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Bioclimatic chart analysis in three climate zones in Cyprus

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Abstract

The concept of bioclimatic design is based on the development of an architectural design adapted to environmental conditions. The utilization of the favourable climatic elements can offer to the users, indoor thermal comfort conditions and at the same time it minimizes the energy consumption which is needed for heating and cooling. This paper provides the bioclimatic analysis for three different climatic zones in Cyprus, coastal, inland and mountainous. The building bioclimatic charts of V. & A. Olgyay are used to examine whether passive strategies can provide indoor thermal comfort in the buildings in these zones. The results of bioclimatic charts are studied in conjunction with the climatic data for the three climatic areas. These are compared and investigated in order to find whether there is sufficient amount of solar radiation for passive heating needed to achieve thermal comfort during winter. The study concludes to a preliminary guide of passive design strategies for buildings, as an outcome of the bioclimatic charts analysis for coastal, inland and mountainous zones in Cyprus. The results can be used for locations with similar climatic conditions.

Keywords

Bioclimatic chart, Bioclimatic analysis, Passive strategies, Solar radiation

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Introduction

High energy consumption causes serious problems in the world today. Buildings are responsible for the 40% of the world energy consumption.[1] Therefore, energy conservation is a fundamental concern nowadays. There is a great need, among public and private sectors for improving the energy performance of new and existing buildings such as schools, hospitals, museums, offices, dwellings, etc. However, users' indoor comfort is imperative and the goal for architects is to succeed in both energy conservation and indoor comfort.[2] Indoor air quality, energy efficiency and thermal comfort conditions are the three main aspects that affect the indoor buildings' environment.[3] Indoor environmental conditions in a building are different from the surrounding outdoor climate; indoor temperatures are usually different from the outdoor ones, even when the buildings are not mechanically heated or cooled. The actual relationship between the indoor and the outdoor environmental conditions depends to a great extent on the architectural design and the construction of buildings. Thus, the indoor climate can be controlled by building design to accommodate human comfort needs.[4,5] The human body adapts to a wide range of environmental conditions. It is impossible to define or to achieve optimal conditions for all the people at the same time or always.[6] So a practical definition of thermal comfort is the absence of discomfort.[7] The desired result of bioclimatic building design is to create conditions without discomfort that is neutral situation.

Air temperature should be considered in relation to other environmental and personal factors as an indicator for thermal comfort. The six environmental and personal parameters that influence the thermal comfort condition

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in a particular place accordingly to American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) standards are air temperature, thermal radiation, air speed, humidity, clothing insulation and activity through metabolic rate.[8] Olgyay and Olgyay[9] reported that the climatic conditions in which people are in bioclimatically comfortable conditions consist of: relative humidity between 30% and 65%, temperature between 21°C and 27.5°C and wind speed up to 5 m/s.

Using solar energy for heating and cooling, as well as enhanced ventilation, the negative impact on environment would be reduced.[10] This is the reason for using bioclimatic charts; they are based on information about the local climate which is defined by its geographical location, topography and meteorological phenomena. The charts of Olgyay and Olgyay[9] plot the dry bulb temperature against relative humidity using Cartesian coordinates. Building bioclimatic charts offer a way of testing whether or not passive control strategies are likely to produce comfortable conditions inside the buildings.

The main aim of this research is to use the bioclimatic charts in order to determine the appropriate techniques and strategies to achieve indoor comfort conditions for the three climatic zones in Cyprus. The available solar radiation is assessed and compared with the thermal needs derived from the analysis of bioclimatic charts. Additionally, its potential and effectiveness for passive heating is examined.

Climatic parameters

The climatic parameters with daily or seasonal characteristics determine the climate and have a high importance in the concept of bioclimatic building design. The climatic parameters that influence bioclimatic design are air temperature, relative humidity, solar radiation and wind speed.[11]

The island of Cyprus has an intense Mediterranean climate with a typical seasonal rhythm. Hot dry summers from mid-May to mid-September and rainy, rather changeable, winters from November to mid-March are separated by short autumn and spring seasons of rapid change in weather conditions. At latitude 35° north and longitude 33° east, Cyprus has a day length between 9.8 h in December to 14.5 h in June. It has hot summers and mild winters but this generalization is modified when considering the topography and the altitude which lowers temperatures by about 5°C per 1000 m and of marine influences which give cooler summers and warmer winters. Differences between day maximum and night minimum temperatures are quite large in Cyprus especially at inland areas during summer. These diurnal fluctuations are in winter 8–10°C on the lowlands and 5–6°C on the mountains increasing in summer to 16°C on the central plain and 9–12°C elsewhere. In July and August the mean daily temperature ranges between 29°C on the central plain and 22°C on the Troodos mountains, while the average maximum temperature for these months ranges between 36°C and 27°C, respectively. In January the mean daily temperature is 10°C on the central plain and 3°C on the higher parts of Troodos mountains with an average minimum temperature of 5°C and 0°C, respectively. Elevation above mean sea level combined with distance from the coast affects considerably the relative humidity. Humidity ranges between 65% and 95% during winter days and nights throughout a year. Near midday the summer humidity is decreased with values on the central plain usually a little over 30% and occasionally as low as 15%. All parts of Cyprus enjoy a very sunny climate compared with other European countries. In the inland and eastern lowlands, the average number of hours of bright sunshine for the whole year is 75% of the time that the sun is above the horizon. Over the whole summer (6 months) there is an average of 11.5 h of bright sunshine per day whilst in winter this is reduced only to 5.5 h in the cloudiest months in December and January.[12]

Methodology

Description of bioclimatic charts

Olgyay and Olgyay[9] were the pioneers of bioclimatic charts (Figures 1 and 2). They proposed a process of building design which is based on human thermal requirements and local climatic conditions. In the bioclimatic charts they determine the comfort zone in relation to air temperature, humidity, mean radiant heat, wind speed, solar radiation and cooling by evaporation. The climatic data that are necessary in order to design the bioclimatic charts are the maximum and minimum air temperatures and the corresponding minimum and maximum relative humidity values, either monthly, daily or hourly. The resulting graphs represent the external conditions. Although the indoor environmental conditions of the building depend on many other factors such as the size, the thermal inertia of the materials and air transportation, the charts clearly show whether indoor conditions are hot, cold or comfortable. Their most important role is that they determine the heating and cooling design strategies for restoring comfort during different months all over the year.[6]

The bioclimatic charts are usually applied in areas with temperate climate and buildings where the activity is mainly sedentary and users wear regular dressing. The dry bulb temperatures are recorded on the abscissa axis and the relative humidity in the ordinate axis. The comfort zone is defined between 21°C and 27.5°C and is

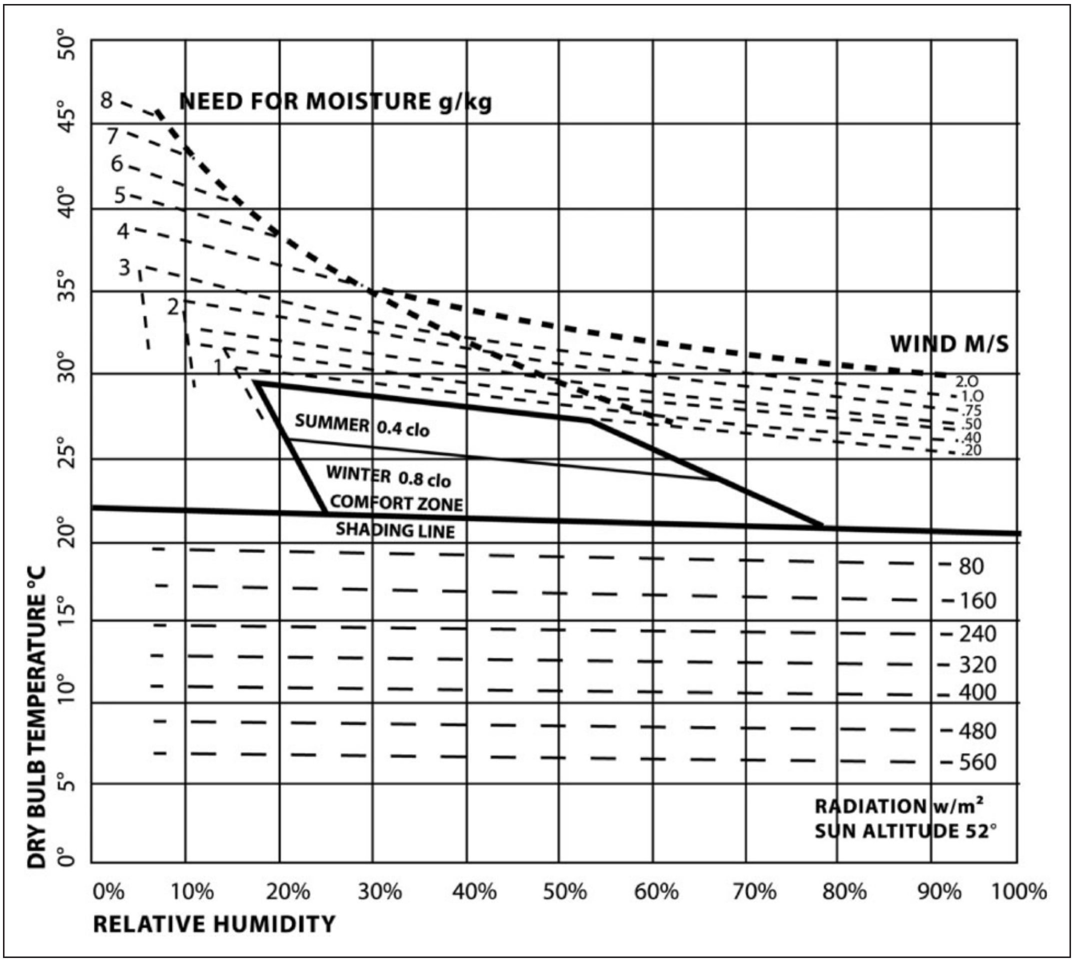


Figure 1. Quantitative bioclimatic chart.

removable slightly down for the winter and slightly upward for the summer. The relative humidity is defined between 30% and 65% with acceptable limits of 20–78%. The lower limit of the comfort zone defines the temperature of 21°C; above that shading devices are required. The area of the trapezoid defines the comfort zone. The comfort zone separates the map into two regions. The region above the boundary line or the shading line is known as over-heated summer period and therefore the sun protection of openings is required. The lower area below the shading line is known as under-heated winter season, and therefore additional heat or solar radiation is necessary.[13]

Through the analysis of the quantitative bioclimatic chart three main areas are clearly shown. If the intersection of temperature and relative humidity is above the comfort zone, to the right side, air movement is needed. The air speed needed is expressed with the parallel lines in units (m/s). The combination of high temperature and low relative humidity creates the feeling of hot, dry environment and increase of the moisture content is required. The dashed curves on the top left of the chart define the required moisture for thermal comfort (g/kg). Below the shading line with temperatures lower than 21°C solar radiation is needed to restore thermal comfort. The amount of the required solar radiation is illustrated with the contours (broken lines) and is expressed in units of W/m^2.

The qualitative bioclimatic chart (Figure 2) has the same basis as the quantitative chart (Figure 1). The qualitative chart defines the strategies to be employed in order to achieve thermal comfort. Twelve different strategies are shown on this chart and often one strategy coexists with another or others. The qualitative chart is divided in the area above the shading line which specifies the cooling strategies and the area below the shading line which defines the heating strategies. The cooling strategies are represented by five bands: the natural ventilation which may be achieved by air movement; the radiative cooling with high thermal mass where materials can retain heat during the day and emit cooling at night; the thermal mass combined with night ventilation; the evaporative cooling through evaporation of water and conventional air

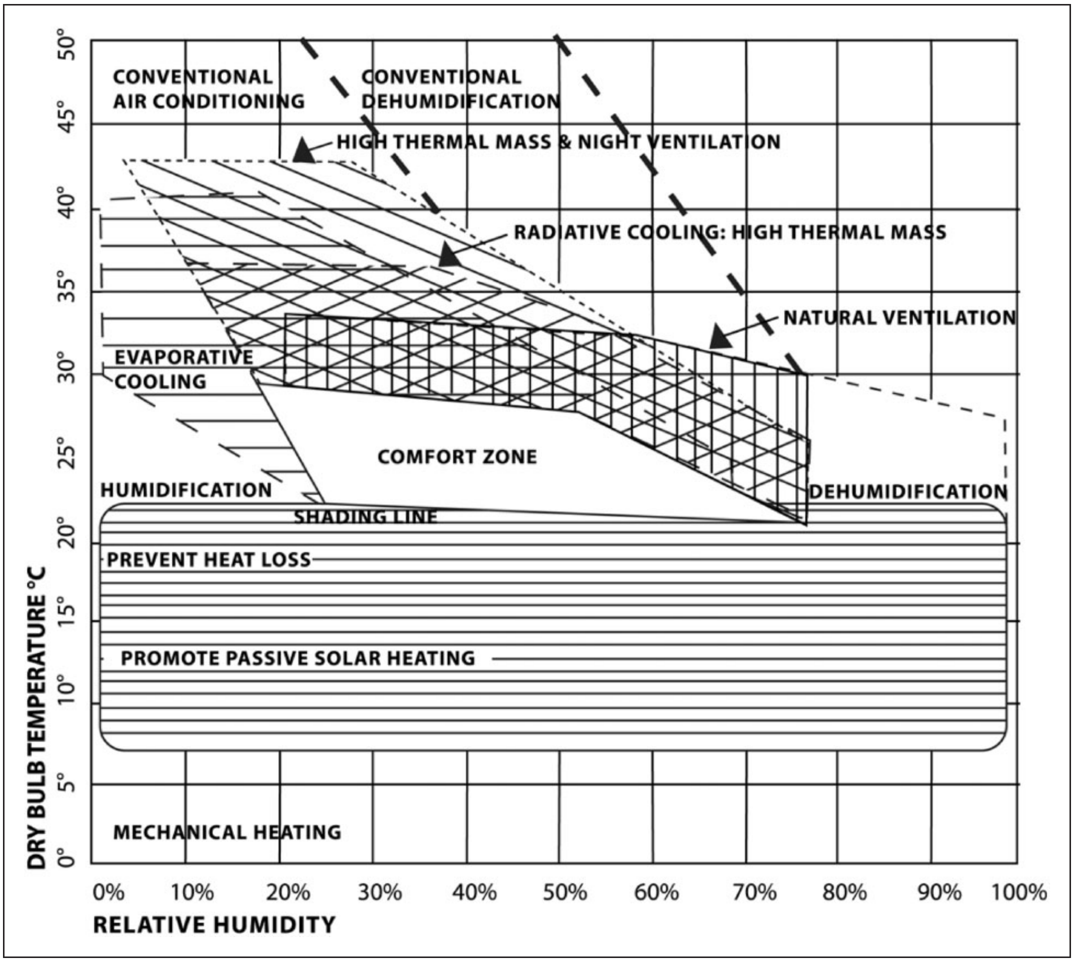


Figure 2. Qualitative bioclimatic chart.

conditioning with mechanical means. This part of the chart is further divided into three more zones which are affected by the levels of relative humidity. These are humidification, dehumidification and conventional dehumidification with mechanical means. Heating strategies are defined by two zones below the shading line: the zone which requires prevention of the thermal losses; this is achieved with proper insulation of the building combined with the provision of passive solar heating which may be obtained from solar radiation and the zone which requires mechanical heating.[6]

Parameters and assumptions for the creation of bioclimatic analysis

During this research three different climatic zones in Cyprus are studied. Data are collected for a coastal, an inland and a mountainous area which are represented by the Limassol city, Nicosia city and the Prodromos village. The incurred bioclimatic analysis is intended as preliminary guide for building design.[6] In order to create the bioclimatic analysis, some assumptions have been made:

- The thermal resistance of clothes is defined in units of Clo. Clothing insulation may be expressed in Clo units (1 Clo = 0.155 k.m^2/W). The clothes would be at average levels of 0.8 Clo during winter and 0.4 Clo during summer according to the ASHRAE Standard 55-2010.[8]
- The values of solar radiation are taken with an average height of the sun at 52° according to the data of the Meteorological Service of Cyprus.[12]
- The taken values of temperature and humidity are those of an average day for each month conferring to the daily measures of Meteorological Service of Cyprus for the last decade. These are presented in pairs of the average maximum temperature and the minimum relative humidity and, respectively, the average minimum temperature with the maximum relative humidity. This is represented with a linear line based on the formula T = f (RH%). Specifically this linear line represents the changes in temperature and humidity on an average day of each month.

Results

Bioclimatic analysis for three different climatic zones in Cyprus

The bioclimatic chart analysis enables us to determine the appropriate strategies to be adopted in the building design in order to achieve indoor thermal comfort. Due to the different climatic conditions in each climatic zone different studies are made.

Climatic data, bioclimatic chart analysis and strategies for a coastal area

For the studies of the coastal area the city of Limassol was selected. Limassol is the second largest city of Cyprus with extensive building development. The meteorological data are obtained from the 'public garden' station which is located at an altitude of 8 m, latitude 34°41′ and longitude 33°03′.

According to the collected data for the last decade from the Meteorological Service of Cyprus, the mean daily minimum air temperature for Limassol in February is 8.5°C and the mean daily maximum temperature in August is 33.3°C. The difference during the day and night is about 8–10°C. The humidity has high values during the early morning hours (Table 1). On the basis of the climatic data the bioclimatic charts are created (Figures 3 and 4). The values of the mean daily minimum and maximum temperatures are combined with the maximum and minimum relative humidity, respectively. The lines are created representing the various months and

Table 1. Mean daily temperatures and corresponding relative humidity for each month in Limassol.

Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean daily maximum temperature		17.6	17.8	20.0	22.9	26.9	30.8	33.2	33.3	31.3	28.6	23.5	18.9
Mean daily minimum temperature		8.8	8.5	10.4	13.0	16.7	20.1	22.4	22.7	20,6	17.7	13.5	10.1
Mean relative humidity	08:00 a.m.	77	73	69	68	68	70	72	74	69	69	73	80
	14:00 p.m.	60	58	55	58	55	57	57	57	55	52	56	60

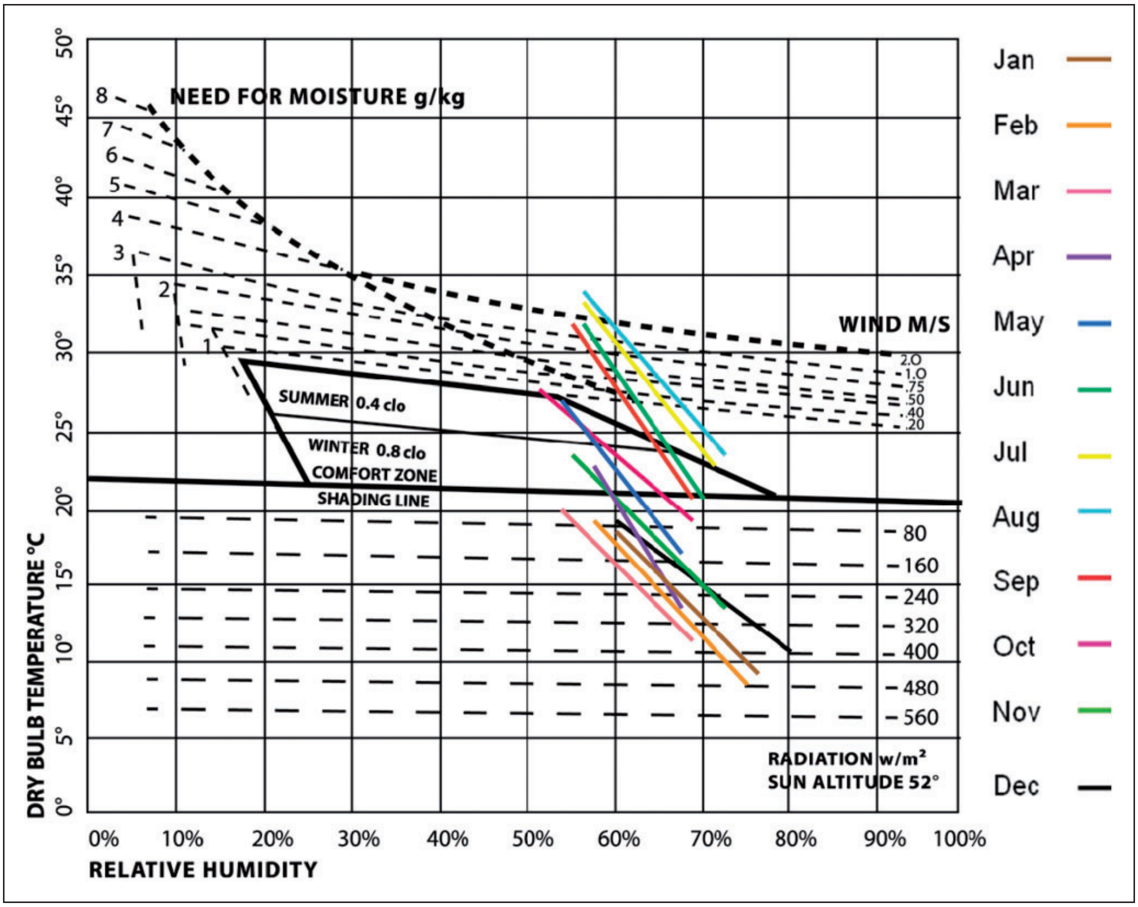


Figure 3. Quantitative bioclimatic chart for Limassol.

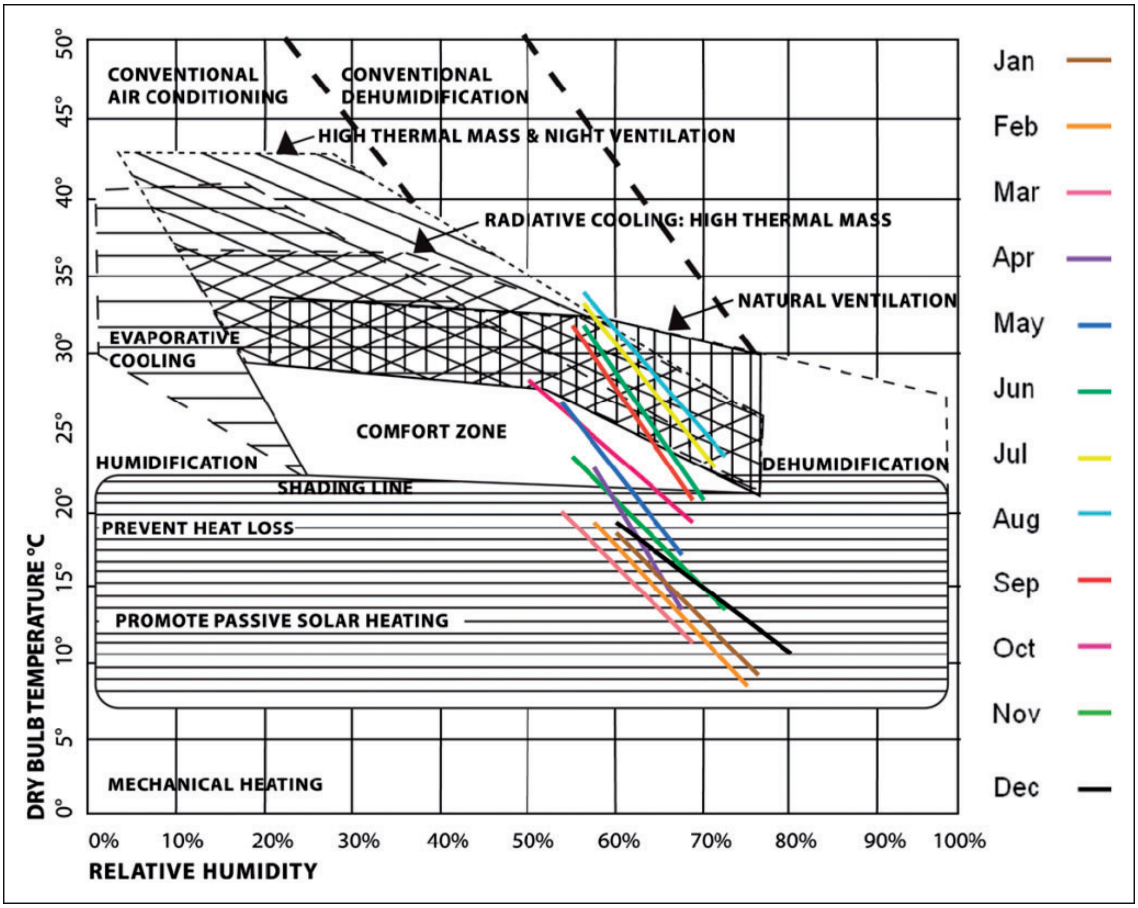


Figure 4. Qualitative bioclimatic chart for Limassol.

reflect the external conditions. For better legibility each month is drawn with a different colour.

From the analysis of bioclimatic charts it is concluded that in this coastal area of Limassol there is no need for mechanical heating or cooling during winter and summer. For the colder months of December, January, February and March, the main strategy for heating is to prevent heat losses and to promote passive solar heating through solar radiation. The solar gains that are needed during these months as indicated on the chart range from 0 to 460 W/m^2. During the months of April and November, the climatic data are identical and the monthly lines fall in two zones specifying different strategies. Part of these months needs prevention of heat losses and promotion of solar radiation. Shading is also partially required to restore comfort. Prevention of heat losses, especially in the first days of May is still needed. In the largest part of May shading is also necessary. June begins in the comfort zone but as July is approaching the high temperatures appear to be more frequent. For this reason the increase of thermal mass combined with night ventilation is a necessary strategy. Natural ventilation with wind speeds up to 1.5 m/s and shading devices are essential. The summer period and especially July and August should be reinforced by natural ventilation with wind speeds up to 2 m/s. Passive cooling by increasing the mass of the building also seems to be appropriate. The high rates of relative humidity during these months demand strategies with enhanced night ventilation. The dehumidification is also required during summer. September is milder than the other hot months. Natural ventilation is still required to achieve comfort. Shading is necessary and high thermal mass of the building is required in conjunction with night ventilation to reduce high temperatures. Most parts of the October month fall within the comfort zone. In the very early days of this month, the temperatures are still high especially during the midday hours and therefore natural ventilation is recommended with wind speed up to 0.3 m/s. Shading is still needed during most of October.

Climatic data, bioclimatic chart analysis and strategies for an inland area

For the studies of the inland area, the city of Nicosia is selected. Nicosia is the capital and the largest city of

Table 2. Mean daily temperatures and corresponding relative humidity for each month in Nicosia.

Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean daily maximum temperature		15.5	16.2	20.1	24.2	29.6	34.6	37.8	37.1	33.4	28.7	22.5	17.2
Mean daily minimum temperature		5.4	5.7	7.8	11.0	15.4	20.2	22.8	22.4	19.2	15.7	10.7	7.3
Mean relative humidity	08:00 a.m.	84	83	73	63	52	47	51	59	60	67	76	85
	14:00 p.m.	56	55	45	40	34	28	27	30	33	38	46	57

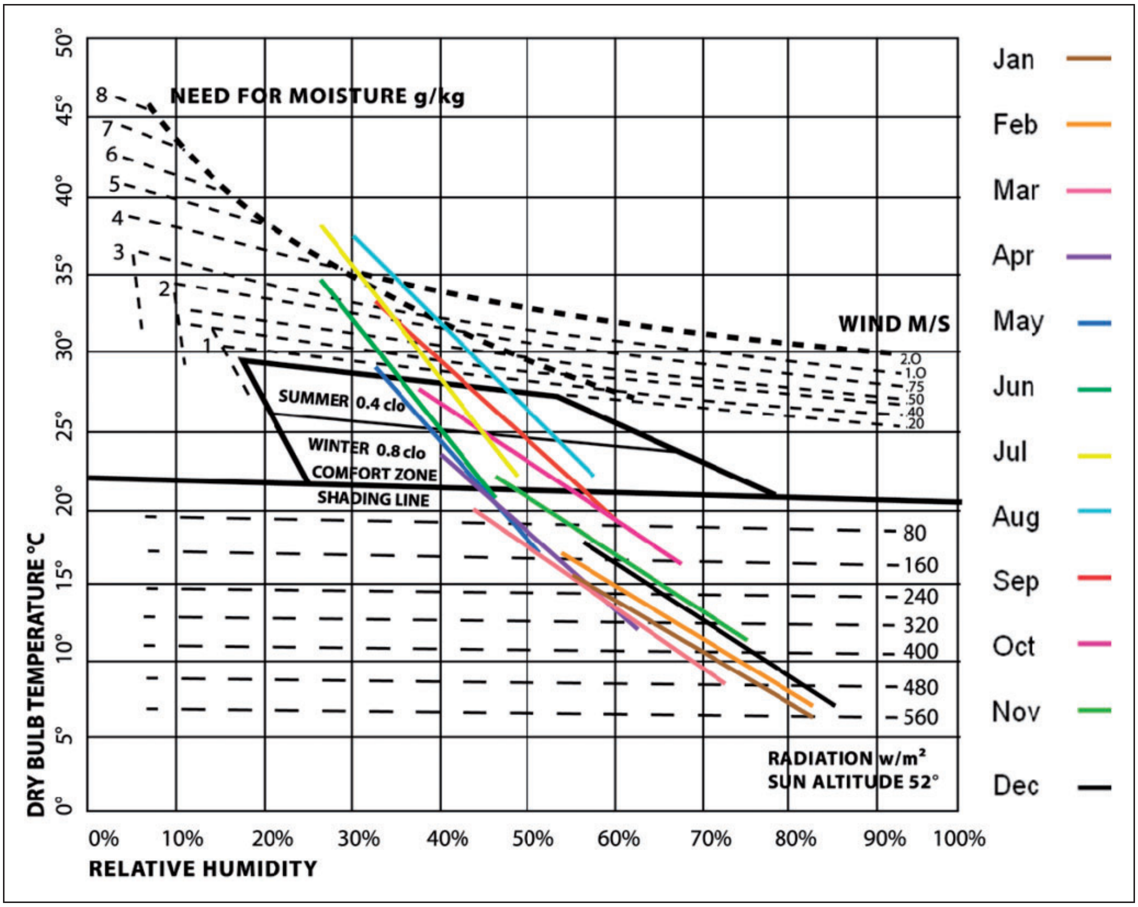


Figure 5. Quantitative bioclimatic chart for Nicosia.

Cyprus. It is located geographically in the centre of the island. The meteorological data are obtained from the 'Athalassa' station which has an altitude of 162 m, latitude 35°09′ and longitude 33°24′. According to the climatic data for the city of Nicosia, the mean daily minimum temperature in January is 5.4°C and the mean daily maximum temperature in July is 37.8°C (Table 2).

On the basis of the climatic data, the bioclimatic charts are created (Figures 5 and 6). It is observed that the monthly lines for Nicosia have longer length than the ones drawn for Limassol. This is due to the increased temperature diurnal fluctuation. Mainly in summer months these differences rise up to 15°C.

From the chart analysis, it is shown that the winter months fall into two different zones. The promotion of passive solar heating and the prevention of heat losses are the main strategies which have to be employed. The heating needs are high and besides passive solar heating mechanical means are needed during the peak days of winter. The solar radiation which is needed is 560 W/m^2. During spring and specifically in March, the temperatures are still low and this can be compensated by solar radiation up to 470 W/m^2. April and May and the autumn months of October and November have similar demands. Three different strategies can offer comfort conditions in the buildings. Parts of these months and during some hours per day, solar gains are still needed.

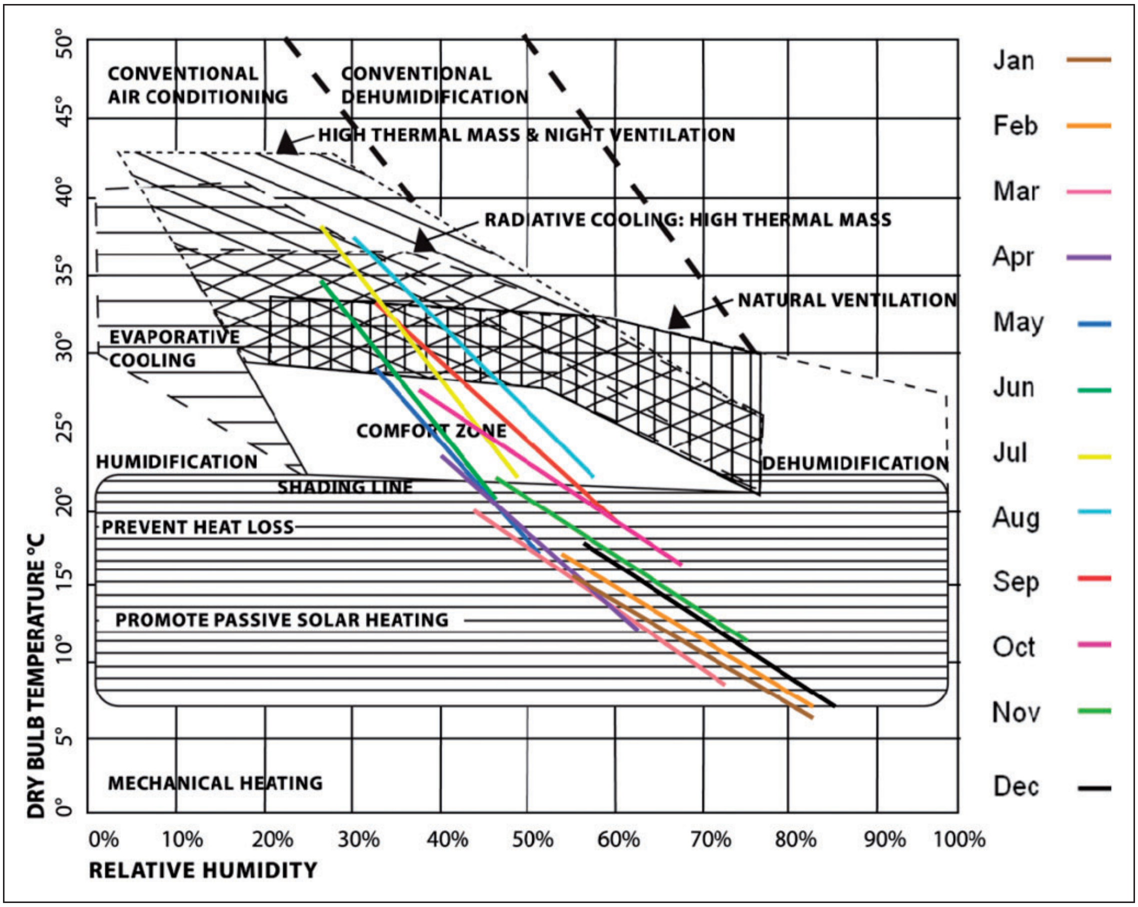


Figure 6. Qualitative bioclimatic chart for Nicosia.

The prevention of heat losses is necessary so as to maintain comfort conditions inside the building. Shading is also required during some hours per day to avoid overheating. As the summer is approaching, natural ventilation with air velocity up to 1.5 m/s in June is needed. June has similar climatic characteristics with September. Thus, September needs 2.0 m/s of wind speed for cooling. Cooling for these 2 months seems to be achieved also by evaporative cooling and high thermal mass combined with night ventilation. Throughout July and August which are the hottest months of the summer, the humidity presents low percentages and an amount of 3–3.5 g/kg of moisture is needed. The bioclimatic charts show that shading is necessary during the day hours of July and August in order to avoid the direct solar radiation and the increase of temperature in the building. This strategy is derived from the linear lines which correspond to these months and are above the shading line of the chart. Natural ventilation with increased wind speeds to 2.0 m/s is also essential. Cooling may also be achieved through evaporative cooling and the increase of thermal mass in conjunction with night ventilation. The combination of these strategies can reach impressive results because of the large daily temperature differences especially in inland areas.

Climatic data, bioclimatic chart analysis and strategies for a mountainous area

For the studies of the mountainous area in Cyprus, Prodromos village is selected. Prodromos is about 60 km northwest of the city of Limassol. It is built at an average altitude of 1380 m and is the highest village in Cyprus. It is characterized by cold and rainy winters and dry summers.

According to the climatic data the mean daily minimum temperature in February is 0.3°C and the mean daily maximum temperature in July is 18.4°C (Table 3).

In Prodromos, the temperature diurnal fluctuation during the day is small and the humidity differences almost do not exist especially in the summer (Figures 7 and 8). Thus, the linear lines representing the months have small length and are almost perpendicular to the **x-axis (abscissa).

Between November and April low temperatures prevail and therefore a combination of strategies must be applied in order to reach thermal comfort conditions. For this reason the available solar radiation must be

Table 3. Mean temperatures and corresponding relative humidity for each month in Prodromos.

Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean daily maximum temperature		6.3	6.6	10.3	15.1	20.5	25.0	28.1	27.9	24.4	19.6	12.8	8.0
Mean daily minimum temperature		0.7	0.3	2.8	6.3	11.1	15.2	18.4	18.2	14.9	11.3	6.2	2.5
Mean relative humidity	08:00 a.m.	78	73	64	54	47	41	34	36	43	54	65	77
	14:00 p.m.	76	71	63	55	49	43	38	42	44	52	65	77

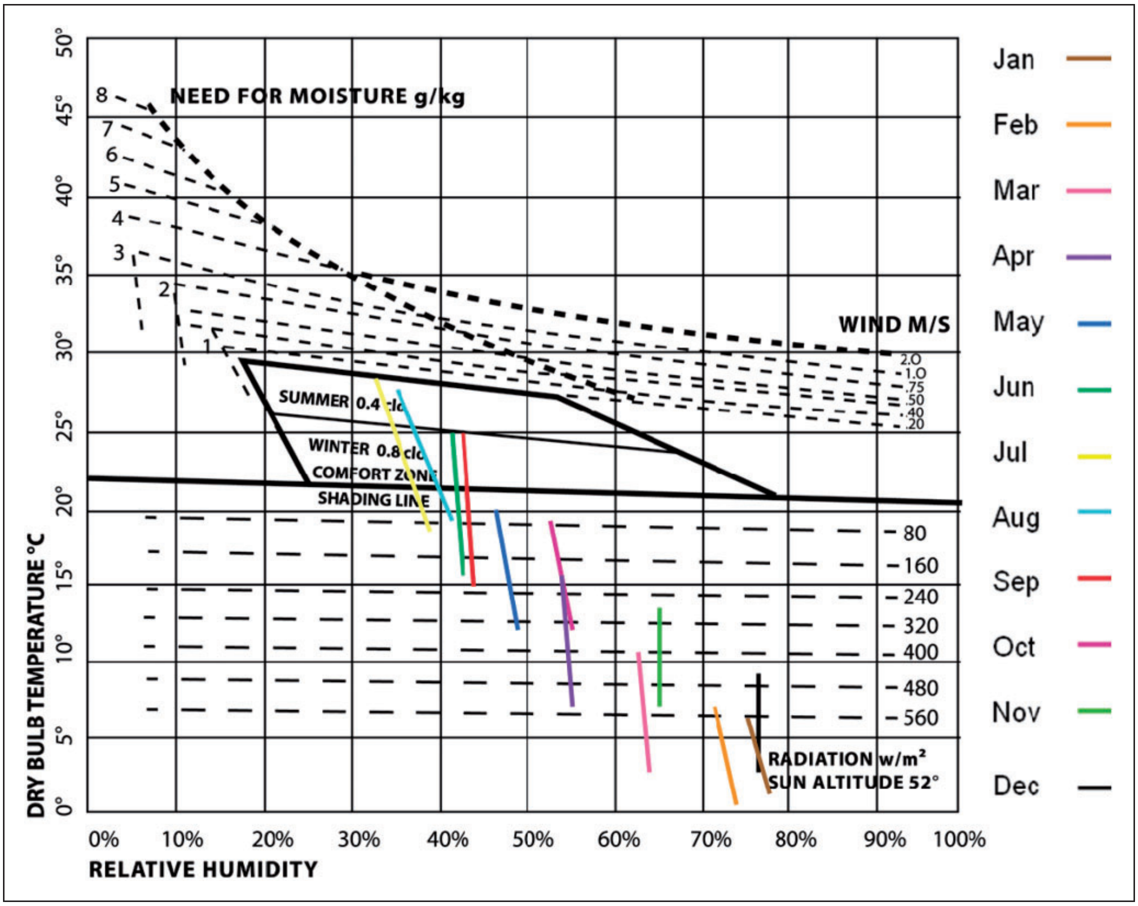


Figure 7. Quantitative bioclimatic chart for Prodromos.

utilized to the maximum level. Furthermore, a combination of strategies and techniques to prevent heat losses must be adopted. The passive heating strategies are not adequate in the mountainous zone and additionally mechanical heating is needed at least between December and March. In the remaining months of autumn and spring, the need of passive solar heating through radiation is still necessary but there is no need for mechanical heating. The months of September and June have similar climatic conditions. The months' lines partially falling to the comfort zone but techniques for prevention of heat losses are still needed. In the early days of September and late June, during the midday hours shading is also required to avoid overheating. The summer months of July and August are mostly at comfort level. Part of these months as shown in the charts still necessitates prevention of heat losses. This corresponds to the low nocturnal temperatures during these months. The results of solar radiation needs and the summer cooling needs, such as shading, wind, moisture, are summarized for all the three climatic regions in Table 4.

Assessment of solar radiation and bioclimatic chart analysis

In this stage the results from bioclimatic charts are compared with the measurements and data of the last

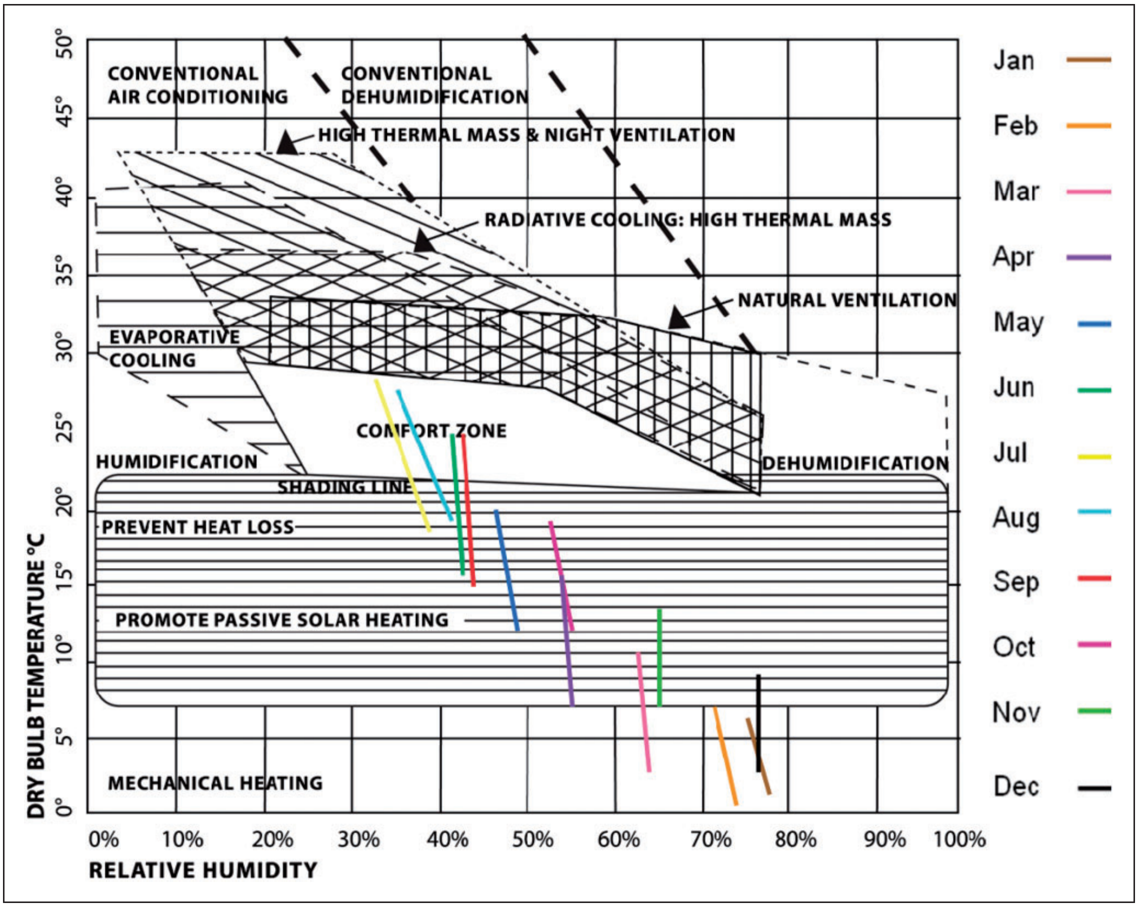
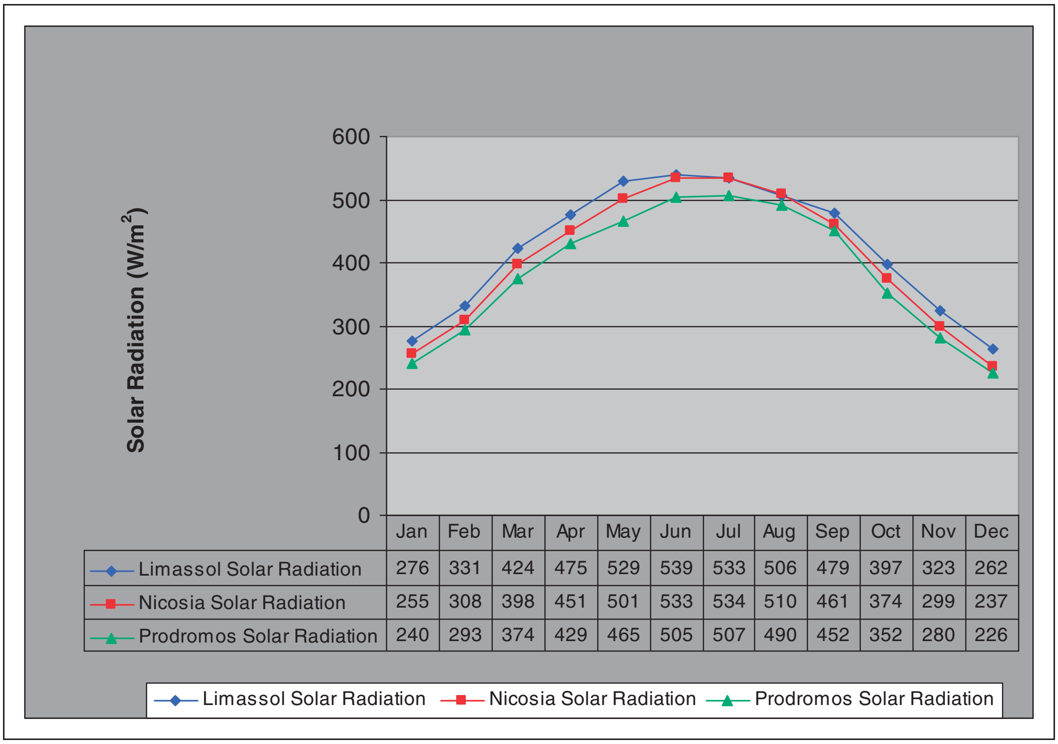


Figure 8. Qualitative bioclimatic chart for Prodromos.

Table 4. Combined results of the passive needs derived from the quantitative bioclimatic chart for costal, inland and mountainous area.

	Required solar radiation (W/m^2)			Required shading (%)			Required wind speed (m/s)			Required moisture (g/kg)		
Months	Costal	Inland	Mountainous	Costal	Inland	Mountainous	Costal	Inland	Mountainous	Costal	Inland	Mountainous
Jan	80–420	180–560	>560	0	0	0	–	–	–	–	–	–
Feb	60–460	120–540	>560	0	0	0	–	–	–	–	–	–
Mar	0–350	0–470	>400	0	0	0	–	–	–	–	–	–
Apr	0–300	0–340	200–540	17	17	0	–	–	–	–	–	–
May	0–140	0–140	0–340	61	59	0	–	0–0.1	–	–	–	–
Jun	0	0	0–230	96	92	38	0–1.5	0–1.5	–	–	0–3.5	–
Jul	0	0	0–90	100	100	70	0–2.0	0–2.0	–	–	0–3.5	–
Aug	0	0	0–80	100	100	75	0–2.0	0–2.0	–	–	0–3	–
Sep	0	0	0–240	96	88	35	0–1.5	0–1.0	–	–	0–3	–
Oct	0–20	0–170	190–320	80	49	0	0–0.3	–	–	–	–	–
Nov	0–260	0–340	260–520	23	7.5	0	–	–	–	–	–	–
Dec	60–380	0–540	>440	0	0	0	–	–	–	–	–	–

30 years for the three climatic zones obtained from the Meteorological Service.[13] The comparisons conclude to whether the available solar radiation is adequate to provide the passive heating necessary to achieve thermal comfort conditions. From the mean daily solar radiation on a horizontal surface for the three climatic zones, it is observed that mean daily solar radiation is ranging between 200 and 550 W/m^2 with higher



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Limassol Solar Radiation	276	331	424	475	529	539	533	506	479	397	323	262
Nicosia Solar Radiation	255	308	398	451	501	533	534	510	461	374	299	237
Prodromos Solar Radiation	240	293	374	429	465	505	507	490	452	352	280	226

Figure 9. Mean daily solar radiation on a horizontal surface for coastal, inland and mountainous.

values on the coastal area and the lower on the mountainous area (Figure 9). During the summer months between June and August, there is an increase of the mean solar radiation in all climatic zones. June has the longest day length of the year and therefore it seems to have slightly more solar radiation than the other months. In July the levels of solar radiation are higher in inland zone than the coastal. It is evident that the mountainous area also enjoys sunshine all year round.

Comparative studies were also carried out between solar radiation needs for thermal comfort in the three climatic zones and the available daily solar radiation at 12 p.m. for January, April and July (Table 5, Figure 10). The amounts of maximum solar radiation in this comparison are much higher than the mean daily global radiation. This is due to the fact that the mean daily solar radiation is the sum of daily solar radiation divided by the average length of day hours. Whereas the daily solar radiation is the radiant energy emitted by the sun during a day, the length of a day is defined as the time of each day from the moment that the upper limb of the sun's disk appears above the horizon during sunrise to the moment when the upper limb disappears below the horizon during the sunset.[12] This explains the lower value of mean solar radiation in comparison with the maximum solar radiation at midday during the 3 aforesaid months.

Table 5. Daily solar radiation at 12 p.m. in the three climatic zones.

Hour		Jan 21 (W/m^2)	Apr 21 (W/m^2)	Jul 21 (W/m^2)
Limassol	12 p.m.	565	933	978
Nicosia		502	966	962
Prodromos		480	862	929

In January there is a substantial need of passive heating and it is observed that for coastal area of Limassol, the value of available solar radiation is much higher than the solar needs. The comparison between the passive heating needs extracted from the charts and the high solar radiation during noon hours verifies the results of bioclimatic charts which concluded that mechanical heating in winter is not needed if maximum solar radiation is utilized. On the other hand, the comparison shows that inland area of Nicosia lags a small amount of solar radiation and Prodromos has the biggest difference between available solar radiation and needed. Comparison between mean solar radiation and maximum solar radiation (Figures 10 and 11) for the three areas shows clearly that the maximum radiation at midday hours is twice higher than the mean radiation during the day.

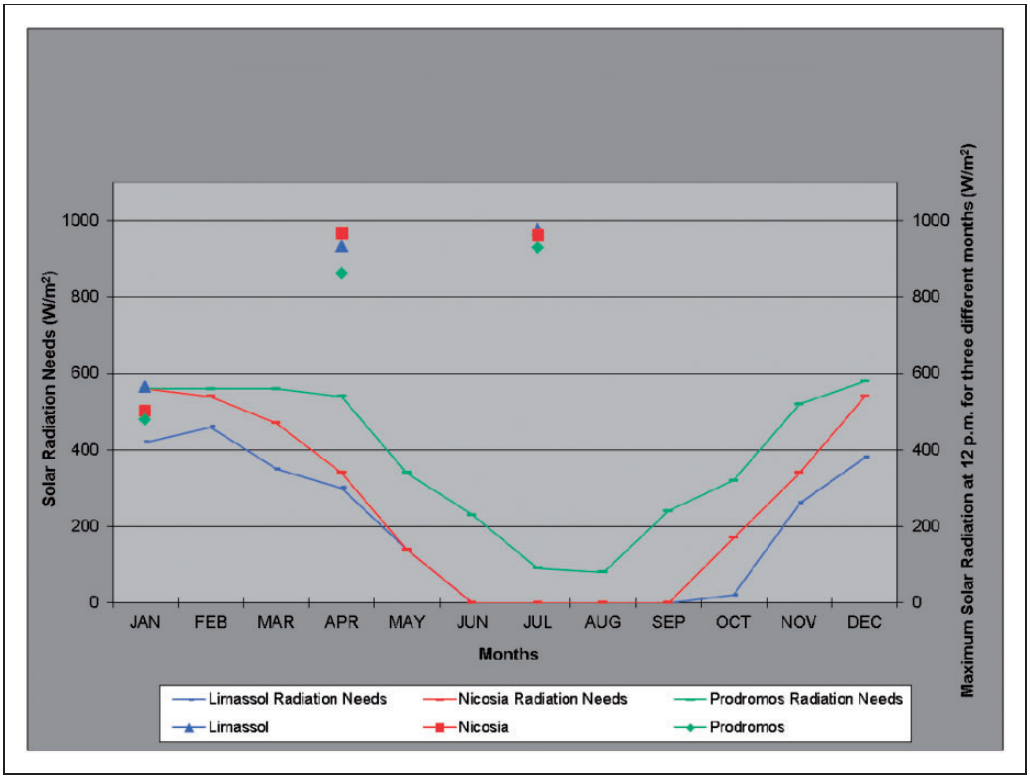


Figure 10. Comparison between solar radiation needs and maximum solar radiation gains at 12 p.m. for the 3 months in three different climatic zones.

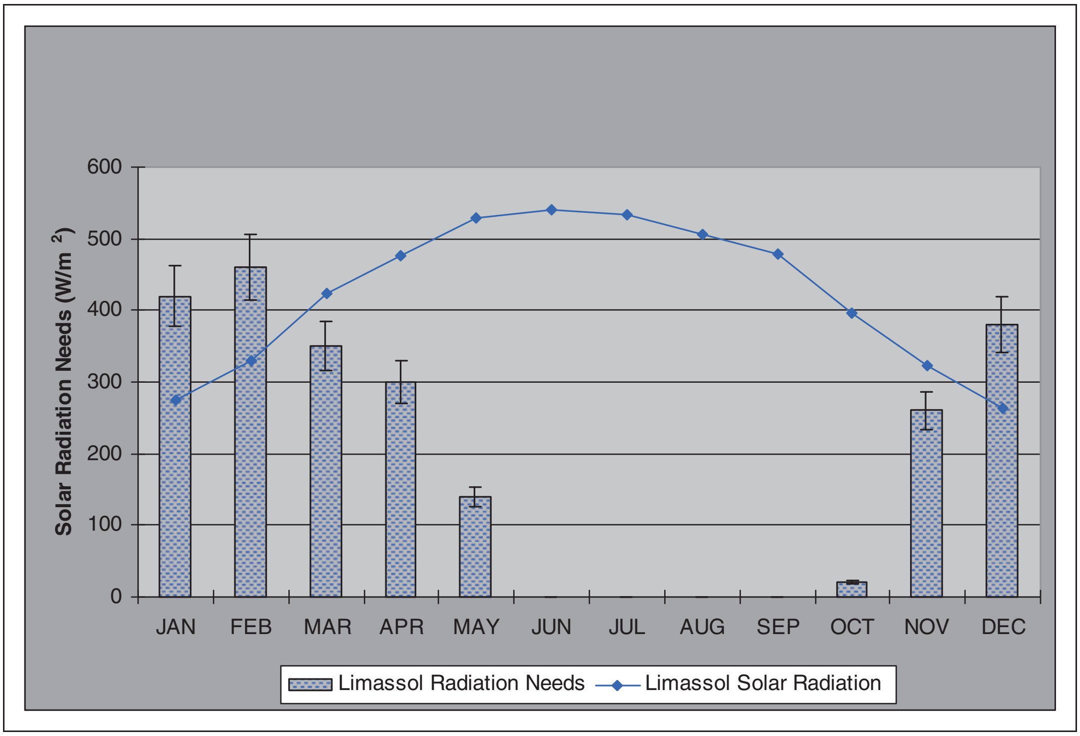


Figure 11. Mean daily solar radiation and the corresponding radiation needs or passive heating in coastal area of Limassol.

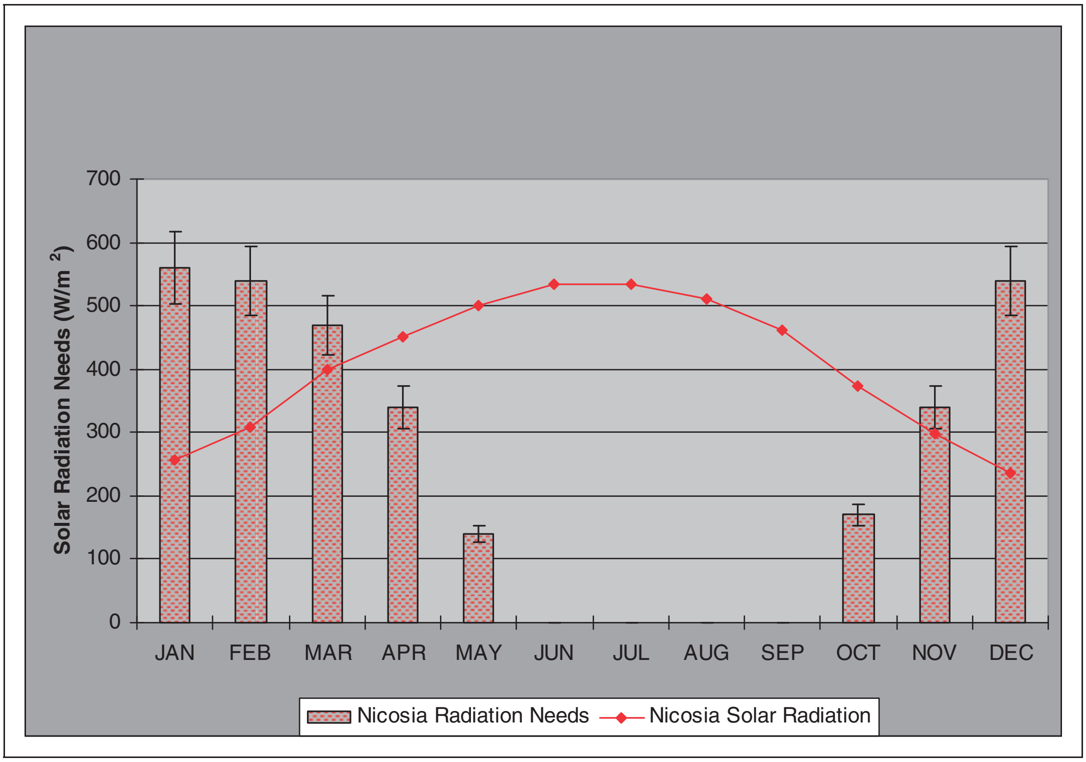


Figure 12. Mean daily global solar radiation and the corresponding radiation need in inland area of Nicosia.

This implies that the solar radiation should be distributed during the hours with less or no solar radiation. This strategy will enable all three areas to utilize solar gains for passive heating and in many cases to avoid mechanical heating during winter.

The mean solar radiation for each climatic zone is further compared with passive solar needs as derived from the bioclimatic charts for each month (Figures 11 to 13). The aim is to indicate whether or not mean solar radiation is sufficient for each region in order to use it for passive heating during winter. For the coastal area the passive heating needs are partially covered by the available daily average values of solar radiation per month (Figure 11). For the fulfilment of needs without the use of mechanical instruments between December and February, additional techniques are required. The utilization of passive heating with the storage of high amounts of solar radiation during the midday hours (Figure 10) and the distribution of heating late at night will serve well in this case.

The statistical error that occurs in the research is calculated. The error is symbolized by the vertical line above and below the bars on graphs and it is the amount by which an observation differs from its expected value (Figures 11 to 13). For coastal and inland areas, the error is 10% and for mountainous areas because of the extreme weather events the error rises up to 20%.

From the analysis of the inland area of Nicosia it is noticed that Nicosia has higher solar needs than Limassol during winter (Figure 12). An increase of solar radiation needs is presented during the months of November to March and it seems that the mean solar radiation is not sufficient to provide thermal comfort conditions. With the appropriate passive techniques the maximum solar radiation of midday hours may be utilized and this may reduce the mechanical heating especially in November and March. Nicosia's bioclimatic charts show that during the winter months the need for mechanical heating cannot be avoided completely. Peak days may also need mechanical heating to restore thermal comfort.

From the analysis of Prodromos mountainous area the mean solar radiation is not sufficient for heating during the winter period and specifically during November to April (Figure 13). April is the only month that can be satisfied if midday solar radiation is used properly. In the mountainous areas the temperatures are too low during the winter period. Therefore, techniques such as greenhouse application could serve well for the utilization of the available solar radiation and the reduction of mechanical heating.

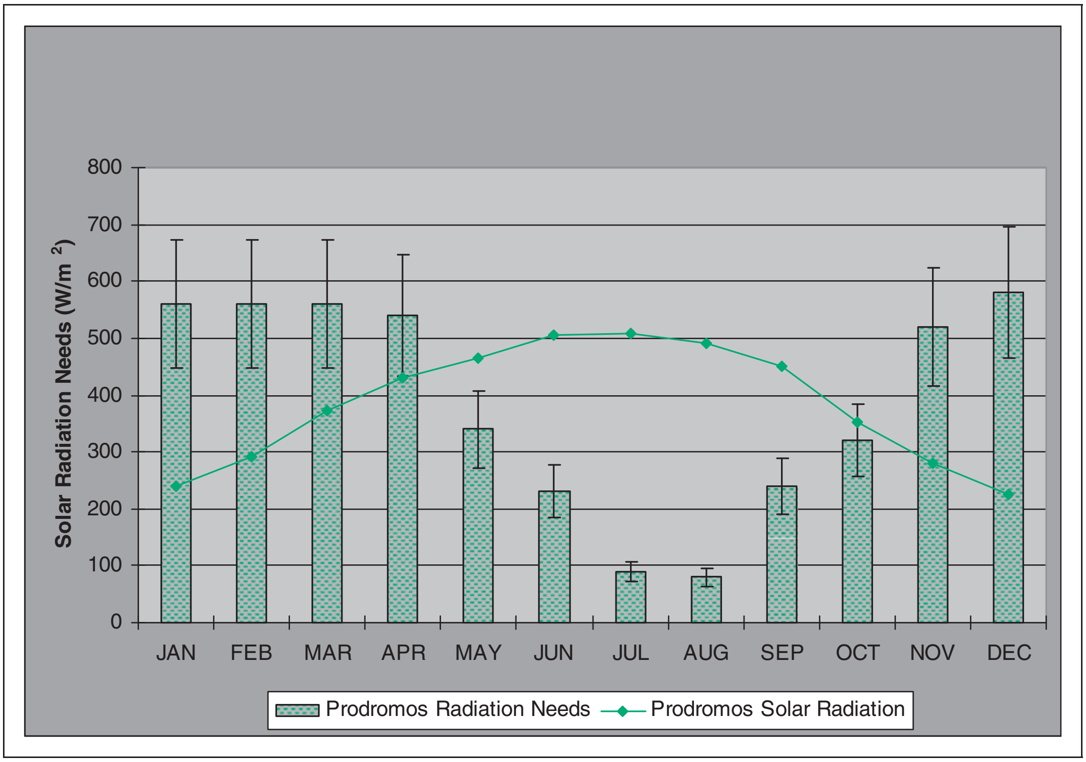


Figure 13. Mean daily global solar radiation and the corresponding radiation needs in mountainous area of Prodromos.

Discussion

The three climatic areas generate dissimilar results through bioclimatic charts' analysis.[14] The results show that different bioclimatic analysis for each climatic region is necessary.[10] An important finding of this research is that none of the three climatic areas need mechanical cooling during summer if all the passive cooling strategies derived through the charts are applied. Cooling by evaporation and thermal mass in a combination with night ventilation will serve effectively for summer. In coastal areas due to the increased humidity levels there is a need for dehumidification by mechanical systems to minimize the discomfort. The mountainous areas of Cyprus do not have any cooling needs during summer time. The area with the greatest needs for cooling seems to be Nicosia as a result of the high temperatures which appear mostly during the day hours in the summer. Although the cooling requirements are high especially in Nicosia, bioclimatic analysis shows that passive cooling techniques are adequate in order to succeed thermal comfort.

On the other hand in the winter period, the available solar radiation is not sufficient to provide the needed passive heating. Mechanical heating is required mainly on the mountainous areas and lesser to the inland and coastal zones mainly during the peak cold days of winter. Prodromos shows increased demands in heating as a result of the low temperatures during winter. However, mechanical heating during winter could be avoided in coastal areas if the appropriate passive strategies which are proposed through the charts are employed. In all three climatic areas the promotion of solar radiation in combination with the prevention of the thermal losses are the two main strategies for passive heating.

It is expected that energy amounts which are now consumed for cooling and heating can be minimized resulting to considerable energy savings.[15] The results on the charts show that Nicosia has the longer comfort periods and Prodromos the shorter ones. The shading requirements in the three climatic areas are vital; particularly in Limassol and Nicosia shading is needed for 8 months of the year. From the charts it is observed that the inland district of Nicosia presents the need of added moisture during the summer period.

The comparative study between the results of bioclimatic charts and the climatic data of available solar radiation indicates whether passive strategies can restore thermal conditions. Comparisons are made with the mean global available solar radiation and the maximum available solar radiation at midday hours. Heating needs are satisfied by the available solar radiation in most months in coastal and inland areas. In the coastal area of Limassol, the available solar radiation in the winter period exceeds the required radiation for passive heating especially during midday hours. The inland climatic zone in the peak days of December, January and February requires mechanical heating. Mountainous area represented by Prodromos, during the months December to March has very high heating demands which exceed 560 W/m^2; thus mechanical heating is necessary. The exact amount of heating demand in such areas is not included in the charts, so a projection is made (through the statistical error) in order to estimate the real needs.

The results of bioclimatic charts are verified through the assessment and the comparison with the available solar radiation. However, studies on bioclimatic design are continuously being carried out throughout the years[16] and more advanced and specific charts are developed.[17] In future work new analysis will be made through more detailed bioclimatic charts in order to find the most suitable tools and methods for bioclimatic analysis.

Conclusions

The prime purpose of this paper was to analyse the bioclimatic charts for three different climatic areas in Cyprus: coastal, inland and mountainous. The aim was to extract the most appropriate and effective applicable design strategies quantitatively and qualitatively, for preliminary passive design of buildings. The bioclimatic charts which are used in this study are plotted for the three main climatic zones of Cyprus concluding to the main strategies which have to be adopted for indoor comfort. The results with the appropriate strategies for each area can be used as a preliminary guide for bioclimatic design before the detailed architectural analysis. It is expected that this approach of bioclimatic analysis and strategies will assist architects and engineers in Cyprus and in similar climatic locations for appropriate bioclimatic design for passive buildings.

Authors' Contribution

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