BcChart v2.0 – a tool for bioclimatic potential evaluation

Mitja Košir[1] and Luka Pajek[1]

[1] University of Ljubljana, Faculty of Civil and Geodetic Engineering, Ljubljana (Slovenia)

Abstract

As bioclimatic design is becoming increasingly important in contemporary buildings, various analytical tools must be developed and introduced to the designers in order to guide them through the design process. Therefore, the BcChart v2.0 software was developed. It executes bioclimatic potential analysis of a location based on the theory of Olgyay's bioclimatic chart. The main advantage of the introduced tool, in contrast to other bioclimatic analysis tools, is that it directly considers the influence of solar radiation, which is factored through substitutive daily comfortable dry-bulb air temperature. The paper presents the theoretical background of the tool. Additionally, the capabilities and functionality of the software are demonstrated through bioclimatic analysis of two different locations with contrasting climates (i.e. Ljubljana, Slovenia and Abu Dhabi, UAE). The conclusions highlight the importance of considering solar radiation when performing bioclimatic analysis of a location in order to thoughtfully design bioclimatic buildings.

Keywords: bioclimatic analysis, climate analysis, bioclimatic potential, bioclimatic chart, solar radiation, sustainable building

1. Introduction

Bioclimatic building design is one of the key approaches to the design of buildings of the future. A building can be declared bioclimatic when it efficiently uses climatic resources of its location (Krainer, 2008). An aforementioned adapted building simultaneously provides comfortable indoor environment and efficiently uses energy sources, primarily with the help of building envelope elements. Although the use of bioclimatic design in architecture and construction industry was introduced decades ago by Victor Olgyay (1963), it was in some way overlooked by the designers and researchers. However, in recent years, research in the field of bioclimatic design is on the rise, as living comfort, energy use and climate change have been brought into the spotlight. Thus, several studies have been made encouraging the bioclimatic approach to building design. The most recent research by Pajek and Košir (2017), by Khambadkone and Jain (2017), or the one by Manzano-Agugliaro et al. (2015) highlighted the importance of bioclimatic analysis of a specific location in order to define the most efficient bioclimatic design strategies to be integrated into buildings.

Several tools can be used to bioclimatically asses a location. In this respect, the most elementary bioclimatic chart was developed by Olgyay (1963) or in a different form by Givoni (1969). Furthermore, new tools for bioclimatic analysis have been made by several other authors (Rohles et al., 1975; Arens et al., 1980; Al-Azri et al., 2013; Martínez and Freixanet, 2014; University of California, 2017). Martínez and Freixanet (2014) presented a comprehensive bioclimatic analysis tool, named BAT. It enables plotting of bioclimatic charts and several other graphs on the basis of climate data imputed by the user. Nonetheless, too many items of information given by BAT can disorient the user, thus lowering the user-friendliness of this tool. Furthermore, the main deficiency of the BAT tool is that the impact of solar radiation is not directly incorporated into the main bioclimatic analysis but is rather presented in a separate section. Another example of a broadly used bioclimatic analysis tool is also Climate Consultant software designed at the University of California, USA (University of California, 2017). The results of climate analysis performed by the Climate Consultant tool give its users an insight into climate specifics of a certain location. The tool also guides the user towards appropriate building design through a set of design strategies necessary to achieve human comfort with either passive or active solutions. However, similar as the BAT tool, Climate Consultant does not directly consider solar radiation in the determination of comfort conditions.

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To summarise, there exist several tools that can be used for a bioclimatic analysis in order to define possible passive building design measures. However, the above referenced tools do not sufficiently consolidate the influence of solar radiation into the calculations and consequential bioclimatic potential of a given location. This is of special interest in the case of locations with temperate and cold climatic characteristics. Although solar radiation is mostly presented as one of the decisive factors influencing bioclimatic potential, its influence is never directly incorporated into bioclimatic potential calculations. It is rather used comparatively as a separate quantity detached from the external air temperature and relative humidity. Such comparison between the two is relevant, but it is also likely prone to human errors. Bioclimatic location analysis is one of the most important initial steps when designing buildings. Thus, a tool used for the analysis must be on one hand very precise and user-friendly on the other. Nonetheless, it is crucial that bioclimatic analysis tool is freely available to the interested audience, as this will widen the number of designers applying bioclimatic solutions to their projects. All mentioned above is taken into account with BcChart v2.0 – a bioclimatic potential analysis tool, developed by the authors and presented in this paper.

2. Description of applied methodology

2.1 BcChart software and bioclimatic charts

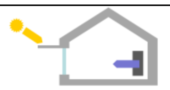
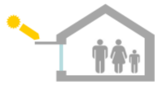
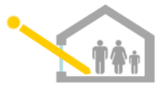
The BcChart v2.0 software was developed at the University of Ljubljana, Slovenia, and has been validated and evaluated through the educational process at the Faculty of Civil and Geodetic Engineering. It can be used for the calculations of bioclimatic potential based on the theory of Olgyay's bioclimatic chart (Olgyay, 1963). Bioclimatic charts are initiated with human comfort, which is calculated for an average person. The basic input climate parameters are average minimum and maximum daily air temperature (*T*) and relative humidity (*RH*). However, in addition to the basic bioclimatic chart input data, the mean and maximum daily solar irradiation is also factored in, resulting in modifications of Olgyay's bioclimatic chart plots. Nonetheless, it has to be noted that the modifications of bioclimatic charts are made only when additional influence of solar irradiation does not cause overheating. In other words, it is presumed that whenever the solar irradiation could cause overheating, effective shading will be used (i.e. when ambient temperatures on the bioclimatic chart are above shading line). Thus, the substitutive daily comfortable dry-bulb air temperature for month *i*, $T_{sub,i}$ is introduced (Equation 1). The derivation of the calculations made with BcChart v2.0 is Equation 1, based on the equation for human body thermal equilibrium, presented by Olgyay (1963). Equation 2 is introduced to describe the influence of actually received solar irradiation.

$$T_{sub,i} = \frac{T_S - (M_m - E + R_i) \times (Clo/c + V.Clo/c)}{S \times S_c} \qquad \text{(eq. 1)}$$

$$R_i = G_i \times S_e \times \alpha \qquad \text{(eq. 2)}$$

Where R_i is radiation in W for month *i*, G_i is the mean daily global solar irradiance in W/m^2 for month *i*, S_e is the effective radiation area for a given subject in a given position and it is assumed as 0.5 m^2, and α = 0.4 is the absorptivity of the radiated surface of a clothed man. T_s is comfortable skin temperature, presumed as 33.9°C, M_m is the observed rate of metabolism 126 W, *E* is the rate of cooling due to perspiration actually evaporated 38 W, *Clo/c* + *V.Clo/c* is clothing insulation and air effect on clothing coefficient (= 0.28) as defined by Olgyay (1963) and adapted to be expressed in m^{2}K/W. *S* is the mean body surface area of clothed man, assumed as 2.14 m^2 and S_c is the fraction of surface areas exposed to radiation and convection (= 0.9). Furthermore, the dry-bulb air temperature at which the passive solar heating (PSH) is still possible ($T_{PSH,i}$) was calculated using maximal daily global horizontal solar irradiance for each month ($G_{max,i}$). The plotted parts on bioclimatic chart, which are below this temperature, represent the part of each month, when passive solar heating cannot be used as an efficient passive strategy, because there is not enough solar energy available at a given location. Therefore, instead of the mean daily global solar irradiance (G_i) in Equations 1 and 2, the maximal values of solar radiation were used ($G_{max,i}$). T_{sub} and T_{PSH} were used only when modified bioclimatic charts were plotted, i.e. the solar radiation was directly incorporated into calculations. The main output of the BcChart v2.0 software is bioclimatic potential of the analysed location. It represents the time, expressed in % and presented either on yearly or monthly level, when the plotted combinations of temperature, relative humidity and solar irradiance fall either in or out of the comfort zone.

Tab. 1. Bioclimatic potential segments as calculated by BcChart.

Label	Colour	Bioclimatic potential	Suggested bioclimatic strategy
Q		mechanical cooling and/or dehumidification needed	
A		potential for passive solutions for hot arid climates	
V		natural ventilation needed	
M		natural ventilation and/or high thermal mass needed	
C_{sh}		comfort achieved with shading	
C_{sn}		comfort achieved with solar irradiation	
R		potential for passive solar heating	
H		no potential for passive solar heating	
S_h		shading needed ($S_h = Q + A + M + V + C_{sh}$)	

The described segments in Table 1 were calculated for every distinct month according to the length of the line plotted by using combinations of monthly average input climate data (Equation 3–14).

$$Q = \sum \frac{x_{q_j}}{l_j} \times \frac{100}{12} \quad \text{(eq. 3)}$$

$$A = \sum \frac{x_{a_j}}{l_j} \times \frac{100}{12} \quad \text{(eq. 4)}$$

$$V = \sum \frac{x_{v_j}}{l_j} \times \frac{100}{12} \quad \text{(eq. 5)}$$

$$M = \sum \frac{x_{m_j}}{l_j} \times \frac{100}{12} \quad \text{(eq. 6)}$$

$$C_{sh} = \sum \frac{x_{c_j}}{l_j} \times \frac{100}{12} \quad \text{(eq. 7)}$$

$$C_{sn} = \sum \frac{x'_{c_j}}{l'_j} \times \frac{100}{12} - C_{sh} \quad \text{(eq. 8)}$$

$$R = \sum \frac{x_{r_j}}{l_j} \times \frac{100}{12} \quad \text{(eq. 9)}$$

$$R' = \sum \frac{x'_{r_j}}{l'_j} \times \frac{100}{12} \quad \text{(eq. 10)}$$

$$H = \sum \frac{x_{h_j}}{l_j} \times \frac{100}{12} \quad \text{(eq. 11)}$$

$$H' = \sum \frac{x'_{h_j}}{l'_j} \times \frac{100}{12} \quad \text{(eq. 12)}$$

$$l_j = \sum x_{ij} \quad \text{(eq. 13)}$$

$$l'_j = \sum x'_{ij} \quad \text{(eq. 14)}$$

Where j = 1–12 or January–December and i = q, a, m, v, c, c', r, r', h or h'. l_j is the total period of the month (i.e. the sum of x_{qj}, x_{aj}, x_{mj}, x_{vj}, x_{cj}, x_{rj} and x_{hj}). l'_j is the total period of the month considering solar irradiance, which is different from l_j because of the consideration of solar radiation, thus the lengths of x_{ci}, x_{ri} and x_{hi} change. x_{ci} is the period of month (i.e. the length of the plotted line) inside the comfort zone when shading is needed, x'_{ci} is the period of month inside the comfort zone utilizing solar irradiance, x_{vi} is the period of month when ventilation in combination with shading is needed, etc. Definition of each calculated segment and the corresponding suggested bioclimatic strategy are explained in Table 1.

In the cases where the plotted lines fall inside the comfort zone, the achieving of comfort is defined as achieved by shading (C_{sh}) or by the use of solar energy (C_{sn}) (Table 1). Further on, the segments presented in Table 1 may also be combined into three main categories: shading needed ($S_h = Q + A + M + V + C_{sh}$), sun needed ($S_n = C_{sn} + R + H$) and comfort zone ($C_z = C_{sh} + C_{sn}$).

2.2 Limitations

The use of the bioclimatic chart used in the BcChart software is directly applicable only to inhabitants wearing customary indoor clothing, engaged in sedentary or light muscular work, at elevations not in excess of 300 m above sea level. The impact of sun radiation is calculated on the basis of Olgyay (1963), assuming the effective area of human body of 0.5 m^2. Internal heat gains cannot be considered when calculating bioclimatic potential, which can be determined as a limitation of the methodology. Another limitation of the BcChart software is that the borders of comfort zone, which is roughly between 21 and 27°C, cannot be manually modified in order to adapt it to different human comfort conditions.

3. BcChart v2.0 – user interface and functionality

The interface of the BcChart v2.0 software was created in MS Excel environment. It consists of 4 consecutive spreadsheets (see Fig. 1 and Fig. 2) guiding the user from input data to the result interpretation:

- Input data (climatological data and basic information about for the analysed location).
- Bioclimatic chart (plot of basic bioclimatic chart w/o the influence of solar radiation and modified bioclimatic chart w/ solar radiation).
- Bioclimatic potential analysis (interpretation of analysed data through yearly and monthly bioclimatic potential of the location).
- About (theoretical background explanation, copyright and terms of use and author contacts).

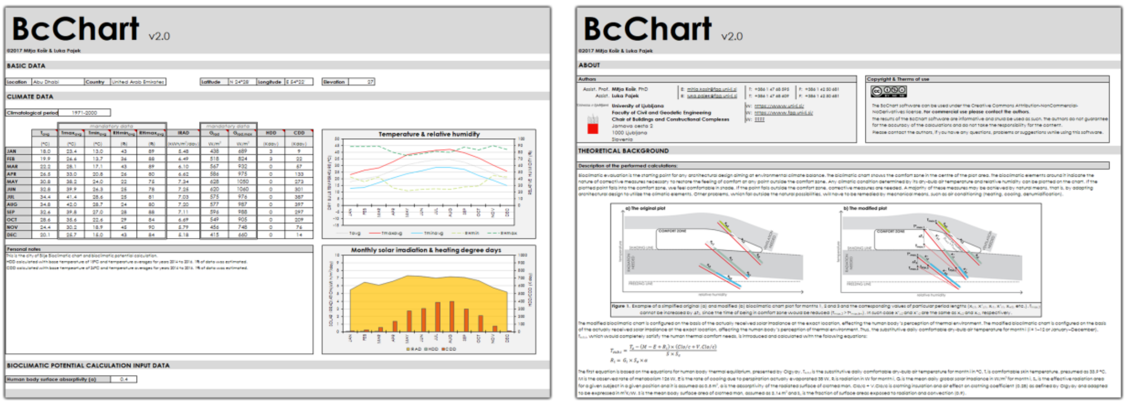


Fig. 1: BcChart v2.0 user interface screen shots: left – Input data (monthly average climatological data), right – About (explanation of calculation background).

In the first spreadsheet named Input data (Fig. 1, left), the user must input the location information data and key climate data used for the calculation of bioclimatic potential. The mandatory data are: average daily maximum ($Tmax_{avg}$) and minimum ($Tmin_{avg}$) dry bulb temperature (°C), average daily maximum ($RHmax_{avg}$) and minimum ($RHmin_{avg}$) relative humidity (%), average (G_{rad}) and maximum ($G_{rad,max}$) global daily irradiance (W/m^2) on the horizontal plane. In addition to the mandatory data necessary for the bioclimatic potential calculation, supplementary climatic characteristics can be entered as well. These are the following: average daily (T_{avg}) dry bulb temperature (°C), average sum of global irradiation ($IRAD$) on the horizontal plane (kWh/m^2) and heating

(*HDD*) and cooling (*CDD*) degree-days (Kday). However, these additional climate data do not influence the bioclimatic potential calculation and are only used in order to enable better interpretation of the bioclimatic analysis. Supplementary data are presented together with the mandatory data through diagrams (Fig. 1, left).

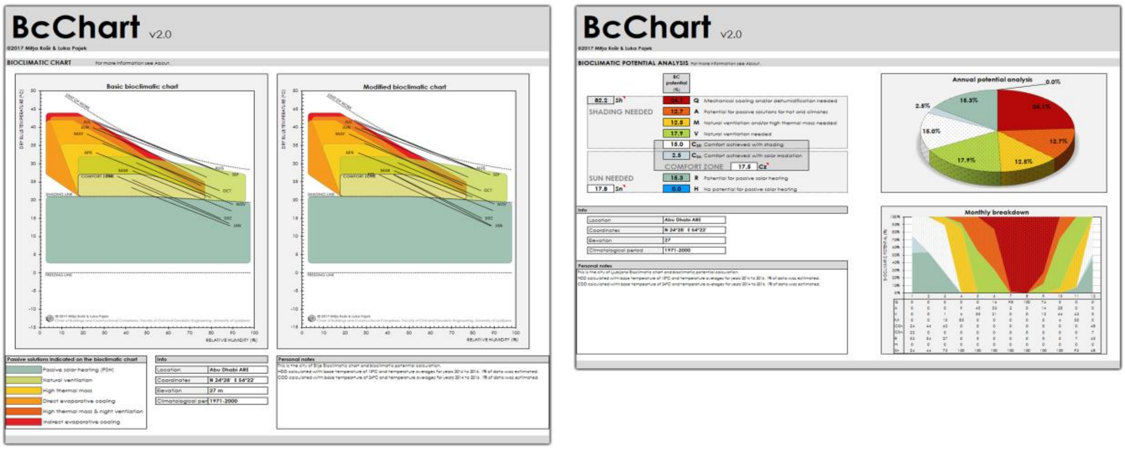


Fig. 2: BcChart v2.0 user interface screen shots: left – Bioclimatic chart (basic and modified bioclimatic chats), right – Bioclimatic potential analysis (yearly cumulative and monthly values of bioclimatic potential).

In the second spreadsheet (i.e. Bioclimatic chart) the basic and modified bioclimatic charts are plotted (Fig. 2, left). In the third spreadsheet (i.e. Bioclimatic potential analysis) the results of the bioclimatic interpretation are given (Fig. 2, right), while the fourth spreadsheet (i.e. About) gives information about the authors, copyright and basic information about used calculation methodology (Fig. 1, right). The results of the bioclimatic analysis can be interpreted directly through the evaluation of bioclimatic chart (Fig. 2, left) and the corresponding passive strategies marked on them, or by the results of yearly and monthly bioclimatic potential calculation (Fig. 2, right), which assist the user in the interpretation of the charts. It must be stressed that the calculated bioclimatic potential with its corresponding evaluation of the most important bioclimatic strategies for the analysed location is only a generic recommendation. Therefore, is up to the user of the software to appropriately apply the proposed solutions to a specific project.

4. Example of performed analysis and discussion

Functionality of the BcChart v2.0 software is presented through the evaluation and determination of bioclimatic potential at two selected characteristic locations. These were chosen in order to demonstrate how the bioclimatic potential analysis is performed with the BcChart v2.0 software. The chosen locations were the following:

- **Ljubljana, Slovenia, Europe** (46.22° N, 14.48°E); Köppen-Geiger climate classification: Cfb (temperate, without dry season, warm summer). In Ljubljana, the minimum average daily dry bulb temperature of –4.9°C occurs in January and the maximum of 26.4°C in July. The lowest average daily minimum *RH* of 43% occurs in July, while the maximum of 98% occurs in October. The lowest average daily global horizontal solar radiation of 17 Wh/m^2 occurs in December and the highest of 687 Wh/m^2 in July.
- **Abu Dhabi, UAE, Middle East** (24.43° N, 54.65°E); Köppen-Geiger climate classification: BWh (arid, desert, hot). In Abu Dhabi, the minimum average daily dry bulb temperature of 13.0°C occurs in January and the maximum of 42.0°C in August. The lowest average daily minimum *RH* of 22% occurs in May, while the maximum of 90% occurs in November. The lowest average daily global horizontal solar radiation of 140 Wh/m^2 occurs in December and the highest of 1020 Wh/m^2 in May.

Firstly, the results of the basic bioclimatic chart analysis (i.e. without considering the influence of solar radiation) are compared with those obtained by Climate Consultant software v6.0 (University of California, 2017) in the section 4.1. Secondly, the results without and with the influence of solar radiation (i.e. basic vs modified bioclimatic chart) are presented in section 4.2. Comparison of the basic and modified bioclimatic potential results will demonstrate the importance and impact of solar radiation on the prevalence of the determined bioclimatic design strategies.

4.1 BcChart vs Climate Consultant

In order to be able to compare the results obtained from both analyses (i.e. BcChart v2.0 and Climate Consultant v6.0), the boundary conditions were equalled as much as possible. Accordingly, the same input climatological data were used, namely the EPW weather data files for Ljubljana and Abu Dhabi (EnergyPlus, 2017). The calculation and the plot of psychrometric chart within Climate Consultant was made according to the ASHRAE Handbook of Fundamentals Comfort Model (up through 2005). Boundaries of comfort zone in the Climate Consultant were set in order to reflect those used by BcChart, i.e. comfort low temperature at 50% *RH* was set to 21°C and comfort high at 50% *RH* was set to 27°C. Minimal dry-bulb temperature when need for shading begins was set to 21°C.

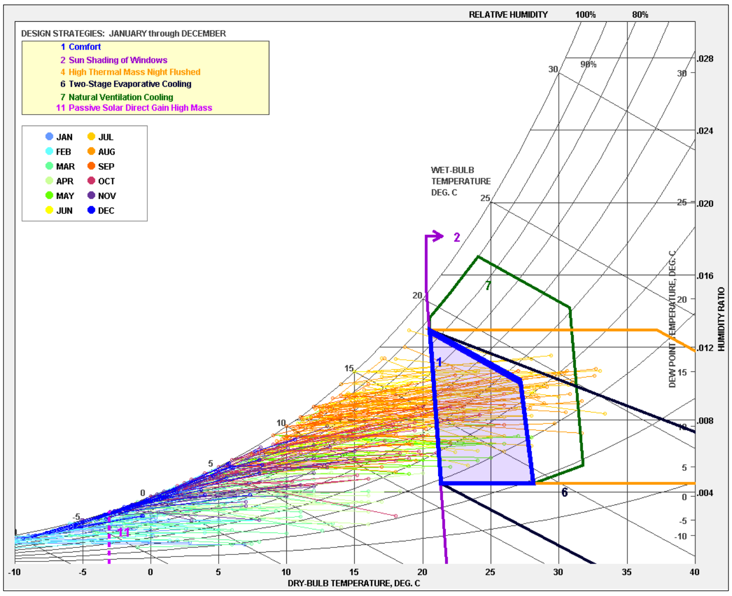


Fig. 3: Bioclimatic analysis for the location of Ljubljana created using Climate Consultant v6.0. Climate data are plotted as daily minimums and maximums in respect to the selected design strategies.

It has to be noted that the results obtained with Climate Consultant are calculated on the basis of hourly climate data, whereas the results obtained with BcChart are calculated using monthly daily averages. Recommended or effective passive measures, displayed on each of the two charts (bioclimatic chart in BcChart and psychrometric chart in Climate Consultant) are comparable but not equivalent. Therefore, a complete equivalency cannot be expected between the results of both tools. Correspondingly, in comparison to BcChart a broader set of passive and active measures is presented and proposed within Climate Consultant. Nevertheless, the results can be to some degree interpreted in such a way to enable the assessment of results between the two applications. For example, value *R* (for the explanation see Table 1) in BcChart can be compared to design strategy number 11 (i.e. passive solar direct gain, high mass) in Climate Consultant. Similarly, value C_z in BcChart is comparable to design strategy number 1 (i.e. comfort), value *V* to design strategy number 7 (i.e. natural ventilation), value *M* to design strategy number 4 (i.e. high thermal mass night flushed) and value *A* in BcChart to Climate Consultant design strategy number 6 (i.e. two-stage evaporative cooling). Other values found in BcChart (*H*, *Q*, C_{sn}, C_{sh}) cannot be directly paired with corresponding strategies proposed by Climate Consultant. All the described passive strategies can be observed and graphically compared in Figures 3 and 4, where the results for Ljubljana calculated with Climate Consultant and BcChart, respectively, are presented.

Because of the different methodology used in each of the selected software and the corresponding results, which cannot be directly compared, the results obtained by BcChart were compared by the Climate Consultant results only through the following three parameters: S_n – sun needed, C_z – comfort zone, S_h – shading needed. These results are presented in Table 2. Value S_n obtained by BcChart can be compared to design strategy number 11 (i.e. passive solar direct gain high mass) in Climate Consultant. Similarly, value S_h can be compared to a sum of design strategies number 1, 13, 14 and 15 in Climate Consultant (i.e. comfort, humidification only, dehumidification only and cooling, add dehumidification if needed). C_z is comparable to design strategy number 1 (i.e. comfort). In order to graphically compare the results, the psychrometric chart from Climate Consultant (Fig. 3) and bioclimatic chart from BcChart (Fig. 4) were plotted for the city of Ljubljana. It can be noted from the results presented in Table 2 that the total sum of all three analysed parameters (S_n, C_z and S_h) is larger than 100%; the reason is that when comfort is achieved, also shading is needed (i.e. the lower boundary of comfort zone overlaps with the shading line – see Fig. 2 and 3). Although the described suggested passive strategies obtained by each of the considered tools are not completely equivalent, a correlation between the results is evident (Tab. 2, Fig. 3 and 4).

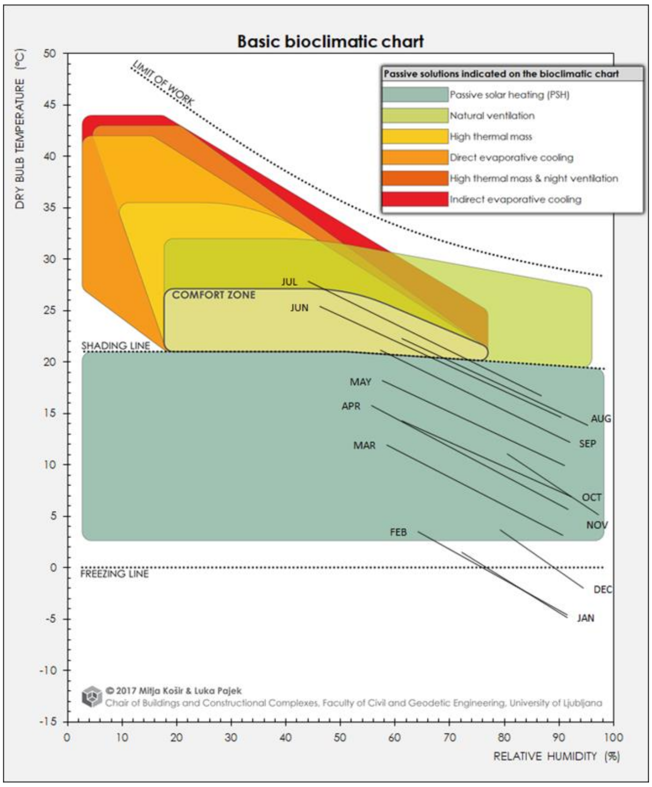


Fig. 4: Basic bioclimatic analysis for the location of Ljubljana created using BcChart v2.0. Climate data is plotted as monthly daily average minimum and maximum in respect to the selected passive solutions.

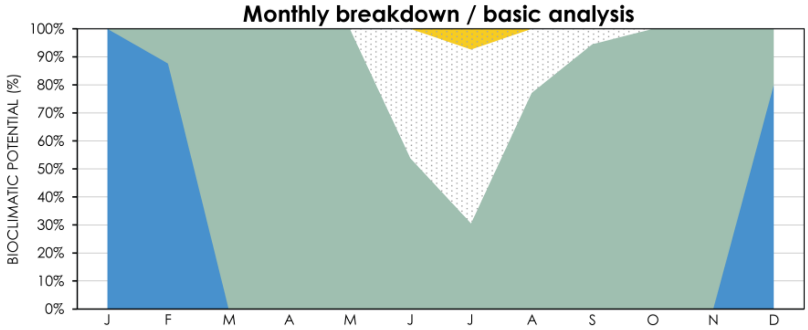
Observing Table 2 it can be concluded that the values of S_n, C_z and S_h, obtained by either BcChart or Climate Consultant are closer together in the case of Ljubljana. The latter was expected since the methodology, which runs in the background of the BcChart software, is more appropriate for the analysis of locations with temperate climate, rather than for locations with hot-arid, hot-humid or polar climate. The differences between the results obtained by BcChart and Climate Consultant in the case of the two selected locations range from 1.3 percentage points (pp) in the case of S_h and 3.9 pp for value C_z, both in Ljubljana (Tab. 2). The observed differences are most probably the consequence of differently processed climate data – Climate Consultant uses hourly, while BcChart uses monthly climate data. Additionally, dissimilarities in the results could also stem from different boundaries of passive (bioclimatic) strategies in both tools (i.e. the “areas of specific passive strategies” in the charts are not equivalent). Nonetheless, the obtained results in both applications can be considered as equivalent. Especially, if a substantial difference in the inputted climatic data is taken into account.

Tab. 2. The selected comparable parameters obtained by bioclimatic analysis using BcChart and Climate Consultant and their absolute differences.

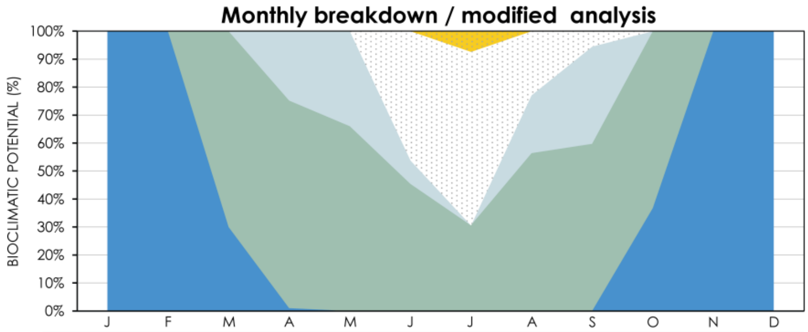
	Abu Dhabi			**Ljubljana**		
	S_n	C_z	S_h	S_n	C_z	S_h
BcChart	17.8%	15.0%	82.2%	87.9%	11.5%	12.1%
Climate Consultant	21.2%	11.3%	78.8%	89.2%	7.6%	10.8%
|Δ|	3.4 pp	3.7 pp	3.4 pp	1.3 pp	3.9 pp	1.3 pp

4.2 Consideration of solar radiation and its effect on BcChart results

In order to assess the influence of the considered solar radiation influence on the BcChart tool results, this section studies monthly breakdown of bioclimatic potential with basic (i.e. original method – no direct consideration of solar radiation) and modified analysis (i.e. actually received solar radiation is included into the calculation) for both locations (i.e. Ljubljana and Abu Dhabi). Figures 5 and 6 represent basic and modified bioclimatic potential for Ljubljana and Abu Dhabi, respectively.



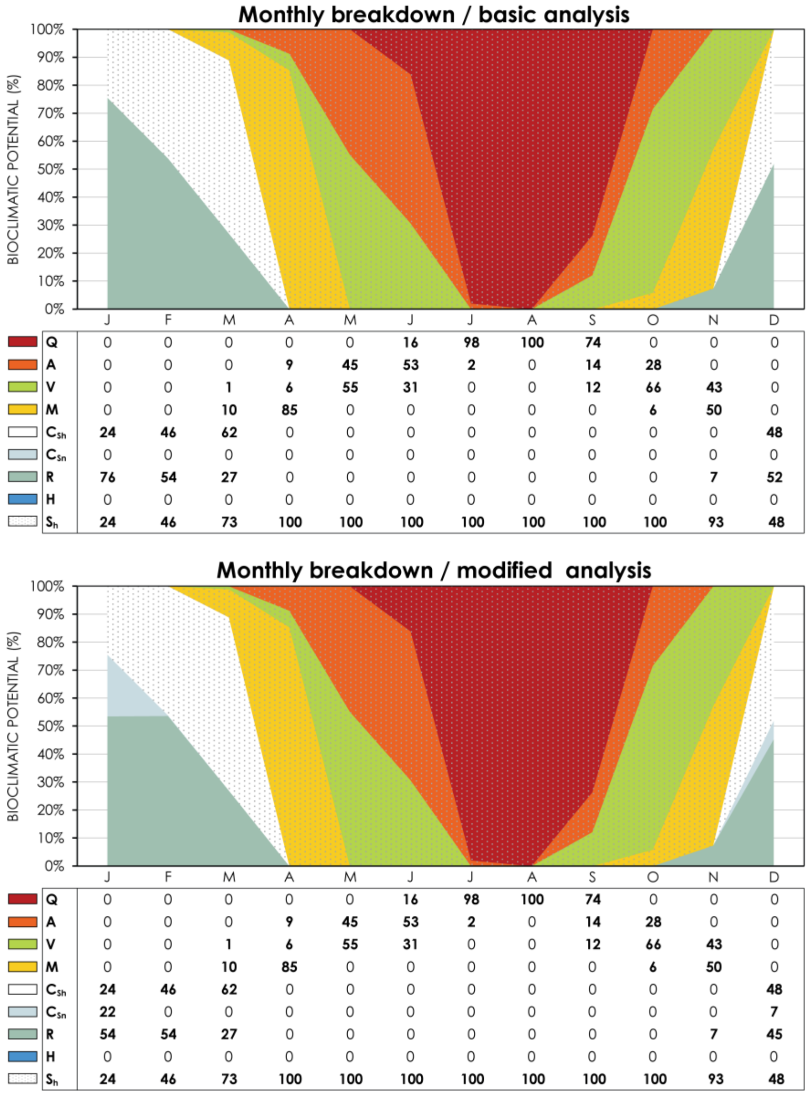
	J	F	M	A	M	J	J	A	S	O	N	D
Q	0	0	0	0	0	0	0	0	0	0	0	0
A	0	0	0	0	0	0	0	0	0	0	0	0
V	0	0	0	0	0	0	0	0	0	0	0	0
M	0	0	0	0	0	0	**7**	0	0	0	0	0
C_{sh}	0	0	0	0	0	**46**	**62**	**23**	**5**	0	0	0
C_{sn}	0	0	0	0	0	0	0	0	0	0	0	0
R	0	**12**	**100**	**100**	**100**	**54**	**31**	**77**	**95**	**100**	**100**	**20**
H	**100**	**88**	0	0	0	0	0	0	0	0	0	**80**
S_h	0	0	0	0	0	**46**	**69**	**23**	**5**	0	0	0



	J	F	M	A	M	J	J	A	S	O	N	D
Q	0	0	0	0	0	0	0	0	0	0	0	0
A	0	0	0	0	0	0	0	0	0	0	0	0
V	0	0	0	0	0	0	0	0	0	0	0	0
M	0	0	0	0	0	0	**7**	0	0	0	0	0
C_{sh}	0	0	0	0	0	**46**	**62**	**23**	**5**	0	0	0
C_{sn}	0	0	0	**25**	**34**	**8**	0	**21**	**35**	0	0	0
R	0	0	**70**	**74**	**66**	**46**	**31**	**56**	**60**	**63**	0	0
H	**100**	**100**	**30**	**1**	0	0	0	0	0	**37**	**100**	**100**
S_h	0	0	0	0	0	**46**	**69**	**23**	**5**	0	0	0

Fig. 5: Monthly breakdown of bioclimatic potential for Ljubljana using basic (top) or modified (bottom) method.

Observing Fig. 5 it can be seen that in Ljubljana, a location with temperate climate, solar radiation has a substantial effect on values C_{sn}, R and H. For example, in February value R changes from 12 to 0% and value H from 88 to 100%, while in April value R drops from 100 to 74%, value H increases from 0 to 1% and value C_{sn} increases to 25% as a consequence of solar energy utilization. The described phenomenon is expected, because values C_{sn} and R represent passive (bioclimatic) strategies, which utilize solar energy (Tab. 1), while value H is reciprocally connected with them. As expected, the modified analysis gives the same results as basic for hot (i.e. summer) months, where shading is needed and the excessive solar radiation is unwanted most of the time (i.e. shading is necessary). If bioclimatic potential in Ljubljana is observed on yearly level, the differences, which occur due to the solar energy consideration, are noteworthy. On yearly level value R decreases from 65.9 to 39.1% and value H increases from 22 to 38.6%, while the overall comfort zone increases by 10.2 pp from 11.5% (basic analysis) to 21.7% (modified analysis) due to the appearance of value C_{sn}. The latter means that in approximately 10% of the year, thermal comfort in Ljubljana can be achieved by utilizing solar energy.



Basic analysis:

	J	F	M	A	M	J	J	A	S	O	N	D
Q	0	0	0	0	0	16	98	100	74	0	0	0
A	0	0	0	9	45	53	2	0	14	28	0	0
V	0	0	1	6	55	31	0	0	12	66	43	0
M	0	0	10	85	0	0	0	0	0	6	50	0
C_{Sh}	24	46	62	0	0	0	0	0	0	0	0	48
C_{Sn}	0	0	0	0	0	0	0	0	0	0	0	0
R	76	54	27	0	0	0	0	0	0	0	7	52
H	0	0	0	0	0	0	0	0	0	0	0	0
S_h	24	46	73	100	100	100	100	100	100	100	93	48

Modified analysis:

	J	F	M	A	M	J	J	A	S	O	N	D
Q	0	0	0	0	0	16	98	100	74	0	0	0
A	0	0	0	9	45	53	2	0	14	28	0	0
V	0	0	1	6	55	31	0	0	12	66	43	0
M	0	0	10	85	0	0	0	0	0	6	50	0
C_{Sh}	24	46	62	0	0	0	0	0	0	0	0	48
C_{Sn}	22	0	0	0	0	0	0	0	0	0	0	7
R	54	54	27	0	0	0	0	0	0	0	7	45
H	0	0	0	0	0	0	0	0	0	0	0	0
S_h	24	46	73	100	100	100	100	100	100	100	93	48

Fig. 6: Monthly breakdown of bioclimatic potential for Abu Dhabi using basic (top) or modified (bottom) method.

Observation of bioclimatic analysis for the location of Abu Dhabi with hot-arid climate in Fig. 6 gives completely different conclusions than in the case of Ljubljana. In Abu Dhabi the consideration of solar radiation has only minor effect on values C_{sn}, R and H. For example, the differences between basic and modified analysis appear only in January and December (Fig. 6), where value R changes from 76 to 54% and 52 to 45%, respectively. Consequentially, value C_{sn} appears only during these two months and amounts to 22 and 7% for January and December, respectively. The influence of solar radiation on bioclimatic potential calculation with BcChart in Abu Dhabi is of minor importance because, as mentioned before, solar radiation affects only values C_{sn}, R and H, which are in Abu Dhabi represented to a lesser extent. If these three values are compared on yearly level, value R decreases by 2.5 pp with a correspondingly equivalent increase of C_{sn}. Value H remains at 0%, as there is always enough solar energy and/or the ambient temperatures are high enough to heat up the living environment to comfortable temperatures.

4.3 Discussion

It is crucial to remember that the presented approach of solar energy inclusion into the bioclimatic analysis is extremely important, because such approach gives more precise results of locations' bioclimatic potential. Thus, the appropriate and most efficient bioclimatic strategies can be more accurately identified. However, the approach used by BcChart is far more useful in temperate, Mediterranean and cold climatic zones and less for the polar and hot-dry and hot-humid climatic zones, which was demonstrated in previous section. The main reason for this is that the relative importance of bioclimatic strategy for solar radiation harvesting is the greatest in the stated climates. Another key note is that this theory used by BcChart applies only, when the actually received solar radiation is considered with a concurrent attention given to shading of transparent part of building envelope.

Further improvements of the BcChart tool are possible. It would be interesting to include in bioclimatic potential calculation the influence of actual wind speed at the analysed location, the same as it was done for solar radiation. However, it is questionable if such improvement would be reasonable, because air movement in buildings is a far more complex issue than solar energy utilization. In particular, air movement is harder to control and predict, due to various influential parameters, such as degree of urbanization, building aerodynamics, stack effect, etc. Additionally, with too many variables the tool would lose its simplicity and the results their universality. For such complex evaluations more sophisticated whole building simulation tools would be far better alternatives. Nonetheless, when quick and basic evaluations of applicable bioclimatic strategies in a specific location are needed, the BcChart tool represents the right choice in the early phases of building design.

5. Conclusions

As has been noted, the main advantage of the bioclimatic analysis using the BcChart v2.0 software is that it is simple and quick. The originality of the presented approach to bioclimatic potential analysis is expressed through the consideration of the actually received solar radiation with the introduction of T_{sub}. For instance, the performed analyses showed that solar radiation essentially influences the results of bioclimatic potential analysis, especially in temperate and cold climates, which was also highlighted by Pajek and Košir (2017). The analysis of the two selected locations determined the importance and usefulness of the approach incorporated in the BcChart v2.0. The indicated is certainly relevant when using climate data for the determination of relative importance of different bioclimatic design strategies.

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