Urban geometry and microclimate effects on building energy performance

The case of Mediterranean climate districts in Turkey

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ABSTRACT: Considering the fact that the arrangement of the built form and urban morphology have a significant impact on building energy consumption, a favourable adaptation of urban form should be prioritised at an early stage of urban planning and design. However, there are few studies that have focused on urban morphology and microclimate related to heating and cooling energy consumption in the context of the Mediterranean climate with distinctive urban morphology features. This study will explore the interrelationship between the impacts of urban form and microclimate on the energy consumption of buildings in the climatic context of Gaziantep by coupling Envi- met results with the Design-Builder. Three different urban forms were defined as traditional and regular formal urban areas. The aim of the research is to make energy consumption comparisons between traditional and formal urban forms. The results show the influence of urban morphology on the cooling performance of the structure and provide ideas for future planning and building design.

KEYWORDS: Microclimate, Urban Form, Envi-met, Building Cooling Energy Consumption

1. INTRODUCTION

The world's population is anticipated to reach 9.7 billion by 2050, with metropolitan regions housing 70% of the population (Ibrahim et al., 2021). Rapid urbanisation has resulted in increasingly complex urban morphologies that include a wide range of constructed densities, layouts, and forms. The variety of urban morphologies has caused various building design and energy issues. Cities now consume 76% of the world's primary energy and emit 43% of CO_2 emissions (Ibrahim et al., 2021). Furthermore, the building industry accounts for roughly 30% of worldwide final energy consumption, 70% of which is shared by the residential sector(Energy Technol. Perspect. 2020). As a result of cities' complicated microclimate circumstances, the majority of this is driven by building industry demands. It is obvious that urban scale studies are an essential element of the discussion regarding the future of built environments.

Numerous geometrical components that make up the urban fabric individually contribute to the creation of the building microclimates. Previous studies also have shown that the urban microclimate environment has a significant influence on building energy consumption (Boccalatte et al., 2020; López-Cabeza et al., 2018; Salvati et al., 2019). According to Liu et al. (Liu et al., 2015), the local microclimate, as defined by the external surface convective heat transfer coefficients (CHTCs), can impact overall cooling energy usage by 4%. Morero et al. (2020) focused on analysing the energy usage at the district level while accounting for the microclimatic impacts brought on by the planning of open and constructed space and taking into account the local climatic trends, the space cooling requirement of the various buildings ranged between -5 and +14 percent on the chosen day. Taleghani et al. (2015) evaluated three typologies within two orientations and concluded that courtyard and NS slab typologies are better for reduced air temperatures, MRT, and PET in a temperate environment. Despite being in a comparable environment, Allegrini et al. (2012) criticised the two typologies for their inferior convective cooling. Natanian and Auer (2020) recently conducted parametric research of four FARs, three widths, and four window-to-wall ratios in a Mediterranean environment to assess the thermal comfort, daylighting, and load match of four distinct typologies (192 total cases). Courtyard typologies outperformed other typologies in thermal comfort and average load match when lower FAR were employed (Natanian & Auer, 2020). As a result, analysing, evaluating, and optimising the geometry of urban form provides the opportunity to create a sustainable built environment with preferable thermal performance and comfort, which will be a positive impact on energy demand. The goal of this research is to investigate the impact of real-world urban geometries and local microclimate on summertime traditional and modern residential buildings' cooling energy consumption in Mediterranean climate.

2. CASE STUDY DESCRIPTION

Gaziantep is located at 37.0585 °N, 37.3510 °E, in the southeast region of Turkey (Fig. 1). The area of the city is 6803 km². According to the 2021 Turkish Statistical Institute report, the city has a population of 2.130.432 (Turkiye Statistical Institute, 2021). Gaziantep is the largest city in the South-eastern Anatolia area and the sixth-largest city in Turkey. Gaziantep has a hot-summer Mediterranean climate (Köppen climate classification, Csa).

Figure 1: Location of Gaziantep

Gaziantep, according to Kurian (2001), is one of the world's oldest inhabited cities. The city's location between Mesopotamia and the Mediterranean,

where the first civilisation born, being at the crossroads of the roads leading from the south and the Mediterranean to the east, north and west has shaped the history of civilization and today. For this reason, Gaziantep has been the settlement and haunt of human communities since is presented, and it is used to assess the energy performance of traditional and formal neighbourhoods in Gaziantep. As the city developed, both the cultural and structural texture began to become cosmopolitan. Unplanned and adjacent regular buildings, devoid of aesthetic concerns, took the place of traditional buildings. Morphologically four different textures were chosen to show these changes and to understand the cooling energy performance of these structures, each neighbourhood has a reference building. The first one is the traditional texture that has formed around streets developing organically, and around streets and dead-end streets. A courtyard completely disconnected from the street is common in traditional houses in accordance with the Mesopotamian tradition. The materials and construction components of traditional Gaziantep dwellings that line narrow streets stand out. The second area includes adjacent and low-height structures. The narrow street concept was also applied; however, the material of the buildings was changed in this area. The third and fourth areas are modern structures. They have wide streets and concrete structures. The only difference is the height of them (Fig. 2). It was modelled by selecting an area with a diameter of 100 meters.

The paper provides a comparative and comprehensive assessment considering the influence of the surrounding urban morphology on the canyon microclimate to evaluate the relationship between urban geometries and building cooling demand.

3.1 Simulation Tools

Two software tools were utilised in this study to better analyse the influence of urban microclimate on energy performance: Envi-met and Design-Builder. Envi-met outputs for energy modelling created a microclimatic EPW weather file for the day having the highest temperature. The ENVI-met simulation tool was used to create a three-dimensional spatial model that included the footprint and height of the buildings for the selected areas. Air temperature, relative humidity, direct radiation, diffused radiation, and wind speed are the meteorological parameters that were adjusted. The simulation was carried out on the highest temperature day (13/08/2019) to calculate the cooling energy performance of the structures. According to the data used in the METAR annual weather report taken hourly weather station (Oguzeli International Airport), the highest temperature day was defined for the simulation. In the first step, the geographic model for the chosen case study is created in ENVI-met (4.4.6), and simulations are run using the basic forcing approach with meteorological data from the chosen day. In the second stage, ENVI-met is utilised to produce meteorological parameters that are then used to adjust each of the EPW files sent to Design-Builder to simulate the energy usage for each area. To assist inform and guiding design decisions, Design Builder gives realistic energy, comfort, cost, and daylighting performance statistics. To execute a cooling energy simulation of the test residence using Energy Plus, the simplified textures were designed in Design Builder.

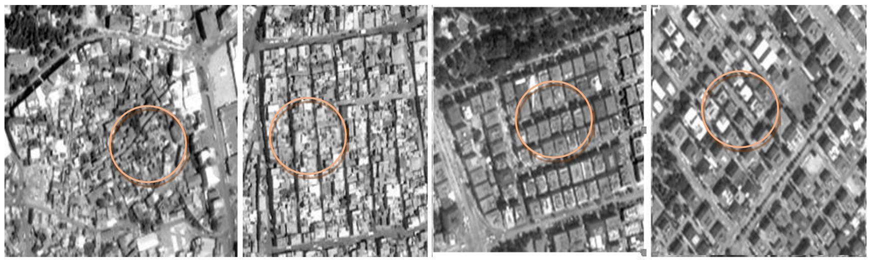

Figure 2: Case study areas (Traditional area(A) and Formal areas (B,C,D)

3. METHODOLOGY

In this research, an approach for integrating urban microclimate, form and building energy simulations

Table 1: Input data for Envi-met simulation and Urban geometry features

Date of Simulation	13/08/2019
Time of Start of Simulation	08:00am
Simulation Period	24 hours
Wind Direction	West-270°
Wind Speed at 10m	8 m/s
Relative Humidity	30%
Min. and Max. Air Temp.	24-43 °C

4. RESULT

4.1. Comparison of Microclimate Data

Geometric Features	Site T1	Site T2	Site F1	Site F2
Building Heights	6-12m	3-12m	12-18m	51-55m
Aspect Ratio(H/W)	1.4-2.6	0.6-1.6	1.6-3	1.4-1.7
Skyview Factor	0.65	0.72	0.48	0.6
Distance between buildings	Courtyards	Adjacent	5m	30m

This section looks into the site-specific climatic data for Gaziantep. The receptor points are defined for each model. The microclimate data for each point are compared.

The comparisons for air temperature, wind speed, relative humidity and mean radiant temperature data are shown in Fig.4. On the hottest day, the air temperature surrounding the building units shows a significant difference between day and night. According to these results, there are no big differences between traditional1 (T1), traditional2 (T2), formal1 (F1) and formal 2 (F2) case areas. However, when the air temperature is compared, the maximum difference is 2 °C between F1 and T2. In formal areas 1 and 2, older structures had a stronger reaction to microclimate impacts, whereas newer, fully insulated buildings exhibited considerably less effect.

To account for the influence of a street canyon's microclimate on the cooling and heating energy consumption of a building, the microclimate output from the ENVI-met simulation is utilised to modify the original EPW file before the Energy Plus simulation is performed.

Table 2: Building Coverage Ratio and Energy demand in the hottest day

Urban Texture	Building Coverage Ratio	Heating Demand kWh/m2	Cooling Demand kWh/m2	Annual Demand kWh/m2
Traditional 1	0.64	16.18	-18.18	34.36
Traditional 2	0.80	13.36	-16.51	29.87
Formal 1	0.40	17.77	-19.26	37.03
Formal 2	0.15	16.92	-20.72	37.64

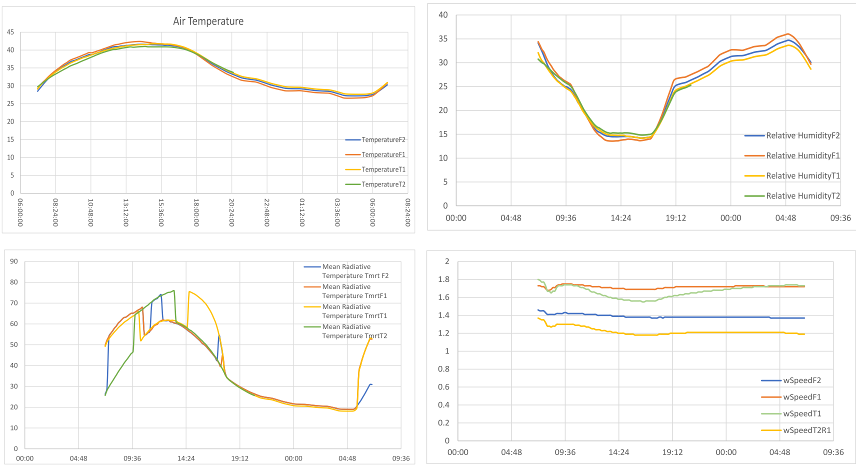

Figure 4: Comparison of the air temperature relative humidity (top), and mean radiant temperature, wind speed (bottom) from average air temperature around the buildings from ENVI-met for the hottest day

The trend lines in Figure 5 depict the variation in the average apartment heating and cooling needs as a function of urban density in the hottest day in Gaziantep. The red line represents the energy use of the same unit in a rural setting. The variance in demand resulting from an increase in the site coverage ratio is thus the consequence of a decrease in solar radiation and indicates the overall effect of urban density on energy demand.

solar radiation is more important than the increased heat island.

Concerning the heating requirement, a nonlinear connection has been discovered in relation to the compactness of the material (R2=0.95). Even in the urban texturing with the lowest value of site coverage ratio, the heating demand is often lower in urban environments than rural ones, as a result of the favourable impact of the UHI intensity.

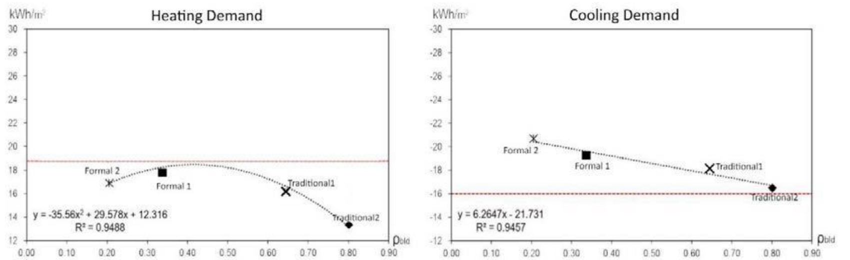

Fig.5: Relationships between the texture's site coverage ratio and the apartment's heating demand and cooling demand for four case studies

There is a strong linear correlation between urban density and cooling demand, with R2 equal to 0.95. The reduction in cooling demand for the test apartment is related to the rise in urban density. According to these results, a high degree of compactness is advantageous during the summer in a Mediterranean environment, since the decreased Due to the gradual reduction of solar radiation, a rise in the texture's compactness initially results in a proportional increase in the heating requirement. There is, however, a threshold value of the texture's coverage ratio (bcr=0.40) above which the heating need begins to decrease again.

Figure 6 depicts the evolution of the yearly energy consumption in response to the ratio of site covered by the texture; the annual demand is the total of the heating and cooling needs. These findings imply that a dispersed urban layout negatively impacts the energy efficiency of buildings. For low values of site coverage ratio, the apartment's energy usage exceeds that of a rural setting. Furthermore, in particularly dense urban textures (bcr approximately 0.64), the conflicting consequences of urban compactness on energy demand balance themselves, defining the same energy demand as a rural environment. Even less energy is used annually in Traditional 2, bcr=0.8, the most compact urban texture in the example studies. Therefore, this research proves that in a Mediterranean environment, compact urban textures (bld > 0.5) are preferable to dispersed and discontinuous urban patterns in terms of energy efficiency.

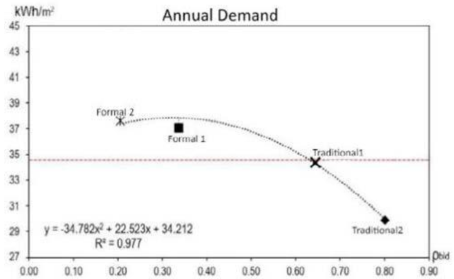

Fig.6: The correlation between the ratio of the texture's site covering and the apartment's heating and cooling needs across four case studies

5. DISCUSSION & CONCLUSION

Recent research has demonstrated that urban compactness and aspect ratio have an essential effect on regulating the microclimate at the street level [8-9]. The study describes a method for quantitatively analysing district-scale energy consumption while accounting for microclimatic effects. In a case study where urban development processes are expected to change microclimatic conditions and, as a result, the energy performance of buildings, a coupling approach that links the simulation tools ENVI-met and Design Builder is used.

The case study in this paper represents traditional and formal areas in Gaziantep with different urban characteristic features. Increasing H/W ratio associated with the reduction of Tmrt. The traditional site has a low aspect ratio, but high Tmrt values can be seen simulation result in Fig.3. However, Sharmin and Steemers highlighted that the relationship between the two parameters should refer to the presence or lack of shade . The shadow of the structures affects the cooling performance of the buildings. The traditional area has the biggest advantage in the summer regarding cooling performance.

By comparing the performance of an isolated building to that of a cluster of buildings in a Mediterranean environment, the findings demonstrate that dense urban texturing with a Building coverage ratio over 0.5 contribute to lowering energy consumption. Based on these findings, it seems that dense and compact urban textures, like the traditional fabric of many city centres, are more energy efficient than the more spread out and modern urban patterns.

Using a standard density metric, such the' building coverage ratio' the connections discovered in this research provide a rough estimate of the energy performance of urban textures. Facilitating the work of designers, planners, and decision makers in establishing a priority of interventions on the built environment would be the capacity to undertake fast evaluations at the district size and provide maps of the energy vulnerability inside the city.

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