

BETTER URBAN MICROCLIMATE VIA A PROPOSED CITY PLANNING TOOL. A CASE STUDY IN GREECE

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SUMMARY

In Greece, the minimum mandatory distance (D) of a building from the plot's boundaries, relates only to the building's maximum height (H), given as D = 3 + 0.10*H. This is the main institutional tool that shapes urban open spaces and, consequently, the urban microclimate in Greece. In this paper, we will illustrate a numerical model for city planning, named D (b) in an attempt to define mandatory minimum distance between building structures on different plots, taking into account the ground relief and climatic conditions of an area. The methodology we used to create the model is based on bibliographical sources for bioclimatic design. In particular, we were interested in identifying data regarding the sun's height angle (V sun), the height of the building causing shading (Z building), the desired shadow height (Z shadow), and the ground slope (ω).

Our model was a pilot one applied in the city planning of a sparsely built area (a separate unit) to be incorporated in the master plan of Serres town in Northern Greece. Two city planning scenarios were developed (one using the presently applied, and the other using the proposed tool), and the results of the expected thermal islet, as given by the two scenarios, were evaluated in comparison.

The results of this pilot program suggest that bioclimatic distance between building structures [D (b)] contributes to the utilization of passive energy saving systems. Thus, it could be institutionally utilized and, in combination with currently observed distances, could constitute a valuable addition to the existing city planning tools in Greece.

KEYWORDS: Urban microclimate, building coefficient (BC), building heights, cylindrical diagrams of solar height and azimuth, bioclimatic distance between buildings.

INTRODUCTION

The typical south European city suffers from: a) traffic congestion, atmospheric pollution and noise, b) lack of open public spaces and green spaces, c) high densities, degradation of the urban environment, and d) insufficient arrangements for adequate sunning. Numerous E.U. policies already address the climatic change aiming to achieve sustainable city planning. A bioclimatic approach to urban planning can reduce adverse effects [1].

Morphological features of the built environment that have a special bearing on urban microclimate are: a) density and building system, b) geometry of urban street canyons, c) structural materials of buildings, and d) open air spaces. Several variations of these featurescan influence: a) sunning and shading of the external surfaces of buildings, b) visibility of the celestial dome and, therefore, the lighting and cooling of buildings and open spaces, c) air permeability of the urban tissue and, therefore, the airing and cooling of the city, d) reflectiveness and thermal capacity of urban tissue and, therefore, the maximum values and variations of air and surface temperature and e) green content that, among others, influences air temperature [2].

In areas with Mediterranean climate like Greece, sunning and solar ray protections are the key objectives for bioclimatic design models [3]. Analytical elements for the specification of the sun's position are height and azimuth angles for every given moment in time. The use of the "apparent observed path of the sun" constitutes an important element for bioclimatic design [4]. Given particular geographical latitude and atmospheric conditions, the controlling factors of sunning are the geographical orientation and breadth of streets, the choice of width for building polygons, and the distance between building structures [5]. Distance between building structures determines the minimum width of building polygons as well as the minimum breadth of streets. An increase in the breadth of streets can occur for functional reasons [6]. Conversely, breadth can be decreased (creation of pedestrian ways) by imposing larger portions of plots as border space between buildings [7].



Despite of the above mentioned, according to the National Building Regulation (NBR) of Greece, the calculation of maximum height allowed for a building is a function of the specific area's building coefficient (B.C.) while distance from plot boundaries is given by the formula D =**3+0.10*H**, where H stands for building height [8].

MATERIALS AND METHODS

Methodology

The selection of December 21st as the critical date offers the simplest definition criterion, since this date represents the period with the smallest solar height angles of the year in the northern hemisphere. Consequently, if the amount of solar radiation (sunning) on a surface at noon on December 21st is high enough, we can naturally assume sunning to be at satisfactory levels during all remaining months and for more hours every day. In that case, we could achieve energy savings between 11% and 16.5% of total yearly energy consumption of buildings (at a latitude almost identical to that of Athens, 37° 58'). Factors influencing the shading of a space by a particular built structure are: a) the height of the built structure, b) the sun's position at any given time, c) the building's function, d) ground slope, and e) distance to the next building that is shaded [9].

According to related legislation in force, for areas undergoing city planning interventions, the maximum Building Coefficient (BC) is set at 0.80 for areas of permanent housing (i.e. not summer or secondary use housing), without excluding certain exceptions. We thereby arrive, indirectly albeit clearly, to the specification of the maximum allowed height of a built structure (as per NBR).

Maximum heat gain at 40° North Geographical Latitude (NGL) occurs when the building's longest axis is orientated in an East-West direction, and its largest façade is directed $\pm 25^{\circ}$ to the east or west of the South compass bearing. According to GBR, sunning is considered to be adequate when the sun is located higher than 7.50° over the horizon, and solar rays fall on the building's façade surface at an angle larger than 22.50° at a horizontal projection.

The intensity of solar radiation reaching the earth's surface a) decreases as the angle of incidence on the atmosphere becomes smaller, b) depends on the cosine of the angle of incidence on a surface, and c) depends on the duration of sunning, which, in turn, is related to the duration of daylight and the conditions of the atmosphere (cloud cover, atmospheric pollution) [10].

In high geographical latitudes, solar radiation reaching the ground is considerably smaller in mid-December and the sun's perpendicular angle is rather small [11]. If, aiming at complete sunning of buildings, distances between buildings are calculated taking into account only the factor of the position of the sun, the gain would be minimal, and such calculation would result in the creation of a thinly knit urban tissue. This would increase the energy cost of people movement and transportation, and render built structures vulnerable to winter winds [12].

The criterion of sunning must be based on a critical date different than December 21st, while the whole procedure must take into account cloud cover statistical data, and energy gain due to sunning conditions.

The sunning of the façade of buildings is less important, depending on the specific use of buildings. Commercial establishments and offices have less significant sunning requirements. Buildings with ground-floor garage, require adequate sunning from the 1st floor above the ground and upwards. In cases where the ground-floor of buildings is designed and constructed above ground level in order to avoid excessive ground moisture, different sunning requirements apply. If the vertical differentiation of space uses is predefined or foreseen (e.g. commercial uses on the ground-floor, offices on the 1st floor, residential uses from the 2nd floor upward), specific sunning requirements of shading height (Zsh) can be adopted, and distances between built structures can be calculated.

Ground slope on the North–South axis, where the impact of solar radiation is controlled and measured, has a positive or negative impact on the calculation of distance depending on whether the ground is sloping upwards or downwards.

In Figure 1, the straight line <u>AB</u> indicates building (obstacle) of height Z, <u>EZ</u> indicates the adjacent building of height Z1 (aiming at securing adequate sunning). AC indicates the solar ray intersecting the ground, <u>BC</u> is the sloping ground, and <u>Zsh</u> is desired shading height as deriving from the factor of use. <u>So</u> is the horizontal distance for unhindered sunning, whereas <u>S1</u> is the horizontal distance so as to achieve the intended shading height for a given perpendicular angle in combination with ground slope.

Applying the ratio of cosines we have:

$$\frac{\mathrm{Sk}}{\sin(90-\mathrm{V})} = \frac{Z}{\sin(\mathrm{V}+\omega)} \tag{1}$$

Sk is the sloping distance of shading on the ground, $\boldsymbol{\omega}$ is ground slope (positive or negative), Z is the height of the obstacle (building), V is the sun's declination angle, and CD is the horizontal distance between solar ray-ground point of intersection and the obstacle.

For rectangle CDB:

$$So = Sk * cos(\omega)$$
 (2)

$$So = \frac{\sin (90 - V)}{\sin(V + \omega)} * Z * \cos \left| \omega \right|$$
(3)

So is the horizontal distance between the shading point of intersection on the sloping ground and the obstacle (building).



FIGURE 1 - Schematic rendering of bioclimatic distance.

The question raising is what is the extent of the building being shaded, given the sun's angle and ground slope when the adjacent building is situated at an horizontal distance S1 from a building considered as a sunning obstacle, and has a height of Z1 [13]?

Applying equality of triangles, we have:

$$\frac{Z}{So} = \frac{Zsh}{So - S1} \implies Zsh = Z - Z * \frac{S1}{So}$$
(4)

Zsh is the shaded height of a building.

Seeking to determine distance S1, for which a given building height and perpendicular solar angle results in shading to a desired height Zsh against a building, we arrive at the following formula:

$$S1 = (Z - Zsh) * \frac{So}{Z}$$
(5)

$$\Rightarrow S1 = \frac{\cos(V)}{\sin(V+\omega)} * (Z-Zsh) * \cos | \omega | (6)$$

RESULTS AND DISCUSSION

A pilot application of the bioclimatic approach is provided here concerning a sparsely built area of the city of Serres, an area that has been lately included in the city's urban master plan through a recently approved city planning study.

The city of Serres is approximately located at 41° 05' NGL, and an alternative application is provided, taking into account the factors already mentioned. Concerning the sun's movement (Table 1), we utilized the cylindrical diagram 40° NGL, with an azimuth clockwise one-way reference and graphical value interpolation, assuming that it approximates data in our geographical area.

TABLE 1 - Movement of the sun.

HOUR	DECEMBER		JANUARY NOVEMBER		FEBRUARY OCTOBER		MARCH SEPTEMBER		APRIL AUGUST		MAY JULY		JUNE	
5	Н	V	Н	V	Н	V	Н	V	Н	V	Н	V	Н	V
5.20													67,5	7.5
5.30											72	7.5		
6.05									83	7.5				
6.40							97	7.5						
7.25					113	7.5								
8	128	5	126	7.5	119	14	111	22	101.5	30	94	34.5	89.5	36
8.15	131	7.5												
12	180	26.5		29.5		39		49		61		69		73
15.45	230	7.5												
16	233	5	236	7.5	242	14	250	22	260	30	268	34.5	272	36
16.35					248	7.5								
17.20							263	7.5						
17.55									278.5	7.5				
18.30											290	7.5		
18.40													294	7.5



Evaluating data of the area's climate and, in particular, those concerning cloud cover, it is assumed that exploitable solar energy must be calculated for a solar declination angle at 12 noon for the period January 21^{st} – November, i.e. 29.50°:

$$D(b) \cong \frac{0.90 * (Zbuilding - Zshading) * \cos |\omega|}{\sin(29.50 + \omega)}$$
(7)

From the ground relief, we calculate the mean ground slope on the N-S axis using the previous equation, and setting the desired degree of shading (Zsh = 0.00, 1.50, 3.00, 4.50, 6.00, 7.50 m), we derive the results shown in Tables 2 and 3.

Therefore, the distance between houses can be determined by calculating whether they are situated within the same building polygon or in different ones. Calculating the breadth of the required public-use area to be used for functional purposes (trunk-road feeder road, local road, pedestrian way), functional distance can be increased or decreased with the introduction of an area defined as border space between buildings.

Formula (7) illustrates the total distance between building structures. Distance D must be an expression of the distance between the building structure and the plot's borders. The calculated distance S1 is, therefore, divided in two segments and the following formula is derived:

D (b) of plot
$$\cong \frac{0.45 * (Zbuilding - Zshading) * \cos |\omega|}{\sin(29.50 + \omega)}$$
 (8)

where ground slope ω is expressed in degrees with a positive sign for upward slopes, and a negative sign for downward ones).

	N D 11			$D(b) = \frac{\cos(29.50)^*(Zbuilding-Zshadow)^*\cos[\omega]}{\cos[\omega]}$										
BC	Max. Build-	Ground slope	Ground slope	$\sin(29.50+\omega)$										
D.C	(Z)	(%)	at angle ω	Zshadow										
				0.00	1.50	3.00	4.50	6.00	7.50					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)					
0.80	10.50	0.00	0.00	18.56	15.91	13.26	10.60	7.95	5.30					
	10.50	4.00	2.29	17.33	14.86	12.38	9.90	7.43	4.95					
	10.50	8.00	4.57	16.26	13.94	11.61	9.29	6.97	4.65					
	10.50	12.00	6.84	15.31	13.12	10.94	8.75	6.56	4.37					
	10.50	16.00	9.09	14.47	12.40	10.33	8.27	6.20	4.13					
0.80	13.50	0.00	0.00	23.86	21.21	18.56	15.91	13.26	10.60					
	13.50	4.00	2.29	22.29	19.81	17.33	14.86	12.38	9.90					
	13.50	8.00	4.57	20.91	18.58	16.26	13.94	11.61	9.29					
	13.50	12.00	6.84	19.69	17.50	15.31	13.12	10.94	8.75					
	13.50	16.00	9.09	18.60	16.53	14.47	12.40	10.33	8.27					
0.80	15.00	0.00	0.00	26.51	23.86	21.21	18.56	15.91	13.26					
	15.00	4.00	2.29	24.76	22.29	19.81	17.33	14.86	12.38					
	15.00	8.00	4.57	23.23	20.91	18.58	16.26	13.94	11.61					
	15.00	12.00	6.84	21.87	19.69	17.50	15.31	13.12	10.94					
	15.00	16.00	9.09	20.67	18.60	16.53	14.47	12.40	10.33					

TABLE 2 - Upward slope with N-S orientation

TABLE 3 - Downward slope with N-S orientation

BC	Max Build-			D(b)=	$D(b) = \frac{\cos(29.50)*(Zbuilding-Zshadow)*\cos[\omega]}{\cos[\omega]}$									
	ing height	Ground slope	Ground slope	sin(29.50+w)										
D .C	(Z)	(%)	at angle ω	Zshadow										
				0.00	1.50	3.00	4.50	6.00	7.50					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)					
0.80	10.50	-4.00	-2.29	19.97	17.12	14.26	11.41	8.56	5.71					
	10.50	-8.00	-4.57	21.62	18.53	15.44	12.35	9.26	6.18					
	10.50	-12.00	-6.84	23.55	20.19	16.82	13.46	10.09	6.73					
	10.50	-16.00	-9.09	25.88	22.18	18.48	14.79	11.09	7.39					
0.80	13.50	-4.00	-2.29	25.68	22.82	19.97	17.12	14.26	11.41					
	13.50	-8.00	-4.57	27.79	24.70	21.62	18.53	15.44	12.35					
	13.50	-12.00	-6.84	30.28	26.92	23.55	20.19	16.82	13.46					
	13.50	-16.00	-9.09	33.27	29.57	25.88	22.18	18.48	14.79					
0.80	15.00	-4.00	-2.29	28.53	25.68	22.82	19.97	17.12	14.26					
	15.00	-8.00	-4.57	30.88	27.79	24.70	21.62	18.53	15.44					
	15.00	-12.00	-6.84	33.65	30.28	26.92	23.55	20.19	16.82					
	15.00	-16.00	-9.09	36.97	33.27	29.57	25.88	22.18	18.48					



Applying the above formula and conforming to bioclimatic distance, both regarding the N-S axis orientation and an orientation $\pm 30^{\circ}$ degrees (Fig. 2), we calculate the minimum schematic arrangements of building polygons for various road orientations (Fig. 2), adopting the maximum allowed BC = 0.80. Thus, we arrived at the city planning arrangement of a unit of the city of Serres, as shown in Fig. 3.





FIGURE 2 - Built structure arrangements in various street orientations, in conformity with bioclimatic distance.

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FIGURE 3 - Schematic arrangement of buildings, in conformity with bioclimatic distance.



The depiction of microclimatic changes, brought about by the impact of human activity on the natural environment, will be underlined and brought forward through a quantitative comparison of the urban heat islet of (a), the currently applied distance between built structures as prescribed by the NBR in force (D = 3.00+0.10*Zbuilding) and (b), the proposed bioclimatic distance. The NBR-prescribed distance D is doubled in order to render the distance between built structures and to allow comparison with the proposed bioclimatic distance D(b).

Based on empirical studies, and taking into account the geometrical characteristics (height and breadth) of a "canyon", the difference of temperature between urban and rural areas is expressed by the relationship:

Δ Ta-u (max) = 7.54 + 3.97 * ln (Height / Breadth).

Table 4 shows comparative data of the two application scenarios, as well as the results of the thermal islet, expected by the application. Comparison of the two formulas is done with a given level (horizontal) ground, since the NBR formula does not provide for ground slope. The proposed bioclimatic distance includes comparisons of shaded heights of 3.00 and 6.00 m. Columns (4), (7), (10) and (13) refer to angle V created by the adoption of the corresponding formula. They express the angle formed (H / B), and can be compared with the solar height angle V in Table 1, to determine the date when the particular point is exposed to solar rays.

TABLE 4 - Thermal islet differences (two scenarios).

B.C	Maximum building height	$\Delta = 2 * (3+0.10*H)$	V angle created	$\Delta T(a-v)max=7.54+3.97ln(Y/II)$	$\mathbf{D}(\mathbf{b}) = \frac{\cos(V \operatorname{sun}) * (Z \operatorname{building})}{0.00) * \cos(\omega)} \sin(V \operatorname{sun} + \omega)$	V angle created	$\Delta T(a-v)max=7.54+3.97ln(Y/II)$	$\mathbf{D}(\mathbf{b}) = \frac{\cos(V \operatorname{sun}) * (Z \operatorname{building}}{3.00) * \cos(\omega)} \sin(V \operatorname{sun} + \omega)$	V angle created	$\Delta T(a-v)max=7.54+3.97ln(Y/II)$	$\mathbf{D}(\mathbf{b}) = \frac{\cos(V \operatorname{sun}) * (Z \operatorname{building}}{6.00) * \cos(\omega)} \sin(V \operatorname{sun} + \omega)$	V angle created	$\Delta T(a-v)max=7.54+3.97ln(Y/II)$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
0.80	10.50	8.10	52.35	8.57	18.56	29.50	5.28	13.26	38.38	6.61	7.95	52.86	8.64
0.80	13.50	8.70	57.20	9.28	23.86	29.50	5.28	18.56	36.03	6.28	13.26	45.52	7.61
0.80	15.00	9.00	59.04	9.57	26.51	29.50	5.28	21.21	35.27	6.16	15.91	43.32	7.31
1.00	13.50	8.70	57.20	9.28	23.86	29.50	5.28	18.56	36.03	6.28	13.26	45.52	7.61
1.00	16.50	9.30	60.59	9.82	29.16	29.50	5.28	23.86	34.66	6.08	18.56	41.64	7.07
1.00	18.00	9.60	61.93	10.04	31.81	29.50	5.28	26.51	34.17	6.00	21.21	40.32	6.89
1.20	18.00	9.60	61.93	10.04	31.81	29.50	5.28	26.51	34.17	6.00	21.21	40.32	6.89
1.60	21.00	10.20	64.09	10.41	37.12	29.50	5.28	31.81	33.43	5.89	26.51	38.38	6.61
2.00	24.00	10.80	65.77	10.71	42.42	29.50	5.28	37.12	32.89	5.81	31.81	37.03	6.42
2.40	27.00	11.40	67.11	10.96	47.72	29.50	5.28	42.42	32.48	5.75	37.12	36.03	6.28
3.00	32.00	12.40	68.82	11.30	56.56	29.50	5.28	51.26	31.98	5.67	45.95	34.85	6.10

CONCLUDING REMARKS

The shaping of residential and urban landscapes is a step of the procedure of an energy wasting community, where solving the individual problem seriously burdens the collective ecological problem, towards an ecologically acceptable community characterized by low inputs.

The bioclimatic distance formula can be utilized by city planners and supervisors of city planning implementation, and by engineers or town planners when issuing new building permits. It is obvious that the generalized use of the formula should result in an easy-to-follow calculation procedure, or a tabulation of related data for standardized use. This simplified formula type may be described as a building condition in the Official Journal Issue, including the text of the city planning study, while related data converted into table form may constitute a control tool for the study.

Finally, the use of bioclimatic distance D(b) with the requisite corresponding specifications and commitments, should constitute an innovative tool for a rapprochement of humans and nature, through the construction-acceptance of the rights of adjacent property owners and the society as a whole.

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REFERENCES

- Herzog Thomas (ed.), (1998), Solar Energy in Architecture and Urban Planning, Prestel, Munchen: London, N.Y., pp. 172-193.
- [2] Wachberger, Michael, and Hedy, (1988), Axiopoiese tes heliakis energeias stin kataskevi ton ktirion (Mit der Sonne bauen: Anwendung passiver Solarenergie), M.Giourdas: Athens, pp. 80-92.
- [3] Tzonos P., (1985), *Heliasmos (Sun Lighting)*, Thessalonique, pp.19-42.
- [4] Yannas S., (1994), Solar Energy and Housing Design, vol.1: Principles, Objectives, Quidelines, Architectural Association Publication: London, pp.30-38.
- [5] Stasinopoulos N.Th. (1999), Geometrikes morfes kai heliasmos (Geometrical shapes and Sun lighting), PhD, National Technical University of Athens: Athens
- [6] Szokolay S., (1996), *Solar Geometry*, PLEA Note 1, University of Queensland, p. 27.
- [7] Yannas S. et al. (2001), "Bioclimatic principles for urban design", in *Pelivallontikos sxediasmos poleon kai anoikton choron (Environmental Design for cities and urban spaces)*, Open University of Greece: Patra, pp. 175-234.
- [8] Amourgis S., Kalogeras N., (2001), «Greek urban and achitectural tradition and natural environment" in *Pelivallontikos* sxediasmos poleon kai anoikton choron (Environmental Design for cities and urban spaces), Open University of Greece: Patra, pp. 190-218.
- [9] Brown G.Z., DeKay Mark, (2001), Sun, Wind, and Light: Architectural Design Strategies, John Wiley & Sons: N.Y, pp.230-256.
- [10] Givoni B., (1998), Climate Considerations in Building and Urban Design, Van Nostrand Reinhold: N.Y, pp. 103-146.
- [11] Kartalis K, (1999), «Meteorology», in Eisagogi sto phisiko kai anthropogenes perivallon, t. A': phsiko perivallon (Introduction to the natural and human made environment, v. A': Natural Environment), Open University of Greece: Patra, pp.249-256.
- [12] Goulding J.R., Lewis J.O., Steemers T.C., (1996), *Energeia stin Arxitektoniki* (The European Passive Solar Handbook), *translated by E. Tsigkas*, Athens, 1997, pp. 185-194.
- [13] Evangelinos E., Zaharopoulos H., (2001), "Methodoi kai sistimata energiakou sxediasmou ktirion (Methods and systems of energy wasting design)", in *Bioklimatikos sxediasmos ktirion (Bioclimatic design of buildings)*, v. A', *Open University* of Greece, Patra, pp.21-153.

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