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INFLUENCE OF TREE SHADE LEVEL ON COMFORT PERCEPTION - A CASE STUDY OF OUTDOOR PUBLIC SPACES OF VIHARAMAHADEVI PARK, COLOMBO

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Abstract
Trees play a vital role in the Sri Lankan context in providing thermal comfort in many outdoor spaces including public parks. But most trees have not been effectively chosen and positioned for public comfort. The research focuses on the impact of sky visibility, through tree canopies, on the perception of comfort for people in outdoor urban public spaces. Viewing the sky has psychological and physical benefits as well as aesthetic appeal. The aim of the research is to find optimum levels of tree shade and sky view that should be provided by trees for human comfort. The study was conducted in Viharamahadevi Park, Colombo. The plant area index (PAI) was used to categorize the tree shade level and was calculated using the software CAN-EYE, based on 'fish-eye' lens photographs, together with a perception survey of users. It was found that satisfactory sky view was proportional to the perceived comfort. In the morning, people were comfortable in moderate to high shade (PAI 0.72 to 4.48), but in the evening people were comfortable in slight to moderate shade (PAI -0.93 to 1.07). The discussion will show that a certain level of sky view does not reduce thermal comfort perception and is necessary for better outdoor comfort.

Keywords: *Comfort Perception, Sky View, Tree Shade, Plant Area Index, Public Outdoor Space.*

1. Background

The demands of the growing population has resulted in urban areas expanding and building densities increasing. This has altered the surface energy and moisture balance of urban areas and led to environmental issues such as the urban heat island (UHI) effect, human thermal discomfort, air quality degradation, and microclimate modification (Zhao et al., 2018). The quality of outdoor spaces in urban areas plays a fundamental role in quality of life within cities (Makaremi et al., 2012). In order to sustain life outdoors it is important that we try to make urban spaces comfortable as far as the ambient climate permits. One such way is providing thermal comfort. Outdoor thermal comfort is a complex function of atmospheric conditions and physical, physiological, psychological, and behavioural factors. But thermal comfort is not the only comfort factor necessary for creating comfortable outdoor spaces, visual comfort is also deemed important.

Landscape must be able to affect the human's visual comfort in a positive way and a highly aesthetic landscape would affect human psychology and behaviour as well (Othman, Mohamed, & Ariffin, 2015). The vegetation density, shade patterns, shadows, view and colour of the sky, sky line and surrounding views impact the visual and aesthetic comfort in an urban setting. Vegetated spaces in urban areas are essential to improve people's living environment ecologically and aesthetically (Song & Wang, 2015). Trees are one of the most important components of urban green infrastructure and is becoming an integral feature of urban designs (Tzoulas et al., 2007). Trees provide multiple microclimate benefits by reducing solar radiation penetration, reducing net energy absorption by canopy shading, blocking the exchange of long-wave (infrared) radiation inside urban canyons and generating evapotranspiration (Wang et al., 2016). The importance of shade to reduce thermal stress in hot climates has been emphasized by several authors (Johansson & Emmanuel, 2006; Vanos et al., 2010). It is very important to understand how spatial environments affect thermal perception. Naturalness and aesthetic appreciation of the environment are some psychological aspects that influence perceived thermal comfort (Nikolopoulou & Steemers, 2003). It is a positive factor that in Sri Lanka shade trees are extensively used in outdoor spaces to provide shade instead of using artificial (built) means. But in choosing trees for urban outdoor spaces, special attention has not been given to comfort that different trees provide with their characteristics and thus, trees are not utilised effectively.

In addition to vegetation, the sky is also an important factor of the environment for outdoor experience. The sky is an element of nature that has been admired by many for its beauty. In addition to its aesthetic qualities, viewing the sky both intentionally and unintentionally has psychological impacts on people. In the "Experience of Landscape" (Appleton, 1975), the sense of prospect is signalled by distant brightness and refuge is signalled by shadow. High prospect environments include open views to the horizon and a luminous sky ('big sky'). A sense of refuge is provided by shadows from tree canopies, cliff overhangs, or other natural forms. The shade solutions provided for thermal comfort in outdoor spaces can block sky visibility during the limited amount of time the urban population spend outdoors. Most of these solutions provided in the daytime is not needed at night and they unnecessarily block the night sky view. An important finding by Smardon (1988) was that the relationship between preference and amount of trees and other vegetation may be non-monotonic, that is, vegetation up to a point which then might flatten out or possibly decline (Smardon, 1988). Therefore, understanding the shade conditions that provide comfort to the person using it, in terms of canopy gaps and the perception of thermal comfort of the users becomes important. A balance between shade and view of the sky needs to be established when designing for urban outdoor environments. Adequate research has not been done on the amount of sky visible that will create the highest outdoor comfort (both thermal and psychological). So the need arises to find the adequate amount of shade for human comfort that provides both thermal comfort and sky visibility. This is deemed to be a worthy study area as it is necessary for the wellbeing of the urban public, increasing the usability of public spaces.

The primary objective of the study is to examine the impact of different tree shade levels - therefore sky visibility - according to their Plant Area Index, on perceived human comfort and analyse which tree shade patterns provide better comfort to the user - both physiologically and psychologically.

1.1. LEAF AREA INDEX (LAI) AND PLANT AREA INDEX (PAI) FOR QUANTIFYING TREE SHADE LEVEL

One well established index that describes the plant cover is the Leaf Area Index (Song et al., 2018). It is defined as projected leaf area per unit ground area (Gower & Norman, 1991 as cited in Song et al., 2018). The LAI and canopy density reflect the differences in the plant spatial structure. The results of many studies have shown that with an increase in LAI, the cooling effects of green space increases (Xiao et al., 2018). In contrast, Kong showed that the cooling effect of green LAI and sky visibility was different at different periods of time, with a peak from 9:00-19:00 and a decline from 13:00-15:00 due to the impact of high temperatures around noon (Xiao et al., 2018). However, instead of LAI this study uses Plant Area Index (PAI) which is an estimate of the fraction of ground shaded by the vertical projection of tree crowns (Pekin & Macfarlane, 2009). PAI may be more appropriate from which to compare the shade of individual trees, as LAI only focuses on the leaves (Breda, 2003), whereas PAI accounts for all the physical elements of the canopy such as branches, twigs, fruits, flowers and leaves (de Abreu- Harbich, Labaki, & Matzarakis, 2015; Macfarlane et al., 2007).

LAI can be estimated directly or indirectly. Direct methods measure LAI through litter fall or destructive sampling. Indirect methods estimate LAI via relationships with other more easily measurable parameters. But indirect measurements actually only allow assessing PAI, because it is not possible to know if some leaves are present behind the stems, branches or trunk. Therefore, masking some parts of the plants to keep only the visible leaves is not correct and could lead to large under-estimation of the actual LAI value, depending on the way leaves are grouped with the other parts of the plant. (Hardwick et al., 2015) Therefore, PAI instead of LAI is used. PAI indirect measurement techniques are based on contact frequency or gap fraction measurements. Contact frequency is the probability that a beam (or a probe) penetrating inside the canopy will come into contact with a vegetative element. Conversely, gap frequency is the probability that this beam will have no contact with the vegetation elements until it reaches a reference level (generally the ground). The term "gap fraction" is also often used and refers to the integrated value of the gap frequency over a given domain and thus, to the quantity that can be measured (Kaufmann et al., 2010), especially using hemispherical images.

2. Method

The study was conducted in a selected area of Viharamahadevi Park, Colombo 07. It is located in Colombo and is popular among the residents of Colombo as an outdoor recreation space because of its location with easy access to public transport, businesses, offices, shops and residences. The park has a large variety of trees. (see Figure 1.)

The behaviour of the people in the study area was recorded and a sample of 120 people were selected for the perception study. Of these 120 people; 5 person sample was chosen, where the users exceeded

tree lable	PAI	tree lable	PAI
76	-3.9	33	1.14
75	-2.05	7	1.23
19	-1.78	58	1.33
74	-1.22	54	1.49
11	-1.08	2	2
41	-1.05	66	2.33
1	-0.93	14	2.6
3	-0.93	36	2.7
40	-0.92	44	2.78
73	-0.6	39	2.81
69	-0.57	17	2.99
12	-0.44	46	3.2
60	-0.22	35	3.42
8	0.04	9	3.52
43	0.07	61	3.58
55	0.08	62	3.69
5	0.35	68	3.89
47	0.45	4	4
67	0.55	56	4.23
34	0.59	59	4.41
28	0.62	13	4.48
57	0.62	29	4.92
64	0.66	37	5.31
10	0.68	42	5.53
63	0.72	15	5.6
6	0.8	16	5.6
49	0.92	31	5.83
45	0.94	30	5.92
32	1	65	6.53
38	1.07	27	6.67
70	1.08	18	6.78
48	1.12		

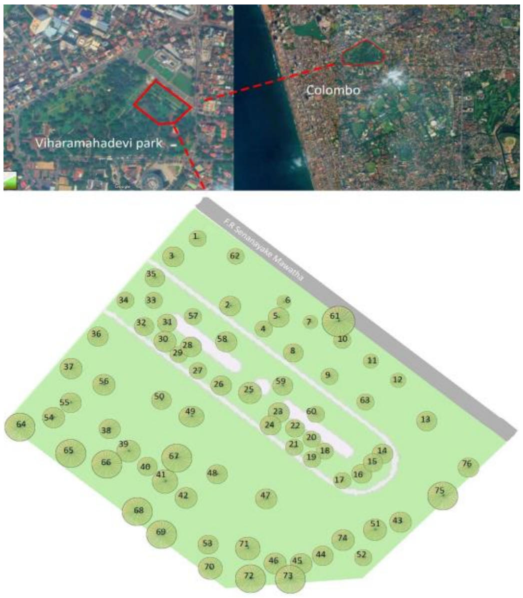

Figure 22. PAI of the trees in the plot with tree label. Orange colour bands for the trees chosen in the morning. Blue colour bands for the trees chosen in the evening

5 under a particular tree, during the two hour study period each in the morning and evening. Fourteen trees had more than five people enjoying its shade, thus surveyed. These included at least 10 people each of; Thin Canopy (PAI less than 1), Dense Canopy (PAI more than 1) and 10 people in Open Spaces with no tree shade were also chosen, in random, as a sample group.

Digital Hemispherical Photographs (DHP) were obtained close to sun rise under uniform sky conditions because the DHPs have to be taken under diffused light conditions. The acquisition parameters followed Macfarlane et.al. (2007). the digital camera was equipped with a (Nikkor 10.5mm fisheye lens). The lens was aligned to magnetic north and pointed upward using a levelled tripod. Upward DHP of each tree canopy in the study area was taken from 6.10am – 6.40am fulfilling the need to be taken under diffused light conditions. The photographs were analysed using the CAN-EYE V6.4.91 software to calculate the PAI of each tree in the study area and the percentage of sky and leaf cover. Subjective behaviour and response data was collected on four weekends; two Saturdays and two Sundays from 9am-11am and 4pm- 6pm on the basis that the selected study area in most active around those times and the sunlight condition was ideal.

Subjective response data were collected through the distribution of questionnaires and conducting interviews on the four weekends, in June 2018. The questionnaire was prepared with the use of Bedford scale 7 point scale of thermal comfort, the McIntyre 3-point scale and the Likert 5 point scale on general comfort. It was distributed to people who were staying in the shade of trees and open spaces in the study area.

The questionnaire collected the following data;

- The place of residence of each person
- Whether they spend most of their time indoors or outdoors.
- The period of time they have been staying in the place
- The reason for choosing the place they were staying at
- Whether they have changed space they were staying at, and if so, the reason for changing relaxing location.

- Their perception of the visible sky
- Their perceived thermal comfort
- Their perceived comfort (psychological and physical)
- Their preference for the amount of sunlight, the brightness of the sun, the illuminance of the space, feeling sleepy, wanting to stay for more than an hour, wanting the sky to be more visible and the feeling of personal safety.

3. Results and Discussion

The range of the PAI of the trees in the study area is from -3.9 to 6.78 (see Figure 1), -3.9 being the tree with the most sky visible through the canopy and 6.78 being the tree with a denser canopy and the least sky visible through the canopy. For the purpose of this study, PAIs were categorised into five shade levels according to the amount of sunlight coming through the canopy; 1) -3.90 to -1.76 : very slight shade, 2) -1.76 to 0.39 : slight shade, 3) 0.37 to 2.50 : moderate shade, 4) 2.50 to 4.64 : high shade, 5) 4.64 to 6.78 : very high shade**.**

3.1. SHADE PREFERENCE DATA ANALYSIS DURING MORNING HOURS

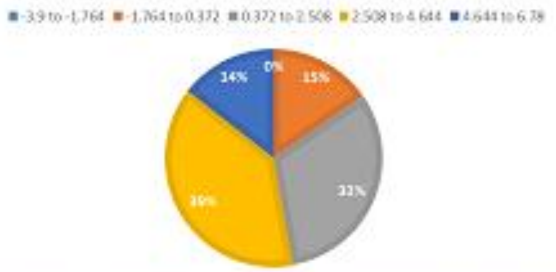

Figure 2. Number of people under tree shade according to tree PAI value intervals -

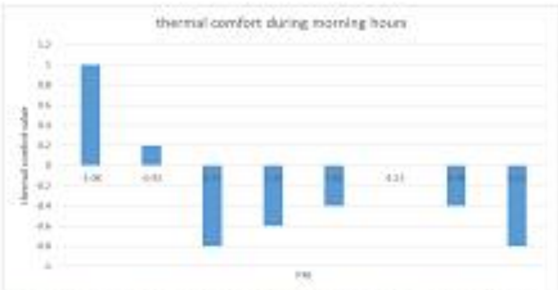

Figure 3. Thermal comfort to PAI relationship - Morning

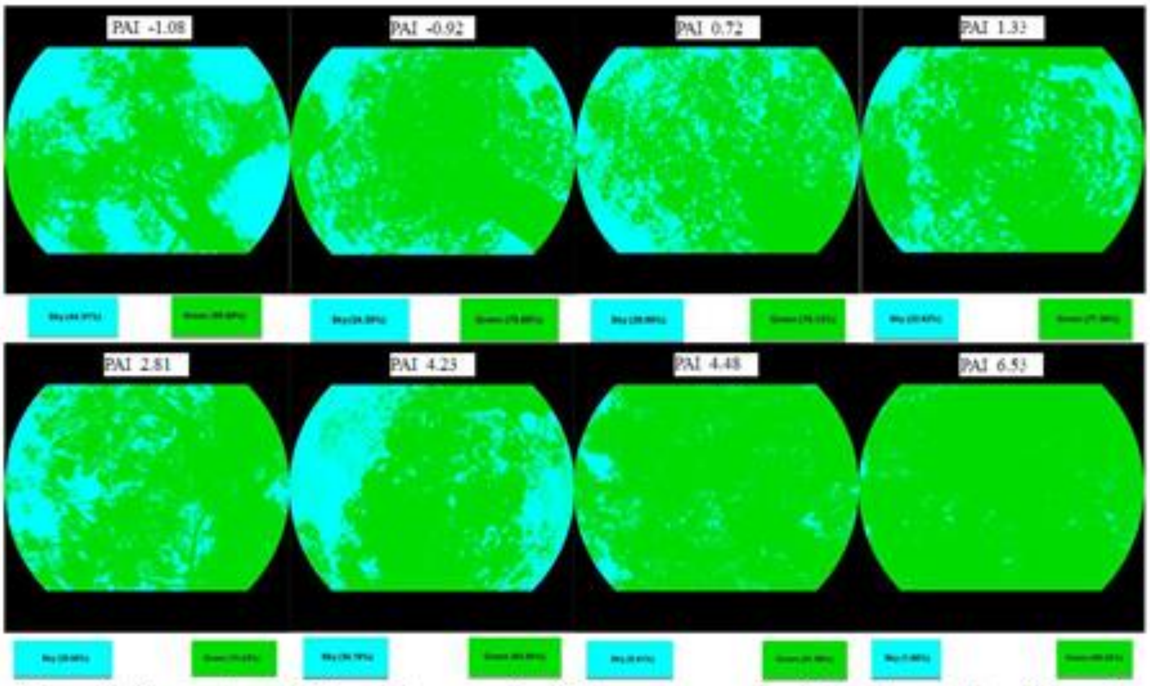

Figure 4. Percentage of sky and green of each tree canopy selected to stay under during the morning. Percentage calculated by CAN-EYE V6.4.91

The average temperature during the morning study period 9am – 11am was 30^{o}C. The trees chosen by the users during the morning hours had a wide range of PAIs. It is seen that there is a tendency for people choosing trees with a denser canopy and less view of the sky during morning hours. (see Figure 2.), although a clear pattern is not evident. An example of this is - during the morning time where the brightness of the sun is high, 15% of the people chose trees with low PAIs. The perceived thermal comfort under the trees in relation to PAI shows a clear pattern where beyond a certain PAI threshold the thermal comfort increases with increasing PAI. (see Figure 3.)

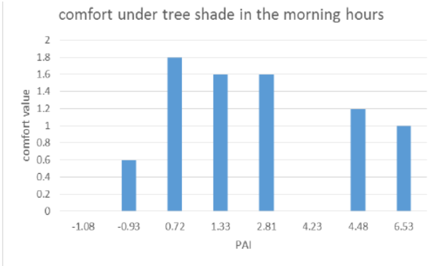

Figure 23. Comfort under the selected trees according to their PAI in the morning

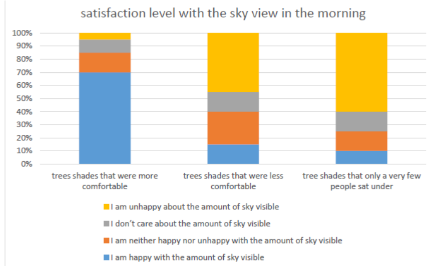

Figure 6. Satisfaction level in relation to the sky view - Morning

In analysing the data on overall comfort - physiological and psychological - the results paint a different picture. The results show a depreciating comfort value for very high PAIs and very low PAIs. Thus, demonstrates an ideal value, where a quantum of sky view is desired by the user. (see Figure 5 / 6.)
Figure 7 shows that the primary reason people relocate from one shade tree to another is the level of shade it provides. (see Figure 7.)

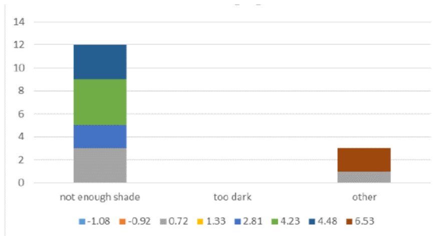

Figure 7. Reason for changing location, in the morning

The trees that gave the most comfortable shade were not the trees that gave the most thermal comfort underneath. The reason for this can be analysed according to the preference votes for the factors that affect comfort. (see Figure 3/4/5)

Comparative analysis of PAI based, survey categories in the morning hours (see Figure 8.) show the sense of safety increases with increasing PAI and with it the desire to stay more than an hour in the setting. The desire for sky view transitions from 'disagree' to 'agree' with the canopy becoming denser with increased PAI, thus signifying the importance of shade to sky view balance. The results also show that beyond a PAI of 2.81, people perceived that it was getting too dark, confirming the statement above.

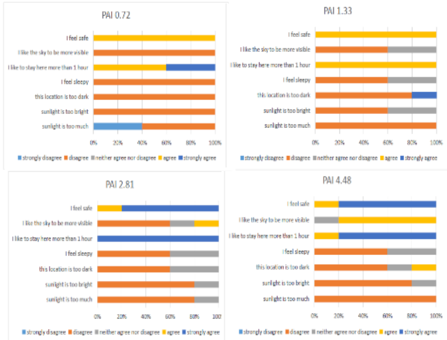

Figure 8 Preference votes of trees with PAI

3.2 SHADE PREFERENCE DATA ANALYSIS DURING EVENING HOURS

The average temperature during the evening study period 4 pm – 6 pm was 31°C. The trees chosen by the users during the evening hours had a short range of PAIs. It is seen that there is a high tendency for people to choose trees with less denser canopies and more view of the sky during evening hours. The highest percentage, 58%, of people were under trees with PAI range from 0.372 to 1.764. The second highest, 29%, were from trees with PAI range from 0.372 to 2.508. These PAI values allow a significant amount of sunlight through the canopy. The highest percentage of people were not under the trees with the highest PAI, as only 8% were under trees with PAI range from 2.508 to 6.78. In the evening, the highest percentage of people preferred to stay under trees with slight shade. The second highest percentage of people preferred to stay under trees with moderate shade. A very small percentage of people were staying under trees with very slight shade and high shade. No people were found staying under trees with very high shade.

Figure 10 compares the perceived thermal comfort of people (5 or more people) under shade trees, in the evening hours, as against the PAI values. A perceived Thermal Comfort Value of zero is defined as comfortable. Unlike in the morning hours, the thermal perception of people surveyed, does not show a clear pattern in relation to the PAI of the trees in question. The values differ by only slight margins, and close to the comfort threshold of '0'. Therefore, it can be deduced that most people were comfortable under trees in the evening. Trees with a PAI of 2.81 was seen as the most comfortable.

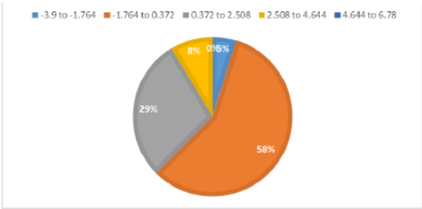

Figure 9. Number of people under tree shade according to tree PAI value intervals - Evening

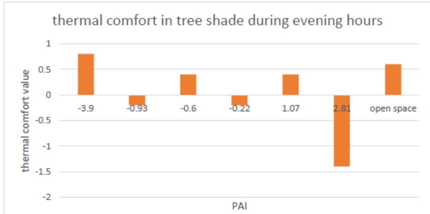

Figure 10. Thermal comfort to PAI relationship - Evening

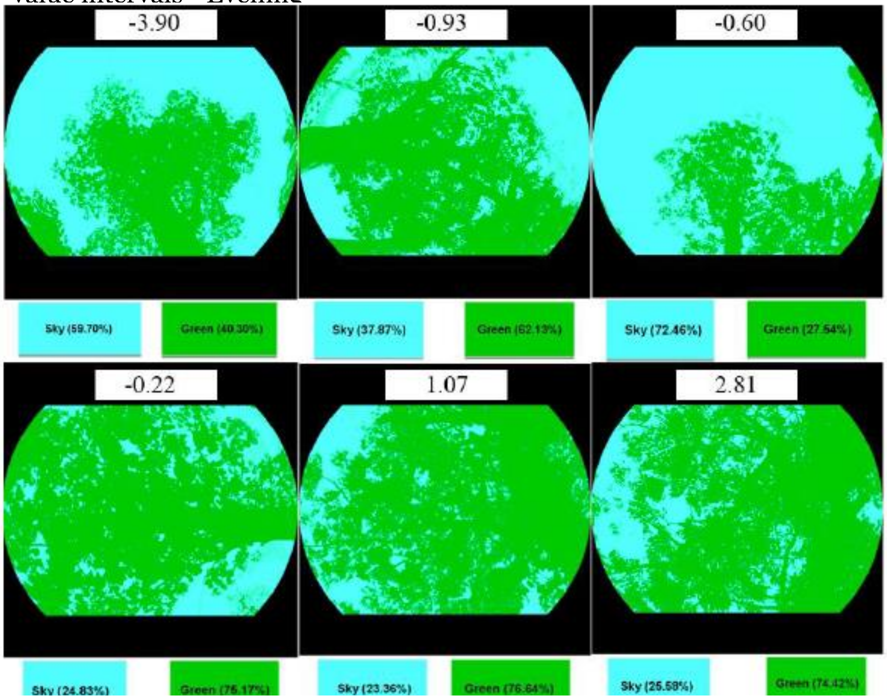

Figure 11. Percentage of sky and green of each tree canopy selected to stay under during the evening. Percentage calculated by CAN-EYE V6.4.91

The percentage of sky for these tree canopies calculated using upward DHP by the CAN-EYE image analysing software are 37.87%, 72.46%, 24.83% and 23.36% respectively. Trees that most of the people were thermally comfortable when underneath during the evening were the trees that have a view of the sky through the canopy from 23.36% to 72.45%, thus a wide range.

As opposed to the lack of a trend in thermal comfort perception, the results for the overall perception of comfort shows a similar trend to that of the morning hours, albeit a narrower range. It is clear that the perception in the evening hours signal an increased desire for views of the sky, together with shade provision. The comfort perception for shade is signified by the lower comfort level in open spaces, as identified by the survey data. (see Figure 12.).

Figure 13 demonstrates the relationship between comfort perception and sky view as a positive element in the space observed. Therefore, the balance between shade and sky view is again signified.

Unlike in the morning hours the primary reason people relocate from one shade tree to another, are reasons beyond the shade level of trees, thus deemed less important. (see Figure 14.)

Comparative analysis of the PAIs of trees in the evening hours (see Figure 15.) shows that all users felt safe and would like to stay for more than an hour. Thus, the correlation between shade level, PAI and perception is not as clear as in the morning. Similarly, the Sun's ingress into the space under the tree canopy was welcomed.

A significant difference is seen in the level of relaxation - signified by the feeling of sleep in the survey - is greatly diminished as opposed to the morning hours.

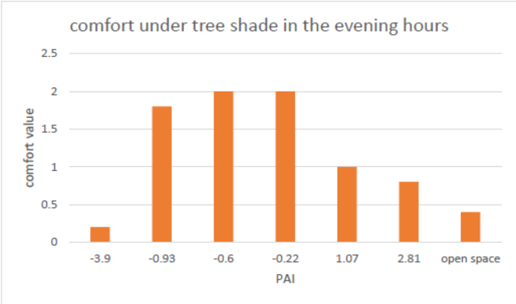

Figure 12. Comfort under the selected trees according to their PAI in the evening

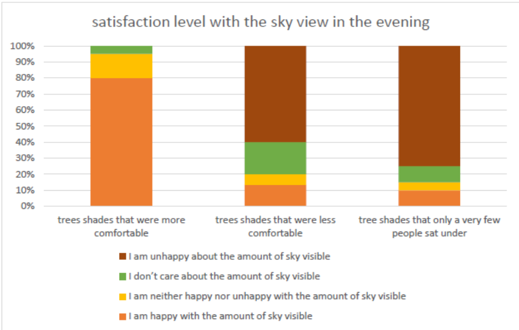

Figure 13. Satisfaction level in relation to the sky view - Evening

Figure 14. Reason for changing location, in the evening

Figure 15. Preference votes of trees with PAI -0.93, -0.6, -0.22 and 1.07 whose shade where chosen as comfortable - Evening

5. Findings and Implications for Landscape Design

The perceived thermal comfort and overall comfort of people in urban parks in Colombo varied according to the tree shade and sky view, particularly in the different time periods of the day considered. The people were found to be well aware of the sky and its contribution to comfort, therefore any design decision needs to consider the quality of the shade provided.

Satisfactory sky view percentage for people using urban parks in Colombo was different in the morning from the evening. In the morning the more satisfactory sky view percentage was 8% to 29%. In the evening it was 23% to 38%. This is deemed to relate to the solar radiation penetrating the tree canopy, with a reduction in the evening, the people are more tolerant and thus conducive for increased views of the sky. The difference in the range of PAIs the people prefer is another indication of this phenomena. Thus, In the morning people chose to sit under the shade of trees having PAIs that spread over a wider range of values, from -1.08 to 6.67 (although the density of people was high only for trees having PAIs in the range 0.3 to 4.7). in the evening people chose to sit under the shades of trees having PAIs that spread over a shorter range of values, from -3.90 to 2.8. Zoning of vegetation in the landscape is key to generate heterogeneity and interest in a particular urban park.

6. Conclusion

This research was conducted to identify the impact that the amount of shade and sky visible through shade tree canopies has on people's perception of comfort and hence identify the level of tree shade that provides the maximum comfort. With the Viharamahadevi Park as a case study we mapped the PAI of trees in a selected area and then surveyed users in this context. The study was limited to a typical day in June and over four weekends.

The two time zones and their differences generated in the perception of users is significant. It highlights the need for landscape design to consider not only thermal comfort of the setting but also the overall comfort, essentially encompassing visual comfort - expressed by the view of the sky through the tree canopy. The selection and application of tree places in an urban park needs to be executed carefully. A designer might opt for a certain level of heterogeneity, thus every tree need not be meant for people to sit under. Thus this study can be expanded to encompass such a mapping protocol, including specific tree species mapping. As explored in the study the PAI can be a useful approach for designers to make informed decisions for the overall well-being of the people in an urban park.

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