International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 06 Issue 04 April 2023
DOI: 10.47191/ijcsrr/V6-i4-01, Impact Factor: 6.789
IJCSRR @ 2023
www.ijcsrr.org

Material Performance of Vertical Surfaces and its Effects on Outdoor Thermal Comfort: Case of Hot and Dry Regions

Jayesh Dashrath Khaire[1], Leticia Ortega Madrigal[2], Begona Serrano Lanzarote[3]
[1,2,3] Department of Architecture, Building, Urban Planning, and Landscape, Polytechnic University of Valencia, 46022, Spain

ABSTRACT: The thermal comfort of outdoor open spaces in hot and dry regions is an important aspect that needs to be considered when designing neighborhoods. Jaisalmer town which experiences harsh conditions during long summers is selected as a study area. This study analyses the material performance of vertical surfaces and their effects on outdoor thermal comfort. The existing site and its surface materials were studied, and on-site measurements were taken in June 2022. The was then compared with other scenarios which were simulated using Envi-MET 5.0.1. The scenarios were developed with the morphology exactly the same as the base case and variation in terms of surface materials. Four different configurations were developed including the base case. The results showed that the Case 1 scenario performed poorly, whereas case 4 showed the lowest temperatures. A strong correlation is observed between surface temperature and thermal parameters as well as albedo and thermal parameters. Making efforts in reducing the surface temperature and albedo can reduce the PET and Tmrt significantly. East-west oriented scenario showed the highest values for all the thermal parameters due to the longer exposure direct solar radiation. This study is an effort to emphasize the attention towards the efficient and appropriate material use which is also in harmony with the climate of the town. The traditional Jaisalmer limestone showed good positive results for all the analyses performed in this paper.

KEYWORDS: Albedo, mean radiant temperature, physiological equivalent temperature, surface temperature, thermal comfort.

INTRODUCTION

The thermal comfort of outdoor open spaces in hot and dry regions is an important aspect that needs to be considered when designing neighborhoods. These open spaces have to bear harsh weather conditions, especially during summer. A user belonging to these regions uses the open spaces for several important day-to-day activities. Some of these activities cannot be ignored even though the weather conditions do not permit to use. In order to promote the use of outdoor spaces and improve the functioning of the town it is necessary to improve the comfort level of the user. Outdoor thermal comfort is one of the critical issues that need to be addressed.

The urban environment is influenced by several entities such as built from its geometry [1]–[3], materials, natural surroundings [4], etc. The influence of form and material was earlier studied in several studies. [5] differentiated the open spaces and their effects of shading, vegetation, water, and material properties on microclimate development and pedestrian thermal comfort. [6] pointed out the differences among the materials due to their physical properties, like albedo, thermal capacity. and density. [7] [8] highlighted that surface materials have an important role in shaping the microclimate.

Jaisalmer lies in the Thar deserts of Rajasthan. It belongs to a hot and dry climatic zone [9]. The town experiences extreme weather conditions. As per [10], the minimum temperature of Jaisalmer drops to 2.8°C in December and the maximum reached 47.8°C in June. The summers are lengthy and typically harsh. The most intense heat waves were recorded in May 2016 when the maximum temperature was recorded at 52.4°C [11]. The study by [12], is the foremost and only study that explored the possibility of developing a design methodology and criteria for climatically responsive buildings and settlements. Although the old city of Jaisalmer including Jaisalmer fort has been enriched with limestone materials for its buildings, there is a lack of knowledge when it comes to the thermal performance and comparison of this material with the modern developments in the town. This study analyses the material performance of vertical surfaces and their effects on outdoor thermal comfort. The study is focused on the extreme summer season.

International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 06 Issue 04 April 2023
DOI: 10.47191/ijcsrr/V6-i4-01, Impact Factor: 6.789
IJCSRR @ 2023
www.ijcsrr.org

MATERIALS AND METHODS

In this study, existing site and its surface materials were studied, on site measurements were taken during June 2022. The was then compared with other scenarios which were simulated using Envi-MET 5.0.1. The scenarios were developed with the morphology exactly same as base case and variation done in terms of surface materials. Four different configurations were developed including the base case. The materials selected for these configurations are exactly similar to the materials which are typically found on the Jaisalmer buildings and their adjacent streets and open spaces. Following are the four cases developed and compared in this paper.

Case 1: Cement plaster, asphalt floor (Base case, existing site)
Case 2: Exposed brickwork, concrete pavers (Simulated scenario)
Case 3: Exposed brickwork, exposed soil (Simulated scenario)
Case 4: Jaisalmer limestone, limestone (Simulated scenario)

Case 1 is a base case which is an existing site, Case 2 and 3 are the conditions typically found in the lated developments of the town. Case 4 condition is taken from the old city where Jaisalmer yellow limestone is used extensively.

SITE AND CLIMATE

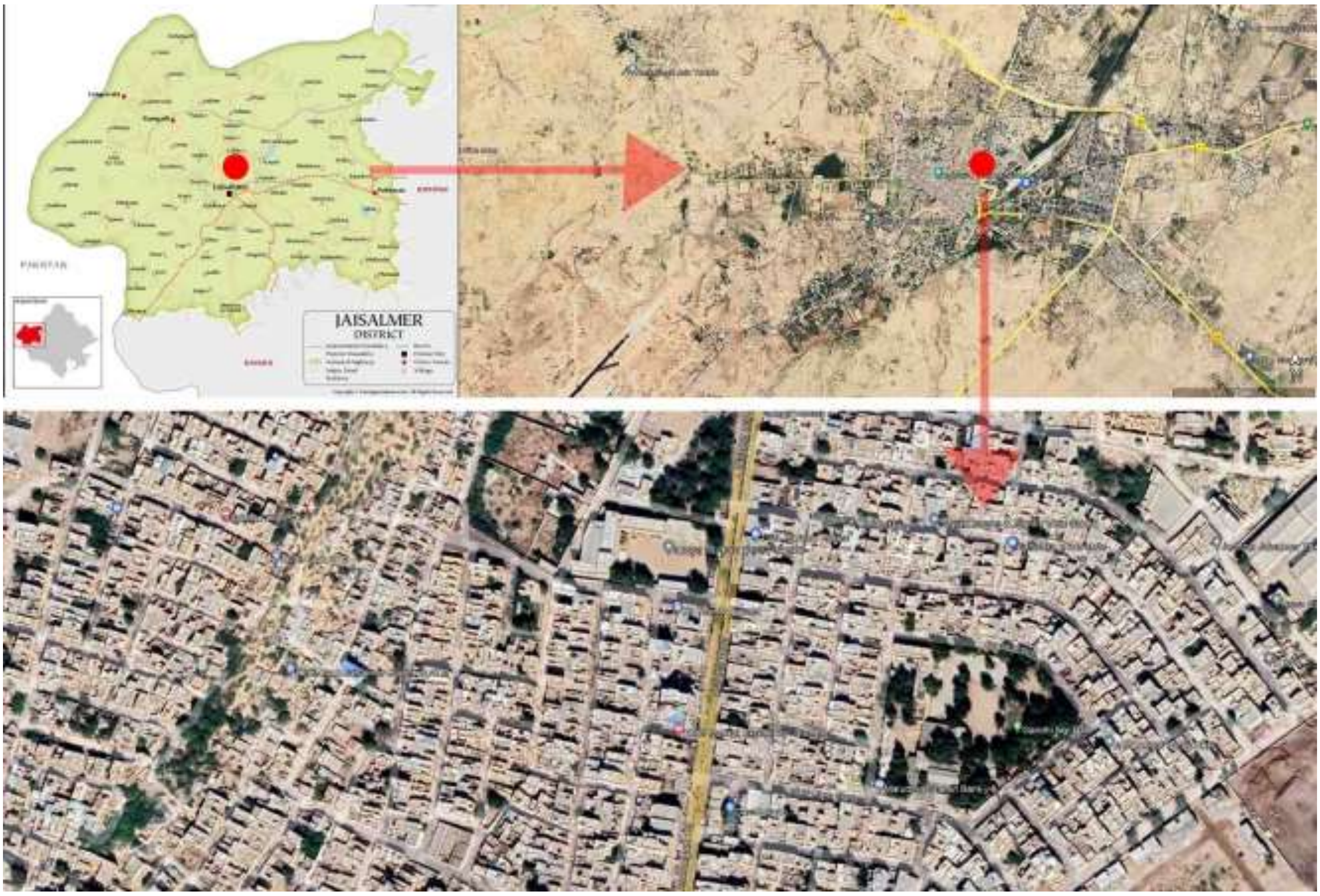


Figure 1: Site selected as a base case

The selected site (Base case/ Case 1) is located at 26°55’ N and 70°55’E. When compared to traditional settlement in Jaisalmer, The selected site is characterized by medium to narrow streets, regular straight oriented pathways and buildings, the orientation is mainly E-W, N-S, and NW- SE. The buildings are more or less of similar heights. The stretches with N-S and E-W orientations were taken as a base case study.

BUILT ENVIRONMENT AND MATERIALS

Table I: Physical properties of the wall materials

Wall material	Emissivity	Specific heat (J/kg.k)	Thermal conductivity (W/m.k)	Density (kg/m^3)
Limestone	0.7	840	2.74 [13]	3006 [13]
Burnt brick	0.9	650	0.44	1500
Plaster	0.9	850	0.6	1500
Concrete	0.9	850	1.6	2220

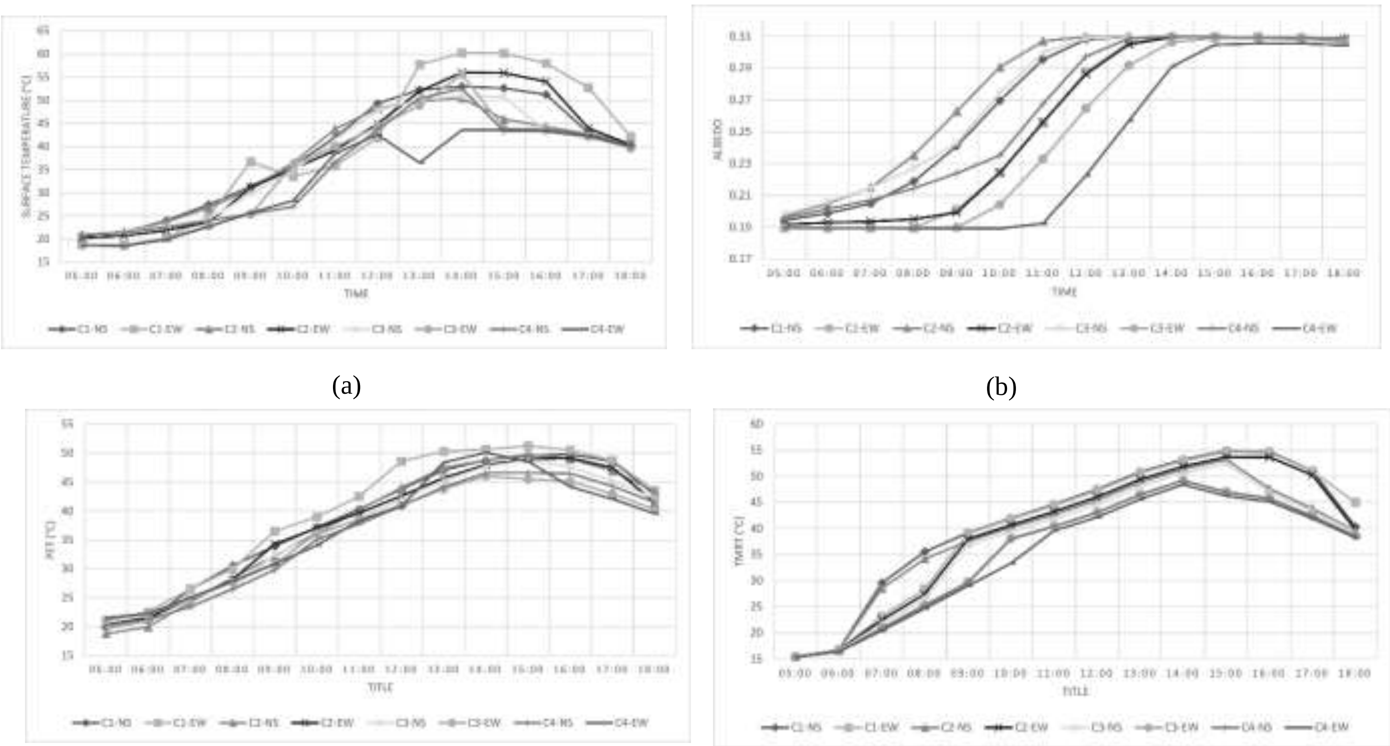
Table II: Albedo and emissivity of the ground surface materials

Ground surface material	Albedo	Emissivity
Asphalt road	0.2	0.9
Cobblestone paving	0.8	0.9
Exposed soil	0.4	0.9

Table I, and Table II shows the physical properties of the materials used for various scenarios. This data is not directly used for the analysis whereas it is used as an input for the simulations. The output of the simulation is taken in the form of various thermal parameters such as surface temperature (Ts), albedo (A), mean radiant temperature (Tmrt) and physiological equivalent temperature (PET).

RESULTS AND DISCUSSION

VARIATION OF THERMAL PARAMETERS



(a) (b) (c) (d)

Figure 2: Hourly variation of (a) Surface temperature (b) Albedo (c) PET (d)Tmrt

International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 06 Issue 04 April 2023
DOI: 10.47191/ijcsrr/V6-i4-01, Impact Factor: 6.789
IJCSRR @ 2023
www.ijcsrr.org

Figure 2 shows the hourly variation for all the cases. The variation is also observed in the N-S oriented and E-W oriented scenarios. Moderate variation in Ts could be seen (Figure 2 a), as the day progresses the variation increases after 1 pm. The base case scenario with E-W orientation showed the higher Ts, followed by C2 E-W. Since the E-W oriented streets receive the direct solar radiation for the longer duration compared to N-S thermal conditions higher temperature could be observed. The similar results are seen in the other studies [14], [15], [16], [17]. From N-S oriented scenarios case 1 showed the highest Ts, which shows the surfaces materials at this scenario are sensitive to the solar radiation and may contribute in the temperature of other thermal parameters. Lowest Ts is observed at case 4 where traditional styled materials are used.

From Figure 2b it can be noticed some interesting observations. The value of albedo starts increasing at different times of the day at all the scenarios, and it also reaches at its peak at different times. It can also be seen that once the values reach the peak, the values are not declining. It can be noticed that, at N-S oriented scenarios the albedo increased earlier than the E-W oriented scenarios. The reason can be due to the presence of E facing surfaces which are available at N-S scenario are exposed early in a daytime to the direct solar radiation. It can be said that the low albedo materials having minimum duration of exposure to direct solar radiation may help reduce the thermal impact on the other thermal parameters. The study [18] also recommends to use low albedo materials to improve thermal comfort level. Moderate differences could be observed between the scenarios throughout the day for PET (Figure 2c) and Tmrt (Figure 2d). Case 1 scenario performed poorly, whereas case 4 showed the lowest temperatures.

EFFECT OF SURFACE TEMPERATURE (TS) ON MEAN RADIANT TEMPERATURE (TMRT)

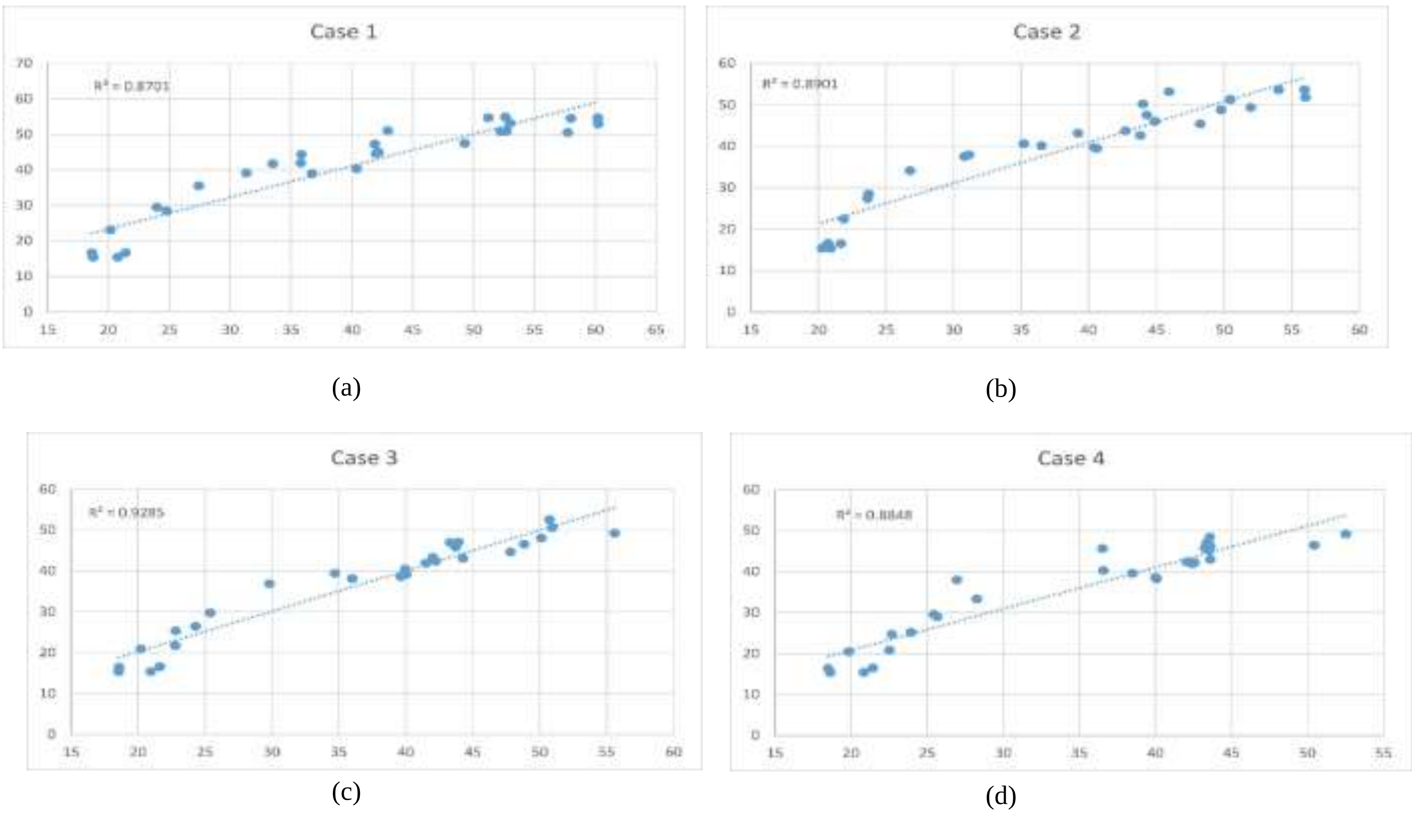
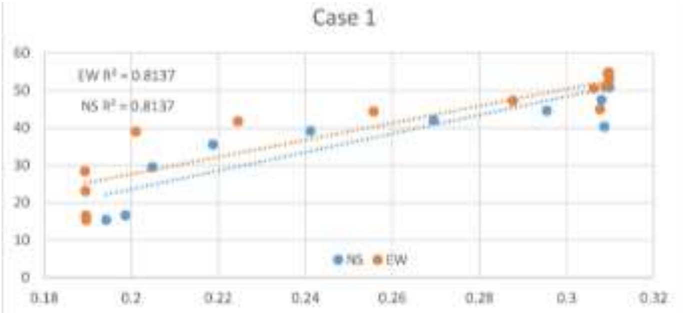


Figure 3: Relationship between Ts and Tmrt

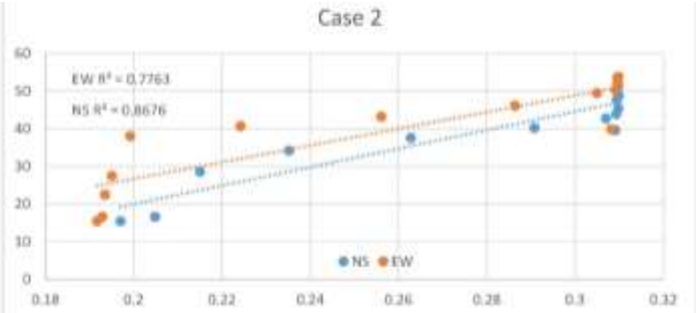
Figure 3 shows the output for the relationship of Ts and Tmrt for the coefficient of determination (R^2) at all the scenarios. The strong positive relationship observed at all the cases. R^2 at case 1 is 0.87, at case 2 it is 0.89, at case 3 it is 0.93 and at case 4 it is 0.88. at all the scenarios it can be seen that the making efforts in reducing the surface temperature can reduce the Tmrt significantly. Since Tmrt is one of the predictors of outdoor thermal comfort the attention should be given to control its value.

International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 06 Issue 04 April 2023
DOI: 10.47191/ijcsrr/V6-i4-01, Impact Factor: 6.789
IJCSRR @ 2023
www.ijcsrr.org

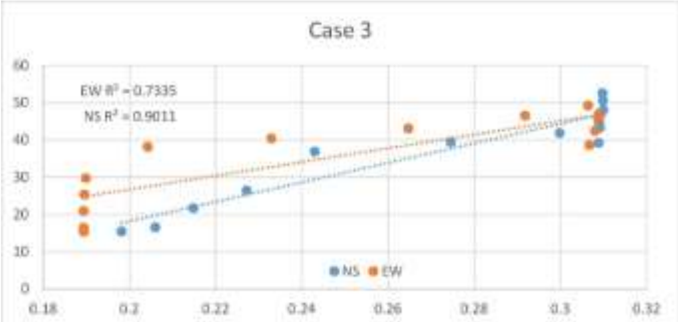
EFFECT OF ALBEDO (A) ON MEAN RADIANT TEMPERATURE (TMRT)



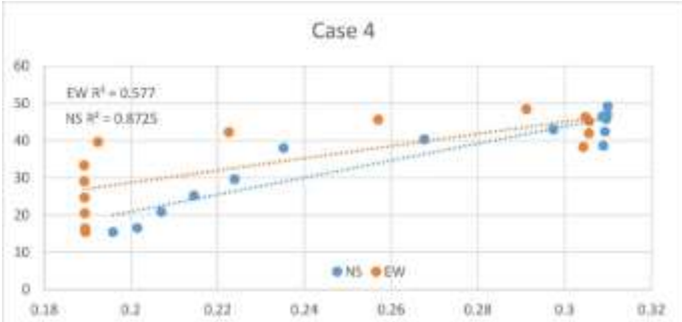
(a)



(b)

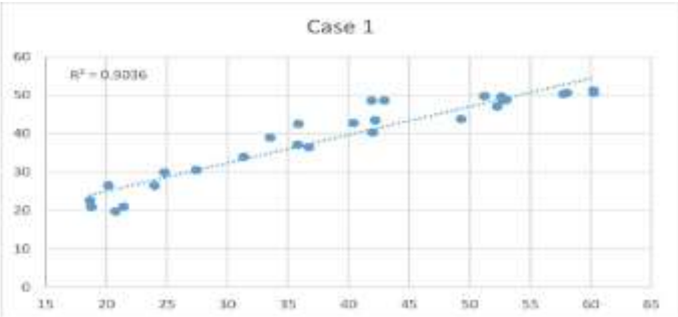


(c)

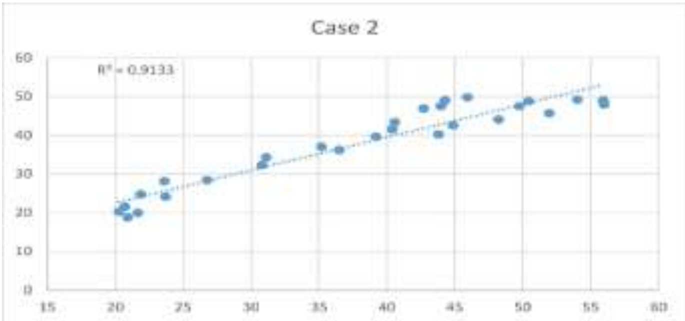


(d)

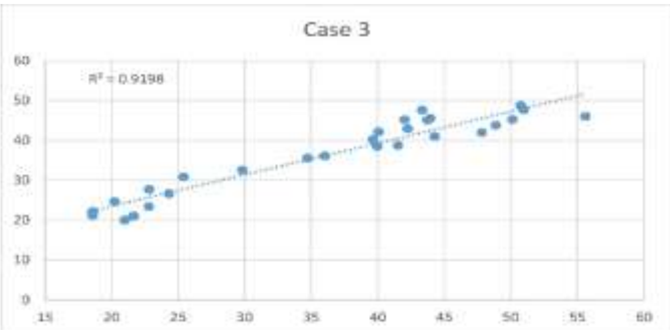
Figure 4: Relationship between A and Tmrt



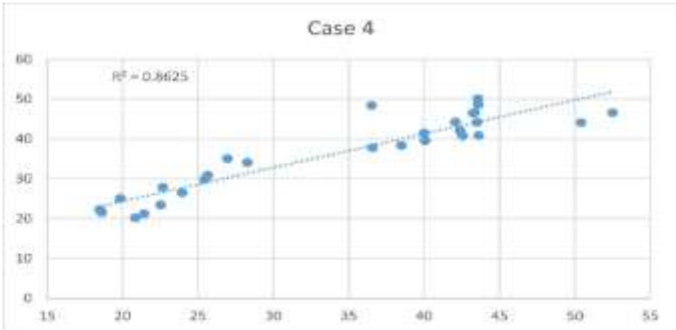
(a)



(b)



(c)



(d)

Figure 5: Relationship between Ts and PET

International Journal of Current Science Research and Review

ISSN: 2581-8341

Volume 06 Issue 04 April 2023

DOI: 10.47191/ijcsrr/V6-i4-01, Impact Factor: 6.789

IJCSRR @ 2023

www.ijcsrr.org

Figure 4 shows the R^2 values at all cases between albedo and Tmrt. Unlike figure 3 where E-W and N-S oriented scenarios did not show the prominent difference in the relationship, Figure 4 shows the variation in the scenarios as per orientations. A strong positive relationship could be seen between albedo and Tmrt. For all the cases the E-W scenarios showed the higher values. The maximum difference occurred for the lowr albedo values, as the value of albedo increased the variation among the orientations reduced.

EFFECT OF SURFACE TEMPERATURE (TS) ON PHYSIOLOGICAL EQUIVALENT TEMPERATURE (PET)

Figure 5 shows the output for the relationship of Ts and PET for the coefficient of determination (R^2) at all the scenarios. The strong positive relationship observed at all the cases. R^2 at case 1 is 0.90, at case 2 it is 0.91, at case 3 it is 0.92 and at case 4 it is 0.86. at all the scenarios it can be seen that the making efforts in reducing the surface temperature can reduce the PET significantly.

EFFECT OF ALBEDO (A) ON PHYSIOLOGICAL EQUIVALENT TEMPERATURE (PET)

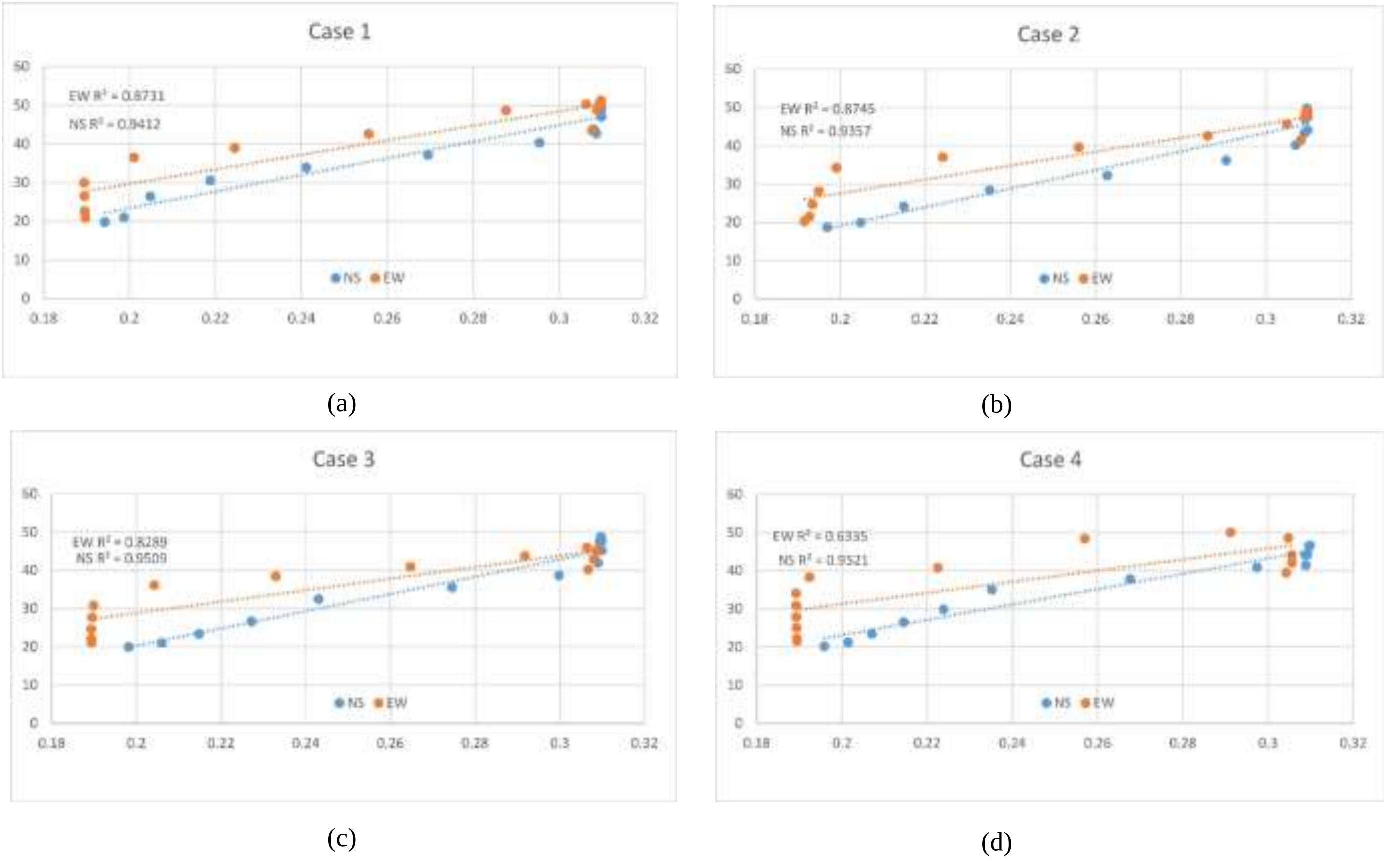


Figure 6: Relationship between A and PET

Figure 6 shows the R^2 values at all cases between albedo and PET. Similar to figure 4 where E-W and N-S oriented scenarios showed the prominent difference in the relationship, A strong positive relationship could be seen between albedo and PET. For all the cases the E-W scenarios showed the higher values. The maximum difference occurred for the lower albedo values, as the value of albedo increased the variation of PET among the orientations reduced.

CONCLUSION

This study analyzed the material performance of vertical surfaces and its effects on outdoor thermal comfort. The study focused on the extreme summer season at hot and dry region of Jaisalmer. The existing site and its surface materials were studied, and on-site measurements were taken in June 2022. The was then compared with other scenarios which were simulated using Envi-MET 5.0.1. The scenarios were developed with the morphology exactly the same as the base case and variation in terms of surface materials. Four different configurations were developed including the base case. There are several conclusions that can be drawn from the study. The modern development in the town which does not responds to the climate in terms of forms, orientations and materials performed poorly. The use of traditional locally available materials may help improve the thermal comfort level. Making efforts in reducing the surface temperature and albedo can reduce the PET and Tmrt significantly. East-west oriented scenario showed the highest values for all the thermal parameters due to the longer exposure to direct solar radiation. The efforts should be made in the future developments where the maximum mutual shading is done.

This study is an effort to emphasize the attention towards the efficient and appropriate material use which is also in harmony with the climate of the town. The traditional Jaisalmer limestone showed good positive results for all the analyses performed in this paper.

REFERENCES

1. J. D. Khaire, L. O. Madrigal, and B. S. Lanzarote, "Role of Built Geometry in the Micro-climatic Modifications : Case of Addis Ababa , Ethiopia," *Int. J. Innov. Res. Sci. Eng. Technol.*, vol. 12, no. 3, 2023, doi: 10.15680/IJIRSET.2023.1203001.
2. L. R. Amirtham, E. Horrison, S. Rajkumar, and L. Rose, "Impact of urban morphology on Microclimatic conditions and outdoor thermal comfort – A study in mixed residential neighbourhood of Chennai, India," *ICUC9 - 9th Int. Conf. Urban Clim. jointly with 12th Symp. Urban Environ.*, no. Oke 1976, 2015.
3. F. Ali-Toudert and H. Mayer, "Numerical study on the effects of aspect ratio and orientation of an urban street canyon on outdoor thermal comfort in hot and dry climate," *Build. Environ.*, vol. 41, no. 2, pp. 94–108, 2006, doi: 10.1016/j.buildenv.2005.01.013.
4. S. B. Ali and S. Patnaik, "Thermal comfort in urban open spaces: Objective assessment and subjective perception study in tropical city of Bhopal, India," *Urban Clim.*, vol. 24, no. October, pp. 954–967, 2018, doi: 10.1016/j.uclim.2017.11.006.
5. A. Chatzidimitriou and S. Yannas, "Microclimate development in open urban spaces: The influence of form and materials," *Energy Build.*, vol. 108, pp. 156–174, 2015, doi: 10.1016/j.enbuild.2015.08.048.
6. V. Dessi, "Urban Materials for Comfortable Open Spaces," *Proc. World Renew. Energy Congr. – Sweden, 8–13 May, 2011, Linköping, Sweden*, vol. 57, pp. 3300–3307, 2011, doi: 10.3384/ecp110573300.
7. J. D. Khaire, L. O. Madrigal, and B. S. Lanzarote, "Effect of Surface Temperature on Outdoor Thermal Comfort : A Case of Varying Morphologies at Composite Climates," vol. 8, no. 3, pp. 834–838, 2023.
8. T. Nottingham and N. E. User, "Sufeljen , Abdusalam (2014) Microclimate and thermal comfort of public enclosed courtyards in hot dry regions , with special reference to Tripoli , Libya . PhD thesis , University of Nottingham . OF PUBLIC ENCLOSED COURTYARDS IN HOT DRY REGIONS , WITH S," 2014.
9. Bureau of Indian Standards, "National Building Code of India 2005," 2005.
10. GOI, "Annual Climate Summary-2019. Ministry of Earth Sciences, India Meteorological Department," 2019.
11. O. Mazdiyasni *et al.*, "Increasing probability of mortality during Indian heat waves," *Sci. Adv.*, vol. 3, no. 6, pp. 1–6, 2017, doi: 10.1126/sciadv.1700066.
12. A. Krishan, "Habitat of two deserts in India: hot-dry desert of Jaisalmer (Rajasthan) and the cold-dry high altitude mountainous desert of Leh (Ladakh)," *Energy Build.*, vol. 23, no. 3, pp. 217–229, 1996, doi: 10.1016/0378-7788(95)00947-7.
13. R. T. Sataloff, M. M. Johns, and K. M. Kost, "ECBC 2017."
14. F. Ali-Toudert and H. Mayer, "Erratum to 'Numerical study on the effects of aspect ratio and orientation of an urban street canyon on outdoor thermal comfort in hot and dry climate' [Building and Environment 41 (2006) 94-108] (DOI:10.1016/j.buildenv.2005.01.013)," *Build. Environ.*, vol. 42, no. 3, pp. 1553–1554, 2007, doi: 10.1016/j.buildenv.2005.12.013.
15. F. Ali-Toudert and H. Mayer, "Effects of asymmetry, galleries, overhanging façades and vegetation on thermal comfort in urban street canyons," *Sol. Energy*, vol. 81, no. 6, pp. 742–754, 2007, doi: 10.1016/j.solener.2006.10.007.
16. N. Shishegar, "Street Design and Urban Microclimate: Analyzing the Effects of Street Geometry and Orientation on Airflowand Solar Access in Urban Canyons," *J. Clean Energy Technol.*, vol. 1, no. 1, pp. 52–56, 2013, doi: 10.7763/jocet.2013.v1.13.

17. D. E. Bhaskar and M. Mukherjee, "Optimizing street canyon orientation for Rajarhat Newtown, Kolkata, India," *Environ. Clim. Technol.*, vol. 21, no. 1, pp. 5–17, 2017, doi: 10.1515/rtuect-2017-0012.
18. R. H. Haseh, M. Khakzand, and M. Ojaghlou, "Optimal thermal characteristics of the courtyard in the hot and arid climate of Isfahan," *Buildings*, vol. 8, no. 12, pp. 1–28, 2018, doi: 10.3390/buildings8120166.