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Building Heat Elements Influencing Ground Surface Temperature in Urban Environment: A Systematic Literature Review on Recent Evidence

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Abstract

Urban area worldwide is experiencing increased temperatures due to the heat generated by buildings and other anthropogenic activities, intensifying the urban heat island (UHI) effect. Notwithstanding numerous research, a methodical knowledge of how building heat elements specifically influence ground surface temperature (GST), energy consumption, and outdoor thermal comfort (OTC) remains limited. Hence, this study systematically reviews recent literature on building heat elements that affect urban thermal environments. Guided by the Reporting Standards for Systematic Evidence Synthesis (ROSES) and the PICo framework, a rigorous methodological approach was employed comprising systematic database searches (Scopus, Web of Science, Science Direct, Emerald, Springer Link), thorough screening processes, quality assessment using the Mixed-Method Appraisal Tool (MMAT), data extraction, and thematic analysis utilizing NVivo software. The analysis revealed three key themes: microclimate, building characteristics, and urban attributes, which were further divided into 17 sub-themes. The findings emphasize critical factors, including high-albedo materials, optimal building designs and urban green spaces, as significant determinants of GST variations and urban thermal performance.

Keywords: *Systematic literature review, building heat element, ground surface temperature, urban heat island, ROSES protocol.*

Introduction

The urban heat island (UHI) is a significant issue in the 21st century due to the urbanisation and industrialisation of human civilisation (Rizwan et al., 2008). Urban heat islands are a phenomenon when the temperature in an urban region rises relative to the surrounding area. Numerous factors, including a rise in land use, unsustainable construction structures, and human activity that raises carbon dioxide emissions, can contribute to this problem (Ramly et al., 2024). A lot of research has been done on UHI phenomena using land surface temperature (LST) and outdoor air temperature (OAT) (Hong, T., & Heo, Y., 2023). The rising temperatures in urban climates lead to an increase in energy consumption within buildings by altering their heating and cooling requirements. Conversely, the anthropogenic heat emissions generated by buildings can further exacerbate urban warming, thereby establishing a feedback loop that intensifies the heat within these areas (Wang et al., 2022). The primary standard for building energy efficiency and design in Malaysia includes thermal comfort, with a minimum dry bulb temperature of 22°C and recommended indoor temperatures for comfort between 23°C and 26° (MS 1525: 2007). To fulfill the standard requirements, mechanical ventilation and air conditioning system might need for some premises indirectly increase energy consumption and heat emission to the environment (Salamanca, 2014). Researchers have recently become interested in the phenomenon of urban heat islands, or UHIs (Jabbar et al., 2023). When there are many studies on urban heat islands that add to the body of knowledge, researchers can benefit from a thriving pile of research from various angles while remaining in line with the field of study. However, there are also several research gaps that can be identified, and researchers may benefit by contributing to the body of knowledge and one of the ways to find the research gap is by having a systematic literature review (Bangdiwala, 2024).

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Lot of studies focus on the effect and factor contributing UHI, but less focus given to the building elements as one of the biggest factors in rising the outdoor temperature in urban area. A systematic literature review (SLR) may be necessary to fill the knowledge gap regarding the ways in which building elements impact outdoor temperatures and contribute to the urban heat island phenomenon. Research conducted by Nazarian et al., (2019) on promoting the concept of "Outdoor Thermal Comfort Autonomy," evaluates how well outdoor areas perform in terms of thermal comfort and not looking into the relationship with building components and elements that contribute as part of outdoor heat source. Meanwhile (Jabbar et al., 2023) in their research focus on several contributing factors and effects on UHIs by having data of intensity from land usage, human activities which may produce heat from buildings, energy consumed, transportation, urban activities and industrial processes but lacking in the building components and elements as one of the important sources in contributing to rising outdoor temperatures in urban areas. Building materials also play important roles in UHIs effect by having the right materials will influence the rate of energy absorbs and released to the environment as been discussed by Tabatabaei, S. S., & Fayaz, R. (2023) where the mean radiant temperature is higher for materials with high albedo and lower for materials with low emissivity and high thermal mass. Yet the materials mainly focused on the building façade and structure but still there are lot other building elements that contribute a lot in the UHI phenomenon such as the external unit of air conditioner, exhaust fans, backlit signage and more. It is important to have an SLR to dig deeper and focused into the defined building elements that may contribute to the urban heat island rather than traditional literature review where all factors contribute to UHI be covered in general.

Methodology

This SLR is guided by the Reporting Standards for Systematic Evidence Syntheses (ROSES) protocol that aims to enhance the robustness and transparency of systematic reviews, particularly those concerning environmental management. This is relevant as the review explores the intersection of building heat elements with urban environmental conditions—a core focus within environmental studies. The adaptability of ROSES to diverse research scenarios makes it particularly suited for this review, which delves into the multifaceted impacts of building design and urban planning on outdoor temperature, energy consumption, and thermal comfort. The methodological framework provided by ROSES supports a comprehensive and replicable synthesis of research, accommodating the heterogeneity inherent in urban studies and sustainability research. Guided by the principles of ROSES, the review process commenced with the formulation of research questions using the PICo framework; 'P' for Population or Problem, 'I' for Interest, and 'Co' for Context. These questions aim to dissect how various building heat elements affect urban microclimates and energy dynamics. Following establishing research questions, a detailed document search strategy was designed, encompassing three systematic phases: identification, screening, and eligibility. This structured approach ensures that all relevant studies are captured and assessed for their quality and relevance to the research questions. A quality appraisal was conducted using criteria adapted from Hong et al. (2018), ensuring that only studies of high methodological quality were included in the review. The selected articles underwent meticulous data extraction and analysis stages. Data extraction was directly aligned with the primary research questions, ensuring that all relevant data points were captured for analysis. A thematic synthesis approach was employed for data analysis, enabling the identification of key themes and sub-themes related to the impact of building heat elements on urban environments.

Formulation of the research question

In formulating the research question, the PICo framework was used to assist authors in developing suitable research questions for the review, which are based on three main concepts: Population or Problem, Interest, and Context (Lockwood et al., 2015). Based on these concepts, the authors included three main aspects of the review: building heat elements as the problem, the influence of building heat elements on outdoor temperature and thermal comfort as the interest, and the urban environment as the context. These considerations led to the formulation of the main research question; “How do building heat elements influence GST in urban environments?”

Systematic Searching Strategies

Shaffril et al. (2018) proposed that three systematic phases are involved in the search strategies: identification, screening, and eligibility. These three main phases were applied to gather relevant articles from various databases. This structured approach facilitated the authors' comprehensively locating and synthesizing the studies, ensuring the SLR was well-organized and transparent (Shaffril et al., 2021).

Identification

Based on the formulated research questions, the authors selected three main keywords: “building heat,” “ground surface temperature,” and “urban environment.” To expand this keyword list, the authors employed several strategies to enrich the search terms using an online thesaurus, such as thesaurus.com. Additional keywords were also derived from previous studies and consultations with subject matter experts in the fields of urban planning and environmental engineering. As a result of this comprehensive process, several related keywords were added to enhance the search, including urban heat island, building heat sources, environmental impact, thermal, and GST. These keywords were then combined using advanced search functions such as field code functions, phrase searching, wildcards, truncation, and Boolean operators. The searches were conducted in two major academic databases, Scopus and Web of Science, ensuring a broad and thorough exploration of the literature, as shown in Table 1. In addition, the searching process included a manual searching technique called' handpicking' used in databases like Science Direct, Emerald, and Springer Link Journals. These databases were selected for their comprehensive coverage of environmental science, urban planning, and construction technology, thereby ensuring the inclusion of high-impact peer-reviewed literature in the analysis. Building heat significantly impacts indoor and surrounding temperatures, influencing microclimate and urban environments. This impact results from various factors, including heat generated from the buildings, the thermal properties of building materials, and the interaction between buildings and external environmental conditions, which reduce Outdoor Thermal Comfort (OTC). Thus, it is worth noting that this study specifically addresses outdoor environmental temperatures and thermal comfort. From our comprehensive search across various databases, 264 potential journal articles were identified from the selected databases.

Table 1: Search String used in the selected database

Database	String
Scopus	TITLE-ABS-KEY (("building heat" OR "building heat elemen*" OR "building heat sourc*" OR "anthropogenic heat") AND ("ground surface temperature" OR "land surface temperature" OR "urban temperature") AND ("urban environment" OR "urban heat island" OR "urban area"))
Web of Science	TS=(("building heat" OR "building heat elemen*" OR "building heat sourc*" OR "anthropogenic heat") AND ("ground surface temperature" OR "land surface temperature" OR "urban temperature" OR "outdoor temperature") AND ("urban environment" OR "urban heat island" OR "urban area"))

Screening

As the authors dealt with many available articles, the following process was screening, where articles were either included or excluded from the study based on specific criteria. Kraus et al. (2020) highlight that the SLR process can be tailored to various research aims depending on the maturity of the research field. Applying this concept, this review specifically focused on articles published between 2021 and 2024. This timeline was selected to ensure that the review reflected the most current research developments, considering that recent publications provided a sufficient body of work for a representative analysis. The screening was limited to empirical research papers as these provide primary data. Moreover, only articles published in English were included to avoid confusion. As this study's objectives centered on building and environmental sciences, the review targeted studies within specific subject areas related to environmental and urban planning impacts on thermal comfort and energy consumption. This process excluded 164 articles as they did not fit the inclusion criteria, and 100 articles remained for evaluation in the following process.

Table 2: Inclusion and exclusion criteria

Criterion	Inclusion	Exclusion
Timeline	Between 2020 and 2024	2019 and earlier
Literature type	Articles	Review article, chapter in book, book, conference proceeding, etc
Language	English	Non-English
Subject area	Environmental science, social sciences, engineering, building and construction technology, urban and	Purely Medical or Biological Sciences and non-technical social science

	regional planning, sustainable architecture	

Eligibility

According to Shaffril et al. (2021), in this eligibility process, the authors were required to manually monitor the retrieved articles to ensure all the remaining articles aligned with the established inclusion criteria by reading the title, abstract, or the entire paper. During the title screening stage, 40 articles were excluded, and 26 articles were removed during the abstract screening stage. The authors excluded another nine articles after the content reading of the selected articles. The process excluded 74 articles as they did not focus on the impacts of building heat elements on GST. They were conducted in non-Asia Pacific Countries, focused on review data, and published as a chapter in the book. Finally, only 22 articles were selected for the quality appraisal stage.

Quality Appraisal

In this process, all selected articles underwent a quality appraisal to minimise bias and ensure the quality and integrity of the articles (Shaffril et al., 2020; Hadday et al., 2018). All authors individually reviewed the quality by reading all articles and then discussing the quality. For this purpose, the Mixed-Method Appraisal Tool (MMAT) by Hong et al. (2018) was used to ensure that the methodology and analysis of the selected studies were completed satisfactorily. According to Hong et al. (2018), this method enables researchers to appraise a systematic mixed studies review. It covers five studies: qualitative research, randomised controlled trials, non-randomised studies, quantitative descriptive studies, and mixed methods studies. The appraisal starts with two initial screening processes to verify the research questions' clarity and the collected data's adequacy to address the research questions. The selected articles were then assessed based on five main criteria established in the research design, as shown in Table 1, with three options provided from 'Yes,' 'No,' and 'Do not know/comment.' A 'Yes' response indicates confidence that the article fulfilled the criterion, 'No' indicates that the article did not fulfill the criterion, and 'Do not know/comment' was selected when there was uncertainty over the articles' adherence to the criterion. All decisions on the assessment were based on mutual agreement, and any disagreement was quickly discussed among the authors. Based on this process, the authors agreed that 14 articles fulfilled all criteria, and eight articles fulfilled at least four criteria, making all the articles deemed eligible for inclusion in the review.

Table 3: Quality assessment tools, scales and checklist for assessing quality of diverse research designs in a review

Research design	**Methodological quality criteria**
Screening questions	Are there clear research questions?
	Do the collected data allow to address the research questions?
Qualitative	Is the qualitative approach appropriate to answer the research question?
	Are the qualitative data collection methods adequate to address the research question?
	Are the findings adequately derived from the data?
	Is the interpretation of results sufficiently substantiated by data?
	Is there coherence between qualitative data sources, collection, analysis and interpretation?
Quantitative (descriptive)	Is the sampling strategy relevant to address the research question?
	Is the sample representative of the target population?
	Are the measurements appropriate?
	Is the risk of nonresponse bias low?
	Is the statistical analysis appropriate to answer the research question?
Quantitative (non-randomised)	Are the participants representative of the target population?
	Are measurements appropriate regarding both the outcome and intervention (or exposure)?
	Are there complete outcome data?
	Are the confounders accounted for in the design and analysis?
	During the study period, is the intervention administered (or exposure occurred) as intended?

Mixed methods	Is there an adequate rationale for using a mixed methods design to address the research question?
	Are the different components of the study effectively integrated to answer the research question?
	Are the outputs of the integration of qualitative and quantitative components adequately interpreted?
	Are divergences and inconsistencies between quantitative and qualitative results adequately addressed?
	Do the different components of the study adhere to the quality criteria of each tradition of the methods involved?

Source:

Table 4: Results of the quality appraisal

Articles	**Research Design**	**QA1**	**QA2**	**QA3**	**QA4**	**QA5**	**Number of criteria fulfilled**	**Inclusion in the review**
Li et al. (2020)	QT (DC)	/	/	/	X	/	4/5	/
Firozjaei et al. (2020)	QT (DC)	/	/	/	C	/	4/5	/
Tepanosyan et al. (2021)	QT (DC)	C	/	/	/	/	4/5	/
Nath et al. (2021)								
Yuan et al. (2021)	QT (DC)	/	/	/	/	/	5/5	/
Chen et al. (2021)	QT (DC)	/	/	/	/	/	5/5	/
Lu et al. (2021)	QT (DC)	/	/	/	/	/	5/5	/
Li et al. (2021)	QT (DC)	/	/	/	/	/	5/5	/
Yang et al. (2021)	QT (DC)	/	/	/	X	/	4/5	/
Liu et al. (2022)	QT (DC)	/	/	X	/	/	4/5	/
Zhou et al. (2022)	QT (DC)	/	/	/	/	/	5/5	/
Yu et al. (2022)	QT (DC)	/	/	/	/	/	5/5	/
Hu et al. (2022)	MM	/	C	/	/	/	4/5	/
Kim et al. (2022)	QT (DC)	/	/	/	/	/	5/5	/
Vahmani et al. (2022)	QT (DC)	/	/	/	X	/	4/5	/
Kamath et al. (2023)	MM	/	/	/	/	/	5/5	/
Hong & Heo (2023)	QT (DC)	/	/	/	/	/	5/5	/
Patel & Kaushik, (2023)(S. Patel et al., 2024)	QT (DC)	/	/	/	/	/	5/5	/
Zhou et al. (2024)	MM	/	/	/	X	/	4/5	/
Liou et al. (2024)	QT (DC)	C	/	/	/	/	4/5	/
Lin et al. (2024)	QT (DC)	/	/	/	/	/	5/5	/
Patriota et al. (2024)	QT (DC)	/	/	/	/	/	5/5	/
Wang et al. (2024)	QT (DC)	/	/	/	/	/	5/5	/

Notes: QA = Quality assessment; QT (DC) = Quantitative descriptive; MM = Mixed-method; C = Comment

Data Extraction and Analyses

Integrating data from mixed modes, qualitative and quantitative studies offers a broader range of perspectives, views, and solutions (Hong et al., 2018). This study adopted a qualitative synthesis technique for all selected articles.Thus, the extracted data must be in qualitative descriptions. The primary objective of the extraction process was to identify empirical data concerning building heat elements impacting GST in urban areas. The authors focused on four sections of each article: abstract, results, discussion, and conclusion. Data identified in other sections of articles were also extracted if deemed pertinent to the review. Once the extraction process was completed, the data was analysed. Since qualitative synthesis was the primary analysis method, thematic analysis was adopted, as

Flemming et al. (2019) suggested, due to its flexibility in analysing data from diverse research designs. Thematic analysis aims to identify and notify the pattern of existing studies by detecting any similarities or relationships between the extracted data (Braun and Clarke, 2019). This study used Nvivo Pro 14 software to analyse the qualitative data. This process resulted in three groups, each representing a central theme: urban attributes, building characteristics, and microclimates. The process further involved identifying similarities and relationships between the data for each theme, resulting in 17 sub-themes. All the main themes and sub-themes were systematically re-examined to determine the suitability and relevancy of the themes to the research question. The validity and reliability of the themes were further reinforced through experts' validation. The experts agreed that all the themes and sub-themes demonstrate that the building heat elements influenced the GST.

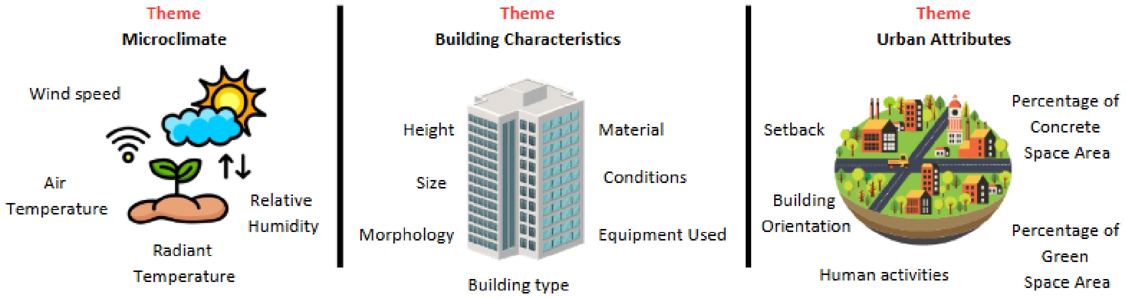

Figure 1: Infographic on the developed themes

Results and Discussion

Background of selected articles

This study SLR was based on 22 selected articles. Most studies adopted quantitative methods, and three utilised mixed methods research designs. Regarding publication date, three studies were published in 2020; five were published in 2021; seven were published in 2022, two in 2023, and the remaining four were published in 2024. Most of the studies were conducted in Asian countries. Twelve were undertaken in China, three in Korea, and one in Taiwan. Additionally, four studies were conducted in the USA, one in the UK, and one with a global focus. This underscores a significant emphasis on research in urban settings across different geographical regions.

Themes and Sub-themes

This section reviews the main themes of microclimate, building characteristics, and urban attributes. These themes include critical factors that affect urban thermal environments. The microclimate theme examines environmental parameters directly impacting the urban thermal landscape, such as wind speed, air temperature, radiant temperature, and relative humidity. The variables are crucial for comprehending the dynamic interaction between urban surfaces and atmospheric conditions. As for building characteristics, the theme emphasizes the significance of physical and structural features of buildings in urban heat dynamics. Key sub-themes include building height, building size, building morphology, building materials, building conditions, building type, and the equipment used in the building. These characteristics are significant determinants of heat retention, energy consumption, and microclimatic modification within urban environments. The urban attributes theme highlights urban planning and design elements influencing thermal variation. This theme includes building setbacks, building orientation, human activities around the building, percentage of concrete space area, and percentage of green space area. The factors affecting the UHI effect are essential for developing strategies to mitigate urban heat and enhance thermal comfort. This study integrates three themes to provide a holistic framework for analysing and addressing the factors contributing to UHI phenomena.

Building Characteristic

Buildings can significantly alter the thermal dynamics of their surroundings through various parameters such as building height (Zhou et al., 2024; Vahmani et al., 2022; Li et al., 2020; Lu, Yue & Huang, 2021; Chen et al., 2021; Nath. Et al., 2021; Yu et al., 2022; Li et al., 2021; Hong & Hoe, 2023; Patriota et al., 2024; Hu et al., 2022; Lin et al., 2024; Yuan et al., 2024; Liou et al., 2024; Tepanosyan et al., 2021; Firozjaei et al., 2020; Kim et al., 2022; Wu et al., 2023; Patel & Kaushik., 2023; Kamath et al., 2023; Wang et al., 2024; Liu et al., 2022; Yang et al., 2021), size (Lu, Yue & Huang, 2021; Nath et al., 2021; Yuan et al., 2021; Patel & Kaushik., 2023; Kamath et al., 2023; Wang et al., 2024, Liu er al., 2022; Yang et al., 2021), material properties (Zhou et al., 2024; Vahmani et al., 2022; Li et al., 2020; Hong & Hoe, 2023; Wu et al., 2023; Patel & Kaushik, 2023; Wang et al., 2024), building shape and design (Zhou et al., 2024; Vahmani et al., 2022; Li et al., 2020; Lu, Yue & Huang, 2021; Chen et al., 2021; Yu et al., 2022; Li et al., 2021; Patriota et al., 2024; Hu et al., 2022; Tepanosyan et al., 2021; Firozjaei et al., 2020; Kim et al., 2022; Wu et al., 2023; Kamath et al., 2023; Wang et al., 2024; Liu et al., 2022; Yang et al., 2021), conditions (Vahmani et al., 2022; Li et al., 2021; Patel & Kaushik., 2023; Liu et al., 2022), equipment used in the building (Zhou et al., 2024; Lu, Yue & Huang, 2021; Chen et al., 2021; Nath et al., 2021; Li et al., 2021; Kim et al., 2022; Wang et al., 2024) and type of building (Zhou et al., 2024; Li et al., 2020; Dos Satos et al., 2020; Hong & Hoe, 2023; Wu et al., 2023; Wang et al., 2024). Modifying local microclimates and GST due to building characteristics are mainly attributed to UHI effects.

Research indicates that building height substantially influences local thermal environments via various mechanisms, including shading, alteration of wind flow, and heat retention within an urban canyon. Increasing building height creates a shading effect that reduces daytime GST by limiting direct solar radiation exposed at ground level, thereby reducing GST (Hong & Heo, 2023). A study conducted in Tokyo and Jakarta by Kamath et al. (2023) found that high-rise buildings lower GST in the morning, indicating that shading effects play a cooling role during peak sunlight hours. Moreover, building height up to a threshold of 66m led to notable cooling effects due to the reduction of direct sunlight on the ground and increased shadowing effects (Patel & Kaushik., 2023; Szatmári et al., 2022). Additionally, the alteration of wind flow around high-rise buildings might create turbulence, improving the local thermal environment (Hong & Heo, 2023). However, this effect varies based on the building density, where high-rise building in dense urban areas creates deep urban canyons that trap heat, resulting in localised warming at night (Shih et al., 2020) compared to medium-rise buildings provide balance shading, reducing excessive solar heating while allowing airflow for cooling (Szatmári et al., 2022). This indicates that the building height alone does not increase GST; rather, the arrangement and interaction with adjacent structures, such as urban density, wind circulation, shading effects, and material selection, influence their thermal effects.

Another causal relationship with GST is building size, where the difference in the size of the building contributes to GST variations through solar exposure, wind flow pattern, and thermal mass effects. For example, larger buildings typically present expansive impervious surfaces that can absorb more solar radiation, leading to elevated surface temperature. Research by Nath et al., 2021 found that buildings with larger floor areas in high-density urban areas can exacerbate the UHI effect by trapping heat during the day, leading to night-time warming. Nevertheless, in a study conducted by Han (2023), the floor area of a building had relatively little effect on the urban GST variation compared to building height, where the result shows that the building Floor Area Ratio (FAR) contributed less than 5% to GST variation. This is particularly evident in urban areas where even larger floor areas may have a greater total heat–absorbing surface, as most of this area is shaded by nearby structures. Consequently, it highly depends on the materials used on the building and urban surfaces. Similarly, building morphology, such as shape and design, as this parameter affects the microclimatic variables (Patel & Kaushik, 2023). The relationship between building morphology and microclimate directly affects energy consumption as it influences building thermal load. Yang et al. (2021) found that cylinder-shaped buildings in mild weather regions have the best thermal performance when the window-to-envelop area is higher than 20%. The performance results from improved airflow over curved surfaces, which reduces heat accumulation while maintaining a stable internal temperature, reducing the need for an excessive air conditioning system, thereby reducing energy consumption and greenhouse gas emissions.

Beyond building size, shape, height, and design, the material used on the building's façade, rooftop, and surrounding surface is another parameter that influences GST. He and Reith (2023) and Zaki et al. (2020) highlighted that using dark materials in buildings and hard pavements causes an increase in heat absorption, thereby contributing to high urban temperature. Conversely, high-albedo materials can reduce heat absorption, potentially decreasing the UHI effect (Hong & Heo, 2023). Moreover, materials with high thermal mass, such as concrete and brick, store heat for extended periods, causing increased night-time GST in urban areas (Li et al., 2022), whereas lightweight materials like glass and insulated cladding disperse heat quickly, contributing to faster cooling and lower GST. A study conducted by Zeeshan and Ali (2022) found that replacing conventional materials with cool materials significantly reduced heat in urban microclimates, highlighting the efficacy of reflective surfaces in lowering ambient temperature. These findings suggest that selecting building materials is a key determinant of GST variations, affecting urban thermal comfort, energy efficiency, and sustainability.

Physical conditions reflect how new and older buildings modify GST through material properties, structural integrity, and thermal performance variations. Technically, new buildings are designed using modern construction techniques with energy-efficient materials that can control solar radiation and retain less heat, thus reducing GST (Patel & Kaushik, 2023). Contrast with older buildings, which are characterized by deteriorated surfaces, faded coatings, and cracked walls that may lead to air leakage, moisture infiltration, and heat loss, reducing energy efficiency and thermal comfort. Research indicates that aging structures with deteriorated materials and inadequate insulation can increase local GST by 4 – 5˚C relative to newly constructed or well-maintained buildings (Vahmani et al., 2022). Besides, the equipment used in the building, including Heating, Ventilation, and Air Conditioning (HVAC) systems, heat pumps, and industrial machinery, has a close relationship with GST variation. This equipment contributes significantly to anthropogenic heat release, directly affecting the surrounding microclimate and potentially leading to increased GST (Nath et al., 2021; Kim et al., 2022). For example, HVAC causes the temperature in office areas of Tokyo to rise by 1 – 2˚C or more (Ohashi et al., 2007), while in Singapore, 26% of the residential regions have a temperature rise of 0.4 – 1˚C (Yuan et al., 2020).

In addition, Zhou et al. (2024) found that HVAC outdoor units markedly affect heat accumulation, particularly at the windward position, where maximum heat retention is observed. The study also indicated that middle floors experience a 2. 3˚C higher outdoor temperature than upper floors due to restricted airflow and heat retention, which results in energy consumption of 6.3W/m2 . Moreover, the building use type further contributes to GST variations, as different functions dictate heat generation, energy consumption, and thermal interactions with the surrounding environment. For example, office buildings with artificial lighting and reflective glass facades exhibit GST fluctuations of 2 – 4˚C, intensifying night-time heat retention (Patel & Kaushik, 2023). Similarly, industrial buildings often operate machinery and equipment that emit a large amount of heat, thus raising the surrounding surface temperature (Tepanosyan et al., 2021). This finding reinforces the causal link between building physical condition, equipment usage, and building function in influencing GST.

Urban Attributes

The ongoing economic and social development has led to an increase in urban buildings, and human activities have modified the urban land surface characteristics, resulting in negative impacts on the urban microclimate. The urban attributes are closely related to human thermal comfort, where existing studies have proved that natural parameters, including air temperature, humidity, wind speed, solar radiation, and ground temperature, are very sensitive to any three-dimensional changes in an urban setting (Yang et al., 2021). These meteorological parameters are directly affected by urban morphology and surface materials. In addition, other urban attributes elements such as building setbacks (Yu et al., 2022; Hong & Hoe, 2023; Patel et al., 2022; Lin et al., 2024; Firozjaei et al., 2020; Yang et al., 2021; Liou et al., 2024), human activities around buildings (Vahmani et al., 2022; Nath et al., 2021; Hong & Hoe, 2023; Patriota et al., 2024; Lin et al., 2024; Firozjaei et al., 2020; Kim et al., 2022; Wu et al., 2023; Yang et al., 2021), the percentage of green (Zhou et al., 2024; Vahmani et al., 2022; Li et al., 2020; Lu, Yue & Huang, 2021; Chen et al., 2021; Yu et al., 2022; Li et al., 2021; Hong & Hoe, 2023; Hu et al., 2022; Lin et al., 2024; Yuan et al., 2024; Liou et al., 2024; Tepanosyan et al., 2021; Kim et al., 2022; Wu et al., 2023; Patel & Kaushik., 2023; Kamath et al., 2023; Liu et al., 2022; Yang et al., 2021) and impervious space areas (Vahmani et al., 2022; Li et al., 2020; Lu, Yue & Huang, 2021; Chen et al., 2021; Yu et al., 2022; Li et al., 2021; Hu et al., 2022; Lin et al., 2024; Yuan et al., 2024; Wang et al., 2024; Liu et al., 2022) and building orientation (Zhou et al., 2024; Hong & Hoe, 2023; Hu et al., 2022; Patel & Kaushik., 2023; Liou et al., 2024) are further influence the thermal environment and GST.

Research indicates that appropriate setback distances improve natural ventilation and daylight access, subsequently lowering indoor temperatures and energy demands for cooling. Ali et al. (2023) highlighted that increased setbacks enhance thermal performance by facilitating improved airflow and minimising heat stress, which is particularly significant in hot climates. Compared to areas with narrow setbacks, they have limited space between buildings that restricts ventilation, causing reduced convective cooling and localised heat accumulation at the ground level. This effect is particularly pronounced in high-density urban environments, where compact building arrangements form urban canyons that trap heat (Yu et al., 2022; Patel et al., 2022; Liu et al., 2022). This element closely interacts with building orientation (Patel et al., 2022), as setback distances influence solar exposure, heat absorption, and airflow efficiency. Lapisa (2019) mentioned that compact buildings with a square shape and a small envelope surface in contact with outdoor air will absorb less solar heat gain in the hot area (by radiation and convection) than incompact ones. She further found that buildings with appropriate building orientation can reduce the energy consumption for heating and cooling systems by up to 81%, depending on the geographical condition where the building is located. This suggests that optimisation of building setbacks and orientation should be considered in tandem, as compact structures with narrow setbacks may elevate thermal stress. In contrast, strategically orientated and spaced buildings can improve passive cooling and lower energy requirements.

Moreover, urban surfaces like green space areas and vegetation are most mentioned by authors, who highlighted that these spaces can enhance airflow and provide shade, helping to lower ground temperatures (Zhou et al., 2024; Vahmani et al., 2022; Li et al., 2020; He & Reith, 2023). The presence of vegetation is significant, as it can mitigate the effects of high air and radiant temperatures through evapotranspiration, which cools the surrounding air and surfaces (Meili et al., 2020). In short, the impact of landscape intervention on air temperature and relative humidity was most distinct (He & Reith, 2023). Research has shown that urban areas with a minimum of 30% green space coverage can reduce GST ranging from 2 to 5C , depending on vegetation type, density, and climate conditions (Yu et al., 2022; Li et al., 2021). The cooling effect of green spaces is further emphasized by Hong and Hoe (2023), who highlight that area with greater vegetation coverage experience higher evaporation rates, favoring latent heat exchange over sensible heat exchange. Each subdivision has distinct surface morphological characteristics defined by the amounts and types of vegetation and the size or roughness of different elements. These differences result in variations of flux partitioning across a city and the development of distinct micro- to local-scale climates (Nath et al., 2021). In contrast, impervious surfaces contribute significantly to increased GST. These surfaces absorb and store heat, leading to higher land surface temperatures (LST) in urban areas than peripheries, where natural vegetation is more prevalent. There is a strong positive relationship between the proportion of impervious surfaces and LST (Hong & Hoe, 2023).

Besides buildings producing anthropogenic heat through equipment used in the building, outdoor human activities around buildings also significantly influence GST, including traffic congestion, industrial operations, and commercial centres (Vahmani et al., 2022; Nath et al., 2021). Active urban zones intense with human activity, such as markets, shopping centres, and public plazas, can experience localized temperature increases due to waste heat from transport and mechanical systems and increased surface contact from pedestrian movement (Lin et al., 2024). Moreover, anthropogenic heat from traffic congestion and transportation emissions contribute to global surface temperature by releasing engine-generated heat, exhaust gases, and pavement friction. Zhou et al. (2022) also found that small-scale changes in road components effectively influence the outdoor thermal environment. The relationship between human activities and the built environment highlights the necessity of urban design strategies that integrate thermal resilience with functionality.

Microclimate

Microclimate refers to localized climatic conditions present within a small or specific region. These conditions may vary markedly from the broader regional climate due to multiple variables, including vegetation and ground cover, soil composition, topography, land use, and anthropogenic activity. The parameter of wind speed (Zhou et al., 2024; Vahmani et al., 2022; Kamath et al., 2023; Patel & Kaushik., 2023; Liu et al., 2022), air temperature (Chen et al., 2021; Nath et al., 2021; Firozjaei et al., 2020; Guo et al., 2024; Hu et al., 2022; Kamath et al., 2023; Kim et al., 2022; Li et al., 2021; Li et al., 2020; Lin et al., 2024; Liou et al., 2024; Liu et al., 2022; Lu et al., 2021; Patriota et al., 2024; Tepanosyan et al., 2021; Wang et al., 2024; Wu et al., 2023; Yu et al., 2022; Yuan et al., 2021; Zhou et al., 2024; Patel & Kaushik., 2023), radiant temperature (Chen et al., 2021; Nath et al., 2021; Firozjaei et al., 2020; Kamath et al., 2023; Li et al., 2020; Liou et al., 2024; Liu et al., 2022; Patriota et al., 2024; Tepanosyan et al., 2021; Yu et al., 2022; Zhou et al., 2024), sky view (Li et al., 2020; Lin et al., 2024; Yuan et al., 2021; Kim et al., 2022; Patel & Kaushik., 2023; Liu et al., 2022) and relative humidity (Hong & Heo, 2023; Patel & Kaushik., 2023; Kamath et al., 2023) are among the most influential microclimatic parameters affecting GST. Current studies have proved that natural parameters such as wind speed, air temperature, relative humidity, solar radiation, and soil temperature are highly responsive to any three-dimensional changes in an urban setting. Urban geometry significantly influences urban microclimate conditions (Omar, David, & Hatem, 2020; Tania, Koen, & Andreas, 2017). These meteorological parameters are directly affected by urban morphology and surface materials. They are all closely related to LST and the thermal environment and are the most important climatic parameters that affect thermal comfort (Cao, Zhou, Zheng, Ren, & Wang, 2021; Goldblatt, Addas, Crull, Maghrabi, & Levin, 2021; Nasrollahi, Ghosouri, Khodakarami, & Taleghani, 2020; Tsoka et al., 2018a, 2018b; Yang, Shi et al., 2020; Yang, Wang et al., 2020).

Wind speed significantly affects microclimates' thermal dynamics by influencing the heat exchange rate between the ground and the atmosphere through convection. High wind speeds can lead to more efficient cooling of these surfaces, thus reducing GST. Conversely, low wind speeds may result in heat retention and elevated temperatures. According to Yang et al. (2021), studies have shown that wind speed tends to increase due to the channelling effect between buildings, particularly in medium-density areas, promoting better airflow and lower GST. In high-density areas, complex structures and varied surface materials can obstruct the natural wind patterns, leading to localized areas of stagnant air that can trap heat and raise surface temperatures, exacerbating the UHI effect. These findings underscore the importance of integrating ventilation corridors into urban planning to optimize airflow and reduce GST.

Perini et al. (2022) also highlighted that urban greenery can modify wind patterns, affecting the microclimate. For example, trees and plants can act as windbreakers, reducing wind speeds in their immediate vicinity. This reduction can lead to localized warming due to decreased evaporative cooling and increased heat retention (Ren et al., 2023). However, as explained in the urban attribute section, vegetation can enhance thermal comfort by providing share and increasing humidity through evapotranspiration, which can counterbalance the effects of reduced wind speed (He & Reith, 2023). Higher humidity from transpiration can create localized cooling, while ground temperatures may remain elevated in dry areas. Relative humidity influences air quality, thermal comfort, and GST (Hong & Hoe, 2023).

Air temperature is the most mentioned factor by the authors that significantly influences GST, especially in urban areas where heat absorption, retention, and exchange occur at a higher rate due to the city's expansion. The correlation between air temperature and GST is predominantly regulated by convective heat transfer, wherein heat exchanges occur between the surface and the atmosphere. In densely urban areas, elevated air temperatures contribute to higher GST by enhancing sensible heat flux, particularly in regions with minimal vegetation and high impervious surface density (Chen et al., 2021). Multiple mechanisms from urbanization have modified this relationship. First, heat-absorbing surfaces such as ash asphalt, concrete, and metal roofs retain solar radiation during the day and gradually release it at night, resulting in sustained surface warming (Li et al., 2021). Next, the combination of anthropogenic heat sources, like vehicle emissions, building systems, and human activities, contributes to higher air temperature as the heat from the air has been transferred to the ground. Research by Fauzan et al. (2022) and Tepanosyan et al. (2021) indicated that urban areas typically exhibit a temperature rise of several degrees Celsius relative to rural areas, largely due to heat produced by human activities and thermal surface materials. Last, restricted air circulation in high-density areas diminishes natural heat dissipation, resulting in heat retention close to the ground and maintaining elevated GST levels (Yang et al., 2021). Yet, it differs from the radiant temperature, which refers to the surface temperature influenced by solar radiation. Radiant temperature is directly influenced by surface properties, including emissivity, absorptivity, and reflectivity (Liu et al., 2023; Vahmani et al., 2022).

In Dogan et al. (2023) study, there were variations in radiant temperature on the radiant wall and ceiling heating system, which led to significant changes in ground temperature with mean radiant temperature fluctuating up to 8˚C which air temperatures changed only about 2˚C. This study indicates that radiant temperature has a more immediate and pronounced effect on GST than air temperature alone. Building configurations can obstruct wind flow and create shadows, affecting solar radiation and contributing to temperature inversions, thereby complicating the thermal dynamics in urban areas (Zhou et al., 2024).

Moreover, sky view is another parameter that significantly influences GST. This parameter typically correlates with solar exposure and surface material proportion. A higher Sky View Factor (SVF) will potentially increase solar radiation received by a horizontal surface, and research indicates a positive relationship between moderate to high SVF values and LST. (Kim et al., 2022). Chen et al. (2021)

revealed that regions with higher SVF experienced markedly higher daytime temperatures due to higher solar radiation absorption. In contrast, during night-time, regions with lower SVF demonstrated a greater capacity for heat retention, resulting in increased night-time temperatures. These findings highlight the importance of incorporating open space, green areas, and reflective surfaces in high SVF areas to moderate GST fluctuations.

Table 5: Summary of Literature on Building Characteristics, Urban Attributes, and Microclimatic Factors in Urban Heat Studies

Country	Author/ Year	Main Themes/Sub-themes																
		Building Characteristic							Urban Attributes					Microclimatic				
		BH	BS	BM	B-Mat	BC	B-Eqp	BU	B-SB	H-Ac	PGS	PIS	BO	RH	AT	RT	WS	SV
China	Zhou et al. (2024)	/		/	/		/	/			/		/		/	/	/	
USA	Vahmani et al. (2022)	/		/	/	/				/	/	/			/	/	/	
China	Li et al. (2020)	/		/	/			/			/	/			/	/		
China	Lu, Yue & Huang (2021)	/	/	/			/				/	/			/			
USA	Chen et al. (2021)	/		/			/				/	/			/	/		
New York	Nath et al. (2021)	/	/	/	/					/					/	/		
China	Yu et al. (2022)	/		/					/		/	/			/	/		
China	Li et al. (2021)	/		/		/	/				/	/			/			/
Korea	Hong & Hoe (2023)	/			/			/	/	/	/		/	/				
Brazil	Patriota et al. (2024)	/		/						/					/			
China	Hu et al. (2022)	/		/							/	/	/		/			
China	Lin et al. (2024)	/							/	/	/	/			/			/
China	Yuan et al. (2021)	/	/								/	/			/			/
Taiwan	Liou et al. (2024)	/							/		/		/		/			
Armenia	Tepanosyan et al. (2021)	/		/							/				/			

USA, Greece, Turkey, Iran, China	Firozjaei et al. (2020)	/		/					/	/					/			
Korea	Kim et al. (2022)	/		/			/			/	/				/			/
China	Wu et al. (2023)	/		/	/			/		/	/				/			
Global	Patel & Kaushik., 2023	/	/		/	/			/		/		/	/	/		/	/
USA	Kamath et al. (2023)	/	/	/							/			/	/	/	/	
China	Wang et al. (2024)	/	/	/	/		/	/				/			/	/		
China	Liu et al. (2022)	/	/	/		/					/	/			/	/	/	/
China	Yang et al. (2021)	/	/	/					/	/	/		/	/	/	/	/	/

Note: BH = Building height; BS = Building size; BM = Building morphology; B-Mat = Building material; BC = Building condition; B-Eqp = Building equipment used; BU = Building used type; B-SB = Building setback; H-Ac = Human activities around building; PGS = Percentage of green area space; PIS = Percentage of impervious space; BO = Building orientation; RH = Relative humidity; AT = Air temperature; RT = Radiant temperature; WS = Wind speed; SV = Sky view.

Conclusion

The impact of building heat components on GST in urban areas has been systematically reviewed with critical attention. By synthesizing recent empirical data, three main themes—microclimate, building features, and urban characteristics—were major influences on the formation of urban thermal environments. The results show that GST fluctuations are influenced by building shape, material qualities, urban geometry, and anthropogenic heat emissions, affecting OTC, building energy consumption, and UHI intensity. The findings highlight how complicated shading and wind flow interactions in high-rise buildings—especially in crowded cities—showcase the influence on GST. Although taller buildings might offer daytime cooling effects, their contribution to night-time heat retention is still problematic. Likewise, high thermal mass building materials (such as concrete, asphalt, and brick) aggravate heat accumulation and reinforce urban overheating. Although its application is still uneven across urban planning strategies, green infrastructure—e.g., green roofs, vertical vegetation, permeable surfaces—has been shown as a successful mitigating technique.

From the standpoint of urban planning and sustainability, these results highlight the need for data-driven urban design concepts. Priority should be given to including high-albedo materials, ideal building orientations, more natural cover, and urban wind corridors to help reduce GST variations. The study supports the use of methodical building heat evaluations in urban development rules and strengthens the need to include microclimatic modelling in construction permit approvals. Even with the great synthesis of present material, some restrictions should be addressed. First, the study mainly covers investigations carried out in Asia-Pacific and Western areas, therefore restricting the generalisability of results to desert, tropical, and fast-urbanising places in Africa and South America. Furthermore, even if this study reveals quantitative links between building heat factors and GST, a lack of consistent evaluation models across research hampers direct comparisons. To improve prediction models for urban heat control, future research should prioritize longitudinal field studies, advanced simulation models (e.g., Computational Fluid Dynamics (CFD) machine learning-based forecasting), and remote sensing technologies.

Moreover, although the influence of building-specific characteristics (such as window-to-wall ratios or façade materials) has been studied, interactions between indoor-outdoor heat transfer and GST remain under-researched. Integrating real-time microclimate monitoring systems into smart city architecture is desperately needed to evaluate the dynamic interaction of energy use, anthropogenic heat emissions, and GST variations.

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