The Impact of Urban Heat Island on Cooling Needs in Urban and Suburban Areas of Hyderabad Sindh Pakistan

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Abstract

The urban heat island phenomenon is causing numerous problems, and studying its effects in rapidly developing cities is crucial to meet the Sustainable Development Goal 14 for sustainable building and cities. This research focuses on investigating the characteristics of the Urban Heat Island in Hyderabad Sindh, specifically in a densely populated commercial area and a rural suburb known as TandoJam. The study utilized weather station data from the Pakistan Meteorological Department and temperature sensors from Qasimabad to compare air temperature differences between the urban and reference rural areas. The UHI intensity was determined by calculating the air temperature difference between urban and rural areas. Results showed that the UHI effect was more prominent during winter and nighttime than during summer and daytime, with only a few months, like June, showing some UHI effects during daytime. The study also used cooling degree days and cooling degree hours as a measure of energy required for cooling, and all areas observed higher numbers of CDDs and CDHs. However, urban areas had more CDDs than rural areas, indicating that the maximum cooling degree days in urban areas are a direct consequence of the UHI. The 7-year average data revealed that TandoJam experienced the least number of CDDs compared to its urban area, suggesting better thermal comfort in the rural area. The study's findings were further validated through a day UHI analysis in the town of Qasimabad Hyderabad, which showed high CDHs and higher UHI intensity in Qasimabad than in other rural towns in Hyderabad.

Keywords—Urban heat island effect, Cooling degree days, CDHs, UHI and its impact on cooling needs in urban areas

1 Introduction

The effect of Urban Heat Islands on cooling requirements in urban and suburban settings is a complicated matter that takes into account a number of variables [1]. The constructed environment, which includes the architecture, building supplies, and building orientation, is one of the important variables [2]. For instance, huge glass windows that receive little shading can let a lot of heat into a structure during the day, requiring a lot of cooling during the night. In a similar vein, structures facing the sun can absorb more heat, which can raise the cooling load. The usage of air conditioning equipment, which is widespread in both urban and suburban regions, is another crucial element [3]. While air conditioning can help you escape the heat, it can also use more energy and emit more greenhouse gases. In fact, one of the major factors contributing to increasing energy demand in metropolitan areas, especially during heatwaves, is the use of air conditioning [4]. To address these issues, a range of strategies have been proposed to reduce the impact of UHIs on cooling needs [5]. For example, urban planners and designers can incorporate green infrastructure into their plans, such as parks, green roofs, and tree-lined streets [6]. These green elements can provide shade and evaporative cooling, which can help to reduce temperatures and the need for air conditioning [7]. Another strategy is to use reflective materials for roofs and pavements, which can reflect sunlight and reduce the amount of heat absorbed by buildings and streets

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[8]. Additionally, building design can be optimized to improve ventilation and reduce heat gain, such as by using double- glazed windows, shading devices, and natural ventilation systems [9]. An urban heat island effect is the phenomenon by which the temperature of urban area tends to remain at higher side than the suburb or its close rural area. now a days it is seen that most of the cities have highest temperature than their rural area [8], [10], [11]. This higher temperature in urban areas can incline the cooling demands in the summer season whereas the summer season already of 8 months which can have the serious impact on the cooling needs of urban areas [12]. In this way the UHI creates huge problems because to make the environment thermally comfortable the air needs to be conditioned which consumes lot of electricity and has burden on national grid [13], [14]. The concept of cooling degree days and heating degree days is useful in this approach, the heating degree days can be calculated when the temperature fall below the reference base temperature which is basically the thermally comfortable temperature of human beings taken and cooling degree days can be calculated when the temperature rise above the base temperature whereas there is lot of discussion on the base temperature and researchers have not fully agreed to single base temperature ,mostly used base temperature for calculation of CDD is 24°C and for HDD is 18°C in Pakistan[15]. Urban heat island normally is to select urban and one or more surrounding rural areas, in the first part of this study the hourly air temperature records of one urban and one rural area was taken to analyze UHI trends in one urban and one in rural or suburb area with lush vegetation [16]. The urban heat island intensity was determined by comparing well developed and populated areas and less developed but with lush vegetation suburb or rural area [17]. In the second part the CDDs are compared to analyze the impact of UHI on cooling demand of Hyderabad and TandoJam [18] [19]. This study helps to achieve SDGs which are designated by World organization because emissions from vehicles and industrial burning can cause urban heat island effect in urban areas and be used for policy studies [20]. Urbanization has transformed many cities and suburbs into concrete jungles, with buildings, roads, and other infrastructure replacing natural landscapes [20], [21]. This transformation has led to the creation of urban heat islands (UHIs), which are characterized by higher temperatures in urban areas compared to rural areas [1]. This is because the built environment tends to absorb and retain heat more than natural surfaces such as soil and vegetation [22]. It is well known how UHIs affect the environment and people's health. For instance, they can make heat-related illnesses worse, use more energy to cool, and cause air pollution [23]. These problems are especially important in urban and suburban regions, where UHI impacts can be amplified by high population densities and the presence of vast built-up areas [24]. The interest in creating mitigation solutions has increased as a result of UHIs' major impact [2], [3], [5]. To assist lower temperatures in metropolitan areas, this includes the use of green infrastructure, such as trees, parks, and green roofs and walls. UHIs can be lessened by adjusting building materials and design, such as using reflecting surfaces and enhancing ventilation [25]. Understanding the impact of UHIs on cooling needs in urban and suburban areas is an important step towards developing effective strategies for mitigating their effects [26]. This is because UHIs can significantly increase energy consumption for cooling, which can in turn contribute to climate change and other environmental problems [27]. Therefore, by reducing the impact of UHIs on cooling needs, we can not only reduce energy consumption and costs but also contribute to a more sustainable and healthier urban environment.

1.1 Causes of Urban Heat Island

An urban heat island (UHI) is the urban or metropolitan area that is usually warmer than the surrounding rural or sub-urban area. This will result in a larger temperature difference at night as compared to today [28]. UHI are significantly noticeable when winds are weak. Urban heat island is much more noticeable during summers as well as in winters. UHI is generated in areas which have lots of activities and lots of people. Urban heat island is contributing to global heat warming all around the world. The following are the causes for the generation of urban heat island:

- Dark colored surfaces of roofs, walls and roads may cause urban heat islands because dark colors are good absorber of heat and solar radiation which will result in heat up of urban area than surrounding rural area.
- Different materials used for building such as concrete and asphalt have significantly different thermal bulk properties (including heat capacity and thermal conductivity & surface radiative properties (albedo and emissivity) than the surrounding rural areas which will cause rise of temperature in urban area.
- Decrease in evapotranspiration and lack of vegetation may also cause urban heat island significantly. As a result of that cities will have less shade and cooling effects of trees will also be lesser and quantity of carbon dioxide will also decrease.

- Geometry of building may also cause urban heat island such as the taller buildings have much larger area for absorption and reflection of solar radiation which will give rise to urban heat island. This effect is known as "Urban canyon effect."
- Larger buildings will block the flow of wind which also hinders cooling by convection and averts pollutants from dissipating and will generate urban heat island.
- Large amounts of waste from automobiles exhaust industries and homes are further contributing to urban heat island [18], [24], [26], [28].

The Urban Heat Island (UHI) effect is a phenomenon where the temperature in urban areas is higher than that of the surrounding rural areas. This phenomenon is caused by various factors such as the lack of vegetation, large areas of impervious surfaces, and human activities that generate heat. The Fig 1. Demonstrates the effects and generation parameters of Urban heat island in the cities, different conditions mentioned in the figure play a pivotal role in UHI generation. The UHI effect may significantly affect energy use, the environment, and human health. In many places throughout the world, especially as urbanization keeps rising, it is a major worry. In this situation, it is essential to comprehend the root causes and effects of the UHI effect to create efficient mitigation plans. The Urban Heat Island effect, its causes, and the mechanisms that contribute to it are all elaborately introduced in this article. Several interrelated elements interact to create the complex phenomenon known as the urban heat island effect. The process of urbanization itself is one of the main causes of UHI. As cities expand and develop, impervious surfaces like concrete, asphalt, and buildings frequently replace natural surfaces like wetlands, grasslands, and forests. Higher nighttime temperatures result from these surfaces' ability to collect and store heat during the day and release it back into the atmosphere at night. The lack of vegetation is another contributing factor to UHI. Trees and plants provide shade and release water vapor through transpiration, which cools the surrounding area. In urban areas, trees and green spaces are often replaced by buildings, which absorb and store heat, further exacerbating the UHI effect. Human activities such as transportation, industrial activities, and energy consumption also contribute to UHI. In addition to the energy used for air cooling and other purposes, vehicles and industrial processes also contribute to the overall heat load in metropolitan areas. Human health may be significantly impacted by the UHI effect, particularly during heatwaves. The danger of heat-related illnesses and even death can increase with rising temperatures. The UHI effect may also result in higher energy demand, which raises air pollution and greenhouse gas emissions [7], [29], [30], [30], [25].

1.2 Cooling Degree Days

Degree days method is more appropriate for estimating energy consumption or energy needs in any area or location. It can be very useful in estimating cooling energy needs in any city and can also be used to assess how UHI affects ener- gy needs. This method was developed by ASHRAE, which is well known for its method.[1], [16], [20], [30], [32], [33].

In conclusion, the impact of UHIs on cooling needs in urban and suburban areas is an important issue that requires attention from policymakers, urban planners, and designers. By implementing strategies to reduce the impact of UHIs on cooling needs, we can create more sustainable and healthier urban environments, reduce energy consumption, and mitigate the impacts of climate change.

2 Research Methodology

1) Define the study area: The study area should be defined based on the extent of urbanization and its surroundings, and its boundaries should be clearly defined.
2) Collect meteorological data: Collect meteorological data from weather stations located within and outside the urban area for a specific period (e.g., 24 hours, one week, one month). The data should include air temperature, humidity, wind speed, and direction.
3) Define urban and rural stations: Based on the study area, select weather stations that are located within the urban area (urban stations) and weather stations that are located outside the urban area (rural stations).
4) Calculate the temperature difference: Calculate the temperature difference (ΔT) between urban and rural stations for each time (e.g., hourly, daily) by subtracting the rural temperature from the urban temperature ($= T_urban - T_rural$).
5) Interpret the results: Interpret the results of the analysis and draw conclusions about the magnitude and spatial extent of the UHI effect in the study area.

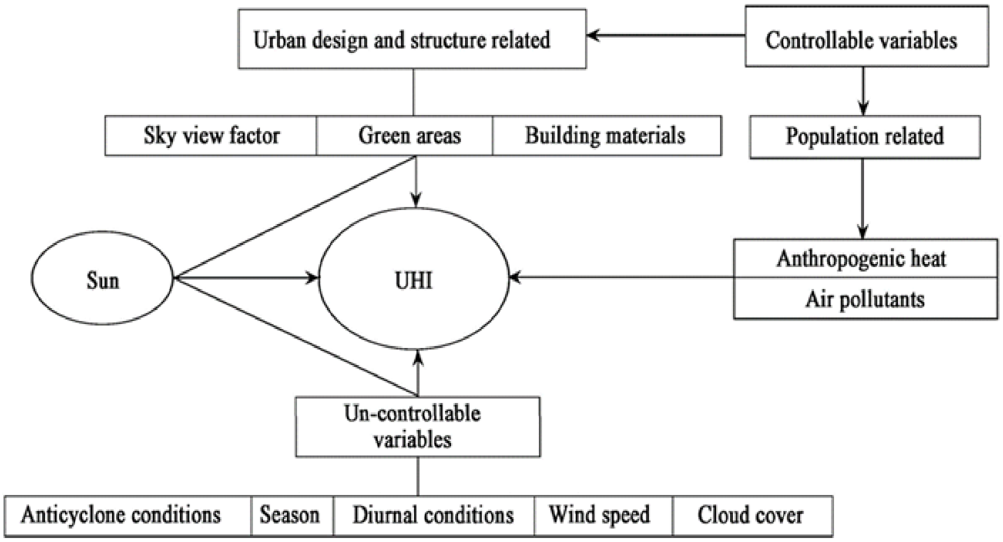


Fig. 1: Generation of Urban Heat Island (UHI) [10].

Fig. 2: A view of Hyderabad depicting the location of weather stations and land utilization

TABLE 1: Details of location and data record periods for selected area

Data recorded period	Location	Classification	Altitude (m)
2015-2021	Hyderabad (Airport)	Urban	13
2015-2021	TandoJam	Suburban /rural	23

6) The normal thermocouple sensor was also used to measure the temperature in Qasimabad, a suburb area of Hyderabad.
7) 7. The temperatures used to analyze this research were obtained from Pakistan Meteorological Department who have weather stations located in Hyderabad and TandoJam.

During the research work data was taken from two weather stations in Hyderabad and TandoJam as TandoJam is around 15 KM away from Hyderabad and is lush vegetated less populated suburb or rural area which seems good for the study of urban heat island effect and its effect on cooling needs of urban and sub urban area of Hyderabad.

The meteorological data from two weather stations were obtained from Pakistan meteorological department, one of the weather stations is in highly densely populated area of Hyderabad and other station is in TandoJam a sub urb but lush green vegetated area in vicinity of Hyderabad both areas come in district Hyderabad, TandoJam being less populated compared with Hyderabad city and mostly agricultural area with an agricultural university. Human activity in Hyderabad is high due to high flux of migrants from interior Sindh due to educational facili- ties and better opportunities that's why the heat generating source might be high and the emission of automobile is also high and UHI might be higher in Hyderabad due to high rising buildings because of population flux. In the first part of this study the daily urban heat island intensity was obtained for each month during the period of 2015-2021. In this part of study obtain the maximum mean daily UHII and minimum mean daily UHII and mean daily average UHII of Hyderabad. Basically, UHII urban heat island intensity is worked out by temperature dif- ference between urban and sub urban or rural area. Diurnal trend is also tabled for the maximum UHII day in a month of a year. In the 2nd half of the study the CDDs were calculated using the

TABLE 2: Details of location and data record periods for selected area

Data recorded period	Location	Classification
18/09/2022	Qasimabad Hyderabad	Urban
18/09/2022	Hyderabad	Sub-urb

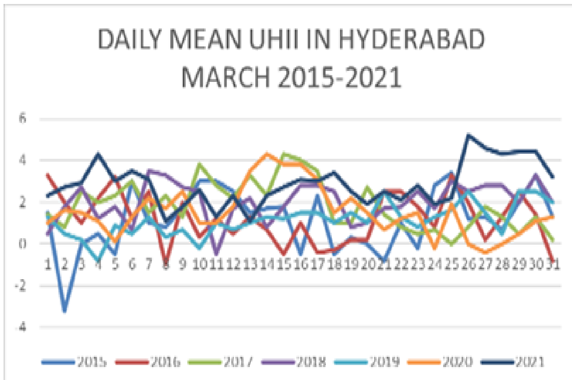


Fig. 3: Daily UHII in Hyderabad January

given ASHRAEs method below.

$$CDD = (T_m - T_b) + ... \quad (1)$$

[32]
In this the T_m denotes the mean temperature of the day and T_b is the base temperature taken to be 24°C in this case. The main reason to calculate the CDDs was to show the impact of UHI on cooling energy needs of Hyderabad. In the final part the Diurnal UHII of Qasimabad Tehsil of Hyderabad during a selected day was calculated using temperature sensor planted in densely populated and developed area of urban infrastructure and more absorbing surfaces and the other data of surface temperature was taken from the less dense and less developed area in Hyderabad with less development to check the concept of UCI effect and UHI Effect in city like Hydera- bad. For UHII Calculation:

$$\Delta T = T_urban - T_rural \quad (2)$$

[8]

3 Results and Discussion

Fig 3 shows that urban heat island intensity is growing at a rapid pace in Hyderabad in the month of January throughout the period of 7 years, the highest UHI seen in this month is in year 2021 which is around 50C,

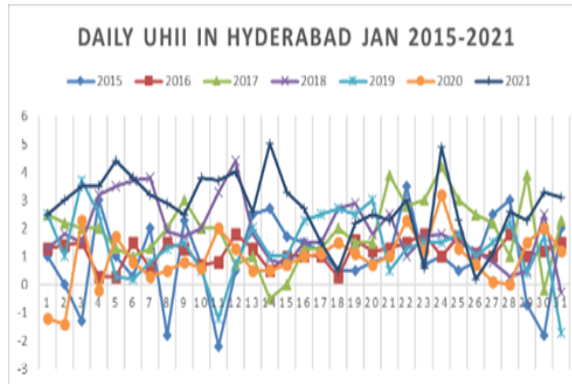


Fig. 4: Daily UHII in Hyderabad February

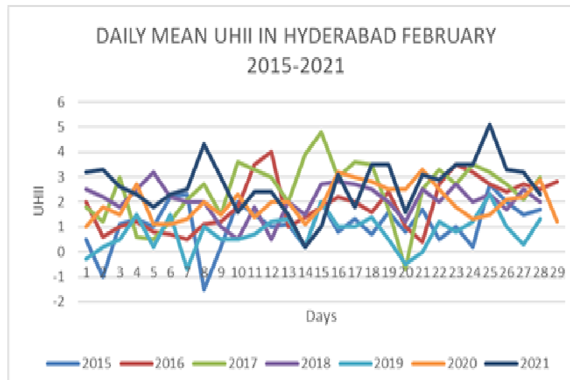


Fig. 5: Daily UHII in Hyderabad March

Basically UHII is the Urban heat island intensity it is the level of intensity of heat.

Fig 4 shows that UHI is growing at a pace in the month of february as in winter months. In general, UHI is more pronounced in winters than in summers, especially during clear and calm weather conditions. This is be- cause the winter nights are longer and the sky is often clear, which allows for more radiative cool- ing of rural are- as, leading to a greater temperature difference between urban and rural areas. In addition, in winters, there is less vegetation cover in urban areas, which exacerbates UHI effects, as vegetation has a cooling effect on the environment.

Fig 5 shows a similar trend as the previous months but in this month, there tends to be thermal comfort and considerably low UHI as compared with previous months.

Fig 6 shows low UHI as compared with other previous months as the temperature of the succeeding months tends to increase. In contrast, in summers, there is more vegetation cover, and the increased mois- ture from evapotranspiration helps to cool the envi- ronment. Furthermore, the windier conditions during summers can help to dissipate the heat generated by

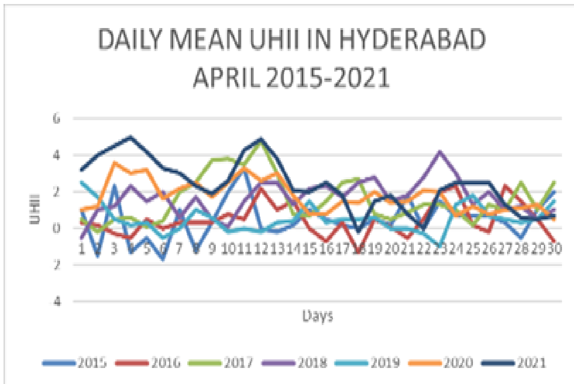


Fig. 6: Daily UHII in Hyderabad April

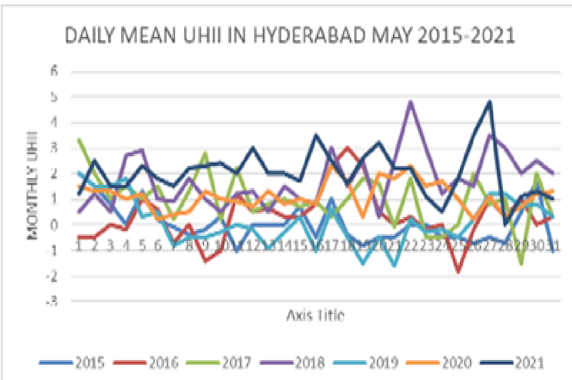


Fig. 7: Daily UHII in Hyderabad May

urban activities, reducing the UHI effect.

Fig 7 follows the trend as in Summers the UHI tends to be low can be seen in fig above, although the UHI tends to increase every year.

Fig 8 shows very low UHI as this month is one of the hottest in summers.

Fig 9 shows the characteristic pattern followed during month in respective years, here note that mostly the local climate has influence in formalizing this pattern as shown.

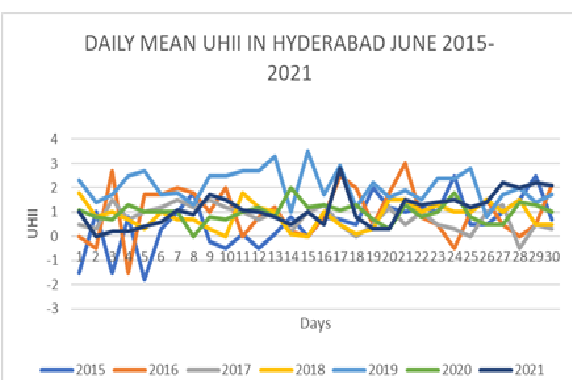


Fig. 8: Daily UHII in Hyderabad June

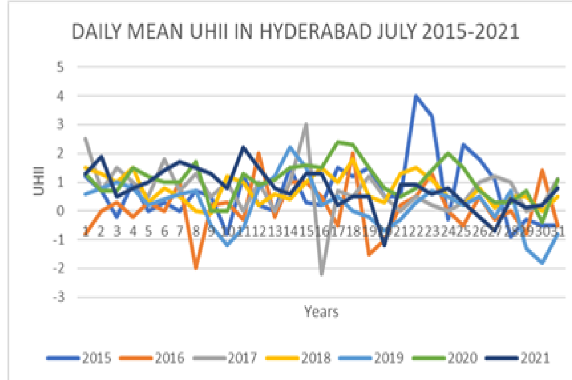


Fig. 9: Daily UHII in Hyderabad July

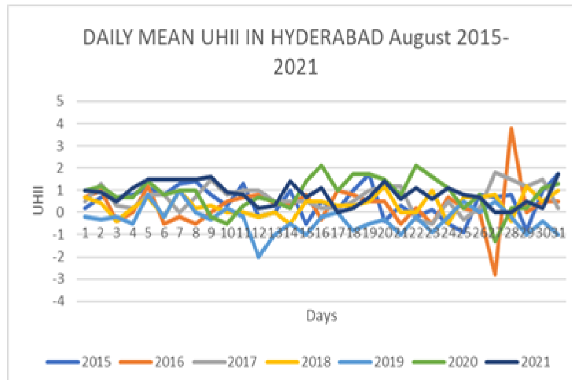


Fig. 10: Daily UHII in Hyderabad August

Fig 10 shows low UHI due to winds which are high during this season in August, it is important to note that the trend is same and in 2021 UHI is high as compared to other years during study.

Fig 11 shows low UHI as winds speed tends to be high in September.

Fig 12 shows the rise in UHII value as the season tends to be pleasant or colder.

Fig 13 shows the rise in similar manner as in previous month but with steep rise as compared with

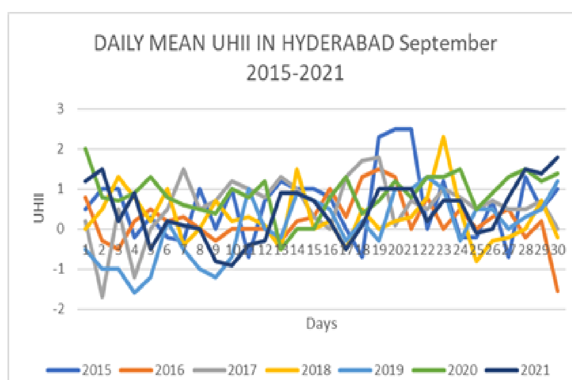


Fig. 11: Daily UHII in Hyderabad September

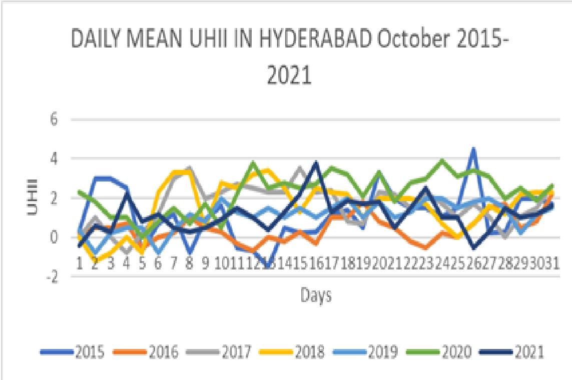


Fig. 12: Daily UHII in Hyderabad October

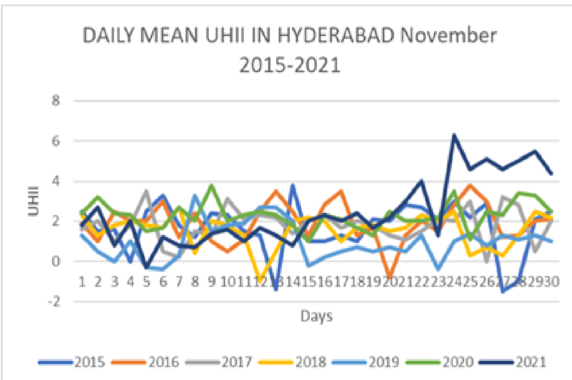


Fig. 13: Daily UHII in Hyderabad November

November.

Fig 14 shows the steep rise in UHII as compared with November. In general, UHI is more pronounced in win- ters than in summers, especially during clear and calm weather conditions. This is because the winter nights are longer and the sky is often clear, which allows for more radiative cooling of rural areas, leading to a greater tem- perature difference between urban and rural areas. In addition, in winters, there is less vegetation cover in urban areas, which exacerbates

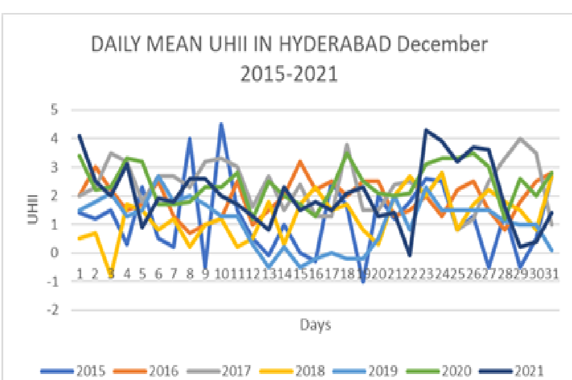
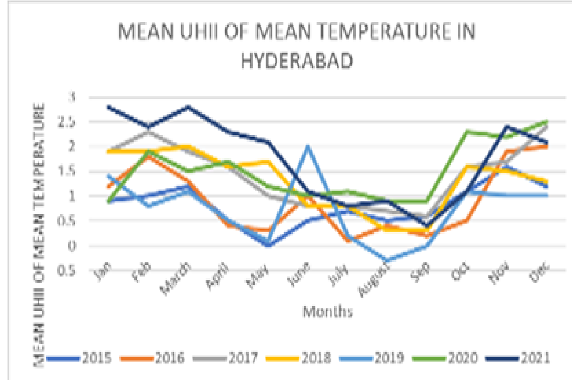
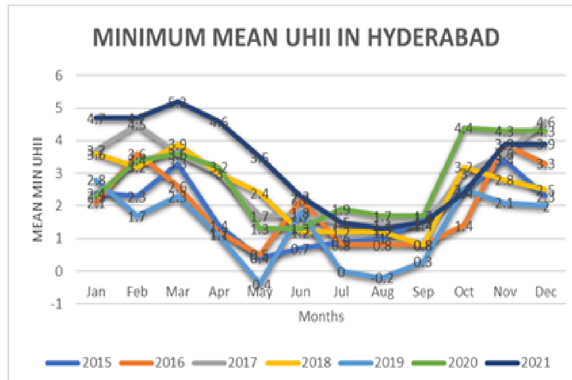


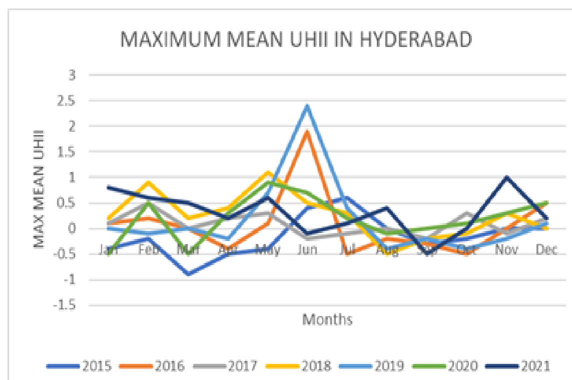
Fig. 14: Daily UHII in Hyderabad December



(a) Mean UHII of mean temperature in Hyderabad



(b) Mean UHII of min temperature in Hyderabad



(c) Mean UHII of max temperature in Hyderabad

Fig. 15: UHII of mean, min and max temperature in Hyderabad

UHI effects, as vegetation has a cooling effect on the environment.

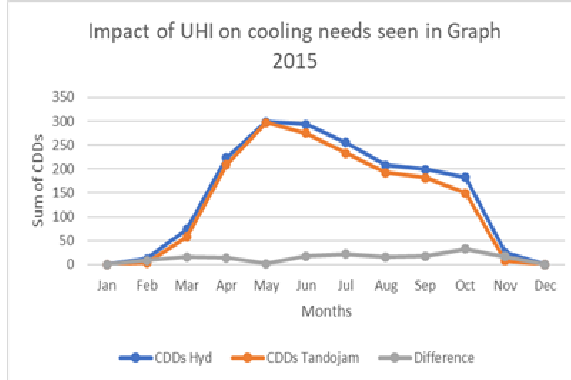
Fig 15 (a) shows that UHII tends to be high in winter months during study and it related to the other study show- ing same results, thus validating the research. Fig 15 (b) shows the same results with variety of data being analyzed during the study. Fig 15

(c) shows the same results and trends as the previous figures and graph line ovelapes each other.

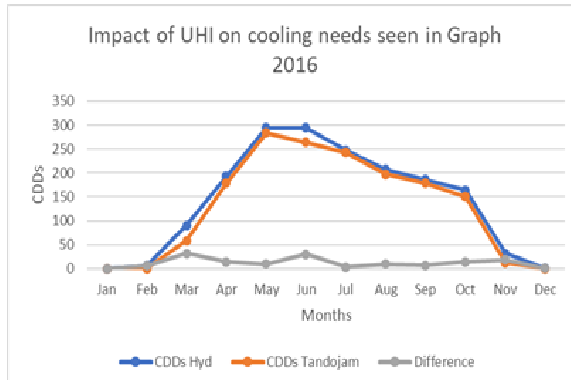
Fig 16 (a) shows the the effect of UHI on cooling needs in Hyderabad in 2015, as Cooling degree days demon- strates about how much the area is hot or it requires cooling, and it clearly shows that Hyderabad has higher CDDs as compared to its rural counterpart. Fig 16 (b) shows the the effect of UHI on cooling needs in Hyderabad in 2016, as Cooling degree days demon- strates about how much the area is hot or it requires cooling, and it clearly shows that Hyderabad has higher CDDs as compared to its rural counterpart. In the above figure it shows that month of June in 2016 will have highest cooling need in Hyderabad. Fig 16 (c) shows the the effect of UHI on cooling needs in Hyderabad in 2019, as Cooling degree days demon- strates about how much the area is hot or it requires cooling, and it clearly shows that Hyderabad has higher CDDs as compared to its rural counterpart. In the above figure it shows that month of June in 2019 will have highest cooling need in Hyderabad. Fig 16 (d) shows that Cooling need is increased as the summer season begins in 2021, overall CDDs of Hydera- bad are high so the demand for cooling need is increased.

As discussed earlier the UHI is high in Winters as compared to summer, in this figure it is clearly shown, and the pattern followed by both graphs is characteristic curve of UHII during diurnal period. Fig 17 (a) shows the UHII effect in winters throughout 24 hours and fig 17 (b) shows the UHII in summer months.

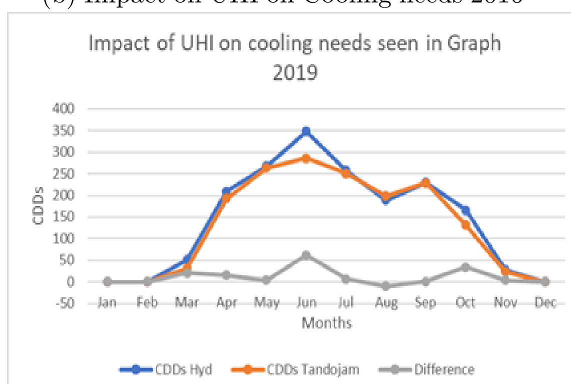
Fig 18 (a) and (b) shows cooling degree hours which are high for Hyderabad during 24-hour period. Cooling De- gree Hours (CDH) is a related concept to Cooling Degree Days (CDD), but instead of measur- ing the total number of degree-days, it measures the number of hours that a cooling system needs to be in operation to maintain a cer- tain indoor temperature below a reference temperature. CDH can be a more precise measure of cooling energy usage than CDD, as it considers the actual hours of operation of the cooling system, rather than assuming a con- stant cooling load throughout the day. CDH is often used in conjunction with CDD to estimate cooling energy usage and demand for different types of buildings and cooling systems. Stronger UHII is seen during night- time. However, at night, the urban surfaces cool down more slowly than the rural areas due to the thermal properties of the materials used in construction, the thermal inertia of buildings, and the heat stored in the surfaces during the daytime. Additionally, urban areas tend to have less vegetation cover, which means that there is less evapora- tive cooling during the night.



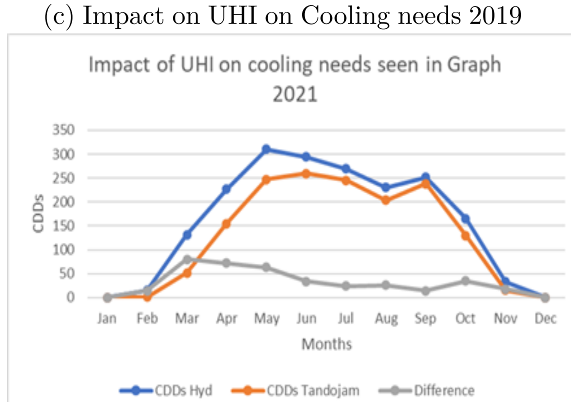
(a) Impact on UHI on Cooling needs 2015



(b) Impact on UHI on Cooling needs 2016

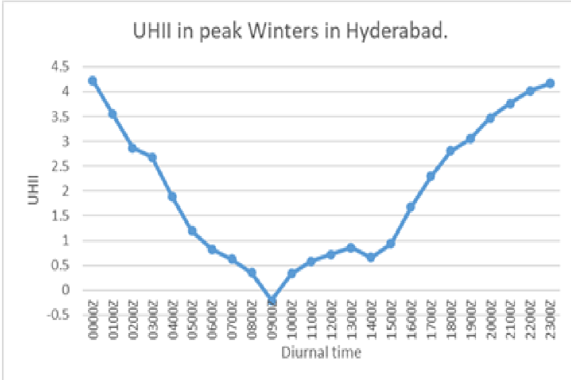


(c) Impact on UHI on Cooling needs 2019

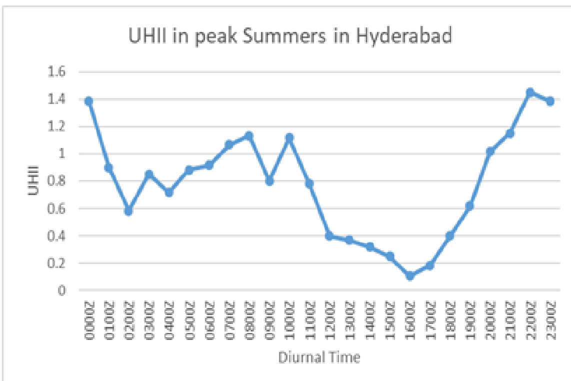


(d) Impact on UHI on Cooling needs 2021

Fig. 16: Impact on UHI on Cooling needs from various years

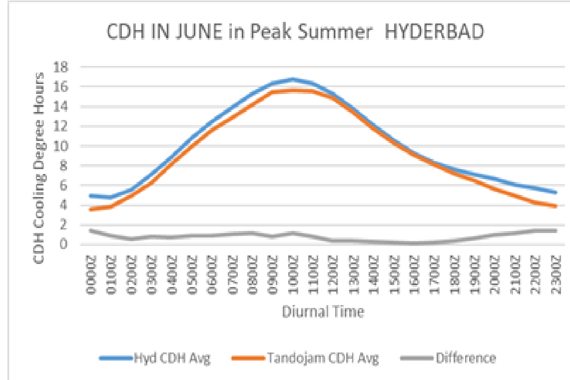


(a) Mean UHII in winters in Hyderabad

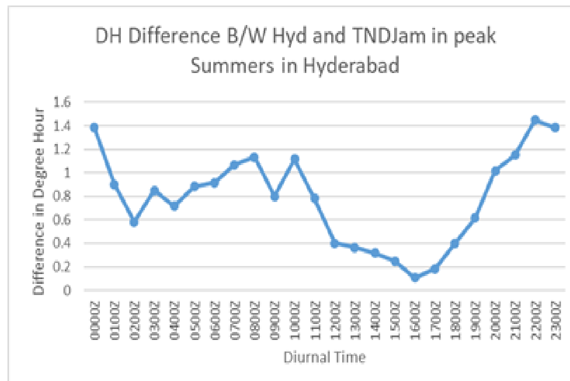


(b) Means UHII in Summers in Hyderabad

Fig. 17: Means UHII in Summers and Winters in Hyderabad



(a) Cooling degree hour June in Hyderabad



(b) DH difference b/w Hyd and Tandojam Summers

Fig. 18: Cooling degree hours which are high for Hyderabad during 24-hour period

This causes the temperature in urban areas to remain high during the night, lead- ing to a stronger UHI intensity.

In fig 19 (a) and (b) the temperature between Hyderabad and its suburb can be seen at different time periods and in nighttime UHII is more evident as compared to daytime. Thus, more cooling is needed in urban areas and the cooling needs are increased overall.

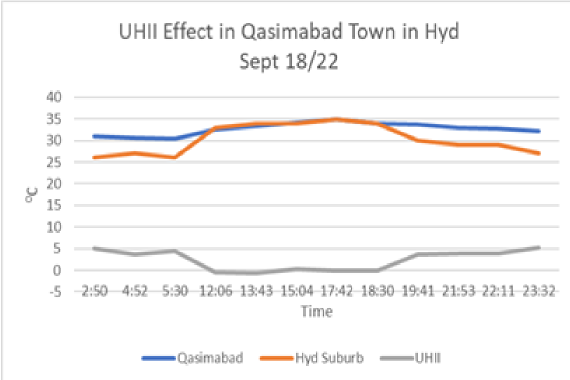
a It can be seen in Figure no 3 that Hyderabad has strongest urban heat island effect and through the study of 7 years data it came out that winters has more urban heat island effect as compare to summers which has more UCI urban cool island effect it may be due to less reflection of sun light by urban surface as compare to in summers so it has benefit as in winters we need to warm the environment for thermal comfort we need less energy for thermal comfort from the figure no 3 it can seen that Nov has highest in- tensity of urban heat island in whole decade whereas sept has lowest intensity in a decade[3][15].

b In June 2019 which had more UHII recorded in summers showed in Fig 4 and it is evident from the above fig 4 that UHI is more in winter months like Nov, Dec, Jan, Feb in Hyderabad [4].

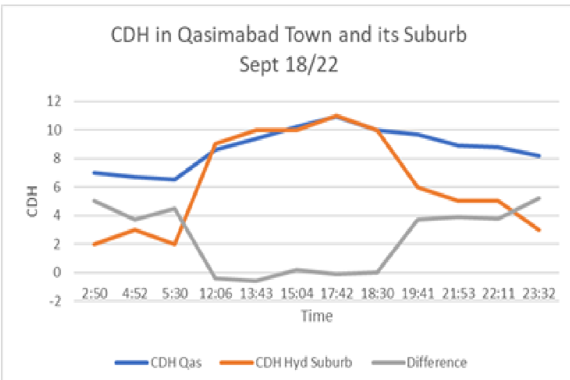
c The trend for UHI Analysis showed much balance in summer months as compared with winter months which increased with change in year [6].

d To show the impact of UHI on cooling needs the study was carried in this paper which depicted that some months in summer has stronger UHI effect at time and due to UHI cooling degree days tends to increase year by year this was due to population growth which accelerates the heat generation source in urban areas and may be due to construction of high rising building which increase the UHI effect [8].

e To check at which time during the day UHI is increasing diurnal study was carried and it showed in Fig 6 that it was highest at 00:00 in a day and then decreases as the time increases and then after 4:00PM it increases very steadily till again at 00:00 in Winters, in summers the was almost



(a) UHII Effect Qasimabad town Hyd on 18/09/22



(b) CDH in Qasimabad vs its Suburb on 18/09/22

Fig. 19: Temperature between Hyderabad and its suburb at different time periods in daytime and in nighttime

the same but from 2:00AM till 12:00 it was of irregular nature after that it resembles the trend shown in fig 6 (a)[15].

f Fig 7 shows that the UHII mean intensity of UHI which is highest at nighttime till early morning and is validated by most researchers in papers [10,11,12].

g To check at what time the cooling energy need is highest the study was carried out in hottest month of summer June it showed in figure 7 (a) the high CDH in Hyderabad are evident from above fig 7 (a) due to UHI effect possibly it is showing that some part of day and some part of night has CDHs the meeting point mean low or 0 CDH at 16:00 to 17:00 during the day due to UHI is evident to show the above study in this paper[4].

h To further validate the above study another attempt was done to find out the UHII in Fig 8 (a) during this time the temperature sensors were used to see the effect in Densely populated tehsil in Qasimabad and less developed suburb in Hyderabad which showed stronger UHI effect at nighttime and it was al- most zero during daytime in Qasimabad and it then again increased after 6:00 PM Till 0:00 then decreas- es And during this time cooling energy need is maximum in Qasimabad Hyderabad as shown in Fig 8 (b)[18].

4 Conclusion

The aim of this research is to examine the urban heat island (UHI) phenomenon in Hyderabad Sindh, both in urban and suburban areas. The investigation was carried out by analyzing climatic data from two weather sta- tions in Hyderabad and TandoJam, as well as one day of data from Qasimabad Hyderabad. The study included areas with varying degrees of development, such as densely populated and commercialized urban areas, and remote, thinly populated rural areas with abundant vegetation. The results of the UHI analysis indicated that temperatures in Hyderabad were generally higher than in the other areas on most days. The UHI effect was more pronounced during colder months and off-peak solar hours in urban areas. The hourly diurnal cycle of UHI demonstrated higher values during off-peak solar hours, while low or negative values were observed during peak solar hours in both winter and summer. To compare each area's cooling energy demand, Cooling Degree Days (CDDs) were determined. The findings suggested that UHI has been useful in reducing cooling energy demand, as UHI was higher during the winter and at nighttime. Among the different areas, TandoJam was found to be the best regarding thermal comfort and minimum cooling demand due to the presence of lush vegetation and agricultural areas. In conclusion, the annual cooling demand was high in both urban and rural areas, but it was significantly higher in urban areas due to the impact of the UHI effect.

5 Recommendations

In view of this work, we can shape strategy for execution of alleviation procedures to lessen UHI in metropolitan areas of Pakistan and from this we can accomplish the SDGs objectives for a worldwide temperature decrease. We can perform this research study in numerous areas of Pakistan so that we can check the additional power which is consumed due UHI and in therefore can establish energy policy framework in Pakistan. UHII of various urban cities in Pakistan can be measured to see intensities of UHI in those cities. The establishment of water ponds in cities or areas densely populated can greatly reduce the temperature of that area from 10C to 20C. Cost analysis of increased monthly and annual energy consumption due to UHI can be carried out. Correlation between UHI and energy consumption for other cities of Pakistan can be calculated using the study done in this paper.

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