RESIDENTIAL NEIGHBORHOOD ASSESSMENT IN THE CITY OF AL AIN, UNITED ARAB EMIRATES, AND THE IMPACT ON CLIMATE CHANGE (HEAT ISLAND EFFECT ANALYSIS)

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ABSTRACT

Al Ain is an important city that has gone through major urban transformation over the last 50 years. These changes impact the development of neighborhoods, especially residential neighborhoods. The morphology of the urban blocks also impacted the heat island effect (UHI). UHI is one of the contributors to climate change. Therefore, having sustainable neighborhoods' means reducing the UHI and making cities more livable. The methodology to be followed in this study is as residential blocks in Al Ain for analysis of current conditions and proposal for UHI reduction through different strategies, modelling and simulations to create and analyze the models in Rhino Grasshopper and discussing the findings and results. The aim is to divide the work for the two cities and then analyze the current conditions of the neighborhoods. Based on the findings, different strategies can be applied in the residential blocks to reduce the surface temperature of the streets and buildings, therefore reducing the UHI effect. Having sustainable neighborhoods has a direct impact in making cities more livable and improving the climate change. The main tools to be used are Rhino/Grasshopper. Through advanced software, the findings can be optimized and contribute to more sustainable neighborhoods.

Keywords: climate change, neighborhood assessment, grasshopper, walkability.

1 INTRODUCTION

Al Ain is one of the world's oldest inhabited communities, located at the crossroads of the ancient regions of the Arabian Peninsula and Mesopotamia (3,000 BC). The oasis around which a Bedouin tribe resided gave Al Ain its name, and the city became known as the United Arab Emirates' "Garden City" [1]. In barely over 30 years, Al Ain has transformed from a desert oasis to a thriving contemporary city [2]. Several reasons drew civilization to Al Ain throughout antiquity, including the availability of freshwater, date oases, low humidity, and Al Ain's function as a transit hub between interior areas and the Arabian Gulf [3]. Al Ain is noted for its infrastructure, which is a mix of contemporary and traditional. In contrast to the abundant towering skyscraper typology in Abu Dhabi and Dubai, Al Ain has instituted a policy of allowable maximum building height of four stories including the ground level, which was established by the country's founder, Sheik Zayed, to preserve the city's cultural quality [4]. When it comes to traffic patterns, Al Ain has a system of roundabouts that are now being converted into traffic signals. Al Ain is a favorite weekend and vacation destination for families from all around the UAE, especially Abu Dhabi. Al Ain has grown in popularity as a tourist destination, attracting people from around the Gulf Cooperation Council (GCC) [5]. The latest construction activity, which is distinguished by the city's mountain, Jebel Hafeet, consists of around 11,000 big Mediterranean-style houses with extensive green landscaping and an artificial canal [1]. Other higher education institutions, an international airport, and several tourist attractions are also located in the city.

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1.1 Planning of Al Ain

As they came into touch with Islamic culture, the Arab Gulf cities are considered as a fusion of many civilizations and eras, eventually resulting in the urban structures and morphological forms observed in current Arab cities. As a consequence of growing income and a move to an urban services-based economy, many Arab cities' urban design and settlement patterns have altered considerably. Climate and social-religious restrictions shaped traditional Arab urban form. The master-planning phase, which is normally carried out by western experts, is incompatible with the Gulf's economic, political, socio-cultural, and environmental dynamics. Traditional Arab communities took one of two forms: "planned" or "spontaneous" urban layouts.

The main objectives of the first General Master Plan of Al Ain city [17]. Continuation of the traditional role of Al Ain as a center for educational, cultural, and recreational activities of national importance, as the main agricultural producer of the Emirate:

1. Minimization of water consumption to ensure a reserve of groundwater;
2. Economic diversification to provide stable conditions for local businesses;
3. Agricultural self-sufficiency for products which Al Ain is suited;
4. Reducing work contracts and increasing employment for citizens, to support the sustainable economic development of the region;
5. Maintenance of high-level services.

1.2 Building typology of Al Ain

Al Ain contains a city center as well as additional commercial structures made up of mid-rise buildings that are four to five stories tall. The villa is the most common type of residential structure in Al Ain, and it is frequently found in a compound with a similar model organization with periodically or as individual units. It also has many districts with substandard tenement housing and the Al Ain municipality initiated a campaign that stands against unlicensed construction and building code violations [18].

1.3 Urban heat island effect

The goal of sustainable development is to create a blueprint that represents peace and prosperity. An issue city around the world faces is the urban heat island effect. The urban heat island effect is a type of heat buildup phenomenon caused by human activities and urban building construction in an urban area. This occurs when natural grounds are replaced with large concentrations of heat-absorbing buildings, pavement, and different surfaces. This increase causes a high increase in energy consumption cost, material flow, energy flow, illnesses due to heat, mortality, and air pollution. The urban heat island effect develops from solar radiation that is absorbed by the constructed surfaces of tall buildings, concrete structures, roofs, and roadways, which is then released as a form of heat. "Urban heat island" refers to built-up areas that have higher heat energy levels from the surrounding environment [10], [12]. It makes you more susceptible to respiratory and airborne illnesses. The demand for power rises when air conditioning is required to temper the heat, increasing the greenhouse effect. The need for water is likewise increasing [11].

1.4 Influence factors

Many factors have a prominent role in increasing UHI throughout cities. Minimum landscape or decreasing the amount of natural landscape in an urban area; planting/utilizing vegetation, water bodies, and trees provide shading which makes the area cooler. Additionally, Sidewalks, roofs, buildings, roads, and parking have a dry, solid surface in an urban area which results in low shade and moisture from natural landscaped areas which lead to an increase in temperature. The properties of materials also have a noticeable effect; when compared to trees, vegetation, and other natural surfaces, conventional materials that are human-made and are being used in urban contexts have low reflectivity and have a high emission of heat energy. Wind movement and the ability of urban materials to absorb and release solar energy are influenced by the proportions and spacing of structures inside a city. Surfaces and structures obscured by nearby buildings produce huge thermal masses that cannot easily release their heat in densely urbanized areas. Cities with a lot of small streets and towering buildings produce urban canyons, which can hinder natural wind flow and reduce cooling. Additionally, heat is emitted into the urban environment by vehicles, air conditioning systems, buildings, and industrial operations. Heat island effects can be exacerbated by these sources of human-generated, or anthropogenic, waste heat [13].

Finally, the weather is a critical element to consider in regards to UHI. By maximizing the quantity of solar radiation hitting urban surfaces and decreasing the amount of heat that can be moved away, calm and clear weather conditions result in more severe heat islands. Intense winds and cloud cover, on the other hand, prevent heat islands from forming. The heat island effect can be influenced by geographical factors as well. Nearby mountains, for example, can prevent wind from reaching a city or produce wind patterns that pass past it [13].

1.5 Effects on sustainability

The urban heat island effect can cause temperature rises in cities, which can have a variety of consequences for the three pillars of sustainability. Economy, people, and the environment are the three foundations. High energy consumption is a prominent result of UHI. As the temperature rises, the need for cooling rises as well, placing additional strain on the electrical grid. There is also a notable increase in emissions of greenhouse gases and air pollutants. As more electricity is required to cool the building’s surfaces, the demand for energy rises, resulting in increased emissions of greenhouse gases and air pollutants from power plants. Regarding water demand, water usage is high both indoors and outdoors [8].

1.6 Neighborhood assessment

Bande et al. [15] investigated how to efficiently cut energy consumption for the villa typology, a significant building form for Abu Dhabi and many other towns in the area. The goal of this study is to use a calibrated model to highlight the effects of suggested energy efficiency improvements on a villa and to show that, owing to the importance of the urban heat island effect, the model must be run using urban weather data rather than rural weather data to be correct. Construction properties, on-site (urban) weather data, occupancy-related loads and schedules, and rural weather data are among the data sources for this case study. Weather data customization integrating urban and rural weather variables, model calibration using a genetic algorithm-based tool, and simulation of retrofit schemes were the four primary processes. The results reveal that the cool roof, cool walls, SSEER, and atrium shades are the best techniques for a villa. This study's recommended mix of solutions reveals that overall energy savings may be lowered by 25%. The authors recommend that more research be done to improve the software so that the techniques can work at their best [15].

Another study looked at temperature variations in desert city-regions [14]. In order to explore land cover and temperature relationships, the authors developed a multi-sensory strategy. The temperature trend was linked to NDVI and ISA percentage fluctuations in the research. Finally, in arid city locations, the inversion of the Urban Heat Island phenomena was highlighted. Due to the urban heat island effect, the center area of the city is typically anticipated to have higher temperatures. This effect, however, is commonly inverted in desert conditions, as demonstrated in this study. The comparatively high amount of vegetation in urban regions compared to suburban areas, where bare land and sand are more plentiful, is one of the key causes for this inversion [14].

Another paper attempts to investigate the amplitude of UHI and its relationship with the key meteorological factors (temperature, wind velocity, and wind direction) in the context of Dubai, United Arab Emirates. A clustering approach was used to post-process five years of hourly weather data ranging from 2014 to 2018 collected from weather stations in an urban, suburban, and rural region. Six clusters were studied, each with a different range of wind directions. According to the findings, UHI is influenced by synoptic weather conditions (e.g., sea breeze and warm air from the desert) and is greater at night. It is also emphasized that air temperature and evening Urban heat island intensity in the urban region are 1.3°C and 3.3°C higher than in the rural area, respectively, throughout a five-year period, and the Urban heat island effect and air temperature are only independent of each other when the wind originates from the desert [16].

2 METHODOLOGY

The research follows a linear methodology. The study starts with the neighborhood assessment, then weather analysis, modelling and simulations. The aim is to understand the district physiognomy and the connection to the surface temperature, solar radiation, outdoor thermal comfort (OTC).

2.1 Case study selection

The selected case study are 6 districts located int eh city of Al Ain. The typology is low rise and mid-rise Buildings. Table 1 shows the main areas, with the plan and site images. Table 2 shows more data on the area, Breen area available and shading devices if there are any. The six main districts are: Asharej: Mriefa compound complex, City Centre: Al Radi Street, AL Jimi: Jebel Hafeet complex, AL Jimi: Al Mada residential complex, Al Mu'tarid: Hazza bin Zayed stadium Area, Jebel Hafeet: New look medical center.

2.2 Al Ain weather conditions

The climate in Al Ain is considered a desert climate with minimum rainfall. Based on the latest climate analysis graphs of the weather in Al Ain using the graphics-based computer program Climate Consultant, Al Ain has an average temperature of 28°C which is considered above the comfort level. The favorable wind comes from north to west which carries a cool lightweight wind with a breeze, and the unfavorable wind comes from the north side which carries dust and has a hot breeze. Al Ain has prominent levels of solar radiation and illumination but the humidity level is low which results in low levels of rainfall. Al Ain has

Table 1: Selected districts.

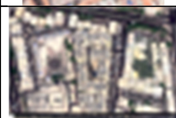
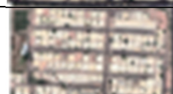
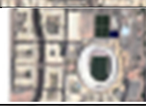
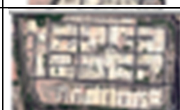
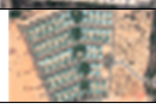
District	Neighborhood	Plan	Site images
Asharej	Mriefa compound complex		
City Centre	Al Radi Street		
AL Jimi	Jebel Hafeet complex		
AL Jimi	Al Mada residential complex		
Al Mu'tarid	Hazza bin Zayed stadium area		
Jebel Hafeet	New look medical center		

Table 2: District details.

District	Building typology	District area	Green area/ number of trees	Shading furniture
Mriefa compound complex	Low rise	58,105.34 m^2	11	n/a
Al Radi Street	Low rise	91,480.27 m^2	46	n/a
Jebel Hafeet complex	Low rise	4.52 km^2	10	n/a
Al Mada residential complex	Mid-rise	24,062.25 m^2	10	n/a
Hazza bin Zayed stadium Area	Mid-rise	187,645.1 m^2	120	Three urban shading devices
New look medical center	Mid-rise	249,259.45 m^2	65	n/a

a unique microclimate in contrast to the larger, more humid coastal cities in the UAE. Despite its location in a hot and arid climate, the irrigated greenery proves to be a viable source of evapotranspiration and humidity (Figs 1 and 2) [7].

2.3 Modelling and simulation, tools and resources

Rhinoceros 3D-Rhinoceros, often known as Rhino or Rhino3D, is a CAD program created by Robert McNeel and Associates that allows users to explore a variety of three-dimensional

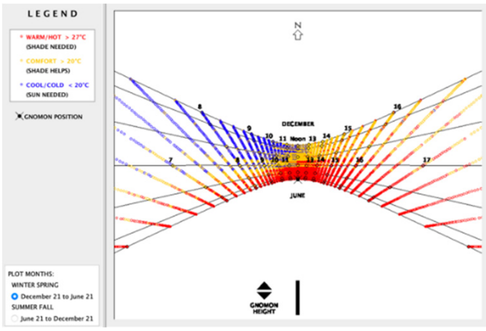


Figure 1: Temperature range graphs: ASHRAE Standard 55-2004 using PMV.

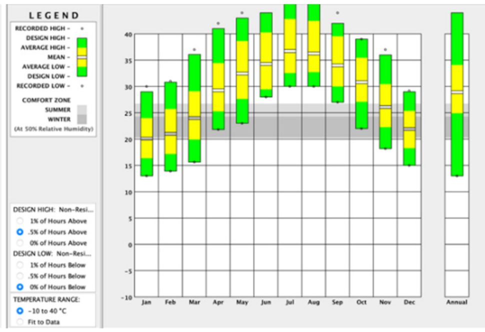


Figure 2: Temperature range graphs: ASHRAE Standard 55-2004 using PMV.

capabilities such as volume creation and design. Non-uniform rational B-splines, or NURBS, are used by Rhino3D to allow users to actualize concepts and designs.

Grasshopper: The Rhinoceros 3D application uses the Grasshopper visual programming language. Grasshopper is primarily used to develop generative algorithms in the shape of boxes and arrows; boxes are viewed as entities, with arrows representing relationships connecting them. Grasshopper, like its parent application Rhinoceros 3D, is a very adaptable tool with several plug-ins that may be used for a variety of applications.

Ladybug: In Grasshopper, Ladybug displays and analyses weather data. This comprises geometric studies such as radiation analysis, shade studies, and view analysis, as well as diagrams such as the sun route, wind rose, psychrometric chart, and so on.

Honeybee: Honeybee connects Grasshopper3D to proven simulation engines, such as EnergyPlus/OpenStudio (for energy performance, HVAC sizing, thermal comfort, and so on) and Radiance (for efficiency measures, HVAC sizing, thermal comfort, daylighting, and glare simulation, Fig. 3)

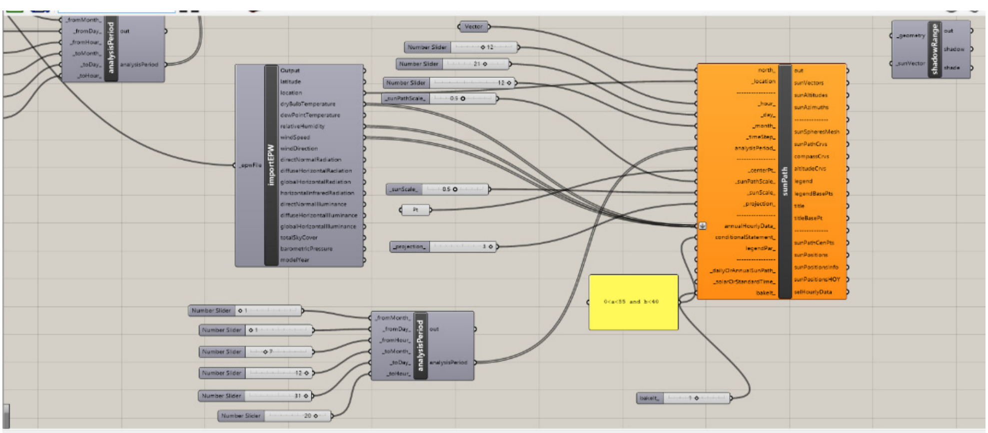


Figure 3: Python script for Grasshopper application.

2.4 Challenges faced during simulation

Both analyses were conducted in grasshopper using the ladybug plugin. the scripts were obtained from Hydrashare GitHub, a website where script creators share scripts for several types of analysis. Some of the models were manually modeled while the others were obtained from a purchased 3DS file for Al Ain city. There were several faults in the file as the 3D models were mostly for non-residential buildings, and those for the residential areas were not accurate for some cases and had to be remodeled. Moreover, it was difficult to locate neighborhoods and select specific buildings in the model, since it did not specify locations or have any labels. Running the scripts was a volatile process, and sometimes it ran promptly other times it took a few hours. Overall, the speed of the script depended on the GPU strength of the PCs used. To conclude, grasshopper could obtain the different results presented in this paper to be used in the research.

3 RESULTS

The results of the simulations refer to the solar radiation of the streets surface analyzed in the base case scenario and the modified scenario where the shades are inserted in the main streets and inner space of districts. Table 3 refers to the solar radiation in equinox and solstice days. Table 4 refers to the solar radiation in the six districts on a yearly analysis. Table 5 refers to the results of the UTCI of the basic case (large-scale) of the districts. Fig. 4 is a graphic representation of the solar radiation in one of the districts, Hazza Stadium area.

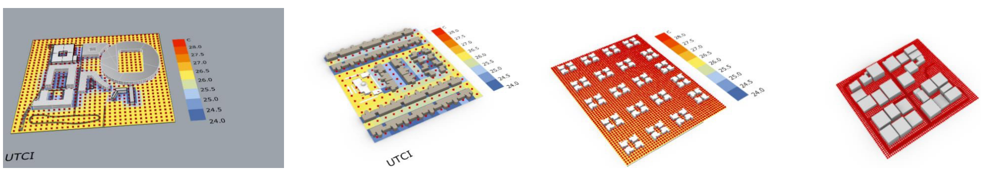


Figure 4: UTCI results.

4 DISCUSSION

The main focus of this study was to understand the impact of the district design and height of the buildings on the solar radiation and outdoor thermal comfort. Through the application of shading structure, the biggest impact is shown in low rise districts. Conducting this study was challenging due to the lack of available free data. Also collecting material on the base case was challenging.

The software used was Rhino/Grasshopper. The modelling and analysis of each case was proven to be challenging due to the complexity of the python language. Furthermore, the modelling phase needed more efforts due to the lack of data. Also parts of the software were customized as per each case.

However, the results are promising in understanding the relevance in designing sustainable neighborhoods in order to fight the climate change, improve walkability through reducing the heat island effect and improving the outdoor thermal comfort.

5 CONCLUSION

The aim is to divide the work for the two cities and then analyze the current conditions of the neighborhoods. Based on the findings different strategies can be applied in the residential

Table 3: Solar radiation analysis results.

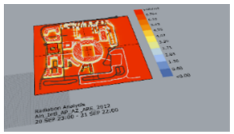
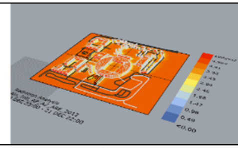
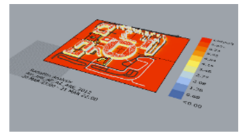
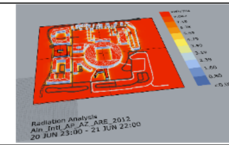
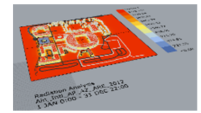
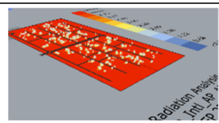
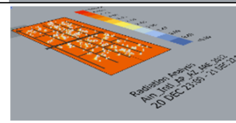
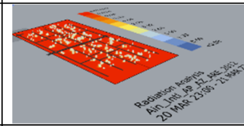
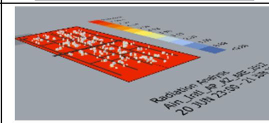
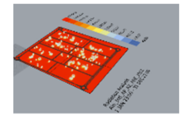
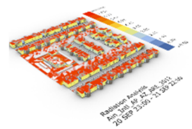
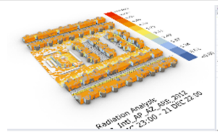
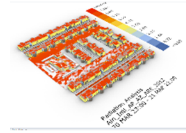
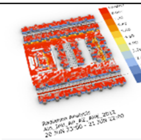
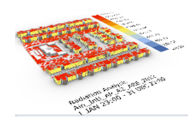
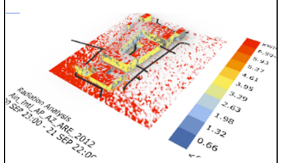
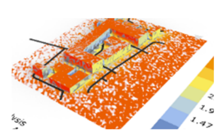
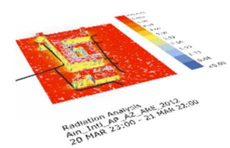
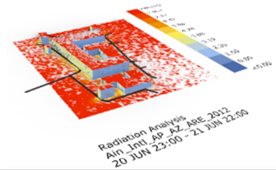
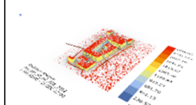
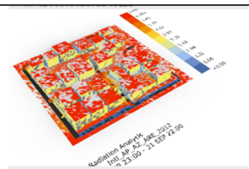
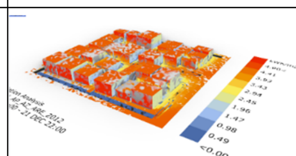
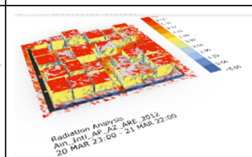
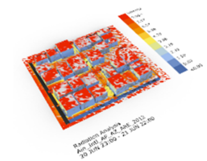
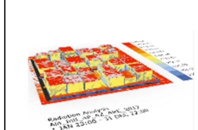
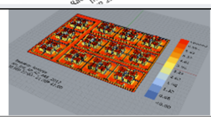
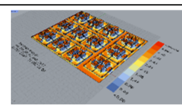
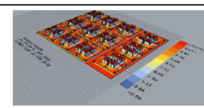
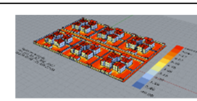
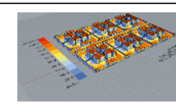
Name	September 21	December 21	March 21	June 21	Annual data
HBZ stadium neighborhood					
New look clinic					
Mriefa compound complex					
City center Medclinic					
Al Radi Street					
Jebel Hafeet					

Table 4: Solar radiation results.

	Mriefa compound complex		Jebel Hafeet complex		Al Radi Street		New look medical center		Hazza bin Zayed stadium		Al Mada residential complex	
	No T.	With T.	No T.	With T.	No T.	With T.	No T.	With T.	No T.	With T.	No T.	With T.
January	63.9	58.3	53.4	44.0	44.1	38.2	52.3	50.1	50.9	32.7	59.1	52.6
February	66.9	62.1	58.6	49.2	46.7	40.8	55.2	52.8	53.9	33.5	62.5	56.3
March	83.3	78.3	77.1	65.3	59.3	52.5	69.1	66.1	67.7	40.6	78.7	71.6
April	98.6	85.0	87.5	75.1	64.7	57.7	74.7	71.2	72.3	41.8	84.8	77.6
May	63.9	78.3	96.8	84.3	70.8	63.4	81.6	77.6	78.4	44.6	92.1	84.4
June	95.1	93.3	92.4	80.6	68.4	61.2	71.2	74.9	75.5	42.8	88.7	81.2
July	97.3	86.7	95.2	83.1	69.9	62.6	80.6	76.6	77.2	43.8	90.8	83.2
August	93.6	92.2	91.7	79.1	67.1	60.0	77.5	73.7	74.6	42.7	87.6	80.3
September	83.4	88.5	78.2	66.8	59.7	52.9	69.2	66.2	67.4	39.8	78.7	71.7
October	77.2	78.7	78.2	58.0	54.2	47.3	63.7	61.0	62.3	38.2	72.2	65.2
November	63.6	58.4	53.6	44.4	44.2	38.2	52.1	49.9	50.8	32.3	59.0	52.6
December	60.3	57.4	49.7	40.8	41.6	36.0	49.4	47.3	47.9	31.0	55.9	49.5
Annual	947.6	918.0	932.1	796.0	691.2	630.7	797.4	792.3	779.5	478.9	939.4	852.8

Table 5: UTCI values.

	Mriefa compound complex		Jebel Hafeet complex		Al Radi Street		New look medical center		Hazza bin Zayed stadium		Al Mada residential complex	
	No T.	With T.	No T.	With T.	No T.	With T.	No T.	With T.	No T.	With T.	No T.	With T.
January	23.3	15.2	23.8	23.2	22.9	22.5	22.7	22.6	23.1	15.2	23.2	22.7
February	23.1	15.9	23.7	23.0	22.7	22.3	22.5	22.4	22.9	15.9	23.	22.6
March	25.9	20.2	26.4	25.8	25.6	25.2	25.3	25.3	25.7	20.2	25.9	25.4
April	30.7	27.0	31.2	30.7	30.4	30.1	30.2	30.2	30.6	27.0	30.7	30.3
May	34.2	31.6	34.6	34.1	33.9	33.5	33.7	33.7	34.0	31.6	34.1	33.8
June	36.3	34.2	36.7	36.2	36.0	35.7	35.9	35.8	36.2	34.2	36.3	35.9
July	39.1	37.5	39.5	39.0	38.8	38.5	38.7	38.6	39.0	37.5	39.1	38.7
August	38.2	36.6	38.7	38.2	38.0	37.7	37.8	37.8	38.1	36.6	38.2	37.9
September	35.6	33.3	36.1	35.6	35.4	35.0	35.2	35.1	35.5	33.3	35.6	35.2
October	32.3	28.9	32.8	32.2	32.0	31.7	31.8	31.8	32.2	28.9	32.3	31.9
November	27.1	21.5	27.6	27.0	26.8	26.4	26.6	26.5	26.9	21.5	27.1	26.6
December	24.2	17.3	24.7	24.1	23.8	23.4	23.6	23.5	24.0	21.5	24.1	23.7
Annual	30.8	26.6	30.8	30.2	30.0	29.6	30.3	30.3	30.1	27.0	30.3	29.9

blocks in order to reduce the surface temperature of the streets and buildings, therefore reduce the UHI effect. Having sustainable neighborhoods has a direct impact in making cities more livable and improving the climate change. The main tools to be used are rhino/grasshopper. Through advanced software, the findings can be optimized and contribute to more sustainable neighborhoods.

Future work is needed to investigate other means of reducing the solar radiation in the streets of the city. This study can contribute to improving the OTC, reducing heat island effect in the city and the UAE.

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