Brescia, 14 March 2024

M1: Report assessing the thermal and acoustic properties of the refurbished wall

WP2 - Disadvantaged contexts analysis *(5 months. Responsible UniBS). This work package concerns the identification and characterization of disadvantaged contexts where the panels made of EoLHM can be installed. The aim of this activity is to identify the typical building technology, dwelling dimensions, wall thermal resistance, wall periodic thermal resistance, and the outdoor climatic condition (indoor and outdoor temperature, humidity and solar radiation) necessary to the definition of numerical models in WP3. Data is collected from the literature, abacus and standards (such as the UNI/TR 11552:2014). The contexts will be characterized also from an acoustics point of view through noise maps (if available from the municipalities), or by making sound pressure level measurements inside and outside the dwellings. On the basis of the information gathered, it will be possible to define classes of buildings and identify how they can be refurbished to meet the thermal and acoustic performance required by national and local regulations. Moreover, it will be identified a test case where the panels can be installed. Also, a real test case is identified in the Brescia province where the in-situ tests described in WP6 will be performed.*

THERMAL ASPECTS.

The context - UNI/TR 11552:2014 - Abacus of structures constituting the opaque building envelope. Thermophysical parameters.

The technical report UNI/TR 11552:2014 provides reference information for assessing the thermal performance of opaque components of the envelope of existing buildings, which can be used in the lack of more detailed information. In the case of existing buildings, it is indeed very often not possible to obtain certain information on the stratigraphies of the envelope components and the properties of the used materials. The technical report contains the main thermophysical parameters (thermal transmittance U, areic thermal capacity κ_i and periodic thermal transmittance Y_{ie}) of the opaque envelope components most commonly used in existing buildings in Italy. The main typologies for external walls, floors and roofs are considered. The types concerning the external walls are listed below.

1. Solid brick walls
    a. Solid brick masonry (MLP01)
    b. Solid brick masonry – exposed bricks (MLP02)
    c. Semi-solid brick masonry (MLP03)
2. Stone walls
    a. Stone masonry listed with brick (MPI01)
    b. Stone wall (MPI02)

DIPARTIMENTO DI INGEGNERIA MECCANICA E INDUSTRIALE
Via Branze 38
25123 Brescia BS
Italy
Partita IVA: 01773710171
Cod. Fiscale: 98007650173
dimi@cert.unibs.it

   c. Tuff squared block masonry (MPI03)
   d. Stone cavity masonry (MPI04)
   e. Stone cavity masonry (MPI05)
3. Composite walls
   a. Brick and stone masonry (MCO01)
   b. Masonry with weakly tied filling (MCO02)
   c. Hollow concrete block masonry (MCO03)
   d. Cavity masonry with concrete blocks (MCO04)
   e. Cellular concrete solid block masonry (MCO05)
4. Cavity walls
   a. Hollow brick cavity masonry, example 1 (MCV01)
   b. Hollow brick cavity masonry, example 2 (MCV02)
   c. Solid brick masonry with cavity or light insulation, example 1 (MCV03)
   d. Solid brick masonry with cavity or light insulation, example 2 (MCV04)
   e. Hollow brick cavity masonry and exposed hollow bricks (MCV05)
   f. Hollow brick cavity masonry and exposed solid bricks (MCV06)
5. Prefabricated walls
   a. Concrete wall (MPF01)
   b. Brick wall + prefabricated panel (MPF02)
   c. Precast insulated concrete wall, example 1 (MPF03)
   d. Precast insulated concrete wall, example 2 (MPF04)

The main characteristics and the variability range of the thermophysical properties of the structures are collected in Table 1. In most cases, the change in total element thickness d is due to the change in thickness of a single material, so an increase in thickness corresponds to a decrease in transmittance U and periodic thermal transmittance Y_{ie}. Variation in air cavity thickness, when present, has no influence on these properties. The unique exception is the MPF02 element, for which there is a variation in the thickness of both the semi-solid brick load-bearing layer and the fiberglass insulation layer: in this case, in fact, it is the variation in the thickness of the insulation that has the greatest influence on transmittance and periodic thermal transmittance. The areic heat capacity κ_i, on the other hand, depends on several factors, and the trend is not observed to have a clear thickness dependence.

The report also gives broad indications of the geographical diffusion of the analyzed structures in eight Italian regions: Abruzzo, Campania, Liguria, Lombardia, Piemonte, Emilia Romagna, Toscana and Veneto. In general, cavity walls have appeared since 1950 (only in Piemonte since 1930) while previously only solid brick walls, stone walls and composite walls without cavity and without insulation were used. Prefabricated walls have been used only in Piemonte, the types with insulation since 1975.

Table 1. Main characteristics and range of thermal transmittance, areic thermal capacity and periodic thermal transmittance of the structures: ↑ means that the values of the property increase when the thickness *d* increases , ↓ means that the values of the property decrease when the thickness *d* increases, * means that the values of the property have neither an increasing nor a decreasing trend with thickness *d*, and it is possible that the maximum and/or minimum value is not obtained at the extreme values of the thickness.

Structure	*d* [cm]	*U* [W/(m²K)]	κ_i [kJ/(m²K)]	Y_{ie} [W/(m²K)]
MLP01	16 – 68↑	0.90 – 2.58↓	61.8 – 68.6*	0.011 – 1.639↓
MLP02	13.5 – 65.5↑	0.93 – 2.79↓	62.2 – 70.0*	0.014 – 2.000↓
MLP03	29 – 34↑	0.90 – 1.18↓	53.7 – 58.5↓	0.197 – 0.423↓
MPI01	16 – 68↑	1.07 – 2.82↓	64.3 – 71.8*	0.016 – 1.757↓
MPI02	44 – 104↑	1.57 – 2.58↓	72.3 – 77.9*	0.010 – 0.385↓
MPI03	34 – 74↑	0.67 – 1.30↓	58.7 – 61.9*	0.004 – 0.229↓
MPI04	42.5 – 90↑	1.67 – 1.94↓	82.8 – 87.9↓	0.065 – 0.229↓
MPI05	44 – 64↑	1.28 – 1.43↓	82.8 – 87.2↓	0.038 – 0.134↓
MCO01	44 – 104↑	0.75 – 1.50↓	62.1 – 65.2*	0.002 – 0.227↓
MCO02	42 – 57↑	0.95 – 1.19↓	48.9 – 50.2↓	0.039 – 0.144↓
MCO03	24 – 34↑	1.22 – 1.61↓	60.2 – 65.1↓	0.239 – 0.656↓
MCO04	17.5 – 60↑	1.02 – 1.47↓	53.3 – 57.6*	0.258 – 1.099↓
MCO05	27 – 43↑	0.35 – 0.55↓	33.3 – 36.7↓	0.039 – 0.229↓
MCV01	26.5 – 71↑	0.62 – 1.10↓	52.4 – 57.9↓	0.089 – 0.594↓
MCV02	39 – 49↑	0.27 – 0.67↓	52.7 – 55.8↑	0.029 – 0.109↓
MCV03	26.5 – 80↑	0.87 – 1.30↓	48.9 – 56.4↓	0.044 – 0.541↓
MCV04	28 – 54↑	0.54 – 0.68↓	53.0 – 56.4↓	0.018 – 0.228↓
MCV05	28.5 – 56↑	1.00	56.7	0.379
MCV06	28.5 – 56↑	1.17	57.0	0.45
MPF01	11 – 31↑	1.43 – 2.80↓	48.7 – 65.4*	0.374 – 2.383↓
MPF02	30 – 37↑	0.46 – 0.71*	12.5 – 18.8*	0.034 – 0.104*
MPF03	12 – 37↑	0.67 – 0.94↓	28.6 – 33.1*	0.082 – 0.818↓
MPF04	15 – 35↑	0.82 – 1.14↓	24.4 – 27.7*	0.113 – 0.766↓

The constrains - Transmittance limits for walls undergoing energy retrofitting according to DM 162/2015

The legislative basis for energy requirements for buildings in the European Union is the Directive 2010/31/EU on the energy performance of buildings. At Article 4, "Setting of minimum energy performance requirements", it establishes guidelines for actions to be taken by Member States. Specifically:

- "Member States shall take the necessary measures to ensure that minimum energy performance requirements for buildings or building units are set with a view to achieving cost-optimal levels."
- "Member States shall take the necessary measures to ensure that minimum energy performance requirements are set for building elements that form part of the building envelope and that have a significant impact on the energy performance of the building envelope when they are replaced or retrofitted, with a view to achieving cost-optimal levels."
- "When setting requirements, Member States may differentiate between new and existing buildings and between different categories of buildings."
- "These requirements shall take account of general indoor climate conditions, in order to avoid possible negative effects such as inadequate ventilation, as well as local conditions and the designated function and the age of the building."
- "A Member State shall not be required to set minimum energy performance requirements which are not cost-effective over the estimated economic lifecycle."

Article 7, "Existing buildings", in particular concerns existing buildings:

- "Member States shall take the necessary measures to ensure that when buildings undergo major renovation, the energy performance of the building or the renovated part thereof is upgraded in order to meet minimum energy performance requirements set in accordance with Article 4 in so far as this is technically, functionally and economically feasible."
- "Those requirements shall be applied to the renovated building or building unit as a whole. Additionally or alternatively, requirements may be applied to the renovated building elements."
- "Member States shall in addition take the necessary measures to ensure that when a building element that forms part of the building envelope and has a significant impact on the energy performance of the building envelope, is retrofitted or replaced, the energy performance of the building element meets minimum energy performance requirements in so far as this is technically, functionally and economically feasible."
- "Member States shall determine these minimum energy performance requirements in accordance with Article 4."

The DM 162/2015, "Applicazione delle metodologie di calcolo delle prestazioni energetiche e definizione delle prescrizioni e dei requisiti minimi degli edifici" is the transposition in Italy of Directive 2010/31/UE. At Paragraph 1.4 it defines major renovations and retrofitting. Specifically:

- A “major renovation” is defined as an intervention affecting the integrated elements and components constituting the building envelope that enclose a temperature-controlled volume from the external environment and from non-air-conditioned rooms, with an incidence of more than 25% of the total gross dispersion area of the building. "Major renovation" interventions are divided into:
  - (a) first-level major renovations: the intervention, in addition to affecting the building envelope with an incidence of more than 50% of the total gross dispersion area of the building, also includes the renovation of the thermal system for winter and/or summer air conditioning service of the entire building. In such cases, the energy performance requirements apply to the whole building and refer to its energy performance related to the service or services concerned;
  - (b) second-level major renovations: the intervention affects the building envelope with an incidence of more than 25 percent of the total gross dispersion area of the building and may affect the thermal system for winter and/or summer air conditioning service. In such cases, the energy performance requirements to be verified concern the thermophysical characteristics of the only elements of the building envelope affected by the energy retrofitting and the overall coefficient of heat transfer by transmission (H'_T) determined for the entire wall, including all the components on which work has been performed.
- An "energy retrofitting of a building" is defined as all other interventions that have, however, an impact on the energy performance of the building. Such interventions thus involve an area of less than or equal to 25% of the overall gross dispersion area of the building and/or consist of the new installation, renovation of a thermal system serving the building or other partial interventions, including the replacement of the generator. In such cases, the required energy performance requirements apply only to the building components and systems being renovated, and refer to their relative thermophysical or efficiency characteristics.
- In the case of energy retrofitting of the opaque envelope that involves thermal insulation from the inside or thermal insulation in the cavity, regardless of the size of the area involved, The transmittance limits to be met by the elements subject to the intervention are increased by 30% compared to the case where the insulation is applied outside.

Table 2 summarizes the U_{lim} transmittance limit values that a vertical wall undergoing energy retrofitting or second-level major renovation must meet, provided by Appendix B of DM 162/2015. It also shows the values increased by 30 percent that must be met if the insulation is applied from the inside, which is the case covered in this STAR project, or in the cavity. It should be noted that in the case of first-level or second-level major renovations, additional verifications will also have to be done, such as on the overall exchange coefficient H'_T. In addition, if it is desired to access potential fiscal incentives, it will be necessary to check the requirements set each time.

Table 2. Transmittance limits for vertical walls undergoing energy retrofitting: U_{lim} is the the limit to be met if the insulation is applied outside since 2021 (from Table 1 of DM 162/2015 – Appendix B); U_{lim} + 30% is the limit to be met if the insulation is applied inside or in the cavity.

Climatic Zone	**U_{lim} [W/m^{2}K] (2015)**	**U_{lim} [W/m^{2}K] (2021)**	**U_{lim}+30% [W/m^{2}K]**
A e B	0.45	0.40	0.52
C	0.40	0.36	0.47
D	0.36	0.32	0.42
E	0.30	0.28	0.36
F	0.28	0.26	0.34

Thermal resistance of the panel to be installed from inside

Tables 3 and 4 summarize the minimum thermal resistance values that insulation panels to be installed from the inside must have to meet the minimum requirements given in Table 2 for climate zones A, B and C (Table 3) and climate zones D, E and F (Table 4), respectively. They were calculated from the equation:

$$R_{\text{panel}} = (U_{\text{lim}}{+}30\%)^{-1} - (U)^{-1}$$

Table 3. Thermal resistance values that insulation panels to be installed from the inside must have to meet the minimum requirements of DM 162/2015: climatic zones A, B and C. --- means that the structure already meets the requirements.

Structure			Panel to be installed inside or in the cavity					
			Zone A		Zone B		Zone C	
UNI/TR 11552:2014	Umax [W/(m2K)]	Umin [W/(m2K)]	Rmax [(m2K)/W]	Rmin [(m2K)/W]	Rmax [(m2K)/W]	Rmin [(m2K)/W]	Rmax [(m2K)/W]	Rmin [(m2K)/W]
MLP01	2.58	0.90	1.54	0.81	1.54	0.81	1.75	1.03
MLP02	2.79	0.93	1.56	0.85	1.56	0.85	1.78	1.06
MLP03	1.18	0.90	1.08	0.81	1.08	0.81	1.29	1.03
MPI01	2.82	1.07	1.57	0.99	1.57	0.99	1.78	1.20
MPI02	2.58	1.57	1.54	1.29	1.54	1.29	1.75	1.50
MPI03	1.30	0.67	1.15	0.43	1.15	0.43	1.37	0.64
MPI04	1.94	1.67	1.41	1.32	1.41	1.32	1.62	1.54
MPI05	1.43	1.28	1.22	1.14	1.22	1.14	1.44	1.36
MCO01	1.50	0.75	1.26	0.59	1.26	0.59	1.47	0.80
MCO02	1.19	0.95	1.08	0.87	1.08	0.87	1.30	1.08
MCO03	1.61	1.22	1.30	1.10	1.30	1.10	1.52	1.32
MCO04	1.47	1.02	1.24	0.94	1.24	0.94	1.46	1.16
MCO05	0.55	0.35	0.10	---	0.10	---	0.32	---
MCV01	1.10	0.62	1.01	0.31	1.01	0.31	1.23	0.52
MCV02	0.67	0.27	0.43	---	0.43	---	0.64	---
MCV03	1.30	0.87	1.15	0.77	1.15	0.77	1.37	0.99
MCV04	0.68	0.54	0.45	---	0.45	0.07	0.67	0.28
MCV05	1.00	1.00	0.92	0.92	0.92	0.92	1.14	1.14
MCV06	1.17	1.17	1.07	1.07	1.07	1.07	1.28	1.28
MPF01	2.80	1.43	1.57	1.22	1.57	1.22	1.78	1.44
MPF02	0.71	0.46	0.51	---	0.51	---	0.73	---
MPF03	0.94	0.67	0.86	0.43	0.86	0.43	1.07	0.64
MPF04	1.14	0.82	1.05	0.70	1.05	0.70	1.26	0.92

Table 4. Thermal resistance values that insulation panels to be installed from the inside must have to meet the minimum requirements of DM 162/2015: climatic zones D, E and F. --- means that the structure already meets the requirements.

Structure			Panel to be installed inside or in the cavity					
			Zone D		Zone E		Zone F	
UNI/TR 11552:2014	Umax [W/(m2K)]	Umin [W/(m2K)]	Rmax [(m2K)/W]	Rmin [(m2K)/W]	Rmax [(m2K)/W]	Rmin [(m2K)/W]	Rmax [(m2K)/W]	Rmin [(m2K)/W]
MLP01	2.58	0.9	2.02	1.29	2.36	1.64	2.57	1.85
MLP02	2.79	0.93	2.05	1.33	2.39	1.67	2.60	1.88
MLP03	1.18	0.9	1.56	1.29	1.90	1.64	2.11	1.85
MPI01	2.82	1.07	2.05	1.47	2.39	1.81	2.60	2.02
MPI02	2.58	1.57	2.02	1.77	2.36	2.11	2.57	2.32
MPI03	1.3	0.67	1.63	0.91	1.98	1.25	2.19	1.47
MPI04	1.94	1.67	1.89	1.81	2.23	2.15	2.44	2.36
MPI05	1.43	1.28	1.70	1.62	2.05	1.97	2.26	2.18
MCO01	1.5	0.75	1.74	1.07	2.08	1.41	2.29	1.63
MCO02	1.19	0.95	1.56	1.35	1.91	1.69	2.12	1.91
MCO03	1.61	1.22	1.78	1.58	2.13	1.93	2.34	2.14
MCO04	1.47	1.02	1.72	1.42	2.07	1.77	2.28	1.98
MCO05	0.55	0.35	0.59	---	0.93	---	1.14	0.10
MCV01	1.1	0.62	1.49	0.79	1.84	1.13	2.05	1.35
MCV02	0.67	0.27	0.91	---	1.25	---	1.47	---
MCV03	1.3	0.87	1.63	1.25	1.98	1.60	2.19	1.81
MCV04	0.68	0.54	0.93	0.55	1.28	0.90	1.49	1.11
MCV05	1	1	1.40	1.40	1.75	1.75	1.96	1.96
MCV06	1.17	1.17	1.55	1.55	1.89	1.89	2.10	2.10
MPF01	2.80	1.43	2.05	1.70	2.39	2.05	2.60	2.26
MPF02	0.71	0.46	1.00	0.23	1.34	0.57	1.55	0.78
MPF03	0.94	0.67	1.34	0.91	1.68	1.25	1.89	1.47
MPF04	1.14	0.82	1.53	1.18	1.87	1.53	2.08	1.74

Outdoor Thermal data

The standards for climatic data concerning outdoor conditions on Italian territory are the following:

- **UNI 10349-1:2016 + EC 1-2017 UNI 10349-1:2016** Heating and cooling of buildings - Climatic data - Part 1: Monthly means for evaluation of energy need for space heating and cooling and methods for splitting global solar irradiance into the direct and diffuse parts and for calculate the solar irradiance on tilted planes
- **UNI/TR 10349-2:2016** Heating and cooling of buildings - Climatic data - Part 2: Data for design load
- **UNI 10349-3:2016** Heating and cooling of buildings - Climatic data - Part 3: Accumulated temperature differences (degree-days) and other indices

For the dynamic simulations to be carried out in WP4, it will be used the climate data taken from these standards or alternatively available online at official sites such as ENEA.
Instead, the transmittance limits are defined according to the climate zones into which Italy has been conventionally subdivided on the basis of degree-days determined according to standard UNI 10349-3:2016, which are

- Zone A: 0 – 600 degree-days;
- Zone B: 601 – 900 degree-days;
- Zone C: 901 – 1400 degree-days;
- Zone D: 1401 – 2100 degree-days;
- Zone E: 2101 – 3000 degree-days;
- Zone F: > 3000 degree-days.

For this reason, the minimum thermal resistance that the insulation panels must have has been calculated for the different climate zones (see Tables 3 and 4).

ACOUSTICS ASPECTS

Actual characteristics

The noise insulation of a panel mainly depends on the structure of the specimen and on its mass per unit area.

In case of homogeneous panels, neglecting the effects of the resonances and of the coincidence effect, the mass law can be applied to determine the sound reduction index R under diffuse incidence of the sound waves:

$$R(f) = 20\log(m''f) - 45$$

Where m'' is the mass per unit area of the panel and f is the frequency.

For more complex structures, such as double walls, the sound reduction index is a more complicated function and depends on the so-called pumping frequency. Below this frequency the wall behaves like a single wall, so the mass law can be applied. The mass m'' is equal to the sum of the single walls masses of the leaves composing the overall structure. Above this frequency, the two walls behave independently, so that the slope of the sound reduction index curve becomes 12 dB/oct.

An important aspect is that for walls embedding doors, windows or in general different elements than the opaque structure, the overall sound reduction index is an average of the SRI of the different elements, weighted for their area:

$$R_{tot} = -10\log\left(\frac{1}{S_{tot}}\sum_{i=1}^{N} 10^{\frac{-R_i}{10}}\right)$$

As concerns the absorption, several techniques can be exploited depending on the nature of the surface of the wall facing the sound source.

If the material is porous, then it can be characterised through measurements in reverberation room (diffuse field) or in impedance tube (normal incidence). If the material does not present any porosity, it can be used as a vibrating panel (low frequency sound absorption) or it can be perforated to feature a set of Helmholtz resonators (must be tuned).

Law Requirements

The DPCM 05/12/97 is the only law requiring some acoustic insulation parameter to be respected. In particular:

$D_{2m,n,T}$ = single valued façade sound insulation normalised over the reverberation time ≥ 40 dB

R_w = single valued sound reduction index for airborne sound (to be applied between dwellings) ≥ 50 dB

There are no requirements concerning the absorption area in a room. Still, being the sound pressure level due to a source inversely related to the amount of absorption installed in the volume, it is plain that the higher is the absorption area, the better.

What the panel have to do

Since the sound reduction index of a façade is dominated by the weakest elements, it can be of interest to design doors and windows panels able to increase the sound insulation. In case the panels are intended only as sound absorbing materials, then it is important that they possess a sound absorption coefficient that is already good enough in the low frequency range and a value of the surface exposed to sound that is as large as possible.

Outdoor Acoustics data

The WHO consider a sound pressure level of 55 dB(A) as a limit for the noise exposure during the night time inside dwellings. For this reason, it could be of interest to select a dwelling on which perform an acoustic retrofitting that is close to a road or railroad where the equivalent sound pressure level exceeds 55 dB(A). The outdoor acoustic data can be retrieved through sound pressure level measurements or a model once the location of the dwelling and the traffic data are known.

SOME CHARACTERISTICS OF THE DISADVANTAGED CONTEXTS FROM THE LITERATURE

Few studies have also addressed the characteristics of settlements and outdoor climate conditions in less privileged neighborhoods. Chundeli and Berger [1] undertook a case study on low-income housing units in Vijayawada, Andhra Pradesh, India. Based on the 2011 census data, Vijayawada boasts a population of 1,048,000 residents. Records from the India Meteorological Department (IMD) indicate that the peak temperature in Vijayawada reached 44 degrees Celsius in May 2019 and escalated to 46 degrees Celsius in May 2020. Climatological data reveals an annual average ambient temperature of 27.92 degrees Celsius. Notably, throughout the summer of 2019 (March to July), the average ambient temperature consistently surpassed 31 degrees Celsius. During the May 2019 heatwave, the maximum ambient temperature reached values close to 46 ◦C for four consecutive days. A typical settlement unit dimensions are presented in Table 5.

Table 5. Representative dwelling unit dimensions and characteristics in a less privileged area of India [1]

Building dimension (ft)	**Building area (ft^2)**	**Number of floor**	**Number of occupants**	**% of the window opening**	**Building orientation**	**Annual energy consumption (kWh/m^2)**
12×28	672	2	4	3.3	west	24

In another study by MacTAvish et al. [2] an investigation was conducted on deprived areas in Greater Accra Metropolitan Area of Ghana identified with the help of united nations mapping information in Acra urban core. Out of the 4,615 urban enumeration areas in the GAMA, 899 (19%) were identified as having a high likelihood (>80%) of being deprived areas. These areas were estimated to accommodate approximately 745,714 residents, constituting 22% of the urban population in GAMA. Table 6 has the details of dwelling characteristics.

Table 6. Variables drawn out of categorical census in urban GAMA in Ghana [2]

<table>
<tr><td rowspan="3">Dwelling type</td><td>Rooms in a compound house</td><td>Rooms in Compound House: 58.7%</td></tr>
<tr><td>Separate house, semi-detached, or flat/apartment</td><td>Separate House: 15.4%
Semi-detached House: 8.4%
Flat/Appartement: 6.7%</td></tr>
<tr><td>“Other” dwelling type</td><td>Hut/Building: 0.9%
Tent: 0.2%
Improvised Home: 6.1%
Living Quarters Attached to Shop: 0.8%
Uncompleted Building: 2.6%
Other: 0.3%</td></tr>
<tr><td>Wall Materials</td><td>Cement/Concrete walls</td><td>Cement/Concrete: 83.6%</td></tr>
</table>

	"Other" walls	Mud Brick/Earth: 1.8% Wood: 10.7% Metal Sheet: 1.2% Stone: 0.3% Burnt Bricks: 0.4% Landcrete: 0.3% Bamboo: 0.1% Palm Leaves/Raffia: 0.1% Other: 1.6%
Roof Materials	**"Other" roof type**	Mud/earth: 0.3% Wood: 0.9% Slate/asbestos: 43.1% Cement or concrete: 3.9% Roofing tiles: 1.5% Bamboo: 0.2% Thatch/raffia: 0.4% Other: 0.7%
	Metal sheet roof	Metal Sheet: 49.1%
Floor Materials	**Cement/Concrete floor materials**	Cement/Concrete: 80.0%
	"Other" floor materials	Mud/Earth: 4.8% Stone: 0.5% Burnt Bricks: 0.2% Wood: 3.9% Vinyl Tiles: 2.7% Ceramic/Marble/Granite: 4.0% Terrazzo Flooring: 3.5% Other: 0.4%

In their research, Haddad et al.[3] explored the connections among urban microclimate, indoor air temperature, housing attributes, and residents' quality of life. This investigation involves both subjective and objective evaluations of indoor environmental quality in 106 low-income residences throughout the winter and summer of 2018–2019 in New South Wales, Australia. Thermal performance and indoor environmental quality of dwellings in social housing in Australia are frequently disregarded when compared to the broader building inventory. In the 2018/19 period, social housing constituted a minor fraction (<5%) of Australia's overall housing inventory. A significant portion of social housing residents, accounting for 54%, live alone, while 32% reside in two-person households, and 14% live in households with three or more individuals. All residences surveyed were rental properties, primarily constructed between 1975 and 2000, with only a quarter built after 2000. The floor area of these dwellings ranged from 24 m^2 to 135 m^2, averaging around 70 m^2. Approximately 63% of respondents resided in apartment units, while 37% lived in detached or semi-detached houses. All dwellings featured single-glazed windows and were reported to have inadequate insulation. Figure 1 details the characteristics of housings along with their noise issues.

	Sydney urban (n = 101)	Western Sydney (n = 80)	Western region (n = 19)
Type of residence			
Apartment	40 (85.1 %)	29 (50.9 %)	0 (0 %)
House	7 (14.9 %)	28 (49.1 %)	5 (100 %)
Year built			
Before 1950	1 (2.1 %)	4 (7.0 %)	0 (0 %)
1950–1975	17 (36.2 %)	15 (26.3 %)	4 (80 %)
1975–2000	16 (34.0 %)	24 (42.1 %)	1 (20 %)
2000–2010	3 (6.4 %)	4 (7.0 %)	0 (0 %)
After 2010	10 (21.3 %)	10 (17.5 %)	0 (0 %)
Year of tenancy			
<10	37 (78.7 %)	36 (63.2 %)	1 (20.0 %)
10–20	7 (14.9 %)	15 (26.3 %)	2 (40.0 %)
20–30	2 (4.3 %)	3 (5.3 %)	2 (40.0 %)
>30	1 (2.1 %)	3 (5.3 %)	0 (0 %)
Floor area (m^2)			
<60	19 (40.4 %)	19 (33.3 %)	2 (40.0 %)
60–90	23 (48.9 %)	27 (47.4 %)	1 (20.0 %)
>90	5 (10.6 %)	11 (19.3 %)	2 (40.0 %)
Neighbourhood safety*			
Yes	41 (87.2 %)	37 (64.9 %)	2 (40 %)
No	6 (12.8 %)	20 (35.1 %)	3 (60 %)
Noise problems			
Yes	17 (36.2 %)	23 (41.1 %)	2 (40 %)
No	30 (63.8 %)	33 (58.9 %)	3 (60 %)

Figure 1. Characteristics of dwellings and occupants' perception in three residential regions

Approximately 39 % of all households were experiencing excessive noise in their homes or neighborhoods. The indoor environmental variables during the entire monitoring period are presented in Figure 2.

		Entire monitoring period
T_a (°C)	Mean	22.8
	Minimum	4.9
	Mean minimum	13.6
	25th percentile $T_{a,\ \mathrm{min}}$	11.5
	50th percentile $T_{a,\ \mathrm{min}}$	13.2
	Maximum	39.8
	Mean maximum	32.6
	75th percentile $T_{a,\ \mathrm{max}}$	34.7
	95th percentile $T_{a,\ \mathrm{max}}$	37.7
RH (%)	Mean	54.0
	Minimum	12.0
	Maximum	86.0

Figure 2. Statistical analysis of indoor environmental factors observed over the monitoring period.

Its noteworthy to add that the lowest indoor air temperature (Ta, min) recorded across all residences ranged from 4.9°C to 19.3°C, whereas the highest indoor air temperature (Ta, max) surpassed 39.0°C.

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[2] Robert MacTavish, Honor Bixby, Alicia Cavanaugh, Samuel Agyei-Mensah, Ayaga Bawah, George Owusu, Majid Ezzati, Raphael Arku, Brian Robinson, Alexandra M. Schmidt, Jill Baumgartner, Identifying deprived "slum" neighborhoods in the Greater Accra Metropolitan Area of Ghana using census and remote sensing data, *World Development*, Volume 167,2023, 106253,

[3] Shamila Haddad, Riccardo Paolini, Afroditi Synnefa, Lilian De Torres, Deo Prasad, Mattheos Santamouris, Integrated assessment of the extreme climatic conditions, thermal performance, vulnerability, and well-being in low-income housing in the subtropical climate of Australia, *Energy and Buildings*, Volume 272, 2022, 112349

IDENTIFICATION OF DISADVANTAGED CONTEXTS AND PRELIMINARY ASSESSMENT OF BUILDING SIZES – DATA FROM ALER BRESCIA

The Azienda per l'Edilizia Residenziale (A.L.E.R.) of Brescia-Cremona-Mantova, (in the following ALER Brescia) is a public company, which builds and manages housing for the most disadvantaged social categories, while respecting the company's economic balance.

The UniBS research unit contacted ALER Brescia to collect information on the characteristics of the residential buildings for the disadvantaged population and to identify a building in which the panels could be installed for the in situ testing. ALER Brescia gave its availability for both aspects.

Dwellings characteristics. Below is listed some information about the building stock of ALER Brescia.

- Average dwelling size and average cadastral consistency:
  - For the 7074 dwellings in the Brescia (BS) province, the average dwelling size is 68.26 m^2 and the average cadastral consistency is 5.02;
  - For the 3985 dwellings in the Cremona (CR) province, the average dwelling size is 67.03 m^2 and the average cadastral consistency is 5.30;
  - For the 3495 dwellings in the Mantova (MN) province, the average dwelling size is 68.48 m^2 and the average cadastral consistency is 5.21.

  The cadastral consistency of a dwelling is calculated starting from the number of usable rooms. In particular the main rooms are added together by their actual numbers, the accessory rooms directly serving the main rooms (e.g. bathrooms, corridors, entrances or hallways, storerooms) are counted as 1/3 of a room, and the indirect (or complementary) accessory rooms, accessed from outside the main rooms, are counted as 1/4 of a room. To the sum of the rooms thus calculated, a maximum addition (or deduction) of 10% may be made, to take account of dependencies and elements that may bring advantages (or disadvantages) to the dwelling.
  It can be observed that both the average dwelling size and the average cadastral consistency are rather uniform in the three provinces.
- Average number of occupants per dwelling (for the stock for which household data is available):
  - For the 6260 dwellings in the Brescia (BS) province, the average number of occupants per dwelling is 2.50;
  - For the 2975 dwellings in the Cremona (CR) province, the average number of occupants per dwelling is 2.50;
  - For the 2592 dwellings in the Mantova (MN) province, the average number of occupants per dwelling is 2.36.

  If calculated on the 11827 total dwellings, the average number of occupants per dwelling is 2.47 and it is rather uniform in the three provinces.

- Age of the building stock (in Table 7).

Table 7. Age of the ALER building stock in the provinces of Brescia, Cremona and Mantova.

Construction period	Brescia	Cremona	Mantova	Total	%
1900-1945*	471	117	16	604	4%
1946-1960	942	591	258	1791	12%
1961-1975	960	1048	871	2879	20%
1976-1990	3125	1861	1586	6572	45%
1991-2005	816	285	294	1395	10%
2006-2023	760	83	470	1313	9%
TOTALE	7074	3985	3495	14554	100%

Since the test dwelling will certainly be located in the province of Brescia (most likely in the city), Figure 3 shows the distribution of dwellings over time for the sole province of Brescia (7074 dwellings).

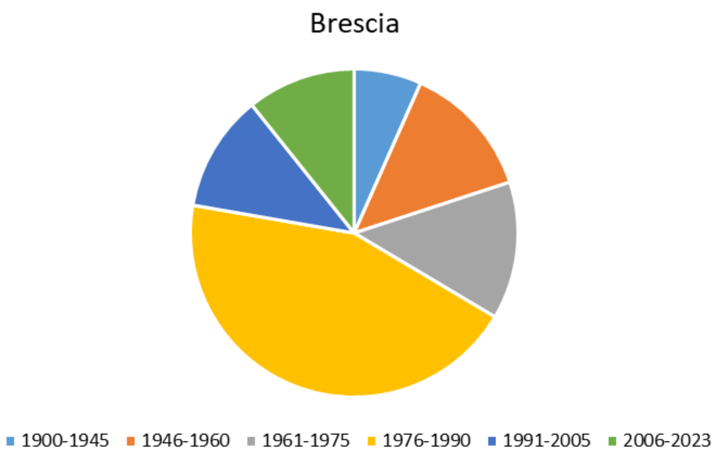


Figure 3. Distribution of dwelling units construction time in Brescia out of 7074 units registered in the region

Test in-situ. With regard to the in situ tests, ALER has given its availability to allow the use of an empty dwelling during the 2024-2025 winter season to test the thermal and acoustic performance before and after the installation of panels on one or more walls. The panels will be removed at the end of the tests. To facilitate acoustic testing, the dwelling should be on the ground floor, not inhabited, located near a noisy street, with the façade facing the source with a few windows, possibly small.

At the time of writing this report ALER has not yet communicated the exact location of the dwelling to be used for testing.

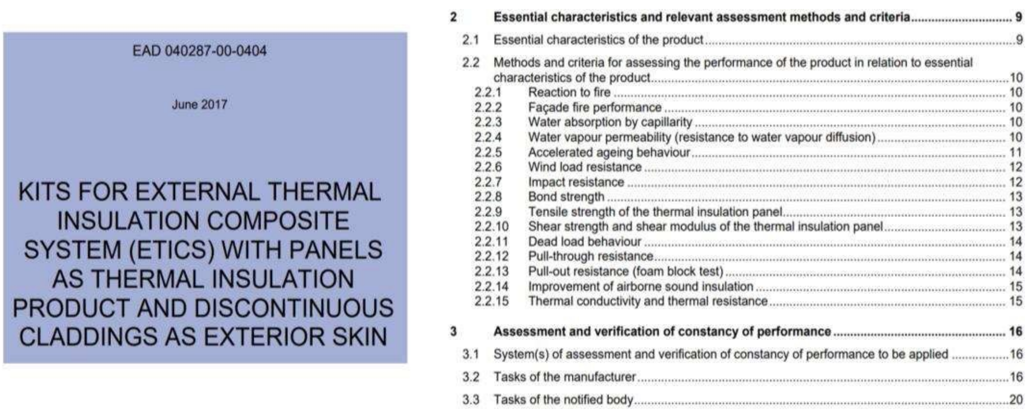
AN OUTLOOK BEYOND --- ANALYSIS OF REGULATIONS FOR PANEL MARKETING

Part of the activities involved the analysis of regulations reporting the tests to which insulation panels must undergo in order to be marketed. In order to obtain CE certification, which allows the free movement of products in the European community, a product must be tested in accordance with the harmonized standard. Manufacturers of insulation materials must identify the standards that could be applied to their product, check whether a compliance test performed by an independent institute is necessary, test the product and verify its compliance, draw up the necessary documents for obtaining the mark, and finally affix the mark to the product (or packaging).

To facilitate the marketing in European markets of non-standardized products, if a product is not covered by a harmonized European technical standard, it is necessary to introduce a European Technical Assessment ETA issued by TABs (Technical Assessment Bodies). The ETA provides information on the performance assessment of the essential characteristics of a product concerning its intended use.

The basis for ETAs are European Assessment Documents (EADs), which are harmonized technical specifications developed by the ETA. EADs provide a way for manufacturers to obtain CE marking for construction products that are not or not fully covered by a harmonized European standard (hEN) under the Construction Products Regulation (EU) 305/2011. EADs are documents containing the general description of the construction product, the list of essential characteristics agreed between the manufacturer and EOTA, the methods and criteria for assessing product performance in relation to those essential characteristics, and the principles for factory production control to be applied.

The list of EADs are available at the following link and an example is shown in Figure 4.



EAD 040287-00-0404

June 2017

KITS FOR EXTERNAL THERMAL INSULATION COMPOSITE SYSTEM (ETICS) WITH PANELS AS THERMAL INSULATION PRODUCT AND DISCONTINUOUS CLADDINGS AS EXTERIOR SKIN

Figure 4. Example of EAD for kits intended for outdoor installations.

Products to be marketed must ensure (1) mechanical strength and stability, (2) fire safety, (3) hygiene, health and environment, (4) safety and accessibility in use, (5) protection against noise, (6) energy conservation and heat retention, and (7) sustainable use of natural resources.

- Hygiene, health and environment

Regarding item 3 'hygiene, health and environment; it is *specified that 'Construction works* must *be designed and built in such a way that they do not, throughout their life cycle, pose a threat to the hygiene or health and* safety *of workers, occupants or neighbors and that they do not exert an undue impact, throughout their life cycle, on the quality of the environment or climate, during their construction,* use *and demolition, ... due to any of the following: 1. (b)* emissions *of hazardous* substances, *volatile organic compounds **(VOCs),** greenhouse gases or hazardous particulate matter to indoor or outdoor air." The reference standard is **EN 16516:2017+A1:2020** Construction products: Assessment of release of dangerous* substances - *Determination of* emissions *into indoor air.*

Regarding item 7 'sustainable use of natural resources', reference is made to the standard ***EN 16783:2017 Thermal insulation products* - *Product*** **category** ***rules (PCR) for*** **factory** ***made and in- situ farmed products far preparing environmental product declarations.***

-Fire reaction

In Annex I of CPR (Construction Product Regulation), with reference to "safety in case of fire," it is stated that: "construction works shall be designed and built in such a way that, in the event of fire: a) the load- bearing capacity of the building can be ensured for a specified period of time; b) the generation and spread of fire and smoke within them shall be limited; c) the spread of fire to neighboring construction works shall be limited; d) the occupants can leave the construction works or be otherwise rescued; and

e) the safety of rescue teams shall be taken into account."

A critical aspect for building materials-any product manufactured for the purpose of being permanently incorporated into construction works-is reaction to fire. The classes are from highest-performing to lowest-performing: A1, A2, B, C, D, E and F (see Figure 6). If an untested product is not in class E, it is classified in class F. Some materials are classified A1 and A1FL without being tested, including expanded clay, expanded perlite, rock wool, concrete, fiber cement, iron, gypsum, ceramic, lime, and glass.

Definizione	Classificazione secondo la norma UNI EN 13501-1				
	Materiali da costruzione			Materiali per pavimenti	
materiali incombustibili	A1			$A1_{fl}$	
	A2 - s1 d0 A2 - s2 d0 A2 - s3 d0	A2 - s1 d1 A2 - s2 d1 A2 - s3 d1	A2 - s1 d2 A2 - s2 d2 A2 - s3 d2	$A2_{fl}$ - s1	$A2_{fl}$ - s2
materiali combustibili non infiammabili o difficilmente infiammabili	B - s1 d0 B - s2 d0 B - s3 d0	B - s1 d1 B - s2 d1 B - s3 d1	B - s1 d2 B - s2 d2 B - s3 d2	B_{fl} - s1	B_{fl} - s2
	C - s1 d0 C - s2 d0 C - s3 d0	C - s1 d1 C - s2 d1 C - s3 d1	C - s1 d2 C - s2 d2 C - s3 d2	C_{fl} - s1	C_{fl} - s1
materiali combustibili normalmente infiammabili	D - s1 d0 D - s2 d0 D - s3 d0	D - s1 d1 D - s2 d1 D - s3 d1	D - s1 d2 D - s2 d2 D - s3 d2	D_{fl} - s1	D_{fl} - s1
	E	E - d2		E_{fl}	
materiali combustibili facilmente infiammabili	F			F_{fl}	

Classe accessoria			Definizione livello
livello emissione di fumo durante la combustione	s	1	quantità e velocità di emissione assenti o deboli
		2	quantità e velocità di emissione di media intesità
		3	quantità e velocità di emissione elevate
livello di gocciolamento durante la combustione	d	0	nessun gocciolamento
		1	lento gocciolamento
		2	elevato gocciolamento

Figure 5. Classification of components or materials according to reaction to fire.

The potential contribution of an element to a fire also depends on the end-use conditions (freestanding, attached to an element, forming a cavity), and all construction products (no floors) must be tested in the vertical position. Therefore, a product may obtain multiple classifications depending on the end application. If the product is fixed to a substrate during the test, the validity of the results is limited to those conditions. If adhesives are used, the results are valid for all similar adhesives. As shown in Figure 5, classification is made on the basis of UNI EN 13501-1, which allows the classification of products based on results obtained from experimental tests reported in the following standards:

- **EN ISO 1182-** Test of non combustibility of homogeneous products and major components of nonhomogeneous products. Observed are: mass loss[%], total persistent flame duration [s], furnace temperature rise [OC].
- **EN ISO 1716** - Evidence of calorific value. Heat release of a fully burned product. The values determined are PCS and PCI in [MJ/kg].
- **EN ISO 11925-2** lgnitability test of products subjected to direct flame attack--test using a single flame on specimens in a vertical position in the absence of radiant flux. It is evaluated

whether combustion has occurred, whether the flame front is greater than 15 cm above the point of flame application, and the instant at which it occurs, presence of flaming droplets/particles, physical behavior of the specimen.

EN 13823 - Evidence on a single burning element. The determined values are FIGRA_0.2MJ and FIGRA_0.4MJ representative of fire growth rate, THR600s thermal release within 600 s [MJ], SMOG RA smoke growth rate [m^2/s^2], TSP_600stotal smoke production [m^2]. In addition, heat production, smoke production, flame spread in the horizontal direction, and the fall of ignited particles and droplets are observed. Some tests can be performed on the individual elements that will comprise the kit or final element, while others must involve the building element in the final installation configuration.

Products must be laid in accordance with the actual manner of installation and laying to which it has been tested and taking into account the possible extensions of the classification result defined in paragraph 13 of EN 13501-1 d in EN 13238. If the products are not installed in adherence to the construction elements (i.e., delimiting a horizontal and/or vertical cavity within which possible sources of ignition are present), the reaction-to-fire class relative to the surface inside the cavity must also be determined in the case of products with asymmetrical cross-sections.

When talking about insulation materials, especially with overcoat applications, in terms of fire safety, it is necessary to refer to the Ministerial Decree of January 25, 2019 and the "Guide for the determination of fire safety requirements of facades in civil buildings" issued in Circular 5043 of April 15, 2013. In the latter, the definition of "kit" comes into play for the first time, understood as a product consisting of a series of at least two separate components that need to be joined to be permanently installed in the works.

The KIT, in the meaning of the Construction Products Directive (CPD) and the new Construction Products Regulation, must be placed on the market allowing the purchaser to buy it in a single transaction from a single supplier, and it is equivalent to a construction product. A construction product is a kit when it consists of a set of at least two separate components that need to be joined together to be permanently installed in the works (e.g., to become an assembled system). The kit must possess characteristics that enable the works in which it is incorporated to meet the essential requirements, when the works are subject to rules providing for such requirements. There are two possible types of kits: those in which the number and type of components are predefined and remain constant, and those in which the number, type, and arrangement of components change in relation to specific applications.

According to the European Commission 2000/147/EC of 8/2/2000 stated that the insulating products in a facade must be class 1 reaction to fire (corresponding to B-S3-d0), if the insulating function is provided by a set of components together marketed in the form of a kit, the performance refers to the latter considering its final operating conditions. There are exceptions (except for elements near windows x 0.6 m, and those placed at the base of the facade up to 3 m off-roof) may not comply with the limits as long as they are installed in accordance with the following guidelines (including inside cavity).

Preliminary information indicates that insulation panels can be installed if reaction at least B-S3-d0, or C-s3-d2 protected with A2, D-s3-d2 protected A1.

TABELLA 1

CLASSI DI REAZIONE ALL'AZIONE DELL'INCENDIO PER I PRODOTTI DA COSTRUZIONE AD ECCEZIONE DEI PAVIMENTI (*)

CLASSE	METODO(I) DI PROVA	CRITERI DI CLASSIFICAZIONE	CLASSIFICAZIONE AGGIUNTIVA
A1	EN ISO 1182 [1]; e	∍T δ 30 °C; e ∍m δ 50 % e t_f = 0 (cioè incendio non persistente)	
	EN ISO 1716	PCS δ 2,0 MJ.kg^{-1} [1]; e PCS δ 2,0 MJkg^{-1} [2] [2a]; e PCS δ 1,4 MJ.m^{-2} [3]; e PCS δ 2,0 MJ.kg^{-1} [4]	–
A2	EN ISO 1182 [1]; o	∍T δ 50 °C; e ∍m δ 50 %; e t_f δ 20s	–
	EN ISO 1716; e	PCS δ 3,0 MJ.kg^{-1} [1]; e PCS δ 4,0 MJ.m^{-2} [2] PCS δ 4,0 MJ.m^{-2} [3] PCS δ 3,0 MJ.kg^{-1} [4]	–
	EN 13823 (SBI)	FIGRA δ 120 W.s^{-1}; e LFS margine del campione; e THR$_{600s}$ δ 7,5 MJ	Produzione di fumo [5]; e Gocce/particelle ardenti [6]
B	EN 13823 (SBI); e	FIGRA δ 120 W.s^{-1}; e LFS margine del campione; e THR$_{600s}$ δ 7,5 MJ	Produzione di fumo [5]; e Gocce/particelle ardenti [6]
	EN ISO 11925-2 [8]: *Esposizione = 30s*	Fs δ 150 mm entro 60s	
C	EN 13823 (SBI); e	FIGRA δ 250 W.s^{-1}; e LFS margine del campione; e THR$_{600s}$ δ 15 MJ	Produzione di fumo [5]; e Gocce/particelle ardenti [6]
	EN ISO 11925-2 [8]: *Esposizione = 30s*	Fs δ 150 mm entro 60s	
D	EN 13823 (SBI); e	FIGRA δ 750 W.s^{-1}	Produzione di fumo [5]; e Gocce/particelle ardenti [6]
	EN ISO 11925-2 [8]: *Esposizione = 30s*	Fs δ 150 mm entro 60s	
E	EN ISO 11925-2 [8]: *Esposizione = 15s*	Fs δ 150 mm entro 20s	Gocce/particelle ardenti [7]
F	Reazione non determinata		

Figure 6. Table given in UNI 13501-1 for classifying materials according to their reaction to fire.

Textile fibers and hemp fibers. For materials such as textile fibers and hemp fibers, or other materials with a classification lower than B-S3-D0, there emerges a need to install elements with a reaction to fire rating of A2, which can be represented by gypsum board panels. For this, EN 13950 - Gypsum board thermal/acoustic insulation composite panels was evaluated. Definitions, requirements and test methods to evaluate the tests to which they should be subjected.

The list of characteristics to be evaluated for this type of product are:

- Fire behavior (standards cited 13501-1, EN 13823, EN 11925-2)
    - Reaction to fire
    - Fire resistance
- Water vapor permeability (standards cited EN 12572)
- Flexural strength (EN 520, EN 15283-1, EN 15283-2)
- Impact resistance (ISO 7892)
- Sound insulation from direct airborne noise (EN 10140)
- Sound absorption (EN 354)
- Panel thermal resistance (EN 10456, EN 12939, EN 12667)
- Dimensions and tolerances
- Offset
- Composite flatness
- Adhesion/cohesion of insulation material
- Hazardous substances (evaluate national regulations)