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Reflective Building Façades: The Effect of Albedo on Outdoor Thermal Comfort – A Case Study of Low-Rise Apartments

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ABSTRACT

In tropical locations, where urban areas experience considerable temperature rises relative to rural areas, the Urban Heat Island (UHI) effect is becoming more and more evident. Reflective building façades, global warming, and hardscape areas are all contributing issues. Because they reflect solar heat, materials like glass, high-pressure laminates, and metallic sheets raise outdoor temperatures, which affects both human comfort and the environment. This study looks into ways to lessen the negative impacts of reflecting façades on urban heat islands (UHIs), with a particular emphasis on how albedo affects microclimates and urban canyons. We examine the impacts of albedo on outdoor thermal comfort by analyzing research from 2003 to 2022. Thermal comfort indices can be calculated with ENVI-met software, which is useful for specialists in urban planning and architecture. To demonstrate these consequences, a case study of a low-rise housing complex located in Greater Noida, India, is provided. With a subtropical climate, this region sees wide changes in temperature, with summer highs frequently reaching 43°C and winter lows of about 7°C. The study uses ENVI-met simulations to evaluate how reflective façades affect thermal comfort in real-world conditions. This highlights the pronounced heat island effect and the localized heat buildup in urban areas during peak daytime h. The simulation revealed significant temperature variations throughout the day, with air temperatures peaking above 43.77°C by mid-afternoon between buildings, demonstrating the pronounced heat island effect. Relative humidity levels were low, around 39% to 40%, contributing to dry air discomfort. Wind velocities exceeded 1.5 meters per second at certain junctions, intensifying discomfort by amplifying the perceived heat. These findings indicate that the use of reflective materials on building façades in Greater Noida exacerbates human thermal discomfort outdoors. The study provides an opportunity to further measure and analyze these effects to develop targeted strategies for mitigating the urban heat island phenomenon and enhancing outdoor comfort in the region.

INTRODUCTION

The urban heat island (UHI) phenomenon has grown dramatically during the past few years. The UHI effect has become a significant global issue, and numerous UHI mitigation measures have been implemented globally (Huang & Lu 2018, Taha et al. 1988, Yuan et al. 2013, Akbari & Matthews 2012).

People who live in cities frequently feel the reflected sunlight from buildings, and while this can occasionally be inconvenient, we generally accept it as a characteristic of urban life. However, because of the type and amount of glass used in their façades as well as their curved shapes, buildings have the potential to have more severe effects. About 2% of the surface of the globe is covered by cities. As more individuals relocate from the countryside to urban centers, city populations are experiencing swift growth (Madlener & Sunak 2011). The Urban Heat Island (UHI) phenomenon and its severity in urban areas are largely shaped by local atmospheric and geographical factors (Mohajerani et al. 2017). It has been shown that asphalt surfaces release 200 $W.m^{-2}$ more in the perceptible portions of the spectrum and 150 W/m2 more infrared radiation than bare soil surfaces do at summertime's highest temperature (Asaeda et al. 1996). Retro-reflective (RR) materials for building façades have been suggested as a potential alternative to diffuse highly reflective (DHR) materials as a successful approach for UHI reduction because they can redirect sunlight hitting the building façades upward towards the sky, preventing the storage of negative heat in the urban canyon (Morini et al. 2018, Yuan et al. 2013, 2015)

In numerous recent investigations, the impact of RR materials on the possibility of Efforts to mitigate UHIs has been assessed (Yuan et al. 2019, Takashi et al. 2013, Morini et al. 2018, Rossi et al. 2015, Yuan et al. 2013). Yuan et al. (2016)developed a 2D analytic model to assess the possibility of UHIs in Osaka, Japan. The findings indicated that when compared to glass beads with refractive indices of 1.5 and 2.2, glass beads with a refractive index of 1.9 are more successful at mitigating UHIs. A new RR heat-shielding film was recommended for building windows, and its RR property was assessed with regard to the amount of solar radiation that was reflected from the building windows and the sky view factors. According to the findings, the suggested RR film enhances the ability of city structure shapes to reflect more solar radiation upwards, thereby aiding in UHI mitigation (Ichinose et al. 2017). Based on experimental and analytical studies evaluating the angular reflectivity of RR films, such materials could be effectively used as overlays on urban pavements and building façades. They are crafted to boost solar radiation reflection throughout city streets and over city rooftops (Rossi et al. 2014). RR tiles of three different sorts were created and put to the test using an optical experiment. According to the findings, all three varieties of microsphere RR tiles may exhibit strong reflection characteristics for incident light directions spanning from 0 to 60 degrees relative to the surface perpendicular (Morini et al. 2017).

Based on the above studies, it is possible to forecast how RR materials will affect outdoor thermal comfort using measurements acquired on the site. This prediction can then be further developed using CFD analysis and simulation techniques using different software. Several pieces of literature have been examined in the context to better understand the gap between using a reflecting façade on a structure and reducing outdoor thermal comfort.

The transfer of heat from building exteriors to interiors is assessed to look at the impact of three distinct façades (DHR, SR, RR) on the cooling demands of air conditioning. The research shows that building façades incorporating RR (reflective and radiant) and SR (solar reflective) technologies are highly effective in lowering Mean Radiant Temperature (MRT) and reducing heat transfer from Outer surfaces to the inner surfaces, thus decreasing the cooling demands of air conditioning. Nevertheless, these façades also result in greater solar radiation reflection and heat flux directed towards the ground (Yuan et al. 2021). The majority of research (Rossi et al. 2014, Yuan et al. 2016) showed that when the angle at which sunlight strikes a surface surpasses a predetermined value of roughly 60°, the surface's retro-reflectivity decreases and its downward solar reflectivity increases. High albedo materials applied to the vertical and horizontal limits of urban environments result in a decrease in thermal comfort and rises in PMV that can reach 2.3 in the summer. The severity of this degradation is specifically inversely related to the high albedo surfaces' sky view factor (Salata et al. 2015)

Although reflective façades aid in lowering a building's internal temperature and cooling requirements, they also have an adverse effect on the outside that is generally ignored in research. This study has been undertaken for further steps to further suggest the current scenario to comprehend and analyze the temperature outside.

Knowing the various approaches to be used for calculating the heat and discomfort produced outside, as well as its percentage contribution, will help you choose whether or not this issue can be overlooked. As there is very little study on how much heat is produced by reflective external façades, this review may offer suggestions for how to expand the research.

Aim of the Study

This study aims to clarify how reflecting building façades affect outdoor thermal comfort and the surrounding natural environment. The research investigates how surface reflectivity affects comfort experienced outdoors through a comprehensive review of literature spanning from 2003 to 2022. To investigate practical applications and implications, a comprehensive case study of a low-rise residential complex in Greater Noida, India, is a crucial part of the research.

The purpose of the research necessitates conducting a comprehensive literature review with a particular emphasis on the following criteria.

1. The implications of albedo on Outdoor thermal environment.
2. Application of Parameters in the Calculation of Thermal Comfort in Outdoor Environments Using Simulation Methods.
3. Justifying the negative impacts that reflected façades have.

4. The number of articles that concentrate on environmental considerations and thermal comfort indices.

Using ENVI-met simulations to offer insights into actual conditions, the case study especially examines the effects of various building constructions and surrounding vegetation on outdoor thermal comfort.

MATERIALS AND METHODS

The methodology for analyzing the effect of albedo on outdoor thermal comfort is mostly simulation-based, with field measurements planned for future research. The study focuses (Fig. 1) on Sector Omega in Greater Noida, where the rise in outdoor air temperature due to surface characteristics is investigated. ENVI-met simulation software is used to model thermal conditions based on meteorological data from May 22, including critical parameters such as air temperature, wind velocity, and relative humidity. This Simulation helps to understand the impact of various albedo levels on outdoor thermal comfort.

The findings will be analyzed to identify research gaps and investigate the potential benefits of using greener surfaces and vegetation to reduce heat stress. Future studies will incorporate extensive field measurements, utilizing both fixed and mobile rigs, to evaluate and supplement the modeling results. Furthermore, future research will compare these findings to greener settings to determine the impact of vegetation in improving outdoor thermal comfort.

Urban Albedo

Typically, an urban canyon's urban albedo is viewed as a crucial indicator for buildings' energy-saving efforts and for minimizing the UHI effect (Yuan et al. 2020). Oke (1988) recommended typical urban albedos of 0.14 for urban centers (range 0.09-0.23) and 0.15 for residential regions (range 0.11–0.24). The urban albedo is calculated by dividing the light reflected upward from urban structures by the total incoming light. Regardless of the angle of incidence of the halogen lamp light source, it was shown that RR surfaces have an urban albedo around 0.08 (8%) higher than DHR surfaces (Yuan et al. 2022). So, as the angle of solar radiation incidence rises, the value of urban albedo also rises, which diminishes the efficacy of the buildings' reflective façades and makes it the major source of radiation that is reflected into the atmosphere. Urban albedo is directly related to the net energy absorbed from short-wave radiation by urban substrate materials, as demonstrated in (Taha 1997).

$$(1-\alpha)I + L^* + Q_f = H + \lambda E + G$$

Here α represents the urban albedo; I represent solar

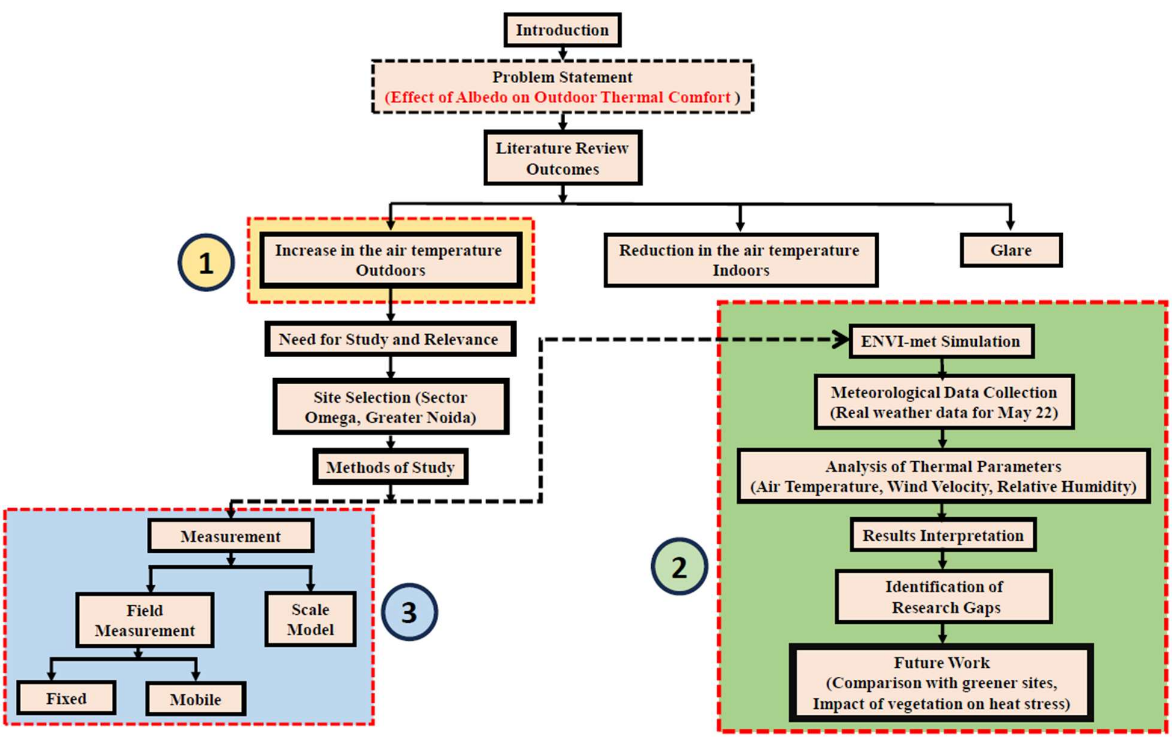

Fig. 1: This diagram outlines the research process, including the identification of outdoor temperature increases due to high albedo (Step 1), analysis of heat stress in low-rise apartments in Greater Noida (Step 2), and field measurements as part of future research (Step 3).

Table 1: Summary of effect of albedo on outdoor environment.

References	Location	Effect of Albedo on Outdoor Environment
(Tsoka et al. 2018)	Greece	The use of a surface of high albedo will be a drawback since it needs maintenance very frequently, and the effectiveness is reduced by 40% to 15% every 12 months.
(Falasca et al. 2019)	Milan, Italy	To counteract the effects of heat waves, the building itself uses high-albedo materials, which significantly reduce energy demand. From the perspective of pedestrian thermal comfort, this mitigation method is not a desirable solution.
(Yuan et al. 2021)	Osaka, Japan.	It can be seen that, in comparison to the DHR Diffuse Highly Reflective building façade, the Specular Reflective SR and Retro Reflective RR building façades will add a significantly greater amount of downward solar radiation and heat flux to the ground inside an urban canyon.
(Mehaoued & Lartigue 2019)	Algiers, Algeria,	The reflectance of reflective surfaces ranges from 30 to 90% in order to lower the cooling load. However, the reflected sunlight not only floods the surrounding area with more light but also increases its thermal load.
(Naboni et al. 2020)	(Copenhagen, Madrid, Brindisi and Abu Dhabi).	It is evident that changes in ground emissivity and reflectivity (albedo), the reflectance of reflective surfaces ranges from 30 to 90% in order to lower the cooling load. However, the reflected sunlight not only floods the surrounding area with more light but also increases its thermal load. The former by reflecting short-wave radiation that reaches the measuring stations and the latter by emitting long-wave radiation whose magnitude is proportionate to the ground temperature, actively contributing to variations in Tmrt.
(Lee & Mayer 2018)	Stuttgart (Southwest Germany)	According to the study, pedestrians' daytime thermal comfort is systematically harmed when wall albedo increases.
(Fahed et al. 2020)	Lebanon	The findings demonstrated that, depending on the form of the urban canyon, high-reflectance materials may have opposite effects on outdoor thermal comfort and albedo. Despite the positive impact on air temperature, it also reduces outdoor thermal comfort at street level because of an increase in interreflections that raise the mean radiant temperature.
(Lai et al. 2019)		According to certain simulation studies, pedestrians' thermal comfort deteriorates as reflected solar radiation increases and long-wave radiation decreases due to reflective surfaces.
(Taleghani 2018)	Netherlands	Raising the albedo in a confined environment, such as a courtyard, increases the body's reradiation and reduces thermal comfort. This study demonstrated that while cool pavements lower air temperatures, they also increase radiation exposure, which will be harmful to pedestrians.
(Fabbri et al. 2020)	Italy	SVF contributes to temperature rise when combined with solar reflectance. In Urban Canyon, outdoor space has less of an impact from reflected façades.
(Yuan et al. 2021)	Osaka, Japan	The solar reflectance of diffuse and specular reflecting directional building coatings is released back into the atmosphere, which helps to warm the surrounding area.
(Takashi et al. 2013)	Tokyo	The thermal environment of the streets surrounding the structure was found to be negatively impacted by the heat insulation of the building façade.
(Fabbri et al. 2022)	Bologna, Italy.	The emissivity value influences the outdoor microclimate. This outside environment can be influenced by emissivity in relation to the building blocks.
(Speroni et al. 2022)	Milan, Italy	Moreover, retro-reflectors show the highest ratios of upward to downward reflection when the angles of incidence are low. A single tall building with a flat diffusive surface and an albedo of 0.86, which corresponds to a clean white, can increase the solar irradiance on the ground by up to 20%, resulting in an intensity of 1.2 suns at pedestrian level.
(Res et al. 2007)	Pettah, Colombo (Sri Lanka) and downtown Phoenix, Arizona (USA)	Here, high albedo causes much lower daytime temperatures, which might lessen the photochemical synthesis of some pollutants. However, thermal comfort may not be improved by using this option.
(Yang et al. 2011)	Shanghai	But during the day, this albedo adjustment raises Tmrt by 8–148C, overpowering the very thin Tmrt reduction of less than 48Cat at night. Consequently, there is a decline in overall thermal comfort as evidenced by a rise in PET of 5–78C during the day and a fall in PET of less than 18C at night.
(Rosso et al. 2018)	Italy	On the other hand, when a building's envelope faces a canyon, an increase in albedo combined with low sky view factors suggests many reflections, which raise air and mean radiant temperatures.
(Salvati et al. 2022)	London	The findings demonstrated that, depending on the form of the urban canyon, high reflectance surfaces may have different effects on outdoor thermal comfort and albedo.
(Qin et al. 2016)	China	When the angle at which sunlight radiates on the RR surface rises above a specific point (about 40°), the surface loses its retroreflectivity.

radiation; L* represents net long-wave radiation from the surface; λe the latent heat of vaporization, H is the sensible heat, o_f is the heat produced by humans, E is the rate of evaporation, and G is the variation in the amount of heat stored in urban volumes.

To address UHI, increasing urban albedos is therefore recommended (Taha 1997), and research on how urban albedos affect other, more general issues like global warming has also been conducted (Akbari et al. 2009).

To systematically assess the current understanding of reflective building materials, the author explored three primary databases. (Science Direct, Google Scholar, Web of Science).

Reflective Façades

Urban heat islands are substantially influenced by the excess solar heat absorption by urban structures. (Santamouri 2013) By reflecting the heat from building façades and urban roads, reflective surfaces play a significant part in raising the air temperature. Materials such as glass, aluminum composite panels, metal cladding sheets, titanium panels, and many others are functioning in the same direction, and as a result, they harm the thermal well-being of pedestrians. Regardless that reflective surfaces help to cool down cities, several simulation studies assert that increased solar radiation reflected off of pedestrians often makes them feel more uncomfortable.

Table 1 is a collection of research that has been undertaken regarding reflecting façades for the past 10 years (2013 - 2022) and how they impact outdoor thermal well-being. Even though the majority of studies discuss the negative impact of reflectance returning back into the atmosphere, some say it is a favorable material option because it reduces the inside temperature. The majority of the research is conducted in Japan, along with Italy, Greece, Algeria, Germany, the Netherlands, and Tokyo.

Thermal Comfort Indices

Thermal Comfort Calculation Parameters

Four fundamental parameters, including air temperature, thermal radiation, wind speed, and humidity, are necessary to define the thermal environment of humans in metropolitan open spaces. (Lai et al. 2019) Each of the fundamental parameters separately characterizes the thermal environment. In (Lai & Chen 2016) and Lai et al. (2017), The connections among these factors in calculating different heat gains and losses concerning the human body are explained by (Lai et al. 2017)

Thermal radiation is the most complex of the four fundamental characteristics. The mean radiant temperature refers to the uniform surface Temperature of a virtual space where radiant heat exchange between a human body and the surroundings equals that of an enclosure with varying temperatures. (Tmrt), It is often used to characterize thermal radiation within urban open spaces (ASHRAE 2009).

To measure the Heat stress of the outdoor conditions on the human body), the four basic factors can be included in “equivalent temperatures.” These “equivalent temperature” factors permit a person to compare the cumulative effects of complicated outdoor thermal conditions to their own inside experiences.

The standardized temperature represents the ambient climate of a designated reference setting. That induces the same physiological reaction in a typical individual as in the actual environment. Physiologically equivalent temperature (PET) is an example of such a parameter (Höppe 1999). The standard effective temperature (SET*) (Gonzalez et al. 2021) and the universal thermal climate index (UTCI) (Bröde et al. 2012). Several approaches can be employed to calculate the reflected heat in the environment and the impacted temperature to analyze the above factors.

Methodologies for Acquiring Urban Thermal Environment Characteristics Measurements

Measurements made on-site are another way to collect data for environmental factors like temperature, relative humidity, and wind speed for use in simulations to produce thermal comfort indices. During the summer, on-site measurements of air temperature (Tair) and relative humidity (RH) were taken to determine the microclimatic parameters of the research region before any intervention scenario (Tsoka et al. 2018). Measurements are taken using equipment such as HOBO micro-station(Temperature, relative humidity, and air velocity on the roof), Hygro-thermometer Testo 635(Temperature, relative humidity, and air velocity at 2m from the ground), Thermograph ThermaCAM® B2(Thermograms of the façades) (Mehaoued & Lartigue 2019). Dry bulb temperature and relative humidity were recorded using TESTO 174H data loggers inside the courtyard, while outside measurements—comprising wind speed and direction, relative humidity, and dry bulb temperature-were obtained from a weather station (model PCE-FWS 20) installed on the building’s roof (Lopez-Cabeza et al. 2022).

The data obtained from the meteorological agency and the measured data may occasionally differ. Since the real-time measurements are more accurate than the recorded data, it is crucial to measure the data on the spot before making a decision. We cannot get the true image and results through simulated data.

Simulations

The advancement of microclimate prediction tools like SOLENE (Miguet & Groleau 2007), ENVI-met (Huttner & Bruse 2009), Rayman (Freitas & Scott 2007), SOLWEIG (Lindberg et al. 2014), STREAM, STEVE (Jusuf & Hien 2009), and CityComfort+ (Huang et al. 2014) has been going on for the past 20 years. In addition to temperature, Tmrt, and thermal prediction of air indices including PET, Expected Mean Vote Comfort (PMV), Standard Effective Temperature (SET*), and Universal Thermal Climate Index (UTCI).

ENVI-met employs computational fluid dynamics to study airflow patterns and evaluate environmental pollution. (Aydin et al. 2019). Physics-based prediction tool called RayMan can predict Tmrt, SVF, global radiation, and some thermal indices for a site of interest, including PMV, PET, SET*, UTCI, and perceived temperature (PT) (Aydin et al. 2019). A "non-stationary model that can compute the spatial variations of Tmrt" is SOLWEIG. (Lindberg et al. 2014). The STEVE tool uses albedo data, solar radiation, and features of the urban setting to create a regression model that only calculates ambient air temperature and SVF (building, pavement, greenery) (Jusuf & Hien 2009).

Studies indicate that a variety of simulation software has been utilized to calculate thermal comfort throughout the previous decade. ENVI-met is among the most extensively utilized Simulation software in the world. Many countries have approved ENVI-met v4.4.5, one of the most extensively used Computational Fluid Dynamics (CFD) tools for urban microclimate simulations on a worldwide scale (Tsoka et al. 2018). ENVI-met is a microclimate simulation tool that accurately computes the spatial and temporal distribution of microclimate parameters within urban areas at a high resolution (Huttner & Bruse 2009).

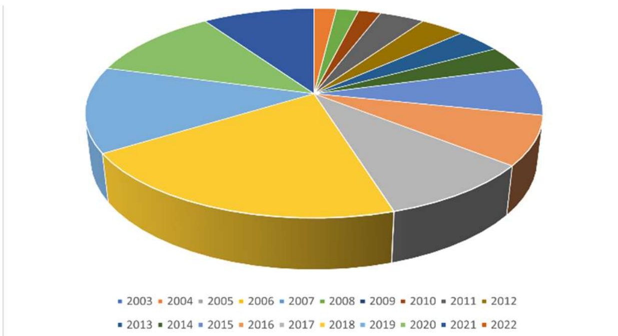

Fig. 2: Pie Chart depicting the role simulation studies to calculate the Thermal Comfort Indices.

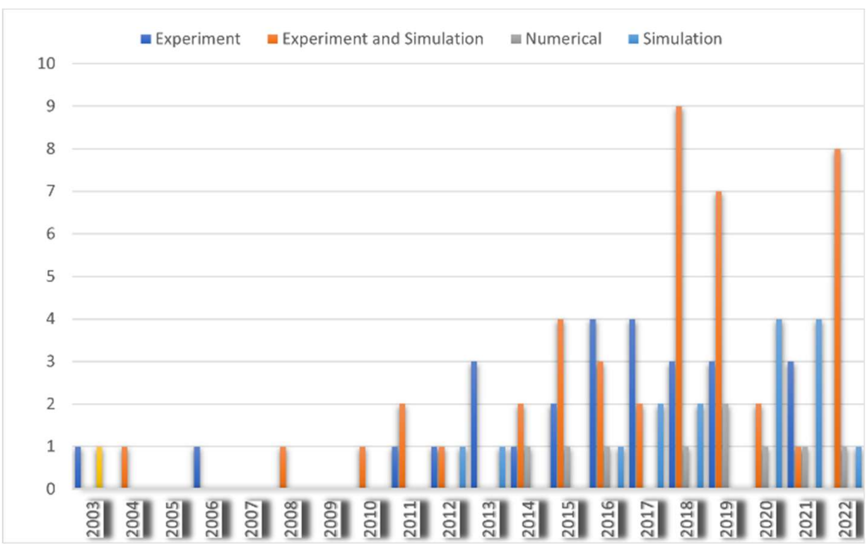

Fig. 3: No and typology on a paper published on the calculation of environmental factors (temperature, relative humidity, and wind speed) and thermal Comfort indices (Tmrt PET, UTCI, SET).

A simulation tool is used to calculate outdoor thermal comfort after several parameters are assessed. In particular, wind speed, material albedo, air temperature, and relative humidity are examined. These parameter values are produced as outputs by the tool using site location, building material requirements, vegetation data, and weather files as inputs. As previously discussed, various simulation tools are used to calculate thermal comfort indices, including STREAM, ENVI-met, ANSYS, and ENERGY PLUS.

ENVI-met's limitation includes modeling structures as blocks where the width and length align with grid cells, resulting in uniform thermal properties and lacking thermal mass variability. Moreover, all structures have identical albedo and heat transmission (U-value) for walls and roofs. (Res et al. 2007). Simulation software can also be used in conjunction with onsite measurement data to provide precise results. Using ENVI met with measurements and cooling loads gathered by Ecotect was another method for determining the effects of reflecting glass façade on the environment.(Mehaoued & Lartigue 2019b) .

The study examines how street configurations influence ambient temperatures and pedestrian comfort. It shows a strong correlation between on-site measurements, comfort assessments, and urban climate simulations conducted with ENVI-met. The simulation techniques have been extensively employed over time to analyze the thermal comfort indices, as can be observed from the prior studies. The article's usage of simulation studies is depicted in the pie chart below (Fig. 2).

Few have, according to the literature review, also employed the STREAM simulation program to calculate outdoor thermal comfort. The STREAM and ENVI met interfaces, however, are completely different.

Putting the studies in chronological order makes it abundantly evident that there is an increasing interest in investigating the outside human thermal perception during the years 2003–2022 (Fig 3**)**. Since 2011, there has been an increase in the number of research that use thermal comfort indicators. As a result, one of the fundamental variables that goes into determining whether or not someone is comfortable in their environment is the type of tools that they utilize. As a direct consequence of this, simulations can play a significant role in the process of calculating reflection values.

However, there are several simulation tools used to simulate the thermal comfort parameters to comprehend their impact on comfort in outdoor temperatures. Despite its reported limitations, the bulk of research indicates a disparity in outcomes when measurements and simulations are compared. One must, therefore, be cautious while entering data into the software to achieve near-perfect results in comparison to measurements done on-site.

Future Studies

As a result of a 20-year study of the literature, it is clear that there is a need for additional research in the area that has received little attention.

1. Very little research has been done on the numerical output of RR material use on façades and how it affects outdoor thermal comfort. There is a substantial quantity of heat dissipated in the atmosphere as opposed to using reflecting materials as part of lowering indoor temperatures.
2. Research studies on the reflected heat with the use of Albedo on building façades are not calculative. Its, indicating a notable research gap.
3. Retro-reflective façade materials function at a specific angular dependence of the solar radiations. As a result, it is less effective at reflecting the heat in the same direction that it is coming from. The angle of incidence for the specific city must be determined before installing such materials, and it must be compared with the number of h per day that reflecting façades are operational.
4. It is necessary to perform a numerical calculation to determine how much heat is reflected into the atmosphere to comprehend the severity of the issue it is posing. Also, to determine which of the following roads, roofs, and building façades is harming the environment more so that future studies can go in the same direction.

RESULTS AND DISCUSSION

Site Conditions

An investigation of the site conditions of the urban enclave located in the thriving Delhi NCR region's Greater Noida, UP (Fig. 4) area indicates a distinctive interaction between environmental elements and urban dynamics. The climate in this heavily populated region, which is distinguished by low-rise housing complexes, is characteristic of North India's subtropical zones. Maximum temperatures increase in the summer, frequently reaching over 43°C, while lowest temperatures in the winter drop to about 7°C.

A low-rise apartment building located in the omega sector of greater Noida is punctuated by a 12-meter-wide road system, enabling the community's vehicle and pedestrian traffic flow. The presence of green areas, such as a large park for leisure purposes and a kid-only swing park, is a noteworthy aspect of the location that provides a break from the bustle of the city. The internal block-paved pathways contrast with the asphalted peripheral highways, adding visual interest and guaranteeing functional diversity.

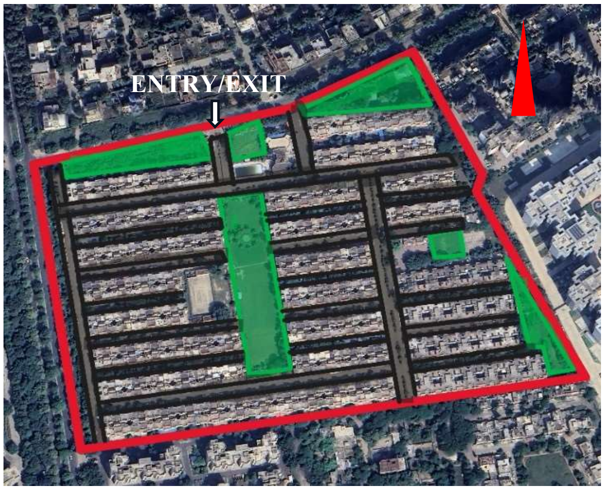

Fig. 4: Google Earth image of a Low-rise apartments in Greater Noida, Delhi NCR.

Covering a vast 25.65 acres with a Floor Area Ratio (FAR) of 1.2, the development consists of 22 12-meter-tall low-rise blocks that blend in with the surrounding urban fabric. This thorough comprehension of site conditions provides the groundwork for well-informed design choices, promoting livable and sustainable urban environments.

Simulations for Heat Stress

About the Software: ENVI-met is a microclimatic simulation tool that calculates thermal indices and offers information on the impacts of thermal strain on outdoor habitats. Through the use of several graphs customized for particular days and weather, findings may be obtained to identify any discrepancies.

ENVI-met needs certain input factors, such as weather, urban structure, and the physical characteristics of flora and surfaces inside the urban area, to simulate the microclimate.

Table 2: Boundary Conditions and initial settings for ENVI met 5.5 modeling.

Location	28.4744° N, 77.5040° E (Greater Noida, India)
Climate	Composite Climate
Date/Time simulated	22/05/2023
Start Simulation Hour (hh: mm)	10:00 am
Total Simulation time (h)	7 h
Model Domain	50 x 50 x 20
Atmospheric Boundary Conditions	
Max Temperature	42°
Min Temperature	32°
Humidity	Min 50 % to 65%
Cloud Cover	0

Direct and diffuse solar radiation, longwave radiation, and a vertical profile of atmospheric parameters (temperature, velocity, and humidity) estimated from 0 to 2500 meters above ground are among the computed weather parameters. Envi-met, developed by Bruno, is capable of simulating comprehensive microclimatic conditions at the neighborhood level by integrating various physical processes such as airflow amidst buildings, the impact of vegetation and water bodies on urban heat islands, and interactions between soil surfaces and building façades.

Description of the Model: The analysis in this study is focused on a 50 × 50 × 20 model area that includes a low-rise residence in Greater Noida, India. The boundary conditions and initial settings of the model are given in Table 2. Three different building constructions, A, B, and C, as well as the surrounding vegetation, are the main subjects of the analysis. At twelve meters high, these constructions are primarily made of brick walls, a material often used in building construction that is renowned for its strength and insulating qualities. To precisely replicate the real world. Due to its capacity to incorporate a wide range of physical phenomena, including airflow between buildings, the effect of vegetation and water surfaces on urban heat islands, and the exchanges between soil surfaces and building walls, the modeling tool Envi-met, created by Bruno, enables realistic microclimate simulation at the district scale.ld circumstances, a particular day, May 22, 2023, in May, was selected for the study. This specific day is used as a representative sample to identify possible weather fluctuations and seasonal variations.

Ten hours are allotted to the simulation, which starts at 9:00 am and ends at 7:00 pm. This period encompasses a considerable amount of the day, making

Fig. 5: Envi Met Model of the Low-rise apartment in Greater Noida, Delhi NCR.

it possible to conduct a thorough examination of the environmental elements influencing the structures and their environs.

To ensure that the simulation included accurate weather, data was used from the reliable website www.wunderground.com. Important characteristics, including air temperature (minimum and maximum), relative humidity, wind speed, cloud cover, and wind direction are all included in this report. The simulation software can precisely describe and predict the thermal behavior and environmental impact on the buildings and surrounding landscape by using this extensive dataset. The study intends to offer important insights into the thermal performance and comfort levels within the built environment under varied climatic conditions by incorporating real-world data into the simulation process.

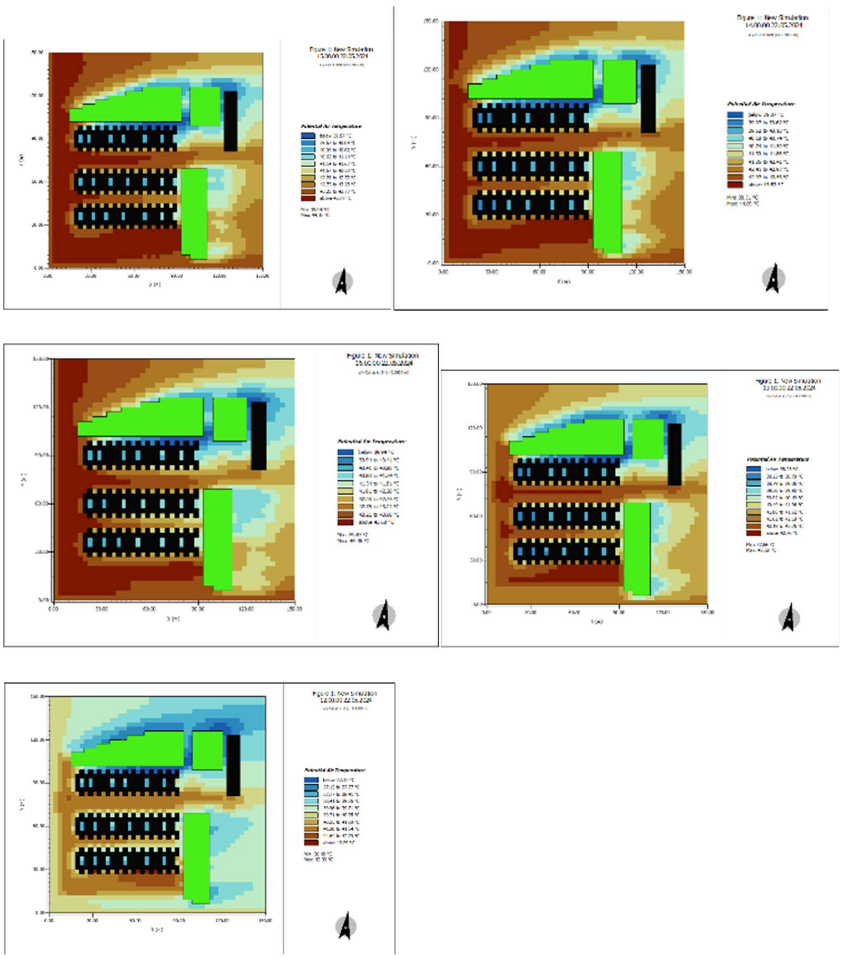

Fig. 6: Envi Met Results of Air temperature at 12:00 pm, 1:00 pm, 2:00 pm, 3:00 pm, and 4:00 pm h of the day of 22nd May 2024.

Simulation Results: Thermal indices were calculated using ENVI-met simulations, considering variables such as air temperature, relative humidity, and wind velocity. These simulations were applied to a model of Jalvayu Vihar in Greater Noida, which incorporated building blocks, windows, roads, and vegetation to improve result accuracy (Fig. 5). Specific materials were assigned to each entity in the model: building blocks were represented with moderate wall brickwork, windows with float glass, roads with asphalt, and vegetation with trees and turf grass. While the materials can be customized within the software for specific outcomes, the materials mentioned above were utilized for this project's simulation.

Air Temperature Analysis

Air temperature graphs were generated for May 22, 2024, from 12:00 pm to 4:00 pm. Although the simulation encompassed a total duration of 7 h, only the critical h were analyzed. The primary criterion for assessing the heat island effect involved calculating air temperature values. The following graphs depict the conditions during these critical hours, illustrating the adverse effects of air temperature within the premises.

The outdoor ambient air temperatures were analyzed over different times of the day, revealing significant variations (Fig. 6). Temperatures between 39 to 40 degrees Celsius were observed on the roads between the blocks, while temperatures near the green patches were 2 to 3 degrees lower. At 1:00 pm, the temperature was higher compared to the noon simulation, with road temperatures exceeding 42 degrees Celsius. The temperature continued to rise at 2:00 pm, reaching over 43.55 degrees Celsius on the roads. By 3:00 pm, the temperature peaked, exceeding 43.77 degrees Celsius. However, at 4:00 pm, the temperature began to decrease but remained above 43.68 degrees Celsius on the roads.

Relative Humidity Analysis

The comfortable range of relative humidity is between 30% and 60%. When humidity falls below 50%, the air feels excessively dry, leading to discomfort, such as dry skin and irritated eyes. In the range of 50% to 65%, humidity is optimal for comfort, maintaining skin moisture, and facilitating respiratory ease. However, when relative humidity exceeds 65%, the air feels too humid, resulting in sweating and potential respiratory issues.

The graph indicates that relative humidity on the roads is between 39% and 40%, suggesting that the air is relatively dry. To address this, increasing humidity by incorporating water bodies along the wind path could help regulate the temperature and improve comfort levels.

Wind Velocity Analysis

The comfortable wind velocity for human thermal comfort generally ranges from 0.3 to 1.5 meters per second ($m.s^{-1}$) (Fig. 7). Wind velocities below 0.3 $m.s^{-1}$ can feel stagnant and uncomfortable, particularly in warm environments. A range of 0.3 to 1.5 $m.s^{-1}$ provides a comfortable, gentle breeze that aids in cooling and ventilation. However, wind velocities exceeding 1.5 $m.s^{-1}$ may feel too windy and cause discomfort, especially in cooler conditions.

The graphs indicate that wind velocity exceeds 1.5 $m.s^{-1}$ at junctions and T-intersections on the roads. This high wind velocity, when combined with elevated air temperatures, can exacerbate discomfort by intensifying the perception of heat, making the environment more oppressive for individuals.

In our analysis of "The Effect of Albedo on Outdoor Thermal Comfort," we look at how surface reflectivity affects urban heat islands (UHIs) and microclimates. The case study of a low-rise residential complex in Greater Noida offers an important foundational understanding of the current thermal stress in the area, even though it does not include reflecting façades.

We provide a baseline for evaluating the possible effects of adding reflecting materials by looking at the heat stress that this subtropical environment experiences. This case study aids in our comprehension of the existing levels of thermal

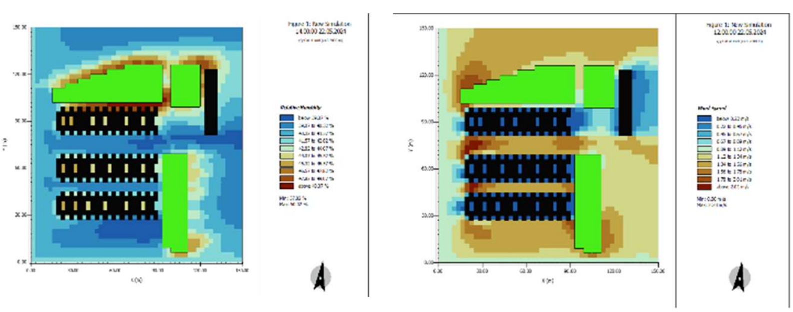

Fig. 7: Envi Met Results of Relative Humidity and Wind Velocity on 22nd May 2024.

comfort as well as the elements that lead to heat stress, such as the kind of construction materials used and the amount of flora present. It is possible to forecast how reflecting façades can change the local microclimate using the Greater Noida research results. For example, the addition of reflecting materials might alter surface albedo and mean radiant temperature (MRT), which would affect thermal comfort in general. Urban planners can assess the advantages and disadvantages of utilizing reflecting materials in comparable situations with the help of this comparative analysis.

The case study also emphasizes the significance of context-specific urban planning techniques. Planners can employ high-albedo materials to reduce UHI effects and improve outdoor thermal comfort by having a better understanding of the Greater Noida area's distinct thermal dynamics.

In summary, the case study offers insightful information that enhances our evaluation with its thorough examination of heat stress in an unreflective setting. It ensures that our suggestions for enhancing outdoor thermal comfort are based on actual facts and circumstances by bridging the gap between theoretical notions of albedo and practical applications. Although ENVI-met simulations provide useful information about urban heat stress in Greater Noida, there are several limits to consider. Using only simulation data may not provide a complete picture, even if real meteorological data from a specific day in May is included. Several variables can influence heat stress generation, which may not be adequately captured in simulations. Incorporating actual site measurements and comparing them to simulation findings would yield more robust and accurate knowledge. This identifies a potential research gap and emphasizes the necessity for additional research to validate the findings with actual data.

CONCLUSIONS

As has been observed, research has shown the importance of the angle of incidence and its impact on retro-reflecting materials, as well as how it affects materials other than these highly reflective materials on the quality of the outdoor environment. However, there haven't been many empirical investigations to back up the claim. So, to draw a conclusion, an experimental setup must be used. Nonetheless, the majority of research holds that retroreflective materials are the solution for lowering the thermal load in buildings and improving thermal comfort. The quantification of solar reflectance in the environment still has to be done.

A consistent rise in wall albedo results in a gradual decline in daytime thermal comfort for pedestrians. To lower the reflectivity value in the atmosphere, façade trending materials like DSR and RR & Low-E double-glazed façades are used where the limitations extend even to the materials.

The most crucial characteristic of retro-reflective materials is retro-reflectivity. However, the previously delivered retro-reflective materials have a serious defect, which is that the retro-reflectivity will shapely degrade under the high incidence angle of solar radiation. That is the primary area for retro-reflective material optimization.

In the experimental setup and computational analysis, the governing principles of retro-reflective materials have indeed been acquired on the urban thermal conditions and the thermal environment of buildings. The effectiveness of using materials with high reflectivity in a single building or group of buildings needs to be continuously monitored and assessed. Merely simulation won't solve the problem because the values of measurements and simulations might sometimes differ by up to 20%. Instead, monitoring the data logging in the software also needs attention.

Several simulation software options have been covered. All with different advantages, but as seen in the thorough review studies, ENVI met proves to be useful for computing thermal comfort indices. Nevertheless, depending on the subject matter being researched, various software may be used.

This review offers the researchers the chance to focus their research on quantifying the value of solar reflectance in conjunction with other environmental parameters to comprehend its role in the atmosphere.

Based on the comprehensive analysis conducted using ENVI-met simulations in the low-rise residential area of Greater Noida, India, several key findings have emerged regarding the microclimatic conditions and their impact on thermal comfort:

Air Temperature Variations: The simulations revealed significant variations in air temperatures across the study area throughout the day, peaking above 43.77 degrees Celsius by mid-afternoon on the roads between the buildings. This highlights the pronounced heat island effect and the localized heat buildup in urban areas during peak daytime h.

Relative Humidity Insights: Relative humidity levels were observed to be relatively low, around 39% to 40%, suggesting dry air conditions. This can contribute to discomfort, such as dry skin and irritation, indicating a need for strategies to increase humidity, such as incorporating water bodies or green spaces, to enhance comfort levels.

Wind Velocity Considerations: The analysis indicated that wind velocities exceeded 1.5 meters per second (ms) at certain locations, particularly at junctions and T-intersections. While moderate wind speeds are generally beneficial for cooling and ventilation, excessively high velocities in conjunction with high temperatures can exacerbate discomfort by intensifying the perception of heat.

In conclusion, the findings underscore the importance of microclimate modeling in understanding and mitigating thermal challenges in urban environments. Effective urban planning strategies, including the incorporation of green spaces, water bodies, and consideration of building materials, are crucial for enhancing thermal comfort and mitigating the adverse effects of heat islands. By integrating these insights into urban design and policy-making, cities can work towards creating more livable and sustainable environments for their residents. Furthermore, a comparative analysis of several low-rise housing sites in greener, more densely vegetated environments might be simulated and compared to the current Sector Omega location. This would be useful in determining the impact of vegetation on outdoor thermal comfort in the area. The extent to which vegetation can lower outdoor heat stress is unknown, however, such a study could offer insight into greenery's good impact in alleviating heat.

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