322: Evaluation of sustainable performances for the "rammed earth" material. A case study in Abruzzo region, Italy

Luca Buoninconti [1]*, Cristian Filagrossi Ambrosino [2]

Dipartimento di Configurazione ed Attuazione dell'Architettura
*Università degli studi di Napoli "Federico II", Napoli, Italy[1]**
E-mail: l.buoninconti@adbarchitetti.it
Dipartimento di Configurazione ed Attuazione dell'Architettura
Università degli studi di Napoli "Federico II", Napoli, Italy[2]
E-mail: cristian.filagrossi@gmail.com

Abstract

The need to pursue sustainable and biocompatible targets can be very often obtained in small buildings through employment of low technologies. The case study in Abruzzo Region, monitored and evaluated, allows to verify how a "poor" material, like rammed earth, can have extremely interesting thermo hygrometric performances, even if employing simple technologies that, moreover, belong to traditional background.
The research, divided in several stages, is aimed to verify on one hand the thermo hygrometric behaviour and on the another the sustainability of the material.
The stage of control and verification is developed acquiring climatic data from weather stations, which can match with the data obtained with a complex monitoring system, extended to the four seasons. Therefore, the acquisition campaign was carried out for a whole year, and it has been preceded by a complete plan. The acquired data, then, have been organized into an evaluation matrix, which estimates the thermo hygrometric efficiency.
At the same time, we proceeded to find data about construction, maintenance and eventually demolition of the rammed earth building, in order to calculate the employment of energy and material. Also in this case, some data were inserted into the matrix which evaluates the environmental impact and the sustainability.
In this way it has been possible to achieve a global evaluation of the building, and to establish, in scientific way, the sustainable performances of the rammed earth product.

Keywords: Soft Technologies, thermo hygrometric comfort, rammed earth, sustainability

1. Introduction

Our target is to evaluate the behaviour of the rammed earth envelope and its suitability to offer high thermo hygrometric conditions without conditioning plants; so we have developed an evaluating system which allows to measure several meaningful parameters and to "homogenize" them with weights.
Abruzzo is an Italian region very rich of country houses built with rammed earth technology; in 1934 we can number 780 buildings in the province of Pescara, 755 in Teramo and 683 in Chieti: about 20% of the whole construction estate.
The usual typology is a house with two floors, the ground floor is a storehouse, and the first, the apartment. An internal or external staircase connects the two levels.
The common way of execution is named *massone* (also *maltone*), consisting in a mixture of clay and straw so as to obtain a plastic product; afterwards, with a hoe chop, the workers separate a small quantity to perfect it manually.
The product is carried to the building site and creates a layer of 50 – 70 cm high along the outer edge of the house; each layer dries in the sun for five or six days.

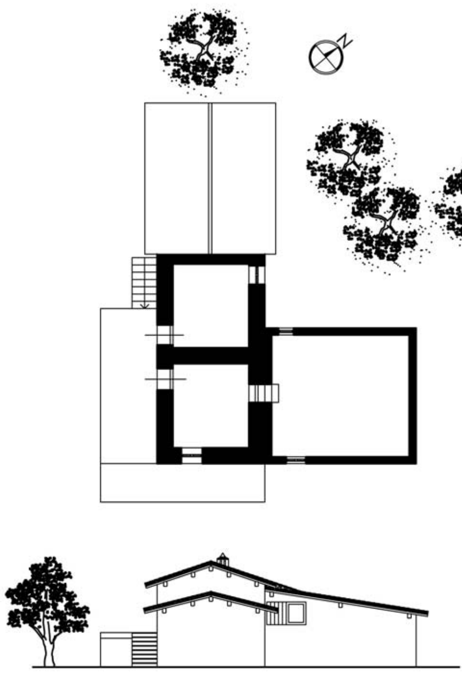

Fig 1. First floor plant and East front

2. Monitoring system

2.1 General remarks

The case study selected is a country house built with *massone* technique, and, thus it has intrinsic non homogeneous characteristics, typical of an handmade product, where materials are assembled observing traditional "trade rules", but without the quality standards of a modern product. Therefore the simulation approach is very complex, because it is difficult to find valid data for the whole building envelope: thermo hygrometric parameters of the wall depend on several conditions, such as: more or less straw in the mixture, climatic conditions during the drying process of the rammed earth. It is also possible to evaluate the thermo hygrometric behaviour of the building by a monitoring campaign aimed at measuring directly the parameters.

2.2 The measuring plan

The measuring plan has been organized considering facility and operational criteria. For example it has been necessary to find a room with electric plugs (to charge the multi - acquiring control unit), and empty so as to avoid human presence or other modifying factors during the measuring time.
The multi - acquiring control unit has been provided with a sensor to detect the dry and wet bulb temperature of indoor air, thermometers to detect the indoor radiant temperature, luxmeters to detect indoor and outdoor Illuminance (to evaluate solar access), and another thermometer to detect outdoor temperature. All the sensors are produced in accordance with the standards ISO 7726, ISO 8995 and UNI 10380.
All measures have been taken by putting sensors in a barycentric position, at the side of the unique window; the measurement length was more than 24 hours and the range of interval was 10 minutes. The acquisition campaign went on for a whole year, extended to the four seasons[1].

3. The data analysis

3.1 Data processing

Once obtained the output data for each season, the following step is to make qualitative and quantitative evaluations.
During the first step the data acquired immediatly after the control unit had started and are recorded, until anyone enters the room to switch off the system: the data which came out from the entrance of the operators till the stop activation, are cut off, so as to reduce at minimum every interaction with the human presence in the room.
During the second step, we have calculated the average in every hour: in this way, we reduce value fluctuations, too high in this physical phenomena.
Four tables are obtained, one for each season, with which we can calculate the minimum, the maximum and the average of each parameter. In particular, $T_{db\ i}$, $T_{wb\ i}$, $T_{rad\ i}$, RH e I_{in} are the dry and wet bulb and radiant Temperature, the Relative Humidity and the Illuminance in the room; $T_{db\ o}$ e I_{out} are the dry Temperature and Illuminance recorded outside.
Table 1 shows the minimum, the maximum and the average data in winter; we observe small fluctuations of dry bulb Temperature inside; wet bulb, radiant Temperature and Relative Humidity fluctuations are instead bigger but still between 2-3° C. Solar access is very small, and its phenomenon is very similar to that of the radiant Temperature.

Table 1: Minimum, maximum and average data in the winter

	$T_{db\ i}$	$T_{wb\ i}$	RH	$T_{rad\ i}$	$T_{db\ o}$	I_{int}	I_{est}
min	7,06	4,9	64,32	6,49	2,99	0,03	5
h_{min}	8.00	11.00	11.00	11.00	6.00	17.00	17.00
med	7,98	6,34	78,52	7,90	5,80	0,23	16,12
max	8,73	7,21	81,12	8,86	8,8	0,82	56,83
h_{max}	13.00	12.00	12.00	13.00	13.00	12.00	10.00

Table 2 shows the data processed during spring; dry bulb temperature variations increase, and are above 4°C; similar behaviour can be observed for wet bulb and radiant Temperature. The Relative Humidity values are 10% less than in the winter, due also to the increasing external Radiation; solar access is always very small.

Table 2: Minimum, maximum and average data in the spring

	$T_{db\ i}$	$T_{wb\ i}$	RH	$T_{rad\ i}$	$T_{db\ o}$	I_{int}	I_{est}
min	19,68	15,32	47,88	19,41	18,46	0,03	5
h_{min}	5.00	11.00	11.00	11.00	4.00	19.00	0.00
med	20,93	16,63	63,05	21,02	21,54	0,09	65,70
max	23,83	18,34	71,3	23,23	25,23	0,33	189,2
h_{max}	10.00	10.00	22.00	10.00	10.00	9.00	12.00

Table 3 indicates values calculated in summer; a general increase in Temperature is noticed, with a considerable Humidity decrease and the external Radiation growth. Indoor wet bulb and radiant Temperature are the same: indeed low internal Illuminance confirms small solar access also in summer. Wet bulb temperature is steady and always 7-8°C below than dry bulb data, for the reduction of Humidity.

Table 3: Minimum, maximum and average data in the summer

	$T_{db\ i}$	$T_{wb\ i}$	RH	$T_{rad\ i}$	$T_{db\ o}$	I_{in}	I_{out}
min	28,65	22,01	48,32	28,67	23,24	0,03	3,17
h_{min}	5.00	12.00	15.00	4.00	4.00	18.00	21.00
med	30,13	22,83	52,38	30,19	30,78	0,06	1321
max	31,7	23,81	55,78	31,88	41,41	0,12	5341
h_{max}	15.00	17.00	23.00	15.00	7.00	5.00	7.00

At last, table 4 contains the values assessed in the Autumn; here the Temperature is lower than

[1] The measure instruments are: the multi – acquiring control unit BABUC A; psycrometric sensors BSU102 and BST131 LSI-Lastem; radiant thermometers BSR001 and BSR003; luxmeters BST 101 LSI-Lastem

that of summer, but also comparing with spring, it appears still lower, principally because Relative Humidity is increasing about 20% more than the summer one (the average is instead similar to the winter data).
The difference between dry bulb and wet bulb Temperature decreases (about 3°C), and external Radiation is more than in spring.
Radiant temperature is always almost equal to the dry bulb Temperature, and solar access is very small.

Table 4: Minimum, maximum and average data in the autumn

	$T_{db\ i}$	$T_{wb\ i}$	RH	$T_{rad\ i}$	$T_{db\ o}$	I_{int}	I_{est}
min	17,22	14,2	70,95	17,34	12	0,03	4,33
h_{min}	7.00	7.00	7.00	6.00	5.00	17.00	18.00
med	18,40	15,49	72,87	18,45	16,03	0,05	230
max	19,64	16,99	77,55	19,64	20,6	0,1	631,7
h_{max}	17.00	14.00	15.00	17.00	12.00	13.00	12.00

3.2 Simultaneous data evaluation

All considerations we have done about average data need to be completed with simultaneous assessment of value trends during the day.
A very interesting comparison has been made between indoor and outdoor dry bulb temperature, and its relationship with Illuminance (and thus with solar load).
Indoor temperature (thick line) shown in fig. 2 has small fluctuations, on the contrary outdoor temperature fluctuations (medium line) are huge: the envelope produces a good thermal inertia phenomenon because contributes to reduce the difference between the external and internal temperature amplitude. As obvious, outdoor temperature is linked to solar radiation (thin line), and we remark its maximum during daytime, with peaks in between 10.00 AM and 12.00 AM. The thermal time lag due to the rammed earth wall is about one hour.

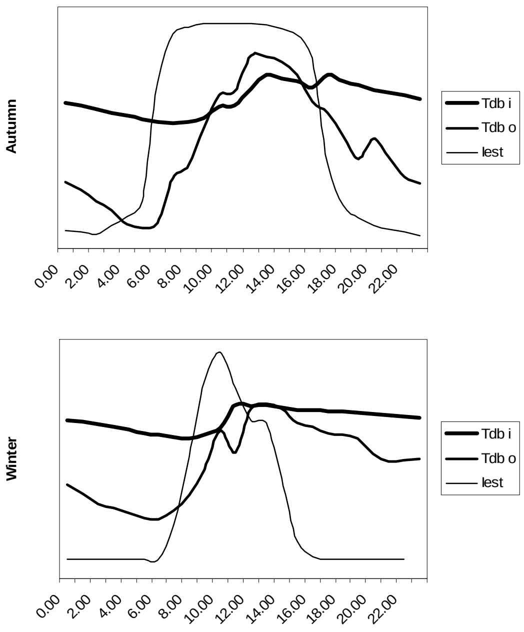

Fig 2. Dry bulb indoor and outdoor temperature and irradiation behavior in cold seasons

In Fig. 3 we can also observe a similar behaviour between data recorded in spring and those in summer, but the diagram is more complex.
The thermal time lag decreases, and its value is about 40 minutes.

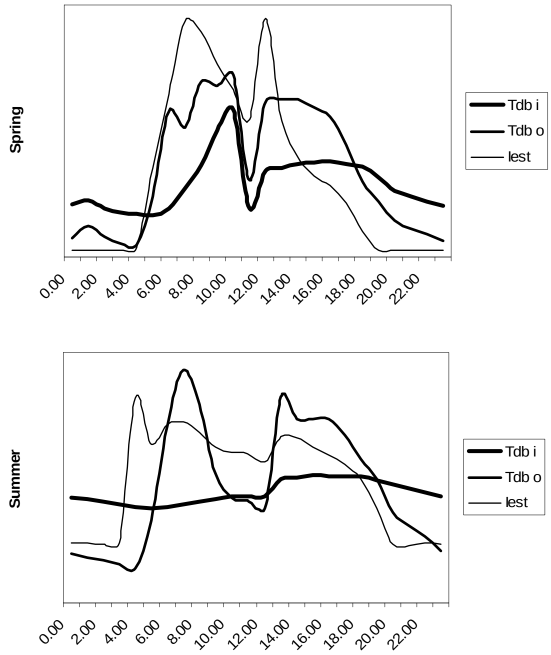

Fig 3. Dry bulb indoor and outdoor temperature and irradiation behavior in warm seasons

4. Evaluation of the environmental impact and the sustainability

4.1 Material Sustainability

Every thought about the relationship between industrial production and environment should take into account the non renounceable fact that sustainability is not only a target to achieve, as often nowadays is meant, but also a direction to take [1]. In this sense, not every improvement on environment (such as the plain energy saving), can be considered sustainable. The binding requirements for defining a product as really sustainable have been far-back well outlined:
1. employing renewable sources (with a use rate that does not outpass the regeneration one);
2. optimizing non renewable sources;
3. not harming the site;
4. not harming human health.
Considering these requirements, it is fairly clear how the existing production system of industrialized societies is far from sustainable.

4.2 The evaluation method

The environmental and thermal performances of rammed earth have been verified through the application of an evaluation method for the sustainability of building materials, specifically modified for the exterior walls.

Such method consists of a format divided in two classes: ecosustainability and biocompatibility [2, 3]. The first is related to the impacts that the material/product provides on the environment (in terms of material and energy consumption and of polluting emissions), the second instead deals with the impacts provided on the users' health and safety (in terms of emissions, radioactivity, comfort, etc.).
Any class can be identified by a number of parameters, which define performances and requirements of the employed material.
Each parameter is, on its turn, specified by qualitative and quantitative indicators, to which a value will be given.

Table 5. Samples of indicator range of values and scores

Indicator	Range of values
Energy Consumption (Production)	1= over 3500 MJ 2= from 2500 to 3500 MJ 3= from 1500 to 2500 MJ 4= from 800 to 1500 MJ 5= from 0 to 800 MJ
Hygrothermal Comfort (Heat Storage)	1 = time lag < 0,5 h 2 = 0,5 h < time lag < 1 h 3 = 1 h < time lag < 2 h 4 = 2 h < time lag < 6 h 5 = time lag > 6 h

Table 6. Weights given to classes, subclasses and parameters

CLASS	SUBCLASS	PARAMETER
Ecosustainability		
45 %	*Resources Savings*	
	45 %	Material Consumption 60%
		Energy Consumption 40%
	Ecosystems Protection	
	55 %	Polluting emissions: CO2 25%
		Polluting emissions: CFC 20%
		Polluting emissions: COx, NOx, SOx 25%
		Polluting Emissions: Eutrophication 15%
		Polluting Emissions: Photochemical ozone formation 15%
Biocompatibility		
55 %	*Health*	
	55 %	Toxic emissions: VOC 30%
		Toxic emissions: Radon 20%
		Toxic emissions: Formaldeyde 30%
		Toxic emissions: Microrganisms 20%
	Hygrothermal Comfort	
	45%	Temperature 45%
		Humidity 30%
		Sun 25%

The scores for each indicator are given considering a defined range of values, every one of which corresponds to a determinated value, from 1 (worst performance) to 5 (best performance).
The satisfaction level of performance for each indicator provided by each material is thus represented by the specific value (from 1 to 5) appointed to the indicator itself.
Moreover different weights are provided for each class, subclass and for groups of parameters, according to their importance (as known in any multicriteria method). So the ecosustainability class has a weight corresponding to the 45% of the total, and the biocompatibility weights for the remaining 55% (see Table 6).
The final result will be provided as a comparison value within the multicriteria method, for the ecosustainability and biocompatibility of two different materials.
In the end, it can be said that the shown method takes into account not only the inputs (energy and material) and outputs (toxicity and pollution), both in the production and distribution phases, but also involves, deeply, in the architectural application the materials and the technical systems whose selection has to be set in the geographical climate.

4.3 The case study

After being applied to the case study, the method provided a number of results. Such output shows how the use of rammed earth had caused very low environmental loads, thanks to the fact that the material has a very high level of naturality and requires low energy consumptions. In fact the production of walls was made up simply by animal and human energy. Moreover this material does not produce relevant polluting emissions.

Table 7. Summary of evaluation output data

Ecosustainability					
45 %	*Resource Savings*		III level	II level	I level
	45 %	Material Consumption	2,76	1,98	3,5
		Energy Consumption	1,65		
	Ecosyst.				
	55%	CO2	1,15	4,76	
		CFC	1		
		COx, NOx, SOx	1,2		
		Eutrophication	0,66		
		Photochemical ozone	0,75		
Biocompatibility					
55 %	*Health*				2,65
	55%	VOC	0,99	2,02	
		Radon	0,6		
		Formaldehyde	1,5		
		Microorganisms	0,6		
	Comfort				
	45%	Temperature	1,23	3.43	
		Humidity	1,2		
		Sun	1		

Thus the ecosustainability value is very high reaching score of 3.5. A little bit lower is the score about biocompatibility (2.65), because of Radon and VOC emissions that can be present in the ground, although the hygrothermal comfort is very high, confirming the good rammed earth performances as far as the indoor temperature and humidity control are concerned.

Table 8. The ecosustainability scores in detail

Class		*Parameter*	*Indicator*	*Val*	*Tot*
Ecosustainability	*Resource Saving*	Material Consump.	Percentage of prime materials employed	1	4,6
			Availability	5	
			Presence in nature	5	
			Water Consumption	4	
			Durability	5	
			Maintenance	5	
			Reparability	5	
			Recycling	5	
			Re-use	5	
			Biodegradability	5	
			Components splitting	5	
			Hazardous Wastes	5	
			Non Hazardous Wastes	5	
		Energy Consump.	Preproduction	5	4,1
			Production	4	
			Distribution	5	
			Use	5	
			Dismantle/Recycling	4	
			Energy from renewable sources	5	
			Energy from wastes	1	
	Ecosystems Protection	Polluting Emissions: CO2	Preproduction	5	4,6
			Production	5	
			Distribution	5	
			Use	5	
			Dismantle/Recycling	3	
		Polluting Emissions: CFC	Preproduction	5	5
			Production	5	
			Distribution	5	
			Use	5	
			Dismantle/Recycling	5	
		Polluting Emissions: COx, NOx, SOx	Preproduction	5	4,8
			Production	5	
			Distribution	5	
			Use	5	
			Dismantle/Recycling	4	
		Polluting Emissions: Eutrophic.	Preproduction	5	4,4
			Production	4	
			Distribution	5	
			Use	5	
			Dismantle/Recycling	3	
		Polluting Emissions: Photochemical ozone	Preproduction	5	5
			Production	5	
			Distribution	5	
			Use	5	
			Dismantle/Recycling	5	

Table 9. The biocompatibility scores in detail

Class		*Parameters*	*Indicators*	*Val*	*Tot*
Biocompatibility	*Health*	Toxic Emissions: VOC	Effects to target	4	3,3
			Intensity emission	5	
			Time emission	1	
		Toxic Emissions: Radon	Effects to target	4	3
			Intensity emission	4	
			Time Emission	1	
		Toxic Emissions: Formaldehyde	Effects to target	5	5
			Intensity emission	5	
			Time emission	5	
		Toxic Emissions: Microorganisms	Effects to target	4	3
			Intensity emission	3	
			Time emission	2	
	Hygrothermal Comfort	Temperature	Range of external winter temperatures	4	2,7
			Range of external summer temperatures	4	
			Range of internal winter temperatures	1	
			Range of internal summer temperatures	2	
		Humidity	Range of internal winter humidity	3	4
			Range of internal summer humidity	5	
		Sun	Internal Air Temperature Radiant / Temperature Ratio	3	4
			Radiant Temperature / Solar Gain Ratio	5	

5. Conclusions

From monitoring and evaluation data, shown in this paper, it is possible to understand that rammed earth, a very poor material, which wastes a very low amount of resources, can have high hygrothermal performances, also without the aid of conditioning plants. It has very astonishing performances regarding humidity and solar gains, while it is a little bit less efficient for heat losses.

Finally the evaluation system shows the great results of using rammed earth in terms of environmental performances. The energy and material consumptions are very low, due to the extremely poor and common raw materials used in the manufacturing process. High scores are also reached for the polluting and toxic emissions, with insignificant or inexistent quantities of CO_2, CFC, photochemical ozone and formaldehyde. The rammed earth can, instead, cause some troubles according to radon, voc and microrganisms emissions, but the values are, in fact, within the normal range of safety.

6. References

1. Manzini E., Vezzoli C. (1998), *Lo sviluppo di prodotti sostenibili. I requisiti ambientali dei prodotti industriali*, Maggioli, Rimini
2. Francese D. (2007). *Architettura e Vivibilità*. Franco Angeli, Milano

3. Sasso U. (2003), *Bioarchitettura. Forma e formazione*, Alinea Editrice, Firenze