

## Thermo-hygrometric and comfort analysis of a vernacular multi-room settlement in the Sassi of Matera

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<https://doi.org/10.18280/ijes.620202>

### ABSTRACT

**Received:** 8 September 2018

**Accepted:** 16 October 2018

#### Keywords:

*dynamic energy simulation, vernacular buildings, thermo-hygrometric comfort, microclimate analysis, bioclimatic strategies*

The present work is focused on the thermo-hygrometric and comfort analysis of a vernacular multi-room settlement in the Sassi of Matera. The vernacular multi-room settlement is composed of n. 8 rooms divided into two levels, partly built and partly excavated into the calcareous rocks. The case study hypothesizes a possible low-level environmental system solution able to respect with the strictest design standards, within a structure located in the Sassi district of Matera.

Our first goal is to outline a microclimate profile of typical environment of Sassi of Matera. To do this we carried out a comparative analysis of climatic data from different sources: Energy Plus weather data, ALSIA-Matera data and [ilmeteo.it](http://ilmeteo.it)- Gioia del Colle data. From the analysis conducted we have found that Energy Plus weather data series presents temperature lower than ALSIA-Matera and [ilmeteo.it](http://ilmeteo.it)- Gioia del Colle data series with an average of absolute deviation in winter and summer season respectively of 0.9 °C and 0.45 °C.

Measures conducted have been useful to analyse the energy behavior in spontaneous regime i.e. without heating or cooling system. In this case thermal comfort is not acceptable. Assuming to install absorption heat pump in all multi-room settlement comfort is acceptable.

## 1. INTRODUCTION

Vernacular architecture is often characterized by a high-efficiency bioclimatic strategies because of the necessity of ancient population to adapt to the climate and the site, unlike many modern buildings [1-4]. For this reason vernacular architectures that developed through the centuries has much original and interesting design practices and technologies to satisfy the various necessities [5-6]. Different climates require different architectural responses.

This produced the development of a different kind of house for each territory [7-9]: there are no universal models and each zone generates its own building typology linked not only to the climate but also to the availability of the materials present. The vernacular building construction technique and specifications are more based on knowledge achieved by trial and error rather than conventional practices. Vernacular architecture provides a good solution to the climatic constraints, and there is more than one approach to solving the same climatic constraint [5, 10]. This kind of structure evolves over time to reflect the environmental, cultural and historical context in which they exist, [5, 11]. Construction techniques have evolved continuously from cave dwellings to modern high-rise buildings. Traditionally, buildings are constructed with locally available materials like stone, wood, mud and lime. In recent years, modern construction materials such as cement and steel have replaced most of the local materials, due to the high durability, low maintenance, low likelihood of corrosion and decay, and ease of construction of the former. However, modern construction materials are energy intensive and eco-destructive [12].

Another important factor is the thermal comfort of the indoor space, achieved using mechanical air-conditioning systems that are not only energy intensive but cause high environmental impacts. In the past, thermal comfort was achieved by designing the building to suit the local climatic conditions. In dry, the temperature fluctuation of the outdoor air is high. So the buildings were constructed with a high thermal mass to reduce the temperature fluctuation of the indoor space.

Vernacular buildings of Matera adopted several bioclimatic strategies:

(1) the characterization of the horseshoe plant with the presence of an internal atrium: this aspect favoured natural ventilation

(2) openings in the highest areas of the wall: it took the name of "sopraluce" and this also contributed to optimizing ventilation;

(3) presence of vaults and niches, and thick stone walls; this last feature acts as a hermetic seal and adequately protects the internal environment from the external climate.

Vernacular Mediterranean architecture has three typical features: thick walls with high thermal inertia; few, small and deep window openings; the white colour of the lime-wash. In fact, in ancient times, the regular use of the lime-wash was determined for its easy availability, low cost, simple production and laying; however light colours reflects solar radiation, so the places, where it is used seem to be larger; considerable hygiene and brightness, thanks to direct and reflected light [13].

Still, observing the historical centre of the city of the Lucanian province, it is easy to notice that most of the houses

face the south, a constructive strategy that allowed to make the most of the hours of light and heat.

The case study is a typical vernacular building of Sassi of Matera and presents most of the thermos-hygrometric discomfort linked to high humidity and high thermal gradient between indoor and outdoor environment.

The goals of this study is to conduct a thermo-hygrometric and comfort analysis for a vernacular structure of Sassi of Matera composed of a multi-room settlement in two different case: without plant and with it.

## 2. THERMAL COMFORT OF CASE STUDY

The Matera area is characterized by a unique morphology consisting of valleys, canyons and plateaus of sandstone calcarenite. The case study is located in the Sassi of Matera, a town in Southern Italy characterized by a warm sea climate. In Matera, the climate is warm and temperate. The winter months are much rainier than the summer ones. Analyzing climate data provide by ALSIA (Lucana Agency Development and Innovation in Agriculture), the annual average temperature in Matera, considering the time step 2010-2016, is 15.6 °C. In the time step 2010-2016, the average rainfall is 652.3 mm [14].

The case study hypothesizes a possible low-level environmental system solution able to respect with the strictest design standards, within a structure located in the Sassi district of Matera in order to guarantee thermal comfort. To be able to hypothesize this is necessary to observe first of all a series of aspects which characterize the structure, its geographical position and the relative climate.

The building examined is a complex distributed on three levels each of which provides a series of rooms, each with separate entrances. The case study is almost totally exposed to any meteorological agent and receives light in most of its extension, for almost the entire day [Figure 1 and 2].



Figure 1. The case study



Figure 2. Multi-room settlement case study

Internally the rooms are presented as a series of aisle, sometimes communicating with each other and almost totally "dark" because the only source of light is the entrance that leads to them. The case study is located in the historical center of the city of Matera, so its location will be the reason why the particularity of the building, responds exactly to those that are the typical and peculiar characteristics of a structure in the Sassi. In particular, it is located in the area of the "Sasso Barisano" of the renowned historical center.

Externally the building appears as a vernacular multi-room settlement composed of n. 8 rooms (20 zones) distributed on three levels each of which provides a series of zones, each with separate entrances partly built and partly excavated into the calcareous rocks. [Figure 3 and 4].



Figure 3. Inner of multi-room settlement



Figure 4. Inner of multi-room settlement

These structures are characterized by a high thermal inertia due to the material used. Hypogeal architecture can be particularly effective in hot climates. The great thermal inertia of the terrain mitigates the severity of external conditions, reducing peaks of temperature. Ventilation and contact with the outside can be controlled through open spaces upwards and protected from solar irradiation.

As shown in Figure 5 some walls are characterized by high humidity levels. The moisture is due to infiltration, condensation or capillary rise but also there are many thermal bridges, associated with change of the material that exists between the facade and the excavated part of the house and with the inclusion of posthumous dividing walls. In fact, these structures have few openings to the outside to avoid both excessive radiation in summer and excessive heat loss in winter. However the repaired surfaces are subject to the night condensation with the development of lichens which caused a degradation of the finishing surface layers.



**Figure 5.** Inner of multi-room settlement

The non-hypogean part follows the same principles of mitigating conditions hot climates through the use of masonry built with materials extracted from the ground (raw earth, stone, clay-based bricks) with high thermal inertia.

The first methodological step is to outline a microclimate profile of the environment under consideration.

To do this we carried out a comparative analysis of climatic data from different sources in winter and summer season [Figure 6 and 7] from 2002-2016 years.

Analyses compare the trends over time with temperatures taken from:

(1) Website "Ilmeteo.it": the temperatures taken from here refer to a meteorological station located near the town of Gioia del Colle. This town has an altitude of 365 m s.l.m. against the 401 m of the Lucanian province and is far 36.5 km from the city of Matera, we used this weather station because weather data used by dynamic regime software, Energy Plus Code [15], refers to this climate zone.

(2) Local body of the city of Matera "ALSIA" (Lucan Agency of Development and Innovation in Agriculture)

The meteorological data acquired from website "Ilmeteo.it" are average daily detail, while meteorological data acquired from "ALSIA" are average hourly detail.

For each data set we calculated the average temperature relative to the winter season and to the summer season. This value are used to calculate the average of absolute deviations  $D_m$  (Eq. 1) between the averages temperature of winter season calculated for 2002 – 2016 period of ALSIA-Matera data series, indicated as  $T_{m1,n}$  and the averages temperature of winter season calculated for 2002 – 2016 period of ilmeteo.it-Gioia del Colle data series, indicated as  $T_{m2,n}$  and relative deviation  $D_{r,m}$  (Eq. 2)

Average of absolute deviations  $D_{a,m}$  was calculated with Eq. 1:

$$D_{a,m} = \frac{\sum (T_{m1,n} - T_{m2,n})}{n} \quad (1)$$

where  $n$  is the number of year.

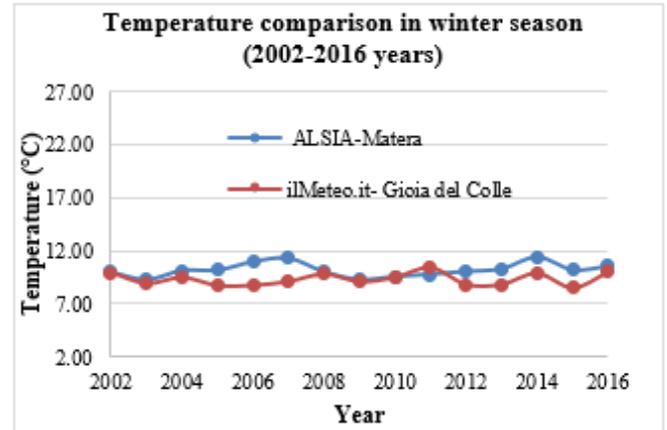
Subsequently, we calculated the average of relative deviation  $D_{r,m}$ :

$$D_{r,m} = \frac{D_{a,m}}{\sum T_{m2,n} / n} \quad (2)$$

As is shown in Table 1 and Figure 6, in winter season temperature of ALSIA- Matera source results higher than Gioia del Colle data reported by ilmeteo.it sources with an average of relative deviation is of 0.10

**Table 1.** Average air temperature of winter season for 2002-2016 period, average deviation and relative deviation of weather data in winter season for 2002-2016 period

Winter season			
	$T_m$ [°C]	$D_{a,m}$	$D_{r,m}$
ALSIA-Matera	10.2	0.9	0.10
ilmeteo.it-Gioia del Colle	9.3		

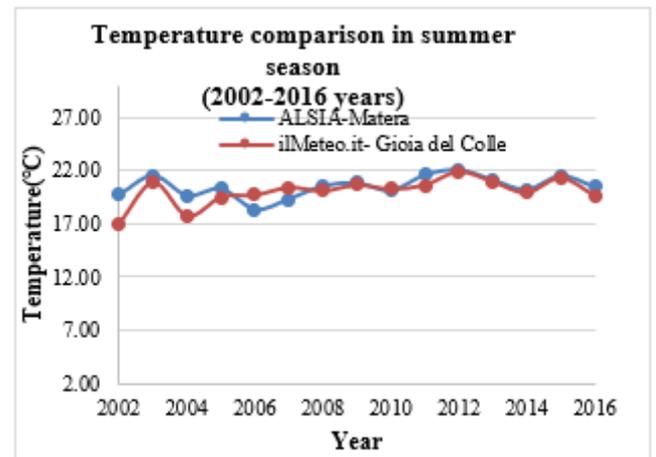


**Figure 6.** Temperature comparison in winter season between ilmeteo.it- gioia del colle data and alsia-matera data

As is shown in Table 2 and Figure 7, in summer season, temperature of ALSIA- Matera data series results higher than ilmeteo.it-Gioia del Colle data only for 2002-2004 period.

**Table 2.** Average air temperature of summer season for 2002-2016 period, average deviation and relative deviation of weather data in summer season for 2002-2016 period

Summer season			
	$T_m$ [°C]	$D_{a,m}$	$D_{r,m}$
ALSIA-Matera	20.48	0.45	0.02
ilmeteo.it-Gioia del Colle	20.03		



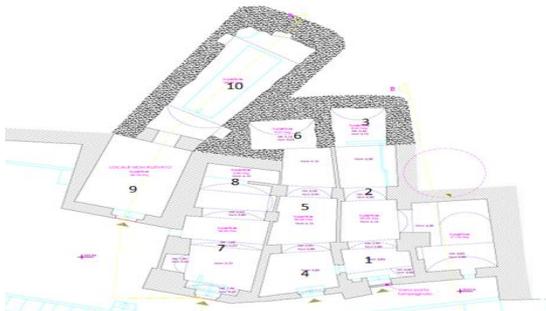
**Figure 7.** Temperature comparison in summer season between ilmeteo.it- gioia del colle data and alsia-matera data

We conduct some experimental studies of temperature and humidity in summer because in this period there is a high thermal gradient between indoor and outdoor environment.

To facilitate the study, the interior rooms were divided in different zone classified according to the "depth" (i.e. position with respect to the entrance).



**Figure 8.** First floor of multi-room settlement



**Figure 9.** Second floor of multi-room settlement

The multi-room settlement is composed of 8 rooms. The first floor is composed by n. 4 rooms (Figure 8):  
 (1) Room 1 is divided in zone 1 and zona 2;  
 (2) Room 2 is divided in zone 3, zona 4 and zone 5;

(3) Room 3 is divided in zone 6, zona 7 and zone 8;

(4) Room 4 is divided in zone 9 and zone 10;

The second floor is composed by n. 4 rooms (Figure 9):

(1) Room 5 is divided in zone 1, zona 2, zona 3;

(2) Room 6 is divided in zone 4, zona 5 and zone 6;

(3) Room 7 is divided in zone 7 and zona 8;

(4) Room 8 is divided in zone 9 and zone 10.

This classification accumulates all those internal zones, as well as for their position, for the almost identical behaviour in response to variation of external climatic factors.

The case study examines two of the three levels of which the construction site is composed and each measurement was carried out in the individual internal rooms of the building.

For each room, the values of temperature and relative humidity were measured.

It must be emphasized that the internal environment of the complex studied does not present any division by means of partition walls, however, due to the shape of the building, internal divisions are anyway.

The complex "excavated" in the calcarenitic rock appears to be free of openings and therefore does not reach the interior; this lack will justify the diversity and the increase in the percentage of humidity as we proceed with the "depth" in the horizontal direction of the building.

Measured period goes from 26 June 2017 to 8 July 2017.

The instrument used for this type of measurement consists of a hygrometer, Flir Systems MR77 Pinless Moisture Pyschrometer, equipped with a sensor capable of detecting temperature and humidity values in an environment.

As is shown in Table 3 temperature decreases going towards the deep rooms, while relative humidity increases (Table 4).

Data reported in Table 3 and 4 refers to measurement taken at 3:00 PM.

The second floor is characterized by the same trends: temperature decreases going towards the deep zones (Table 5), while relative humidity increases (Table 6).

**Table 3.** Temperature of different zones located in first floor

FIRST FLOOR										
Temperature [°C]										
DATA	Room 1			Room 2			Room 3		Room 4	
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10
26/06	30.6	28.4	28.0	26.1	26.0	25.5	24.6	24.4	27.0	25.1
27/06	29.3	26.7	26.3	25.2	24.9	24.8	23.0	22.0	25.0	24.5
28/06	30.6	28.8	27.5	26.6	26.0	24.5	26.6	25.5	24.0	26.0
29/06	31.6	30.0	29.2	27.3	26.6	26.8	25.8	24.5	27.2	25.0
30/06	28.4	27.3	27.5	22.5	25.0	25.8	24.3	23.0	26.0	25.0
01/07	32.0	30.6	30.0	29.0	27.0	26.9	25.0	24.5	27.0	25.0
02/07	25.3	24.3	24.0	22.2	22.1	23.7	22.3	21.3	23.3	22.1
03/07	26.0	25.0	24.1	25.6	24.3	23.1	24.8	23.8	25.0	23.0
04/07	33.0	30.5	29.5	28.1	26.9	26.9	25.3	24.0	26.1	24.4
05/07	31.7	28.5	30.0	26.7	26.0	26.0	24.6	23.6	27.1	25.0
06/07	32.2	30.0	29.5	27.1	26.3	29.2	25.3	24.5	28.5	25.5
07/07	31.8	29.8	29.7	26.6	26.0	27.0	24.8	24.0	28.8	25.7
08/07	30.5	29.3	32.0	28.3	27.5	28.7	26.0	25.0	30.0	26.6

**Table 4.** Relative humidity of different zones located in first floor

FIRST FLOOR										
Relative Humidity [%]										
DATA	Room 1			Room 2			Room 3		Room 4	
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10
26/06	52.0	56.0	54.0	58.0	59.0	62.0	63.0	65.0	58.0	67.0
27/06	55.9	62.6	61.3	65.1	66.3	65.0	72.0	71.0	73.0	72.0
28/06	47.5	51.0	50.0	57.5	60.2	60.0	61.0	65.0	62.0	65.0

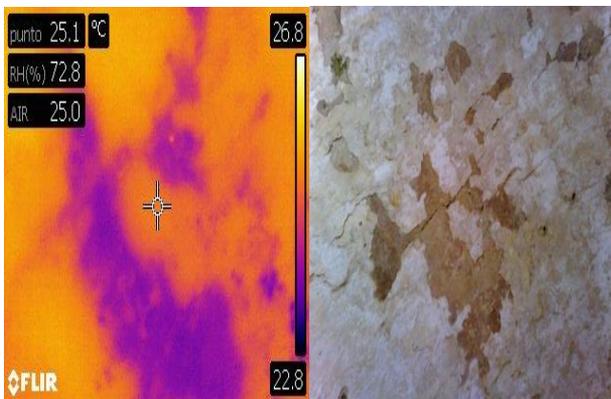
29/06	47.0	48.0	52.0	57.9	53.0	55.6	58.0	61.0	51.2	59.5
30/06	56.0	59.0	55.0	61.0	65.0	61.0	64.5	68.0	65.5	70.0
01/07	47.5	49.4	46.0	50.0	54.0	59.0	61.6	64.0	59.0	65.0
02/07	59.0	63.0	62.0	57.2	67.2	63.8	69.8	72.9	64.5	71.2
03/07	52.4	55.0	57.5	58.0	61.3	64.0	56.0	70.0	62.0	65.0
04/07	42.8	47.5	43.9	46.3	49.0	55.1	60.8	62.5	60.0	64.5
05/07	47.5	52.8	44.4	51.8	55.1	58.0	64.3	65.4	61.0	65.4
06/07	46.5	51.2	46.0	53.0	53.8	52.0	62.0	63.5	58.0	65.0
07/07	46.0	51.2	41.6	46.0	48.3	55.0	59.2	61.3	53.2	64.3
08/07	48.4	52.6	41.0	46.6	49.4	52.4	58.4	60.2	52.0	61.5

**Table 5.** Temperature of different zones located in second floor

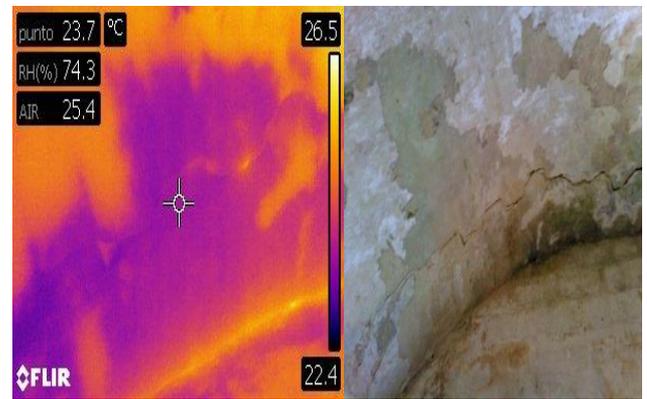
SECOND FLOOR										
Temperature [°C]										
	Room 5			Room 6			Room 7		Room 8	
DATA	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10
26/06	28.6	27.7	27.0	26.4	26.0	27.1	26.0	28.8	26.0	27.0
27/06	26.8	26.1	25.7	25.0	26.1	25.6	27.0	24.0	23.0	25.0
28/06	29.0	28.4	27.0	27.0	27.0	27.8	27.3	28.1	25.0	24.0
29/06	29.3	28.2	27.2	27.0	27.6	27.0	27.8	27.0	26.8	27.2
30/06	28.8	27.3	26.5	25.0	25.6	25.3	25.6	25.5	25.2	26.0
01/07	29.0	28.0	27.3	26.6	26.5	26.0	26.7	26.3	24.6	27.0
02/07	24.5	23.6	23.6	23.8	23.5	24.0	23.8	22.0	22.2	23.3
03/07	27.7	26.1	25.0	24.8	24.5	24.3	25.6	24.8	24.0	25.0
04/07	28.6	27.2	26.4	26.0	25.8	25.4	26.7	25.8	25.5	26.1
05/07	29.0	27.9	26.7	25.9	26.0	25.8	27.7	26.3	25.0	27.1
06/07	31.4	30.0	28.0	27.0	26.6	25.9	28.6	26.8	25.5	28.5
07/07	31.4	29.1	27.9	26.5	26.6	26.9	28.6	26.9	25.5	28.8
08/07	31.3	30.0	28.8	27.4	27.7	26.9	27.2	26.4	25.7	30.0

**Table 6.** Relative humidity of different zones located in second floor

SECOND FLOOR										
Relative Humidity [%]										
	Room 5			Room 6			Room 7		Room 8	
DATA	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10
26/06	53.2	57.0	58.0	58.5	60.4	60.0	63.6	53.0	62.5	56.0
27/06	66.0	69.0	69.0	69.0	68.7	70.4	61.2	66.9	62.1	65.5
28/06	52.0	56.0	59.0	63.0	60.0	58.0	59.0	60.0	63.3	59.0
29/06	50.8	52.0	52.0	53.3	54.0	56.0	53.5	52.9	55.0	58.0
30/06	54.5	62.0	61.4	64.0	63.0	65.0	67.5	66.2	64.0	62.0
01/07	54.0	56.0	59.0	60.0	61.0	61.6	63.0	62.0	65.0	64.0
02/07	51.0	55.0	56.0	54.0	54.0	60.7	61.4	56.0	63.7	69.5
03/07	45.0	48.0	54.0	57.2	52.9	57.0	57.2	57.0	63.1	61.8
04/07	42.0	44.7	45.6	46.2	48.8	51.9	55.0	54.5	57.3	58.4
05/07	44.5	46.0	50.6	48.7	52.3	54.0	54.0	57.6	60.6	58.0
06/07	42.5	44.5	51.2	52.0	53.7	54.0	53.0	58.5	60.2	56.6
07/07	39.5	40.2	41.2	42.3	46.0	46.5	52.0	52.3	55.7	54.9
08/07	38.5	40.0	43.9	49.0	47.8	48.8	59.1	60.0	67.4	58.7



**Figure 10.** Thermography of roof of multi-room settlement



**Figure 11.** Thermography of roof of multi-room settlement

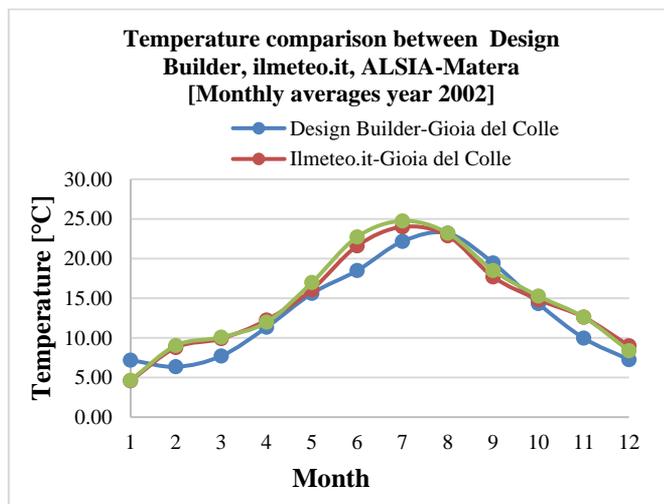
The possibility of connecting the instrument to a thermal imaging camera has also allowed to associate the evolution of the microclimate with the observation of real photographs taken on walls inside the building.

As is shown in Figure. 10 and 11 the thermography allows you to identify wet areas as a result of infiltration from the upper floors. The moisture therefore is due to infiltration or condensation or capillary rise. There are also many thermal bridges, associated with change of the material that exists between the facade and the excavated part of the house and with the inclusion of posthumous dividing walls [16].

### 3. ENERGY AUDIT OF CASE STUDY

Meteorological analysis conducted in paragraph 2 was necessary to understand the error refers to the 2002 Meteorological data of Design Builder weather data respect to actual climate condition. Measures conducted and analysed have been useful to analyse the energy behaviour in spontaneous regime i.e. without heating or cooling system. These data have been used to calibrate the numerical model built using Design Builder in order to evaluate the thermo-hygrometric improvement that can be achieved by using heating systems. This hypothesis is due to improve the indoor air quality of this vernacular multi-room settlement.

To evaluate the reliability of Design Builder [17] weather data, related to the municipality of Gioia del Colle, we compared this data with the climatic trend of Gioia del Colle weather station (ilMeteo,it souce) and ALSIA- Matera weather station. The data set refers to 2002 year (Figure 12).



**Figure 12.** Temperature comparison between desing builder, ilmeteo.it and alsia-matera weather data.for 2002 year

As is shown in Figure 10, Design Builder temperature are lower than ilmeteo.it and ALSIA-Matera data.

Even in this case we calculated the average temperature relative to the winter season and to the summer season for 2002 year. This value are used to calculate the average of absolute deviations  $D_m$  (Eq. 1) between the averages temperature of the two data series in 2002 year (data series considered are ALSIA-Matera data series and ilmeteo.it- Gioia del Colle data series) (Table 7 and 8).

Design Builder weather data temperatures are underestimated around 13 % in winter and 5 % in summer. Hence the heating energy calculated from it must be reduced,

while the cooling energy must be increased. These differences can be assumed around -13 % and +5 %, as indicative values. In any case we could not evaluate the differences in solar energy, so the deviation could be even slightly higher.

**Table 7.** Average of absolute deviation of temperature between designbuilder weather data of gioia del colle and average temperature (alsia-matera and ilmeteo.it-gioia del colle) in winter season for 2002 year

Winter season			
	$T_m [^{\circ}C]$	$D_{a,m}$	$D_{r,m}$
Design Builder – Gioia del Colle	8.8	-1.2	-0.13
Average Temperature	9.8		

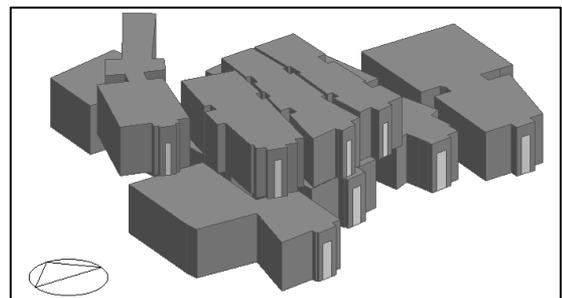
**Table 8.** Average of absolute deviation between designbuilder weather data of gioia del colle and average temperature (alsia-matera and ilmeteo.it-gioia del colle) in summer season for 2002 year

Summer season			
	$T_m [^{\circ}C]$	$D_{a,m}$	$D_{r,m}$
Design Builder – Gioia del Colle	18.4	-1.0	-0.05
Average Temperature	20.0		

To set the case study model (Figure 13) we used material characteristic in which both in situ and laboratory measurements were carried out in [18]. Conductance of the building walls of Sassi were measured in situ according to ISO 9869 [19]. In [18] for the wall of the calcareous stone structures a mean thermal conductance of 1.37 W/m<sup>2</sup>K (corresponding to a mean thermal conductivity of 0.66 W/(mK) with a thickness of 0.48 m) was obtained.

In [20] thermal conductivity  $\lambda$  was linked to moisture contained in calcareous rocks. In particular thermal conductivity  $\lambda$  goes from 0.56 W/mK (0% moisture) to 2.01 W/mK (29,36% moisture). Using this data to characterized case study building material we provided to set case study model.

To detect the values of temperature and relative humidity on the inside and outside of the buildings we used a psychrometric non-penetrating with incorporating an infrared thermometer. These data are necessary to calibrate the boundary condition of Design Builder model.



**Figure 13.** Design builder model of multi-room settlement

A first analysis was conducted in free-floating regime to evaluate the thermo-hygrometric comfort using Fanger Index through PMV and PPD values, respectively Predicted Mean Vote e Predicted Percentage of Dissatisfied and energy behaviour. The calculation of the PMV and PPD coefficient depends not only on microclimatic parameters, but on other factors that are

closely linked to the individual at the level of perception, therefore indicated as subjective factors. The metabolic rate (met) was fixed at a value of 0.9; while the coefficient of clothing factor (clo) in summer can be set at a constant value of 0.3.

The result of the analysis of the PMV and PPD parameters reveals a totally inefficient thermo-hygrometric well-being in all the interiors studied (Table 9).

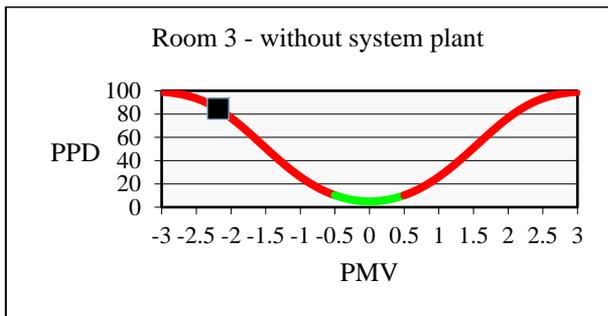
The PMV values is between slightly cool or cool as result from scale of PMV index reported by UNI EN ISO 7730:2006 [21].

**Table 9.** PMV and PPD of case study in spontaneous regime in experimental period

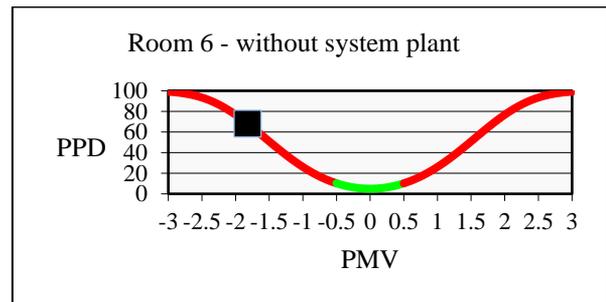
	Air temperature	Mean radiant temperature	Air speed	Relative humidity	PMV	PPD	Operative temperature
	[°C]	[°C]	[m/s]	[%]	-	[%]	[°C]
Room 1	29.3	22.6	0.0	50.15	-0.9	22.2	25.9
Room 2	26.7	22.3	0.0	54.89	-1.6	56.0	24.5
Room 3	24.9	21.8	0.0	57.96	-2.2	84.5	23.4
Room 4	25.7	22.4	0.0	60.86	-1.8	67.4	24.0
Room 5	27.7	22.4	0.1	51.41	-1.4	43.2	25.1
Room 6	26.0	22.1	0.0	55.99	-1.8	68.3	24.1
Room 7	26.4	22.3	0.1	58.32	-1.6	59.0	24.3
Room 8	25.7	22.4	0.0	60.86	-1.8	66.3	24.1

**Table 10.** PMV and PPD with system plant in June –July period

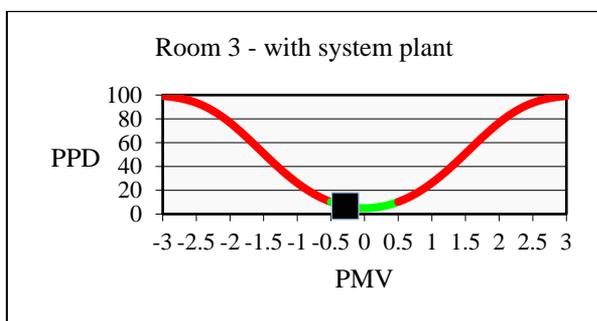
	Air temperature	Mean radiant temperature	Air speed	Relative humidity	PMV	PPD	Operative temperature
	[°C]	[°C]	[m/s]	[%]	-	[%]	[°C]
Room 1	27.2	27.6	0.0	44.8	-0.4	7.6	27.4
Room 2	27.0	27.2	0.0	45.3	-0.5	10.1	27.1
Room 3	27.4	27.7	0.0	44.6	-0.3	6.7	27.5
Room 4	27.5	27.9	0.0	44.3	-0.2	5.9	27.7
Room 5	26.6	26.8	0.1	46.0	-0.7	15.0	26.7
Room 6	26.8	27.0	0.0	45.6	-0.6	12.0	26.9
Room 7	27.2	27.4	0.1	44.9	-0.4	8.5	27.3
Room 8	26.9	27.1	0.0	45.4	-0.6	11.4	27.0



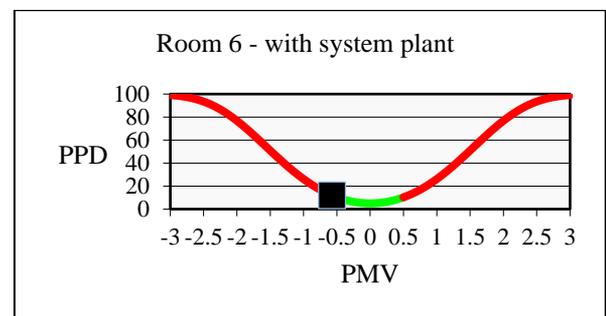
**Figure 14.** PMV and PPD in Room 3 without system plant (first floor)



**Figure 16.** PMV and PPD in Room 6 without system plant (second floor)



**Figure 15.** PMV and PPD in Room 3 with system plant (first floor)



**Figure 17.** PMV and PPD in Room 6 with system plant (second floor)

In order to improve the thermo-hygrometric conditions of these rooms, it has been suggested to install an absorption heat

pump system with underflooring emissions terminals. This system has an energy efficiency around 139% and a utilization of renewable energy around 40%. A problem in these structures is the high level of humidity in the interiors of buildings linked to the type of material that makes up these environments. A high index of voids, that characterizes calcareous rocks, increases the ability to retain water, when the rock itself comes into contact with this fluid mass.

This behaviour causes a high level of relative humidity; therefore an adequate system must be able to eliminate this discomfort. In table 10 we reported PMV and PPD index derived from dynamic simulation considering June and July months.

In Figure 16 and 18 we can observe the PMV and PPD indexes for room n. 3 located at the first floor and room n. 6 located at the second floor room n. 3 and room n.6. In Figure 17 and 19 thermal comfort improvement after installation of system plant calculated for room n.3 and room n. 6 is shown. The major problem of these rooms is linked to the high relative humidity presents on calcareous rocks.

#### 4. CONCLUSIONS

The paper focuses on the thermos-hygro-metric analysis and internal comfort of a multi-room settlement. Regarding the analysis of different weather data sources we concluded that Gioia del Colle weather data are in line with ALSIA- Matera weather data with a relative deviation in summer season of 0.02. Regarding Design Builder, which utilizes the data of 2002 (type year) of Gioia del Colle, we found an underestimate of the temperatures. This implies an indicative decrease around 13 % of the heating energy and an indicative increase around 5 % of cooling energy.

The analyzes carried out have shown that the vernacular structures of the Sassi di Matera, which are partly excavated and partly built, are characterized in the summer by a bad thermal comfort due to the relative humidity that increases with increasing depth of the rooms. To improve this bad condition we assumed to install an absorption heat pump system in order to reduce relative humidity and to guarantee better indoor comfort condition.

Observing carefully the values obtained it is easy to notice that the indexes that mark the ratio of PMV and PPT reveal a clear microclimatic change inside the building following the insertion phase of the plant. The result obtained following the implantation hypothesis is revealed in this final phase, a totally positive success.

#### ACKNOWLEDGMENT

We would like to thank ALSIA of Matera to weather data given.

#### REFERENCES

[1] Montalbán Pozasa B, González FJN. (2016). Hygrothermal behaviour and thermal comfort of the vernacular housings in the Jerte Valley (Central System, Spain). *Energy and Buildings* 130: 219–227.

[2] Charter on the Built Vernacular Heritage, México. (1999). 12th General Assembly ICOMOS

[https://www.icomos.org/images/DOCUMENTS/Charters/vernacular\\_e.pdf](https://www.icomos.org/images/DOCUMENTS/Charters/vernacular_e.pdf)

[3] Rubio-Bellido C, Pulido-Arcas J, Cabeza-Lainez J. (2015). Adaptation Strategies and Resilience to Climate Change of Historic Dwellings. *Sustainability* 7: 3695–3713. <http://doi.org/10.3390/su7043695>

[4] De Luxan M, De Diego Garcia, Roman Lopez ME, Gómez Muñoz G. (2014). Sustainable Living. Environmental. [http://oa.upm.es/37093/1/INVENMEM\\_2014\\_197162.pdf](http://oa.upm.es/37093/1/INVENMEM_2014_197162.pdf)

[5] Soleymanpour R, Parsaee N, Banaei M. (2015). Climate comfort comparison of vernacular and contemporary houses of Iran. *Procedia - Social and Behavioral Sciences* 201: 49–61.

[6] Singh MK, Mahapatra S, Atreya SK. (2009). Bioclimatism and vernacular architecture of North-East India. *Building and Environment* 44(5): 878–888.

[7] Jiménez M, Gonçalves L. (2015). Bioclimatic analysis for a vernacular Guarani house. In: Mileto C, Vegas F, García Soriano V, Cistini V (Eds.) *Vernac. Archit. Toward a Sustain. Futur* 377–380. <http://www.crcnetbase.com/doi/abs/10.1201/b17393-67>

[8] Tang L, Nikolopoulou M, Zhang N. (2014). Bioclimatic design of historic villages in central-western regions of China. *Energy Build* 70: 271–278. <http://dx.doi.org/10.1016/j.enbuild.2013.11.067>

[9] Baran M, Yildirim M, Yilmaz A. (2011). Evaluation of ecological design strategies in traditional houses in Diyarbakir, Turkey. *J. Clean. Prod* 19: 609–619. <http://dx.doi.org/10.1016/j.jclepro.2010.11.001>

[10] Rakoto-Joseph O, Garde F, David M, Adelard L, Randriamanantany ZA. (2009). Development of climatic zones and passive solar design in Madagascar. *Energy Conversion and Management* 50(4): 1004–1010.

[11] Helena C. (1998). Bioclimatism in vernacular architecture. *Renewable and Sustainable Energy Reviews* 2(1): 67–87.

[12] Leo Samuel DG, Dharmasastha K, Shiva Nagendra SM, Maiya M. (2017). Thermal comfort in traditional buildings composed of local and modern construction materials. *International Journal of Sustainable Built Environment*. <http://doi.org/10.1016/j.ijsbe.2017.08.001>

[13] Convertino F, Di Turi S, Stefanizzi P. (2017). The color in the vernacular bioclimatic architecture in Mediterranean region. *Energy Procedia* 126: 211–218.

[14] Rospi G, Negro E, Cardinale T, Cardinale N. (2017). Microclimate of territory of Matera and the heat island effect. *Energy Procedia* 133: 2–15. <https://doi.org/10.1016/j.egypro.2017.09.361>

[15] EnergyPlus.gov. Energy Plus vers. 8.3 - Program Energy Efficiency, Energy Technologies and Renewable Energy. <https://github.com/NREL/EnergyPlus/releases/tag/v8.3.0>, 2015

[16] Cardinale T, Balestra A, Cardinale N. (2015). Thermographic mapping of a complex vernacular settlement: The case study of Casalnuovo District within the Sassi of Matera (Italy). *Energy Procedia* 76: 40 – 48.

[17] Design Builder Software Italia. Design Builder v.2.2.5004 <http://www.designbuilderitalia.it/>, 2010.

[18] Cardinale N, Rospi G, Stefanizzi P. (2012). Energy and microclimatic performance of Mediterranean vernacular buildings: The Sassi district of Matera and the Trulli district of Alberobello. *Building and Environment* 59: 590–598. <http://doi.org/10.1016/j.buildenv.2012.10.006>

- [19] Standard ISO 9869-1, Thermal Insulation – Building Elements – In Situ Measurement of Thermal Resistance and Thermal Transmittance, 2014.
- [20] Cardinale N, Guida A, Ruggero F. (2001). Thermohygrometric evaluation in the recovery of rocks buildings of the “Sassi of Matera” (Italy). *Journal of Building Physics* 24(4): 301-315. <http://doi.org/10.1106/1d9b-dnln-r5hj-k01t>
- [21] UNI EN ISO 7730, Ergonomics of the thermal environment - Analytical Determination and Interpretation of Thermal Comfort Using Calculation of The PMV and PPD Indices and Local Thermal Comfort Criteria, 2006.

## NOMENCLATURE

$D_{a,m}$	average of absolute deviations, dimensionless
$n$	Number of year considered, year
$D_{r,m}$	Average of relative deviation, dimensionless
$T_{m1,n}$	averages temperature of winter season calculated for 2002 – 2016 period of ALSIA-Matera data series, °C
$T_{m2,n}$	averages temperature of winter season calculated for 2002 – 2016 period of ilmeteo.it- Gioia del Colle data series, °C