AgriEngineering

IMPACT FACTOR 3.0

CITESCORE 4.7

Article

A Bioclimatic Approach for Enhanced Wine Cellar Design: General Formulation and Analysis of a Case Study in Mexico

Verónica Jiménez-López, Anibal Luna-León and Stefano Benni

MDPI

https://doi.org/10.3390/agriengineering6030140

AgriEngineering

Article

A Bioclimatic Approach for Enhanced Wine Cellar Design: General Formulation and Analysis of a Case Study in Mexico

Verónica Jiménez-López [1], Anibal Luna-León [1] and Stefano Benni [2,*]

[1] Facultad de Arquitectura y Diseño, Universidad Autónoma de Baja California, Mexicali 21280, Mexico; veronica.jimenez90@uabc.edu.mx (V.J.-L.); anibal@uabc.edu.mx (A.L.-L.)
[2] Department of Agricultural and Food Sciences, University of Bologna, Viale G. Fanin 48, 40127 Bologna, Italy
* Correspondence: stefano.benni@unibo.it; Tel.: +39-051-20-96166

Abstract: Winemaking facilities require specific interior hygrothermal conditions for wine production and aging, often necessitating the use of electromechanical cooling and humidification systems that increase energy consumption costs. This study aimed to assess the potential application of bioclimatic strategies in artisanal wine cellars within the Guadalupe Valley, Baja California, Mexico, using a quantitative theoretical method. Psychrometric charts incorporating estimated and measured meteorological data from the study area were employed to analyze bioclimatic strategies for two key areas of a wine cellar: (1) Production and (2) Aging. Our findings highlight that integrating high thermal mass and shading techniques represents an effective strategy for wine cellar design, offering reduced reliance on active systems and promoting substantial energy savings. This research underscores the viability and benefits of bioclimatic design approaches in enhancing the sustainability and efficiency of wine cellar operations, particularly in regions with specific climatic challenges. like the Guadalupe Valley.

Keywords: bioclimatic design; bioclimatic strategies; wine cellar; psychrometric chart; Guadalupe Valley

check for updates

Citation: Jiménez-López, V.; Luna-León, A.; Benni, S. A Bioclimatic Approach for Enhanced Wine Cellar Design: General Formulation and Analysis of a Case Study in Mexico. *AgriEngineering* **2024**, *6*, 2395–2416. https://doi.org/10.3390/agriengineering6030140

Academic Editor: Piernicola Masella

Received: 11 June 2024
Revised: 15 July 2024
Accepted: 19 July 2024
Published: 23 July 2024

1. Introduction

The energy consumption for indoor climate control of buildings is a common issue in the wine industry, extensively investigated by various authors primarily focused on improving energy efficiency through industrial process optimization and the integration of renewable energy sources [1–3]. The wine sector emits 1 ton of CO_2 per ton of wine produced [4,5], mainly due to temperature control during production processes and the quality of constructed facilities dedicated to product packaging and aging.

The fermented grape must can reach temperatures of up to 30 °C in red wines and 19 °C in white wines [6,7]: the heat generated in this process is transferred to the environment of the winery, which is why it is necessary to maintain the interior production space within an appropriate temperature range, so as not to damage the wine fermentation process, especially in the warm period. Controlling relative humidity is also essential for the wine aging area, aiming to prevent condensation and reduce wine loss through evaporation within barrels, which can range from 1% to 9% of the total stored production [7].

For this work, a farm winery, also referred to as wine cellar, was defined as the space intended for the production, conservation and storage of wine. The wine cellar is a construction that requires controlled indoor environmental conditions (temperature, humidity, lighting and sound) to ensure the quality of the final product [8]. The aging area and the production area of a winery were analyzed: in the first one, barrels and bottles are located for preserving the wine; in the second one is the machinery necessary for the processes of destemming, extraction of grape must and fermentation.

The Guadalupe Valley, Mexico, is considered as the study area of this research. In that context, 77% of producers use traditional winemaking processes, which is why they are considered artisanal, with a production of less than 90 m^3 of wine per year. The other 23% is made up of medium-sized and industrial-type producers, the latter with an annual production greater than 450 m^3. The need for internal environmental control, combined with little or no adaptation of the wine cellars to the local climate, directly affects the artisanal producers of the study area, since they are the ones who have the least economic capacity to cover the cost of electrical energy needed. This causes an increase in the final price of their products and reduces possibilities of competition in the market.

Bioclimatic design is a discipline from which the characteristics of the climate and the correct application of building elements and technologies can be analyzed to control the heat transfer process [9]. The term bioclimatic does not exclude the use of electromechanical systems, when required, to optimize the thermal performance of the building [10]. The use of various passive strategies in agri-food buildings has been studied in Italy [11–13], Spain [14,15], Australia [16], and Mexico [17,18] from various approaches, such as energy efficiency, sustainability, and climate change, to name a few.

Identifying the bioclimatic strategies that most effectively reduce energy demand from HVAC systems, hence alleviating energy bills, and mitigating GHG emissions in buildings across various climatic conditions, is increasingly important. In this context, it is thus crucial to precisely evaluate the performance of bioclimatic strategies and their potential application in new or existing winery buildings through specific variables, such as air temperature, air velocity, air humidity, and thermal comfort limits, for wine production and aging spaces [9].

The objective of this study was to determine bioclimatic design strategies for artisanal wine cellars based on theoretical ranges of dry bulb temperature and relative humidity and a psychrometric analysis with estimated and measured data of the local microclimate. This allowed definition of the potential use of each strategy to achieve the necessary interior conditions for wine production and aging. The study was carried out with reference to the climate conditions of the Guadalupe Valley in Mexico. This work provides opportunities for future research on the bioclimatic design of wine cellars, making the necessary adaptations to the climatic conditions of the study area. Defining the optimal limits and potential use of bioclimatic design strategies will serve as a critical reference for architects and engineers in developing appropriate design solutions for agro-industrial buildings.

2. Materials and Methods

The research design included four stages:

1. Characterization of the study area,
2. Microclimatic monitoring,
3. Psychrometric analysis, and
4. Results analysis.

The research approach was theoretical and quantitative, based on the calculation of bioclimatic strategies, appropriate indoor ranges of dry bulb temperature and relative humidity for wine cellars, and the measurement of meteorological variables. This approach enabled the graphical representation of the relationships between the local microclimate and the potential use of bioclimatic strategies on a psychrometric chart.

Firstly, the characterization of the study area was conducted to gather detailed information about the geographical and climatic specificities of the region. This foundational step ensured a thorough understanding of the environmental context in which the subsequent analyses are to be conducted.

Secondly, the microclimatic monitoring phase involved the precise measurement of local atmospheric conditions over a defined period. This step was crucial for capturing the variability and dynamics of microclimatic factors, such as temperature, humidity, and wind patterns. Advanced meteorological instruments were utilized to obtain accurate and high-resolution data.

The third stage, psychrometric analysis, involved using this data to assess the psychrometric properties of the air in the study area. This analysis focused on understanding the relationships between temperature, humidity, and other thermodynamic properties. By plotting this data on a psychrometric chart, the researchers can visualize the "comfort zones" and the effectiveness of various bioclimatic strategies for maintaining optimal conditions within wine cellars.

Finally, the stage of results analysis synthesized the data and insights gained from the previous steps. This comprehensive analysis aimed to determine the best strategies for controlling the indoor environment of wine cellars. The findings highlighted the potential for leveraging local microclimate characteristics to implement efficient bioclimatic solutions. The graphical representations provided clear evidence of how these strategies could be applied to maintain ideal storage conditions, thereby ensuring the quality and preservation of wine.

Overall, the research employed a robust theoretical and quantitative approach, integrating environmental data and bioclimatic principles to offer practical solutions for wine cellar management. This method not only facilitated a deeper understanding of the microclimatic influences but also demonstrated the feasibility of using bioclimatic strategies to achieve optimal indoor conditions.

2.1. Study Area

The Guadalupe Valley is located in the Northwest of Mexico (32°05′47″ N and 116°34′21″ W) in the Municipality of Ensenada, Baja California, 100 km from the southwest border of the United States (Figure 1). It is a rural area with a territorial extension of 663.53 km^2 and a population of 5316 inhabitants, divided into three delegations: Francisco Zarco, San Antonio de las Minas and El Porvenir.

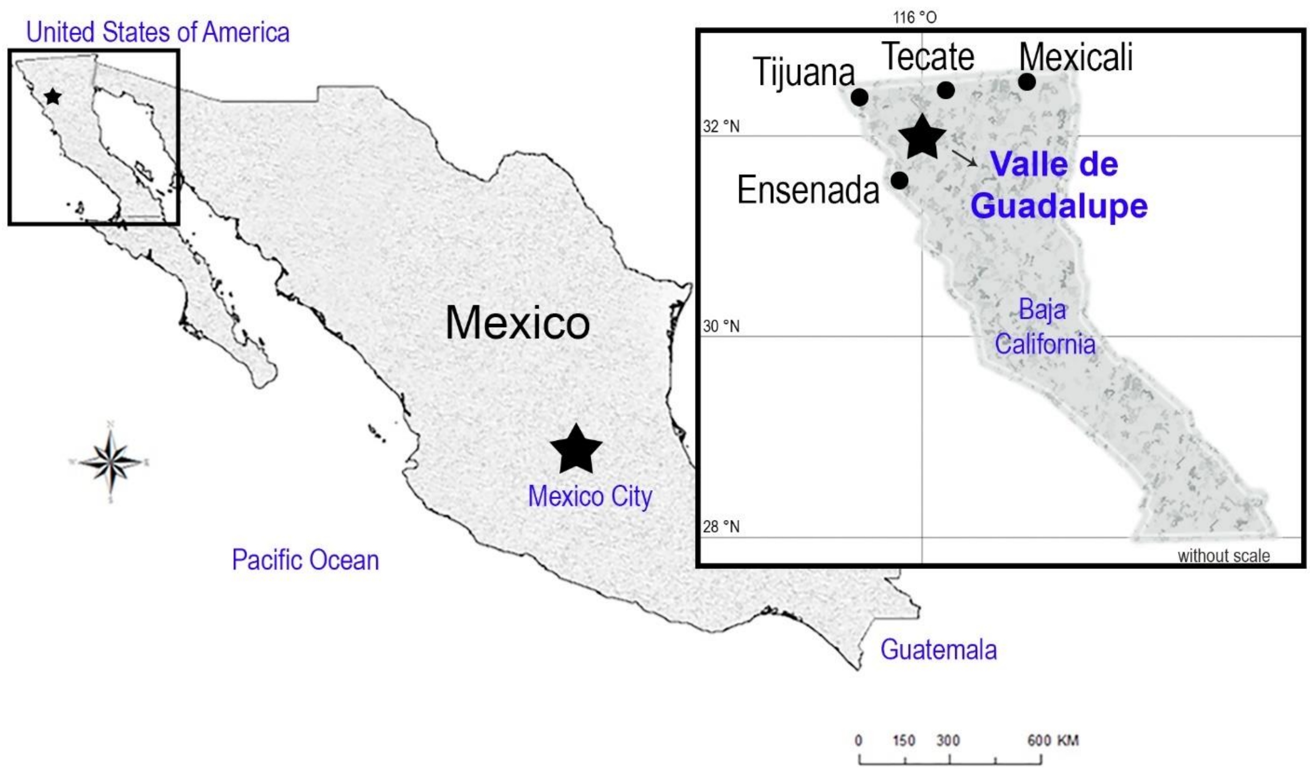

Figure 1. Location of Guadalupe Valley in Mexico (source: elaboration by the authors).

The wine produced in this area is estimated at 17,000 m^3, representing 90% of the total annual national production [5,19]. Its geographical location, situated between 30° and 50° north latitude and known as one of the world's wine belts, results in a Mediterranean-type climate. This creates an optimal environment for vine cultivation [20], enabling the region to compete with wines from France, Spain, and Italy.

The topography of this region ranges between 250 and 500 m above sea level (a.s.l.), and the mountain range surrounding the area reaches a height of up to 1050 m a.s.l. The climate is Mediterranean-type BSks(e) [21] with an average maximum temperature of 32 °C during the warm period and an average minimum temperature of 3 °C during the cold period. The mean annual temperature is 12 °C to 18 °C, with dominant winter rains with a historical average of 295 mm a^{-1} and a high potential evaporation rate of 1618 mm a^{-1} [22]. Rainfall in the Guadalupe Valley is not enough to satisfy vineyard needs; therefore, irrigation is necessary. Water stress and energy dependence threaten the valley's grape cultivation and wine production.

The presence of more than 80 wineries was recorded in the study area, of which 20 were visited and characterized, representing 25% of the total number of existing cellars (Figure 2). These visits included comprehensive tours of the wineries, during which key features and operational practices were documented. The information gathered during these visits allowed the characterization of the wine cellars and facilitated the identification of appropriate locations for two meteorological stations to monitor the local microclimate. Furthermore, these tours also revealed a significant amount of work yet to be done for winery buildings to become energy efficient. Artisanal producers are the most concerned and have adopted various strategies to reduce electricity consumption in their wine cellars.

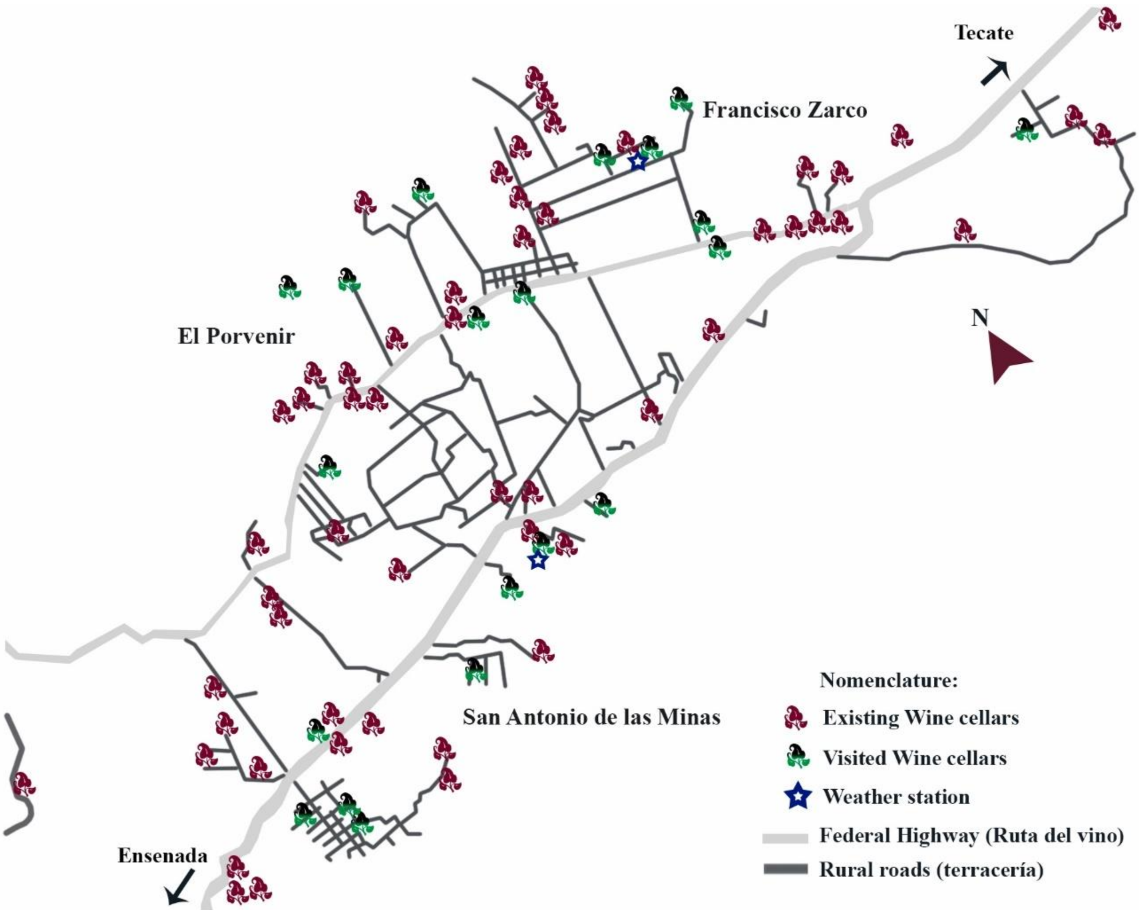

Figure 2. Location of artisanal wine cellars until 2016 in the Guadalupe Valley (source: elaboration by the Authors).

Figure 2 depicts the positions of the two weather stations placed to cover both the northern and southern regions of the study area. These locations were chosen to ensure comprehensive monitoring of the microclimatic conditions prevalent throughout the entire area. The northern station was situated at Francisco Zarco, while the southern station was positioned at San Antonio de las Minas.

2.2. Microclimate Monitoring

To monitor the microclimate of the study area, the following parameters were considered:

1. Characteristics of the site, rural type without buildings of more than three levels, topography with hills that surround the area and that modify the speed and intensity of the wind coming from the Pacific Ocean;
2. Instrumentation, referring to the available number of meteorological stations for measuring dry bulb temperature, relative humidity, atmospheric pressure, wind direction and speed, precipitation and solar radiation;
3. Availability of producers for access, placement and security of the instrumentation;
4. Design of a structure to support the sensors;
5. Calibration;
6. Placement of instrumentation and
7. Testing period for data recording.

Two meteorological stations were placed in the area, and the location criteria mentioned by the World Meteorological Organization (WMO) in its guide to climatological practices were considered [23]. In this study, the data measured from one of the stations was used, which was considered to have greater reliability due to having new sensors with factory calibration.

Data were recorded every 30 min and dry bulb temperature and outdoor relative humidity were analyzed for the months of December, January, February (cold period), May, June and July (warm period) and compared with the meteorological data estimated with the Meteonorm program. The measurements and values obtained with these instruments allowed the potential use of bioclimatic design strategies for wine production and aging to be graphically analyzed in psychrometric charts.

2.3. Psychrometric Analysis

The psychrometric analysis was carried out in the following stages:

1. A psychrometric chart was generated for the study area.
2. The dry bulb temperature and relative humidity ranges suitable for the aging area and the wine cellar production area were estimated.
3. The limits of bioclimatic strategies were calculated.
4. The strategies were delimited in the psychrometric chart and
5. The potential use of bioclimatic strategies was analyzed.

In stage 1, a psychrometric chart was used with the height above sea level (meters) and barometric pressure (kPa) of the Guadalupe Valley [24]. In stage 2, the range of indoor air temperature for the wine aging area was estimated, the minimum average and maximum average of the values proposed in Table 1 (a) were calculated, and the range was from 10 °C to 15 °C with a maximum limit. of 20 °C. For the production area, it was decided to use the minimum and maximum value of the values in Table 1 (b), and a range of 15 °C to 25 °C was estimated.

Table 1. Optimal indoor temperature ranges for aging and production of wine.

(a) Wine Aging and Preservation		
Author	**Dry Bulb Temperature (°C)**	
Boulton et al. (1995)	5–15	
Hidalgo (2003)	9–12	
Steiner (2010)	13–20	
Mazarrón, Cid–Falceto and Cañas (2012)	8–15	
Troost, referenced in Barbaresi, et al. (2014)	9–15 for red wines.	
Bondiac, referenced in Barbaresi, et al. (2014)	10–12	
Marescalchi, referenced in Barbaresi, et al. (2014)	15–20	
SEPSA, referenced in Barbaresi, et al. (2014)	8–14	
Vogt, referenced in Barbaresi, et al. (2014)	8–12 for white wines and 12 for red wines.	
Marrara et al. (2014)	12–16	
Theoretical range for Neutral Zone	10–15	
(b) Wine Production		
Author	**Red Wine Dry Bulb Temperature (°C)**	**White wine Dry Bulb Temperature (°C)**
Boulton et al. (1995)	25–35	15–20
Eisenman (1998)	21–32	4–13
Wilker, Harris, Odneal and Dharmadhikari (2001)	25–30	20–25
Grainger and Tattersall (2005)	20–32	10–18
Ramos-Sanz and Blasco-Lucas (2011)	24–35	18–23
Induráin (2013)	20–28	----
Johnson y Robinson (2013)	22–30	12–17
Nigam (2014)	24	7–21
Considine and Frankish (2014)	23–28	15–18
Theoretical range for Neutral Zone	15–25	

Source: elaboration by the authors based on the cited papers.

The relative humidity range considered for the neutral zone was from 30% to 75% [25]. Control of relative humidity is essential for the wine aging area, with the intention of avoiding the presence of mold on barrels or walls [26] and the loss of wine through evaporation, which can be from 1% to 9% of the total stored production.

In stages 3 and 4, the methods of Docherty and Szokolay [27] and Climate Consultant version 6 were used to delimit the bioclimatic strategies in the psychrometric chart. However, since these tools are designed to define strategies based on human comfort [28], the values and zones were appropriate according to the requirements for wine production and aging.

Because the artisanal wine production process requires 100% labor (with a moderate level of activity and a level of clothing of 0.60 clo), the interior thermal load is variable, as well as schedules and occupancy levels, compared to the aging area, where the barrels and wine are the only thermal mass to consider. For the analysis of bioclimatic strategies in the production area, it was decided to use the Luna method [29,30], which calculates relative humidity with the Tejeda method, and neutral temperature (the parameter for studying thermal comfort conditions) with the Auliciems model.

On the psychrometric chart, a vertical line was drawn on the 10 °C line of dry bulb temperature DBT to define the minimum limit of the neutral zone for aging up to 75%

relative humidity RH, and on the 15 °C line of DBT up to 50% RH to define the maximum limit. 50% RH was used because the graphic mean of the optimal range for the wine was 52.5% (Figure 3).

To draw the maximum limit of the neutral zone, the corrected effective temperature (T_e) was used, understood as the sum of the black globe temperature and the wet bulb temperature that considers the effect of wind speed. In this study, dry bulb temperature was used instead of radiant temperature, as reported for indoor spaces in IS0 7243 [31].

$$T_e = 0.3DBT + 0.7WBT - V \tag{1}$$

where:

- T_e = Effective Temperature (°C)
- DBT = Dry Bulb Temperature (°C)
- WBT = Wet bulb temperature (°C)
- V = Air Velocity (m/s).

In the neutral zone for wine aging, it was considered to draw the maximum limit with the effect of the effective temperature (T_e), for which in Equation (1) the DBT was equal to the maximum tolerable temperature value for the aging area, which was 20 °C, the WBT was defined from the psychrometric chart, the value obtained was 14 °C, while the wind speed (V) was considered as 0 because ventilation was not necessary due to the humidity levels required in the interior, and a controlled space was assumed without infiltration or air movement from mechanical systems.

By substituting values in Equation (1), the T_e for the neutral aging zone was 15.8 °C, and this value was added to 15 °C of DBT until 75% RH was reached. The area was defined as shown in Figure 3.

To calculate the limits of the high thermal mass strategy (HTM, 12 h of thermal delay), in Equation (2), an effectiveness of 30% was considered, because in summer the thermal mass is considerably affected by solar radiation, which reduces the effect of this coefficient, which can be up to 25% [28].

$$HTM = L_{MAX} + 0.3(AT_{MAX} - AT_{MIN}) \tag{2}$$

where:

- HTM = High Thermal Mass limit (°C)
- L_{MAX} = Maximum neutral zone limit (°C)
- AT_{MAX} = Maximum average outdoor temperature in Summer (°C)
- AT_{MIN} = Minimum average outdoor temperature in Summer (°C)

The average maximum summer temperature (AT_{MAX}) obtained for the study area was 33 °C, while the average minimum temperature (AT_{MIN}) was 20.3 °C, i.e., the difference in average daily temperature for summer between the exterior and the interior was 12.7 °C. By substituting values in Equation (2), the dry bulb temperature limit for high thermal mass (HTM) was 18.81 °C.

To calculate the effective temperature (Equation (1)), the DBT value obtained was used as a limit for thermal mass (18.81 °C) and wet bulb temperature of 24 °C, which corresponds to the maximum average outdoor summer temperature (33 °C). The T_e obtained was 22.44 °C.

On the psychrometric chart, the limit of high thermal mass was located, 18.81 °C, at 50% RH and this point was linked to the T_e obtained, 22.44 °C with 0% RH. The maximum limit of the strategy was drawn from the maximum limit of the neutral zone for the aging area, and the minimum limit of the strategy was drawn with a line parallel to the absolute humidity, the beginning of which was the minimum limit of the zone neutral wine aging (Figure 3).

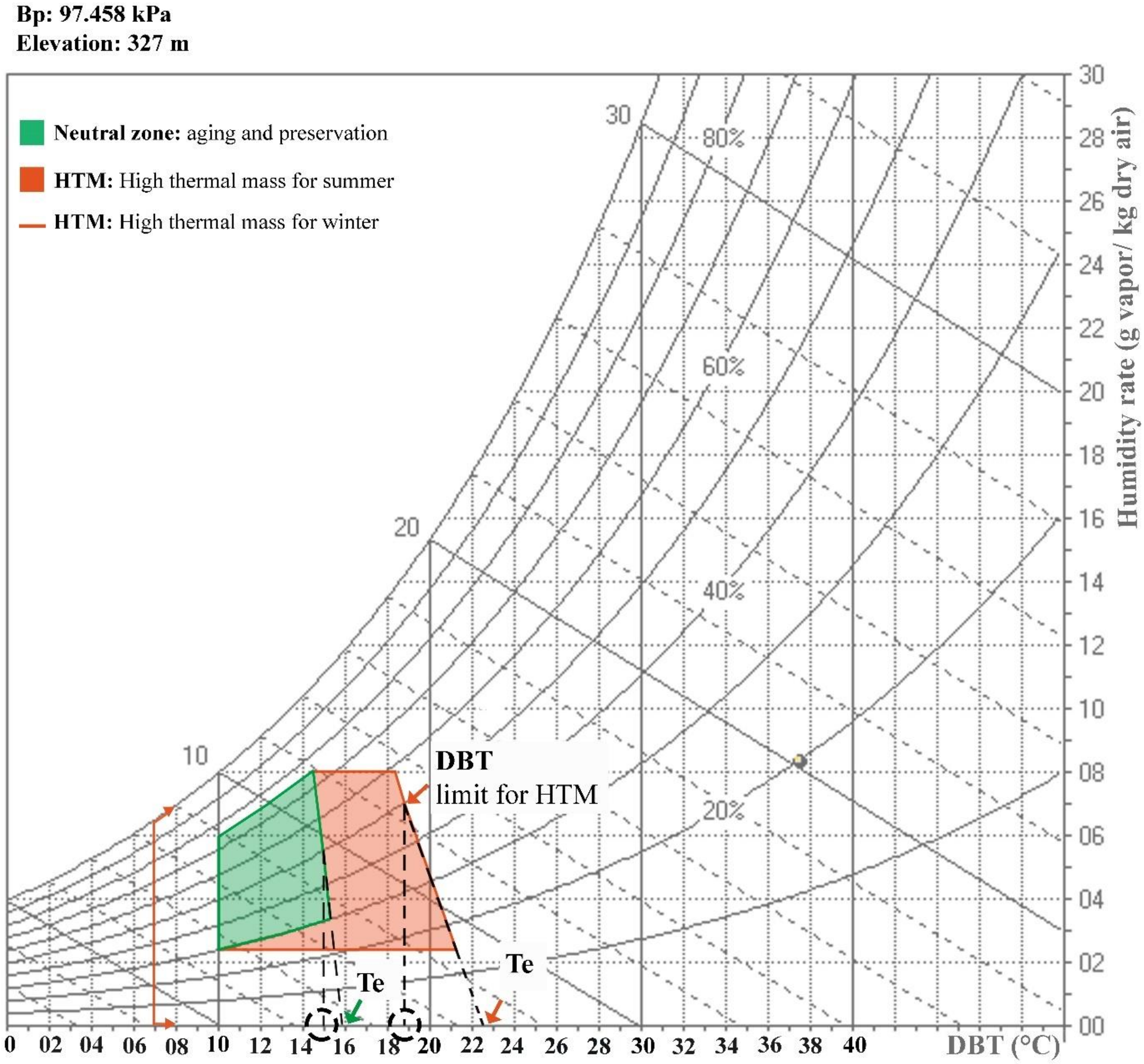

Figure 3. Psychrometric chart with plots of the neutral zone and thermal mass strategy for the wine aging area (source: elaboration by the authors).

To calculate the high winter thermal mass strategy (12 h of thermal delay), the following equation (Equation (3)) was used. The values of L_{MIN}, which were equal to 10 °C, AT_{MAX} of 13.9 °C and AT_{MIN} of 6.3 °C, were substituted in Equation (3). The result obtained was 6.96 °C as the limit of high winter thermal mass. On the psychrometric chart, the point was located on the DBT axis and a vertical line was drawn to delimit the use of said strategy (Figure 3):

$$HTM = L_{MIN} + 0.4(AT_{MAX} - AT_{MIN}) \quad (3)$$

where:

- HTM = High Thermal Mass Limit for Winter (°C)
- L_{MIN} = Lower Limit of neutral zone (°C)
- AT_{MAX} = Maximum average outdoor temperature in Winter (°C)
- AT_{MIN} = Minimum average outdoor temperature in Winter (°C).

Docherty and Szokolay [27] mention that, to determine the limit of the direct evaporative cooling effect (DEC) in relation to the dry bulb temperature (DBT), the neutral temperature (T_n) plus 12 °C (T_n + 12 °C) is considered. In this study, Equation (4) was used to calculate the potential limit of this strategy and the maximum wet bulb temperature for evaporative cooling (25 °C) and the effectiveness of the system (75% to 95%) were taken as reference with ASHRAE Handbook Fundamentals [32]:

$$DEC = (DBT - WBT) \times E \quad (4)$$

where:

- DEC = Direct evaporative cooling limit (°C)
- DBT = Dry bulb temperature (°C)
- WBT = Wet bulb temperature of the initial environmental condition (°C)
- E = System effectiveness (%).

The average outdoor DBT for summer considered as the initial environmental condition was 33 °C, which is equal to 24.9 °C wet bulb temperature (WBT) under 50% RH conditions. The effectiveness for direct evaporative cooling that was considered for this research was 95%. By substituting values in Equation (4), the maximum DEC potential obtained was 7.6 °C. To delimit the strategy, the effective temperature of the neutral zone equal to 15.8 °C + 7.6 °C (T_e + 7.6 °C) was used; the value obtained as the DEC limit was 23.4 °C.

On the psychrometric chart, a line parallel to the absolute humidity was drawn from the maximum point of the neutral zone and intersected with the wet bulb temperature WBT, which for this strategy was 14 °C. The estimated DEC limit (23.4 °C) with 0% RH was located on the DBT axis and a line was drawn on the DBT axis until it joined the WBT line. The DEC strategy was delimited by joining the minimum limit of the neutral zone and the DBT axis with another line parallel to the WBT axis (Figure 4).

To calculate the indirect evaporative cooling effect (IEC) limit, Docherty and Szokolay [27] use the neutral temperature plus 15 °C (T_n + 15 °C). In this research, Equation (4) was used to define the potential of the strategy with a system effectiveness of 80%. The IEC potential obtained was 6.4 °C. To delimit the strategy, the effective temperature of the neutral zone equal to 15.8 °C + 6.4 °C (T_e + 6.4 °C) was used; the value obtained as the IEC limit was 22.2 °C.

On the psychrometric chart, the IEC limit was located (22.2 °C) and a line was drawn up to 50% RH. Starting from the maximum limit of the neutral zone, a line was drawn parallel to the absolute humidity and joined with the line of dry bulb temperature; in the upper corner of the strategy a cut was made with a line parallel to the wet bulb temperature and was delimited as shown in Figure 4. The efficiency and therefore the effect of the IEC is lower compared to the DEC strategy due to the relative humidity of the study area.

The last strategy defined was shading, which was defined based on the minimum DBT limit for the neutral aging zone, i.e., at 10 °C. The above was determined based on the method of the Climate Consultant program (2017, version 6). On the psychrometric chart, said value was located on the DBT axis and a vertical line was drawn only for its delimitation. The dehumidification strategy was plotted over the neutral zone (Figure 4).

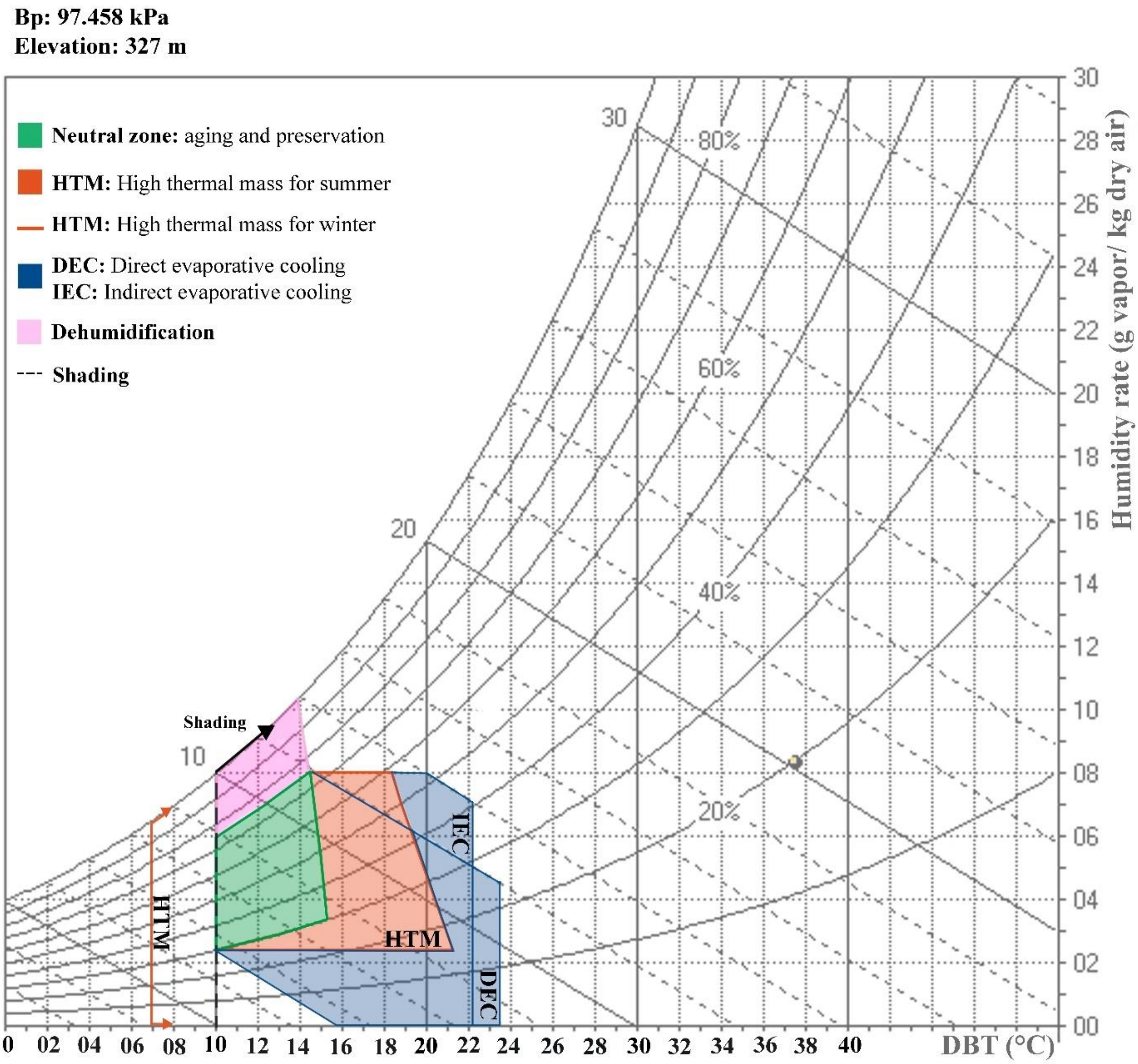

Figure 4. Delimitation of bioclimatic strategies for aging area (source: elaboration by the authors).

When calculating the strategies for the production area, the indoor environmental conditions suitable for the wine and for people were taken into account. The neutral zone for production, the high thermal mass strategy (12 h of thermal delay) for summer and winter, direct and indirect evaporative cooling, dehumidification and shading were drawn on the psychrometric chart (Figure 5).

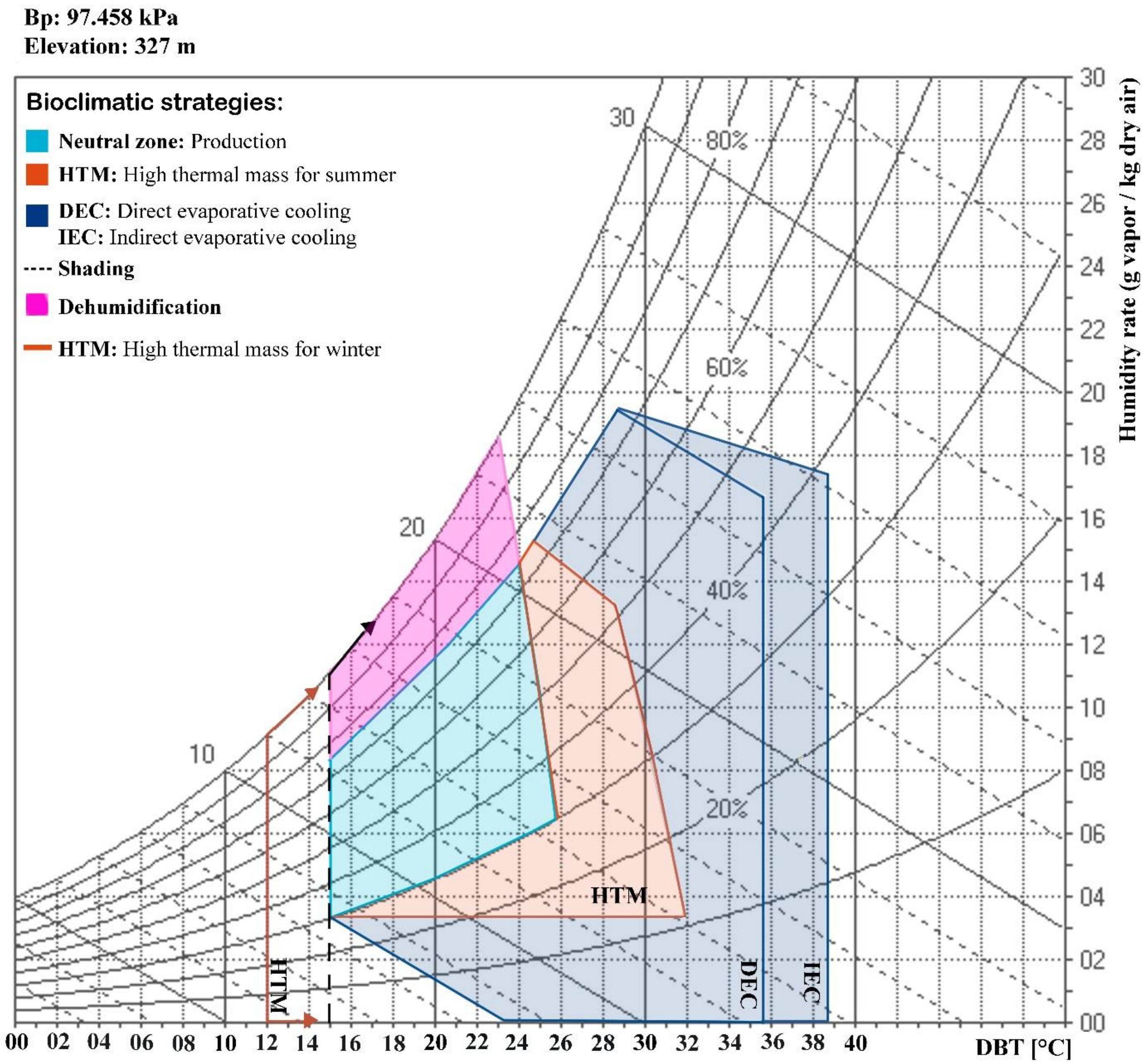

Figure 5. Delimitation of bioclimatic strategies for production area (source: elaboration by the authors).

2.4. Data Analysis

After defining the strategies in the psychrometric chart, an analysis was conducted to evaluate their potential effectiveness under the climatic conditions of the Guadalupe Valley. The data analysis was divided into two stages. The first stage involved processing the data measured by the weather stations to obtain dry bulb temperature and relative humidity values, averaged hourly on a monthly basis for two distinct periods (cold and warm). The second stage focused on assessing the potential of using bioclimatic strategies in wine cellars, specifically in both the production and aging areas. This analysis utilized both estimated data and microclimatic monitoring data to evaluate the effectiveness and applicability of various bioclimatic strategies. The estimated data was sourced from Meteonorm software, while the microclimatic data was derived from on-site measurements conducted within the Guadalupe Valley.

The methodology of the study is summarized in the flowchart of Figure 6.

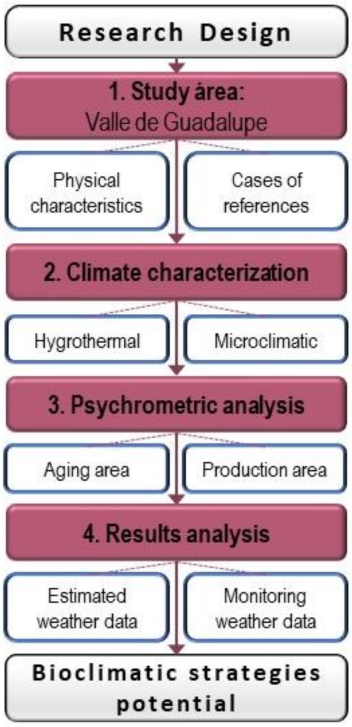

Figure 6. Framework of the study (source: elaboration by the authors).

3. Results

The results were divided into two sections: the potential of bioclimatic strategies using estimated data, which includes two psychrometric charts showing temperature and humidity levels obtained with the Meteonorm software based on monthly average hours; and the potential of bioclimatic strategies using monitoring data, presenting two psychrometric charts with monthly average hourly dry bulb temperature and relative humidity data measured in the Guadalupe Valley. In total, four psychrometric charts were produced.

3.1. Potential of Bioclimatic Strategies with Estimated Data

The estimated values of dry bulb temperature and relative humidity corresponding to the monthly average hours of a design year were located in the psychrometric charts. Although temperature and relative humidity data are presented for all months of the year, only the cold period (December to February) and the warm period (May to July) were considered in the analysis of results.

In the aging area, the results obtained with the psychrometric chart were the following:

- For 9.7% of the monthly average hours of the year, the dry bulb temperature and relative humidity were located within the neutral zone, and 25% of those hours correspond to the cold period.
- A proportion of 38.9% of the cold period could use the indirect evaporative cooling strategy.
- High thermal mass is required 54.2% of the year, in the winter months.
- The window and building shading strategy is required 92.7% of the year, especially in the summer months for 75% of the hours (Figure 7).

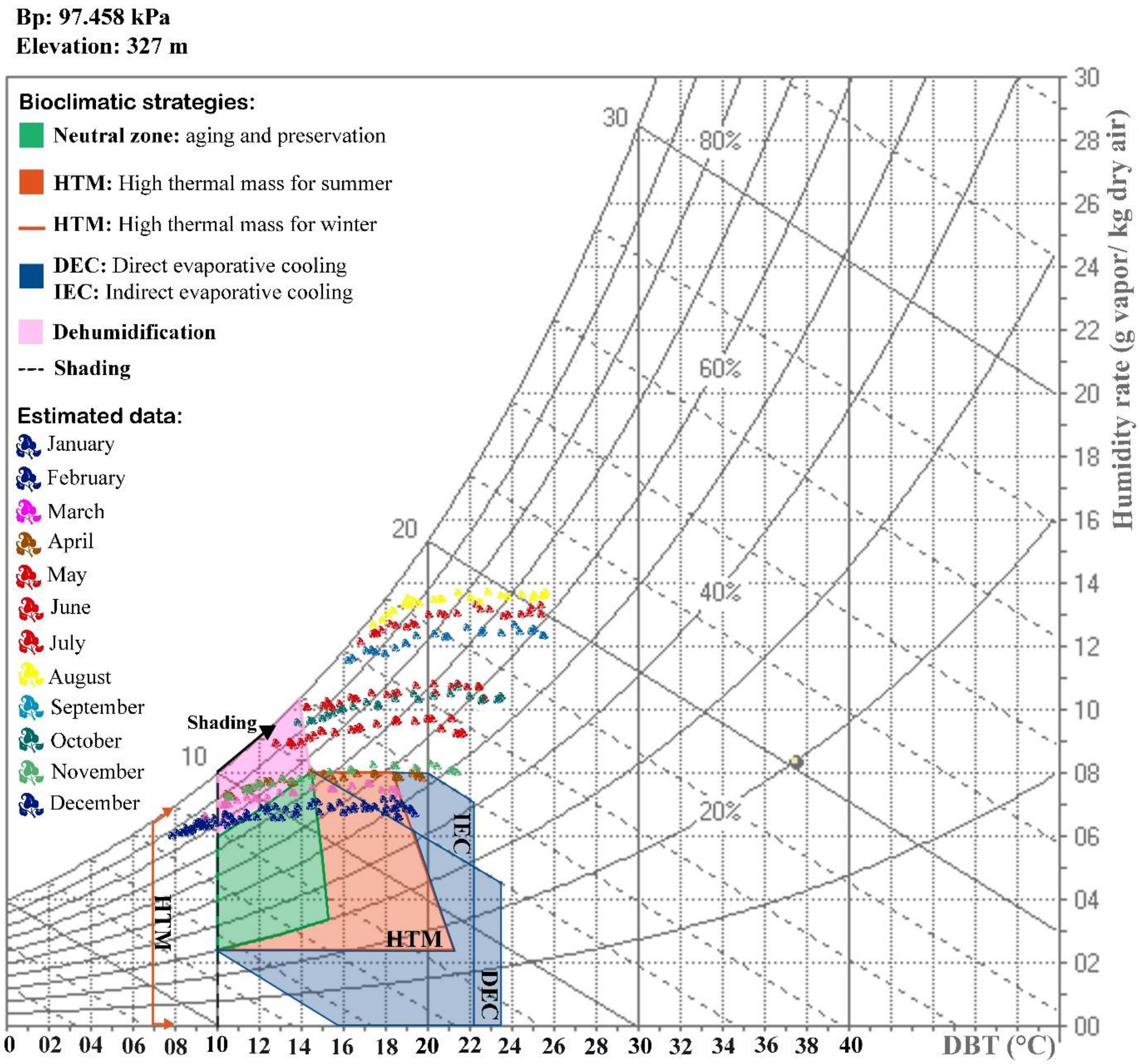

Figure 7. Bioclimatic strategies and estimated monthly average hours: aging area (source: elaboration by the Authors).

In the production area the results were the following:

- 43.1% of the monthly average hours of the cold period and 41.7% of the hours of the warm period were located within the neutral zone.
- High thermal mass and evaporative cooling presented equal percentage values; 34.7% of the hours of the cold period and 48.6% of the warm period can use any of these strategies.
- Shading is required for the 70.8% of the warm period (Figure 8).

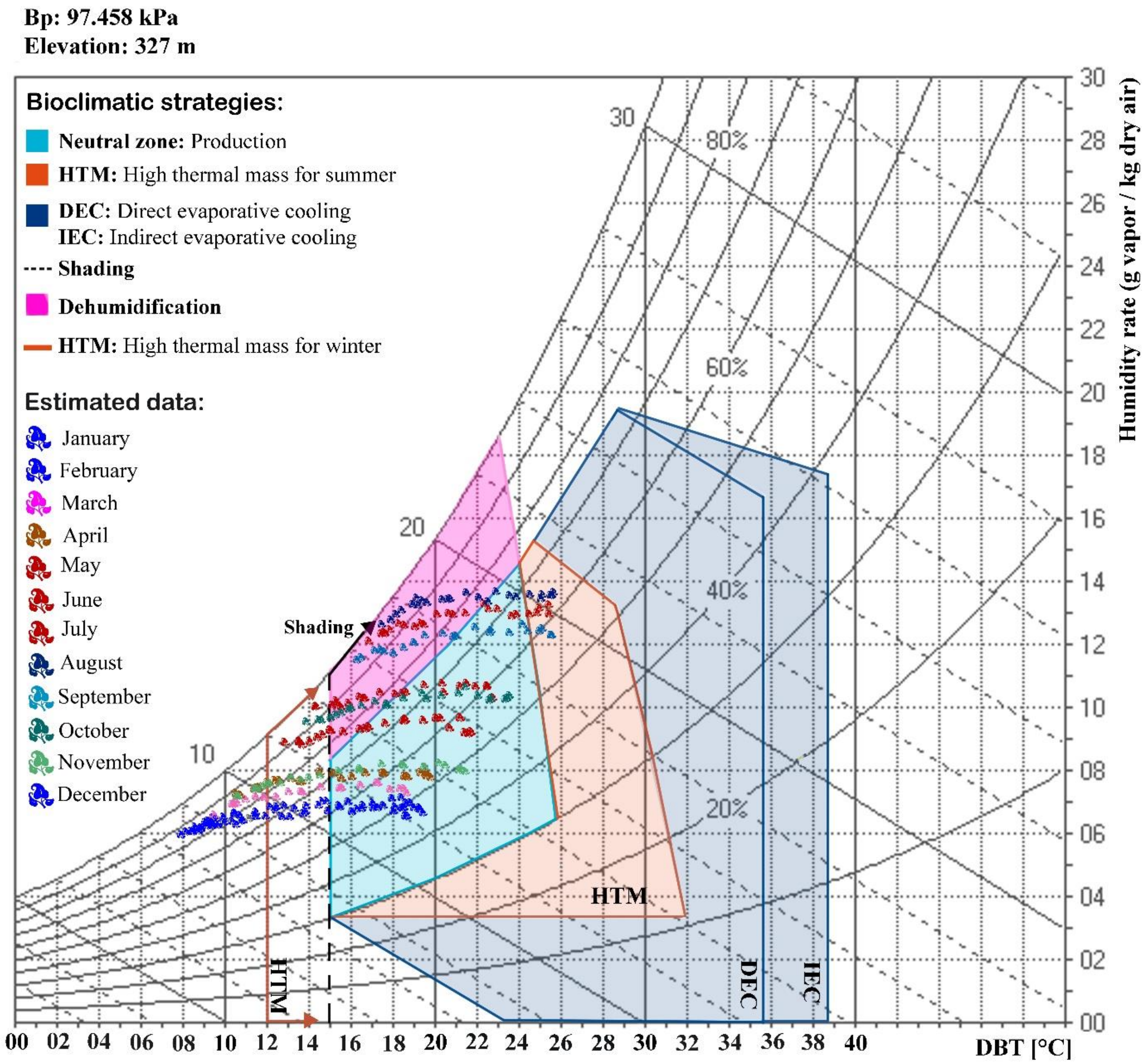

Figure 8. Bioclimatic strategies and estimated monthly average hours: production area (source: elaboration by the Authors).

The bioclimatic design strategies with the greatest potential for use, by seasonal percentage obtained for the aging area, were shading and high thermal mass while, in the production area, evaporative cooling, high thermal mass and shading are required. Table 2 shows a numerical analysis of the bioclimatic charts in Figures 7 and 8.

Table 2. Analysis of the potential use of bioclimatic strategies by seasonal period, with estimated meteorological data.

AGING AREA									
BIOCLIMATIC STRATEGY	COLD PERIOD (Winter)			TOTAL	WARM PERIOD (Summer)			TOTAL	POTENTIAL USE *
	DECEMBER	JANUARY	FEBRUARY		MAY	JUNE	JULY		
1.1 Neutral zone	25.0%	25.0%	25.0%	25.0%	0.0%	0.0%	0.0%	0.0%	N/A
1.2 High thermal mass (Summer)	58.3%	54.2%	50.0%	54.2%	0.0%	0.0%	0.0%	0.0%	✓

Table 2. *Cont.*

BIOCLIMATIC STRATEGY	COLD PERIOD (Winter)			TOTAL	WARM PERIOD (Summer)			TOTAL	POTENTIAL USE *
AGING AREA									
	DECEMBER	JANUARY	FEBRUARY		MAY	JUNE	JULY		
1.3 High thermal mass (Winter)	33.3%	29.2%	25.0%	29.2%	0.0%	0.0%	0.0%	0.0%	
1.4 Direct evaporative cooling	16.7%	25.0%	20.8%	20.8%	0.0%	0.0%	0.0%	0.0%	
1.5 Indirect evaporative cooling	41.7%	37.5%	37.5%	38.9%	0.0%	0.0%	0.0%	0.0%	✓
1.6 Dehumidification	4.2%	8.3%	12.5%	8.3%	33.3%	16.7%	0.0%	16.7%	
1.7 Shading	58.3%	58.3%	62.5%	59.7%	75.0%	75.0%	75.0%	75.0%	✓
PRODUCTION AREA									
BIOCLIMATIC STRATEGY	**COLD PERIOD (Winter)**			**TOTAL**	**WARM PERIOD (Summer)**			**TOTAL**	**POTENTIAL USE ***
	DECEMBER	JANUARY	FEBRUARY		MAY	JUNE	JULY		
2.1 Neutral zone	58.3%	37.5%	33.3%	43.1%	54.2%	50.0%	20.8%	41.7%	N/A
2.2 High thermal mass (Summer)	33.3%	37.5%	33.3%	34.7%	54.2%	50.0%	41.7%	48.6%	✓
2.3 High thermal mass (Winter)	20.8%	16.7%	25.0%	20.8%	33.3%	8.3%	0.0%	13.9%	
2.4 Direct evaporative cooling	33.3%	37.5%	33.3%	34.7%	54.2%	50.0%	41.7%	48.6%	✓
2.5 Indirect evaporative cooling	33.3%	37.5%	33.3%	34.7%	54.2%	50.0%	41.7%	48.6%	✓
2.6 Dehumidification	0.0%	0.0%	0.0%	0.0%	16.7%	41.7%	58.3%	38.9%	✓
2.7 Shading	33.3%	37.5%	33.3%	34.7%	66.7%	70.8%	75.0%	70.8%	✓

Note: Monthly hourly averages were used for percentage estimation. * Bioclimatic strategy by total percentage requirement in warm and cold periods. Source: elaboration by the authors.

3.2. Potential of Bioclimatic Strategies with Monitoring Data

The dry bulb temperatures and relative humidity values corresponding to the data measured with the meteorological station for the months of December, January, February (cold winter period) and May, June and July (warm summer period) were analyzed to obtain hourly averages, monthly, these values were located in the psychrometric charts, and the potential use of each bioclimatic design strategy was obtained.

In the aging area:

1. A proportion of 29.2% of the monthly average hours of the cold period were located within the neutral zone, while in the warm period the recorded values were located outside this zone.
2. For 77.8% of the hours of the cold period, it is necessary to use high thermal mass.
3. A figure of 75% evaporative cooling can be used.
4. In 23.6% of the cold period and 15.3% of the warm period, the interior space needs to be dehumidified and
5. Shading is 100% relevant in summer and 70.8% in winter (Figure 9).

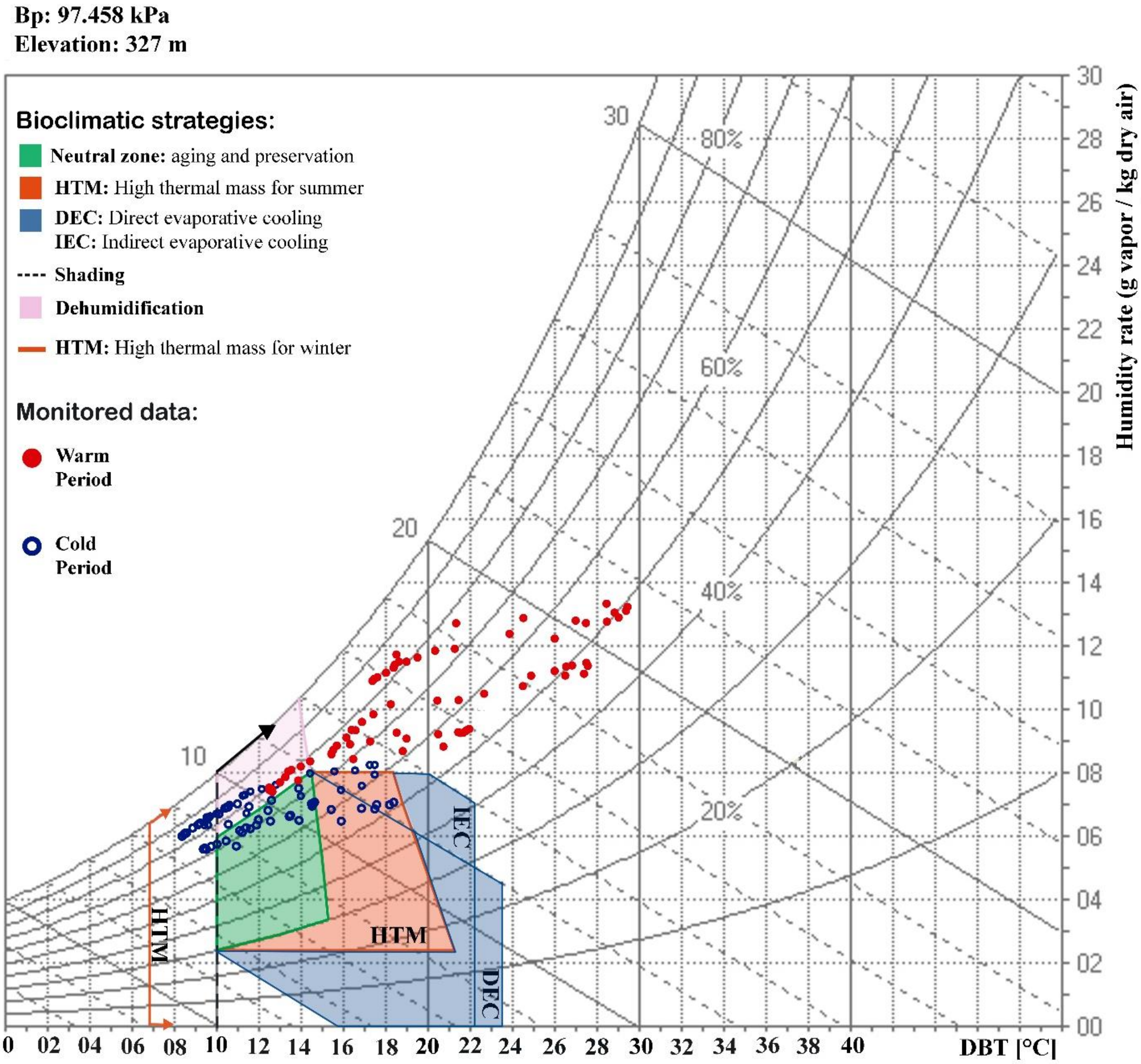

Figure 9. Bioclimatic strategies and monthly average hours with measured data: aging area (source: elaboration by the authors).

In the production area:

1. 34.7% of the monthly average hours of the warm period months were located within the neutral zone and 19.4% in the cold period.
2. The high thermal mass strategy is necessary for 66.7% of the warm period and 22.2% of the cold period.
3. Evaporative cooling can be used in summer by 38.9%, mainly in the months of June and July.
4. Dehumidification is required 33.3% in the warm period and
5. The shading strategy is required in both periods, 84.7% in summer and 19.4% in winter (Figure 10).

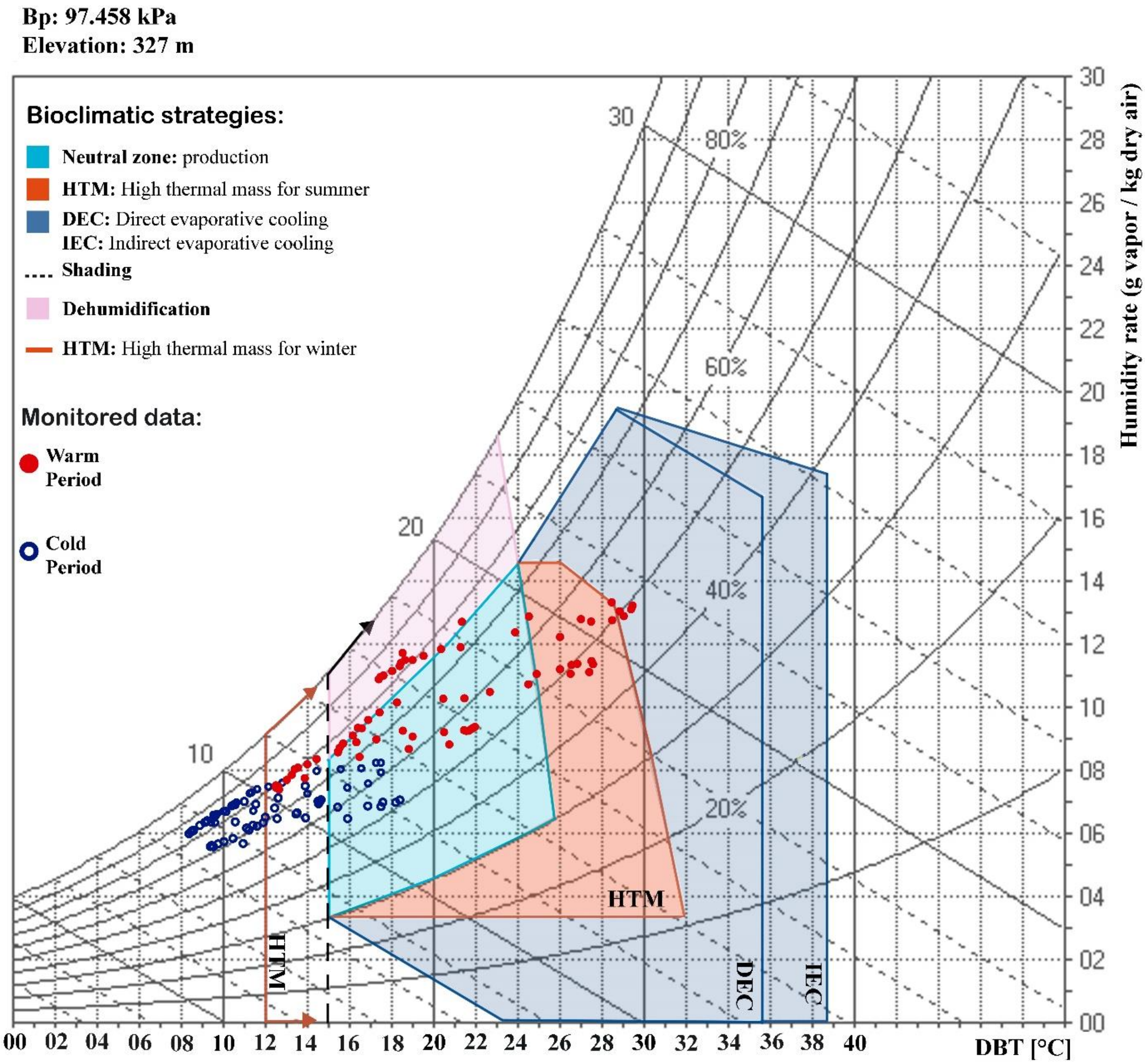

Figure 10. Bioclimatic strategies and monthly average hours with measured data: production area (source: elaboration by the authors).

The strategies with the greatest application potential for the aging area were shading, high thermal mass and evaporative cooling, while for the production area they were shading, high thermal mass, evaporative cooling and dehumidification, as is shown in Table 3.

Table 3. Analysis of the potential use of bioclimatic strategies for cold and warm periods, using meteorological data obtained through monitoring.

AGING AREA									
BIOCLIMATIC STRATEGY	COLD PERIOD (Winter)			TOTAL	WARM PERIOD (Summer)			TOTAL	POTENTIAL USE *
	DECEMBER	JANUARY	FEBRUARY		MAY	JUNE	JULY		
1.1 Neutral Zone	50.0%	29.2%	8.3%	29.2%	0.0%	0.0%	0.0%	0.0%	N/A
1.2 High thermal mass (summer)	79.2%	29.2%	37.5%	48.6%	0.0%	0.0%	0.0%	0.0%	✓

Table 3. *Cont.*

AGING AREA									
BIOCLIMATIC STRATEGY	COLD PERIOD (Winter)			TOTAL	WARM PERIOD (Summer)			TOTAL	POTENTIAL USE *
	DECEMBER	JANUARY	FEBRUARY		MAY	JUNE	JULY		
1.3 High thermal mass (Winter)	20.8%	41.7%	25.0%	29.2%	0.0%	0.0%	0.0%	0.0%	
1.4 Direct evaporative cooling	66.7%	29.2%	12.5%	36.1%	0.0%	0.0%	0.0%	0.0%	✓
1.5 Indirect evaporative cooling	79.2%	0.0%	37.5%	38.9%	0.0%	0.0%	0.0%	0.0%	✓
1.6 Dehumidification	0.0%	29.2%	41.7%	23.6%	45.8%	0.0%	0.0%	15.3%	
1.7 Shading	79.2%	58.3%	75.0%	70.8%	100.0%	100.0%	100.0%	100.0%	✓
PRODUCTION AREA									
ESTRATEGIA BIOCLIMÁTICA	COLD PERIOD (Winter)			TOTAL	WARM PERIOD (Summer)			TOTAL	POTENTIAL USE *
	DECEMBER	JANUARY	FEBRUARY		MAY	JUNE	JULY		
2.1 Neutral Zone	29.2%	0.0%	29.2%	19.4%	54.2%	37.5%	12.5%	34.7%	N/A
2.2 High thermal mass (summer)	0.0%	0.0%	0.0%	0.0%	66.7%	66.7%	33.3%	55.6%	✓
2.3 High thermal mass (Winter)	16.7%	33.3%	16.7%	22.2%	33.3%	0.0%	0.0%	11.1%	
2.4 Direct evaporative cooling	0.0%	0.0%	0.0%	0.0%	0.0%	66.7%	50.0%	38.9%	✓
2.5 Indirect evaporative cooling	0.0%	0.0%	0.0%	0.0%	0.0%	66.7%	50.0%	38.9%	✓
2.6 Dehumidification	0.0%	0.0%	0.0%	0.0%	0.0%	50.0%	50.0%	33.3%	✓
2.7 Shading	29.2%	0.0%	29.2%	19.4%	54.2%	100.0%	100.0%	84.7%	✓

Note: Monthly hourly averages were used for percentage estimation. * Bioclimatic strategy by total percentage requirement in warm and cold periods. Source: elaboration by the authors.

4. Discussion

The results showed that, for the aging area, 100% of the average monthly monitoring hours during the warm period (May to July) fall outside the limits of bioclimatic strategies. This suggests that, during these months, the use of electromechanical cooling systems is necessary to achieve the appropriate conditions within the neutral zone, considering a strict dry bulb temperature range of 10 °C to 15 °C. Conducting studies with dynamic thermal simulation is recommended to identify the potential percentage reduction in active cooling system usage during summer that a wine cellar employing bioclimatic design strategies could achieve compared to a non-bioclimatic scenario. In this regard, some authors have reported the environmental impact and energy savings of various bioclimatic strategies applied to buildings using multi-objective simulations [33,34]. According to the findings of Wang et al. [34], shading is crucial in summer, with 100% relevance for the aging zone and 84.7% for the production area. Similarly, further studies in the literature, such as that of Khakian et al. [35], have confirmed the importance of shading. They demonstrated that installing an overhang in a building located in a region with a hot semi-arid climate reduced cooling loads by 12.7% compared to the case without an overhang. Additionally, it was proven that the installation of overhangs led to a reduction in cooling demand by 4.1% in the Mediterranean climate [36].

The use of direct evaporative cooling techniques is recommended for wine cellars; however, it is important to consider the potential impact on indoor relative humidity levels, as it involves a humidification process, especially in the production area, where the operational efficiency of various equipment should be considered. Additionally, certain active systems require inlet and outlet ducts connected to the outdoor environment and specific positioning relative to the building. Nevertheless, passive evaporative cooling strategies have demonstrated their efficiency when combined with other solutions, such as natural ventilation [37], or when incorporating switchable building envelope systems to achieve optimal results [38]. This strategy can be replaced by the exploitation of thermal mass, which effectively reduces dry bulb temperature without increasing relative humidity and is independent of water availability; it can also be combined with the use of recycled water for its application in the wine aging area.

Thermal mass also involves design solutions with potentially high-quality characteristics, at the environmental and architectural level, for application in commercial buildings, such as green roofs or vegetated walls. They can be used to regulate indoor temperature fluctuations and shift the timing of peak temperature occurrence. As a consequence, such solutions can improve thermal comfort and reduce heat gain from the outdoor environment. Moreover, underground cellars have demonstrated thermal stability during the summer months and provide better indoor conditions, thereby reducing losses compared to above-ground aging rooms [39]. Rodrigues et al. [40] have demonstrated that high thermal mass structures are likely to be more effective in hot climates, while in cold climates they may increase energy use: this is in alignment with the results obtained, where high thermal mass shows greater potential benefits for the indoor microclimate in warm months.

Nevertheless, cost–benefit studies are extremely appropriate to complete the framework regarding the application of design strategies to new and existing buildings in the Guadalupe Valley, aiming to inform producers, architects, and engineers about the economic advantages and benefits of bioclimatic design for winery buildings. Elaouzy and Fadar [41] conclude that not all passive techniques are cost-effective, particularly those with high initial costs, such as phase change materials, shading, green roofs, and green walls, which result in longer payback periods. However, combining multiple passive methods, such as PCMs (Phase change materials), reflective paint, thermal insulation, glazing, and shading strategies in hot climates, and insulated glazing systems in cold climates, offers significant opportunities for enhancement of the performance of buildings. Energy and life cycle cost savings ranged from 6.7% to 66.2% and 12% to 52%, respectively, with payback periods ranging from 0.5 to 84 years.

Additionally, it is pertinent to mention that dynamic simulations were conducted using diverse building configurations and a combination of bioclimatic strategies tailored to the weather conditions of the Guadalupe Valley. These simulations analyzed thermal performance and the cost per energy consumption of each proposed model. The findings from these analyses will be disseminated in forthcoming papers.

Furthermore, it is important to note discrepancies in the microclimate monitoring data of the study area regarding exterior relative humidity measurements compared to estimated data. The estimated maximum relative humidity in summer reached 98.5%, while the highest monitored measurement was 86%. The monitored data was collected for two seasonal periods and not for the entire year, as the microclimate monitoring continued beyond the conclusion of this study.

5. Conclusions

The results of the study showed that, based on the monitoring data and the physical characteristics of the area, bioclimatic strategies can be effectively designed for winery buildings that require specific interior hygrothermal conditions for wine aging and production. The method employed represents a valuable, educational, and simplified tool which enables the identification of bioclimatic adaptation techniques by considering estimated and monitored weather data. The main findings of this study are summarized as follows:

- High thermal mass (HTM) for summer and shading has the major potential of use for wine cellar design in the climate conditions of the Guadalupe Valley since they do not require water availability or electrical energy, which would benefit small artisanal producers.

- The importance is established of strategic cooling interventions in wine cellar design to ensure optimal aging conditions, especially during warmer months. Dynamic thermal simulations would provide valuable insights into the effectiveness of bioclimatic approaches in reducing reliance on energy-intensive cooling systems, thus optimizing both operational costs and environmental impact.
- In particular, the results suggest the use of direct evaporative cooling with some considerations, and not for the entire year, and emphasize the potential of thermal mass as an alternative method for maintaining optimal conditions without compromising humidity control. The observed discrepancies in relative humidity measurements underscore the need for ongoing monitoring to comprehensively assess environmental conditions and inform design decisions for wine cellar facilities in the Guadalupe Valley.
- Bioclimatic design techniques identified through psychrometric charts can ensure that interior conditions are optimized for wine aging while providing a comfortable environment for workers (production area) and visitors.

In conclusion, utilizing simulation-based approaches informed by monitoring data offers a practical means of achieving energy efficiency and user comfort objectives in the design of winery facilities. This integrated approach aligns with sustainable practices and contributes to the overall success and longevity of the wine production environment. The results of this paper can represent a starting point to contribute to the more global and ambitious goal of reducing electricity demand and CO_2 emissions for climatic control in buildings.

Author Contributions: Conceptualization, V.J.-L., A.L.-L. and S.B.; methodology, V.J.-L. and A.L.-L.; software, V.J.-L.; validation, V.J.-L., A.L.-L. and S.B.; formal analysis, V.J.-L.; investigation, V.J.-L., A.L.-L. and S.B.; resources, V.J.-L. and A.L.-L.; data curation, V.J.-L. and A.L.-L.; writing—original draft preparation, V.J.-L.; writing—review and editing, V.J.-L. and S.B.; visualization, V.J.-L. and S.B.; supervision, A.L-L. and S.B.; project administration, V.J.-L. and A.L.-L.; funding acquisition, V.J.-L., A.L.-L. and S.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The original data presented in the study are openly available in AMS Acta, ISSN: 2038-7954 at doi.org/10.17616/R3P19R.

Acknowledgments: Víctor Torres Alegre; Aimé Desponds; Víctor Fuentes Freixanet; Instituto de Ingeniería y Facultad de Arquitectura y Diseño, Universidad Autónoma de Baja California; Consejo Nacional de Ciencia y Tecnología.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. González-Torres, M.; Pérez-Lombard, L.; Coronel, J.F.; Maestre, I.R.; Yan, D. A review on buildings energy information: Trends, end-uses, fuels and drivers. *Energy Rep.* **2022**, *8*, 626–637. [CrossRef]
2. Mainardis, M.; Gubiani, R. Energy use and management in the winery. In *Improving Sustainable Viticulture and Winemaking Practices*; Academic Press: Cambridge, MA, USA, 2022; pp. 221–238. [CrossRef]
3. D’Ammaro, D.; Capri, E.; Valentino, F.; Grillo, S.; Fiorini, E.; Lamastra, L. Benchmarking of carbon footprint data from the Italian wine sector: A comprehensive and extended analysis. *Sci. Total Environ.* **2021**, *779*, 146416. [CrossRef] [PubMed]
4. Scrucca, F.; Bonamente, E.; Rinaldi, S. Chapter 7—Carbon Footprint in the Wine Industry. In *Environmental Carbon Footprints*; Muthu, S.S., Ed.; Butterworth-Heinemann: Oxford, UK, 2018; pp. 161–196. [CrossRef]
5. Van Leeuwen, C.; Sgubin, G.; Bois, B.; Ollat, N.; Swingedouw, D.; Zito, S.; Gambetta, G.A. Climate Change Impacts and Adaptations of Wine Production. *Nat. Rev. Earth Environ.* **2024**, *5*, 258–275. [CrossRef]
6. Maicas, S. Advances in Wine Fermentation. *Fermentation* **2021**, *7*, 187. [CrossRef]
7. Nelson, J.; Knoesen, A.; Boulton, R. Nonlinear Model Predictive Control of Wine Fermentation Kinetics. *Eng. Proc.* **2023**, *37*, 107. [CrossRef]
8. Gómez-Villarino, M.T.; Barbero-Barrera, M.D.M.; Mazarrón, F.R.; Cañas, I. Cost-Effectiveness Evaluation of Nearly Zero-Energy Buildings for the Aging of Red Wine. *Agronomy* **2021**, *11*, 687. [CrossRef]

9. Pan, Y.; Zhong, W.; Zheng, X.; Xu, H.; Zhang, T. Natural Ventilation in Vernacular Architecture: A Systematic Review of Bioclimatic Ventilation Design and Its Performance Evaluation. *Build. Environ.* **2024**, *253*, 111317. [CrossRef]
10. Givoni, B. Indoor Temperature Reduction by Passive Cooling Systems. *Sol. Energy* **2011**, *85*, 1692–1726. [CrossRef]
11. Barbaresi, A.; De Maria, F.; Torreggiani, D.; Benni, S.; Tassinari, P. Performance Assessment of Thermal Simulation Approaches of Wine Storage Buildings Based on Experimental Calibration. *Energy Build.* **2015**, *103*, 307–316. [CrossRef]
12. Barreca, F.; Praticò, P. Assessment of Passive Retrofitting Strategies to Improve the Thermal Performance of Extra-Virgin Olive Oil Storage Area in Traditional Rural Olive Mills. *Sustainability* **2020**, *12*, 194. [CrossRef]
13. Conti, L.; Barbari, M.; Monti, M. Design of Sustainable Agricultural Buildings. A Case Study of a Wine Cellar in Tuscany, Italy. *Buildings* **2016**, *6*, 17. [CrossRef]
14. Mazarrón, F.R.; López-Ocón, E.; Garcimartín, M.A.; Cañas, I. Assessment of Basement Constructions in the Winery Industry. *Tunn. Undergr. Space Technol.* **2013**, *35*, 200–206. [CrossRef]
15. Martín Ocaña, S.; Cañas Guerrero, I. Comparison of Analytical and on Site Temperature Results on Spanish Traditional Wine Cellars. *Appl. Therm. Eng.* **2006**, *26*, 700–708. [CrossRef]
16. Amienyo, D.; Camilleri, C.; Azapagic, A. Environmental Impacts of Consumption of Australian Red Wine in the UK. *J. Clean. Prod.* **2014**, *72*, 110–119. [CrossRef]
17. Covarrubias, J.; Thach, L. Wines of Baja Mexico: A Qualitative Study Examining Viticulture, Enology, and Marketing Practices. *Wine Econ. Policy* **2015**, *4*, 110–115. [CrossRef]
18. Donatti, C.I.; Harvey, C.A.; Martinez-Rodriguez, M.R.; Vignola, R.; Rodriguez, C.M. Vulnerability of Smallholder Farmers to Climate Change in Central America and Mexico: Current Knowledge and Research Gaps. *Clim. Dev.* **2019**, *11*, 264–286. [CrossRef]
19. Hernández, A.L.; Alarcón, S.; Meraz Ruiz, L. Segmentation of Wine Tourism Experience in Mexican Wine Regions Using Netnography. *Int. J. Wine Bus. Res.* **2022**, *34*, 427–446. [CrossRef]
20. Zecca, G.; Labra, M.; Grassi, F. Untangling the Evolution of American Wild Grapes: Admixed Species and How to Find Them. *Front. Plant Sci.* **2020**, *10*, 1814. [CrossRef] [PubMed]
21. García, E. *Modificaciones al Sistema de Clasificación Climática de Kóppen, para Adaptarlo a las Condiciones de la República Mexicana*, 5th ed.; Universidad Nacional Autónoma de México: Ciudad de México, Mexico, 1964; p. 90.
22. CONAGUA, 2015. Actualización de la Disponibilidad Media Anual de Agua en el Acuífero Guadalupe (0207). Estado de Baja California. Available online: https://www.gob.mx/cms/uploads/attachment/file/103407/DR_0207.pdf (accessed on 15 May 2024).
23. Secretariat, W.M.O.; Secretariat, W.M.O.; Warn, E.; Adamo, S.B. The Journal of the World Meteorological Organization. 2013. Available online: https://environmentalmigration.iom.int/sites/g/files/tmzbdl1411/files/documents/2023-08/bulletin_63-2_en.pdf (accessed on 15 May 2024).
24. Didier Thevenard, P. Updating the ASHRAE Climatic Data for Design and Standards. *ASHRAE Trans.* **2010**, *116*, 444.
25. Tinti, F.; Barbaresi, A.; Benni, S.; Torreggiani, D.; Bruno, R.; Tassinari, P. Experimental Analysis of Shallow Underground Temperature for the Assessment of Energy Efficiency Potential of Underground Wine Cellars. *Energy Build.* **2014**, *80*, 451–460. [CrossRef]
26. Ocón, E.; Gutiérrez, A.R.; Garijo, P.; Santamaría, P.; López, R.; Olarte, C.; Sanz, S. Factors of Influence in the Distribution of Mold in the Air in a Wine Cellar. *J. Food Sci.* **2011**, *76*, 169–174. [CrossRef] [PubMed]
27. Szokolay, S.; Docherty, M.J. *Climate Analysis (PLEA Note 5)*; PLEA (Passive & Low Energy Architecture) Int.: Brisbane, Australia, 1999.
28. Ibtissame, B.; Imane, B.; Salima, L. Towards Low Energy and Thermal Comfort of Buildings through Passive Cooling or Heating Strategies in Hot Arid Climates. *J. Adv. Res. Fluid Mech. Therm. Sci.* **2022**, *93*, 173–182. [CrossRef]
29. Toris-Guitron, M.G.; Esparza-López, C.J.; Luna-León, A.; Pozo, C.E. Evaluation of the Thermal Performance of Traditional Courtyard Houses in a Warm Humid Climate: Colima, Mexico. *Herit. Sci.* **2022**, *10*, 187. [CrossRef]
30. Sánchez, F.G.C.; Tostado, L.P.M.; Ixta, I.A.C.; Morales, G.B. Análisis del Desempeño Térmico de un Sistema Constructivo de Ensamblado en Clima Cálido Seco Extremoso. *Rev. Cienc. Tecnológicas* **2021**, *4*, 256–274. [CrossRef]
31. Olesen, B.W. International Standards and the Ergonomics of the Thermal Environment. *Appl. Ergon.* **1995**, *26*, 293–302. [CrossRef] [PubMed]
32. American Society of Heating, Refrigerating and Air-Conditioning Engineers. *ASHRAE Handbook Fundamentals*; ASHRAE: Atlanta, GA, USA, 2021.
33. Amani, N.; Kiaee, E. Developing a two-criteria framework to rank thermal insulation materials in nearly zero energy buildings using multi-objective optimization approach. *J. Clean. Prod.* **2020**, *276*, 122592. [CrossRef]
34. Wang, Y.; Hu, L.; Hou, L.; Cai, W.; Wang, L.; He, Y. Study on energy consumption, thermal comfort and economy of passive buildings based on multi-objective optimization algorithm for existing passive buildings. *J. Clean. Prod.* **2023**, *425*, 138760. [CrossRef]
35. Khakian, R.; Karimimoshaver, M.; Aram, F.; Zoroufchi Benis, S.; Mosavi, A.; Varkonyi-Koczy, A.R. Modeling Nearly Zero Energy Buildings for Sustainable Development in Rural Areas. *Energies* **2020**, *13*, 2593. [CrossRef]
36. Sghiouri, H.; Mezrhab, A.; Karkri, M.; Naji, H. Shading devices optimization to enhance thermal comfort and energy performance of a residential building in Morocco. *J. Build. Eng.* **2018**, *18*, 292–302. [CrossRef]

37. Mohamed, S.; Al-Khatri, H.; Calautit, J.; Omer, S.; Riffat, S. The impact of a passive wall combining natural ventilation and evaporative cooling on schools' thermal conditions in a hot climate. *J. Build. Eng.* **2021**, *44*, 102624. [CrossRef]
38. Wu, Y.; Zhao, H.; Sun, H.; Duan, M.; Lin, B.; Wu, S. A review of the application of radiative sky cooling in buildings: Challenges and optimization. *Energy Convers. Manag.* **2022**, *265*, 115768. [CrossRef]
39. Mazarrón, F.R.; Cañas, I. Hygrothermal conditions for the aging of red wine from experimental data. *LWT-Food Sci. Technol.* **2023**, *173*, 114272. [CrossRef]
40. Rodrigues, E.; Fereidani, N.A.; Fernandes, M.S.; Gaspar, A.R. Diminishing benefits of thermal mass in Iranian climate: Present and future scenarios. *Build. Environ.* **2024**, *258*, 111635. [CrossRef]
41. Elaouzy, Y.; El Fadar, A. Energy, economic and environmental benefits of integrating passive design strategies into buildings: A review. *Renew. Sustain. Energy Rev.* **2022**, *167*, 112828. [CrossRef]