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Effect of Surface Temperature on Outdoor Thermal Comfort: A Case of Varying Morphologies at Composite Climates

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Abstract:- **The role of surface temperature is rarely been studied when it comes to thermal comfort issues. This paper aims to identify the effect of the surface temperature of vertical entities of built masses on thermal comfort parameters. The existing neighbourhood at NOIDA, Delhi NCR with varying morphological character and variation in heights and orientations was selected. The results showed that Surface temperature did not affect greatly to PET, whereas the effect on Tmrt was significant for most of the scenarios. The relationships with the east-facing surfaces could be observed whereas due to the longer exposure to direct solar radiation, the relationship with S, SW, SE surfaces is moderate. A negative effect on thermal comfort was observed as the height of the vertical surface increased. The study will help improve the understanding of the morphological configuration to reduce the surface temperature and eventually in achieving a better thermal comfort level.**

Keywords:- *Outdoor Thermal Comfort, Surface Temperature, Vertical Surfaces, Composite Climate*.

I. INTRODUCTION

Currently, more than half of the world lives in urban areas. Urban residential neighbourhoods are important for the growth of their inhabitants. It is important that these neighbourhoods are safe, habitable and comfortable in all aspects. The outdoor thermal comfort level of these neighbourhoods is one of the aspects which needs to be considered since most of the day-to-day activities are dependent on outdoor open spaces. Recently attention is being given to understanding the outdoor thermal comfort in Indian cities. Several studies have evaluated thermal neutrality (Banerjee et al., 2020; Deevi & Chundeli, 2020a; Kumar & Sharma, 2021a; Rajan & Amirtham, 2021a), whereas some studies tried to identify the factors affecting thermal comfort (Amirtham et al., 2014; Bhaskar & Mukherjee, 2017; Horrison & Amirtham, 2016; Rajan & Amirtham, 2021a)

Delhi National Capital Region (NCR), is located in the composite climate as per the Climatic zones of India (Bureau of Indian standards, 2016; Bureau of Indian Standards, 2005). The zone has the characteristics of long summers with high temperatures. The temperature of the region reaches 43°C which makes it the inhabitants difficult to use outdoor open spaces.

Out of several factors which may affect the thermal comfort level of the user, the surface temperature is one of the reasons. The role of surface temperature is rarely been studied when it comes to thermal comfort issues. This paper aims to identify the effect of surface temperature on thermal comfort parameters. In this paper, the surface temperature of only vertical surfaces is taken for analysis. The study will help improve the understanding of the morphological configuration to reduce the surface temperature and eventually in achieving a better thermal comfort level.

II. METHODOLOGY

The primary approach in this paper is to analyse the Surface temperature (Ts) variations at various morphological scenarios. The study also analysed the other thermal parameters Mean radiant temperature (Tmrt), Physiological equivalent temperature (PET), Wind velocity (Va), and Predicted mean vote (PMV). The physical/ geometrical parameters include height and orientation.

- *Study Area*

The site selected for the research is a residential neighbourhood at NOIDA (Delhi NCR), sector 74, located between 28°34’19” N to 28°34’38” N and 77°23’12” to 77°23’37” E. The buildings are of varying heights and orientations. Eight different orientations are studied depending on the directions they are facing and having an equal angle of increase to observe the pattern in the variation more accurately. These orientations are North facing (N), South facing (S), East facing (E), West facing (W), North-East facing (NE), North-West facing (NW), South-East facing (SE), and South-west facing (SW). Variation in terms of height is also considered which was observed as 15m, 24m, 33m, 42m, 63m and 84m.

The surface temperature of vertical entities of the neighbourhood was recorded using an infrared thermometer (Fluke 59 max) having a range of -30°C to +350°C and an accuracy of ± 2%, on the typical summer week between 5th June 2022 and 12th June 2022. The measurements were performed from 7 am to 6 pm and hourly values were recorded and taken into the analysis. The other thermal parameter in this study were calculated with the software Rayman Pro (Matzarakis et al., 2007).

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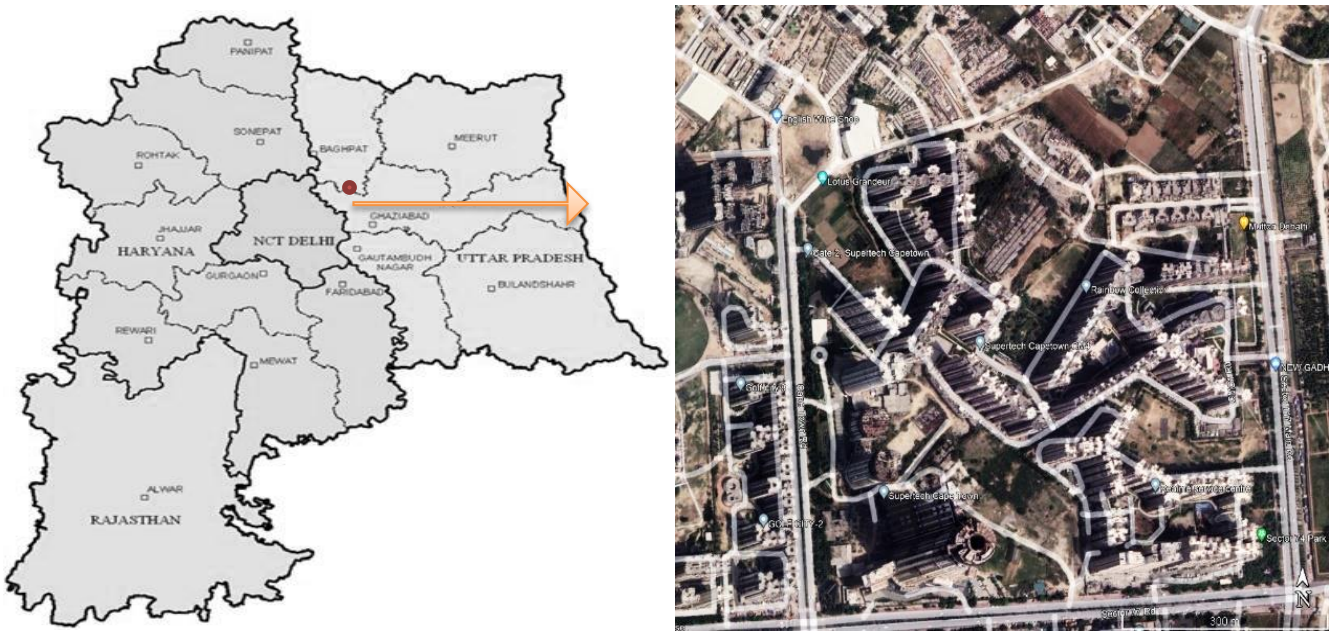
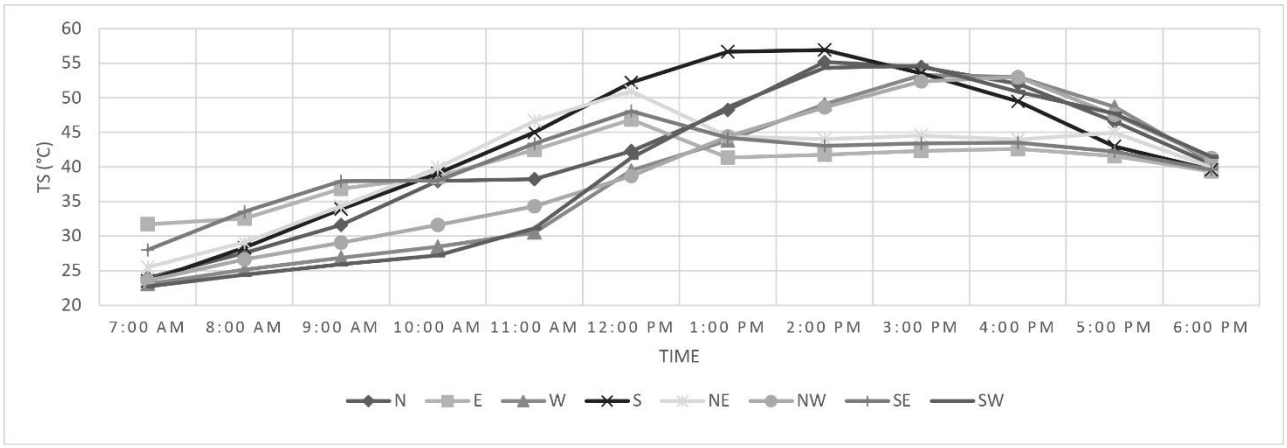


(a) (b)

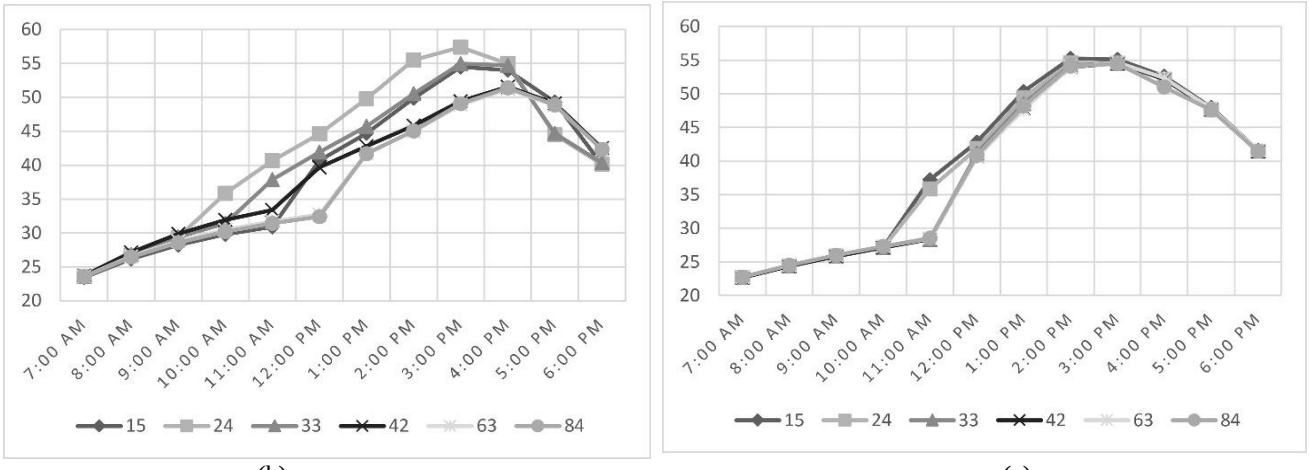
Fig 1: Study area (a) location of the site in the context of Delhi NCR (b) Selected neighbourhood

III. EXPERIMENTAL RESULTS

➢ *Variation of Surface temperature (Ts):*



(a)



(b) (c)

Fig 3: Variation of surface temperature (a) at all the orientation scenarios (b) at NW facing orientation (c) at SW facing orientation

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Figure 3 shows the variation in the surface temperatures (Ts) among the studied scenarios. The average Ts at south-facing vertical surfaces is higher than the rest of the scenarios. At 1 pm maximum difference could be observed. Ts at South facing surfaces, whereas E facing scenario showed the lowest temperature followed by SE and NE.

When comparing the scenarios in terms of height variations of vertical surfaces, the maximum variation occurred in the NW scenario and the least variation occurred in the SW scenario. Higher the height of the surface lower the temperature at the NW scenario. It may be due to the partial shading that occurred in this scenario due to the solar angle. Due to the less shading at the low-height surfaces higher Ts occurred. SW-facing surfaces receive direct solar radiation in the afternoon hours for this reason the temperature variation among all the height scenarios is negligible. This result is in agreement with the other study (Mohammad et al., 2021) which found similar results for surface temperature.

➢ *Effect of Ts on Thermal Parameters:*

Table 1: Correlation among thermal parameters

		Ts (°C)	Tmrt (°C)	PET (°C)	Va (m/s)
Ts (°C)	Pearson Correlation	1	.835**	.915**	-.890**
	Sig. (2-tailed)		.001	.000	.000
	N	12	12	12	12
Tmrt (°C)	Pearson Correlation	.835**	1	.976**	-.583*
	Sig. (2-tailed)	.001		.000	.047
	N	12	12	12	12
PET (°C)	Pearson Correlation	.915**	.976**	1	-.741**
	Sig. (2-tailed)	.000	.000		.006
	N	12	12	12	12
Va (m/s)	Pearson Correlation	-.890**	-.583*	-.741**	1
	Sig. (2-tailed)	.000	.047	.006	
	N	12	12	12	12

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Pearson's correlation (2-tailed) for all the thermal parameters studied in this paper is shown in Table 1. A significant correlation could be observed between Ts and other thermal parameters Tmrt, PET, and Va.

After identifying the correlation, the coefficient of the determinant (R^2) values was identified. Tmrt is highly influenced by Ts (Cohen et al., n.d.)

Strong positive R^2 between Ts and Tmrt was observed for E-facing (R^2=0.93), W-facing (R^2=0.75), and SE- facing (R^2=0.96) scenarios, whereas a good to a moderate relationship was observed for S-facing (R^2=0.41), and NW-facing (R^2=0.61). The rest of The scenarios resulted in poor relationships.

The relationship between Ts and PET is good positive only for SW-facing (R^2=0.62), moderate for N-facing (R^2=0.42), and E-facing (R^2=0.43), whereas, a poor relationship was observed for the rest of the scenarios.

➢ *Effect of Geometry*

The effect of geometry or physical parameters of the built environment is seen on the thermal parameters in many earlier studies (Galal et al., 2020). One of the study in Kolkata, India (Bhaskar & Mukherjee, 2017) explored various scenarios of the street orientations whereas (Amirtham et al., 2015; Horrison & Amirtham, 2016) studied various morphological aspects such as height to width ratio.

In this study, the effect of height and orientation of vertical surfaces is observed on Ts. The height of various scenarios of orientations is correlated with Ts. The E- facing vertical surfaces showed strong negative relation with Ts (R^2=0.99), followed by SE- facing (R^2=0.69). A moderate negative relationship was observed at N-facing (R^2=0.69), W-facing (R^2=0.56), NW- facing (R^2=0.56), and SW-facing (R^2=0.51) vertical surfaces.

The effect of built geometry can also be seen in the hours of solar access at the open space and on the building surfaces. In this study, the relationship between the hours of solar access and the Ts were observed for various orientations. A strong positive relation was observed for E-facing (R^2=0.87), SE-facing (R^2=0.82), and SW-facing (R^2=0.78) vertical surfaces, whereas a moderate positive relationship was observed for N-facing (R^2=0.56) and NW-facing (R^2=0.56) vertical surfaces. S-facing surfaces yielded to poor relationship for all the analysis performed in this study.

➢ *Effect of Ts on Outdoor Thermal Comfort*

Outdoor thermal comfort level was calculated based on Fagner's Predicted mean vote (PMV) (Fagner, 1972) model.

Several studies emphasized using the PMV model to evaluate the thermal comfort level. The index was originally used for indoor environments later on it was adapted to outdoor environments (Ghaffarianhoseini et al., 2019; Potchter et al., 2018).

A strong positive correlation was observed at N-facing (R^2=0.95), and NW-facing (R^2=0.75), whereas a moderate positive relationship was observed for W-facing (R^2=0.95), and SW-facing (R^2=0.48). This means higher the vertical surfaces in these orientations higher the PMV value i.e., worsen the level of thermal comfort.

A moderate negative correlation was observed at S-facing (R^2=0.34), and SE-facing (R^2=0.56), which means higher vertical surfaces in these orientations lower the PMV i.e., better the thermal comfort level.

IV. CONCLUSION

This paper aimed to identify the effect of the surface temperature of vertical entities of built masses on thermal comfort parameters. The existing neighbourhood at NOIDA, Delhi NCR with varying morphological character and variation in heights and orientations was selected. After analyzing the surface temperature of vertical surfaces and relating it to thermal and geometrical parameters, following conclusions can be made.

- South facing surfaces resulted into higher Ts the variation could not be observed for variation in the height for this orientation. For the rest of the orientation the variation as per the height observed.
- Surface temperature (Ts) has a strong correlation with thermal parameters Tmrt, and PET. The aim of controlling Ts would significantly lower the Tmrt (r=0.83) and PET (r=0.91) values resulting into the improvement of thermal comfort level.
- Ts did not affect greatly to PET, whereas effect on Tmrt was significant for most of the scenarios.
- The relationships with the east facing surfaces could be observed whereas due to the longer exposure to the direct solar radiation the relationship with S, SW, SE surfaces is moderate.
- Negative effect on thermal comfort observed as the height of the vertical surface increased.

The study will help improve the understanding of the morphological configuration to reduce the surface temperature and eventually in achieving the better thermal comfort level.

REFERENCES

[1]. Amirtham, L. R., Horrison, E., & Rajkumar, S. (2014). Study on the microclimatic conditions and thermal comfort in an institutional campus in hot humid climate. *30th International PLEA Conference: Sustainable Habitat for Developing Societies: Choosing the Way Forward - Proceedings*, *2*(December), 361–368.

[2]. Amirtham, L. R., Horrison, E., Rajkumar, S., & Rose, L. (2015). Impact of urban morphology on Microclimatic conditions and outdoor thermal comfort – A study in mixed residential neighbourhood of Chennai, India. *ICUC9 - 9th International Conference on Urban Climate Jointly with 12th Symposium on the Urban Environment*, *Oke 1976*.

[3]. Banerjee, S., Middel, A., & Chattopadhyay, S. (2020). Outdoor thermal comfort in various microentrepreneurial settings in hot humid tropical Kolkata: Human biometeorological assessment of objective and subjective parameters. *Science of the Total Environment*, *721*, 137741. https://doi.org/10.1016/j.scitotenv.2020.137741

[4]. Bhaskar, D. E., & Mukherjee, M. (2017). Optimizing street canyon orientation for Rajarhat Newtown, Kolkata, India. *Environmental and Climate Technologies*, *21*(1), 5–17. https://doi.org/10.1515/rtuect-2017-0012

[5]. Bureau of Indian standards. (2016). *National Building Code of India 2016*.

[6]. Bureau of Indian Standards. (2005). *National Building Code of India 2005*.

[7]. Cohen, S., Palatchi, Y., Potchter, D., Yaakov, Y., Tanny, J., Shashua-bar, L., & Potchter, O. (n.d.). *Mean Radiant Temperature in urban spaces from solar calculations , climate and surface properties – theory and ' Mr . T ' software*. 17.

[8]. Deevi, B., & Chundeli, F. A. (2020a). Quantitative outdoor thermal comfort assessment of street: A case in a warm and humid climate of India. *Urban Climate*, *34*(October), 100718. https://doi.org/10.1016/j.uclim.2020.100718

[9]. Deevi, B., & Chundeli, F. A. (2020b). Quantitative outdoor thermal comfort assessment of street: A case in a warm and humid climate of India. *Urban Climate*, *34*. https://doi.org/10.1016/j.uclim.2020.100718

[10]. Fagner, P. O. (1972). Thermal Comfort: Analysis and Applications in Environmental Engineering. *New York: McGraw-Hill Book Company*.

[11]. Galal, O. M., Sailor, D. J., & Mahmoud, H. (2020). The impact of urban form on outdoor thermal comfort in hot arid environments during daylight hours, case study: New Aswan. *Building and Environment*, *184*(August), 107222. https://doi.org/10.1016/j.buildenv.2020.107222

[12]. Ghaffarianhoseini, A., Berardi, U., Ghaffarianhoseini, A., & Al-Obaidi, K. (2019). Analyzing the thermal comfort conditions of outdoor spaces in a university campus in Kuala Lumpur, Malaysia. *Science of The Total Environment*, *666*, 1327–1345. https://doi.org/10.1016/j.scitotenv.2019.01.284

[13]. Horrison, E., & Amirtham, L. R. (2016). Role of built environment on factors affecting outdoor thermal comfort - A case of T. Nagar, Chennai, India. *Indian Journal of Science and Technology*, *9*(5), 3–6. https://doi.org/10.17485/ijst/2016/v9i5/87253

[14]. Kumar, P., & Sharma, A. (2021a). Assessing outdoor thermal comfort conditions at an urban park during summer in the hot semi-arid region of India. *Materials Today: Proceedings*, *xxxx*. https://doi.org/10.1016/j.matpr.2021.10.085

[15]. Kumar, P., & Sharma, A. (2021b). Assessing the monthly heat stress risk to society using thermal comfort indices in the hot semi-arid climate of India. *Materials Today: Proceedings*, *xxxx*. https://doi.org/10.1016/j.matpr.2021.06.292

[16]. Kumar, P., & Sharma, A. (2021c). Assessing The Thermal Comfort Conditions In Open Spaces: A Transversal Field Survey On The University Campus In India. *International Journal of Built Environment and Sustainability*, *8*(3), 77–92. https://doi.org/10.11113/ijbes.v8.n3.786
[17]. Matzarakis, A., Rutz, F., & Mayer, H. (2007). Modelling radiation fluxes in simple and complex environments—application of the RayMan model. *International Journal of Biometeorology*, *51*(4), 323–334. https://doi.org/10.1007/s00484-006-0061-8
[18]. Mohammad, P., Aghlmand, S., Fadaei, A., Gachkar, S., Gachkar, D., & Karimi, A. (2021). Evaluating the role of the albedo of material and vegetation scenarios along the urban street canyon for improving pedestrian thermal comfort outdoors. *Urban Climate*, *40*(September), 100993. https://doi.org/10.1016/j.uclim.2021.100993
[19]. Potchter, O., Cohen, P., Lin, T.-P., & Matzarakis, A. (2018). Outdoor human thermal perception in various climates: A comprehensive review of approaches, methods and quantification. *Science of The Total Environment*, *631–632*, 390–406. https://doi.org/10.1016/j.scitotenv.2018.02.276
[20]. Rajan, E. H. S., & Amirtham, L. R. (2021a). Impact of building regulations on the perceived outdoor thermal comfort in the mixed-use neighbourhood of Chennai. *Frontiers of Architectural Research*, *10*(1), 148–163. https://doi.org/10.1016/j.foar.2020.09.002
[21]. Rajan, E. H. S., & Amirtham, L. R. (2021b). Urban heat island intensity and evaluation of outdoor thermal comfort in Chennai, India. *Environment, Development and Sustainability*, *23*(11), 16304–16324. https://doi.org/10.1007/s10668-021-01344-w