary sensing element is a cylindrical thermopile sensor. The contact surface has got an 80 mm radius and its thickness is 5,5 mm. The main metrological characteristics are: span (measurement field): −300 to 300 W/m^2; resolution 0,01 W/m2 ; unbias: ±5%.

The measuring chain is also composed of wireless wiring in the ISM 2,4 GHz band and is compatible with the IEEE 802.15.4 protocol. The system also includes a data logger with an integrated RAM. The main metrological characteristic software and data logger are: resolution 16 bit, 30 channels and maximum sampling speed is 1 min on each of the 30 channels.

In order to obtain sufficient data, fourteen RTD sensors and four heat-flux sensors (which also include four temperature thermopile sensors) are fixed. A sample measurement rate of 5 minutes is chosen, taking into account the velocity variation of the environmental parameters measured. Surface temperatures and heat-flux output data are returned by a wireless data logger, while air temperatures in the two chambers Are measured through TGU2 data loggers. The data are subsequently transferred and processed through dedicated spreadsheets. The instrument scheme is shown in Figure 3.

The method requires the measurement of surface temperatures and heat-flux through the specimen by the use of heat-flux meters, [14, 15]. All sensors and measurement systems are provided with individual calibration certificates by the Italian Calibration Service SIT.

4 EXPERIMENTAL RESULTS

4.1 PRELIMINARY ANALISYS

The first test was aimed at measuring the thermal steady state conductivity. The test was carried out in conditions similar to the winter operating ones.

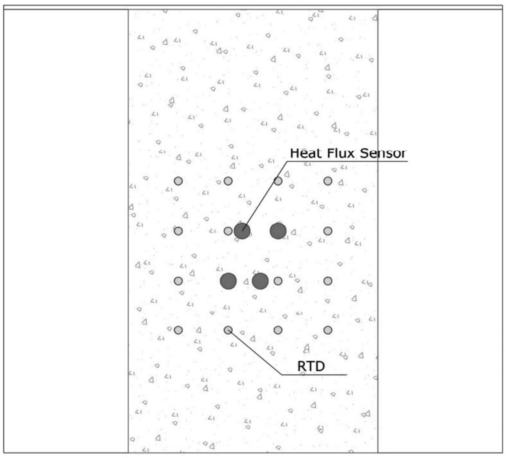

Figure 3 Position of the heat flux sensors (red) and of the RTD (green) in the indoor face.

The details of the environmental parameters are summarized in Table I.

Table I - Simulation conditions

	Indoor Chamber	Outdoor Chamber
Air temperature [°C]	22	2
Relative humidity [%]	40	40
Air velocity [m/s]	0,1	1,0

The measurements were carried out maintaining a mean surface temperature difference between the indoor and the outdoor chamber of about 20°C, as in Figure 4.

The heat flux calculated as the surface wall temperature difference became constant (after about 20 hours) maintaining a value approximately of 3,5 W/m²K. A measurement analysis of thermal conductivity was carried out with the progressive means method according to the EN 12494:1996 standard (Figure 5).

The results of the conductance Cs analysis are shown in Figure 5. A peak of 0,105 W/m^{2}K is evident after 8 hours, than after 50 hours, the conductance became constants, assuming a value of approximately 0,145 W/m^{2}K. This value, imposing the declared value for the OSB conductivity (0,130 W/mK), was used to determine the thermal conductivity of the cellulose (0,054 W/mK), different from the declared value, but similar to [16] that found a value of 0,050 W/mK.

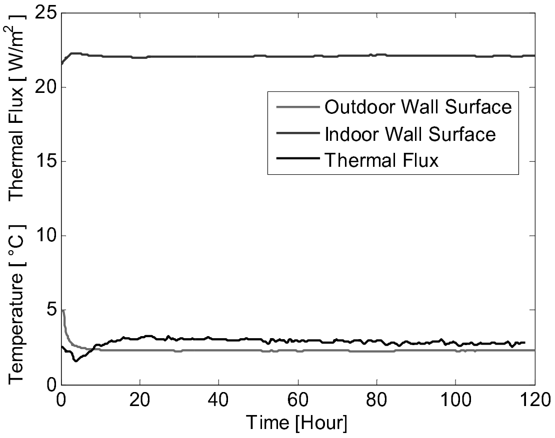

Figure 4 Surface walls temperature in the indoor (blue line) and outdoor (red line) chamber, and thermal flux (black line).

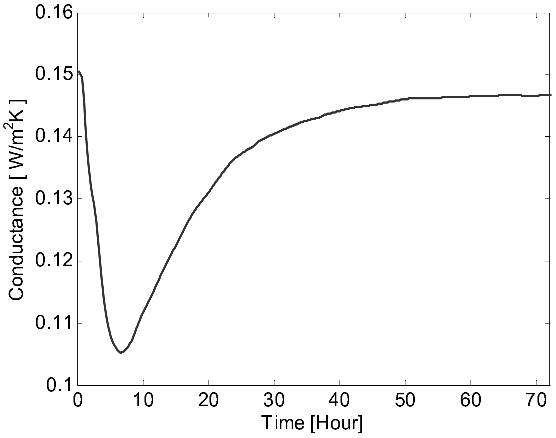

Figure 5 Evolution of conductance measured.

4.2 DETERMINATION OF THE SPECIFIC HEAT CAPACITY OF THE SPECIMEN

In this paper on use an original simple method to calculate the heat capacity throw heat flux meters.

The test began with the following environmental conditions: air temperature: about 40 °C and air velocity about 1 m/s, the relative humidity was set to 22%. Such conditions remained for approximately 10 days, in order to allow the evaporation of the residual humidity, and an isotropic thermal distribution inside the specimen.

Then the indoor and outdoor chambers were brought to 25°C, and the humidity to 50% (to maintain the same vapour pressure between the two faces of the specimen) (Fig. 6). The test run until the temperature variation of the specimen became negligible.

Calculating the heat capacity was calculated as the integral of the thermal flux (Q) measured by heat flux meters, divided by the areal density of the specimen (m), and by the temperature difference (Δt):

$$C = \frac{\int Q}{m \cdot \Delta T} \tag{1}$$

a specific heat of 1277 J/kgK has been evaluated.

4.3 DYNAMIC PARAMETERS UNDER THE EN ISO 13786

The results both for steady state and dynamic analysis are summarized in Table II, where the equivalent wall is a homogeneous wall with the same parameters of the specimen.

Table II - Wall parameters

	s [cm]	λ [W/m^{2}K]	C [J/kgK]	ρ [kg/m^3]
Equivalent Wall	39,5	0,0572	1277	128,35

With these data it is possible to evaluate the dynamic characteristics according to [17, 18] (Table III).

Table III - Dynamic values calculated

Thermal transmittance (U)	0,141	[W/(m^{2}K)]
Periodic thermal transmittance (Yie)	0,026	[W/(m^{2}K)]
Thermal lag	11,24	[h]
Decrement Factor (fa)	0,187	[-]
Internal thermal admittance	0,765	[W/(m^{2}K)]
External thermal admittance	0,806	[W/(m^{2}K)]
Internal area heat capacity	10,752	[kJ/(m^{2}K)]
External area heat capacity	11,303	[kJ/(m^{2}K)]

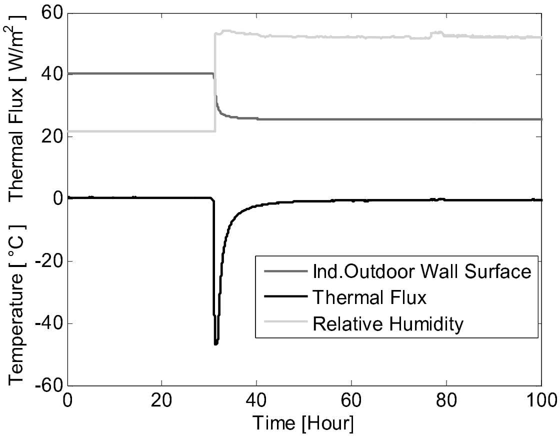

Figure 6 Surface wall temperature in the indoor and outdoor chamber (red line), Thermal Flux (black line) and Relative Humidity (green line).

5 CONCLUSIONS

The tests carried out assessed the thermo-physical values of a light construction technique highlighting both its static and dynamic characteristics. The calculated value of thermal conductance conforms with the performance standards of natural insulating materials present on the currently market. In steady state conditions the tests on the thermal transmittance value of the opaque wall give a good efficiency result, close to the standards for low energy dwellings. The tests on the dynamic parameters allow us to confirm a high specific heat value, which nonetheless, even in the absence of a high volume mass, guarantees sufficient value of thermal lag. The Italian guidelines for energy certification of buildings define the optimal qualitative evaluation for an opaque envelope as being longer than 12h, with an decrement factor below 0,15. The building solution analysed can be classified between the average and sufficient class (II<class<III).

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