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Relevance of Urban Geometry and Outdoor Thermal Comfort in Urban Heat Island Mitigation – A Review

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Abstract: UHIs' environmental and energy implications are well-known, but their significance in aggravating heat stress in populations is only recently being recognised. Planners, health managers, and public administrators now prioritise UHI prevention. Urban geometry, material finishes, and green and blue infrastructure are prominent UHI mitigation options. This paper examines urban geometry as a key parameter and reviews UHI research. This report also identifies information gaps and emphasizes the need for this type of research in key Indian metropolitan centers. The anticipated study will help public health planners and administrators.

Methods: Authors compiled extensive literature on UHI and related concepts. The outcome intent was to understand the relevance of urban geometry parameters in UHI intensity and how it impacts outdoor thermal comfort. Various electronic databases were searched for publications meeting the criteria of outdoor thermal comfort and urban planning characters (urban geometry) as a mitigation strategy, ranging from 2000 to 2020.

Summary: The impact of UHI on human comfort conditions cannot be ignored. Appropriate planning measures at the initial stages of city planning via urban geometry parameters can certainly yield encouraging results to reduce the intensity of UHI and improve outdoor thermal comfort conditions.

Keywords: Urban heat island; Urban geometry; Outdoor thermal comfort; Heat stress.

Introduction

Changes to the natural environment and land use patterns brought on by rapid urbanization have an effect on our planet's climate. When the average temperature of an urban area is significantly higher than that of its rural or suburban neighbours, this typical process is known as an urban heat island (UHI), warm pockets or islands of higher temperature are created (Oke, 1981). With uncontrolled growth of population and high economic targets, the fast pace of urbanisation is paying no heed to the deterioration of ecology or falling standards of human comfort or health issues. Local air quality, heat stress, mortality, and energy usage may all be affected by an increase in urban heat islands as a result of global climate change (Corburn, 2009). Increased emissions of air pollutants and greenhouse gases, negative effects on human health and comfort, and degraded water quality are the major impacts of UHI in our cities (EPA, 2011).

Climate change implications include soaring summer temperatures which can become an environmental disaster in the form of heat waves. In urban areas, the severity of heat waves gets increased because the effect is exacerbated by UHI which may be fatal for the human population. Studies have confirmed that the intensity of heat waves and frequency will be on the rise in the near future globally (IPCC, 2014). Urbanisation's economic growth led to a rise in heat sensitivity during the summer (Li et al., 2020). In the Indian context, mean temperatures across the country have increased by more

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than 0.5°C over the last five decades, with observable and significant gains in heat waves. Already, climate change is altering India's terrain, and its effects are predicted to worsen in the decades to come (Sharma and Joshi, 2014). Findings suggest that even small increases in average temperatures can have significant effects on the number of deaths attributed to heat (Mazdiyasni et al., 2017). A study in IMD, Pune, calculated Heat Index HI for all surface meteorological stations for the past six decades (1951-2010). IMD, Pune conducted a study in which they determined the HI for all surface weather stations across a sixty-year time span (1951-2010). Conclusions from their study showed that heat-related public health issues may worsen in highly urbanised areas since practically all megacities showed substantial growing trends in Heat Index (HI) throughout summer and in monsoon season (Jaswal et al., 2017). A study in Delhi confirmed the rising surface temperature for the national capital and associated it with urbanisation (Shahfahad et al., 2021).

UHI has raised building energy use for cooling indoor environments and degraded outdoor environments, making people uncomfortable. This reduces outdoor activity, urban open space use, and car use. In India, outdoor spaces have a special social, economic and cultural context (Correa, 1996). As a result, climate-responsive urban planning can provide optimal, comfortable, thermal conditions for outdoor spaces while reducing air conditioning demand in buildings in a country with a majority of low- and middle-income inhabitants. Urban characteristics (size, population, topography) and urban planning aspects like urban geometry, built-up density are factors that are of paramount importance towards UHI impact (Jusuf et al., 2019). Urban form impacts the wind velocity to decrease, causing slow dissipation of heat and the heat energy fluxes in urban streets (Arnfield, 2003). A study in Istanbul using a regression model confirmed the role of urban geometry to manage surface temperatures (Maragno et al., 2020). More than 70% of SUHI creation may be attributable to the correlation between urban fabric measurements and LST patterns.

A multi city analysis done by Mohammad and Goswami, studied 150 Indian cities falling under various climatic zones in India. This study is a thorough examination of the SUHI phenomenon in Indian towns, taking into account the idea of the climatic zone and the greatest SUHI drivers that can exist (Mohammad and Goswami, 2021). This was the first study that has been investigated elsewhere but not in India. A review study by Kotharkar et al. (2018) presented that most UHI research in South Asia quantifies the phenomena without investigating its sources or impacts. Most publications fail to adequately describe their "urban" and "rural" observation points, making identifying a city's physical form exceedingly vague. This is found to be true for Indian cities as per a report by Lall et al. (2014). This analysis confirms that, in contrast to international studies, Indian research has mostly concentrated on UHI's effects on temperature and has only just begun to explore the relative efficiency of mitigation techniques like urban planning. The current paper plans to confirm this concern about Indian studies exploring UHI. Another objective is to explore the relevance of studying urban geometry and how it manipulates outdoor thermal comfort. This paper seeks to identify this gap by critically evaluating the prior work on UHI globally, methodically evaluating its practical consequences, and pointing the scientific community in the direction of areas that urgently require exploration. The authors of the study believe that better urban design alternatives for UHI mitigation can be achieved by the incorporation of UHI impact assessment into planning and design procedures but the need is to understand the relevance of urban geometry studies. Authorities in charge of planning and design will be able to utilise more of intensive studies on UHI and affecting parameters as a support and feedback tool to better understand the impact of their decisions on local climate.

Methods

The authors started with investigating research where the focus was urban planning to improve outdoor thermal comfort or mitigate UHI. An extensive review of the impact of key indicators of urban design and urban features on outdoor thermal comfort and the surface urban heat island is provided in this study. Search terms such as "UHI," "Outdoor thermal comfort," "pedestrian thermal comfort," "urban geometry," "urban form," "street geometry," and "street canyon" were used to scour Science Direct and Google Scholar for relevant articles. References addressing the relevance of urban geometry on UHI and UHI and outdoor thermal comfort, urban design recommendations to minimise thermal stress and UHI, or field measurements or simulation models to quantify thermal heat stress were screened. The paper selection time was unspecified. Furthermore, the authors listed Indian studies sharing their objectives and identified the research gap.

Inclusion Criteria for Studies

Types of Studies

Considering that this study's overarching goal was to reflect a research deficit and provide overviews of existing research, all sorts of empirical research designs, publication types, and time frames were considered. All years and publication types were considered for the same purpose. The review did not include any works that were not based on empirical evidence. These works included theoretical articles, opinion pieces, historical overviews, unsystematic reviews, and works that were not researched.

Types of Outcomes

The findings of the study needed to be useful to city officials and policymakers concerned with urban street canyons. The review covered both quantitative and qualitative findings. The study's intended or desired qualitative results were operationalised. If the literature studied only outdoor thermal comfort without references to street geometry, they were excluded from the selection.

Types of Study Areas

The study areas/population/climate had to be relevant for the field setting of India so that significant information can be summarised for example in the case of calculation of outdoor thermal comfort, residential neighbourhoods or street geometry was mapped.

Urban Planning as Mitigation Measure

Oke discovered that by dissipating heat, increasing wind speed in metropolitan areas can assist lessen the intensity of UHI (Oke, 1981). Oke later proposed that urban geometry and high-albedo surface materials are crucial for reducing the intensity of UHI (Voogt and Oke, 1998). Yamamoto highlighted mitigation strategies for various Japanese cities from the standpoint of urban planning, noting that the majority of these strategies are intermittent and do not provide long-term relief, such as water sprinkling and greening walls and rooftops (Yamamoto, 2005). In order to clearly explain the consequences of UHI, she used components like water, greenery, wind paths, and permeable walkways in regional planning as support for her claim. Similarly to this, Taslim conducted a study as part of an urban design strategy to reduce UHI in hot, dry cities (Taslim, 2015). The study, which was derived from studying a variety of literature, claims that vegetation, orientation, the material's reflectivity and conductivity, and the height of the buildings relative to the width of the nearby street are all crucial factors in reducing the intensity of UHI. A complete tool for execution strategy to make cities climate proof on an urban scale was created as a result of another study that examined the climate and spatial planning of numerous Dutch cities (Kleerekoper et al., 2012). The effects of UHI on cities, a study of urban and small scale mitigation options, and tools for stakeholders to analyse UHI were all outlined by Filho et al. (2017). According to their research, mitigation and adaptation plans that are created with consideration for the unique characteristics of each city can help make such cities more robust to UHI. In order to design thermally resilient cities we need to understand which components of urban morphology namely land use zones or open green spaces or socio economic parameters hold significance in manipulating temperature and in what order of significance. The research plans to understand this correlation, its causalities and processes so that effective urban planning concepts and effective mitigation planning can be designed. Lack of methodology to incorporate findings from such studies is the reason urban planners are not very active on UHI study fronts (Yoo, 2018).

Relevance of Urban Geometry and Outdoor Thermal Comfort

UHI reduces human thermal comfort, making UHI reduction studies important. Thus, urban design should incorporate any method to measure surface thermal behaviour on human comfort along with urban climate variables including temperature, relative humidity, wind patterns, and solar radiation. The sustainable urban design would prioritise the correlation between outdoor thermal comfort and microclimate factors like UHI to alleviate heat exhaustion. For the sake of health and a low-carbon economy, India needs to take steps toward reducing heat stress and creating outdoor thermal comfort. Here, roadways serve as meeting places and shopping areas. Urban forms create microclimates that affect pedestrian comfort. An urban street that provides thermal comfort to pedestrians reduces traffic loads, encourages walking, and helps identify urban elements that lessen UHI severity. All key features of urban street geometry may show how they affect microclimates. Heat reduction has many benefits since repeating street design becomes city geometry. Planners can use those factors to create thermally resilient cities. Heat-mitigating characteristics depend on location and climate. Thus, each city's heat mitigation and heat stress reduction standards will depend on its geography and climate. Table 1 summarises a few global studies where urban geometry and UHI were shown to be correlated. Building shape, orientation, construction materials, and vegetal mass water bodies can influence various environmental parameters (Manteghi, 2015). Comfortable outside minimises inside energy use. In a time when technology and social sciences are extending urban design, research on urban environmental challenges and design aspects is active (Ahmed, 2003)

Indian Studies on UHI

According to the detailed review, most research is on the capital city of New Delhi. 30% of the studies concern the Delhi heat island's development and impact. Bangalore is the second place where the UHI studies are concentrated more after Delhi. Table 2 lists the major cities that were taken up for the UHI study by researchers. Figure 1 presents the location of these cities in the map of India. The literature review also revealed that maximum studies were done using Satellite data (MODIS and LANDSAT) (Gupta 2012; Kumari et al., 2018; Shahfahad et al., 2020; Surawar et al., 2017). Further 70 % studies explored Land Surface Temperature (LST) while only 30% explored atmospheric temperature. Many studies still explored field measurement studies using weather station or Indian Meteorological Data (IMD) (Devadas and Rose, 2009; Kotharkar and Bagade, 2018; Mohan et al., 2012). With the latest trends and more advanced outputs through numerical modelling, the methodology of quantitatively modelling and analysing the genesis of urban heat islands is picking up in Indian studies. High-end computational resources and appropriate inputs are needed for this. The models are categorised as mesoscale and microscale models based on the spatial scale. Many studies in recent years have utilised these modelling systems to not only calculate UHI intensity but also explore various permutations of urban geometry parameters (Bhaskar and Mukherjee, 2017; Mukherjee and Sood, 2020).

Figure 1: On the map of India location of cities that are being studied for UHI.

Theoretical, observational, experimental, and numerical methods are the primary rationalisation of UHI study methodologies (Veena et al., 2020). The outcomes of UHI are analysed using statistical techniques. The spatial resolution of numerical models is superior to that of satellite data (Albdour and Baranyai, 2019). Due to their ability to reach higher spatial resolution than other numerical models, including mesoscale meteorological models and remote sensing data, CFD studies are currently becoming more and more popular on a global scale (Yuan et al., 2020).

Identified Research Gap

Though researchers have presented that pedestrian thermal comfort especially in peak summers and mortality have a strong correlation (Harlan et al., 2006), even then the total studies exploring elements of urban geometry and heat stress are not very encouraging. The majority of research work explores all but a few elements of canyon geometry to interrelate with outdoor thermal stress or UHI through numerical simulation models.

While the aspects of planning and building form to mitigate UHI and reduce heat stress have been widely explored by researchers globally to design thermally resilient cities, India is yet to explore the potential of this area fully. Maximum studies in India are limited to evaluating the intensity of UHI only on the basis of Local climate zones or remote sensing (Lall et al. 2014; Surawar et al., 2017).

The author could only locate a few studies which explored the elements of urban geometry to correlate with temperature or thermal comfort in Indian urban streets. To the authors best knowledge only a handful of studies researched the thermal behaviour of an urban canyon using infrared image sensors to study micro climatic variations of UHI. (Table 3). A study done in

Table 1: Global studies reviewing impact of urban street geometry characteristics on UHI and outdoor thermal comfort

Study area	*Focus of the study*	*Findings*	*Source*
Vancouver, Canada	Relation in nocturnal UHI & canyon geometry	UHI is proportional to city size. Urban geometry, sky view factor important elements to calculate UHI.	Oke (1981)
Malmo Sweden	Canyon geometry and street temperature affecting UHI	Street geometry is fundamental in generating land surface temperature (city center). Sky obstruction is most important geometric effect.	Bärring et al. (1985)
Global	Urban design morphology and thermal performance	Urban forms should be compact, dispersed, clustered as per climate zone. Air movement, temperature factor of street design, orientation and form of a city.	Golany (1996)
Goteborg, Sweden	Nocturnal temperatures, street geometry and land use.	Surface, air temperature patterns are different, street geometry had small influence on thermal performance. City parks and city center showed great variation in temperature.	Eliasson (1996)
Singapore	Surface temperature related to urban morphology	Weak relationship of air temp with urban morphology, strong for surface temperature.cooling effects from plants, grass are evident	Nichol (1996)
Atlanta, USA	Urban form and thermal Efficiency	More thermal energy is radiated from each parcel in a more sprawling style of urban residential development.	Stone and Rodgers (2001)
Morocco	The impact of city layout on thermal comfort in the open	In summers a deep canyon is comfortable while in winters a shallow is warm and preferable. Compact design forms with deep canyon is preferred	Johansson (2006)
USA Metropolitan regions	Urban forms and extreme heat events EHE	Rate of increase in Extreme Heat Events (EHE) is more visible in sprawling cities than in compact form cities. Increase in density, trees, green roofs can reduce vulnerability.	Stone and Rodgers (2001)
Tel Aviv Israel	Effect of built form and vegetation on UCL for residential streets, courtyards and woodland Passive cooling techniques.	Four built forms studied-colonaded, continuous, separated, and courtyard Simulation,field studies confirmed the negative relation between built forms and trees. Trees are more suitable than lawn area. Colonaded courts are more effective to bring down temperature than street houses.	Shashua-Bar et al. (2006)
Curitiba, Brazil	Impact of urban geometry (SVF, Orientation) on air quality and outdoor thermal comfort	Field measurements and simulations (ENVI,) helped confirm high SVF related positively with temp during summer time though results are reversed during low temp days. But High SVF supports ventilation and dispersal of pollutants.	Krüger et al. (2011)
São José do Rio Preto, Brazil (hot humid)	Impact of urban geometry (H/W) on nocturnal heat island as per Oke model	The field measurements corroborated well with oke model of simulations. High H/W ratio canyons presented the highest nocturnal Uhi intensity.	Nakata and de Souza (2013)

(*Contd.*)

Table 1: (Contd.)

Study area	*Focus of the study*	*Findings*	*Source*
Damascus, Syria (hot dry)	Urban planning for hot and dry climate	The aspect ratio and tree orientation of a street can have a significant impact on the comfort level of a building. Deep canyons should be preferred and urban guidelines be revised according to permit narrow streets and tall buildings.	Yahia and Johansson (2013)
Brazil, Sao Paulo	Nocturnal heat island intensity and urban geometry	Urban geometry influences nocturnal UHI	Salata et al. (2017)
Global	Literature review on studies on urban geometry and outdoor thermal comfort	Urban green and urban geometry most promising to improve pedestrian thermal comfort. Important to study geog features and urban conrext of city before formulating UD guidelines.	Jamei et al. (2016)
Global	Literature review on studies of urban design to mitigate UHI and achieve OTC	It confirms the necessity of conducting UD research to achieve climatic resilience. It confirms that impact of UD on thermal environment is dependent on time, season, local climate and urban context.	Lin et al. (2017)
Seoul, Korea	Thermal imaging camera to study urban streets	Detailed investigation on urban geometry to study impact of land use, building use, materials and vegetation.Shading best way to mitigate UHI	S. Lee et al. (2018)
Greece	Microclimate design for open space,for pedestrian thermal comfort. Simulation studies used	Surface materials, urban geometry, vegetation,water elements shape micro climates and influence pedestrian thermal comfort.	Chatzidimitriou and Yannas (2016)
Shiraz, Iran	Urban morphology landscape structure affect surface temperature	Low LST is common in developed, compact areas with lots of gardens and few roads. LST was also decreased in locations with a variety of housing densities.	Azhdari, Soltani, and Alidadi (2018)
Egypt (hot and arid)	Urban planning guidelines for plazas and streets as per SVF, aspect ratio	Aspect ratios in the 2to4 range and SVFs as low as 0.2 are optimal for N-S-oriented streets in a grid like urban setting. For E-W canyons, an aspect ratio of 2-3 is ideal, and an SVF of 0.3-0.5 is optimal.	Ghanem (2019)
Malacca, coastal city, Malaysia	Influence of street geometry and water body on urban micro climate	Field study to explore proximity to water body, temperature, humidity, orientation, wind speed, aspect ratio, axis affecting UHI	Golnoosh Manteghi (2016)
	Editorial: “Urban Heat Island (UHI) and its Mitigation through Urban Planning, Design, and Landscaping”	A dedicated issue sharing various studies on similar theme.	Jusuf et al. (2019)

Jinju, Korea	Examining the Impact of Street Shades on Passengers' Temperature Comfort Along an East-West Corridor	The most efficient way to provide outdoor thermal comfort for pedestrians in sidewalk is to shade the pavement, road, and building surfaces.	N. Lee (2018)
Eilat, Israel Adelaide, Australia Singapore Göteborg, Sweden	Heat stress in urban street canyons and the role of high-albedo materials	While using high-albedo materials in canyon surfaces can reduce air temperature, this benefit is not sufficient to compensate for the additional radiative loads that result.	Erell et al. (2014)
Hong kong	Differences in urban albedo and street surface temperature as a result of variations in building density and building height.	Simulation study confirmed the role of surface material albedo on surface temperature.	Yang and Li (2015)
Dhaka	Acceptable level of outdoor thermal comfort in tropical urban settings environments.	Outdoor comfort based on field investigations conducted. Compact built up is more heat stressed.	Ahmed (2003)
Frieberg, Germany	Dependence of outdoor thermal comfort on street design in hot and dry climate	The unshaded zones of streets cause more thermal stress on human body.	Toudert (2005)
European/North American cities	Street Design and microclimate	H/W ratio is directly associated with UHI . urban geometry and microclimate of streets have a direct relationship.	Oke (1988)
Negev, Israel	Urban canyons in arid regions: a microclimate study	An energy-balance model describing pedestrian-street canyon thermal exchanges is merged with empirical data from extensive full-scale observations in several low-rise urban street canyons in the arid Negev region of Israel.	Pearlmutter, Bitan, and Berliner (1999)
American cities	Albedo , Evapotranspiration , and Anthropogenic Heat affecting UHI	Changes in surface albedo and vegetation cover have been shown to effectively modify the near-surface climate .	Taha (1997)
Malacca,	Influence of Street axis and proximity to water.	Wind direction, speed, and street orientation seem to affect cooling. The riverside region cooled by about 3-4° C during the hottest days.	Gonoosh Manteghi (2015)
Guangzhou, China	Impact of urban morphology heterogeneity on LST.	Density affected LST more than height.	Guo et al. (2016)

Table 2: Indian studies reviewing UHI intensity

Study area	*Focus of the study*	*Methods*	*Issues*	*Findings*	*Authors/Source*
New Delhi	Study of winter temperature trends	Mobile surveys for months(dec-march) using psychometers	Urban heat island in winter months	4-7°C of heat island intensity, maximum at congested old Delhi	Bahl and Padmanabhamurty (1979)
Delhi	Study of land surface temperture using RS	LANDSAT 7 ETM+	Variation of LST with LULC	LST is strongly correlated with NDVI	Javed Mallick and Bharath (2008)
Delhi NCR	Study of temperature trends in Delhi region	diurnal temperature trends with in situ measurements for summer month (30 sites)	UHI intensity across Delhi over various land use land cover sites.	Increased daytime, nighttime temperature in commercial areas, due to land use pattern and Anthopogenic heat	Mohan, Kandya, and Battiprolu (2011)
New Delhi	Summertime UHI and impact of aerosols	Remote sensing, LST	Temperature variation between core and surrounding parts of Delhi	Sharp variation in temp, from 4 to 7°C in April to 7 to 10°C in May June	Pandey et al. (2012)
Mumbai, Delhi	UHI analysis between Delhi and Mumbai	Thermal mapping using LANDSAT	LULC changes	Intensity of UHI In Mumbai is high than Delhi	Grover and Singh (2015)
Pune	Structure of heat and moisture islands	Mobile survey for 170 locations in the city	Influence of topography morphological variation on temperature	High UHI intensity at night	City and Deosthali (2000)
Bangalore	Urban growth and UHI	Remote sensing and and in situ data	Built up using green and blue infrastructure	Increase in impervious surfaces and major reduction in green and blue cover	Ramachandra and Kumar (2010)
Bangalore	Urban planning characters to mitigate UHI	Field Measurement and thermal mapping	Role of vegetation, urban geometry and water body	High H W ratio, high density, increased heat in street canyon result in high UHI intensity at night	TERI (2017)
Guwahati	Summertime UHI in urban and suburban pockets	Fixed weather stations and mobile measurement	Urban sprawl	Comparable day, night time UHI temperature found.	Borbora and Das (2014)

Chennai	Role of built geometry	Temperature and relative humidity, site measurements	Role of urban density	UHI Intensity high in winter than summers	Horrison and Amirtham (2016)
Vishakapatnam	UHI intensities and impacts on city	Field surveys, LST	Topography and urban geometry	Interseason variation in UHI	Devi (2006)
Jaipur	Spatiotemporal variation in UHI	Satellite data and GIS	LULC variation	13.12% of the city has moderate UHI potential and 0.97 percent has high potential.	R. Gupta (2012)
Bhopal	UHI and air quality	LANDSAT 5	More builtup and reducing green area	Due to pollution and gas emissions, Old City has high UHI.	A. Gupta, Dey, and Goel (2009)
Nagpur	UHI assessment	LANDSAT 7,ETM+,	Variation of LST with LULC,decrease in pervious surfaces	Increase in building density causes decrease in vegetation cover, and increase in LST.	Surawar, Meenal; Kotharkar (2017)
Mumbai	Assessment of Urban Heat Island (1990-2018)	LANDSAT, NDVI, NDBI	Study on increasing LST trends	Increase in builtup area and reduction in vegetative land areas	Shahfahad et al. (2021)
Chandigarh	Assessment of changes in hotspots of UHI during summer and winter months	LANDSAT, DBI, EBBL, DL, BA	Study of spatiotemporal variation in UHI	Changes in LULC are directly related to hotspot areas. DL impacts UHI more than BA	Sultana and Satyanarayana (2020)
150 Indian cities (various climate)	Assessing Diurnal and seasonal variation in UHI in various climatic zones of India	MODIS LST	Variation of LST as per climate and diurnal variation	Vegetation and ET affect SUHI during the day, while BI, surface albedo, and nocturnal lighting affect SUHI at night.	Mohammad and Goswami (2021)

Table 3: Indian studies reviewing role of urban street geometry characteristics on UHI and outdoor thermal comfort

Study	*Parameters studied*	*Methods/Observation*	*Reference*
Microclimatic study in urban canyons of Tiruchirapalli, Tamil Nadu	Canyon axis, aspect ratio, sky view factor to evaluate PE T. Simple comparative study.	PET With Rayman pro, field measurements. Result aspect ratio more than 2 needs minimum intervention, tree selection also important.	Kannamma and Sundaram (2015)
Urban planning character to mitigate UHI Bangalore, Karnataka	Temperature, orientation, green cover%, H/W,vertical or surface finish, type of vegetation and temperature , humidity	Field data, thermal imaging (resi/comm.)Result- proximity to green, tree shading, aspect ratio more than 2, and low density helps achieve less UHI	TERI (2017)
Optimizing street canyon orientation for Rajarghat new town, Kolkata	Canyon orientation impact on wind,air temp and mean radiant temperature and PET-	Numerical model to study axis orientation using ENVI met . result- 30 -60° N performs best to reduce outdoor thermal stress in that particular city.	Bhaskar and Mukherjee (2017)
Built form and outdoor urban thermal comfort, Chennai metropolitan area	SVF , H/W, vegetation, builtup density, PET in 6 residential neighbourhoods.	Field data (data loggers) and simulation for PET using Rayman. The built-up area reduced PET values, improving daytime comfort. Nighttime comfort decreased as built-up area rose PET levels.	Rose et al. (2011)

Bangalore, a mega city with a moderate climate, explored characteristics of urban planning including elements of canyon geometry like H/W, vegetation and material to measure the temperature variation in residential and commercial typologies through field experimentation (TERI, 2017). While this study recorded the thermal signatures at street level to interpret urban geometry for six different sites, the study did not explore the thermal variations if any present along the whole street length of monitoring sites. Another study in the Newtown area in Kolkata used numerical model ENVI met to study the patterns of change in orientation on street canyons (Bhaskar and Mukherjee, 2017). The study emphasised on the axis orientation criteria only and correlated it with outdoor thermal stress pattern and did not explore the interactions of urban elements. (Horrison and Amirtham (2016) stimulated the air temperature data and humidity level for nine different locations in T Nagar, Chennai using Rayman Pro to analyze the SVF sky view factor and H/W to ascertain thermal comfort. But the study did not consider variation in building typologies or surface character of streets which are important parameters to ascertain outdoor thermal comfort. Kannamma and Sundaram (2015) recorded the microclimatic stress, measured by PET in the urban canyons of the city of Tiruchirapalli in Tamil Nadu through numerical simulations of various scenarios of H/W and aspect ratio. While the study concluded that PET is an effective thermal index to study thermal stress it only covered three parameters of urban geometry to simulate PET.

As observed, the Indian cities presenting the numerical or field data for urban geometry belong to the southern part of India where the climate is tropical barring Bangalore which has a composite climate. Northern Indian states exhibiting temperate climates cannot benefit much from these cities since the local and micro climatic conditions vary majorly. Every urban area has its own pre requisites to be explored to reach a condition of thermal comfort. As Harari explained in his book, "*Cities in bad shape* : *Urban geometry in India"*, "*The observed spatial structure of a city at a given point in time is the result of the interaction of exogenous factors, such as geography, and factors endogenous to population, such as the city's growth rate and urban policy*" (Harari, 2015).

The authors propose a need for more studies that will present the thermal behaviour of urban elements like H/W, vegetation, building use type, land use type, surface materials, road finish and axis orientation and the role they play in an urban canyon heat generation.

Results

Following a comprehensive assessment of studies from around the world that investigated urban geometry as an important parameter, we have resolved many significant issues. Sky view factor and aspect ratio most promising factors of street geometry to reduce temperature variations followed by Street Axis, Built up density, vegetation and water body proximity. Studies done with field observations and simulation experiments. Rayman and ENVI- met most utilised simulation software. Field Experiment periods were long study periods ranging from 3 years to single day field observation. Only 17% of studies explored urban geometry patterns as per different typologies of landuse types, most studies were done in residential neighbourhoods (62.5%). Nocturnal UHI was also a studied phenomenon (20%) while most observed diurnal changes in UHI. The study area's geographic location and regional climate were discovered to have an impact on each parameter's ability to lessen the intensity of UHI. This is extremely critical for deciding the preferred orientation for the layout of the street axis depending on the requirements of sun/shade in the streets.75% of studies explored indices of outdoor thermal comfort and only 12.5 % defined the heat stress index for street canyons. PET is the most utilized scale for outdoor thermal comfort. Pedestrian greening brings maximum comfort to outdoor thermal conditions through shading and the process of evapotranspiration (62.5% studies). Only 12.5% of studies concluded albedo of surface materials is an important criterion to influence urban street energy balance. The study areas taken, are mostly from developed (72%) countries. Indian studies especially of hot and humid climates were missing from urban geometry and UHI studies. Globally studies understanding and assessing the impact of urban geometry on outdoor thermal comfort and UHI have given very relevant conclusions that can be adapted by urban planners and designers to improve the thermal quality of the cities manifold. It's high time Indian studies also deliberate on it because the country is seeing the highest ever growth rate.

Conclusion

Citywide urban planning relies heavily on the study of urban geometry, which can also serve as the basis for the creation of neighbourhood ordinances. As a result, rehabilitation and new construction will benefit from a climate-aware urban design that has been prepared. The current review confirmed that few research works in India have examined the connection between UHI and urban geometry at the block level, despite the fact that many studies elsewhere can draw connections between the importance of urban geometry for UHI advances. If this knowledge gap can be closed, it will be much easier for cities to create urban design rules that take climate change into account. Such studies can help major cities rethink their building codes and urban planning strategies to reduce the negative effects of UHI on residents' outdoor comfort. It will also guarantee the purposeful and well-structured installation of green infrastructure in the city's most at-risk areas.

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