PLEA 2020 A CORUÑA
Planning Post Carbon Cities

Evaluation of thermal comfort and energy performance of a case study in vernacular architecture of Cyprus

Chryso Heracleous[1], Aimilios Michael[1], Chrysanthos Charalambous[1], Venizelos Efthymiou[1]

[1] FOSS Research Centre for Sustainable Energy, University of Cyprus, Nicosia, Cyprus

ABSTRACT: The conservation and rehabilitation of buildings of vernacular architecture is a sustainable approach, not only because it leaves a small ecological footprint, compared to the erection of new buildings, but also due to the passive bioclimatic design features integrated in vernacular buildings. This paper will investigate the thermal performance of vernacular architecture in lowland area in diverse climatic contexts. The findings of the current research are based on an on-site investigation carried out in a representative vernacular building that is going to be upgraded to a hands-on technology exhibition area of renewable energy systems complimented with visual means to enhance the experience of visitors under a Research European Programme (Horizon 2020). The current study provides a basis for the formulation of a site-specific design strategy to improve thermal conditions and achieve energy conservation within lowland constructions in diverse climatic conditions. Understanding and analysing the thermal behaviour of these spaces is the first step towards this strategy. The quantitative analysis reveals the various challenges faced and opportunities provided by lowland structures and contributes to informing current design policies. Moreover, the analysis will inform the sizing of the technical systems throughout the year.

KEYWORDS: Thermal comfort, Vernacular architecture, Mediterranean climate, Lowland region

1. INTRODUCTION

The conservation and rehabilitation of buildings of vernacular architecture is a sustainable approach, not only because it leaves a small ecological footprint, compared to the erection of new buildings, but also due to the passive bioclimatic design features integrated in vernacular buildings [1-3]. The vernacular architecture of Cyprus, as well as of other eastern Mediterranean areas with similar climatic conditions and building typologies, can be characterized as an excellent example of bioclimatic architecture, since it incorporates a series of environmental features, appropriate for both the heating and cooling period [4-8]. In addition, a series of recent studies performed on vernacular architecture of Cyprus indicate the environmental adaptability of traditional settlements located in different climatic regions of the island [9, 10]. A traditional building was selected to be an example where a hybrid electrical-thermal storage system will be installed in the Mediterranean region as part of an ongoing research programme i.e. HYBUILD, which is funded by the European Union through HORIZON 2020. The selection aims at the rehabilitation of vernacular buildings and the promotion of both bioclimatic features incorporated in vernacular architecture and new technologies that can be adapted in such buildings. This study focuses on the environmental assessment of these spaces, through the monitoring of air temperature and relative humidity. These structures are quite common in the vernacular architecture of the island; therefore, their scientific examination produces useful knowledge in terms of energy savings.

2. METHODOLOGY

2.1. Case study building and area

For the purpose of the present study, a representative vernacular dwelling was selected for an in-depth investigation. The study of a representative case study, in terms of typology and building materials, allows the wider exploitation of the research results. The building under study is located in the core of the traditional settlement of Aglantzia (lowland region - climatic zone 2). Like the rest of the island, Aglantzia has a Mediterranean climate with hot-dry summers and relatively cold-wet winters. With regard to typology, the building plan is "I"-shaped as a more compact and simple form of linear placement of the individual spaces. The interior arrangement of the central part of the building volume is divided to double bay (dichoro). The traditional buildings are characterized by main spaces with high ceiling of approximately 3.5-4.5m. The high ceilings help in the isolation of heat gains on upper levels maintaining indoor spaces cooler during the summer period while enhancing the potential for natural ventilation. The traditional buildings were mostly made of materials available in the region. Thick masonry walls made of adobe and stones are the most common materials. The building under study has a 50-55cm thick stone masonry wall with rubble infill providing high thermal inertia. The thermal conductivity of the stone is estimated at 0.538W/m^{2}K based on laboratory measurements and calculations. The roof is slightly inclined and originally was comprised of a thick layer of beaten earth which was laid on matting. The roof layers were supported by timber beams. At the retrofitting stage the beaten earth was replaced with OSB and thermal insulation of 12cm extruded polystyrene giving a thermal conductivity of U value = 0.28 W/m^{2}K. The windows consists of single glazing with 30% of surface to be wooden frame of total U value 4.7 W/m^{2}K.

Figure 1. External view of the building under investigation, located at the traditional core of Aglantzia.

2.2. Field measurements

For the investigation of the thermal performance of the vernacular building, a field study has been carried out from January 2019 and is still in progress, covering all seasons. During the period under investigation, specific environmental parameters were recorded in the outdoor and indoor environment. Specifically, air temperature, and relative humidity, were measured using the UX100-003 HOBO data logger (DL) and mean radiant temperature, globe temperature and air velocity using the LSI-Lastem Heat Shield base module (ELR610M). As per the European standard EN ISO7726:2001 [11], all parameters were logged at 1.1m height from the floor. The equipment was placed in selected locations, as shown in Fig. 2.

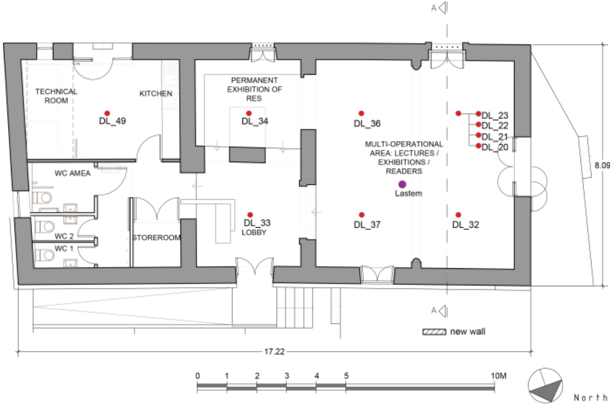

Figure 2. Plan of the building with positions of measurement equipment.

In addition, data loggers were placed in one selected position along different heights of the room, i.e. 1.1 m, 1.7 m, 2.3 m, 2.9 m in order to examine the contribution of temperature along the height. An outdoor weather station is installed in Aglantzia at the University of Cyprus at a height of 3-4 m above street level, at a small distance from the demo-site of Aglantzia (less than 1.8km).

2.3. Data analysis methodology

The objective was to evaluate the thermal comfort conditions of traditional buildings. Thermal comfort is assessed using the Adaptive Comfort Standard (ACS) which is incorporated in ASHRAE 55 [12]. The acceptable indoor operative temperatures are determined within the 80% and 90% acceptability limits, calculated as a moving average of the mean daily outdoor air temperatures (Trm), using a seven-day moving average. Particularly, the 80% acceptability limits are calculated as indicated in Eqs. (1) and (2), while the corresponding 90% acceptability limits result after subtracting 1°C from the upper 80% acceptability limit and adding 1°C to the lower 80% acceptability limit:

Upper: Tc (°C) = 0.31Trm +21.3 1)
Lower: Tc (°C) = 0.31Trm +14.3 (2)

where, Tc is the predicted comfort temperature when the running mean of the outdoor temperature is Trm.

With regards to the thermal environment, the degree-hours which fall outside both the higher and lower limit margins can be employed as a performance indicator when building either for warm or cold seasons.

3. RESULTS

The analysis of the onsite recordings includes maximum, minimum and mean temperatures of different spaces of the building, the percentage of spaces within the comfort zone and the heating and cooling degree hours throughout the year. It is worth noting that the building was free of users while the shutters, where available, were closed during the monitoring period. Figure 3 shows the indoor temperatures evolution in the different rooms of the building and outdoor temperature throughout the year.

The outdoor temperature during the winter period i.e. December to February varies from -0.59°C to a peak of 23.06°C with a mean diurnal fluctuation of 11.43°C (Fig. 4). The outdoor mean average temperature during the winter period was 11.6°C. Based on the onsite recordings, mean average temperatures in all spaces are found to be low but stable and all rooms show similar behaviour in terms of temperature. Nevertheless, it is interesting to mention that, during the winter period, the building shows much higher temperatures compared to the outside conditions. Specifically, the mean average indoor temperatures in the building during winter period range from 12.1 to 16.3°C. The results indicate that the south-oriented spaces (kitchen/technical room (DL_47) and the permanent exhibition space (DL_34) exhibits generally slightly higher temperatures and diurnal temperature fluctuations compared to the north-oriented one. Specifically, the mean maximum temperature during the winter period in the multi-purpose area (DL_20, DL_32, DL_36, DL_37) ranges from 12.3 to 16°C with a mean diurnal fluctuation varying from 0.3°C to 0.5°C; while in the south-oriented space of the kitchen/technical room and permanent exhibition (DL_47 and DL_34) the mean maximum temperature range from 12.9°C to 16.3°C with mean diurnal fluctuation varying from 1 to 1.7°C. This variation in temperatures of spaces with different orientation is mainly attributed to the impact of direct solar radiation. It is worth noting that these spaces are also not shaded by external shutters. The mean maximum temperature in the spaces under study remains lower compared to the outdoor environment however, indoor temperature fluctuations indicate that temperatures in spaces remain fairly constant. Due to their high thermal stability, all spaces present a beneficial thermal effect during night-time hours when temperatures are minimal. Specifically, mean minimum temperatures in the building range from 11.8°C to 16.0°C while the mean minimum temperature in the outdoor environment is between 4.5°C-6.7°C (Table 1).

The outdoor temperature during the intermediate spring period, i.e. March to May, varies from 2.8°C to a peak of 42.2°C with a mean diurnal fluctuation of 14.6°C. The outdoor mean average temperature during the mid-season period was 19.2°C. Regarding indoor temperatures, the highest temperatures are recorded again in south-oriented spaces i.e. kitchen/technical room (DL_47). The mean average indoor temperatures in the building ranges from 14.9°C to 15.5°C during March, from 17.4°C to 17.7°C during April and from 23.1°C to 23.7°C during May, i.e. a mean difference of 0.3-0.6°C between the spaces. It is worth mentioning that only during May the mean average temperature is within comfort levels. The building keeps thermal stability, having slightly higher mean diurnal fluctuation in each individual space, compared to the winter period ranging from 0.5 to 1.7°C. Again, the indoor mean minimum temperatures that appear during night-time are above the minimum outdoor temperatures. Specifically, the indoor mean minimum temperatures range from 14.6°C to 14.9°C during March, from 16.9°C to 17.2°C during April and from 22.7 to 23°C during May while the mean minimum temperature of the outdoor environment is 8.7°C, 11.8°C and 16.1°C respectively (Table 1).

The outdoor temperature during the summer period, i.e. June to August varies from 15.4°C to a peak of 41.1°C with a mean diurnal fluctuation of 15.1°C (Fig. 5). The outdoor mean average temperature during the summer period was of 28.8°C. Only during June and July, the average temperature of all spaces falls within the comfort zone. Regarding indoor temperatures, throughout the examined seasons, indoor maximum temperatures are, to a great extent, below maximum outdoor temperatures i.e. of 9-10°C lower and with small diurnal fluctuation i.e. from 0.7 to 1.8°C in different spaces. However, due to this low fluctuation, the indoor average temperature is always higher than the corresponding outdoor one during the whole summer period ranging from 27.7-31.7°C. The highest temperatures are again recorded in south-oriented spaces, i.e. kitchen/technical room (DL_47). Specifically, the mean maximum temperature in the kitchen ranges from 29°C to 32.8°C compared to the multi-purpose area (DL_20) that ranges from 28.6°C to 31.8°C. The indoor mean minimum temperatures that appear during night-time are, to a great extent, above the mean minimum outdoor temperatures i.e. 7.4-7.6°C during June, 7.7-8.1°C during July and 8.6-8.9°C during August, above the minimum outdoor temperature. Specifically, the indoor mean minimum temperatures range from 27.4°C to 27.6°C during June, from 29.8°C to 30.2°C during July and from 30.7 to 31°C during August while the mean minimum temperature in the outdoor environment is 20°C, 22.1°C and 22.1°C respectively.

The outdoor temperature during the intermediate autumn period i.e. September to November varies from 6°C to a peak of 15°C with a mean diurnal fluctuation of 14.3°C. The outdoor mean average temperature during the autumn period was of 21.8°C. The highest indoor temperatures are also recorded in south-oriented spaces i.e. kitchen/technical room (DL_47). The mean average indoor temperatures in the building range from 20.2°C to 30.1°C during autumn in all spaces. The average temperature indicates that the building is within the comfort levels most of the time. The mean diurnal fluctuation in each individual space ranges from 0.5 to 2.2°C. Again, the high thermal mass masonry construction leads to indoor mean minimum temperatures during night-time above the minimum outdoor temperatures, keeping the building warmer during night. Specifically, the indoor mean minimum temperatures range from 20.1°C to 29.4°C from September to November while the mean minimum temperature in the outdoor environment ranges from 10.4°C to 19.6°C (Table 1).

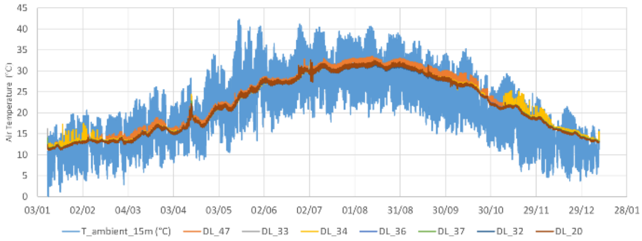

Figure 3. Indoor temperatures evolution in the different rooms of the building and outdoor temperature throughout the year.

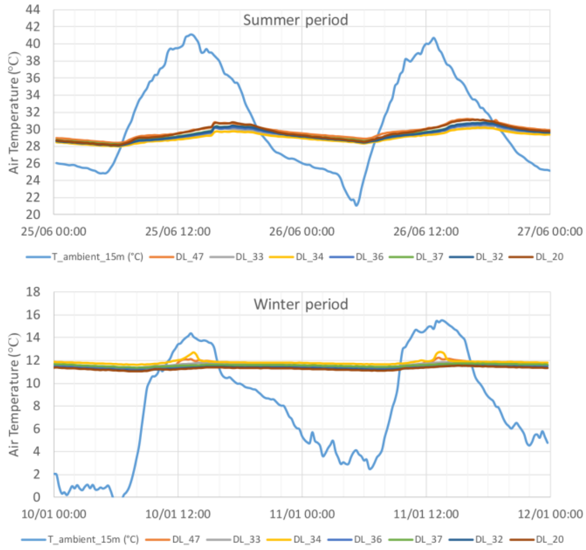

Figure 4. Indoor temperatures evolution during the warmest and coldest week of the year.

The results indicate that spaces with southern orientation could provide a warmer space during a cold, sunny winter day while spaces with northern aspect could offer greater thermal stability and a cooler space during a hot, summer day.

The results of different data loggers along different heights of the room show that during the winter period the difference is negligible (0.1°C) while during the summer period, the mean difference between the lower data logger at 1.1m and the higher data logger at 2.9m is about 0.5°C. Taking into account that the building has a mean height of 4.30m, the difference is expected to be much higher at the top. This shows the positive contribution of high ceilings, keeping indoor spaces cooler during the summer (Fig.5).

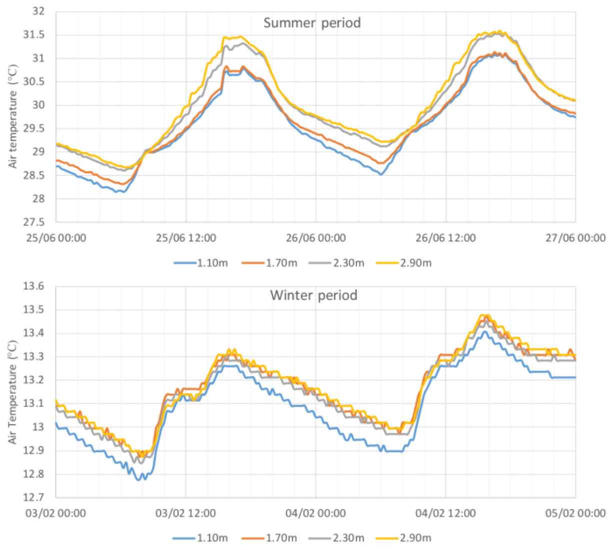

Figure 5. Indoor temperatures evolution along different heights of the room, i.e. 1.1 m, 1.7 m, 2.3 m, 2.9 m.

Table 1.Synthesis table of all the recorded temperature values (°C) carried out for the investigation of thermal comfort from January to December 2019.

Months	Mean temp.	Outdoor	DL_47	DL_33	DL_34	DL_36	DL_37	DL_32	DL_20
Jan	Min	4.5	12.0	12.0	12.2	12.0	12.1	11.9	**11.8**
	Max	16.3	12.9	12.6	**13.9**	12.4	12.5	12.3	12.3
	Average	10.0	12.3	12.2	12.4	12.2	12.3	12.1	12.1
	St. Dev.	4.2	0.6	0.5	0.6	0.5	0.5	0.6	0.6
	Diurnal flactuation	11.8	1.0	0.6	1.7	0.3	0.4	0.4	0.4
Feb	Min	6.7	13.1	13.1	13.4	13.2	13.2	**13.0**	**13.0**
	Max	17.8	**14.4**	13.5	**14.4**	13.5	13.5	13.5	13.5
	Average	12.0	13.5	13.3	13.5	13.3	13.4	13.2	13.2
	St. Dev.	3.8	0.5	0.2	0.3	0.2	0.2	0.2	0.3
	Diurnal flactuation	11.1	1.3	0.5	1.1	0.3	0.3	0.5	0.5
Mar	Min	8.7	14.9	14.6	14.9	14.8	14.8	**14.6**	14.6
	Max	21.5	**16.6**	15.3	15.5	15.3	15.3	15.3	15.3
	Average	14.7	15.5	14.9	15.2	15.0	15.0	14.9	14.9
	St. Dev.	4.5	1.4	1.3	1.3	1.3	1.3	1.3	1.3
	Diurnal flactuation	12.8	1.8	0.7	0.5	0.5	0.5	0.7	0.7
Apr	Min	11.8	17.1	**16.9**	17.2	17.1	17.1	**16.9**	17.0
	Max	24.9	**18.7**	17.9	18.1	18.0	18.1	18.0	18.0
	Average	18.1	17.7	17.4	17.5	17.4	17.5	17.4	17.4
	St. Dev.	5.2	1.7	1.6	1.7	1.7	1.7	1.7	1.7
	Diurnal flactuation	13.1	1.7	1.0	1.0	1.0	1.0	1.0	1.1
May	Min	16.1	23.0	**22.7**	22.8	22.8	22.9	22.8	22.9
	Max	33.9	**24.6**	23.7	23.5	23.7	23.8	23.8	24.0
	Average	24.9	23.7	23.1	23.1	23.2	23.3	23.2	23.4
	St. Dev.	6.7	2.1	2.0	2.0	2.0	2.1	2.1	2.1
	Diurnal flactuation	17.8	1.6	1.0	0.8	0.9	1.0	1.0	1.2
Jun	Min	20.0	27.6	27.4	**27.4**	27.4	27.5	27.4	27.5
	Max	34.8	**29.0**	28.3	28.1	28.3	28.4	28.4	28.6
	Average	27.1	28.2	27.8	27.7	27.8	27.9	27.8	27.9
	St. Dev.	5.0	1.1	1.1	1.0	1.2	1.1	1.1	1.1
	Diurnal flactuation	14.8	1.4	0.9	0.7	0.9	0.9	1.0	1.1
Jul	Min	22.1	30.2	30.0	30.0	29.9	30.0	**29.8**	29.9
	Max	37.1	**32.0**	30.9	30.8	30.9	31.0	31.1	31.2
	Average	29.4	31.0	30.4	30.3	30.4	30.4	30.4	30.5
	St. Dev.	5.1	0.8	0.5	0.6	0.6	0.6	0.7	0.7
	Diurnal flactuation	15.0	1.8	1.0	0.8	1.0	1.1	1.3	1.3
Aug	Min	22.1	31.0	30.8	30.9	30.8	30.8	**30.7**	30.9
	Max	37.5	**32.8**	31.4	31.4	31.5	31.5	31.6	31.8
	Average	29.5	31.7	31.1	31.1	31.1	31.2	31.1	31.2
	St. Dev.	5.0	0.7	0.3	0.3	0.4	0.2	0.4	0.4
	Diurnal flactuation	15.4	1.8	0.7	0.6	0.7	0.7	0.9	0.9
Sept	Min	19.6	29.4	29.2	29.3	29.1	29.1	**29.0**	29.2
	Max	34.0	**31.3**	29.7	29.9	29.7	29.7	29.7	30.0
	Average	26.5	30.1	29.5	29.5	29.4	29.4	29.3	29.5
	St. Dev.	4.7	1.2	1.0	1.0	1.1	1.1	1.1	1.1
	Diurnal flactuation	14.4	1.9	0.5	0.6	0.6	0.6	0.7	0.8
Oct	Min	15.9	25.5	26.2	25.4	26.7	26.7	26.4	**25.3**
	Max	29.8	**27.7**	26.8	25.9	27.4	27.4	27.1	25.9
	Average	22.2	26.2	-	26.6	25.7	27.1	26.8	25.6
	St. Dev.	11.8	2.0	-	1.1	1.7	0.5	0.5	1.8
	Diurnal flactuation	13.8	2.2	0.7	0.5	0.7	0.7	0.7	0.7
Nov	Min	10.4	20.4	20.2	23.0	20.4	20.2	**20.1**	20.2
	Max	25.1	**21.5**	20.7	20.5	20.8	20.6	20.5	20.7
	Average	16.8	20.8	20.3	20.7	20.6	20.4	20.2	20.4
	St. Dev.	5.6	1.3	1.2	1.3	1.2	1.2	1.2	1.2
	Diurnal flactuation	14.8	1.1	0.4	2.0	0.3	0.3	0.3	0.5
Dec	Min	6.4	15.6	15.7	16.0	15.8	15.8	15.6	**15.5**
	Max	18.3	16.3	16.1	**16.9**	16.0	16.0	15.9	15.9
	Average	11.9	16.0	16.0	16.3	16.0	16.0	15.8	15.8
	St. Dev.	4.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3
	Diurnal flactuation	11.9	0.7	0.4	0.9	0.3	0.3	0.3	0.3

*Bold indicates the peak values

Depending on the external conditions, the thermal comfort zone ranges from 17.4°C-23.5°C to 24.4°C-30.5°C for 80% acceptability and from 18.4°C-24.5°C to 23.4°C-29.5°C for 90% acceptability.

During January, February and March, the building fails to maintain indoor thermal comfort as no recorded time falls within 90% or 80% acceptability limits descripted by ASHRAE (Table 2). The maximum average temperature in the building during these three months is 15.47°C. However, it is interesting to mention that the mean minimum temperature indoor is about 7-7.5°C above the outdoor temperature. During April, the percentage within the 80% and 90% acceptability limit is only 10.3% and 3.1% of the time respectively. During May, the building is within the 80% and 90% acceptability limit for 61.7% and 52.9% of the time respectively, while during June the building achieved one of the highest percentages within the comfort zone compared to other months. Specifically, the operative temperature was within the 80% and 90% acceptability limit for 88.1% and 81.1% of the time. During July, the percentage within 80% acceptability limit drops to 46.8%. The percentage within the 90% acceptability limit drops to 4.6%. It is worth noting that the whole building fails to maintain indoor thermal comfort during August as none of the spaces exhibits temperatures within the comfort zone. However, it should be noted that although the outside temperature reaches up to about 40°C, the indoor temperature shows small temperature deviation from the acceptable limits in a range of 1 - 2.3°C difference from the 80% acceptability limit (Fig. 6). The building remained closed; therefore, the heat absorbed by the building could not be released to the outside environment leading to higher indoor temperatures. During September, the building is within the 80% and 90% acceptability limit for 50.4% and 28.6% of the time, while during October, the building is nearly all the time within the comfort zone with a percentage of 99.4% for the 80% acceptability limit. During November, the percentage is reduced to 69.8% and 60.7% for the 80% and 90% acceptability limit, while during December, the temperature falls out the comfort zone most of the time, being only 5.5% of the time within the 80% acceptability limit.

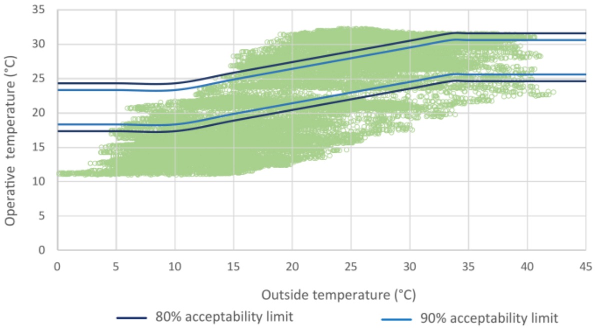

Figure 6. Brager Index of operative temperature in multi-operation area of the building from Jan. to Dec. 2019.

The onsite monitoring results during the winter period, and early intermediate period, show that the thermal comfort conditions of spaces are unsatisfactory and require a large amount of energy to keep indoor thermal comfort (Table 2). During the late intermediate period, and early summer period, the building provides acceptable indoor temperatures without the aid of an artificial system. However, the building requires much less energy for cooling. Specifically, the building needs 13 times less energy for cooling than for heating.

Table 2. Percentage of data within thermal comfort zone for the 80% and 90% acceptability limit and degree hours

	% of data within thermal comfort zone		Degree hours	
	80% acceptability	**90% acceptability**	**heating**	**cooling**
Jan.	0.0%	0.0%	2942.6	0.0
Feb.	0.0%	0.0%	3330.6	0.0
Mar.	0.0%	0.0%	3045.9	0.0
Apr.	10.3%	3.1%	1774.0	0.0
May	61.7%	52.9%	313.1	0.0
Jun.	88.1%	81.1%	0.0	25.0
Jul.	46.8%	4.6%	0.0	139.9
Aug.	0.0%	0.0%	0.0	515.9
Sept.	50.4%	28.6%	0.0	314.7
Oct.	99.4%	79.0%	0.0	0.2
Nov.	69.8%	60.7%	157.1	0.0
Dec.	5.5%	0.0%	1687.8	0.0
Total			13251.0	995.7

The recorded data for relative humidity show that for most of the time (from May to December) the building totally meets the norms with values between 40-70%. During February and March, the building exhibits higher relative humidity due to lower indoor temperatures having only 20-30% of the data between acceptable limits (Table 3).

Table 3. Summary of registered RH values throughout the year

	Absolute values RH (%)			% of data in which RH=40-70%
	max	**min**	**mean**	
Jan	72.1	55.8	67.9	79
Feb.	76.8	64.3	71.6	21
Mar.	77.8	54.1	71.1	26
Apr.	79.2	53.6	69.3	54
May	79.2	53.6	69.3	100
Jun.	71.3	43	59.6	100
Jul.	61.8	44.1	54.1	100
Aug.	64.5	43.8	56.6	100
Sep.	63.5	39.8	56.8	100
Oct.	65	47.7	58.8	100
Nov.	66.8	52.4	61.1	100
Dec.	70.0	50.5	64.6	100

For the improvement of thermal comfort and energy performance, passive measures should be considered during the normal operation of the building. Based on the bioclimatic chart (Fig. 7), during the heating period, i.e. from November to April, passive solar systems and internal gains are required. During the intermediate period, i.e. October and May, the temperatures are mild and overlap the comfort zone for the largest part of the day. During the cooling period, i.e. from June to September, a number of cooling strategies are proposed. The appropriate passive cooling design strategies include ventilation, night ventilation and evaporative cooling. Daytime ventilation should be carefully applied and restricted to the periods of the day when the exterior temperature is lower compared to the interior temperature. The high thermal mass of the building also works beneficially to the cooling of the building when combined with natural ventilation.

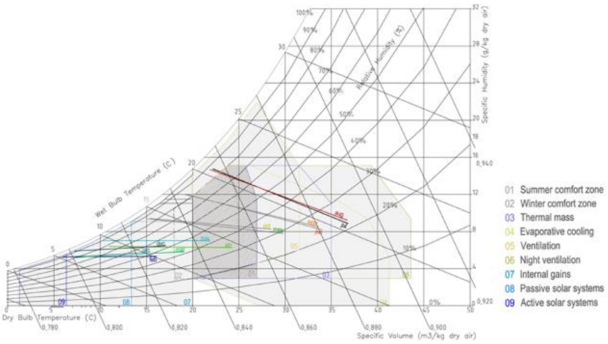

Figure 7. Plotting the Aglantzia's Weather Data at Givoni's chart.

4. CONCLUSION

This paper investigates the thermal performance of vernacular architecture in lowland area Nicosia, Cyprus in diverse climatic contexts. The findings of the current research are based on an on-site investigation carried out in a representative vernacular building that is going to be upgraded to a hands-on technology exhibition area of renewable energy systems complimented with visual means to enhance the experience of visitors under a Research European Programme (Horizon 2020). The results of the current research show that vernacular buildings perform very well during the intermediate and summer period keeping within the comfort zone most of the time, while during the winter period, the building requires additional heat gains to maintain indoor thermal comfort and acceptable relative humidity levels. This study provides a basis for the formulation of a site-specific design strategy to improve thermal conditions and achieve energy conservation within lowland constructions in diverse climatic conditions. Understanding and analysing the thermal behaviour of these spaces is the first step towards this strategy. The quantitative analysis reveals the various challenges faced and opportunities provided by lowland structures and contributes to informing current design policies. Moreover, the analysis will inform the sizing of the technical systems throughout the year.

ACKNOWLEDGEMENTS

The research described in this paper is based on the HYBUILD project funded by the European Union through HORIZON 2020 under grant agreement N° 768824.

REFERENCES

[1] S. Saljoughinejad, S.R. Sharifabad, Classification of climatic strategies, used in Iranian vernacular residences based on spatial constituent elements, Build. Environ. (2015) 475–493.

[2] A.-M. Vissilia, Evaluation of Greek vernacular settlement and its landscape: architectural typology and building physics, Build. Environ. (2009)1095–1106.

[3] M.S. Sozen, G. Z. Gedik, Evaluation of traditional architecture in terms of building physics: old Diyarbakir houses, Build. Environ. (2007) 1810–1816.

[4] M. Philokyprou, A. Michael, Evaluation of the environmental features of vernacular architecture. A case study in Cyprus, Int. J. Heritage Digital Era 1,(2012) 349–354.

[5] M. Philokyprou, A. Michael, The contribution of the courtyard to the environmental perception of residential architecture in Cyprus, in: I. Michaelides, A. Papadopoulos, A. Poullikkas (Eds.), 4th International Conference Renewable Energy Sources & Energy Efficiency, New Challenges, Nicosia, Cyprus, Proceedings, 2013, pp. 166–178.

[6] M. Philokyprou, A. Savvides, A. Michael, E. Malaktou, Examination and assessment of the environmental characteristics of vernacular rural settlements. Three case studies in Cyprus, in: M. Correia, G. Carlos, S. Sousa (Eds.), Vernacular Heritage and Earthen Architecture: Contribution to Sustainable Development, Taylor & Francis Group, London, 2014, pp. 613–618.

[7] A. Savvides, A. Michael, E. Malaktou, M. Philokyprou, Examination and assessment of insolation conditions of streetscapes of traditional settlements in the Eastern Mediterranean area, Habitat Int. 53 (2016) 442–452.

[8] A.M. Papadopoulos, D. Aravantinos, G. Ekonomides, Analysis of the energy significance of openings in modern residential buildings with traditional design in Northern Greece, in: Proceedings of the 11th International Conference Passive and Low Energy Architecture, Negev Israel, 1994, pp.455–462.

[9] E. Malaktou, M. Philokyprou, A. Michael, A. Savvides, Thermal assessment of traditional: partially subterranean dwellings in coastal and mountainous regions in the Mediterranean climate. The case of Cyprus, J. Sustain. Archit. Civil Eng. 3 (16) (2016) 82–96.

[10] M. Philokyprou, A. Michael, E. Malaktou, A. Savvides, Environmentally responsive design in Eastern Mediterranean. The case of vernacular architecture in the coastal, lowland and in the coastal, lowland and mountainous regions of Cyprus, Build. Environ. 111 (2017) 91–109.

[11] EN ISO7726 (2001) Ergonomics of the thermal environment instruments for measuring physical quantities. Brussels: International Standardisation Organisation.

[13] American Society of Heating, Refrigerating and air-conditioning engineers, in: ASHRAE Standard 55- Thermal Environmental Conditions for Human Occupancy, Atlanta, Georgia, 2013.