Shadum Evaporatis.
An Autonomous and Eco-Friendly Tree

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ABSTRACT: The urban microclimatic conditions in the Mediterranean can become very harsh during the summer because of the intense solar radiation and the elevated air temperatures. Athens, Greece is characterised by very hot days, with temperatures, which may reach up to 38 degrees Celsius, while its urban squares are generally deprived of vegetation and water elements. This paper attempts to give an answer to these problems by proposing a multi-functional bioclimatic structure for the open spaces of Athens. It is a structure, which provides shading, cooling, and has the ability to move its parts. Shadum Evaporatis is an autonomous, eco-friendly tree, whose ambition is not to substitute real trees, but to provide, in cases where planting trees is not possible, shading and evaporation. It can also be seen as a city landmark, a path-finding element, and an object, which changes during the day and throughout the year. It is a design object for urban open spaces, which can be natural and low-tech, or sophisticated and high-tech object, depending on variations of its design.

Conference Topic: 3 Comfort and well-being in urban open spaces
Keywords: multi-functional bioclimatic structure, shading, evaporative cooling.

INTRODUCTION

The idea for Shadum Evaporatis has two main starting points. The basic consideration was to find a way to improve microclimatic conditions, which prevail during the summer months in the central squares of Athens. In other words to design a structure, which would provide shading and cooling, thus improving thermal comfort conditions for the people who used these urban open spaces. At a later stage, the design took also into consideration the basic issues, which were posed by [1]. The structure was also seen as an event, an urban open space design object, which could express a reflection on the notions of "ephemerality" and "parasitism" [1]. In this way, Shadum Evaporatis is a landmark structure. It can be used in the squares of Athens -and of other Greek cities- not only during periods of events (e.g. Athens Olympic Games, Patras European Cultural Capital, Thessaloniki Expo, etc.), but also throughout the summer, when Greece hosts a large number of tourists.

2. THE CLIMATE OF ATHENS

2.1 Summer Climatic Conditions

The warm period in Athens is not usually confined to the summer, but extends to the months May and September. The basic climatic data for this period are presented in Table I.

![Table I: Mean maximum temperature (degrees C), relative humidity (%), monthly solar radiation on horizontal plane (kWh/m2), and sunshine (hours per month) for the period May-September, adapted from [3].](image-url)

<table>
<thead>
<tr>
<th></th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Max T (C)</td>
<td>25.0</td>
<td>29.8</td>
<td>32.5</td>
<td>32.6</td>
<td>28.6</td>
</tr>
<tr>
<td>Rel. Hum. (%)</td>
<td>59</td>
<td>51</td>
<td>47</td>
<td>48</td>
<td>55</td>
</tr>
<tr>
<td>Sol. rad. (kWh/m2)</td>
<td>190</td>
<td>204</td>
<td>219</td>
<td>202</td>
<td>149</td>
</tr>
<tr>
<td>Sunshine (hrs/m)</td>
<td>303</td>
<td>335</td>
<td>373</td>
<td>357</td>
<td>277</td>
</tr>
<tr>
<td>Wind Direction</td>
<td>SW</td>
<td>S</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Wind Speed (m/s)</td>
<td>2.3</td>
<td>2.7</td>
<td>3.4</td>
<td>3.3</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Mean maximum temperatures for the period from June to September exceed 27 degrees C and 31 degrees C in July and August. It should be noted that mean air temperatures are significantly lower and are not representative of the temperatures that prevail in urban open spaces during noon and afternoon hours. The monthly solar radiation on horizontal plane is very high. It can be calculated that the mean daily values are over 600 kWh/m2, during the summer, while solar radiation can reach up to approximately 950 W/m2, around 13:00 and 14:00 on a clear summer day in Athens [2]. Furthermore, during the summer, most days are characterised by clear skies, a fact, which is denoted by the many hours of sunshine (approximately 11-12 hours per day, for June, July and August). As a result, large sums of
Climatic data generated with the software Weather Tool [4], were used to plot psychrometric charts with the software Psycho Tool [5] (Fig. 1). It can be seen that the climate of Athens during the warm period is Warm to Hot and Dry. The data points in the Hot-Dry and Warm-Dry Areas of the graph correspond to noon and afternoon values, which occur mainly in July and August. The Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied (PPD) for these hours range from 1.5 and 50%, to 2.9 and 98%, respectively. These values were calculated for a lightly dressed person (0.7 clo) walking (2.3 met), in light breeze (0.6 m/s) and relatively low mean radiant temperature (25 degrees C) conditions.

Finally, the Weather Tool software [4], was also used to plot diagrams of dry bulb temperature and relative humidity for the months May to September (Fig. 2, 3). It can be seen that elevated noon and afternoon values of dry-bulb temperature coincide with minimum relative humidity values. Maximum temperatures are usually between 25 and 40 degrees C, with a mean of approximately 30 degrees C, while minimum relative humidity values range between 20 and 40%, with a mean value of 30-35%.

2.2 The Urban Heat Island
Central Athens has a mesoclimate, which is formed by the equal distance from the sea and the mountains, and especially by the increased density of the urban fabric. During the summer, the microclimate in the central districts of the city is strongly influenced by the urban heat island, which is described and has been largely documented by [6], [7].

The intensity of the phenomenon (i.e. the difference between air temperature in the central districts and the sub-urban and rural areas) can reach up to 14 degrees C, with a mean increase of 10 degrees C [6]. As a result, the already high dry-bulb summer temperatures are further elevated, thus contributing to the further degradation of the microclimatic and thermal quality of urban squares.

3. CITY SQUARES IN CENTRAL ATHENS
3.1 Design
Some of the main, large, urban squares in the centre of the city are designed above underground car parking lots and metro stations. The functional requirements of the underground spaces largely affect the design of the open spaces above them. As a result, the amount of soil, which is needed for the growth of trees, can not be accommodated.

3.2 Existing Conditions
Due to the aforementioned problems, these urban squares in Athens are almost completely deprived of vegetation, which can provide shading and cooling, during the overheated period. The water surfaces, which are usually integrated in the centres of the squares, are far too isolated to provide sufficient cooling, in the summer. Finally, their surfaces are constructed of artificial, dark coloured, heavy-weight materials, which during the day absorb large sums of solar radiation and radiate heat, significantly raising the mean radiant temperature. (Fig. 4, 5)

All the above drastically reduce the use of urban squares in Athens during summer days. People quickly cross these spaces, and search for more shaded and fresh areas to sit and relax.
Figure 4: Omonoia Square, in the centre of Athens, situated over a metro station.

Figure 5: Kotzia Square, in the centre of Athens, situated over an underground car parking.

4. THE PROPOSAL

4.1 A PDEC Tower
Shadum Evaporatis is primarily a passive downdraught evaporative cooling (PDEC) tower, which provides the necessary evaporative cooling for the people congregating at its base. This function is incorporated in the "trunk" of the tree. (see Fig. 6)

The PDEC tower creates a downward air movement, where the air captured at the upper end passes through water "filters" (micronisers [8], wetted cellulose pads [8] or ceramic bricks [9]) in order to be cooled through the process of evaporation. The evaporation of water causes a significant reduction of the ambient air temperature, which may reach 10 to 15 degrees C [10]. The cooled air exits from the lower part of the "trunk" at the circulation level. Also, there can be a fan at the upper end, which apart from capturing air also enhances air velocity and evaporation rate. In the case of Shadum Evaporatis, the use of fans is included in some of the variations, which are presented in a following paragraph (4.3).

4.2 A Shading Element
The "branches" of the tree support the elements - the "leaves"-, that provide shading. These structural parts begin at the upper part of the tree and extend to a certain length in order to provide efficient shading. (see Fig. 6)

Figure 6: Diagram of the cooling and shading functions of Shadum Evaporatis.

4.3 Variations
Similar to every other tree, there are different "species" of Shadum Evaporatis. The different "species" are actually the design variations of the structure in order to fit into the different squares, and act distinctly in every case.

The main variations of Shadum Evaporatis include the different "leaves", which the "tree" can have. These "leaves" can be made of PVC coated membranes, lightweight wooden shades in various sizes, PV cells, or deciduous climbing plants. The different "leaves" provide different shading effects, make the structure look more or less natural, and affect the structure's dependence on the city infrastructure.

In the case of the PV cells "foliage", the structure is energy autonomous. As a result, the PV cells can be used to power a fan at the top of the PDEC tower, in order to augment the air velocity and increase the rate of evaporation of the water. Furthermore, the PV cells can be used to provide the necessary electricity for the motor, which moves the "branches" of the tree.

If deciduous climbing plants constitute the "foliage", the structure obtains the ability of change. As a result, the upper part of the "tree" can become green, blossom and shed its leaves throughout the year. The change of colours and appearance adds the element of change in the static city environment.
Other variations include the base of the structure, which can be designed either as a circulation space, or as a sitting area. In the case of large "trees", people can circulate below the "trunk". On the other hand, there is the possibility of unifying the individual concrete footings of the structure, in order to provide a sitting area at its base.

4.4 Construction and Materials

Shadum Evaporatis is constructed with lightweight materials. Its substructure can be made either of wood with metal junctions, or of aluminium, depending on the variations of the design. Nevertheless, the use of wood is preferable, as it is a renewable, natural material.

The use of wood is also desirable from another point of view. It is a soft, natural material, which forms a direct antithesis with the surrounding permanent man-made environment and the extensive use of hard materials. Conceptually, the structural system and the materials, which are proposed, mainly point out the expression of the "ephemerality" of the design. This "ephemerality", though, is far from unsustainable and energy consuming, as the structure is characterised by the extensive use of renewable (wood) and recyclable (aluminium) materials. Finally, the light structure comes in conflict with the heavyweight concrete constructions, which form almost totally the contemporary Greek cities.

4.5 A Landmark

All the above-mentioned features make Shadum Evaporatis a landmark of urban open spaces. Through its different variations, the structure can also function as path-finding element, and an object that can mark out a square, making it different from other urban squares. The Shadum Evaporatis with the PV cells "foliage" can also function as an element of orientation, within the dense cityscape.

The use of PVC coated white fibre of the "trunk" on the tree permits its artificial lighting during the night hours. In this way, when the sun sets and the structure ceases to enhance the image the urban squares through the shading effects of its "foliage", it can acquire a distinctly different image, by its illumination.

4.6 Schematic investigation

The design and the shading efficiency of Shadum Evaporatis were graphically explored through the construction of a three-dimensional model using the Form Z software [11]. In this way, the different views of the structure, as well as a number of variations were constructed and rendered (see Fig. 8 to 15).

Figure 8: Perspective view. Variations with wooden shades and deciduous plants.

Figure 9: Perspective view. Variations with PV cells and PVC membranes.

Figure 10: Perspective plan. Variations with wooden shades and deciduous plants.

Figure 11: Perspective plan. Variations with PV cells and PVC membranes.

Figure 12: Perspective view of a group of Shadum Evaporatis of various sizes.
Figure 13: Three-dimensional model of a group of Shadum Evaporatis of various sizes.

Figure 14: Perspective plan of a group of Shadum Evaporatis of various sizes.

Figure 15: Perspective night view of Shadum Evaporatis, with internal lighting.

CONCLUSION

The proposal for an autonomous and eco-friendly tree, which was described in this paper, is seen as a way of improving microclimatic conditions in urban squares of Athens, which for various reasons, are completely deprived of vegetation. Shading and cooling are strategies, which are indispensable for the use of the urban squares in central Athens, during the summer. The inability to provide shade and freshness in an open space, immediately minimises its use and deprives it of the vividness and the gathering of people, that it is meant to have.

Shadum Evaporatis is an attempt to provide an answer to these problems. It might be more sophisticated and costly than a real tree. Nevertheless, it appears to be an efficient way of substituting the functions of real trees (shading and evapotranspiration), with the unique spatial experience, which urban squares in Athens should provide during the summer.

REFERENCES