The Effect of Urban Form on Temperature for Hot Arid Zones. The Case Study of Baghdad, Iraq

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Abstract. The research aims to determine optimal urban planning and design indicators of the urban clusters form in hot arid zones through studying of three urban areas in Baghdad, analyzing their urban indicators which include floor area ratio (FAR), urban clusters height, building density or land coverage, green areas, paved areas, shading ratio and how they affect urban temperature.

The research reached the conclusion that air outdoor temperature on urban areas affected primarily by shadows casted on the ground, the effect of shaded area equals (5) times the effect of paved areas and (3.7) times the effect of green areas, this means that increasing urban clusters height in hot arid zones could minimize air outdoor temperature, buildings with (6) levels at minimum seems to be suitable to produce shadows in the ground plane of urban land, increasing urban volumes in the vertical dimension height and compacting clusters or increasing FAR seem to be a smart strategy to minimize the hot dry climate effect and urban temperature.

1. Introduction

Urban form is the physical characteristics that make up built-up areas, including the shape, size, density and configuration of settlements. It can be considered at different scales: from regional, to urban, neighborhood, block and street [1], at any scale, urban form or urban morphology affects urban environment and the microclimate of urban clusters, a growing interest in microclimate issues has been raised as they represent important factors in achieving energy conservation and sustainability inside the cities, where a big amount of the population lives [2], microclimate is normally affected by the urban morphology parameters, the correlation between air temperature variations and urban morphology parameters is widely noticed especially in tropical and arid zones [3].

Many researchers found that most important parameter to affect the daytime air temperature is building height, high-rise buildings will somewhat reduce the air temperature during day-time, as they will create large shadow areas, with lower average mean radiant temperature [4], Building height and site coverage ratio and floor to area ratio FAR most significantly impact many of the studied environmental measures, the dominant design parameter for the defined indicators is the building height. Regarding to wind potential, height overall has a positive impact on thermal comfort via
speeding up wind flow. In addition, the shades created by increasing height demonstrates its importance [5], tall building blocks in urban areas will not increase morning and afternoon ambient temperature, and the evening temperature will drop [6].

Higher exposure of the surfaces to the solar radiation leads to increases in the amount of reflected and diffused solar radiation as well as the emitted thermal, which in turn increases the mean radiant temperature. Thus, the compact urban form represents a climate-sensitive approach and becomes an influential strategy to mitigate the impact of the urban heat island in hot-arid regions. The attached and detached urban forms in these regions should not be adopted from the modern planning models created and developed in other environments. Rather, they have to be modified in order to achieve a suitable and more comfortable outdoor thermal environment [7].

Beside height urban density, vegetation and shading have significant role in minimizing outdoor air temperature. Cooling is not only a function of vegetation and surface materials, but also dependent on the form and spatial arrangement of urban features, at the microscale, urban form has a larger impact on daytime temperatures than landscaping. In mid-afternoon, dense urban forms can create local cool islands. Spatial differences in cooling are strongly related to solar radiation and local shading patterns where dense urban forms can create local cool islands, it does show that the daytime shading properties of tall buildings play a significant role in reducing urban heat [8].

Building morphology and urban ecological infrastructure had dominant effects on land service temperature variations in high-density urban centers. Urban green space and water bodies demonstrated stronger cooling effects, especially in summer. Building density exhibited significant positive effects on land service temperature, urban form could explain more than 90% of the variance land service temperature in summer and winter, urban ecological infrastructure was identified as the dominant contributor of cooling effects, building morphology ranked in the second place, the cooling effects of green spaces and water bodies were much stronger in summer, while the building morphology had relatively weak effects in summer, the reconstruction and update of urban ecological infrastructure and buildings would have a stronger impact on the changes of land service temperature, construction of high-rise and low-density urban buildings may be an effective measure to create a comfortable outdoor thermal environment, apart from increasing the coverage rate of vegetation and water bodies [9].

The concept of shading by trees in the wider streets can be adopted in the existing urban morphology, it can improve the comfort conditions to a significant level [10].

It's clearly found from the above that urban form affects urban temperatures through structural volumes. The floor area ratio (FAR) can affect the temperature differently depending on the value of the coverage ratio, the number of floors, the percentage of green areas, the ratio of open areas and the percentage of shading of the ground plane or pedestrian level.

2. Goal, Tasks, Methods of Study

The purpose of this work is to determine optimal planning and design indicators of the urban form in relation with air temperature in urban areas of Baghdad city. The results of this work are important to practical architects, designers and planners working in the field of new building development evaluation, license and approval process to determine the climate effect of buildings on its environment. To achieve these goals, the following tasks were adopted such as collection of data and information to build a technical database for statistical analysis and modeling, comparing and identifying criteria for the derivation of indicators and design parameters. The main method of the research is an on-site/field survey study of (3) urban areas in Baghdad, the practical value of the research consists in the application of its results for the purpose of new buildings development projects evaluation.
3. Experimental Part
The field study is based on on-site readings of outdoor air temperature in various urban areas of the city of Baghdad, which vary in urban form with comparison of temperature readings with the data of the meteorological station for the same period.

By analyzing the differences in the outdoor air temperature between urban areas and air temperature at the weather station and linking these differences with the urban form, it will be possible to estimate the effect of the urban form on outdoor air temperature.

In order to achieve this objective and to prove the hypothesis and idea of the research, a field survey was conducted for (3) urban areas in the city of Baghdad varied in its urban form. Outdoor air temperature readings were recorded in these areas during the days of 20 June, 21 July, 20 August 2018, five temperature readings recorded during the day at (6:00, 9:00, 12:00, 15:00, 18:00) and the total number of readings are (25) for every area and (75) readings within the single day, an overall (225) readings recorded for all three studied areas, Table.1 shows the urban indicators for the selected study area in Baghdad.

| Urban Zone  | Building Coverage (%) | Green area | Paved area | Floor Area Ratio (FAR) | no. of Levels | Building Height (m) |
|-------------|-----------------------|------------|------------|------------------------|---------------|-------------------|
| BGD-Yarmouk 616 | 18                    | 60         | 22         | 0.36                   | 2             | 8                 |
| BGD-Haifa 6   | 43                    | 20         | 55         | 3.01                   | 7             | 26                |
| BGD-Haifa 8   | 31                    | 42         | 27         | 4.96                   | 16            | 58                |

The indicators of the urban form of the three areas were surveyed in the field to determine the coverage ratio, percentage of green areas and paved areas, the number of floors, the floor area ratio (FAR), percentage of shading, data collected to form a database that was statistically analyzed using correlation and linear modeling.

4. Results and Findings

4.1. FAR Effect on Urban Outdoor Air Temperature

Results show that FAR is reversely proportional with outdoor air temperature in all studied areas, an increase of FAR with an amount of (1) will lower outdoor air temperature by (0.7 C°) compared to weather station temperature record, the effect of FAR on outdoor air temperature could be explained that due to the fact that FAR is the product of urban building land coverage by building level count, it's clearly that increasing FAR will result in more building heights, since building height is the main factor in shadow casting on ground area, the effect of solar radiation will be minimized on surface heating and raising outdoor air temperature as FAR increased.
It seems that outdoor air temperature is a logarithmic function of FAR that could be formulated as:

\[ T_u = -1.574\ln(\text{FAR}) + T + 0.294 \]  \hspace{1cm} (1)

where:
- \( T_u \): urban outdoor air temperature
- \( T \): weather station temperature
- \( \text{FAR} \): floor area ratio

For the equation (1) above, coefficient of determination \((R^2)\) = 0.9822 and correlation coefficient = -0.95.

Applying of equation (1) above, difference in temperature \((\Delta T)\) between urban estimated temperature and weather station records in relation with urban form indicators could be described in Table 2, a weather station temperature record of (38 Cº) applied as a sample.

**Table 2.** Urban form indicators in relation with air temperature.

| TEMPERATURE URBAN | TEMPERATURE WEATHER STATION | \( \Delta T \) | FAR | Green Area | Paved Area | Building Coverage | Total Levels | Ground Shading |
|-------------------|-----------------------------|----------------|-----|------------|-------------|-----------------|--------------|----------------|
| 40.8              | 38                          | 2.8            | 0.2 | 8%         | 75%         | 17%             | 100%         | 1              | 12%            |
| 39.4              | 38                          | 1.4            | 0.5 | 18%        | 59%         | 23%             | 100%         | 2              | 13%            |
| 38.3              | 38                          | 0.3            | 1   | 27%        | 47%         | 27%             | 100%         | 3              | 14%            |
| 37.2              | 38                          | -0.8           | 2   | 35%        | 35%         | 31%             | 100%         | 6              | 17%            |
| 36.6              | 38                          | -1.4           | 3   | 40%        | 27%         | 33%             | 100%         | 9              | 20%            |
| 36.1              | 38                          | -1.9           | 4   | 43%        | 22%         | 35%             | 100%         | 11             | 22%            |
4.2. Ground Surfaces Effect on Urban Outdoor Air Temperature

Results show that green areas effect is reversely proportional with outdoor air temperature in all studied areas. An increase of green areas percentage in urban area with an amount of (10%) will lower outdoor air temperature by (1.36 Cº) compared to weather station temperature record, as green areas lowers outdoor air temperature, solid ground surfaces like streets and paved areas raise outdoor air temperature, if paved ground surfaces percentage increased by (10%), outdoor air temperature will be raised about (1 Cº).

Ground surface shading, while it's a green surface area or a paved area, affects outdoor air temperature notably, results show that in areas where ground shading is about (12%), outdoor air temperature will be (6 Cº) higher than areas with a ground shading of (30%), it's seems that every (2%) increase in ground shading on ground surfaces, outdoor air temperature will drop by (1 Cº), since ground shading is the result of building heights, increasing height will decrease outdoor air temperature.

5. Conclusions

Air outdoor temperature on urban areas affected primarily by shadows casted on the ground, the effect of shaded area equals (5) times the effect of paved areas and (3.7) times the effect of green areas, this means that increasing urban clusters height in hot arid zones could minimize air outdoor temperature, buildings with (6) levels at minimum seems to be suitable to produce shadows in the ground plane of urban land, Increasing urban volumes in the vertical dimension height and compacting clusters or increasing FAR seem to be a smart strategy to minimize the hot dry climate effect and urban temperature.
6. Summary
The study deals with how to quantify the resulting differences in temperature in urban areas in relation to the most common urban form indicators such as coverage, FAR and number of floors through field study, onsite temperature survey for a range of areas in Baghdad and during the hot summer 2018, data analyzed using modeling methods and quantitative statistics to derive a quantitative model, it's found that FAR affects outdoor air temperature as a logarithmic function.

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