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The Impact of Cities on Climate Change: A Literature Review on Urban Heat Island

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Abstract The world's population is increasing rapidly day by day, and this situation causes socio-economic and environmental problems in cities. Due to the increase in the population of cities, the demand for the building required to meet the need for shelter is also increasing. While the town develops due to population growth, unplanned construction causes environmental problems. The intensification of city construction and the increase in impervious surfaces due to the decrease in green areas increase the formation of urban heat islands, one of the microclimatic negativities. Urban heat island, which significantly impacts cities due to climate change and global warming, also negatively affects living life and environmental adaptation. In addition, air temperatures are increasing daily due to climate change and global warming, which increases energy consumption, especially during cooling periods. In areas where the urban heat island is dense, the cooling load increases even more due to the increase in temperature. Energy-efficient and carbon emission-minimising designs should be made in our buildings to prevent climate change and global warming. Green, porous surfaces should be increased on a large scale in urban areas. In this way, energy efficiency will be achieved at the building scale. This study is unique in that it draws attention to this issue by compiling the effects of urban heat islands on climate change and global warming issues and the studies carried out to reduce this effect. The study aims to compile the current studies on urban heat islands in the literature, reveal the missing parts of the subject and direct the researchers who will work on this subject in the future to these issues.

Keywords Urban Heat Island · Climate Change · Global Warming · Energy Efficiency · Sustainability.

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Introduction

Global warming and climate change make life challenging. It is known that higher temperatures are observed, especially in urban centers where construction is dense and human activities are high compared to rural areas. This is the urban heat island, which is a microclimatic phenomenon. It is one of the biggest challenges that make it difficult for living things to adapt to climate change and changing environmental conditions (Parker et al., 2004; Patz et al., 2005; Georgescu et al., 2014 and Sun et al., 2016; Ülker et al., 2018). The increase in the rate of heat-retaining surfaces such as concrete surfaces and asphalt floors in cities and the decrease in green areas accelerate urban heat island formation. In addition, factors such as waste heat arising from the energy used by people while living their lives and traffic mobility also affect the urban heat island (Das, 2022; Philipps et al., 2022). Increasing temperatures in urban areas make life in these areas challenging. For this reason, researchers are working to reduce the Urban Heat Island (UHI).

According to a study conducted in 2023, it was found that the population living in cities in the world constitutes approximately 55%. Considering the rapid increase in urbanization , it is estimated that this rate will be around 70% in 2050 (UNDESA, 2003). The reason for this is that education, job opportunities and quality of life are higher in cities than in rural areas. Population growth in cities brings along social and environmental problems. The increase of urbanization also affects the climate negatively. This makes urban areas an essential component of the world ecosystem (Parker, 2004; Lee et al., 2016; IPCC, 2022).

When we examine the formation of the urban heat island at the scale of the buildings in the city, the shaping and geometry of the buildings and the materials used on the surfaces of the buildings are affected. On the urban scale, the urban areas defined by these city buildings have insufficient green space and low air circulation. During the day, energy from the sun is stored on impervious surfaces such as concrete building surfaces and asphalt floors, which are emitted at night. This causes the air temperature to increase at night. In addition, the heat emitted in urban settlements and industrial activity areas where energy consumption is intense exacerbates this phenomenon. Carbon emissions also cause negative impacts on the climate (Hornsey et al., 2020). In 2022, as a result of the studies of the Intergovernmental Panel on Climate Change (IPCC), it was stated that the current greenhouse gases in the atmosphere will increase their effects until 2040 (IPCC, 2022). Climate change causes a decrease in the world's energy resources, deterioration of the natural physical environment and deforestation of cities (IPCC, 2022, Turkes, 2022).

With the urban heat island effect, temperatures in cities may rise further, increasing heat stress and health risks. As a result, cooling energy demand will increase in indoor areas, and energy use will increase to provide optimum comfort indoors. This results in greenhouse gas emissions that cause urban heat island formation. Green and permeable cities are essential to reduce the effects of urban heat islands. Green roofs are to be used in buildings, and afforestation of urban areas and creating permeable areas away from concrete surfaces can mitigate the urban heat island effect. In addition, the fact that architects consider the reflectivity and heat absorption rate of the roof material and the exterior surface material they choose during building design shows that they act more consciously against the urban heat island. In addition, sustainable urban design strategies should be adopted in the urban design process.

Within the scope of the study, a detailed review of urban heat island, which causes discomfort in cities due to global warming and climate change, has been carried out. Within the scope of the study, recent studies on the subject have been examined and the gaps in the literature on urban heat island have been obtained. The study is unique in guiding researchers who will work on urban heat islands.

Methodology

UHI is a factor that makes life in cities challenging. The study aims to review the current literature on coping with UHI in cities. For this purpose, the keywords 'Urban Heat Island', 'Sustainable Cities', 'Energy Efficiency', 'Climate Change' and 'Global Warming' were determined to search for previous studies in the literature. These keywords were searched in Google Scholar, ScienceDirect, Scopus and ResearchGate databases.

The articles obtained in the literature review were examined in detail. From the articles received, i) those unrelated to the determined keywords and ii) out-of-date studies were determined as out of scope and removed from the bibliography. The articles within the scope of the study were classified according to their subjects. The purpose, method and findings of the classified articles are briefly stated. In addition, the processes and tools used to achieve the aim of the studies were examined in detail. The advantages and disadvantages of the methods of the studies are discussed in detail. The aim here is to help researchers to develop strategies for future studies. Figure 1 shows the methodology used to achieve the research objective.

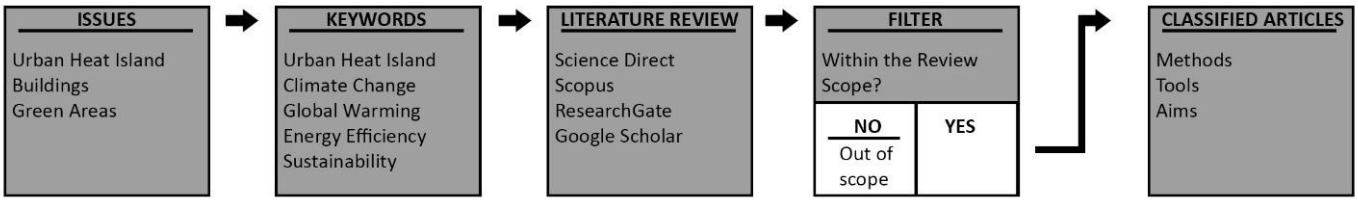

Figure 1. Work flow.

Urban Heat Island

Luke Howard brought to the agenda for the first time that cities are warmer than rural areas and Oke defined this situation as Urban Heat Island (UHI) (Oke, 1982). When the temperature in places is considered, the regions that are warmer than their surroundings are called 'Heat Island' (Voogt et al.,1997). The fact that there are more surfaces in urban areas compared to rural areas affects the temperatures. While the higher temperatures in urban areas compared to rural areas are defined as Urban Heat Island, in some cases, temperatures may be higher in rural areas due to reflections from surfaces. The condition of high temperatures in rural areas is called 'Negative Urban Heat Island' (Du et al., 2016).

Urban heat island is a microclimate phenomenon that causes higher temperatures than rural areas around urban centres during urbanization . The increase in impervious surfaces in urban areas, the decrease in green areas, CO_2 emissions due to energy consumption and the thermal properties of the materials used on building surfaces affect the urban heat island. Urban heat island has a series of negative consequences. The increase in energy demand and air pollution, as well as the negative impact on the health of urban users, are among the consequences of the urban heat island. Figure 2 shows the temperature in cities and rural areas graphically. The figure shows that the temperatures in the cities are higher (Liu, 2023). The image indicates that the temperatures are lower than in urban centres due to the lack of dense concrete surfaces in non-urban areas and that they are more livable places. Changes occur in urban and rural areas over time. Population growth leads to more construction in cities. This situation causes the UHI effect to increase (Landsberg, 1981). In the literature, some studies address parameters such as albedo, storey height, and thermal conductivity to reduce the UHI effect in urban areas (Voogt et. al, 2003). Table 1 compiles the current studies on urban heat islands in the literature. The table briefly lists the region where the studies were conducted, the latitude, the parameters analysed, and the systems studied. The table also mentions the objectives and results of the studies.

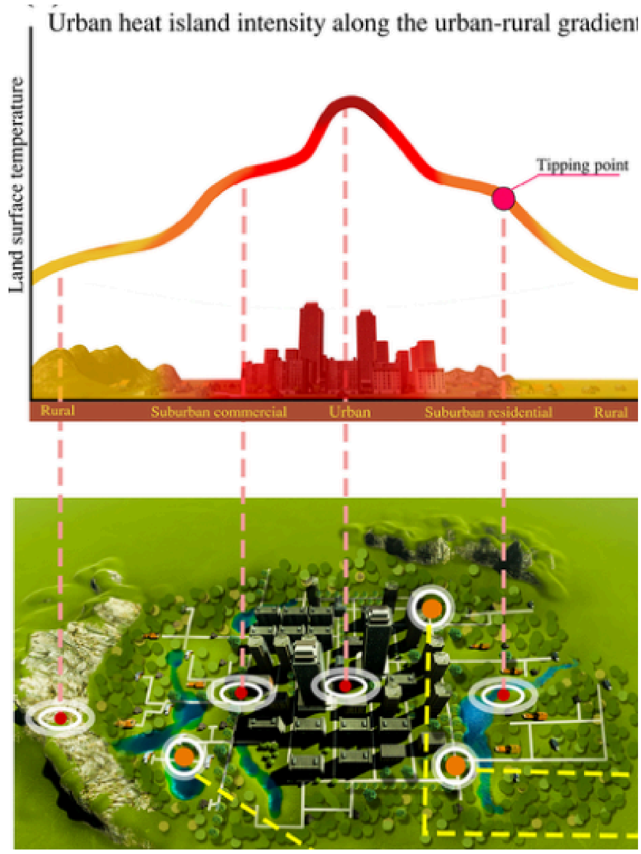

Figure 2. Comparison of temperatures in urban and rural areas (Liu, 2023).

Effects of Urban Planning on Urban Heat Island

Urban planning plays a critical role in the urban heat island effect. While dense development, increased impervious surfaces, and inadequate green infrastructure cause urban temperatures to rise relative to the surrounding environment, sustainable planning approaches can mitigate these effects. In particular, green roofs, vertical gardens, expanded park areas and permeable surfaces provide natural cooling by lowering surface temperatures. These precautions effectively reduce UHI as they reduce the reflective effect of surfaces. In addition, a balanced distribution of building density and energy-efficient designs both reduce anthropogenic heat emissions and provide more livable urban environments. In the literature, studies examine the effects of urban planning on urban heat islands. In 2015, Wang et al. studied the city of Toronto. The study investigates how different design alternatives for this city will affect the urban heat island effect. The study's simulation method was carried out through ENVI-met and CAD programmes. The results of the study showed that cold surfaces, green roofs and urban greenery are effective in reducing the urban heat island (Wang et al., 2015). In addition, there are also studies in the literature that aim to reduce urban heat islands by changing urban planning. Aflaki et al. In their 2017 study, they developed their studies on Kuala Lumpur, Singapore and Hong Kong in this direction. The study aimed to evaluate strategies for reducing the urban heat island in these three cities. The study primarily includes observations and problem identification in the city centre. It is determined that the biggest problem in the examined cities is the need for more green space. After the issues in the towns were identified, the simulation process was carried out. Urban greening strategies generally reduced UHI density directly and indirectly, decreased global air temperature by 4 °C and average radiant temperature by 4.5°C (Aflaki et al., 2017).

In Yildiz's 2019 study, the city of Erzurum was considered a field study. The aim of the study is to determine the effect of land use types on the urban heat island in Erzurum city centre. The study used remote sensing and data analysis methods to achieve the aim. Landsat 8, Erdas Imagine, and ArcGIS tools performed the study's data analysis. The study also aims to find a correlation between building surfaces and city green areas. The results of the study show that green areas reduce urban temperature values while building surfaces increase them. In addition, a negative correlation was found between Ground Surface Temperature (LST) and Normalised Difference Vegetation Index (NDVI), and a positive correlation was found between Normalised Difference Built-up Areas Index (NDBI) (Yildiz et al., 2019). Again, in 2019, there was a study addressing the urban heat island in another region of Turkey. The study conducted by Ersoy Tonyaloğlu in the Efeler and İncirliova districts of Aydın aimed to evaluate the effects of building density and vegetation cover changes on the urban heat island between 2005 and 2015 in the specified regions. Remote sensing and data analysis methods were used in this study. In the study, he made analyses using Landsat TM5, Landsat 8, and Copernicus CLMS maps. Between 2005 and 2015, he concluded that the increase in building density and decrease in vegetation cover caused a 3.19°C increase in ground surface temperature. A negative correlation was found between NDVI and LST and a positive correlation with Heat Island Density (IMD) (Ersoy Tonyaloglu, 2019).

Another study aiming to reduce the urban heat island by reducing densification in urban areas addressed the city of Vienna. In 2019, the survey prepared by Vuckovic aimed to reduce the urban heat island effect and improve outdoor conditions in Vienna using modelling and simulation methods. The results of the study showed that vertical development reduces temperatures and improves thermal comfort with increased shading during daytime hours while creating a slight warming effect at night. These findings suggest intelligent urban densification can be a sustainable model for reducing energy consumption and carbon emissions (Vuckovic et al., 2019). The field study conducted by Ünal in Adana in 2022 aimed to analyse the effects of urban land use on ground surface temperatures. The study adopted remote sensing and data analysis methods to achieve its goal. The study performed analyses with LANDSAT 8 OLI/TIRS satellite images. The results of the survey draw attention to the fact that temperatures are measured higher in the medium-dense urban structure in winter and highest in industrial and commercial units in summer. Surface Urban Heat Island (SUHI) intensity was found to be high on large impervious surfaces (Unal, 2022). In 2023, Saka, working in Yozgat city centre, aimed to determine the effects of the urban development process on the urban heat island. For this purpose, remote sensing and data analysis methods were used. Analyses were made using Landsat 8 satellite images. Between 2012 and 2022, it was concluded that the increase in building density and changes in the proportion of healthy plant surfaces caused an increase of approximately 1.18°C in surface temperatures (Saka et al., 2023).

Discussion on Frequency of Studies

In this study, current studies on urban heat islands were systematically searched in different databases. During the literature review, care was taken to ensure that the studies were conducted in the period from 2015 to the present. Figure 3 shows the classification of the analysed studies according to years. Most of the analysed studies belong to 2023. There is only 1 study from 2021.

The study detailed the methods and tools used by the studies in the literature to achieve their objectives. The primary purpose here is to facilitate the method selection of researchers working on urban heat island in future studies. In the range of 2015-2024, researchers mostly used the Landstad programme in simulations. Ladybug and Dragonfly, plug-ins of Grasshopper, are also popular. Grasshopper evaluates more alternatives in the optimisation process than its counterparts thanks to its parametric modelling. For this reason, Grasshopper plug-ins are primarily used in UHI studies today. SPSS was mainly used for statistical analyses. Figure 4 compiles the tools used in the studies.

Table 1. Literature review on UHI.

Year of Study	Region& Period	Latitude	Analysis/ Parameter	Examined system	Aim	Method	Aim	Method	Tool	Type of Examined Building	Main Findings & Results
2015 (Corumluoglu et al., 2015)	İzmir, Türkiye	38° (N)	UHI, Earth Surface Temperature	Urban Ecosystem and Regional Climate	Determine the impact of UHI on urban ecosystems and climate.	Thermal remote sensing, Landsat 8 TIRS data	Determine the impact of UHI on urban ecosystems and climate.	Thermal remote sensing, Landsat 8 TIRS data	Landsat 8 Satellite Images	Industrial Areas, Green Areas, Water Bodies	High surface temperatures were observed in industrial and densely populated areas, while low temperatures were observed in green areas and water bodies.
2015 (Nuruzzaman, 2015)	Rangpur, Bangladesh	250 (N)	UHI	Urban Heat Island	To investigate the causes and mitigation strategies of urban heat island effect.	Literature Review	To investigate the causes and mitigation strategies of urban heat island effect.	Literature Review	-	Urban Areas	The effects of the urban heat island have been widely studied, and it has been found that green areas and the use of high albedo materials are particularly effective in reducing the UHI.
2015 (Arifwidodo et al., 2015)	Bangkok, Thailand	130 (N)	UHI	Urban Heat Island and Weather Conditions	Determination of urban heat island characteristics and analysing their effects in Bangkok.	Remote Sensing, Data Analysis	Determination of urban heat island characteristics and analysing their effects in Bangkok.	Remote Sensing, Data Analysis	Weather Stations	Urban and Rural Areas	The maximum intensity in Bangkok was found to be 6-70C during the dry season. The UHI effect is most pronounced during the night and increases after sunset.
2015 (Wang et al., 2015)	Toronto, Canada	430 (N)	MRT, LST, TRP, PET	Urban Heat Island and Mitigation Strategies	To compare the effects of urban heat island mitigation strategies in Toronto.	Modelling Simulation	To compare the effects of urban heat island mitigation strategies in Toronto.	Modelling Simulation	ENVI-met, CAD Applications	Urban Areas	Cold surfaces, green roofs and urban greenery are effective in reducing the urban heat island.
2015 (Noro et al., 2015)	Padua, İtalya	45° (N)	UHI Average Radiant Temperature, SVF	Urban Heat Island	To assess the presence of the KIA phenomenon in Padua and to investigate the impact of mitigation strategies.	Simulation Experimental Measurements	To assess the presence of the KIA phenomenon in Padua and to investigate the impact of mitigation strategies.	Simulation Experimental Measurements	ENVImet	Urban and Rural Areas	It is concluded that the urban heat island effect reaches 6-7 °C even in medium-sized cities such as Padua. In the old city centre, narrow streets and impermeable surfaces are observed to increase the urban heat island effect.
2015 (Debbage et al., 2015)	Georgia, USA	330 (N)	UHI	Urban surface temperature, Urban morphology	To assess the extent to which urban restructuring affects UHI impact and mitigate UHI.	Remote sensing, PRISM climate data, spatial analyses	To assess the extent to which urban restructuring affects UHI impact and mitigate UHI.	Remote sensing, PRISM climate data, spatial analyses	PRISM, Landsat, ARCGIS		The spatial cohesion of cities was found to influence the intensity of UHI. A 10 per cent increase increased the annual mean temperature by 0.3 to 0.4 °C.
2015 (Ketterer et al., 2015)	Stuttgart, Germany	48°	Air Temperature, Physiological Equivalent Temperature (PET)	UHI	Determine UHI intensity for urban planning and develop adaptation recommendations.	Frequency analysis, multiple linear regression, microscale modelling	Determine UHI intensity for urban planning and develop adaptation recommendations.	Frequency analysis, multiple linear regression, microscale modelling	ENVI-met, Rayman, statistical analysis	Urban area, high building density	In combating heat stress, measures such as shading and greening can significantly reduce daytime temperatures.
		(N)									
2016 (Ward, et al., 2016).	Berlin, Germany	52° (N)	UHI	UHI Heat Wave Effects	To determine the effects of urban configuration on the formation of urban heat islands and their changes during heat waves in 70 European cities.	Statistical Analysis, GIS	To determine the effects of urban configuration on the formation of urban heat islands and their changes during heat waves in 70 European cities.	Statistical Analysis, GIS	MODIS Satellite Images, R Programming Language	Urban Areas	Urban green areas in the city increase the heat island density during heat waves, and cities with colder climates are more affected by heat waves.
2016 (Cocci Grifoni et al., 2016)	Ancona, Italy	43° (N)	SVF, PPD, PPM	UHI	Reducing UHI by multi-objective optimisation of urban morphology parameters.	Multi-objective Optimisation	Reducing UHI by multi-objective optimisation of urban morphology parameters.	Multi-objective Optimisation	modeFrontier GA	Urban Areas	It has shown that compactness and building-scale energy indicators are critical in designing comfortable cities. Local strategies to reduce the UHI impact are crucial.
2016 (Wang et al., 2016a)	Hong Kong, China	23° (N)	°C	UHI	Describe the behaviour of extreme UHI events and identify their trends over time.	Extreme Value Theory	Describe the behaviour of extreme UHI events and identify their trends over time.	Extreme Value Theory	HKO, TKL, TYW, WGL stations	Urban Areas	A significant increase in extreme UHI impacts is observed during the summer months. Extreme UHI impacts increase health risks due to night-time heat stress.

Year of Study	Region& Period	Latitude	Analysis/ Parameter	Examined system	Aim	Method	Aim	Method	Tool	Type of Examined Building	Main Findings & Results
2016 (Morini et al., 2016)	Terni, Italy	37° (N)	UHI	KIA mitigation strategies in Urban Areas	To investigate the effect of albedo increase on urban heat island reduction in the city of Terni.		To investigate the effect of albedo increase on urban heat island reduction in the city of Terni.		Weather Research and Forecasting (WRF) mesoscale model	Urban and industrial areas	Increasing the albedo of urban surfaces can reduce the KIA effect by up to 2°C. It has been observed that increasing albedo in industrial areas causes temperature decreases not only in these areas but also in the surrounding regions.
2016 (Wang et al., 2016b)	Montreal, Canada	45° (N)	Air Temperature, SVF, MRT	Relationship between street tree planting and UHI	Contribute to future guidance developments of UHI mitigation and urban vegetation systems design.	Modelling Simulation	Contribute to future guidance developments of UHI mitigation and urban vegetation systems design.	Modelling Simulation	ENVI-met	Urban Areas	Increasing tree canopy diameter reduces urban SVF and increases the environmental impact of dense tree planting. Furthermore, urban tree cover reduces the nocturnal UHI effect and the correlation between tree cover and urban air temperature is about 0.64 at midsummer night.
2017 (Canan, 2017)	Konya, Türkiye	370 (N)	0C	UHI and SVF relationship	Determining the UHI effect and SVF relationship based on urban geometry in Konya.	Data Analysis/ Modelling	Determining the UHI effect and SVF relationship based on urban geometry in Konya.	Data Analysis/ Modelling	Model, Townscope III, Fisheye Lens	Urban Areas	The UHI effect is higher in dense urban areas with low SVF. An inverse relationship was found between SVF and KIA effect.
2017 (Aflaki et al., 2017)	Kuala Lumpur, Singapore, Hong Kong	30 (N), 10 (N), 23° (N)	UHI, Environmental Temperature	UHI and Environmental Impacts	Evaluation of strategies for urban heat island mitigation in Kuala Lumpur, Singapore and Hong Kong.	Observation Simulation	Evaluation of strategies for urban heat island mitigation in Kuala Lumpur, Singapore and Hong Kong.	Observation Simulation	-	Urban Areas	Urban greening strategies have directly and indirectly reduced the UHI intensity, lowering the global air temperature by 40C and the mean radiant temperature by 4.50C.
2017 (Schroth et al., 2017)	Berlin, Germany	52°(N)	°C, SVF	Block Typology and UHI Relationship	To analyse environmental intensification approaches for Berlin from a climatic point of view.	Modelling Simulation	To analyse environmental intensification approaches for Berlin from a climatic point of view.	Modelling Simulation	ENVImet, Ladybug, DIVA	Urban Areas	The vertical densification approach provides living space and reduces summer temperatures without adversely affecting the urban microclimate. Trees and permeable surfaces are effective in reducing temperature differences and should be protected as urban density increases.
2018 (Livermore et al., 2017)	Manchester, United Kingdom	530 (N)	UHI, 0C	UHI	Identify the increasing density of urban heat islands in Manchester over time.	Statistical Modelling, Remote Sensing	Identify the increasing density of urban heat islands in Manchester over time.	Statistical Modelling, Remote Sensing	SPSS, Local Climate Data	Urban and Semi-Urban Areas	Urban heat island intensity increased by 0.0210C per year on average, which was associated with a decrease in local vegetation cover and an increase in building density.
2018 (Peres et al., 2018)	Rio de Janeiro, Brazil	22° (S)	LST, 0C	Relationship between UHI and LST	To examine the urban heat island effect in MARJ through the analysis of LST and land use patterns in the period between 1984-2015.	GIS, Statistical Analysis	To examine the urban heat island effect in MARJ through the analysis of LST and land use patterns in the period between 1984-2015.	GIS, Statistical Analysis	SPRING 4.3, Satellite Images	Urban Areas	This study shows that the LST was higher in the period 2000-2015 than in the period 1984-1999. The UHI intensity was 3.3 °C (5.1 °C) in 1984-1999 and 4.4 °C (7.1 °C) in 2000-2015.
2018 (Kim et al., 2018)	Houston, Texas, USA	29° (N)	UHI	UHI strategies	To analyse the effectiveness of urban heat island mitigation strategies in different climate zones, including the USA.	Modelling Simulation	To analyse the effectiveness of urban heat island mitigation strategies in different climate zones, including the USA.	Modelling Simulation	Rhinoceros Grasshopper, Dragonfly	Urban Areas	Urban heat island (UHI) intensity varies depending on climatic conditions, being higher in warmer climates compared to cooler climates.
2018 (Yin et al., 2018)	Wuhan, China	30° (N)	LST, SVF, FAR	UHI	To examine the impact of urban form on UHI impact and inform urban planning to reduce UHI impact.	Spatial regression modelling (SEM)	To examine the impact of urban form on UHI impact and inform urban planning to reduce UHI impact.	Spatial regression modelling (SEM)	Landsat 8 TIRS image, GIS basic data set	Urban Areas	Building density is critical in reducing the urban heat island (UHI) effect, while optimisation of building shape and street layout can reduce the surface temperature.
2018 (Deilami et al., 2018)	Brisbane, Australia	27° (N)	UHI	Spatial and temporal factors of the UHI effect	To systematically analyse the spatial and temporal	Literature review	To systematically analyse the spatial and temporal	Literature review	Landsat TM/ ETM, MODIS, ASTER	Urban Areas	Surface temperature (LST) was found to be related to UHI, especially vegetation cover, building density and seasonal variations were found to be effective on UHI; satellite imagery provides effective analysis.

Year of Study	Region& Period	Latitude	Analysis/ Parameter	Examined system	Aim	Method	Aim	Method	Tool	Type of Examined Building	Main Findings & Results
					factors that increase or decrease the UHI impact.		factors that increase or decrease the UHI impact.				
2018 (Santamouris et al., 2018)	Sydney, Australia	33° (S)	UHI	Urban Heat Island effects	To examine the effects of various reflective surface and green roof applications to reduce the urban heat island effect.	Modelling Simulation	To examine the effects of various reflective surface and green roof applications to reduce the urban heat island effect.	Modelling Simulation	ENVI-met, EnergyPlus	Urban Areas	Solutions that included increasing the overall albedo of the city provided the highest benefits, reducing the peak ambient temperature by up to 3°C and the peak cooling demand of residential buildings by up to 20%.
2018 (Kyriakodis et al., 2018)	Western Athens, Greece	37° (N)	Surface and ambient temperature	Impact of reflective asphalt road on urban heat island	To measure the effect of reflective asphalt in reducing UHI and improving thermal comfort	Monitoring, numerical simulation, comparative analyses	To measure the effect of reflective asphalt in reducing UHI and improving thermal comfort	Monitoring, numerical simulation, comparative analyses	ENVI-met, UV/vis/NIR spectrophotometer, thermal sensors	Urban Areas	The reflective asphalt reduced the ambient temperature by up to 1.5 °C and the surface temperature by up to 11.5 °C. Aging of the cooling asphalt reduces the reflective properties by up to 50%, reducing the UHI reduction potential.
2019 (Yildiz et al., 2019)	Erzurum, Türkiye	390 (N)	LST, NDVI, NDBI	UHI and Area Utilisation	To determine the effect of land use types on urban heat island in Erzurum city centre.	Remote Sensing, Data Analysis	To determine the effect of land use types on urban heat island in Erzurum city centre.	Remote Sensing, Data Analysis	Landsat 8, Erdas Imagine, ArcGIS	Urban and Rural Areas	It was found that green areas decreased urban temperature values while building surfaces increased them; a negative relationship was found between LST and NDVI, and a positive relationship was found between NDBI.
2019 (Ersoy Tonyaloglu, 2019)	Aydın, Türkiye	370 (N)	LST, NDVI, IMD	UHI and Building Density	To evaluate the effects of building density and vegetation cover changes on urban heat island in Efeler and İncirliova districts of Aydın province between 2005-2015.	Remote Sensing, Data Analysis	To evaluate the effects of building density and vegetation cover changes on urban heat island in Efeler and İncirliova districts of Aydın province between 2005-2015.	Remote Sensing, Data Analysis	Landsat TM5, Landsat 8, Copernicus CLMS maps	Urban Areas	Between 2005 and 2015, the increase in building density and decrease in vegetation cover caused a 3.19°C increase in ground surface temperature. Negative correlation was found between NDVI and LST and positive correlation was found with IMD.
2019 (Yue et al., 2019)	Hangzhou, China	30° (N)	UHI	Urban Restructuring and UHI Density	To examine the impact of urban configuration on urban heat island density in 36 megacities in China.	Statistical Analysis	To examine the impact of urban configuration on urban heat island density in 36 megacities in China.	Statistical Analysis	-	Urban Areas	Building density plays a determining role in the intensity of the urban heat island. The UHI effect is more pronounced in densely built-up areas.
2019 (Unal et al., 2019)	İstanbul, Türkiye	410 (N)	LST, UHI	UHI and Climate Impacts	To examine the urban heat island density in Istanbul and to analyse the effects of meteorological variables.	Meteorological Data Analysis	To examine the urban heat island density in Istanbul and to analyse the effects of meteorological variables.	Meteorological Data Analysis	Meteorological Station Data	Urban and Semi-Urban Areas	In Istanbul, the urban heat island reaches up to 80 0C during the day and 60 0C at night in the summer months, and the wind and its speed reduce the UHI intensity of the cloud cover.
2019 (Naserika et al., 2019)	Mashhad, Iran	360 (N)	LST, NDVI, NDBI	UHI	To study the temporal and spatial changes of urban heat island in Mashhad and to evaluate the relationships between LST and NDVI, NDBI.	Remote Sensing Simulation	To study the temporal and spatial changes of urban heat island in Mashhad and to evaluate the relationships between LST and NDVI, NDBI.	Remote Sensing Simulation	ENVI-met, ArcGIS	Urban Areas	In Mashhad, LST increased over the 30-year period, higher temperatures were observed in areas with high NDBI and low NDVI values, decreasing vegetation cover and increasing structural surfaces increase the severity of UHI.
2019 (Vuckovic et al., 2019)	Vienna, Austria	48° (N)	MRT, SVF	Urban Densification	To examine the potential of urban densification to reduce the heat island effect and improve outdoor conditions.	Modelleme ve Simülasyon	To examine the potential of urban densification to reduce the heat island effect and improve outdoor conditions.	Modelleme ve Simülasyon	Rhinoceros, Grasshopper, Ladybug Tools, EnergyPlus	Urban Areas	Vertical development reduced temperatures and improved thermal comfort through increased shading during daytime hours, while creating a slight warming effect during nighttime hours. These findings suggest that smart urban densification can be a sustainable model for reducing energy consumption and carbon emissions.

Year of Study	Region& Period	Latitude	Analysis/ Parameter	Examined system	Aim	Method	Aim	Method	Tool	Type of Examined Building	Main Findings & Results
2019 (Sakar et al., 2019)	Ankara, Türkiye	39° (N)	SVF, UHII	Urban Geometry and UHI Relationship	To propose a parametric model to mitigate the Urban Heat Island effect by analysing it on the basis of SVF.	Modelling Simulation	To propose a parametric model to mitigate the Urban Heat Island effect by analysing it on the basis of SVF.	Modelling Simulation	Rhinoceros, Grasshopper, Galapagos	Urban Regeneration Area	There is an inverse correlation between urban geometry and urban heat island effect. Areas with open sky views showed better thermal performance. Building height, spacing and dimensions are factors that directly affect the UHI.
2019 (Wu et al., 2019)	Dalian, China	38° (N)	LST, DEM, NDVI	UHI	To analyse the seasonal variation of urban heat island effect in coastal cities and to determine the causes of UHI.	Machine Learning, Remote Sensing	To analyse the seasonal variation of urban heat island effect in coastal cities and to determine the causes of UHI.	Machine Learning, Remote Sensing	Cubist Regression Tree Algorithm, Landsat 8 Satellite Images	Coastal Cities	The effect of UHI is observed only in spring and summer and is not significant in autumn and winter. Proximity to the sea and vegetation affected the UHI seasonally, while elevation and slope showed an inverse relationship with surface temperature. Population density was effective on UHI distribution in summer months.
2019 (Chakraborty et al, 2019)	New Haven, ABD	41° (N)	UHI	UHI	Characterisation of surface UHI intensity on a global scale and its influence on the spatio-temporal variability of vegetation cover.	Simplified Urban Area (SUE) algorithm	Characterisation of surface UHI intensity on a global scale and its influence on the spatio-temporal variability of vegetation cover.	Simplified Urban Area (SUE) algorithm	MODIS LST, LU/ LC verileri, Google Earth Engine	Urban and rural areas	It was found that the global average surface UHI intensity was 0.85 °C during the day and 0.55 °C at night, and that the night UHI was higher in arid climates and showed two peaks.
2019 (Kodikara et al., 2019)	Colombo, Sri Lanka	6° (S)	SVF, Impervious surface fraction, Permeable surface fraction	UHI	To develop a parametric model to analyse the urban heat island effect and determine the optimal geometric and surface cover values for outdoor thermal comfort.	Modelling Simulation Optimisation	To develop a parametric model to analyse the urban heat island effect and determine the optimal geometric and surface cover values for outdoor thermal comfort.	Modelling Simulation Optimisation	Rhino Grasshopper, Dragonfly, Ladybug, Colibri, Opposum	Urban Areas	A direct relationship was found between building height and UHI intensity, and high impervious land cover increases UHI. Increasing building heights and reducing impervious areas are recommended to reduce UHI.
2020 (Litardo et al., 2020)	Duran, Ecuador	2° (S)	UHII, SCR, WBH, FSR, TCR, VCR	Urban Microclimate	Determine the Urban Heat Island (UHI) intensity, assess the impact of buildings on energy consumption and propose mitigation strategies to reduce UHI.	Urban Morphology Parameters, Simulation	Determine the Urban Heat Island (UHI) intensity, assess the impact of buildings on energy consumption and propose mitigation strategies to reduce UHI.	Urban Morphology Parameters, Simulation	UWG, TRNSYS, ArcGIS,	Urban area in tropical humid climate	It was found that the city of Duran is significantly affected by the UHI effect from high anthropogenic heat emission and that the UHI increases energy consumption by 30-70% in residential buildings and 10-20% in commercial buildings.
2020 (Asadi et al., 2020)	Austin, Texas, ABD	30° (N)	LST, NDVI, NDBI, SVF	UHI	To investigate the mitigating effects of green roofs on UHI.	Simulation	To investigate the mitigating effects of green roofs on UHI.	Simulation	Artificial Neural Network, Landsat 8 OLI/ TIRS, Sentinel 2A, LiDAR data	Densely built-up urban area	By implementing a green roof strategy, reductions in surface temperature (LST) of up to 9.5 °C were achieved. By greening 3.2% of the total building roofs, the average LST decreased by 1.96 °C.
2020 (Hu et al., 2020)	Beijing, China	39° (N)	LST, NDBI, NDVI, GPI, SVF	UHI	To explore the changing effects of multidimensional urban morphology factors on UHI in different seasons.	Remote Sensing, Augmented regression tree (BRT) model	To explore the changing effects of multidimensional urban morphology factors on UHI in different seasons.	Remote Sensing, Augmented regression tree (BRT) model	Landsat 8 TIRS, Gaofen-2, ZY-3, BaiduMap	Urban Areas	The effects of 2D and 3D urban gauges on UHI were analysed. 3D indicators were found to affect surface temperature (LST) more. NDBI has the largest effect with 45.5% in spring and NDVI in other seasons. NDVI has a negative effect in spring and summer and a positive effect in autumn and winter.
2020 (Oro-peza Perez, 2020)	Mexico City, Mexico	19° (N)	Thermal absorption, Thermal transmittance, Convective heat transfer coefficient	UHI	To analyse the effect of UHI on indoor thermal comfort and to evaluate mitigation strategies.	Numerical Modelling, Simulation	To analyse the effect of UHI on indoor thermal comfort and to evaluate mitigation strategies.	Numerical Modelling, Simulation	EnergyPlus, Microsoft Excel	Urban Areas	Reflective materials, shade vegetation and urban canyons were proposed to reduce the UHI effect. Reflective materials were found to be the most effective method on internal temperature. When the three approaches were used together, an average internal temperature reduction of 5.1 K was achieved.
2020 (Li et al., 2020)	Berlin, Germany	52° (N)	UHI	Urban Canopy Layer	To quantify how urban heat island intensity	Modelling Simulation	To quantify how urban heat island intensity	Modelling Simulation	COSMO-CLM/ DCEP urban climate model	Hypothetical and realistic	Urban sprawl leads to a better thermal environment when we consider the whole urban area.

Year of Study	Region& Period	Latitude	Analysis/ Parameter	Examined system	Aim	Method	Aim	Method	Tool	Type of Examined Building	Main Findings & Results
					depends on urban form and density.		depends on urban form and density.			urban clusters	
2021 (Ghiasi et al., 2021)	Des Moines, Iowa, ABD	41° (N)	EPW, LST, kWh/ m²	UHI	Building density is critical in reducing the urban heat island (UHI) effect, while optimisation of building shape and street layout can reduce the surface temperature.	Sensitivity Analysis and Modelling	Building density is critical in reducing the urban heat island (UHI) effect, while optimisation of building shape and street layout can reduce the surface temperature.	Sensitivity Analysis and Modelling	Rhinoceros, Grasshopper, UMI, EnergyPlus	Urban housing quarter	UHI reduced annual heating loads by 7.5 per cent with trees and increased cooling loads by 21.2 per cent. UHI effects reduced annual heating loads by 8.5% in naturally ventilated buildings.
2022 (Unal, 2022)	Adana, Türkiye	370 (N)	LST, SUHII	UHI and Land Use	To analyse the effects of urban land use on ground surface temperatures in Adana city centre	Remote Sensing, Data Analysis	To analyse the effects of urban land use on ground surface temperatures in Adana city centre	Remote Sensing, Data Analysis	LANDSAT 8 OLI/TIRS Satellite Images	Urban Areas	Temperatures were measured to be highest in the medium dense urban structure in winter and highest in industrial and commercial units in summer. SUHI intensity was found to be high on large impervious surfaces.
2022 (Gunawardhana et al., 2022)	Port City Colombo, Sri Lanka	60 (N)	UHI, MRT, UTCI	UHI and Thermal Comfort	Analyse Urban Heat Island effects and outdoor thermal comfort in areas under development in Colombo Port City and develop mitigation strategies.	Simulation, Statistical Modelling	Analyse Urban Heat Island effects and outdoor thermal comfort in areas under development in Colombo Port City and develop mitigation strategies.	Simulation, Statistical Modelling	Rhino 3D, Grasshopper, Ladybug, Honeybee	City areas	The simulation studies focussed on identifying the potential for UHI mitigation steps for Colombo Port City. Outdoor thermal comfort was analysed using MRT and UTCI.
2022 (Lee et al., 2022)	Bundang and Pangyo New Towns, South Korea	37° (N)	Surface Urban Heat Island Intensity (SUHI)	Urban Planning and SUHI Relationship	To identify and compare changes in the distribution of SUHI in two cities with different urban planning.	GIS, Cellular Automata Markov Chain Model	To identify and compare changes in the distribution of SUHI in two cities with different urban planning.	GIS, Cellular Automata Markov Chain Model	Landsat Satellite Imagery, National Spatial Data Infrastructure (NSDI),	New cities	Higher building density in Bundang city made the SUHI effect more pronounced, while the higher prevalence of non-apartment dwellings in Pangyo city resulted in a lower SUHI effect. These results reveal the role of urban morphology on the SUHI effect.
2022 (Wang, 2022)	Arizona, USA	31° (N)	UHI	UHI	Reconceptualising the Urban Heat Island concept and overcoming the limitations on the urban-rural dichotomy.	Theoretical Review, Data Science	Reconceptualising the Urban Heat Island concept and overcoming the limitations on the urban-rural dichotomy.	Theoretical Review, Data Science	Machine Learning, Genetic Optimisation	Urban Areas	By considering the urban heat island in a broader context, the study allows us to develop innovative strategies for sustainable urban development. This approach can be effective in reducing UHI impacts and creating healthier urban environments.
2022, (Sismanidis et al., 2022)	Bochum, Germany	51° (N)	SUHII	Surface Urban Heat Island Density in Different Climate Zones	To investigate how the seasonal hysteresis of SUHII differs across climates and to provide a detailed typology of day and night SUHII hysteresis cycles.	Data analysis	To investigate how the seasonal hysteresis of SUHII differs across climates and to provide a detailed typology of day and night SUHII hysteresis cycles.	Data analysis	-	Urban Areas	The seasonal hysteresis of SUHII exhibits concave upward, downward, flat and triangle-like complex patterns depending on the climatic conditions and phenological differences of the rural environment. Moreover, it is important to consider the biome characteristics of each city in inter-city comparisons in order to understand the actual temporal and spatial dynamics of SUHII.
2022 (Koc et al., 2022)	Diyarbakır, Türkiye	37° (N)	UHI	Urban surface temperature, Wind corridors, Land use	To determine the temporal and spatial distribution of regions with urban heat island potential.	Remote sensing, Landsat 7 and 8 satellite data, LST (Land Surface Temperature) maps	To determine the temporal and spatial distribution of regions with urban heat island potential.	Remote sensing, Landsat 7 and 8 satellite data, LST (Land Surface Temperature) maps	Landsat TM 7, Landsat TM 8, Arc-GIS 10.2	Urban and environmental areas	It increases UHI potential areas by 14.6 per cent. Surface temperatures in urban areas are higher than in rural areas. UHI occurrences are largely related to urban densification, surface materials and closure of wind corridors, whereas increasing green areas plays a critical role in reducing UHI impacts.
2022, (Marando et al. 2022)	Ispra, Italy	45° (N)	C°, LST, Density of tree cover	Urban green infrastructure and UHI	To assess the role of urban green infrastructure in mitigating	Remote Sensing, Modelling	To assess the role of urban green infrastructure in mitigating	Remote Sensing, Modelling	Landsat 8, Google Earth Engine, Python Programming Language	Urban Areas	Urban green infrastructure reduces temperatures by 1.07 °C on average in European cities and by 2.9 °C in some cities. Furthermore, at least 16 per cent tree cover is required for a temperature reduction of 1 °C. Microclimate regulation ecosystem services depend on

Year of Study	Region& Period	Latitude	Analysis/ Parameter	Examined system	Aim	Method	Aim	Method	Tool	Type of Examined Building	Main Findings & Results
					the urban heat island effect.		the urban heat island effect.				the amount of vegetation cover and transpiration and canopy evaporation.
2022, (Oukawa et al., 2022)	Londrina, Brezilya	23° (S)	°C	UHI	Prediction and mitigation of UHI.	Multiple linear regression (MLR) and Random Forest (RF) models	Prediction and mitigation of UHI.	Multiple linear regression (MLR) and Random Forest (RF) models	-	Urban Areas	RF (Random Forest) models predicted daytime and nighttime air temperatures with R^2 values of more than 96%, whereas MLR (Multiple Linear Regression) models predicted daytime and nighttime air temperatures with lower R^2 values of 0.64 and 0.34, respectively. Meteorological variables and land cover were identified as the main predictors of air temperature.
2022, (Park et al., 2022)	Gwangjin-gu, Seul, Güney Kore	37° (N)	C°, m/sn, PMV	UHI	To investigate the effectiveness of different green roof plant species and cover ratios in reducing the urban heat island effect.	Modelling	To investigate the effectiveness of different green roof plant species and cover ratios in reducing the urban heat island effect.	Modelling	Rhinoceros, Grasshopper, ENVI-Met	Indoor, semi-outdoor and outdoor areas	The ratio of 70% grass to 30% trees in indoor areas and 50% shrubs to 50% trees in semi-open areas were found to be the most effective. These ratios reduce the UHI effect by improving thermal comfort.
2022, (Vásquez-Álvarez et al., 2022)	Cuenca, Ecuador	2° (S)	LST	UHI	To analyse the effects of replacing asphalt roads with concrete roads to reduce the urban heat island effect.	Simulation	To analyse the effects of replacing asphalt roads with concrete roads to reduce the urban heat island effect.	Simulation	ENVI-met		Replacing asphalt roads with concrete reduces the urban heat island (UHI) effect by reducing the surface temperature (LST) by 8°C and the average air temperature by 0.83°C. Concrete absorbs less heat with higher albedo and emissivity. Wind direction and speed play an important role in cooling surfaces. The height of buildings and the width of roads affect the degree of absorption of solar radiation.
2023, (Saka et al., 2023)	Yozgat, Türkiye	390 (N)	LST, NDVI	UHI and Surface Temperatures	To determine the effects of urban development process on urban heat island in Yozgat city centre.	Remote Sensing, Data Analysis	To determine the effects of urban development process on urban heat island in Yozgat city centre.	Remote Sensing, Data Analysis	Landsat 8 Satellite Images	Urban Areas	Between 2012 and 2022, changes in building density and the proportion of healthy vegetation surface resulted in an increase in surface temperatures of approximately 1.18°C.
2023, (Aksak et al., 2023)	İstanbul, Türkiye	410 (N)	LST, °C, m/sn	UHI Impacts and Climate Parameters	Investigation of urban heat island and climate parameters in Istanbul.	Time Series Analysis, Remote Sensing	Investigation of urban heat island and climate parameters in Istanbul.	Time Series Analysis, Remote Sensing	Landsat 8, Landsat TM 5 Satellite Images, Mann-Kendall Method	Urban, Semi-Urban, Rural Areas	Since the 1980s, an increasing trend in temperature has been observed in three different regions of Istanbul, while regional differences were found in precipitation and wind speed. A general increase in LST values was recorded in 1990, 2009 and 2021.
2023, (Bas et al., 2023)	Denizli, Türkiye	370 (N)	UHI	UHI and Climate Change	To analyse the effects of urban heat island at global level and the relationship between these effects and climate change.	Literature Review	To analyse the effects of urban heat island at global level and the relationship between these effects and climate change.	Literature Review	-	Various Urban Areas	The urban heat island effect causes temperature increases and decreases in the quality of life in cities; this situation poses a public health threat, especially for disadvantaged groups.
2023, (Liu et al., 2023)	Guiyang, China	260 (N)	UHI	UHI	To examine the effects of the Urban Heat Island, the factors affecting and mitigation methods.	Bibliometric Analysis	To examine the effects of the Urban Heat Island, the factors affecting and mitigation methods.	Bibliometric Analysis	Cite Space	Urban Areas	It was found that urban heat island research has increased since 2008, concentrated in various countries and in an interdisciplinary field, and identified new research trends.
2023, (Abdi et al., 2023)	Tabriz, Iran	38° (N)	UHI TDP, DP, WS	Relationship between UHI and Building Typologies	To determine the effect of urban form typologies on reducing UHI intensity.	Modelling Simulation	To determine the effect of urban form typologies on reducing UHI intensity.	Modelling Simulation	Rhino Grasshopper, Ladybug, Honeybee, Dragonfly, UWG	Urban and Rural Areas	It was concluded that the UHI intensity was highest in the Rectangle type on the hottest day and in the L type on the coldest day. The Cross typology was found to have the lowest UHI intensity in both cases. The results show that urban form is an important factor in energy consumption.
2023, (Ullah et al., 2023)	Tianjin, China	39° (N)	LUCC, LST, NDVI	UHI	To analyse the relationship between LUCC and UHI density in Tianjin city and predict the future trends	Google Earth Engine and CA-Markov modelling	To analyse the relationship between LUCC and UHI density in Tianjin city and predict the future trends	Google Earth Engine and CA-Markov modelling	Landsat görüntüleri, Google Earth Engine	Urban Areas	Urbanization has been found to increase the surface temperature (LST) and the increase in residential areas leads to a 1.5% increase in LST. The increase in vegetation cover is negatively correlated with changes in use and vegetation cover (LUCC), which has a cooling effect of about 1.40 °C in the city.

Year of Study	Region& Period	Latitude	Analysis/ Parameter	Examined system	Aim	Method	Aim	Method	Tool	Type of Examined Building	Main Findings & Results
					of LUCC and LST.		of LUCC and LST.				
2023, (Makvandi et al., 2023)	Wuhan, China	30° (N)	SVF, μBH, BD/ λp)	UHI	Mitigation of UHI, improvement of air quality, adaptation to climate change are targeted.	Observation, Field Study, Numerical Simulation	Mitigation of UHI, improvement of air quality, adaptation to climate change are targeted.	Observation, Field Study, Numerical Simulation	ArcMap, ANSYS Fluent CFD software	Urban Areas	Rapid urban development in Wuhan has increased the UHI impact in and around Jiangxia. In 1990, urban areas expanded by 489.3 km², while water surfaces decreased by 145.64 km². An increase in temperature and relative humidity was observed in Jiangxia.
2023, (You et al., 2023)	Shanghai,	31° (N)	UHI	UHI	To determine the characteristics of various forms of UHI in new cities, to investigate the land use function (LUF) planning strategies to improve the thermal environment of new cities.	Remote Sensing, Spatial Analysis	To determine the characteristics of various forms of UHI in new cities, to investigate the land use function (LUF) planning strategies to improve the thermal environment of new cities.	Remote Sensing, Spatial Analysis	Landsat-8 OLI/ TIRS data, Gaode Map POI data	Urban Areas	It is found that UHI effects are more common in new cities. It is observed that core type is dominant in suburban new cities, loop type in expanding new cities and bridge type in regional new cities.
	China										
2023, (Huang et al., 2023)	Kempten,	47° (N)	UHI	UHI	Develop UHI design criteria based on the risk of mortality caused by extreme temperatures.	Risk Calculation	Develop UHI design criteria based on the risk of mortality caused by extreme temperatures.	Risk Calculation	Urban Weather Generator (UWG), EPW, MATLAB	Low density residential area	The 50-year UHI intensity was calculated as 0.17°C, within the risk-based tolerance range (0.3°C-13.2°C). The low-density nature of the region keeps the UHI risk within limits.
	Germany										
2023, (Battista et al., 2023)	Rome,	41° (N)	C°	UHI	Reducing the urban heat island effect and lowering the temperature.	Numerical Modelling and Experimental Observation	Reducing the urban heat island effect and lowering the temperature.	Numerical Modelling and Experimental Observation	ENVI-met, meteorological data	Urban Square (dense settlement, low greenery)	The temperature was reduced to 2.5 C with grass parquet and high albedo materials. Grass parquet was found to be the most effective strategy.
	Italy										
2024, (Butuner et al, 2024)	Ankara, Türkiye	39° (N)	UHI, Impervious surface ratio, regional albedo change	Urban transformation area and UHI effect relationship	To explore the effects of urban regeneration on urban heat island.	Modelling, Analysis	To explore the effects of urban regeneration on urban heat island.	Modelling, Analysis	ENVI-Met, Rhinoceros, Grasshopper Ladybug	Urban Transformation Zone	Increasing impervious surface ratio, decreasing albedo and temperature increase at pedestrian level are found to increase the UHI effect. The study emphasises that urban regeneration projects in Turkey should incorporate climate-informed design strategies.
2024, (Unsal et al., 2024)	İstanbul, Türkiye	41° (N)	LST	UHI	To determine the effect of skyscrapers on surface urban heat island (SUHI) formation.	Remote Sensing, GIS	To determine the effect of skyscrapers on surface urban heat island (SUHI) formation.	Remote Sensing, GIS	ARCGIS, Landsat TM 5 (1990, 2009) Landsat 8 (OLI-TIRS) (2021)	Dense Urban Structure	While the surface temperature increase was measured as 2.7°C in areas with skyscrapers, this increase was 6.9°C in low-density residential areas and 10.1°C in unplanned developed areas. The decrease in vegetation and green areas, urban density, and building materials have a significant effect on the formation of SUHI.
2024, (Baykara, 2023)	İstanbul, Türkiye	41° (N)	°C	UHI	Evaluation of the UHI effect on the urban climate of Istanbul.	Data Analysis	Evaluation of the UHI effect on the urban climate of Istanbul.	Data Analysis	MGM Data, CORINE Land Cover Data Sets	Urban and Rural Areas	Night minimum temperatures in urban areas show a more significant increase compared to rural stations. In Istanbul, the UHI effect has increased over time with the expansion of urban areas towards rural areas. In addition, the spread of urban cover is in line with the observed meteorological data.
2024, (Attarhay Tehrani et al., 2024)	Tehran, Iran	35° (N)	UHI	UHI	Understand how different urban forms and structures contribute to UHI impacts.	Deep Learning algorithms (GRU, DNN and ANN)	Understand how different urban forms and structures contribute to UHI impacts.	Deep Learning algorithms (GRU, DNN and ANN)	Rhinoceros, Grasshopper, DragonFly Elk, OpenStreetMap, Urban Weather Generator (UWG)	Urban Areas	The GRU model showed a higher accuracy rate in predicting UHI based on urban morphological variables. The study shows that there is a negative correlation between green areas and urban heat island. Features such as building density, height and volume were identified as important factors that increase the urban heat island. SHAP values quantitatively show the magnitude of the effect of these variables on the urban heat island.

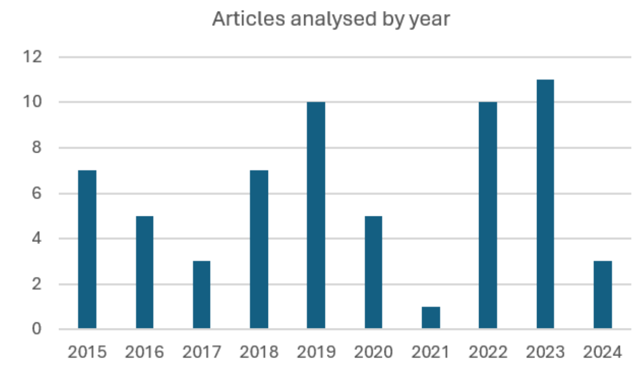

Figure 3. Classification of studies according to years.

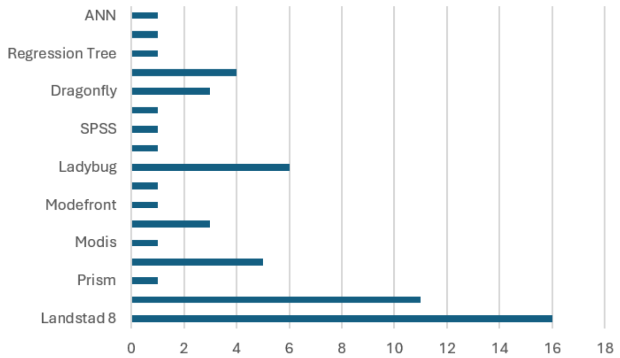

Figure 4. Tools used in the studies.

Figure 5 shows the hemispheres where the analysed studies were conducted. While 90% of the studies were conducted in the Northern Hemisphere, 10% were conducted in the Southern Hemisphere. Approximately 90 % of the world's population resides in the Northern Hemisphere (Northern Hemisphere, Wikipedia). For this reason, artificial surfaces formed due to urbanization are more prevalent in this hemisphere. In addition, the Industrial Revolution and its aftermath took place in the Northern Hemisphere, such as the USA, Europe and China. This situation increases energy consumption and greenhouse gas emissions. For this reason, UHI impact and studies are more prevalent in the Northern Hemisphere.

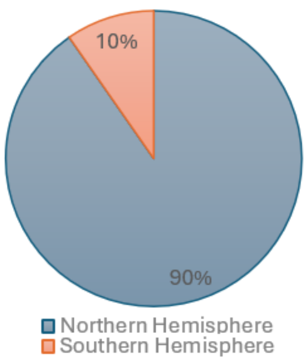

Figure 5. Hemispheres in which studies are carried out.

Conclusion

Global warming and climate change, one of the biggest problems of our age, cause the formation of the phenomenon called urban heat island. Due to the urban heat island, air temperatures in cities are constantly increasing. If this problem is not prevented, air temperatures will increase even more in the future, and the amount of energy required to provide optimum comfort conditions in building interiors will increase, especially during cooling periods. This paper deals with the effects of urban heat islands on climate change and global warming, the causes of this effect and strategies for its mitigation.

The literature draws attention to the increase in building density in urban areas, the widespread use of impermeable surfaces and the decrease in green areas, leading to heat accumulation and increasing the UHI effect. The UHI effect increases the energy consumption and carbon emissions required for building cooling. For this reason, urban planning gains importance. In the literature, it has been determined that air temperatures can be reduced with improvements in urban planning in regions with high population and building density, such as Kuala Lumpur, Singapore and Hong Kong. In addition, the literature has also found that vegetation cover in urban areas is essential in reducing the UHI effect. Studies have investigated the impact of urban planning, vegetation cover in urban areas and surface albedo values on UHI. The literature also states that the decrease in vegetation cover in urban areas will increase the temperatures in the city. Considering that air temperatures will increase in the future with the CC effect, it is essential to reduce the impact of UHI in studies to reduce temperatures in urban areas.

The literature states that local methods have a share in the urban planning phase as a priority for reducing UHI. Sustainability principles should be adopted in the urban design process. Local governments can use optimisation algorithms to minimise UHI in determining the number of storeys and designing green areas while creating zoning plans. On the other hand, users can use materials like green roofs and vertical garden applications to reduce heat accumulation at the building scale. When the literature is examined, recent studies investigating the UHI effect in Türkiye have focused on determining the current situation. In future studies, optimisation studies that minimise UHI can be carried out using future weather scenarios, especially in hot climate regions of Türkiye.

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