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Energy Conservation In Buildings With Passive Heating & Cooling Strategies In Greece's Climatic Zones

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ABSTRACT: *Buildings are a major energy consumer, which at the same time has a high potential for energy savings. With the use of appropriate technical and cost-effective technologies, it is possible to achieve a significant improvement in the energy efficiency of buildings with corresponding environmental and social benefits. In the energy performance of a building, the use of bioclimatic design techniques is of a particular importance. This term describes the design, which, taking into account the local climate, seeks to achieve the best indoor comfort conditions, utilizing the available natural resources and minimizing energy consumption. Passive heating and cooling systems are systems that use natural sources (sun, wind, etc.) to heat or cool a building without the use of mechanical means. The goal of selecting passive systems is to improve thermal comfort while simultaneously saving energy for as long as possible. This document examines the possibility of providing thermal comfort conditions in the regions of Greece with different climatic conditions, with the application of passive heating and cooling strategies. The bioclimatic analysis is carried out with the help of the Olgyay bioclimatic charts, adapted for temperate climates. The results reflect the impact of passive design strategies on the occupants' thermal comfort and give designing guidelines to architects and engineers for energy-independent buildings.*
KEYWORDS: *Passive strategies; Olgyay's method; bioclimatic charts; climatic zones;* comfort zone.

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I. INTRODUCTION

The Chinese philosopher Confucius (551-479 BC) said that if every person solves the minor problems that concern him then the big problems of humanity will also be resolved [1]. One of the most important problems of humanity is the over-consumption of energy in the building sector, which causes adverse effects on the environment. Each user of a building, individually, can help minimize energy consumption. According to Janda (2011), the major problem of climate change is nowadays widely known, resulting in increased public interest and the attention of people, directed to minimizing energy consumption in buildings [2].

Therefore, in the architectural design of buildings, particular attention is given to the recognition of the climatic conditions of each area, which should be taken into account and used accordingly, in order to avoid unnecessary energy losses and to provide thermal comfort to occupants of buildings [3, 4].

According to Roaf et al. (2001), buildings are part of a complex interaction between humans, the climate and the environment. Architectural design of buildings should be based on the following principles:

1. design based on the climate,
2. design based on the environment,
3. time-based design

Buildings should therefore be designed in such a way that they are adapted to the particular climatic and environmental conditions of each place and to the particular requirements of each time period, be it day or night, season of the year or the life of the building [5].

Also, Hui and Tsang (2005) refer to the importance of examining the local climatic conditions of each area in the architectural design of buildings with the aim of reducing energy consumption and ensuring comfortable, sustainable and healthy living space [6].

Bioclimatic design is based on climate analysis, including solar and air energy, uses passive and environmental energy sources to achieve human comfort through the design and construction of buildings, including heating, cooling and lighting [7].

Therefore, the need to protect the environment, by reducing and eliminating, where possible, the use of fossil fuels and consequently energy consumption has led building designers to increasingly apply passive bioclimatic design strategies. In this way, thermal comfort inside buildings, a healthy environment for the occupants and environmental protection are ensured [8].

In short, energy-efficient buildings are the ones that ensure indoor comfort conditions with minimal energy consumption [9]. The comparison between climate and thermal comfort is a fundamental step in the implementation of energy efficiency in buildings. It defines passive and bioclimatic design strategies that best fit in a particular climatic environment, as well as the measures a building designer has to implement in order to build a building based on the principles of bioclimatic design [10].

II. MAJOR CLIMATE PARAMETERS

The main climatic factors that determine the climate of a place and are taken into account in the bioclimatic design of buildings are air temperature, relative humidity, solar radiation and wind speed [11].

Air temperature (T): Air temperature (^{o}C) does not remain constant, it is increasing in the day due to the heat coming from the sun's radiation and decreasing night due to its diffusion to space. It is influenced by the topographical relief of the area, the gradient, the sun and air exposure, the vegetation and the capacity of absorption or reflection of the sun's radiation from the materials of the surrounding environment (soil, water, constructions, etc.) [12]. The air temperature measured by the common thermometers is called a dry bulb temperature and is given in meteorological predictions [13]. During the design process of a building, the following values are taken into account [14]:

- Average monthly maximum temperature
- Average monthly minimum temperature
- Absolute monthly maximum temperature
- Absolute monthly minimum temperature

Relative Humidity (RH): Relative humidity (%) is the ratio of the amount of air vapor content to the amount of water vapor that would be contained if it was saturated under the same pressure and temperature conditions [15]. Inside a building the desired relative humidity is 40%-60%. When the relative humidity is less than 20%, problems are caused to the people respiratory system and to the eyes, and when it rises above 70% to 80%, serious problems are caused on human health [16]. The relative humidity value is higher in the morning when the temperature is low and changes over the rest of the day. It also depends on the presence of lakes, rivers, seas, groundwater and vegetation in the area due to evapotranspiration. The relative humidity value is also influenced by the sun's radiation [15].

Solar radiation: Solar radiation is considered to be the only renewable energy source that all buildings can use and is a source of heat [17]. The energy of the sun reaches the earth's surface, as direct, reflected and diffuse radiation. When the sun's radiation enters a vertical surface, the radiation is direct and produces large amounts of heat. During a cloudy day, 100% of solar radiation can be diffused, while in the sunny day less than 20% is diffused into the atmosphere. Also, the amount of solar radiation that eventually reaches the earth surface depends on cloud, atmospheric pollution, location and time [18].

Wind speed: Knowledge of wind speed is considered necessary in the architectural design of buildings as it helps to exploit the dew resulting from the wind in the summer and to avoid cold winds in the winter. The wind speed, under normal conditions, is about 0.1m/sec. Smaller speeds don’t leave the heat to dissipate from the body. Speeds higher than 0.2m/sec during the winter months are undesirable as they give the feeling of coldness but during summer they relieve the heat [12].

III. INTERPRETATION OF THE BIOCLIMATIC CHART

To identify passive design strategies, a bioclimatic analysis is performed using the Olgyay bioclimatic charts, redrawn for temperate climates, light clothing (0.4 clo for summer and 0.8 clo for winter) [19, 20], limited activity and solar radiation determined for mean altitude of the sun 52° [11, 21, 22].

From the quantitative bioclimatic chart of Victor and Aladar Olgyay (Fig. 1), it is noted that the comfort zone is at the center, with the summer zone above the winter zone. The lowest limit of the comfort zone is the Shading Line. Around the comfort zone and above the shading line, periods of high temperatures (summer) are represented where shading is required in percentage, representing the part of the month or the day that shading is required. Curved lines show the necessary cooling operations to restore the feeling of comfort. Below the shading line, low-temperature periods (winter) are represented where supplementary heat is required [11]. The limits of the trapezoidal comfort zone are defined as follows [23]:

- Temperature 21-27.5°C.
- Relative humidity 30-65%, with acceptable values within the 20-78% range.

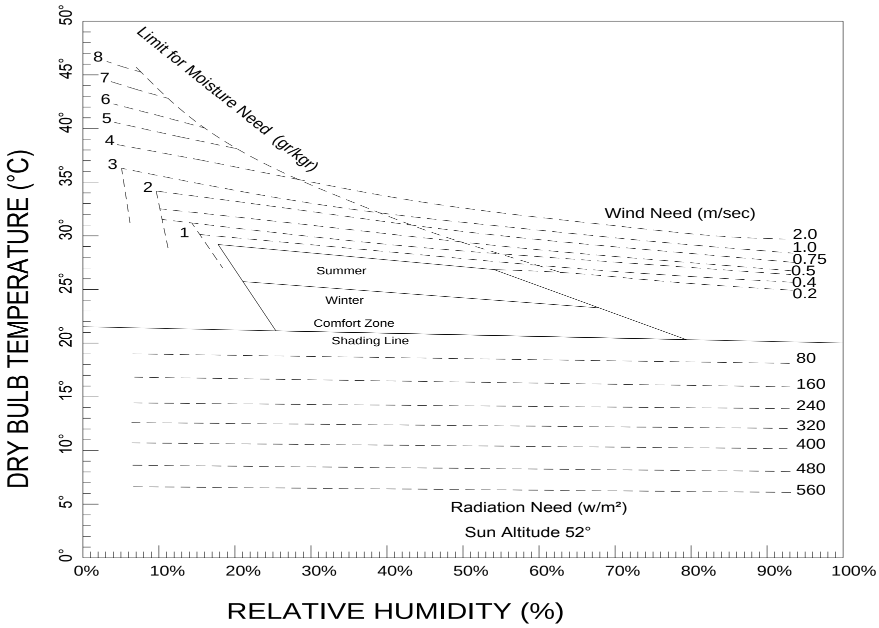

Fig. 1. Quantitative bioclimatic chart of Victor and Aladar Olgyay, adapted to temperate climatic conditions, redrawn by the authors [11, 22].

For the creation of the bioclimatic charts of a region, the air temperature, maximum and minimum values for each month (daily or hourly values) and the relative humidity values minimum and maximum respectively should be known. These values, per month, are placed in a Cartesian coordinate system, with the relative humidity (RH) as abscissa in %, and the dry bulb temperature (T) as ordinate at °C [23, 24]. So the lines, for each month are drawn and they represent the external environmental conditions.

The following cases are distinguished [11].

- If the line is within the comfort zone, the building users feel comfortable, but if it's outside the comfort zone, designing strategies (heating or cooling) must be applied to restore comfort.
- If the line is above the comfort zone and right, i.e. high temperature and relative humidity (summer conditions), cool air is required at the speed (m/sec) specified by the parallel lines in the diagram. This eliminates the excess heat.
- When the temperature is high and the relative humidity is low, i.e. heat and drought (summer conditions), the points are located above and to the left in the bioclimatic diagram. So the humidity of the air must be increased, which can be achieved with evaporation and lowering of temperature. The curved lines on the bioclimatic diagram determine the moisture required in gr/kgr to provide comfort conditions.
- In winter, where low temperatures are present, with points located below the shading line, to obtain comfort, heat from solar radiation is required up to 560w/m^2 (maximum amount of solar radiation in temperate climates) either from another source of energy.

From the qualitative bioclimatic chart (Fig. 2), the strategies that can be applied by the designer of a building in order to ensure thermal comfort conditions are determined. It is also noted that in several cases potential strategies overlap each other [22, 25]. Above the shading line, the cooling strategies are distinguished, which are (Table 1):

- Natural Ventilation: It is achieved by simply moving of the air through windows and other openings, chimneys or ventilation towers, etc.
- High Thermal Mass: The materials of a building have the ability to absorb heat during the day and to re-emit it into the atmosphere during the night. In this way, the thermal mass of the building

contributes to its cooling, during the summer [26].

- High Thermal Mass and Night Ventilation: It combines the emission from the building materials of the heat absorbed during the night, with simultaneous natural ventilation, thus cooling is achieved as the temperature is low at night.
- Conventional Air Conditioning: This is the cooling achieved by the use of mechanical means (air conditioning units).
- Evaporative Cooling: Evaporation of water reduces temperature during the summer.
- Humidification: A decrease in temperature is achieved by increasing the relative humidity levels of the atmosphere.
- Dehumidification: When the relative humidity levels are high, the feeling is that the temperature is much higher and the feeling of discomfort increases, reducing can be achieved by adequate ventilation of the room.
- Conventional Dehumidification: It reduces relative humidity levels by using mechanical means (dehumidifiers, air conditioners, etc.).

Below the shading line, the heating strategies are distinguished, namely:

- Prevent Heat Loss-Passive Solar Heating: The avoidance of heat loss can be achieved by adequate thermal insulation of the building and the use of passive solar systems which utilizes solar radiation.
- Mechanical Heating: Mechanical means are used in order to heat the building.

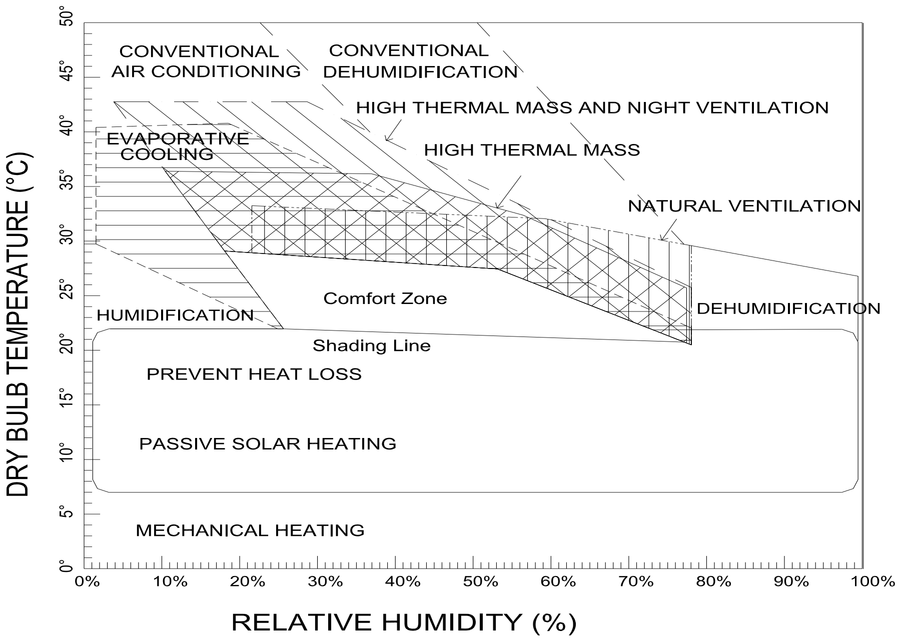

Fig. 2. Qualitative bioclimatic chart of Victor and Aladar Olgyay, adapted to temperate climatic conditions, redrawn by the authors [11,22].

Table 1. Symbolism of applied strategies in the qualitative bioclimatic chart.

Mechanical Heating	M.H.	**Comfort Zone**	C.Z.
Promote Passive Solar Heating-Prevent Heat Loss	P.P.S.H.-P.H.L.	**Evaporative Cooling**	E.C.
Shading Line	S.L.	**Dehumidification**	D.
Humidification	H.	**High Thermal Mass & Nigh Ventilation**	H.T.M. &Ni.V.
Natural Ventilation	N.V.	**Conventional Dehumidification**	C.D.
High Thermal Mass	H.T.M.	**Conventional Air Conditioning**	C.A.C.

IV. APPLICATION OF OLGYAY METHOD FOR CLIMATE ZONES A, B, C, AND D

The topography of Greece is very intense and varied; it includes large mountainous volumes, as well as many coastal areas, plains and many islands. In addition, in coastal areas and islands there are sea-breezes, which differentiate the human sensation in the prevailing environmental thermal conditions [27]. The climate of Greece is characterized as a typical Mediterranean, winters are mild and rainy and summers are relatively hot and dry, and sunshine prevails over long periods of time [28]. According to the article 6 of the K.EN.A.K. 2017, Greece is subdivided into four climatic zones with different climatic characteristics, A, B, C and D (from the warmest to the coldest) [14, 29].

A bioclimatic analysis of a region per climatic zone by applying the method of the Olgyay brothers follows. The measurements from meteorological stations of the National Meteorological Service are used, namely the values of the mean maximum and minimum monthly temperature in °C, as well as the corresponding values of average minimum and maximum monthly relative humidity in % (Table 4, 7, 10, 13), [30].

Applying the mean maximum temperature - mean minimum relative humidity (point 1) and the mean minimum temperature - mean maximum relative humidity (point 2) for each month in the bioclimatic charts, the monthly lines arise, which represent for a given month, the average daily cycle of outdoor climatic conditions and describe a specific climatic situation and its impact on human comfort needs [31]. The lines representing each month are assigned with a different color on bioclimatic charts (Table 3).

- In the climatic zone A, the prefecture of Chania is selected, where the meteorological station is located in Souda (Table 2).
- In the climatic zone B, the prefecture of Achaia is selected, where the meteorological station is located in Araxos (Table 2).
- In the climate zone C, the Prefecture of Thessaloniki is selected, where the meteorological station is located in Mikra (Table 2).
- In the climate zone D, the prefecture of Kozani is selected where the meteorological station is located (Table 2) in Kozani.

These counties represent the remaining prefectures of the zones that are included, as they are characterized by similar climatic characteristics.

Table 2. Meteorological stations of Hellenic National Meteorological Service (HNMS).

Meteorological station	Latitude	Longitude	Altitude
Souda	35° 33’	24° 07’	151,6m
Araxos	38° 09’	21° 25’	11,5m
Micra	40° 31’	22° 58’	4,8m
Kozani	40° 18’	21° 47’	625,0m

Table 3. Color display of months in quantitative and qualitative bioclimatic Olgyay charts.

J	F	M	A	M	J	J	A	S	O	N	D

From the analysis of the quantitative and qualitative bioclimatic charts for the climatic zones A (Fig3, Fig4), B (Fig5, Fig6), C (Fig7, Fig8) and D (Fig9, Fig10), the heating and cooling strategies to be applied in the design and construction of the building are concluded (Table6, 9, 12, 15) as well as the values of sunshine, shading, wind energy and moisture needs (Table5, 8, 11, 14), so as to provide thermal comfort to the occupants.

Table 4. Mean maximum and minimum monthly temperature in °C and corresponding relative humidity in % for climate zone A.

Month			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Climatic Zone A														
Prefecture of Chania														
Point 1	max RH(%)	X1	98,2	98,0	97,2	97,6	97,3	93,2	92,8	93,2	94,9	97,4	97,9	98,1
	min T(°C)	Y1	8,5	8,5	10,1	12,4	15,9	19,9	22,4	22,6	20,1	16,6	13,1	10,2
Point 2	min RH(%)	X2	36,2	34,2	26,2	18,6	22,8	19,2	20,8	23,9	26,9	34,2	37,3	40,8
	max T(°C)	Y2	14,4	14,9	17,3	20,3	24,7	29,2	31,6	31,3	28,1	23,7	19,8	16,0

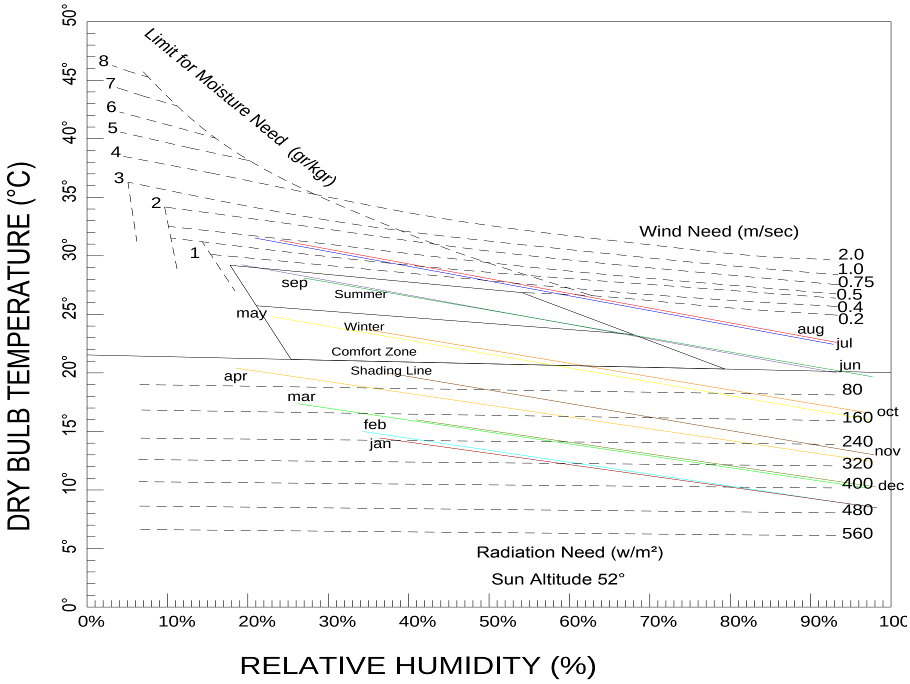

Fig. 3. Quantitative Bioclimatic chart of Chania (climate zone A). Redrawn by the authors [11, 22].

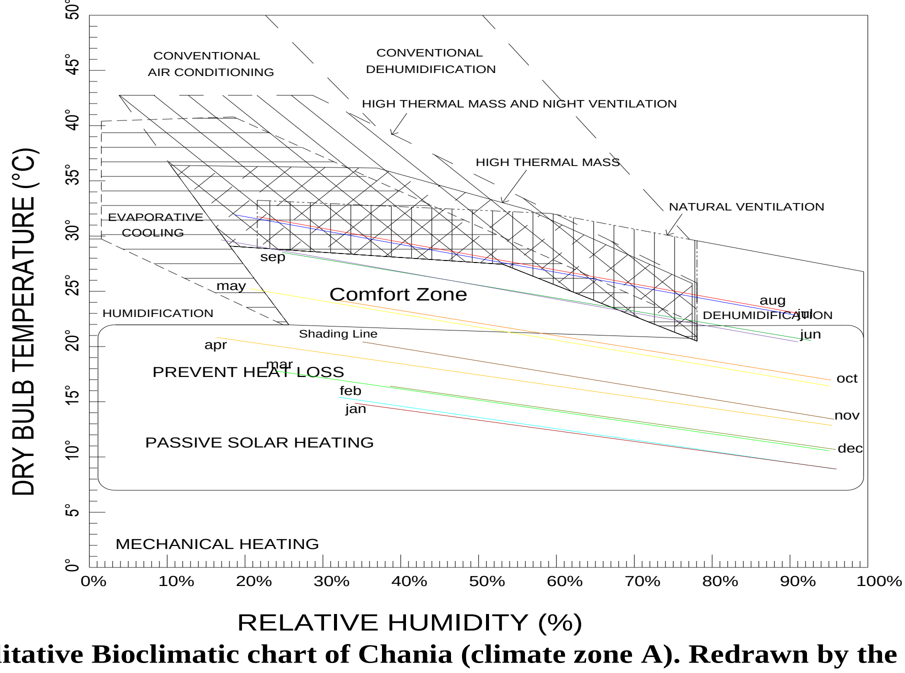

Fig. 4. Qualitative Bioclimatic chart of Chania (climate zone A). Redrawn by the authors [11, 22].

Table 5. Analysis of the quantitative bioclimatic chart of the prefecture of Chania (climate zone A).

Month	Radiation needs (W/m2)	Shading needs (%)	Wind needs (m/sec)	Moisture needs (gr/Kgr)
Jan	240-440	0	-	-
Feb	220-440	0	-	-
Mar	140-400	0	-	-
Apr	20-300	0	-	-
May	0-160	47%	-	-

Jun	0	94%	-	-
Jul	0	100%	0-0.5	0-1.8
Aug	0	100%	0-0.5	0-1.8
Sep	0	100%	-	-
Oct	0-140	44%	-	-
Nov	40-280	0	-	-
Dec	180-400	0	-	-

Table 6. Analysis of the qualitative bioclimatic chart of the prefecture of Chania (climate zone A).

Month	M.H.	P.P.S.H.-P.H.L.	S.L.	C.Z.	E.C.	D.	H.	N.V.	H.T.M.	H.T.M. &Ni.V.	C.D.	C.A.C.
Jan	-	√	-	-	-	-	-	-	-	-	-	-
Feb	-	√	-	-	-	-	-	-	-	-	-	-
Mar	-	√	-	-	-	-	-	-	-	-	-	-
Apr	-	√	-	-	-	-	-	-	-	-	-	-
May	-	√	√	√	-	-	-	-	-	-	-	-
Jun	-	-	√	√	-	-	-	-	-	-	-	-
Jul	-	-	√	-	√	√	-	√	√	√	-	-
Aug	-	-	√	-	√	√	-	√	√	√	-	-
Sep	-	-	√	√	-	-	-	-	-	-	-	-
Oct	-	√	√	√	-	-	-	-	-	-	-	-
Nov	-	√	-	-	-	-	-	-	-	-	-	-
Dec	-	√	-	-	-	-	-	-	-	-	-	-

Table 7. Mean maximum and minimum monthly temperature in °C and corresponding relative humidity in % for climate zone B.

Month			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Climatic Zone B														
Prefecture of Achaia														
Point 1	max RH(%)	X1	98,9	98,1	98,4	98,2	97,9	97,2	95,8	95,4	97,3	98,4	98,8	98,9
	min T(°C)	Y1	5,9	6,5	7,9	10,4	14,0	17,8	20,3	20,8	17,7	14,4	10,6	7,2
Point 2	min RH(%)	X2	31,3	30,2	33,2	30,3	30,0	23,3	24,0	22,3	27,3	33,3	35,7	36,5
	max T(°C)	Y2	13,9	14,5	16,9	20,2	24,7	29,3	32,1	32,6	28,2	23,7	19,5	15,4

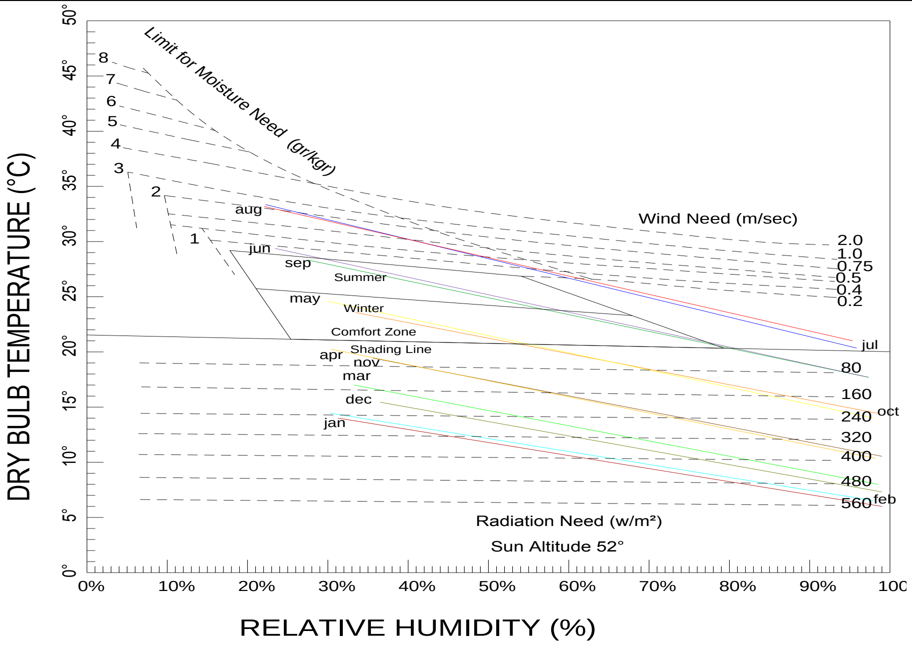

Fig. 5. Quantitative Bioclimatic chart of Achaia (climate zone B). Redrawn by the authors [11, 22].

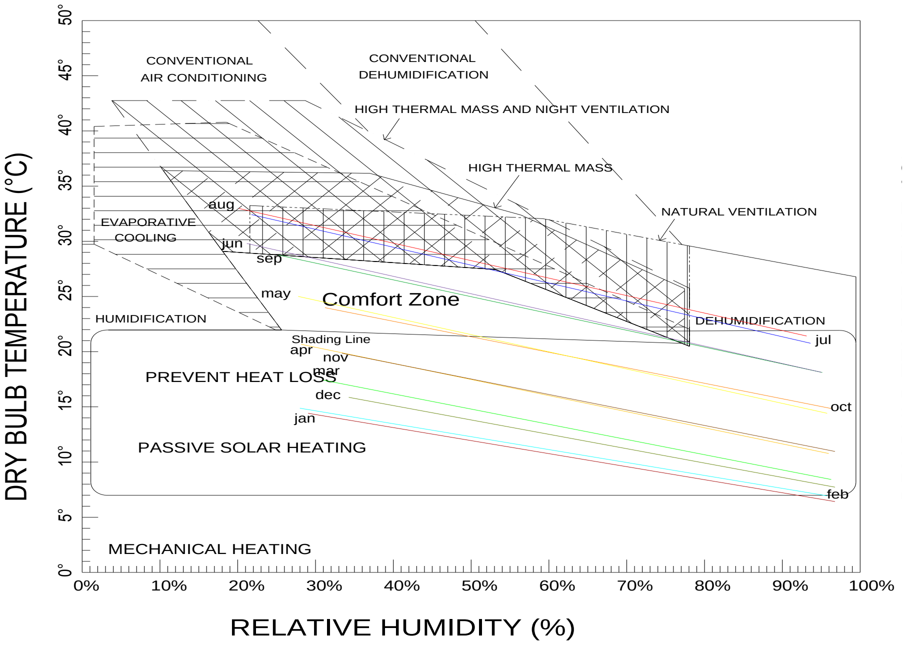

Fig. 6. Qualitative Bioclimatic chart of Achaia (climate zone B). Redrawn by the authors [11, 22].

Table 8. Analysis of the quantitative bioclimatic chart of the prefecture of Achaia (climate zone B).

Month	Radiation needs (W/m2)	Shading needs (%)	Wind needs (m/sec)	Moisture needs (gr/Kgr)
Jan	240-560	0	-	-
Feb	220-560	0	-	-
Mar	140-480	0	-	-
Apr	20-400	0	-	-
May	0-240	37%	-	-
Jun	0-100	78%	0-0.4	0-1.0
Jul	0	100%	0-0.8	0-2.5
Aug	0	100%	0-0.8	0-2.5
Sep	0-100	75%	-	-
Oct	0-220	31%	-	-
Nov	60-400	0	-	-
Dec	200-500	0	-	-

Table 9. Analysis of the qualitative bioclimatic chart of the prefecture of Achaia (climate zone B).

Month	M.H.	P.P.S.H.-P.H.L.	S.L.	C.Z.	E.C.	D.	H.	N.V.	H.T.M.	H.T.M. &Ni.V.	C.D.	C.A.C.
Jan	-	√	-	-	-	-	-	-	-	-	-	-
Feb	-	√	-	-	-	-	-	-	-	-	-	-
Mar	-	√	-	-	-	-	-	-	-	-	-	-
Apr	-	√	-	-	-	-	-	-	-	-	-	-
May	-	√	√	√	-	-	-	-	-	-	-	-
Jun	-	√	√	√	√	-	-	√	√	√	-	-
Jul	-	-	√	-	√	√	-	√	√	√	-	-
Aug	-	-	√	-	√	√	-	√	√	√	-	-
Sep	-	√	√	√	-	-	-	-	-	-	-	-
Oct	-	√	√	√	-	-	-	-	-	-	-	-
Nov	-	√	-	-	-	-	-	-	-	-	-	-
Dec	-	√	-	-	-	-	-	-	-	-	-	-

Table 10. Mean maximum and minimum monthly temperature in °C and corresponding relative humidity in % for climate zone C.

Month			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Climatic Zone C														
Prefecture of Thessaloniki														
Point 1	max RH(%)	X1	97,8	97,9	97,2	96,0	94,6	91,9	88,6	88,1	94,1	96,2	97,3	97,8
	min T(°C)	Y1	2,0	3,4	5,8	9,1	14,0	18,7	21,2	21,1	17,0	12,7	8,1	3,6
Point 2	min RH(%)	X2	33,4	29,8	23,2	23,6	24,0	21,1	21,1	20,0	23,4	28,2	32,6	36,6
	max T(°C)	Y2	9,5	11,5	15,1	19,4	25,1	29,9	32,5	32,4	27,2	21,2	16,0	10,9

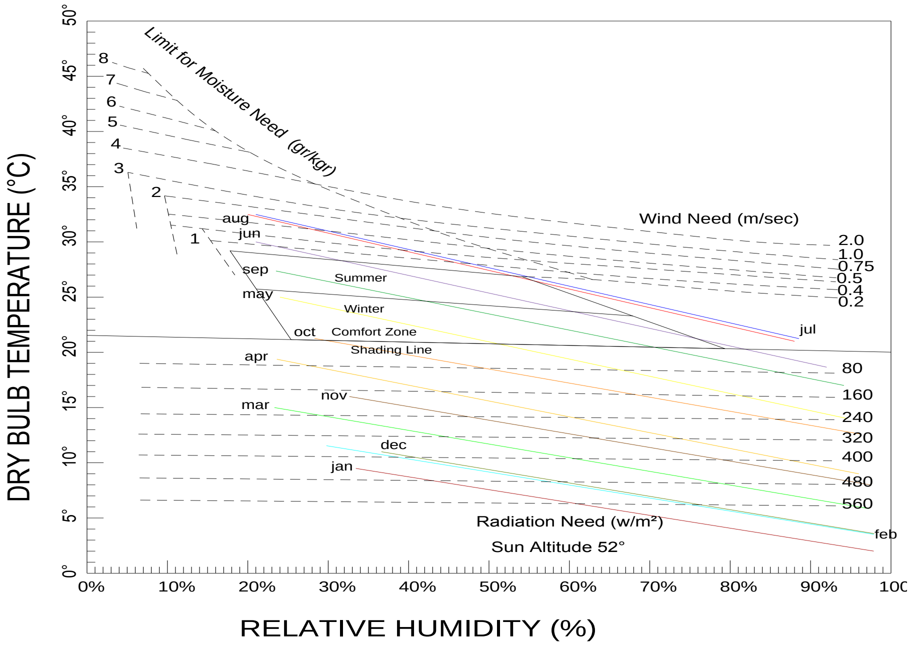

Fig. 7. Quantitative Bioclimatic chart of Thessaloniki (climate zone C). Redrawn by the authors [11, 22].

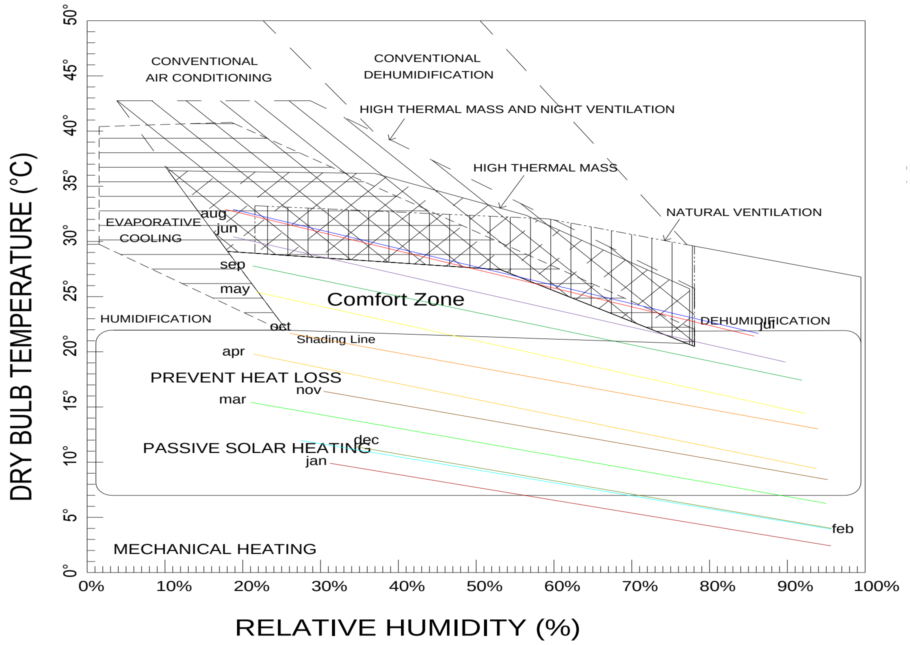

Fig. 8. Qualitative Bioclimatic chart of Thessaloniki (climate zone C). Redrawn by the authors [11, 22].

Table 11. Analysis of the quantitative bioclimatic chart of the prefecture of Thessaloniki (climate zone C).

Month	Radiation needs (W/m2)	Shading needs (%)	Wind needs (m/sec)	Moisture needs (gr/Kgr)
Jan	>560	0	-	-
Feb	>560	0	-	-
Mar	220-560	0	-	-
Apr	60-440	0	-	-
May	0-240	39%	-	-
Jun	0-60	86%	0-0.4	0-1.0
Jul	0	100%	0-0.7	0-2.0
Aug	0	100%	0-0.7	0-2.0
Sep	0-140	67%	-	-
Oct	0-300	0	-	-
Nov	180-480	0	-	-
Dec	>560	0	-	-

Table 12. Analysis of the qualitative bioclimatic chart of the prefecture of Thessaloniki (climate zone C).

Month	M.H.	P.P.S.H.-P.H.L.	S.L.	C.Z.	E.C.	D.	H.	N.V.	H.T.M.	H.T.M. & Ni.V.	C.D.	C.A.C.
Jan	√	√	-	-	-	-	-	-	-	-	-	-
Feb	√	√	-	-	-	-	-	-	-	-	-	-
Mar	-	√	-	-	-	-	-	-	-	-	-	-
Apr	-	√	-	-	-	-	-	-	-	-	-	-
May	-	√	√	√	-	-	-	-	-	-	-	-
Jun	-	√	√	√	√	-	-	√	√	√	-	-
Jul	-	-	√	-	√	√	-	√	√	√	-	-
Aug	-	-	√	-	√	√	-	√	√	√	-	-
Sep	-	√	√	√	-	-	-	-	-	-	-	-
Oct	-	√	-	-	-	-	-	-	-	-	-	-
Nov	-	√	-	-	-	-	-	-	-	-	-	-
Dec	√	√	-	-	-	-	-	-	-	-	-	-

Table 13. Mean maximum and minimum monthly temperature in °C and corresponding relative humidity in % for climate zone D.

Month			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Climatic Zone D														
Prefecture of Kozani														
Point 1	max RH(%)	X1	98,0	97,7	96,8	95,9	95,6	93,2	90,7	89,7	95,3	96,7	98,2	97,9
	min T(°C)	Y1	-1,4	0,3	3,1	6,6	11,1	15,2	18,0	17,9	13,4	9,0	4,3	0,5
Point 2	min RH(%)	X2	28,2	24,8	16,9	23,0	25,3	15,0	15,9	18,7	20,3	26,7	32,7	27,0
	max T(°C)	Y2	6,4	9,3	13,2	17,6	22,7	27,9	31,1	31,0	25,3	19,0	13,2	8,2

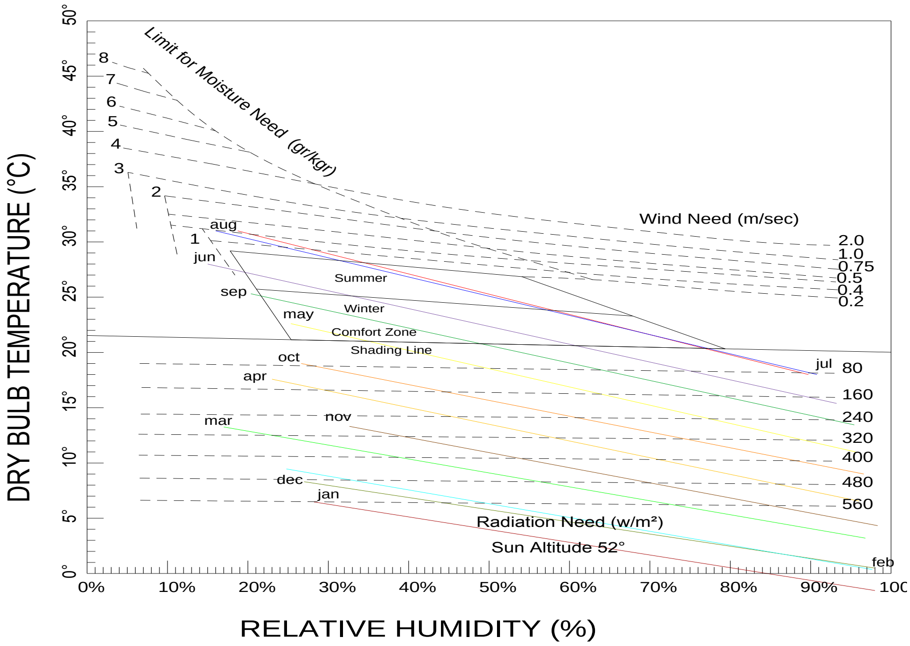

Fig. 9. Quantitative Bioclimatic chart of Kozani (climate zone D). Redrawn by the authors [11, 22].

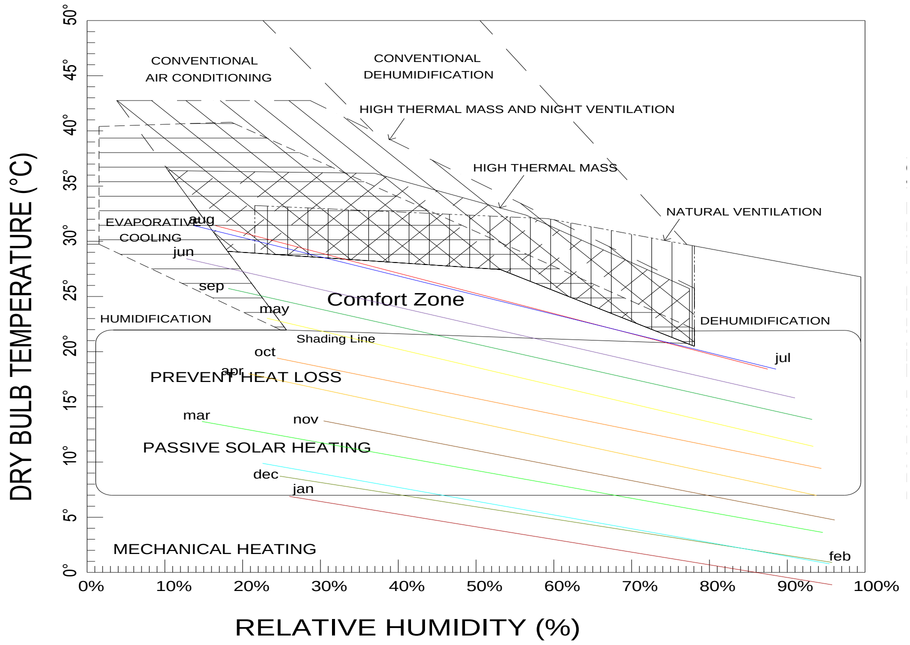

Fig. 10. Qualitative Bioclimatic chart of Kozani (climate zone D). Redrawn by the authors [11, 22].

Table 14. Analysis of the quantitative bioclimatic chart of the prefecture of Kozani (climate zone D).

Month	Radiation needs (W/m2)	Shading needs (%)	Wind needs (m/sec)	Moisture needs (gr/Kgr)
Jan	>560	0	-	-
Feb	>560	0	-	-
Mar	>560	0	-	-
Apr	140-540	0	-	-
May	0-380	14%	-	-

Jun	0-180	59%	-	-
Jul	0-80	82%	0-0.5	0-1.0
Aug	0-80	82%	0-0.5	0-1.0
Sep	0-240	38%	-	-
Oct	80-460	0	-	-
Nov	>560	0	-	-
Dec	>560	0	-	-

Table 15. Analysis of the qualitative bioclimatic chart of the prefecture Kozani (climate zone D).

Month	M.H.	P.P.S.H.-P.H.L.	S.L.	C.Z.	E.C.	D.	H.	N.V.	H.T.M.	H.T.M. &Ni.V.	C.D.	C.A.C.
Jan	√	√	-	-	-	-	-	-	-	-	-	-
Feb	√	√	-	-	-	-	-	-	-	-	-	-
Mar	√	√	-	-	-	-	-	-	-	-	-	-
Apr	-	√	-	-	-	-	-	-	-	-	-	-
May	-	√	√	√	-	-	-	-	-	-	-	-
Jun	-	√	√	√	√	-	-	-	-	-	-	-
Jul	-	√	√	√	√	-	-	√	√	√	-	-
Aug	-	√	√	√	√	-	-	√	√	√	-	-
Sep	-	√	√	√	√	-	-	-	-	-	-	-
Oct	-	√	-	-	-	-	-	-	-	-	-	-
Nov	√	√	-	-	-	-	-	-	-	-	-	-
Dec	√	√	-	-	-	-	-	-	-	-	-	-

V. COMMENTS ON THE QUANTITATIVE AND QUALITATIVE OLGYAY'S BIOCLIMATIC CHARTS

The following conclusions can be drawn from the observation of the results of the quantitative and qualitative bioclimatic charts:

Mechanical heating: Climate zones A and B do not require the use of mechanical heating equipment throughout the year. Climate zone C requires mechanical heating during the months of January, February and December while climatic zone D, which is the coldest of the climatic zones, requires mechanical heating during the months of January, February, March and December.

Solar radiation needs: Passive heating strategies with shielding of the outer shell to avoid thermal losses and the utilization of the incident solar radiation are necessary especially during the cold months. In climatic zone A, there are more sunshine needs during January, February, March and December, with a maximum price of 440W/m^2 while zero requirements are observed during June, July, August and September. In climatic zone B, the same sunshine requirements are prevalent, with a maximum value of 560W/m^2 while small solar radiation requirements are observed during June and September. In climatic zone C, in January, February and December, the maximum solar radiation utilization of 560W/m^2 should be combined with mechanical heating while in climate zone D, the need to exploit the sun's energy is observed throughout the year.

Shading needs: For climatic zones A and B, hot sun rays make it necessary to shade the building to restore comfort from May to October, with maximum shading requirements of about 100% between June and September. In climate zones C and D the shading needs are fewer and shading is not required in October.

Comfort zone: In climatic zones A and B, a large part of the May, June, September and October lines lie within the comfort zone. In climatic zone C, the monthly lines of May, June and September are within the comfort zone while in climatic zone D, within the comfort zone are also the months of July and August.

Wind and moisture needs: During the summer months, July and August, climatic zones A and D, to achieve comfort conditions, require natural ventilation with wind speeds of up to 0.5m/sec and moisture up to 1.8gr/Kgr and 1.0gr/Kgr respectively. Also, night ventilation and increased thermal mass in the building shell are also necessary. Some time, high levels of relative humidity should be dealt with the dehumidification of the atmosphere. In climatic zones B and C, the wind requirements amount to 0,8m/sec and 0,7 m/sec respectively and to moisture of 2,5gr/Kgr and 2,0gr/Kgr respectively. In June there are also needs of wind and moisture.

VI. IMPLEMENTATION OF PASSIVE HEATING AND COOLING STRATEGIES

The most important passive strategies that can be applied in the design process of a building are the following:

- **Location and optimum orientation of the building**

The location and orientation of the building determines the duration as well as the amount of direct solar radiation received by the various areas of the building and the effect of the wind on them [33]. The building should be placed in such a way on the land to ensure sunshine and protection from strong winds during the winter and shading and utilization of cool winds during the summer [34].
This is a very complicated problem, as the effect of the sun on a surface depends not only on its orientation but also on its inclination to receive solar radiation [12].

It has been shown that in the northern hemisphere, in the temperate zone, where the latitude is about 40°, the South is judged to be the optimal orientation for both solar heat increase in winter and summer control [11, 35]. Also, in a survey conducted by Jaber and Salman (2011), it has been shown that in Mediterranean climates the annual energy consumed for heating and cooling is lower when the orientation of the main face of the building is southern [11, 36].

This is due to the sun's trajectory, during winter its position on the horizon is low, with the result that the sun's radiation is more intense to the south facade of the building while in the summer the breadth of solar aperture widens, so the south facade receives a lower intensity of solar radiation [37, 39, 40].

In order to achieve a southern orientation of the main-largest aspect of the buildings, the large dimension of the building blocks should extend parallel to the East-West axis. Deviations from the southern orientation for about 30° from East or West do not adversely affect the energy benefit [38].

Many times, however, the urban roads and the shading from neighboring buildings cause problems to the southern orientation of the building. In order to avoid the risk of shading from obstacles in the neighborhood of the new building, it must be placed on the northern side of the plot and at a distance of at least 1.5 times the height of the neighboring obstacle [38].

- **The optimum building's shape**

The shape of the building shell determines its energy performance. According to Reid (1984), in areas with extreme weather conditions, the cube is the optimal shape of a building in terms of energy efficiency. In temperate zones, the influence of the sun elongates the plan with optimal proportions of dimensions, 1/1.1 in cold latitudes, 1/1.5 or more in temperate regions and 1/1.3 in hot dry regions [41].

In Mediterranean climates, slightly elongated plans along the East-West axis, allow the building to function as a heat collector from the sun with the smallest possible loss in winter and as a source of cooling in the summer providing protection from the hot sun [11, 42, 43].
In Greece, located in the temperate zone, the buildings should have an elongated shape (with optimum ratio of the sides≈1/1.5), with the larger side and the larger openings to the south, with a tolerance of ±30°. On the northern side of the building shell the openings should be so small so as to provide adequate lighting and ventilation inside the building [38].

The "open" form of the building with large openings in the south is applied when the shape of the plot allows the south orientation and there are no obstructions that cause shadowing of the facades. Otherwise, a "closed" building form with small openings and compact insulated building blocks is selected to minimize thermal losses [44].

- **Interior building's design**

The rooms of the building most often used by the occupants throughout the day require higher temperatures, such as dining room, living room, etc. it is customary to be placed on the side of the south-facing building. On the contrary, auxiliary spaces, sanitary spaces, bedrooms, etc. are positioned on the north-facing side and act as a heat loss barrier as they interpose between the main spaces and the exterior of the building [39].

- **Planted roofs**

Planted roofs offer large vegetation surfaces, improve the environment in the cities and at the same time contribute to the improvement of the thermal performance of the building [46, 47]. In cold climates, they contribute to thermal insulation of the roof, while in warm climates, especially in summer, receiving high amounts of solar radiation, they help to avoid overheating [48]. According to

Eumorfopoulou et al. (1998), heat losses in a building with high vegetation in the roof and without thermal insulation are almost the same as in a building with bare roof and thermal insulation [46]. Also, Niachou et al. (2001) have shown that in buildings with planted roofs the required heating and cooling loads are much less independent of the type of thermal insulation. The biggest energy savings during one year on an non-insulated roof was calculated at 37%. This benefit is reduced to just 2% for well-insulated buildings [49].

- **Building's envelope (Insulation-Thermal mass of building's materials-Windows-Passive solar systems)**

For the building's thermal protection, it is necessary to insulate the elements of the outer envelope and use materials such as concrete, bricks, stone etc. with high density and therefore thermal mass, hence great thermal energy storage capacity.

Solar radiation during the day is stored by the materials of the outer envelope and interior mass of the building, stored as heat, and then re-emitted at a later time in the day. Heat storage material is the construction mass of the building called thermal mass (walls, partitions, ceilings and floors) [50, 53].

According to ASHRAE (2001), thermal insulation is a material or a combination of materials which, by their proper application, retard the rate of heat through conduction, convection or radiation and, at the same time, due to their high thermal resistance, the heat transfer inside or outside a building is limited [51]. The thickness of the heat insulating materials, depending on the climate zone of the building, is determined in accordance with the TOTEE 20701-1 (2017) [52].

The solar energy is collected by windows, skylights or any other kind of solar aperture. This allows sunlight to enter the building and be stored by its thermal mass. The large apertures of the building are located on the south, south-east and southwest sides of the building, according to the requirements of each room. On the eastern, western and particularly northern sides of the building the windows should be small [54]. Also, in order to avoid heat gains or losses in the apertures, the ratio of the window surface to the wall surface (WWR: window-to-wall ratio) should be reduced, i.e. as few windows as possible and double / triple glazing, low emissivity glass, filled with inert gas and window frames with good thermal behavior [55, 56].

Passive solar systems are used to collect solar radiation, to store it as solar energy and transmit it in space [5, 54]. The most used are:

• Thermal walls (mass and Trombe walls): they are south-facing walls made of concrete or masonry, their color is dark and they are covered by glazing, so as to collect solar radiation. When the walls have vents, at the top and the base, the air between the glass and the wall circulates in the interior of the building, and they are called Trombe walls [57].

• Sunspaces or solar greenhouse or conservatory: these are enclosed and south-facing spaces with double-glazed windows that absorb the sun's rays and transfer solar energy through the openings to the interiors of the building. Ventilation and part roofing of the space are proposed in order to avoid overheating during the summer [5].

• Solar chimneys: these are conventional chimneys where the southern wall is replaced with glass. They contribute to the natural ventilation and the renewal of the indoor air of buildings [58].

- **Protection from strong winds**

In order to protect the building shell from the winter winds, measures are taken, such as: planting of evergreen trees, windbreaks and parts protruding from the building envelope [38, 45].

- **Building's Protection with Shading**

High summer temperatures and the avoidance of overheating inside the building can be achieved by planting trees or low vegetation in the surrounding area of the building. Vegetation can change the microclimate of a region and provide shading [60]. Trees protect the building from solar radiation, depending on the species (evergreen or deciduous) and the density of their crown cover. They have the ability to reflect a part of the solar radiation and another to use it for the photosynthetic process. Also, the process of evapotranspiration increases the humidity of the atmosphere by offering natural cooling [47, 59, 45]. Deciduous trees are usually placed on the facades of buildings where protection from the sun rays in the summer and sunshine in the winter are necessary. Evergreen trees offer shading throughout the year [12].

Also, protection from the sun rays offer fixed or movable sunshades or architectural prominences on the building's envelope such as balconies. Sun-protective obstacles should be placed vertically in the sun's rays [11, 40].

- **Solar reflectance**

Roofs are those parts of the building shell that receive the greatest amount of incident solar radiation, so they can be either dyed in light colors or planted. In addition, they can be coated with "cool" materials i.e. materials with high solar reflectance and infrared emission [59, 45, 62].
Research results have shown that the coating of the building's roof with 'cool' materials increased the reflection of solar radiation and reduced the cooling loads by 18-93% [61].

VII. CONCLUSIONS

The application of passive heating and cooling strategies is directly related to building's design, in particular its shape, size, orientation, form, site, layout, etc., and plays a key role in reducing energy consumption. Building designers can create shading conditions; improve ventilation and natural lighting by properly shaping the massing and layout of buildings [32].

Applying these passive strategies, while not costing, significantly improves the thermal performance of the building.

In this paper, the first step was to analyze the bioclimatic charts for the four climatic zones of Greece. The aim was to find the most suitable passive heating and cooling design strategies and to provide thermal comfort inside the buildings at the lowest possible cost.
The passive strategies that were proposed after bioclimatic analysis help architects and engineers design low-energy buildings in Greece and in areas with similar climatic conditions.

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