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Research Article

Sky View Factor at Street Canyons and its application in urban heat island.

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ABSTRACT

Studying the thermal properties of urban public spaces, specifically urban streets, is essential for comprehending climate change and environmental sustainability in urban research as it seems to influence the comfort level of people using these spaces. The design characteristics of street canyons were examined in the hot semi-arid setting of Pune, and numerical simulations were employed to analyze the effects of design elements and their implications for Urban Heat Island Intensity. According to the 2021 IPCC Sixth Assessment Report, the global average temperature increased by 1.09°C between 2011 and 2020. Furthermore, this analysis identifies an increase in the frequency and intensity of extreme heat occurrences. Higher Sky View Factors (SVFs) amplify reflections of both short-wave and long-wave radiations, contributing significantly to an uncomfortable outdoor thermal climate, which is critical in the domains of urban morphology and climatology. The numerical study examine the effect of Sky View Factor on thermal comfort in street canyon. The SVFs in residential canyon for selected for the study were analysed using RayMan and ENVI-Met software. It was found that the strong correlation with R^2 of 0.885 between SVF and MRT and R^2 of 0.9994 between PET and MRT. The study will help architects and planners to develop a climate-resilient framework for enhancing thermal comfort in urban canyon.

Keyword: Urban Heat Island, Urban Canyon, Air Temperature (AT), PET, PMV, Aspect Ratio

1.1 Introduction:

Cities have greater temperatures than rural locations, reducing thermal comfort for occupants. In 1933, Luke Howard demonstrated this phenomenon for the first time. Urban climatology has been extensively studied, particularly the Urban Heat Island phenomenon (UHI), which refers to the higher ambient air temperatures in metropolitan areas compared to rural areas ((Oke, 1981),(Bärring et al., 1985a),(Tzavali et al., 2015)).The sun access effects air and surface temperatures, it is critical to understand how shading conditions and solar access impact the microclimate of urban canyons. Canyon shape/geometry (Bärring et al., 1985b) and factors such as street layout, building height/width ratio ((Takebayashi & Moriyama, 2012), (Sadeghi & Bahadori, 2021))and street orientation all influence solar access and shade conditions. As a result, they have a substantial impact on building energy performance and are critical for ensuring thermal comfort in open spaces. Furthermore, it has been claimed that, at the microscale, urban layout is significantly more important than albedo and material thermal behaviour. Because the street consists of shared surfaces between buildings and an open urban canopy.

1.2 The sky view factor (SVF):

The sky view factor (SVF) is a metric of urban canyon (a U-shaped region between nearby building structures) design that affects surface energy balance, local air circulation, and outdoor thermal comfort ((Chen & Ng, 2009),(Dirksen et al., 2019),(Middel et al., 2018)). The sky view function (SVF) measures the degree of sky visibility at a particular location and the shade of surrounding elements on a scale from zero to one, where zero indicates no sky view and one indicates a full sky view(Oke, 1981). According to Oke, there is a "zone of compatibility" in street design that can be established to ensure a compromise between goals that do not always appear to correspond. However, additional study is required to offer quantitative data on the optimum street designs for controlling climatic comfort (Oke, 1988). There are times when the real, location-dependent association between SVF and UHI found in the research is not consistent (Chen & Ng, 2009).

1.3 Aspect ratio (H/W):

Aspect ratio (H/W): Oke investigated the relationship between street layout and urban climate and proposed optimal H/W ratios for mid-latitude cities ((Oke, 1988), (Shishegar, 2013)).
The aspect ratio (H/W) of an urban canyon is another crucial geometric feature that illustrates the density of an urban fabric. Buildings cast shadows on the surrounding areas when the urban fabric is dense, which lowers the amount of heat produced by solar radiation ((Bakarman & Chang, 2015), (Vardoulakis et al., 2003)). According to simulated research conducted in Los Angeles (Taleghani et al., 2016), brightly coloured pavements increased the reflection of sunlight from the ground to pedestrians, ultimately raising the mean radiant temperature. Nastaran Shishegar investigates how airflow and solar access are affected by the geometry (H/W ratio) and direction of a street in an urban street canyon ((Shishegar, 2013), (Letzel et al., 2008)).

2. Need of the Study:

The long-term goal of the India National Cooling Action Plan (IPAC) launched by Government of India in 2019 is to provide socioeconomic and environmental benefits while offering everyone sustainable cooling and thermal comfort. Its goal is to lower cooling-related direct and indirect emissions. The strategy has a 20-year time frame (Ministry of Environment, Forests and Climate Change, 2019). The sky view factor (SVF), a crucial statistic in environmental and urban studies, assesses the relationship between sunlight exposure and sustainable development. There are total 17 Sustainable Development Goals (SDG), none of the any goal that focus on SVF. As United Nation Sustainable Development Goals, they understand that eradicating poverty and other forms of deprivation requires concerted efforts to combat climate change, protect our seas and forests, and enhance health and education, and lower inequality in addition to promoting economic growth. The Goal 7 emphasizes on renewable energy, Goal 11 Sustainable Cities and Communities targets for providing access to affordable housing, green spaces, effective transportations, and more; while Goal 13 i.e. Climate action stresses on how rising temperatures raise the risk of severe weather disasters. To achieve the target of universal power access by 2030 action as more investment in renewable energy and supportive legal frameworks in from of incentives provided are on fast tracks to global energy demand and climate goals. The haphazard urbanisation has created unstable thermal settings, increasing the risk of human heat exposure. To achieve the SDGs of fair development and environmental resilience, it's important to integrate SVF issues into bigger sustainability and urban planning activities. A thorough analysis of the literature found a substantial correlation between MRT and PET with Sky View Factor. In order to increase outdoor thermal comfort, the purpose of this research is to evaluate the effects of changing SVF on Air Temperature (AT), MRT and PET measurements.

2.1 Study area:

This research is conducted for average summertime circumstances in Pune, a city in Maharashtra state in Western India's Deccan plateau (18°31′13′′N 73°51′24′′E, 560m a.s.l). The region has a hot, semi-arid climate (BSh) that borders on a tropical, wet, and dry climate (Aw). Pune has a tropical climate, which is characteristic of its weather. Pune receives far less rainfall in the winter than it does in the summer. Köppen and Geiger have categorised the climate as Aw. Based on available data, Pune's annual mean temperature is 24.3 °C. A little over 1200 mm of rain falls there each year. Since Pune is situated in a moderate climate, it is challenging to classify the seasons there. With an average relative humidity of 57% in May, Pune has a relatively humid climate that is pleasant. Because high temperatures and relative humidity have a combined effect, shading outdoor areas is crucial for improved thermal comfort. The sky view factor (SVF), a crucial statistic in environmental and urban studies, assesses the relationship between sunlight exposure and sustainable development. The study analyzed the building and urban canyon in order to arrive the possible ranges of Sky view Factor for 9 meter wide road with different building height in Pune.

2.2 Modelling description:

Table 1 lists the key simulation settings and building properties used in the case studies. The two long buildings that make up the simulated domain are divided by a 9 m-Wide Street, and the height of the buildings varies according to the aspect ratio. Oke studied for the structure to fit the parameters of an urban canyon, its length must be six times its height(Oke, 1988). As shown in Fig. 1, urban canyons with aspect ratios H/W of 0.33, 0.66, 1.33, and 2.66 have been simulated and tested for east–west, north–south orientations, along with intermediate orientations as NE–SW and NW–SE. The simulated region has a 3 m horizontal and 3 m vertical 3D grid resolution. All of the findings that are described below were estimated for a height of 1.2 metres above ground and are provided for the centre portion of the street, or at the mid-block distance from the street ends, using the ENVI-met programme 5.1.1v. This height serves as a typical value for standing person comfort estimates. At the model border, the wind above roof level is maintained constant and is regarded as perpendicular to the street axis.

In order to analyse the MRT value for SVF values during the crucial month of May, a residential zone was simulated in ENVI-met. Next, in order to determine the ideal SVF with improved comfort, the relationship between SVF and thermal comfort indices (MRT and PET) was examined.

Table 1: General conditions for the simulations

Location	Pune, India, 32.401N, 3.801E, 560 m a.s.l.
Climate type	Hot- Semi Aired
Simulation day	Typical summer day, 15th May 2021
Simulation duration	From 6:00 to 20:00 (12 h)
Model Area (Number of Grids) xyz-Grids	40 x 50 x 30
Size of grid cell in meter(dx, dy, dz)	3 X 3 X 3
Street width	9 m
Building height, H	3, 6, 12, and 24 m
Building length, L	60m (urban canyon)
Building width, W	18 m
Wind speed	2 m/s at 10 m a.g.l., constant
Wind direction	Perpendicular to street axis
Air humidity	VP ¼ 12.5 hPa
Heat transmission	Wall: Uvalue ¼ 1.7 W/m K Roof: Uvalue ¼ 2.2 W/m K
Indoor temperature	20 ˚C constant
Albedo	Concrete road

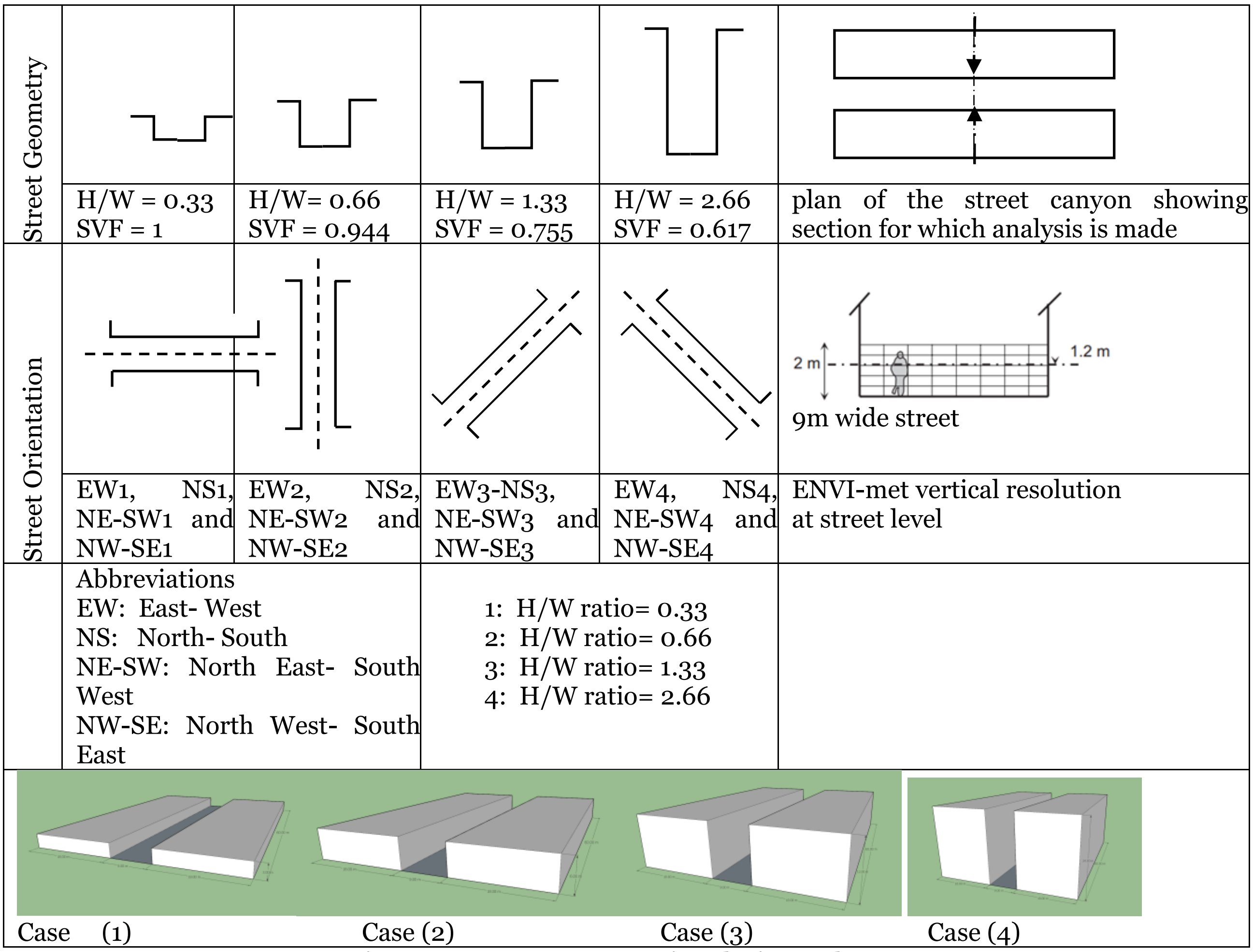


Figure 1. Street canyon simulation schemes

2.3 Thermal comfort factors:

The Munich Energy-balance Model for Individuals (MEMI), which simulates the thermal circumstances of the human body in a physiologically realistic manner, is the foundation for the physiological equivalent temperature (PET) (Höppe, 1999). PET is the air temperature at which, under ideal interior conditions (i.e., no wind and solar radiation), the body's heat budget is balanced, resulting in the same skin and core temperatures as under the complex outdoor parameters that need to be evaluated. In this approach, a layperson can use PET to evaluate the overall impact of complex outside thermal circumstances with what they have personally experienced indoors (Höppe, 1999).

The mean radiant temperature (MRT) Tmrt is one of the most significant meteorological factors influencing human energy balance and thermal comfort (heat load) (Mayer and Höppe, 1987; Ali-Toudert and Mayer, 2007). MRT evaluates thermal comfort and human energy balance models for both indoor and outdoor settings. It includes radiant heat exchange between a human body and its surroundings that is both short wave (visible and solar) and long wave (infrared and terrestrial) (Thorsson et al. 2007). As a result, in the current investigation, thermal comfort was evaluated using MRT and PET. Different methods have also been used to express urban geometry or compute the SVF.

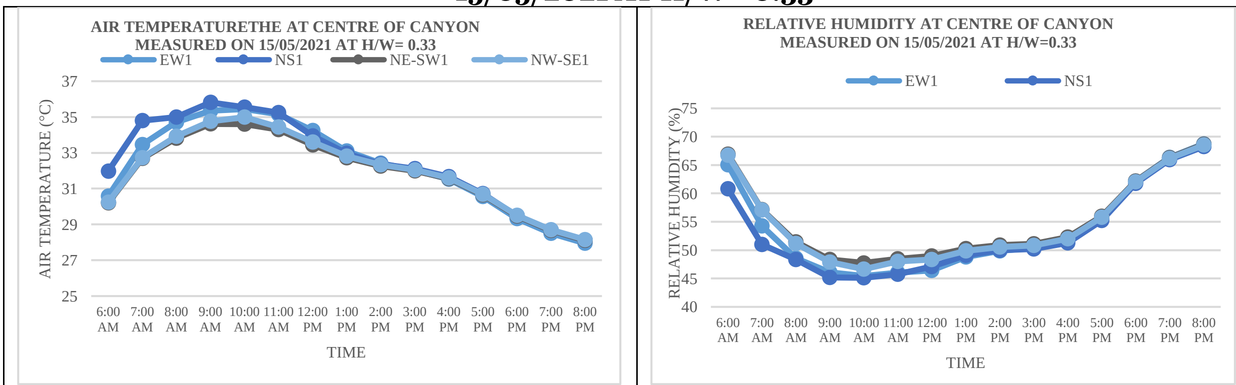
The height/width ratio has been calculated ((Oke, 1981), (Peng et al., 2017)) using a three-dimensional (3-D) building archive ((Toudert, 2005). Sky View factor (SVF) and PET calculate by using RayMan Pro software ((Toudert, 2005),(Matzarakis et al., 2010)). The calculation of the mean radiant temperature at the current location using the local, spherical SVF can be performed (Matzarakis & Amelung, 2008). So, in the study PET and SVF are calculated using RayMan Tool. The present study focuses on building heights and road width the built parameters in urban morphology. The effect of plants and features of orientation on outdoor thermal comfort are not considered. Nonetheless, it is advised that the study take into account the aforementioned characteristics. Krüger et al., Evaluated the impact of canyon geometry and orientation on cooling loads in a high-mass building in a hot dry environment (Krüger et al., 2010). The third factor impacting thermal comfort is the materials used in roadways.

3. Results and Discussion

The results were calculated using Envi-met, the dataset includes temperature readings taken on May 15, 2021, at various times in a canyon with a height-width ratio of 0.33 at four orientation (EW1, EW2, EW3, and EW4). 10:00 AM was the highest temperature ever recorded. EW4: 34.81 °C, EW3: 35.94 °C, EW2: 35.89 °C, and EW1: 35.44 °C. 8:00 PM was the lowest temperature ever recorded. EW1: 27.95°C, EW2: 27.99°C, EW3: 28.1°C, and EW4: 28.23°C were recorded. Morning temperatures may reach a maximum of around 35.5–36 degrees, while evening lows are around 28 °C (Figure 2).

The measurements taken on May 15, 2021, at H/W = 0.33, at the heart of a canyon, are represented in the dataset. From 8:00 AM to 8:00 PM, values were taken for four orientation (EW1, EW2, EW3, and EW4) every hour. Here are the average humidity measurements for NS1, NS2, NS3, and NS4: 52.56%, 54.02%, 55.49%, and 56.74%. But there are significant differences in the readings' range between the sensors. All sensors showed a gradual increase in humidity from morning to dusk. The NS4 sensor registered the maximum humidity at 69.38% (Figure 2).

Figure 2: Air Temperature (°C) and Relative Humidity (%) At Centre of Canyon measured on 15/05/2021 AT H/W= 0.33



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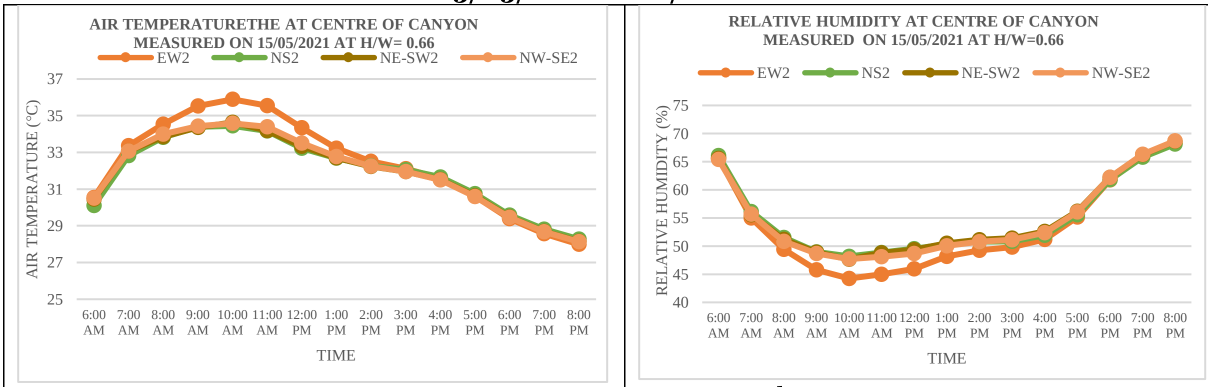
The central canyon air temperature readings from May 15, 2021, are the main subject of the dataset. Within the canyon, there are four separate areas: NS1, NS2, NS3, and NS4. Of these, NS1 has the highest average temperature (32.43) and NS4 has the lowest (31.48). At 7.7°C, NS1 had the widest temperature range. With an average temperature of 32.01°C, NS2 had the second-highest range (6.17°C). The average and range of temperatures for NS3 and NS4 were comparatively lower (Figure 3), results were calculated using Envi-met.

The information shows the relative humidity readings taken on May 15, 2021, at H/W = 0.66, near the centre of a canyon. We read four sensors (NS1 through NS4) between 8:00 AM & 8:00 PM. Here are the average humidity measurements for NS1, NS2, NS3, and NS4: 52.56%, 54.02%, 55.49%, & 56.74%. But there are significant differences in the readings' range between the sensors. Throughout the day, a gradual rise in humidity was noted (Figure 3).

Figure 3: Air Temperature (°C) and Relative Humidity (%) At Centre of Canyon measured on 15/05/2021 AT H/W= 0.66



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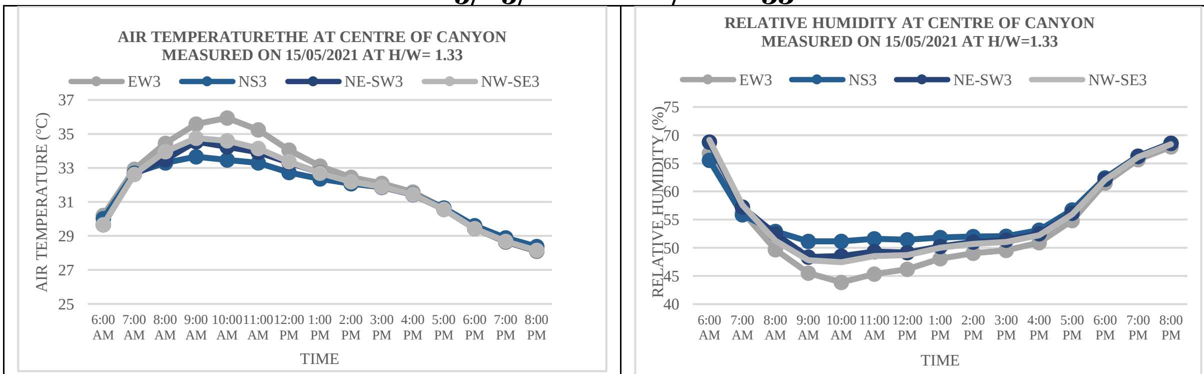
The results were calculated using Envi-met, the air temperature in a canyon's middle, recorded on May 15, 2021, at H/W = 1.33, is provided by the dataset. Four NE-SW paths with significantly varied temperatures at different times of the day have been examined. At 32.02°C on average, with a peak temperature of 34.61°C, NE-SW1 had the highest temperature. With an average temperature of 31.98°C and a high of 34.63°C, NE-SW2 was closely behind.NE-SW3 had a high of 34.55°C and an average of 31.89°C. With a high temperature of 33.53°C, NE-SW4 had the lowest average temperature of 31.61°C (Figure 4).

The relative humidity at the center of canyon was analyzed on 15/05/2021, at H/W = 1.33, for every hour from 8 AM to 8 PM. The given dataset provides these measurements from four different locations NE-SW1 to NE-SW4. NE-SW1 had an average relative humidity of 54.04%, ranging from 47.753% to 68.654%. NE-SW2 maintained similar averages and range as NE-SW1, with a slightly higher average of 54.21%. NE-SW3 consistently averaged 54.33% humidity throughout the day, maintaining a range of 48.382%-68.541%. NE-SW4 accessed the highest average humidity at 55.13%, and a range from 49.87% to 68.465% (Figure 4).

Figure 4: Air Temperature (°C) and Relative Humidity (%) At Centre of Canyon measured on 15/05/2021 AT H/W= 1.33



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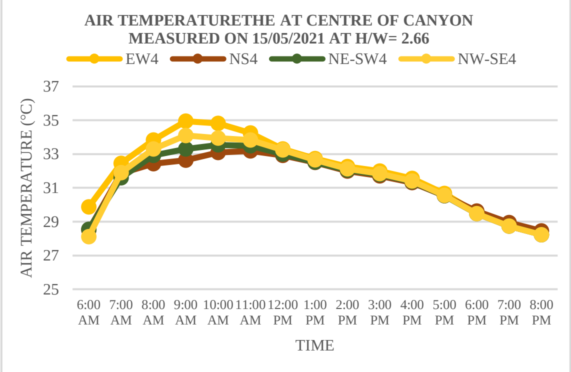
The results were calculated using Envi-met, on May 15, 2021, the height-width ratio at the middle of a canyon was 2.66, and the air temperature was recorded there. Temperature measurements from four distinct orientations (NW-SE1, NW-SE2, NW-SE3, and NW-SE4) at various periods are provided by the dataset. The highest maximum temperature (34.99°C) and average temperature (32.12°C) were recorded by NW-SE1. The lowest recorded temperature was 28.15%C. NW-SE2, NW-SE3, and NW-SE4 had respective average temperatures of 32.02°C, 31.99°C, and 31.80°C. In all regions, the maximum temperature was recorded between 9 and 10 AM, while the lowest temperature was noted about 8 PM (Figure 5).

On May 15, 2021, the relative humidity in a canyon's core was measured at H/W = 2.66. Throughout the day, four regions—NW-SE1 to NW-SE4—were evaluated. Humidity increased gradually throughout the day in all zones, reaching its highest levels around 6 PM. The areas' average humidity varied from 53.68% to 54.40%. The lowest humidity was recorded around 10 AM, with regional values ranging from 46.64% to 49.10%. At 8 PM, the highest recorded humidity was 68.52% to 68.68% throughout all areas when compared to other locations, NW-SE4 consistently reported somewhat greater humidity (Figure 5).

Figure 5: Air Temperature (°C) and Relative Humidity (%) at Centre of Canyon measured on 15/05/2021 AT H/W= 2.66



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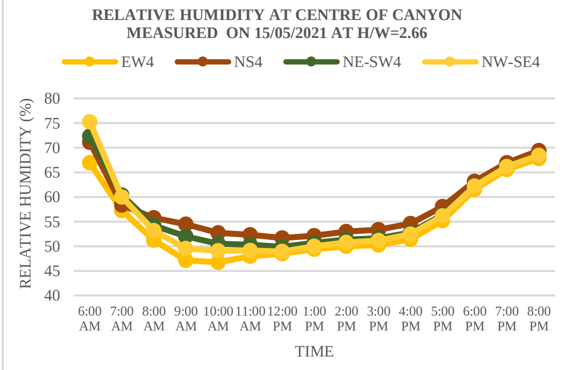

Source: Author

Physiological Equivalent Temperature (PET) and MRT values were obtained for all the 15th May in a year 2021 through RayMan Pro 3.2.1 tool for each of the case selected as H/W of 0.33, 0.66, 1.33 and 2.66 considering N-S Street orientation. The values of 12 p.m. were considered for the analysis as the temperature value is at the peak in the afternoon. A linear regression analysis was carried out to establish the relation between SVF and MRT Values (Fig. 6) showing the strong correlation between PET and MRT values i.e., R2 =0.885. A linear regression analysis was carried out to establish the relation between PET and MRT Values (Fig. 7) showing the strong correlation between PET and MRT values i.e., R2 =0.9994.

Figure 6: Relation Between Mean Radiant Temperature (Tmrt) and Sky View Factor at 12 pm having H/W of 0.33, 0.66, 1.33 and 2.66 for N-S Street orientation.

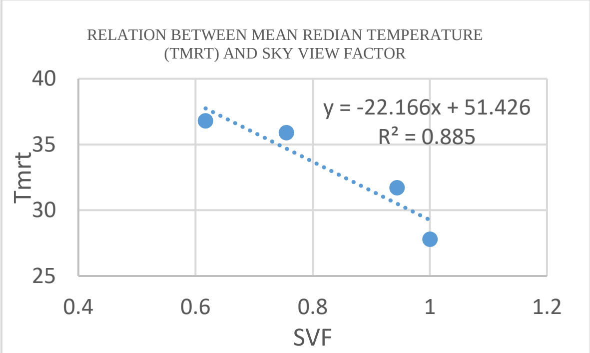

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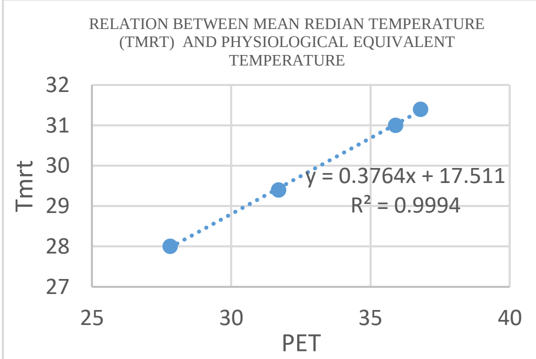
Figure 6: Relation Between Mean Radiant Temperature (Tmrt) and at 12 pm having H/W of 0.33, 0.66, 1.33 and 2.66 for N-S Street orientation.



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4. Discussion and conclusion

These simulations are a component of a larger, continuing investigation into how street design affects comfort in the open air. It was discovered that the urban canyon thermal environment was significantly influenced by both aspect ratio and sun direction.
As the aspect ratio increases, air temperatures somewhat drop, but the radiation fluxes represented by the mean radiant temperature are much more significant. In an E-W oriented urban canyon, it is also challenging to reduce heat stress. Vegetation and vertical projection need to be planned to get better results for reducing heat effect. In an E-W oriented urban canyon (roads direction), it is also challenging to reduce heat stress. The walls barely partially shade the area, even at proportions of H/W = 2.66.
Better comfort conditions result from rotating the roadway to a NE–SW or NW–SE direction for the same aspect ratio since the walls shading effects are more pronounced in these scenarios. Since the roadway is constantly partially shaded, the duration of temperature discomfort for intermediate orientations is shorter, providing pedestrians with an alternate means of adjustment.
In effect, it is likely that the atmosphere will absorb more short-wave radiation, which will lower the radiation fluxes that the human body absorbs. Street plantings with H/W ratio of around 0.33 are appropriate in all situations. Given the extended length of pain, the hot E–W roadways with greater aspect ratios are probably the ones where plant installation is most beneficial. Depending on the aspect ratio and traffic volume, trees should

ideally be placed in the middle of the street or on the south-facing side. Comparing daytime and night time conditions in the canyon by evaluating the impact of geometric decisions on the urban canyon's thermal comfort during the day and its rate of cooling at night would be another intriguing topic. Once more, the significance of the materials' capacity to store heat is paramount.
Arnfield J. (2003) proposed that another crucial question to address the issue of inadequate validation, which still plagues the majority of urban numerical models, is to compare ENVI-met results with field research. To estimate the mean radiant temperature, the same must be changed (Arnfield, 2003).
The "sky view factor" and mean radiant temperature during the day have a reasonably good correlation. The most significant factor influencing thermophysiological comfort indices is the mean radiant temperature. The best way to attain outdoor thermal comfort is to lower the "sky view factor" temperature.
The results of the investigation showed a substantial correlation between the SVF, Mean Radiant Temperature, and Physiological Equivalent Temperature. The analysis from the RayMan Tool concluded that Physiological Equivalent Temperature (PET) and Mean Radiant Temperature) are strongly correlated with Sky View Factor value by 0.9994 equal to 1.
Because of RayMan Tool's assistance in understanding the relationship between different thermal indices, it is possible to determine that Sky View Factor significantly affects outdoor thermal comfort. Built parameters were the only ones used in this investigation.
Furthermore, if winter sun access is also to be taken into account, NE-SW and NW-SE orientations appear to be a suitable balance, as comfort outside indicates that they are almost as efficient as N-S streets in the summer. In contrast to the N-S orientation, they permit a higher level of winter solar exposure for the facades. However, this problem goes beyond the scope of the current work and merits in-depth investigation in future research.
To address some of the aforementioned concerns and enhance outdoor thermal comfort even further, other street design elements are presently being researched. These include the utilisation of greenery, asymmetrical urban canyons, and other architectural elements like galleries and horizontal facade overhangs, and other research methods may be used to collect exact data for developing a design and planning framework for potential climate-resilient recommendations.

5. Further Research

Urban designers, architects and planners can use this study to improve outdoor spaces in hot semi-arid climates and make pedestrians more comfortable.
The adaptive approach, which is based on psychological dimensions for thermal comfort and is essentially complementary to the approach used in this study, is also suggested by the ASHRAE standard for future research. In this approach, a variety of other factors influence thermal comfort results, including context, expectations, culture, and past thermal experiences. The research of thermal comfort should also include a questionnaire and an analysis of the answers acquired from these surveys in order to take the adaptive approach into consideration.
Another suggestion is to use the PET and UTCI thermal comfort indices, which yield more accurate results in outdoor conditions than the PMV thermal comfort index, which could not be used in this study wing to the limitations of the ENVI-met student version.

6. Competing Interests:

Authors have declared that no competing interests exist.

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