Walkability in Urban India
Designing Cool pockets for pedestrian thermal comfort

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ABSTRACT: *Walkability is a measure of how friendly and welcoming neighbourhoods are to pedestrians. Walkability in urban cities is influenced by planning and environmental parameters. People who desire to walk for transport, recreation or health benefits are often faced with challenges such as lack of infrastructure, noise, safety concerns and thermal comfort. Improved walkability creates a shift towards active travel becoming a preferred mode of transport. This shift contributes to better health, an enhanced sense of space, and improved air quality.*

Bangalore, a city considered as the Silicon Valley of India, has undergone swift growth in the last three decades. With Rapid urbanization, Bangalore faces severe effects of climate change. The city has a population of 12.3 million, making it the third most populated city in India. Pedestrians constitute 23% of the population, with people walking for reasons of recreation and transport. This research aims at addressing pedestrian comfort in Bangalore, where uncomfortable summers make walking difficult.

Pedestrian thermal comfort depends on the design of the surrounding space and physiological factors. The discomfort felt by pedestrians varies with the duration of exposure and the build-up of heat stress. For this purpose, it is essential to determine the distance that pedestrians can walk before experiencing discomfort in an outdoor setting.

The approach of this research is to study the thermal discomfort pedestrians experience in the existing scenario and improved conditions. The thermal comfort of pedestrians is analysed during sunshine hours when maximum thermal discomfort is anticipated. As per Universal Thermal Comfort Index (UTCI), in the existing scenario, a pedestrian experiences thermal distress for 43% of sunshine hours. A pedestrian walking at an average speed of 1.4m/s reaches a state of discomfort at 500 meters over a 6-minute duration. By improving the materials of the surrounding built environment and providing shaded walkways, UTCI analysis indicates thermal distress for 9% of sunshine hours. Having improved the surrounding environment, a pedestrian reaches a state of discomfort at 850 meters over 10 minutes.

To enhance neighbourhood walkability, it is vital to design streetscapes conducive to pedestrian needs. Good design provides pedestrians with the option to pick routes that are comfortable and visually pleasing. The outcome of this design process is to create "cool pockets" where people can pause, cool-down in the shade and continue walking to their destination. In this research, the study of time defines the spacing of "cool pockets" in urban neighbourhoods.

Keywords: Walkability, pedestrians, thermal comfort, streetscapes.

INTRODUCTION

At present, India has a total population of 1.32 billion with 34% of it living in urban areas. Projections suggest that by 2030, 50% of the population will be concentrated in urban areas. With technological development and progress that the world has made, the need to walk as a mode as transport has diminished. Bangalore, the third most populous city in India has gone through rapid urbanization in the last three decades. Over the years, the city has begun to experience the effects of unplanned development and climate change. Bangalore has a population of 12.3 million with pedestrians being close to 3 million people.

WALKABILITY

Walkability is a measure of how friendly and welcoming a neighbourhood is towards a pedestrian. A walk-able neighbourhood caters to the needs of residents by having essential land use within a walk-able distance, between 400 to 800 meters. Providing diverse land use mix, housing density, safety, accessibility, urban streetscape, environmental quality, thermal comfort and infrastructure makes a neighbourhood walk-able. Although, one of the many parameters may be more important than the other, each of these parameters are interdependent and affect the ability to achieve the other.

For many centuries, walking from one location to another was the only form of transport that humans knew. Not only is walking the simplest and economically feasible form of transport, it also has health benefits. Traditionally in India, outdoor spaces have been used for social interactions and contact. Walking facilitates social contact with neighbours and brings about the feeling of reclaiming the streets. Bangalore city has many pedestrians who walk for transport as well as recreation. Also, people depend on public transportation which is intrinsically involves walking for last mile connectivity. For pedestrians in Bangalore, the walk involves exposure to heat, and humidity which is a substantial barrier to walkability. This study is undertaken keeping the comfort of pedestrians as priority.


Image 1: Well designed streetscapes encourage walking

GOAL

When pedestrians walk in the absence of shade, discomfort sets in after a few minutes. When there is a transition between an unshaded space to shaded space, the walk becomes more comfortable. With a walk being comfortable, the desire to walk is higher and the pedestrian is willing to walk a longer distance. Creating conducive walking environments with better urban design and interesting streetscapes will motivate pedestrians to remain outdoors longer. It is not always feasible to have shade in all streets and at all locations as it compromises the aesthetics z also the "eyes on the street" safety factor. In such a case, the study of time and walking comfort plays a role to strategically locate the "cool pockets" in the walking path of pedestrians.


Image 2: A precise evaluation of comfort leads to efficient design

SCOPE

Although the study targets walking in the Indian context, the analysis of comfortable walking durations have been made for neighbourhood in Bangalore. The methodology used for the analysis allows for it to be easily adapted and used for other neighbourhoods and cities in India.

NEED FOR THE STUDY

Thermal comfort is typically associated to shade and air temperature. There are additional factors that affect thermal comfort in an outdoor environment and they include relative humidity, infrared radiation, wind, and direct solar radiation. In the case of pedestrians, it is not only the climate parameters, but it is also the metabolic rate, clothing factor and the time of exposure. This research takes into account, the influence of exposure time on the thermal comfort of a pedestrian.

EXISTING RESEARCH

Existing research that has been conducted on the thermal comfort of pedestrians suggest that the temperature of the skin is transient, and it changes with the duration of exposure to the sun. Although, PET has been used in many cases, PET depends on the mean radiant temperatures of the surrounding, but not the exposure time. The change in T_{skin} over a duration of exposure time has been measured on field (Balakrishnan.P, 2015) and using equations (Chen. L, Ng. E, 2011) in the past. On field, the skin temperature can be measured by using a thermal camera and then the temperature substituted in comfort models. The goal here is to use the finding of a comfortable walk duration for the design of efficient walk-able neighbourhoods.

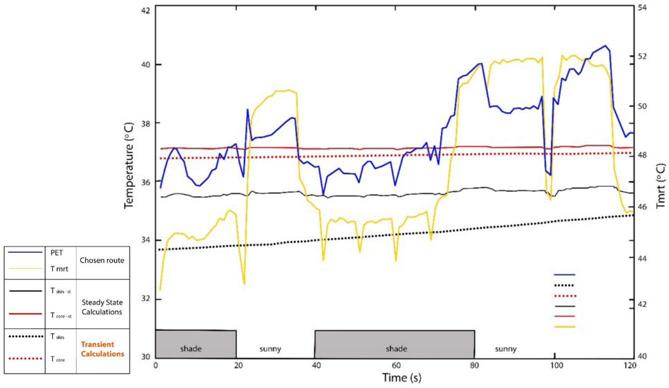


Image 3: Temporal variation of a pedestrian

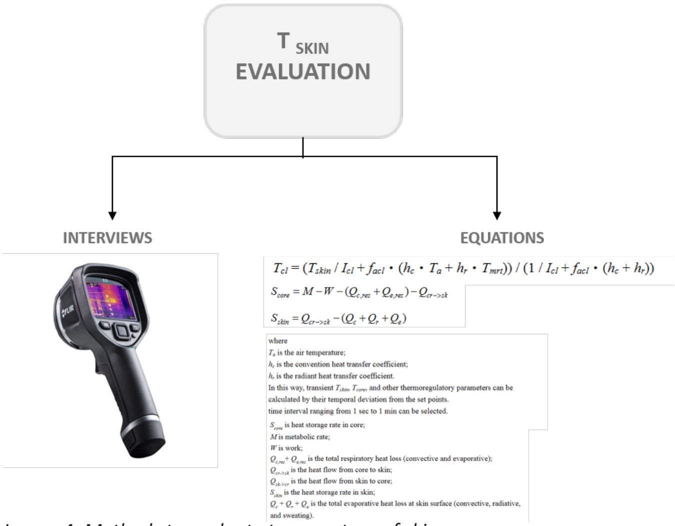


Image 4: Methods to evaluate temperature of skin

THERMAL COMFORT MODELS

Several indices have been developed over the last few decades that link climate and building environments to the thermal comfort of a user. In the last thirty years there has been significant research about the heat exchange that happens between a body and the surrounding environment. Predicted Mean Vote (PMV) is a commonly used index that evaluates the thermal sensation response of a surveyed group of people on a seven-point scale. The scale ranges from -3 to +3, varying from cold to hot respectively. Physiological Equivalent temperature (Mayer & Höppe, 1987) another index measures discomfort in degree Celsius. PET is defined as the physiological equivalent temperature at any given place (outdoors or indoors) and is equivalent to the air temperature at which, the heat balance of the human body is maintained with core and skin temperatures equal to those under the conditions being assessed (Höppe, 1999). Universal thermal Comfort Index introduced in 1994 is defined as the air temperature (Ta) of the reference condition causing the same model response as actual conditions. The offset, i.e. the deviation of UTCI from air temperature, depends on the actual values of air and mean radiant temperature (Tmrt), wind speed (va) and humidity, expressed as water vapour pressure (vp) or relative humidity (RH). (Blazejczyk,K et al,2013).

The models discussed above, do not take into consideration the change in the thermal stress of a person over an extended duration of time. Time plays an important role in the thermal comfort of a pedestrian and this research is undertaken to determine the intervals at which the cool pockets need to be provided. For this purpose, the thermal comfort DISC has been used in this research. DISC is the measure of the thermoregulatory strain that the body goes through to reach a state of comfort and thermal equilibrium. In hot climates, DISC is a function of heat stress and heat strain (Doherty and Arens, 1988). It is measured on an eleven-point scale ranging from -5 to 5. DISC is a function of skin wittedness in warm conditions and is based on the Pierce two node model (Auliciems and Szokolay, 2007).

DISC scale	
0	comfortable, pleasant
-1, +1	uncomfortable but acceptable
-2, +2	uncomfortable and unpleasant
-3, +3	very uncomfortable
-4, +4	limited tolerance
-5, +5	intolerable

Image 5: Eleven - point scale for DISC

THERMAL COMFORT INDEX CALCULATOR

In this research, the WWW Thermal Comfort Index Calculator by de Dear has been utilized to analyse thermal comfort of a pedestrian. Air temperature (Tair), relative humidity (RH), mean radiant temperature (MRT), metabolic rate, clothing factor (Clo), air velocity (Vair) and the time are used as input parameters for the analysis of comfort. With time being an input in this tool, the comfort of a pedestrian can be evaluated for different time steps.

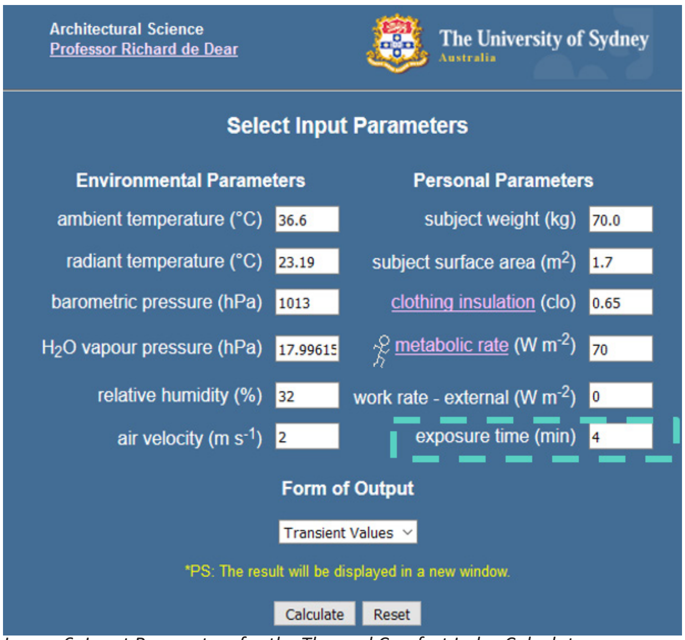
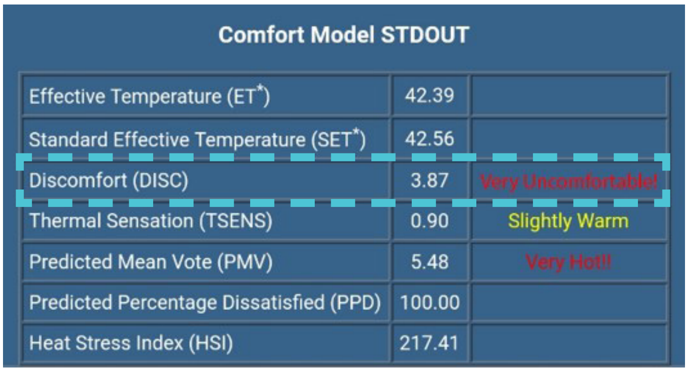


Image 6: Input Parameters for the Thermal Comfort Index Calculator

The comfort model evaluates DISC, which is a measure of thermal comfort in hot climates. DISC has a eleven- point scale ranging from -5 to 5, where values between -2 and 2 are considered acceptable. Since this study is carried out in a hot climate, time steps where comfort readings are greater than two and a pedestrian feels uncomfortable and unpleasant are focused upon.



Comfort Model STDOUT

Effective Temperature (ET*)	42.39	
Standard Effective Temperature (SET*)	42.56	
Discomfort (DISC)	3.87	Very Uncomfortable!
Thermal Sensation (TSENS)	0.90	Slightly Warm
Predicted Mean Vote (PMV)	5.48	Very Hot!!
Predicted Percentage Dissatisfied (PPD)	100.00	
Heat Stress Index (HSI)	217.41	

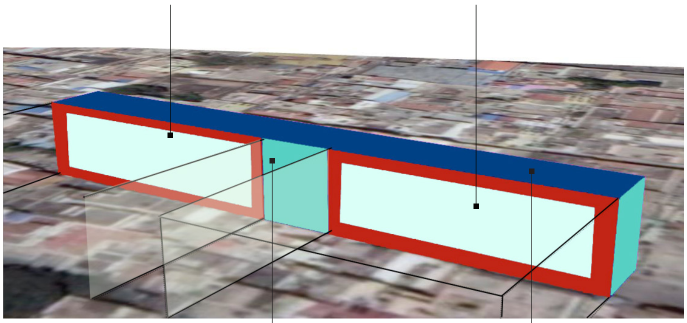
Image 7: DISC, an output from the Thermal Comfort Index Calculator

THERMAL MODEL

Pedestrians are active users of a streetscape in a city. The movement of pedestrians through the street has been simulated similar to a room, but the parameters are altered to match an outdoor setting. The room here has four categories of planes, the ground, the walls and windows of the adjacent buildings, a ceiling, and surfaces with openings that pedestrians walk through. The ceiling is modelled as an opening with no glass and has a temperature exchange with the sky. Vertical surfaces with openings are assumed to have no glass and a pedestrian can walk through these surfaces.

Ext Wall
$T_{boundary}$ = Indoor temperature

Window (Double Glazing)
$T_{boundary}$ = Indoor temperature



Window (No glass)
$T_{boundary}$ = Average indoor temperature of inside wall

Ceiling (no glass)
$T_{boundary}$ = SKY
Inside surface gain = - absorbed energy

Image 8: Thermal model of the street

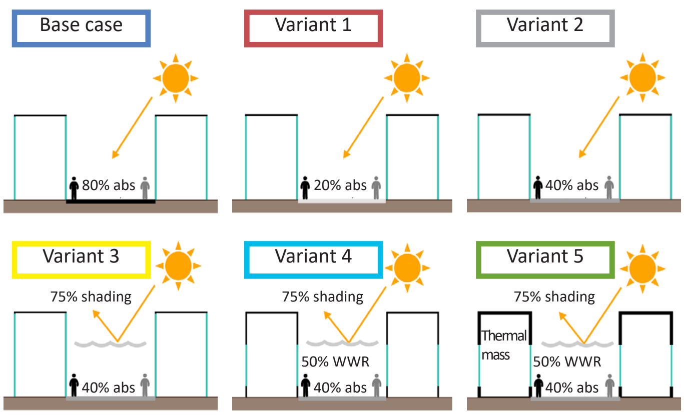


Image 9: Variants of the street that have been simulated

The existing scenario is modelled to have paving with 80% absorption, walls made of light material, 100% window to wall ratio and no shading on the sidewalks. The study has five improved variants of the street canyon for which the Mean radiant temperature (MRT) and Universal Thermal comfort Index (UTCI) are analysed on 28th April, the hottest day in Bangalore. The variants include, paving with 20% absorption, paving with 40% absorption, 75% shading of street, lower window to wall ratio, and increased thermal mass of adjacent walls. With the improved variants of the street, the MRT reduces from 61°C to 41°C and the UTCI reduces from 42°C to 37°C. In the base case, thermal distress is not felt for 12% of sunshine hours. In the best-case scenario (Variant5), 41% of the sunshine hours has no thermal stress and is comfortable.

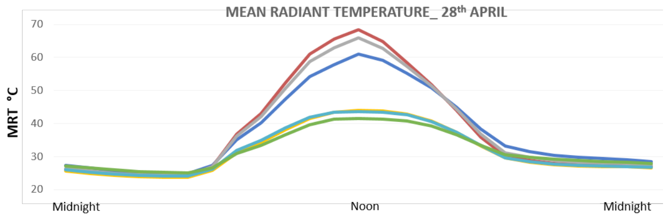


Image 10: Mean Radiant Temperature for variants on hottest day

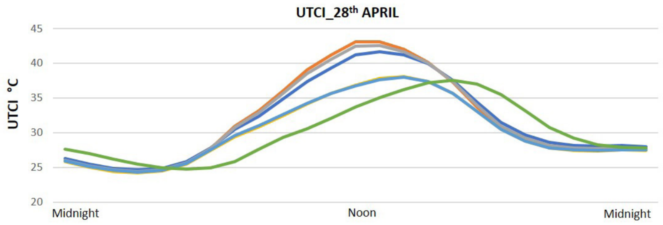


Image 11: Universal Thermal Comfort Index for variants on hottest day

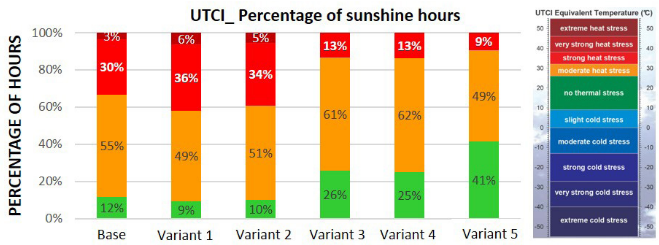


Image 12: Sunshine hours and thermal stress of variants

ANALYSIS OF COMFORTABLE WALKING DURATION

Using the WWW Thermal Comfort Index Calculator by de Dear, the time step at which a pedestrian in Bangalore feels uncomfortable walking in the base case and best-case urban street is simulated. T_{air}, RH, MRT, metabolic rate, Clo, V_{air} and the time steps are fed into the tool until the resultant DISC value is greater than two, where a pedestrian feels uncomfortable and unpleasant.

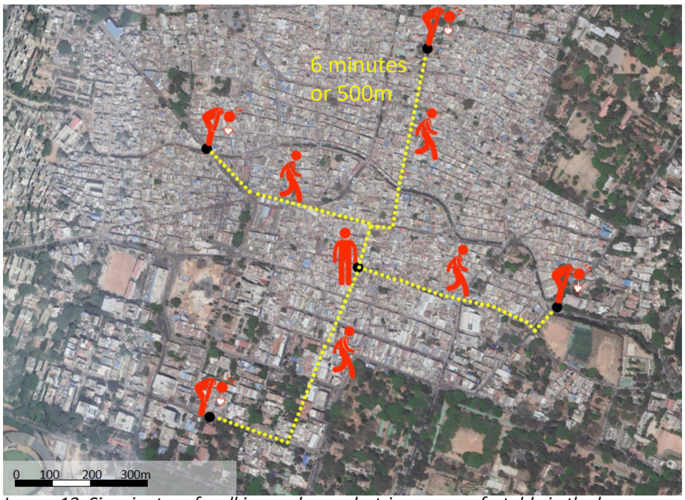


Image 13: Six minutes of walking makes pedestrians uncomfortable in the base case

The resultant comfortable walk duration for the base case is 6 minutes or 500 meters and in the best- case scenario it is 10 minutes or 850 meters. The pedestrian here is assumed to have an average walking speed of 1.4m/s and a metabolic rate of 150W/m2. A differently abled pedestrian moves with a velocity of 1.1m/s and has a metabolic rate of 100W/m2. In the case of a differently abled person, discomfort sets in at 8 minutes in the base case and 12 minutes in the best-case scenario.

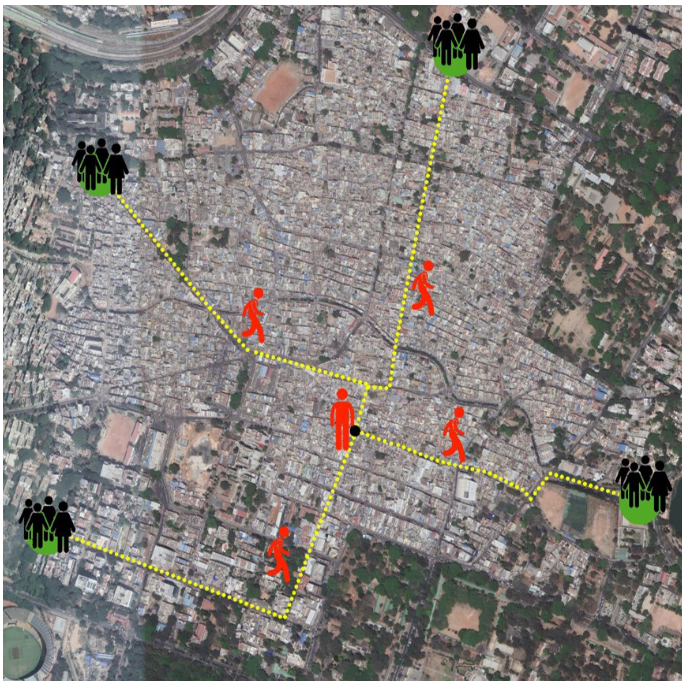


Image 14: Spacing of cool Pockets at 10 minute or 850m

DESIGN OF COOL POCKETS

The analysis of comfortable walking duration gives the average distance at which cool pockets need to be located, the distance being every 850 meters. The cool pocket is modelled with 4 variants, Variant 5 having the properties of the best-case street, with improvements such as 100% shading, addition of evapo-transpiration by having a water-body and green walls, and elevated wind speed of 2m/s. Variant 8, the best performing variant of the cool spot has a UTCI of 34 °C and for 84% of the sunshine hours there is no thermal stress and the space is comfortable. The MRT temperature of the cool pocket is 30.5°C. When a pedestrian enters the cool pocket, the body reaches a state of thermal equilibrium having spent 2 minutes standing or sitting in this pocket park.

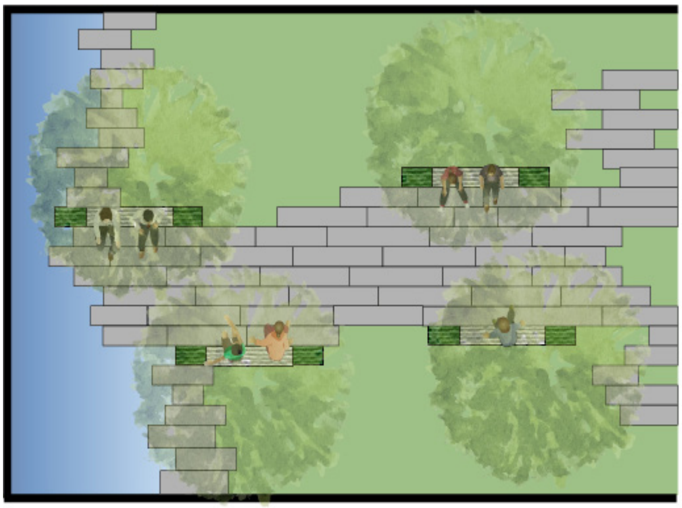


Image 15: Design of cool pocket with 100% shading, water body, green wall, and elevated air movement

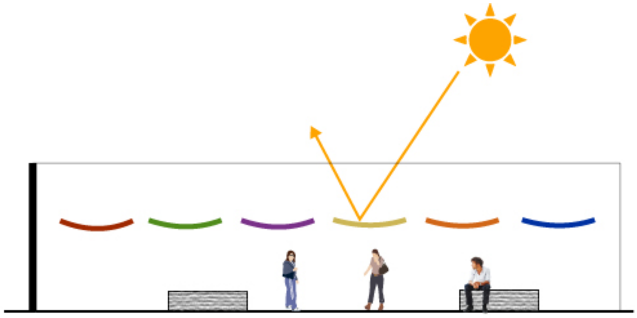


Image 16: Variant 5, Cool Pocket with 75% shading

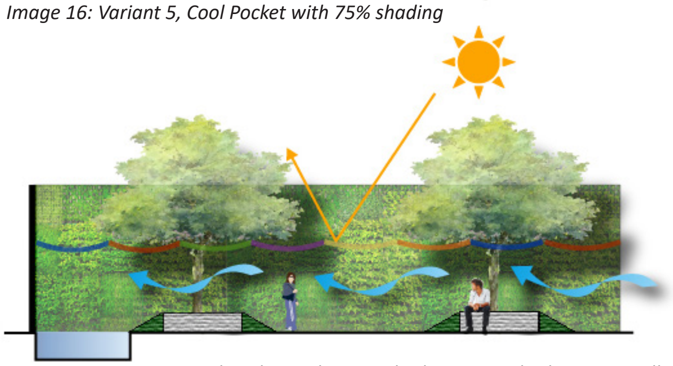


Image 17: Variant 8, cool pocket with 100% shading, water body, green wall, and elevated air movement

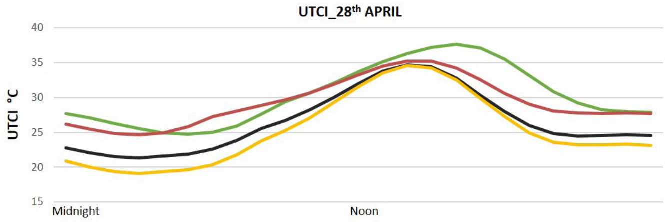


Image 18: Universal Thermal Comfort Index for cool pocket variants

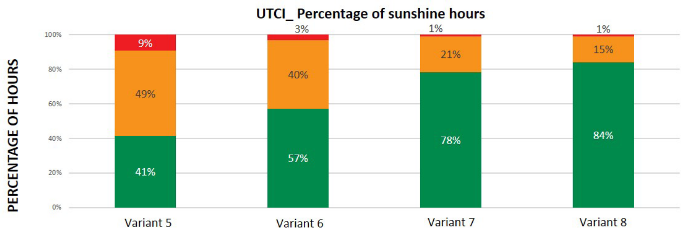


Image 19: Cool Pocket is comfortable for 84% of the sunshine hours

CONCLUSION

If cool pockets were to be designed for the base case scenario, they would be placed at 500m intervals, which is not feasible in a city. In the enhanced scenario of urban streets, cool pockets are required at 850m intervals, as pedestrians can walk longer before getting uncomfortable. Cool pockets and better street design provide healthier urban streetscapes, environmental quality, social interaction, safety, and thermal comfort for pedestrians resulting in an enriched walking experience and better walkability. The outcome of this research, is to facilitate designing of sustainable urban streetscapes that address the parameters of walkability to achieve healthy and happy cities.

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