CREATING PUBLIC SPACES WITH THERMAL COMFORT IN VEHICULAR dominated STREETS IN BULAWAYO

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Abstract:
The Central business district of Bulawayo is made up of 17 avenues and 11 streets which are wide (approximately 27-32 metres), in a grid pattern on a flat terrain. The wide streets are attracting more vehicles including a concentration of vendors lining up on the streets selling their wares. This has resulted in a city centre without usable public and pedestrian space which people can use safely. This research aimed at developing a concept of reclaiming space from vehicular traffic in the streets and use it for attractive public spaces incorporating different social public activities with outdoor thermal comfort being a requirement. The identified needs of the people include; eating spaces, relaxation spaces, street vending spaces and public speaking and street theatre spaces. Space is created from the streets to accommodate the different needs of the people by zoning the city centre into islands. The islands organize the city roads into two different networks; the primary network for high traffic volume of public transport at higher speeds and the secondary network for low traffic volumes of private and emergency vehicles at low speed.
Strategies for achieving thermal comfort in the street spaces between 0700 hrs till 1800 hrs are investigated by first conducting a climate analysis of Bulawayo. The Universal Thermal Climate Index (UTCI) outdoor comfort analysis results show that in the coldest season (June to August) there is a 70% comfortable (no thermal stress) perception and the hottest season (September to November) there is a 40% comfortable (no thermal stress) perception. The main reason for this is because out of the annual total horizontal insolation of 1856kWh/m^2 which Bulawayo receives, 547kWh/m^2/ (29% of the total) is received in the hottest season. This informs the target period of concern for thermal comfort to be the hottest period during the time (0700hrs till 1800hrs).
A thermal behaviour analysis using the software TRNLIZARD proves that outdoor thermal comfort can be achieved during the hottest period to above 70% comfortable (no thermal stress) using the strategies of; shading direct solar radiation, increasing air movement by fans, adiabatic cooling, cooling by plants through evapotranspiration and the use of cool and green surfaces.
The research therefore offers a solution that can reshape the city centre of Bulawayo by providing highly comfortable public spaces in the streets. This ultimately provides an inclusive design that facilitates social inclusion and empowers the local people through enhancement of socio-economic activities.

Introduction

The ever-increasing concentration of people in the cities linked with a focus on the sustainability of cities has led to a new focus on the quality of public urban spaces. The city is urbanising at a very quick pace and now struggling with automobile congestion because the vehicular traffic increases every day. The wide streets (27-32 metres wide) in the city were designed peculiarly for the simple reason to allow a span of oxen pulling carts to turn without difficulty. This was supposed to ease traffic congestion and provide more usable space for citizens but instead, the wider streets are attracting more vehicles.

Figure 1 : Location of the city of Bulawayo in Zimbabwe

Climate context

Zimbabwe's second largest city Bulawayo (20.1325° S, 28.6265° E) under the Köppen climate classification, features a drier version of the humid subtropical climate, and lies on an altitude of 1 358m.

The daily outdoor temperatures range from 3°C - 37°C annually. The coldest period is from June to end of August and the hottest period occurs from September till the end of November. *(see figure 2)*

The daily summer (December – April) temperatures fluctuate between 12°C - 32°C, and is characterized by hot, cloudy and rainy days. The average winter (June – August) temperatures range from 3°C - 27°C and is characterized by dry, sunny days and cold nights. The skies are clear and its windy during the cold season. *(figure 2)*

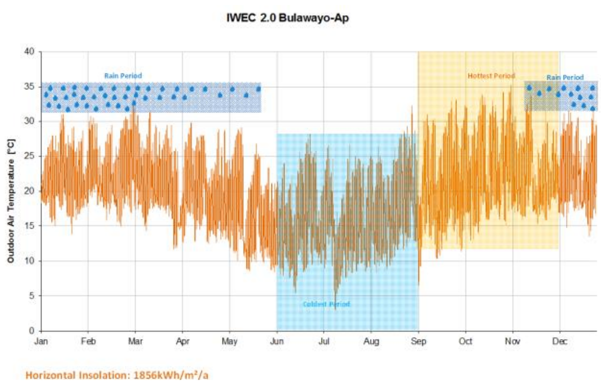

Figure 2: Annual climatic conditions for Bulawayo (Transsolar)

The city experiences wind predominantly from the South Easterly throughout the year. Bulawayo receives a total horizontal insolation of 1856kWh/m^2/a. There is more diffuse radiation than beam radiation from November – March because of the summer cloud cover. *(See figure 3)*

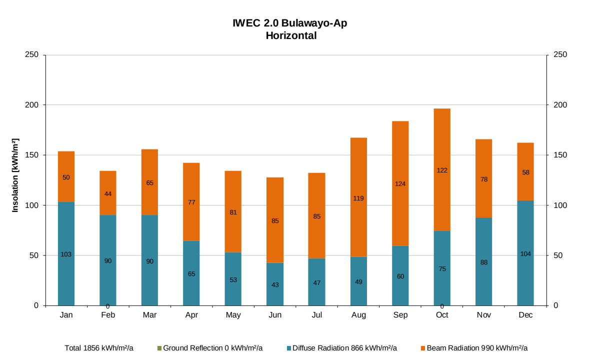

Figure 3: Annual climatic conditions for Bulawayo (Transsolar)

Socio-economic context

Bulawayo is an industrial town which is home to many manufacturing industries. Over the years however many of the industries were affected by the economic meltdown and closed forcing several people into unemployment. The city is strategically located to the borders with South Africa, Botswana and Zambia which enhances cross border trade to be the most common source of livelihood. Informal employment also plays a major part as the poor migrate to seek casual work opportunities in the farms on the outskirts of the city during the agricultural seasons whilst others survive on vending.

Figure 4: A view of the city of Bulawayo (Zimbabwe Tourism Authority)

Motivation

The wide streets in the city centre have attracted more vehicles including the concentration of vendors lining up the streets selling their wares. The result has been a chaotic city centre environment hence the need to provide a solution that fosters attractive spaces incorporating different social public activities with outdoor thermal comfort being a requirement. The solution entails the development of a strategy for the creation of public spaces in the city centre through reclaiming space from vehicular traffic in the streets.

The approach

Firstly, the needs of the people are identified which include: Eating spaces, relaxation spaces, street vending spaces and public speaking and street theatre,
(See figure 5).

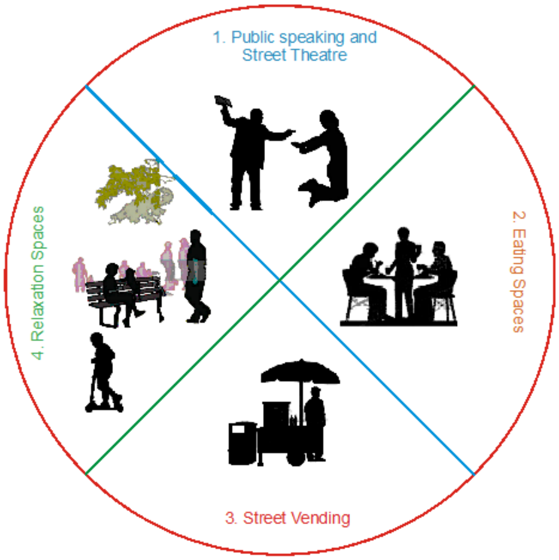

Figure 5: Identification of the needs of people which require space in the city.

The current vehicular circulation in the city is chaotic and not well regulated. Any type of vehicle can just move around using any route. *(see figure 6)*

Figure 6: The existing traffic situation in the city centre.

The creation of space for the people needs is done by creating islands in the city centre, to make it easier to select streets for pedestrian and cycle zoning. The islands organize city roads into two different networks. The Primary network has high traffic volume and is for public transport and vehicles at a higher speed of 50km/h. *(see figure 7)*

The Secondary network has low traffic volumes moving at speeds not more than 20km/h. This one is used by local traffic only and emergency vehicles *(see figure 7).*

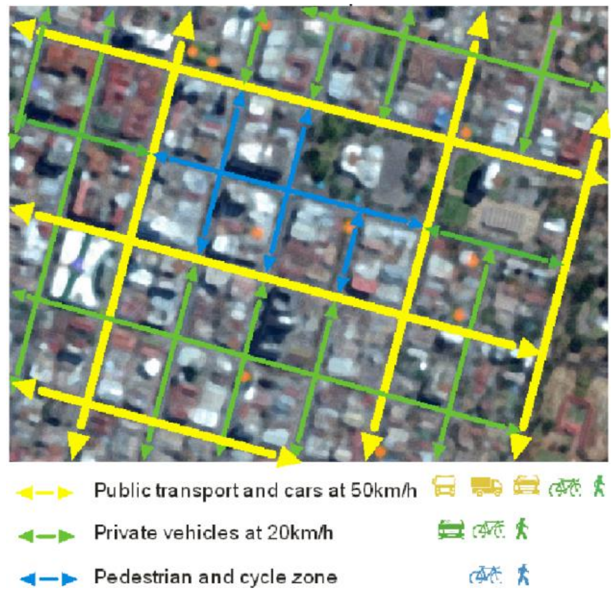

Figure 7: Process of creating space and solving the traffic situation.

After identifying the space, strategies to achieve thermal comfort are developed since the streets are all exposed to weather elements. In this project, the focus area is the pedestrian and cycle zone. *(see figure 7)* The city centre is mainly used during the day which is the reason for designing for thermal comfort between 0700hrs till 1800hrs. All the streets in the focus area are analysed but the results for the street with the extreme conditions are presented in this paper. The street running South-East to North-West has the extreme conditions because it receives direct solar radiation throughout the day during the hottest period.

Outdoor thermal comfort

The main aim of this research is to create spaces in the street with thermal comfort as a way of providing people with high quality outdoor spaces.

A thermal behaviour analysis of the existing streets' condition is done from which design strategies to achieve thermal comfort in the street for people are derived. This research focused on design-dependent strategies and their possible effects on thermal comfort within the streets of Bulawayo. This was all limited to the street, where landscaping could be done, and shading systems created. The numerical thermal behaviour of the street design scenario is simulated using the software TRNLIZARD. To quantify the comfort, the Universal Thermal Climate Index (UTCI) was selected. The UTCI is calculated using the dry bulb temperature, mean radiant temperature (Tmrt), humidity ratio, wind speed, metabolism and clothing. *(see figure 8)* The UTCI indicates what the temperature feels like as an output in °C. The assumption made is that the comfortable (no thermal stress) range is 9-26°C.

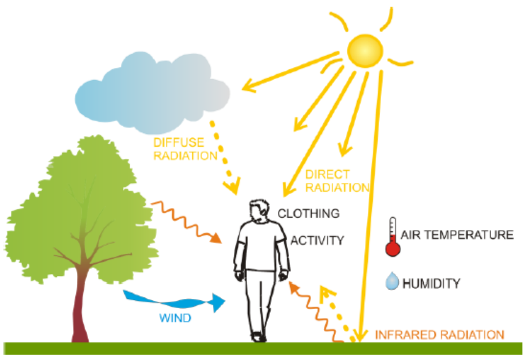

Figure 8: Major parameters characterizing outdoor comfort. (Kessling et al. 2013)

Principle of the UTCI

The Universal Thermal Climate Index (UTCI), derived from the Fiala multi-node model, is defined as the air temperature (ta) of the reference condition causing the same model response (strain: sweat production, shivering, skin wettedness and skin blood flow as well as in rectal, mean skin and face temperatures) as the actual conditions (Fiala et al. 2012).

The offset, i.e. the deviation of UTCI from air temperature depends on the actual values of air temperature (ta) and mean radiant temperature (Tmrt), wind speed (v) and water vapour pressure (vp). The general mathematical terms can be written as below:

UTCI = f (ta ; Tmrt; v; vp) = ta + Offset (ta; Tmrt; v; vp), (Bröde et al. 2012)

The simulations by TRNLIZARD used the equation above to calculate the UTCI. The unknown important value which is calculated by the simulation is the Mean radiant temperature (Tmrt)

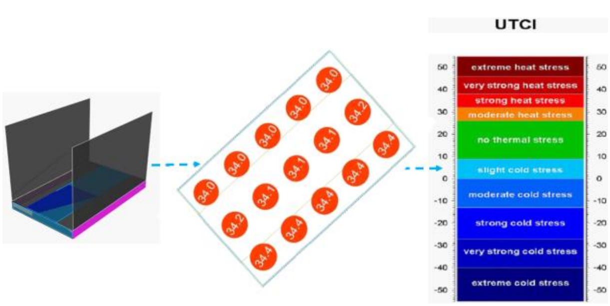

Figure 9: Process of calculating the UTCI

A shoe box model of the exact street was modelled in TRNLIZARD with the parameters mentioned above as the inputs. Comfort points are created to show the thermal perceptions at 15 different points in the street. The existing conditions are simulated for the selected area (pedestrian and cycle zone in figure 7) to understand the current situation.

The worst-case scenarios for the hottest and coldest period were simulated.

The hottest period simulation was based on the extreme conditions that we can have which include; exposure to solar radiation, and no still wind movement. The results show a 30% (no thermal stress) perception as shown in figure 9.

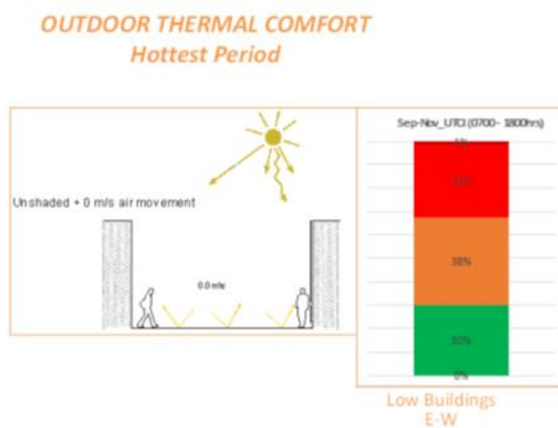

Figure 10: The worst-case scenario simulation results for the hottest period.

The coldest period simulation uses the extreme conditions of high wind velocity at 6m/s and the results show a 58% (no thermal stress) perception. This is shown in *figure 11*.

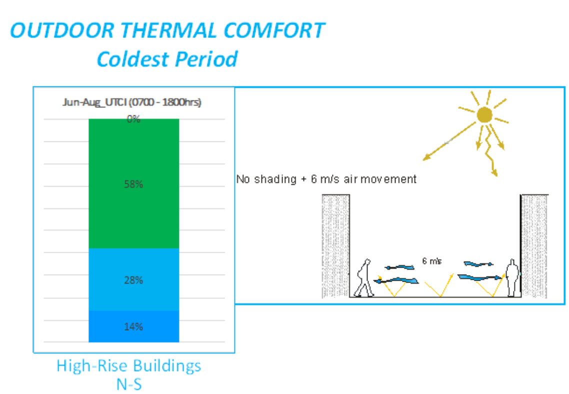

Figure 11: The worst-case scenario simulation results for the coldest period.

The need to create thermal comfort in the street is because its exposed to all weather elements and different environmental effects *(see figure 12)*. A typical layout of the existing street is shown in figure 12 and thermal perception assessment is done at points A; B and C for the hottest period (September - November)

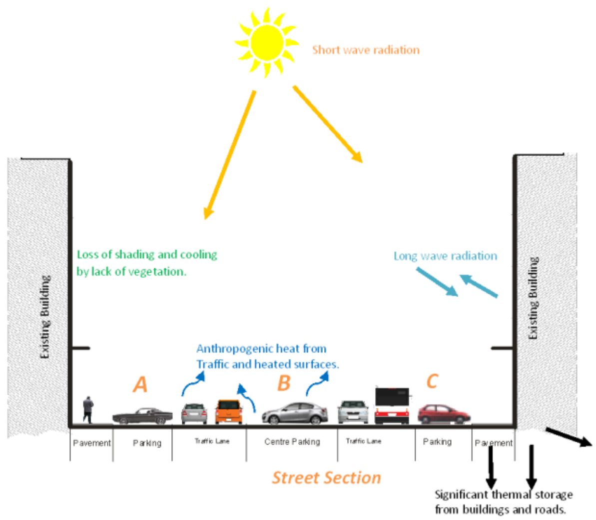

Figure 12: The Existing street section.

The results are quantified in terms of the Universal Thermal Climate Index (UTCI). The results show that there is 28.5% (no thermal stress) perception at point A *(see figure 14).*

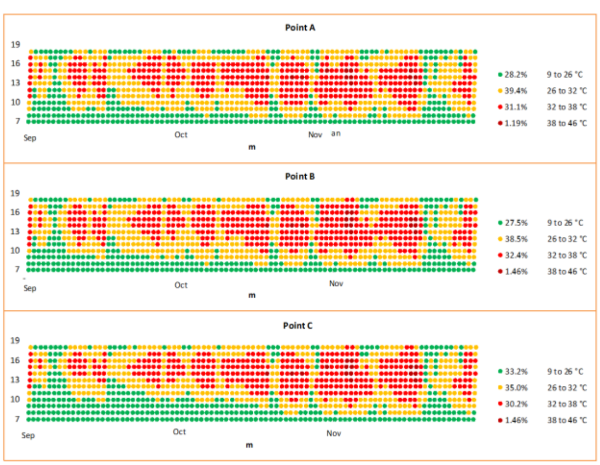

Figure 14: Existing thermal comfort perceptions in the street.

At point B and C there is 27.5% and 33.2% (no thermal stress) perception respectively. *(see figure 11)*

Strategies for the hottest period

The following strategies are employed. The first strategy *(figure 15)* is the application of 50% shading (in the form of a 4m overhang to the side walls) and an increase of 17% in the (no thermal stress) perception is achieved to 47%.

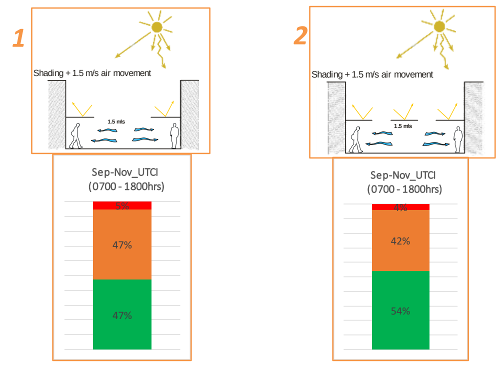

Figure 15: Strategies for the hottest period.

The second strategy *(figure 15)* is an increase in the shading to 75% (using umbrellas, retractable awnings and planting trees in the centre of the streets) and an increase of 7% in the (no thermal stress) perception from the first strategy is achieved to 54%.

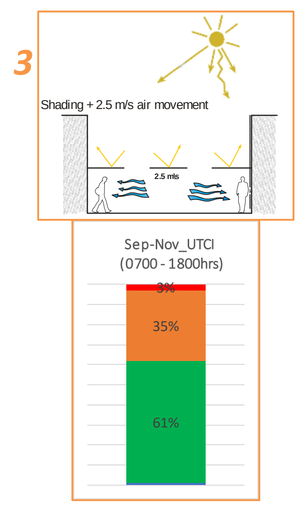

Figure 16: Strategies for the hottest period.

The third strategy (*figure 16)* is increasing the air movement to 2.5m/s using a fan and an increase of 7% in the (no thermal stress) perception from the second strategy is achieved to 61%.

The fourth strategy (*figure 17)* introduces 10% of adiabatic cooling and an increase of 2% in the (no thermal stress) perception. The results show a very small improvement in thermal comfort.

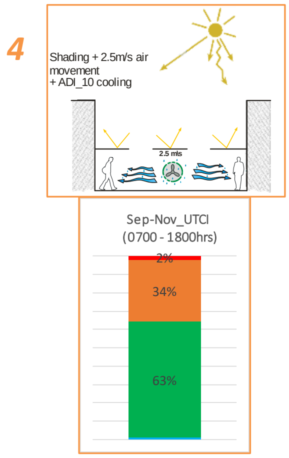

Figure 17: Strategies for the hottest period.

The street design proposal (Discussion)
A strategy of coming up with a street design that provides the spaces required by people is devised. The idea is based on providing outdoor eating spaces close to the buildings and relaxation spaces. Street vending spaces were placed central along the streets to provide circulation space on either side of the centrally positioned vending stalls. *(see figure 18)*
At the intersection of streets, the proposal placed the public speaking and street theatre. This is basing on making the activity to be at the meeting points.

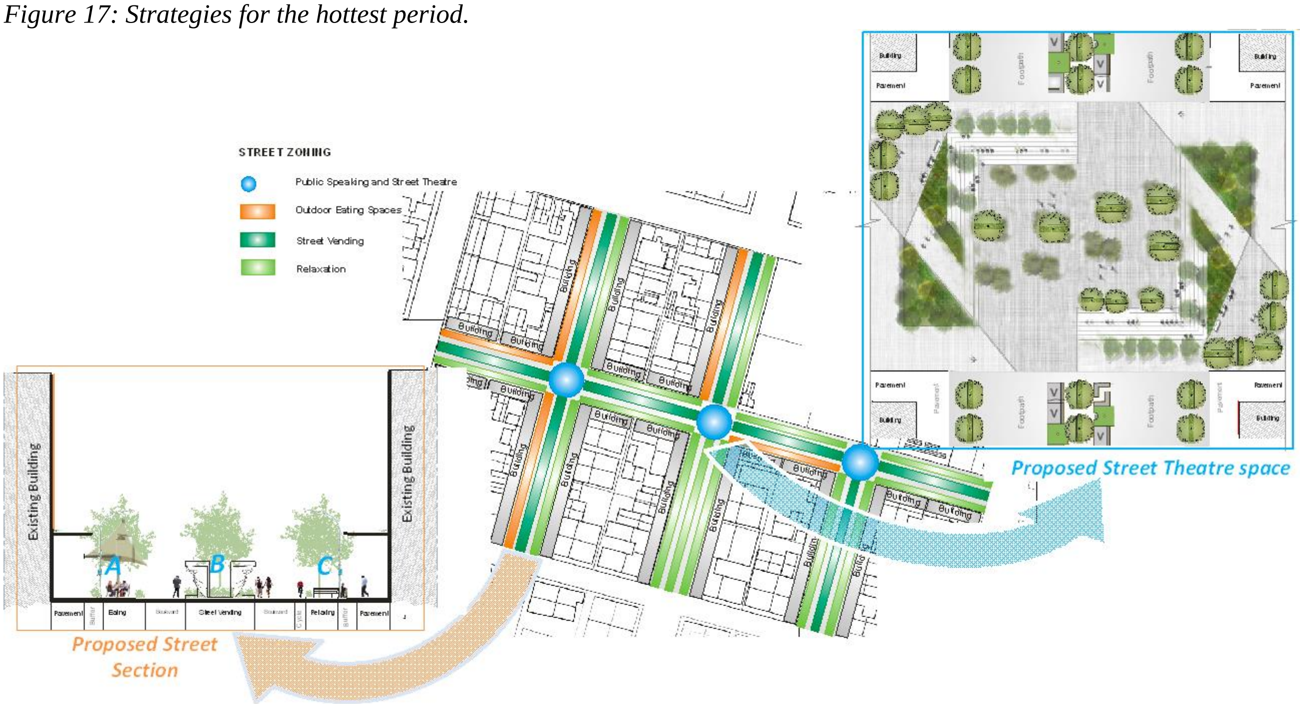

Figure 18: The proposed full street design

Final Results
All the street orientations are evaluated but in this report the South-Easterly to North-Westerly street will be presented because of its exposure to the direct solar radiation throughout the day.
Strategy 1: Providing shading during the hottest period improves the thermal comfort. By taking note of the same street section in *figure 12*, the shading is applied to all the points A, B and C. This is made possible using deciduous trees and movable shading elements. This makes it possible to allow the solar radiation in the coldest period for thermal comfort.

Strategy 2: Increasing the air speed improves the thermal comfort significantly. This is achieved using fans

especially in the vending stalls which can be powered by solar energy.
Strategy 3 : The use of adiabatic cooling is evaluated by using fans with nozzles that spray mist (water droplets) into the air. This is done at a rate of 1.7litres/hr. These can also be used in relaxation and outdoor eating spaces.

Strategy 4 and 5: The effect of cooling by plants through evapotranspiration and using cool and green surfaces are not simulated in this research. Other researches have proved that these help in the sharp reduction in short-wave radiation absorbed directly by the body which reduces both short-wave reflection and long-wave emission due to their reduced radiant temperature.

To achieve comfort on the street theatre and public speaking space, shading is proposed using trees.

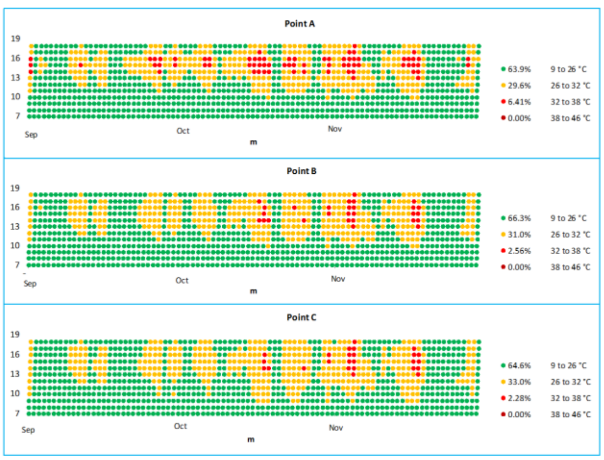

Figure 19: Thermal comfort perceptions after strategies.

The thermal comfort perceptions after using the stated strategies show that at point A we achieve 63.9% of (no thermal stress) from an existing initial value of 28.5%. (*See figure 19).*

At point B 66.3% of (no thermal stress) perception is achieved from an existing initial value of 27.5%. Point C has a 64.6% (no thermal stress) perception value from an initial existing value of 33.2% as shown in *figure 19.*

Conclusion

The research findings show that each strategy makes a clear contribution to improved comfort, with the greatest reduction in thermal stress provided by a combination of shading and increased air velocity.
The solution provides a solution of coming up with heat resilient public spaces which support vitality and usability especially during the Zimbabwean summer and Spring times when outdoor air temperatures go above 30°C. The use of improved climate based design strategies aids in a result of a more balanced urban environment where everyone feels happy and safe including empowering the social and economic capacity of the local community. This is achieved by the provision of vending spaces and spatial expansion of outdoor relaxation and eating spaces. Since outdoor thermal comfort is a key determinant in the use of outdoor public spaces, it helps in making sure spaces are constantly used by making spaces to have a good level of comfort.

Acknowledgements:
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References

1. *Bröde, P., D. Fiala, K. Błażejczyk, I. Holmér, G. Jendritzky, B. Kampmann, B. Tinz* and *G. Havenith* 2012: Deriving the operational procedure for the Universal Thermal Climate Index (UTCI). – International Journal of Biometeorology **56** (3): 481-494.
2. *Fiala, D., G. Havenith, P. Bröde, B. Kampmann* and *G. Jendritzky* 2012: UTCI-Fiala multi-node model of human heat transfer and temperature regulation. – International Journal of Biometeorology **56** (3): 429-441.
3. *Kessling, W., M. Engelhardt, D. Kiehlmann, 2013:* The Human Bio-Meteorological Chart, A design tool for outdoor thermal comfort. – **29th** Conference, Sustainable Architecture for a Renewable Future. Munich. Germany.
4. *Zimbabwe Tourism Authority*: Travel Guide to Bulawayo., *zimbabwetourism.net/index.php/travel-guide/travel-guide-to-bulawayo/*...N.p., 23 Aug. 2017.