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The bearing walls like a "natural thermal governor": the case of "Sassi di Matera"

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ABSTRACT

The bearing walls represent one of the most ancient technological systems in the building process.
It's a simple structural system, but it possesses high quality technical and technological characteristics that makes it competitive. This research involved the values expresses by this particular kind of architecture and the indoor quality produced. We did this with tests "in situ" by monitoring the indoor comfort (as requests by the low UNI EN ISO 7730 1997 e UNI EN ISO 7726 2002 , directive CEE n° 106/89).
This research looks at demonstrating that the bearing walls operate like a "natural governor" of the thermal and hygrometrical comfort and are able to give high quality performances, even without the support of technological systems. The testing activity was verified through experimental applications in the restoration of two urban buildings in the ancient "Sassi" in the town of Matera (Italy).

KEYWORDS

Comfort indoor, ancient technological systems, performance.

1 INTRODUCTION

The bearing walls are one of the oldest technological systems in building process: in fact the built heritage, both historical or monumental, is realized using this particular kind of solution.
It's a simple structural system, but it possesses high quality, in term of technical and technological characteristics, that makes it competitive; just think about the low impact that it produces on the surrounding environment, the low CO_2 loading that it releases in the atmosphere during its life cycle and, furthermore, the possibility to recycle each of its component.
The research - included in a widest on going study, that aims to determine the methodological and operational aspects of the recovery of the ancient "Sassi di Matera" - starts from the analysis of morphological type-specific architectural context, proposing to assess the possibility of obtaining requirements required from residence in building realized with traditional and constructive technical characteristic.
Through tests "*in situ*" to monitoring the comfort "indoor" (as defined by UNI EN ISO 7730 1997 and UNI EN ISO 7726 2002, the EEC Directive No. 106/89), the study aims to show that these structures function as "natural regulators" of thermo-hygrometrical comfort and that they are suitable to the requirements of performances and quality requested for the residential environments (European Directive 2002/91/CE and Italian low D.lgs 192/05 – 311/06) even if they are built with traditional technologies.

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2 THE TRADITIONAL MASONRY

The easy workability of the stone has always allowed the use of square blocks as a structural element. The stone masonry, in fact - throughout the total national landscape – shows, even in the variety of materials and techniques used, recurrent issues as regards the static aspects as well as the comfort ones of the generated environments. Although the masonry have characterized all the ancient architectures, today we have only a few - increasingly sporadic - examples. Generally they were made from stone elements (blocks unprocessed, usually irregular in shape, with different sizes and different materials), usually several combined or poorly interconnected, and mortars of poor quality, both for characteristic and for resistance.
Unlike the rough stone wall, where irregular stone flakes leave each other vacant spaces to be filled with mortar, the blocks thoroughly combined have only a very small thickness of mortar between them. Instead, interior spaces between stone and stone are usually filled with good mortar slivers, re-establishing a monolithic shape, or with inconsistent material, leaving intact the lack of intrinsic resistance to the texture. This particular kind of masonry is called "sack masonry".
This particular structural system utilizes the wide masonry inertia, mainly in order to guarantee the indoor comfort in the so generated spaces.
The cavity inside the masonry, in fact, even if partially filled with inconsistent material, improve the capacity of isolation and transpiration of the wall but it represents, at the same time, a weakness point of the static structure.
The part of scrap - which amounts instead to a 20-30% of total output and comes from cutting - is often recovered to achieve fills and collected, more rarely been reduced in “tufina”, used to prepare the masonry mortars and plasters. The walls has a few well-defined types: the surrounding houses walls, that supports the horizontal structures, and the front walls that enclose the space, they are the two most popular systems. The last type are generally more fine – with a thickness of two blocks - while the first ones involves three spaced blocks.

3 THE INDOOR COMFORT

The term “indoor environment” is used to indicate all those confined environment of life and work that include housing, offices, premises for recreational and/or social where people spends most of their life. Indeed, on average, the population spends more than 70% of their time in these environments undergoing, in fact, a prolonged contact with potential pollutants sources contained therein.
The indoors air, in fact, can be more polluted and harmful to humans than the external one, because, in addition to external pollutants, in the internal part of building there are different harmful agents, whose danger is often underestimated. To the chemical pollutants (carbon monoxide, carbon dioxide, etc.) or physical pollutants (gas radon, natural and artificial electromagnetic fields), it jointed the biological pollutants (mold, bacteria, fungi, etc.). This is a wide problem and for a long time to the bio-medical attention. In 1987 the World Health Organization has recognized the Silk Building Syndrom (SBS) and the Building Related Illness (BIS) and defined them as a complex of symptoms that occur in one or more occupants of the same building.
This highlights the importance of the design process and the need to define spaces that are able to satisfy the requirements required from contemporaries quality standards.
The research aims to verify how, even in a significant architectural area - as the ancient “Sassi di Matera” [Guida A., Mecca I., 2005] - it is possible to achieve satisfying performance requirements required to the current standard applied to housing.
The methodology used for assessing the indoor comfort is out experimentally measurements using *in situ* monitoring parameters microclimatic interior and surface temperatures.

4 THE CASE STUDY: THE “ SASSO BARISANO” IN MATERA (ITALY)

The area is placed in a strategic position, an “hinge” between the “Sasso Barisano” e “Sasso Caveoso” and close to “via Fiorentini”, in the ancient “Rioni Sassi di Matera” [Giuffrè A., Carocci C., 1997].
Matera is a timeless city positioned on a steep hill, where groups of houses branch out starting from the flat and moving downwards in concentric circles thus forming the “Sassi” [Cotecchia V., 1974].
Here there is an enormous building and architectonic heritage, abandoned for over 40 years and today the scene of slow - but careful –interventions to recovery this cultural monument which is under the patronage of UNESCO from 1993.
It is a minute urban agglomeration, collected around the enclosure, the balconies, little street, steps and roads. The quantitative dimension of this recovery operation - partly laboriously already begun - strongly suggest the methodological problems of the interventions on built heritage.

So, identifying some "type-houses" in this context (recovered and currently inhabited) it has carried out to verify and to monitoring the indoor comfort in this environment realized with bearing structures consisting in a walls made with local stone [Cannarile. M., 1995][Buchicchio C., 1997].

4.1 The parameters choice

The analyzed wall have a 50 cm thickness and is composed with two blocks of stone linked each other by lime and cement mortar.
The "type" selected, similar for shape and in technical constructive, was monitored with a unit microclimatic LSI BABUC/A, which allows to analyze the internal thermo-hygrometrical parameters, which was compared with those taken from two external health resort in two different areas of the city of Matera and were managed by ALSIA [Pagliuca A., *et alii* 2008].
In the survey phase, in addition to the microclimatic parameters, were monitored surface temperatures (internal and external) of perimeter walls that composed the building envelope.
The instrumentation used was an environmental monitoring station with multiacquisitore to pluri-entrance LSI BABUC/A, equipped with n.5 microclimatic feelers:

- A globothermometrical feeler, to measure the Average Temperature Radiant;
- A psychrometrical feeler, to measure the Dry Temperature, Humid Temperature, Dew Temperature and Relative Humidity;
- A portable with hot wire anemometrical feeler, to measure the Air Speed;
- Four plate thermometrical feeler, to measure the Surface Temperature.

The measurement were carried out at fixed locations within the two spaces, placing the unit at a height of about 1.70 mt above the groundfloor (average individual height) and the centre. Instead, feeler to measure the surface temperature were placed on two of the four exterior walls that realized the spaces; it was chosen the walls exposed to South and West because those are more exposed to outside climate changes.
For each monitored areas were detected 7 signals with a frequency acquisition of 10 minutes, corresponding to the values of:

- Dry bulb air temperature (Ta);
- Humid bulb temperature to forced ventilation (Tw); from Ta and Tw the unit automatically obtains the dew temperature (Te) and air humidity (Ur);
- Air speed (Va);
- Temperature glob thermometer of Vernon (Tg), from which derives the average temperature radiant (Tr), noted the dry temperature and air speed;
- Internal surface wall temperature;
- External surface wall temperature;

In addition to internal microclimatic parameters were also monitored the external ones by two fixed health resort in Matera (one located in the northern and the other in the southern part of town). The average of these two parameters has given us a good estimate of trend in external climatic conditions of site [Pagliuca A., et alii, 2007]. In addition to measurements of microclimatic parameters carried out in situ, were collected some samples from the near stone quarry and brought in the laboratory where they were carried out measurements of conductivity using the method of source flat.
The use of in situ measurements related to laboratory testing was crucial for understanding the thermo-hygrometrical behaviour structures [Pagliuca A., et alii, 2007a].

4.2 The results analysis

The monitoring was conducted during the May 2006. It been chosen this month because it is characterized by a thermal excursion daily high because it is most representative of annual average thermo-hygrometrical behaviour.
It has provided interesting results. In fact, it was found a constant trend of internal microclimatic parameters against high daily temperature ranges (above 20 ° C): dry average bulb temperature 19-20 °C, wet average bulb temperature 14-15 °C, average globotermometrical temperature 18°C-19 °C, average relative humidity 60%, air speed less than 0.2 m/s.

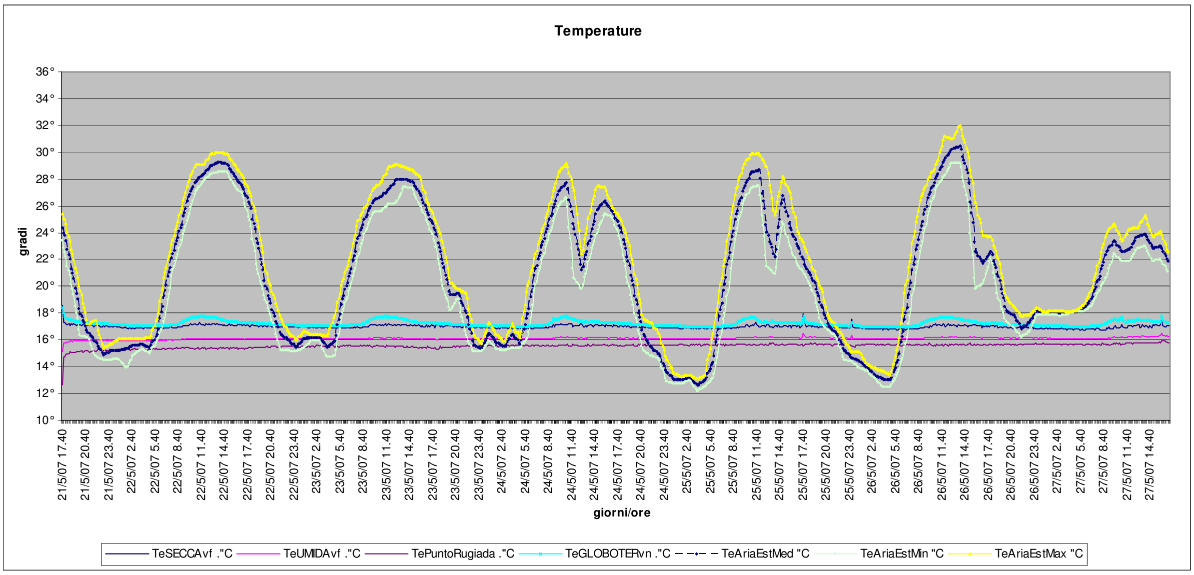

Table 1. Trend of internal and external air temperature

The above chart represents the development of internal and external temperatures of air. Analysing the chart, we can immediately note that the values are constant and in the limits of the standard (UNI EN ISO 7730/1997 and UNI EN ISO 7726/2002). So, we can assert that the spaces enclosed by walls realized with these "traditional" technologies are in a good thermo-hygrometrical comfort. This is due mainly to the ability of massive walls that act as a natural thermal governor.

4.3 Thermal behaviour of masonry

It has been carried out tests both *in situ* and in laboratory [Cardinal N., F. Ruggiero, 2002]. The *in situ* tests were carried out simultaneously with the microclimatic measurements and it intended to monitor every surface temperatures (internal and external) of masonry. This allows to verify not only the development of surface temperatures on the two sides - one in contact with the internal environment and the other in contact with the outside environment - but this measurements was essential to understanding the thermo-hygrometrical behaviour of these structures exposed to different climatic configurations [Cardinal N., *et alii* 2001].

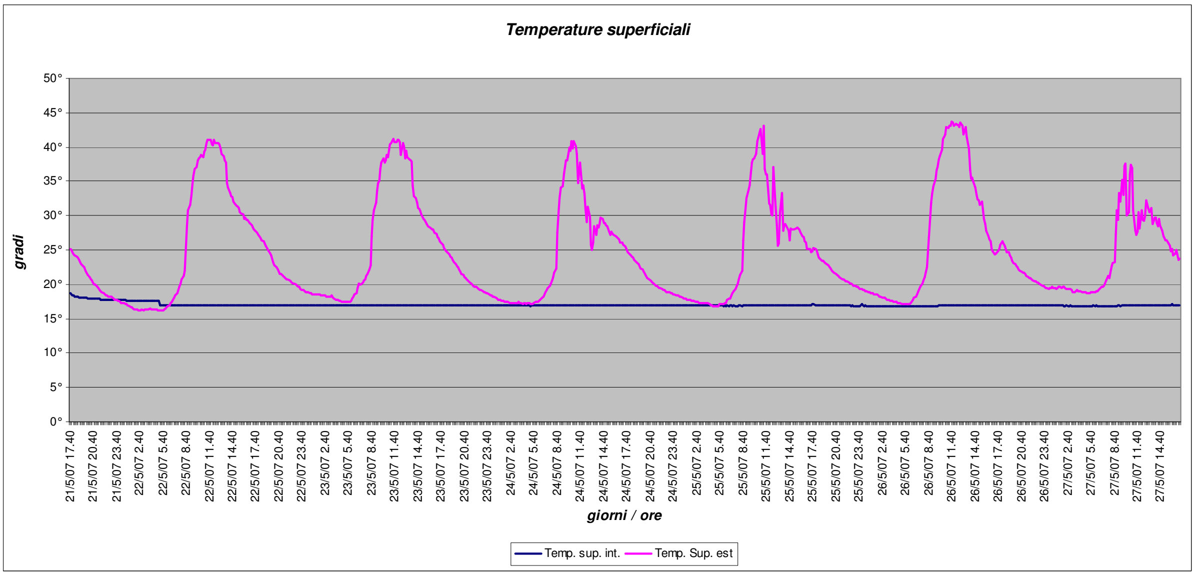

Table 2. Surface (internal and external) temperature of wall - 1

Indeed, even though the high daily temperature ranges, that characterized the measurements is over 20 °C and extreme values of surface temperature reached on the external face of the masonry is about 4 °C at night and over 40 °C day, the surface temperature of wall has not suffered the external conditions and it remained constant throughout the period of measurement (around 22 °C) that is the value of comfort.
After that and before carrying out laboratory tests, it was collected some data on scientific literature, that are interesting to know the physical-chemical composition of limestone rocks of Matera.

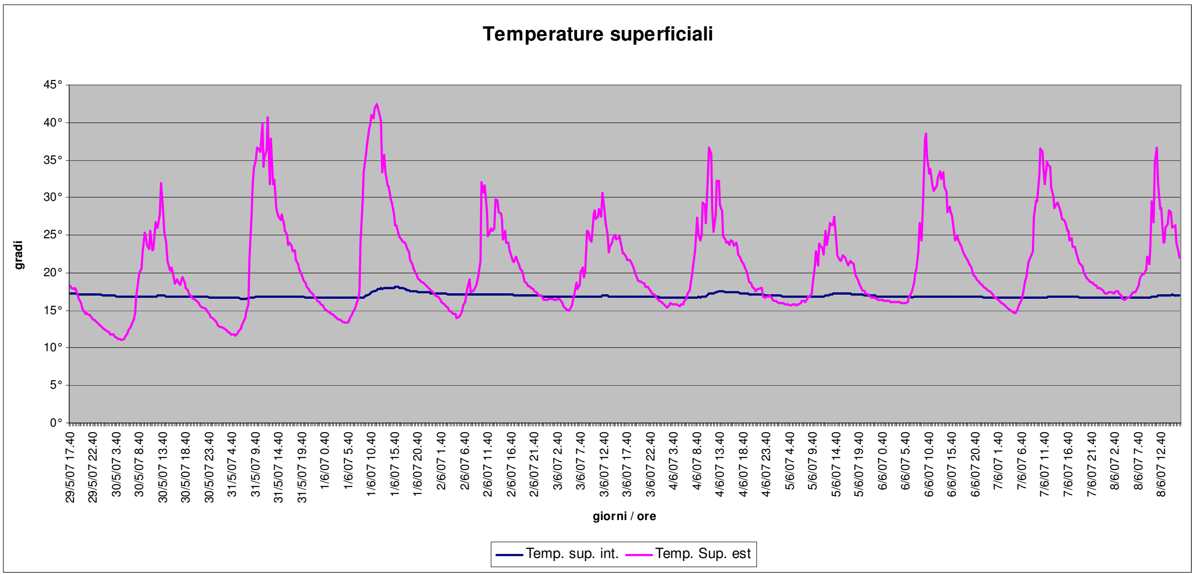

Table 3. Surface (internal and external) temperature of wall - 2

These rocks can be classified as medium-fine grain limestone, on average tenacious.
Analysing some on texture and structural characteristics of these limestone allows us to recognize two basic varieties, represented by "intra-bioclastic" limestone and "bio-intramicritic" ones.
The "intra-bioclastic" limestone are formed by "bioclastic" grains and "intraclasti" ones, cemented by calcite that comes in large mosaics, formed sometimes at the expense of micrite.
There are - among the bioclastic and intraclastic grains, which reach almost 90% - minerals of detritical origin like quartz and feldspars, and minerals autigeni that is recognizableeven macroscopically for the characteristic green color. The porosity - intergranular and intragranular - varies from 30% to 40%.
Following it is made some laboratory tests from which it was derived the physical and technical parameters of limestone rocks of Matera. The tests in laboratory were performed on three samples taken into the limestone quarry. The physical and mechanical characteristics of blocks extracts are the same of the blocks used in the analyzed masonry.
In laboratory tests were performed conductivity of stone material through technical and scientific instruments, a multiacquisitore source and a sensor composed by a flat heat source that is also the temperature sensor. It follows that the temperature trends in time of electrical resistance - as a source of heat plane - is calculated from the measurement of electrical resistance of the source, with its variable temperature, and the knowledge of temperature coefficient of material from which it is made [Rospi G., 2007].
The laboratory tests shows the following values:

- density 1541 Kg/mc
- conductivity (λ) 0,609 W/(m k)
- diffusivity (α) 0,481 x 10^6 mq/s
- specific heat (cp) 1,41 x 10^{-6} J/(kg k)
- average temperature 24,83 °C

Laboratory testing has been useful to calculate the physical and technical parameters.
Once it gets the thermal parameters of block stone it was possible to make the calculation of thermo-physical parameters of the walls that characterized the spaces using the method of calculation described in EN ISO 13786.
The table below is representative of a wall with a thickness of 50 cm composed of two rows of limestone blocks and linked with mortar of lime and cement.

Grandezza		Parte reale	Parte immaginaria	Modulo	Unità di misura	Variazione di tempo [h]
surface mass	Ms	-	-	131,8	kg/mq	-
thermal resistence	R	-	-	0,324	(mq K)/W	-
thermal transmitting	U	-	-	3,085	W/(mq K)	-
periodic thermal transmitting	Y12=Y21	2,2891995	-1,580944541	2,782	W/(mq K)	-2,31
attenuation factor	F	-	-	0,902	-	-
internal admittance	Y11	3,5901541	1,14580331	3,769	W/(mq K)	1,18
external admittance	Y22	4,4320943	3,330380859	5,544	-	2,46
internal thermical air capacity	k1	-	-	41,544	kJ/(mq K)	-
external thermical air capacity	k2	-	-	73,684	kJ/(mq K)	-
transmission matrix	Z11	0,8278135	1,072222185	1,355	-	3,49
	Z21	2,1911603	-9,090068616	9,350	W/(mq K)	18,90
	Z12	-0,295769	-0,204261145	0,359	W/(mq K)	-9,69
	Z22	0,6306091	1,89032836	1,993	-	-19,23
Inverse transmission matrix	Z11'	0,6306091	1,89032836	1,993	-	-19,23
	Z21'	-2,19116	9,090068616	9,350	W/(mq K)	-17,10
	Z12'	0,2957691	0,204261145	0,359	W/(mq K)	2,31
	Z22'	0,8278135	1,072222185	1,355	-	3,49

Table 4. Measure of thermo-physical parameter

Table 4 shows the thermo-physical parameters calculated by low. A careful analysis of this parameter shows that this type of system is characterized by high thermal mass that works quite well as attenuator of high summer temperatures.
One of the characteristic parameters of thermal inertia is the *lag coefficient* (measured in hours), representative of the delay which the element has to release the accumulated heat towards the internal environment, both from solar input and internal sources as well.
The lag coefficient of walls composed by homogeneous material is directly proportional to the square of their height and inversely proportional to a parameter characteristic of the material, called thermal diffusivity (a = λ/ρc, sq.m/s) - the relationship between conductivity (λ, W/m°K) and thermal capacity of a volume unit (ρ c, J/mc°K) - and showing the speed which the heat spreads deep into the material. Except of extreme values, represented by stone (upward) and wood (down), the thermal diffusivity of materials is constant, reaching around the average value of 0.5 mmq/s.
A second parameter for the assessment of thermal inertia, is *the factor of harmonic attenuation* (also known as the coefficient of mitigation or decrease factor), i.e. the ratio - characteristic of a particular mass building - between the wideness of thermal oscillation of the internal and external average air temperature, with dominant cycle of 24 hours.
From these two parameters it is possible to estimate the thermal capacity of the wall and to decrease the thermal gradient that is created between internal and external spaces.

5 CONCLUSIONS

The relationship between the tests made in the laboratory and the measurements made *in situ* has allowed to validate the considerations said above.
In fact, laboratory testing were essential to calculate the thermo-physical parameters necessary for the resolution of numerical calculation; while the test *in situ* allows to verify the calculation made through measurements of microclimatic parameters.
It was precisely this double-control - analytical and experimental - which made it possible to say that the environments and building types analysed show how these structures are particularly compatible with the requirements and qualitative performance today requested to residential environments (European directive

2002/91/EC - Legislative Decree 192/05 and 311/06), although realized with "traditional" technical systems and technology.
The “Sassi di Matera”, therefore, seem to be almost a model of "bioarchiettura" in which natural stone, used "with wisdom", plays the key role of regulation, even through without the aid of technological systems.

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