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EFFECT OF GRASS AND TREES ON OUTDOOR THERMAL COMFORT IN OUTDOOR ENTERTAINMENT VENUES IN HOT ARID CLIMATE

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ABSTRACT

This paper aims to analyze and compare the effect of using grass, or trees with grass as a bioclimatic landscape design strategy. The study is simulation-based, where ENVI-met was used to model and simulate different scenarios. The start-up scenario represented the existing buildings of the selected entertainment venue. A set of scenarios representing 40% and 60% of either grass or trees with grass were then established. Simulations were run on a typical summer day. The Predicted Mean Vote (PMV) for all the scenarios was calculated using BIOMET, also outdoor air temperature was compared. The results of the simulations pointed out that increasing the percentage of different treatments helped in enhancing thermal comfort level with significant effects. However, scenarios using different percentages of grass coverage with trees always resulted in the highest effect. In the case of adding trees to grass surfaces, the simulated PMV results ranged between 3.16 and 1.73. For grass with trees coverage scenarios, the simulated air temperature values ranged between 27.6℃ and 34.38℃. The increase in grass coverage and adding trees caused change between 1℃ drops at 10:00 and 0.36℃ at 14:00. The results showed that adding grass and trees result in significant drop in outdoor thermal comfort and air temperature.

KEYWORDS: Hot arid climate; Landscape treatments; Outdoor thermal comfort.

1. INTRODUCTION

The current rapid urban expansion in Egypt helped escalate the need for outdoor entertainment venues that are becoming a key feature in Cairo’s mixed-use developments despite its hot arid climate. Taking into account the impact of Urban Heat Island (UHI) effect, different strategies must be considered to help mitigate the microclimatic conditions in an attempt to enhance the users’ thermal comfort [1-6].

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Many studies pointed out that using urban greenery and vegetation as a bioclimatic urban strategy has one of the strongest impacts on the surrounding environment and the users' outdoor thermal comfort compared to other strategies [7-11]. For hot climates, shade trees strongly affect the urban microclimate where they minimize the heat storage of exposed surfaces creating "cool island effect". Other studies [12, 13] showed that the integration of water surfaces with vegetation resulted in better modifications to outdoor thermal comfort than using only vegetation where evaporation helps moisturize the air.

The effects of different landscape treatments on thermal comfort can be evaluated by using environmental modelling and simulation software. In case of testing and comparing different scenarios, simulation-based studies are very effective, where using such predictive software as ENVI-met allows researchers to edit the settings of an urban environment easier than in-situ modifications [14]. Recently, many indices, such as Predicted Mean Vote (PMV), have been developed to evaluate outdoor thermal comfort condition. PMV model was originally developed Fanger in 1967 for indoor spaces where a seven-point thermal sensation scale was used in which 0 represents the thermal neutral comfort value [15]. In 1981, Jendritzky and Nübler adapted the PMV model for outdoor climates [16].

2. METHODOLOGY

In order to achieve the study's aim, exploring the effect of specific landscape treatments on outdoor thermal comfort, a simulation-based approach using ENVI-met V.4.3.2. was adopted. The objective was to discover the difference between the existing case and adding grass and trees. The null hypothesis states that there is no difference between different scenarios, while the results reject the null hypothesis.

2.1 Study Area

A representative case in a relatively affluent and new urban area was selected. It is located to the West in the Western end of New Cairo (30°01'01"N, 31°24'44"E) with a total area of around 45,000 m^2 as shown in Fig. 1. The evaluated area is a mixed-use development, building heights are between 1 to 7 floors. The selection of this exact development was based on the high percentage of outdoor area, which reaches around 54% of the whole site. This outdoor area is used as an outdoor entertainment venue which hosts a variety of activities.

Fig. 1. Location of the study area in New Cairo, Egypt.

2.2 Climate

According the Köppen climate classification system, Egypt is classified within group B and subgroup BWh "arid with hot climate" where the annual temperature exceeds 18°C [17]. The 30-year meteorological data obtained from the World Meteorological Organization (WMO) station located in Cairo International Airport (30°07'48"N 31°24'00"E) shows that June and July are the hottest months [18]. However, July was recorded to have the highest mean daily temperature, as shown in Fig. 2. Therefore, simulations were run on the first of July, representing an extreme summer day.

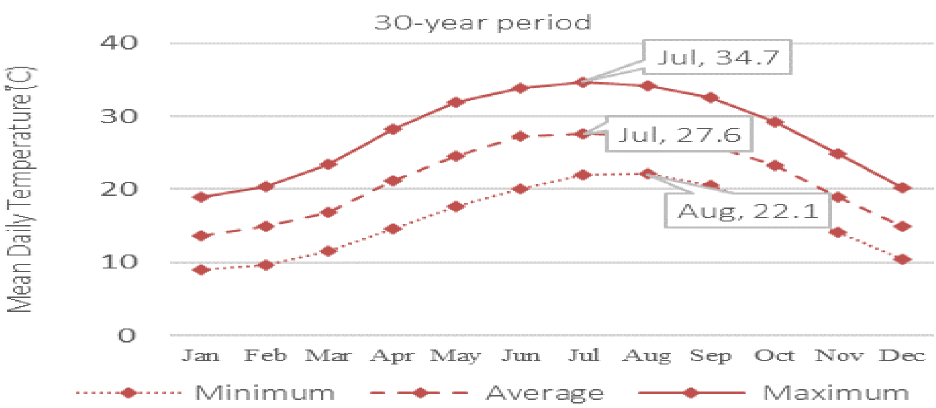


Fig. 2. WMO's climatological data for Cairo, Egypt [18].

2.3 Model Description

This research adopts a simulation-based experimental approach. In this regard, a three-dimensional non-hydrostatic model representing the study area with full basalt tiles coverage as a base case was built using ENVI-met, a 3D modelling and simulation software, on a grid with dimensions 98×98×22 with the resolution of 2.5m×2.5m×2m. The model's boundary total height is 80 m, generated using a telescoping factor of 20% starting after 24 m, which is 2 m taller than the highest building in the model. The base case shown in Fig. 3 represents the development's existing buildings where basalt tiles pavement, the prevailing pavement material, covers the entire outdoor area.

Two scenarios for each treatment were proposed. The target was to simulate the different effects of replacing the existing land basalt surfaces with grass coverage (40% and 60%), or trees on grass coverage. A simple layout was developed where double-cell or triple-cell wide, 5 m or 7.5 m, hard-paved pathways surrounded all the buildings, while the remaining outdoor space representing 60% and 40% of the total outdoor area was allocated to one of the aforementioned soft materials.

For trees on grass coverage scenarios, a fast-growing deciduous tree was selected for more shading during summer and sun exposure during winter. The selected tree reaches a height of 8 to 15 m at maturity and a spread of up to 12 m. This tree is also heat and drought tolerant with a relatively moderate need of water. The positioning of the trees is on a grid covering the whole site with 7.5 m spacing in the East-West direction and 10 m in North-South direction. However, trees located on non-grass areas were removed.

Receptor points are located on a 7×10 grid with a spacing of 12.5m×15m, as shown in Fig. 4. This grid covers the central outdoor area of the development. However, only the output of 38 receptor points was used, as the remaining receptors lied inside the buildings.

2.4 ENVI-met Simulations

The 3D non-hydrostatic model ENVI-met 4.3.2 was applied to carry out these simulations (“ENVI_MET – Decoding Urban Nature,” n.d.). ENVI-met’s model uses detailed soil properties and takes into consideration the evapotranspiration and shading from vegetation. Table 1 shows the simulation input data for the selected date, the first of July, 2019 representing the extreme summer day in Egypt. The simulation time is 8:00 to 23:00 according to the selected development’s opening hours. However, the output analysis was carried out starting from 10:00 to 22:00 only, leaving two hours for simulation initialization and one hour for finalization.

Table 1. ENVI-met simulation settings, general simulation settings

Parameter	Input Value	Notes
Start time (hh:mm)	08:00	-
Total simulation time(h)	15	-
Initial Meteorological Conditions		
Parameter	Input Value	Notes
Atmosphere Temperature, °C	22.9	-
Wind speed, m/s	3	at 10 m height
Wind direction, degrees	310	0: N, 90: E, 180: S, 270: W
Relative Humidity, %	86	in 2 m
Specific Humidity, g/kg	15.24	in 2500 m
Roughness length	0.1	-

The area of the site was resembled in the ENVI-met model on a grid of 98×98×22 cells with the resolution of 2.5m×2.5m×2m. The model’s boundary total height is 80 m, generated using a telescoping factor of 20% starting after 24 m, which is almost as tall as the highest building in the model. The base case shown in Fig. 3 represents the development’s existing buildings. Receptor points are located on a 7×10 grid with a spacing of 12.5m×15m as shown in Fig. 4. This grid covers the central outdoor area of the development. However, only the output of 38 receptor points was used, as the remaining receptors were not usable as they lied inside buildings.

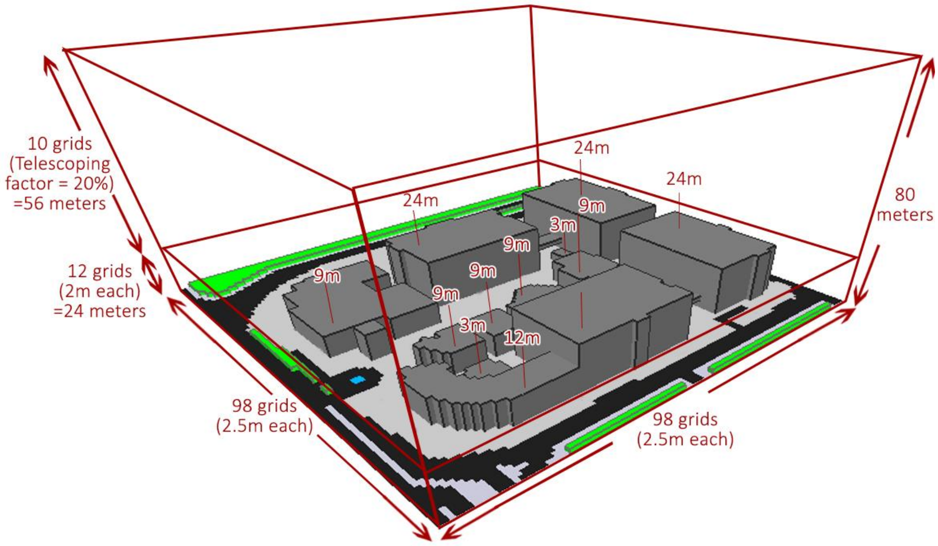


Fig. 3. ENVI-met 3D view of the study area's base case model.

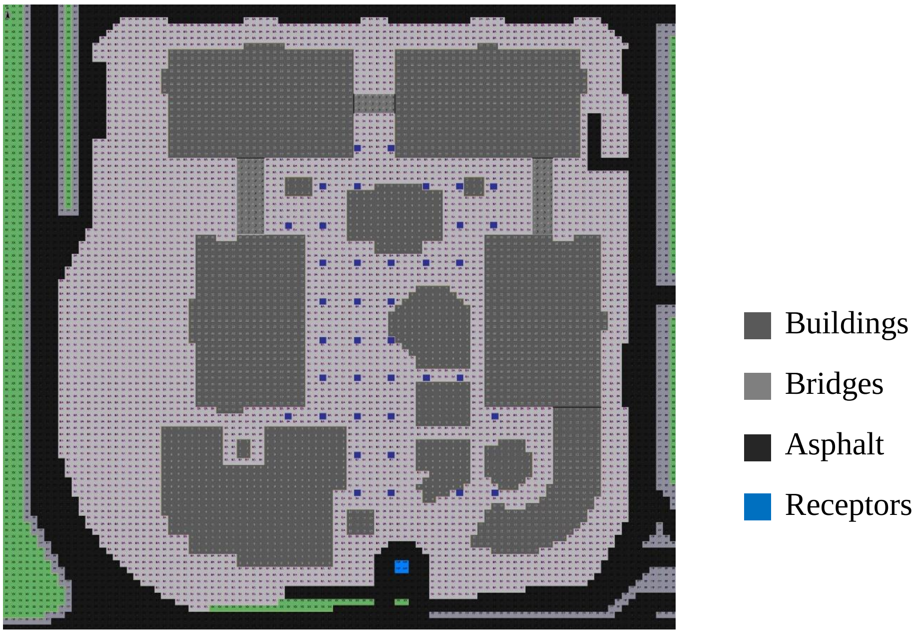


Fig. 4. Base case ENVI-met model with receptor points

2.5 Proposed Scenarios

The developed simple layout included single-cell wide, 2.5 meters, hard-paved pathways surrounding all the buildings, while the remaining outdoor space representing 80% of the total outdoor area is allocated to one of the aforementioned soft materials. In order to vary the percentage of soft materials, the width of the paved pathways was increased, such that the remaining soft areas represented 60% and 40% of the total outdoor area as shown in Fig. 5.

The positioning of the trees is on a grid covering the whole site with 7.5 m spacing in x-direction and 10 m in y-direction. However, trees located on non-grass areas were removed.

In order to evaluate human thermal comfort, a tool inside ENVI-met, BIOMET v1.5, was used to calculate PMV values for the different proposed scenarios.

Normally, the PMV scale is defined between -4 (very cold) and +4 (very hot) where 0 is the thermal neutral (comfort) value.

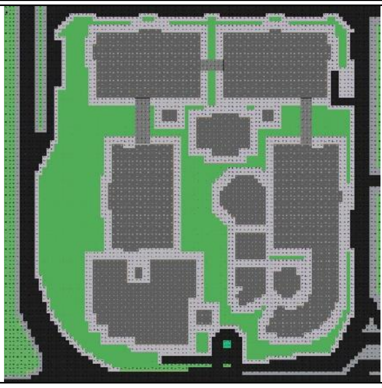
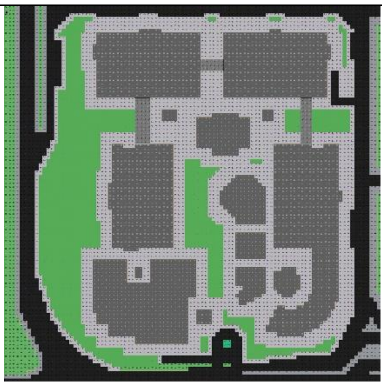
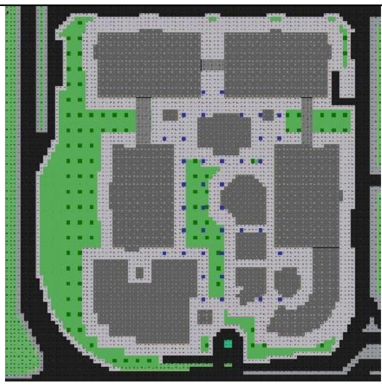
	Grass	Trees with grass
60%		
40%		

Fig. 5. Different simulation scenarios with receptor points.

3. RESULTS

The previous configuration resulted in 38 receptors; all these receptors were laid on paving material in the base case. In case of 40% grass and 60% grass all the receptors were laid on grass in the two scenarios. In case of 40% grass with trees, 23 receptors were on grass and 15 receptors under trees. In case of 60% grass with trees, 15 receptors were on grass and 23 receptors under trees. The following is a comparison of the outcome of PMV and air temperature in each scenario.

3.1 Predicted Mean Vote

The simulated PMV values in the base case scenario ranged between 3.75 and 1.86. In general, adding green surface or trees resulted in a drop in PMV values between every two successive scenarios throughout the simulation hours, the highest and lowest values are highlighted. The drop in PMV values between the 40% grass with trees and 60%grass with trees resulted in improvement throughout the day hours compared to differences between other successive scenarios. While the smallest drop reached 0.03 and was recorded for the base case and 40% grass at 18:00. Noon, 12:00, always resulted in the peak of PMV improvement between every two consequent scenarios with an average of 0.3 except between 40% grass with trees and 60% grass with trees, the peak was at 14: 00. Conversely, at 18:00, always showed the smallest drop in PMV values between every two consequent scenarios with an average of 0.065 as shown in Table 2 and Fig. 6.

In the case of adding trees to grass surfaces, the simulated PMV results ranged between 3.16 and 1.73. A relatively weak improvement in PMV values was recorded only until 18:00. The maximum reduction in PMV values between every two consequent scenarios reached 0.39 at 14:00 as shown in Table 2 and Fig. 6.

Table 2. The PMV value for different scenarios in different hours through the day.

Hours	Base Case Mean PMV	40% grass Mean PMV	60% grass Mean PMV	40% grass with trees Mean PMV	60% grass with trees Mean PMV
10:00	3.746321	3.528737	3.426992	3.164871	2.878997
12:00	4.990150	4.790347	4.702934	4.567363	4.209158
14:00	5.396163	5.282211	5.218945	5.043758	4.655611
16:00	4.395968	4.300853	4.219479	4.082561	3.699097
18:00	1.857153	1.825358	1.815597	1.848303	1.734816

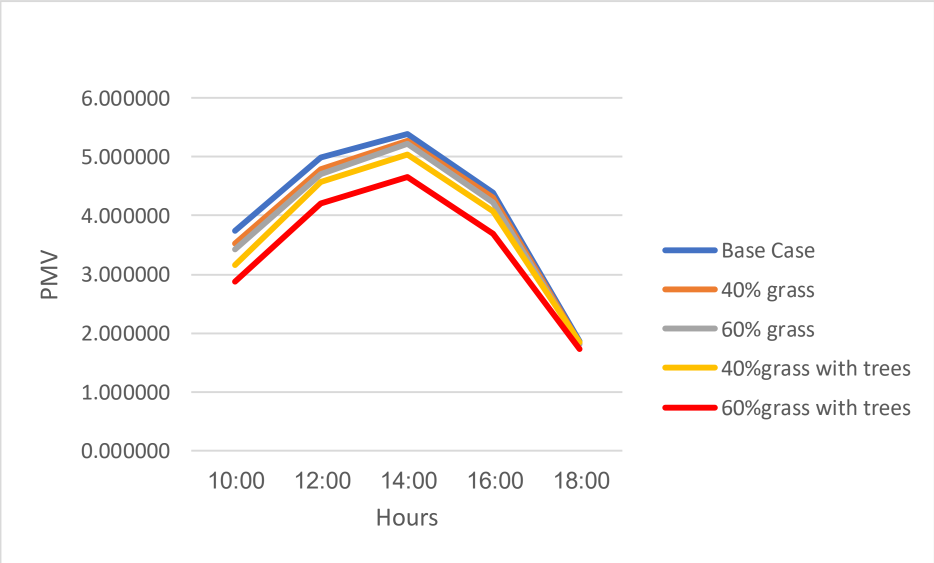


Fig. 6. Different PMV values for different scenarios

Paired samples t-test for PMV: The results showed a statistically significant change in PMV values between different coverages in every two consequent scenarios ($p < 0.05$). Value of t-test, degrees of difference and alpha level are shown in Table 3. In order to study the significance of the effect of adding trees, independent samples t-test for PMV of the 38 receptor points at different times throughout the day for different scenarios with trees were carried out. The results in case of 40% grass with trees showed a statistically significant change in PMV values between different coverages in every two consequent hours ($p < 0.05$) except at 18:00. The value of t-test, degrees of difference and alpha level are shown in Table 3. The results in case of 60% grass with trees showed a statistically significant change in PMV values between different coverages in every two consequent hours ($p < 0.05$). The value of t-test, degrees of difference and alpha level are also shown in Table 3.

PMV for receptors on grass and receptors under trees for 40% grass simulated PMV values in the case of 40% grass with trees ranged between 3.5 and 1.8. In general, adding trees resulted in a drop in PMV values between every two successive hours. In case of 40% grass with trees, 23 receptors were on grass and 15 receptors under trees. At 10:00, the receptors on grass showed lower mean value of PMV than receptors under trees. At 16:00 resulted in the peak of PMV improvement between every two consequent scenarios with an average of 0.28. Conversely, noon always showed the smallest drop in PMV values between every two consequent scenarios with an average of 0.01 as shown in Table 4 and Fig. 7.

Table 3. Paired sample t-test for PMV values throughout the day.

	Case	T	df	Sig. (2-tailed) $p<0.05$
Pair 1	00 10 - 40 grass 10	24.235	37	0.0000
Pair 2	00 12 - 40 grass 12	19.697	37	0.0000
Pair 3	00 14 - 40 grass 14	9.537	37	0.0000
Pair 4	00 16 - 40 grass 16	9.877	37	0.0000
Pair 5	00 18 - 40 grass 18	11.248	37	0.0000
Pair 6	40 grass 10 - 60 grass 10	10.691	37	0.0000
Pair 7	40 grass 12 - 60 grass 12	17.099	37	0.0000
Pair 8	40 grass 14 - 60 grass 14	6.407	37	0.0000
Pair 9	40 grass 16 - 60 grass 16	5.042	37	0.0000
Pair 10	40 grass 18 - 60 grass 18	1.256	37	0.2170
Pair 11	40 trees 10 - 60trees 10	11.731	37	0.0000
Pair 12	40 trees 12 - 60 trees 12	19.698	37	0.0000
Pair 13	40 trees 14 - 60 trees 14	10.207	37	0.0000
Pair 14	40 trees 16 - 60 trees 16	7.496	37	0.0000
Pair 15	40 trees 18 - 60 trees 18	11.173	37	0.0000

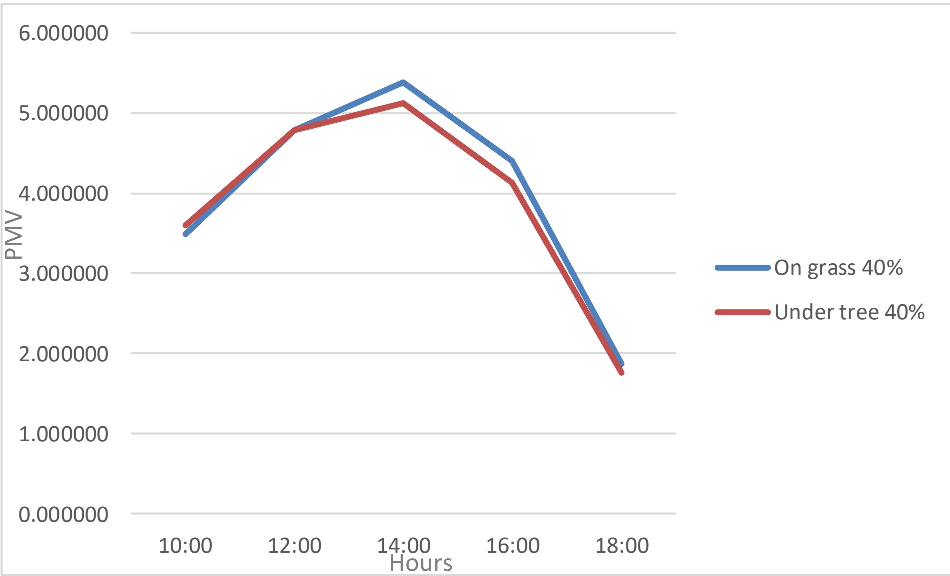


Fig. 7. Different PMV values receptors on grass and under trees for 40% grass with trees.

Table 4. PMV values throughout the day for receptors on grass and under trees for 40%grass with trees.

Time	On grass	Under trees
10:00	3.485348	3.595267
12:00	4.793483	4.785540
14:00	5.387874	5.120193
16:00	4.410487	4.132747
18:00	1.868543	1.759140

In order to study the significance of the effect of adding trees, independent samples t-test for receptors laid on grass and receptors under trees at different times throughout the day were carried out. The results showed a statistically significant change in PMV values between different receptors only at 14:00 ($p < 0.05$). The value of t-test, degrees of difference and alpha level are shown in Table 5.

Table 5. Independent samples test for PMV values throughout the day.

40 % grass with trees	T	df	Sig. (2-tailed) P<0.05
10:00	1.686	36	.100
12:00	1.854	36	.072
14:00	3.879	36	.000
16:00	1.812	36	.078
18:00	1.123	36	.269

PMV for receptors on grass and receptors under trees for 60% grass, the simulated PMV values in the case of 60% grass with trees ranged between 5.0 and 1.7. In general, adding trees resulted in a drop in PMV values between every two successive hours in case of 60% grass with trees, 15 receptors were on grass and 23 receptors under trees. At 16:00 resulted in the peak of PMV improvement between every two consequent scenarios with an average of 0.64. Conversely, 10:00 always showed the smallest drop in PMV values between every two consequent scenarios with an average of 0.25 as shown in Table 6.

In order to study the significance of the effect of adding trees, independent samples t-test for receptors laid on grass and receptors under trees at different times throughout the day were carried out. The results showed a statistically significant change in PMV values between different receptors at all timings, ($p < 0.05$). The value of t-test, degrees of difference and alpha level are shown in Table 7.

Table 6. PMV values throughout the day for receptors on grass and under trees for 60% grass with trees.

Hour	On grass 60% Mean	Under tree 60% Mean
10:00	3.027693	2.782022
12:00	4.403000	4.082739
14:00	5.021053	4.417278
16:00	4.099440	3.438004
18:00	1.772313	1.710361

Table 7. Independent samples test for PMV values throughout the day.

60% grass with trees	T	df	Sig. (2-tailed)
10:00	2.189	36	.035
12:00	3.266	36	.002
14:00	4.690	36	.000
16:00	3.701	36	.001
18:00	2.892	36	.006

3.2 Temperature

In general, the simulations showed a pattern in all the scenarios where air temperature rises through the morning hours until 14:00 when it started to decrease. In the base case scenario, the simulated air temperature ranged between 28.38℃ and 34.44℃. When comparing the effect of adding 60% of grass surfaces with trees, it was noticed that the initial step (between base case and 60% with trees) had the highest effect throughout the simulation hours where temperature decreased by average 1℃ in the morning and 0.7 at end of day at 16:00. The lowest drop reached 0.020℃ at 10:00 between base case and 40% grass scenarios. The highest average drop of 0.95℃ in air temperature values between every two consequent scenarios appeared at 12:00 between 60%grass and 40%grass with trees scenarios as shown in Table 8 and Fig. 8.

For grass with trees coverage scenarios, the simulated air temperature values ranged between 27.6°C and 34.38°C. The increase in grass coverage and adding trees caused effects on air temperature values, mostly a decrease, where the change ranged between 1°C drop at 10:00 and 0.36°C at 14:00 as shown in Table 8 and Fig. 8.

Air temperature for receptors on grass and receptors under trees for 40% grass, the simulated air temperature values in the case of 40% grass with trees ranged between 27.5°C and 34.5°C. In general, adding trees resulted in a drop-in air temperature values between every two successive hours. In case of 40% grass with trees, 23 receptors were on grass and 15 receptors under trees. At 10:00 the receptors on grass showed higher mean value of air temperature than receptors under trees. At 14:00, the peak of air temperature improved between the two different groups of receptors with an average of 0.33°C. Conversely, the smallest drop in air temperature between the two different groups of receptors was always observed at 18:00 with an average of 0.125°C as shown in see Table 8 and Fig. 8.

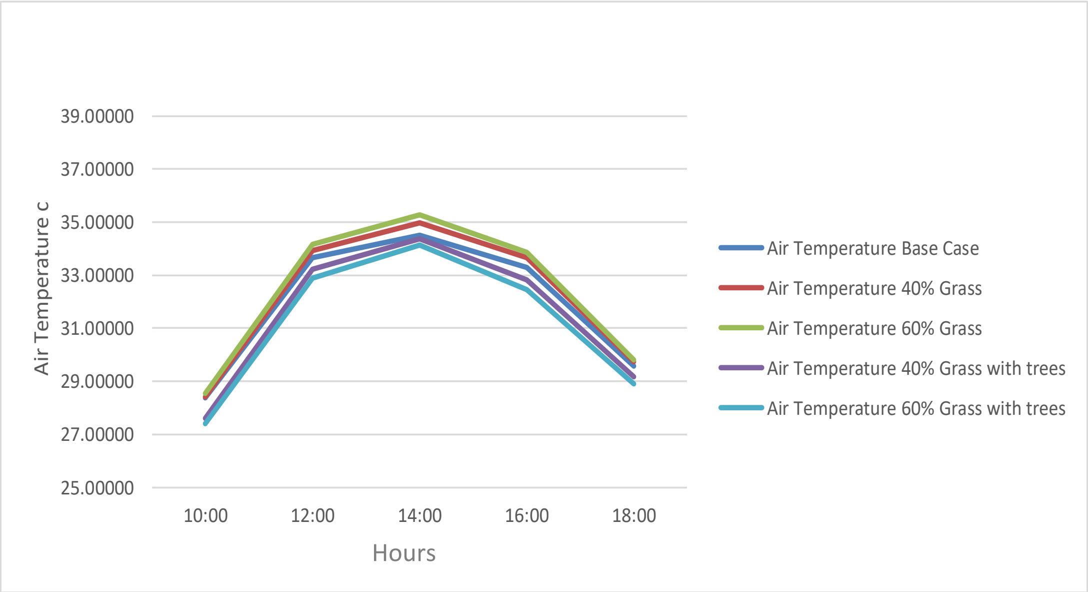


Fig. 8. Different air temperature values for different scenarios.

Table 8. Air temperature values for the different scenarios at different hours throughout the day.

Hour	Case	t	df	Sig. (2-tailed) $p<0.05$
10:00	Base case - 40%grass	-0.995	37	0.326
12:00		-7.568	37	0.000
14:00		-17.709	37	0.000
16:00		-37.271	37	0.000
18:00		-68.849	37	0.000
10:00	40% grass versus 60% grass	-19.952	37	0.000
12:00		-36.052	37	0.000
14:00		-53.523	37	0.000
16:00		-54.425	37	0.000
18:00		-50.607	37	0.000
10:00	40% grass with trees versus 60% grass with trees	9.854	37	0.000
12:00		14.598	37	0.000
14:00		10.92	37	0.000
16:00		18.968	37	0.000
18:00		28.84	37	0.000

4. CONCLUSION

The importance of green surfaces and trees using either grass or trees with grass was proven via simulations under hot arid climates. It may be concluded that the use of soft materials within the outdoor area helps improving PMV values with varying effects ranging from 0.9 at 10:00 to 0.1 at 18:00. The use of grass surfaces resulted in the slightest improvement in PMV values where the maximum effect did not exceed a drop of 0.217. On the other hand, the strongest improvement appeared in trees with grass scenarios where the maximum effect reached a drop of 0.388 in PMV values. Despite these improvements, PMV did not leave the “extreme” or “strong heat stress” ranges during the morning hours.

The higher PMV improvement when using shade trees rather than grass surfaces corporates with previous results in the literature. The findings of this study are limited to hot arid climates and are not to be generalized for other climatic conditions.

DECLARATION OF CONFLICT OF INTERESTS

The authors have declared no conflict of interests.

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تأثير النجيلة والأشجار على الراحة الحرارية في أماكن الترفيه الخارجية في مناخ حار جاف

يهدف البحث إلى تحليل ومقارنة تأثير استخدام النجيلة أو الأشجار مع النجيلة كاستراتيجية تصميم وتأثيرها على الطبيعية المناخية باستخدام ENVI–met لنمذجة ومحاكاة سيناريوهات مختلفة، يمثل سيناريو البداية المباني القائمة لمكان ترفيه مختار تلاه مجموعة سيناريوهات تمثل ٤٠ ٪ و ٦٠ ٪ من نسب لنجيلة أو الأشجار مع النجيلة و تشغيل المحاكاة في يوم صيفي نموذجي و حساب متوسط التصويت المتوقع (PMV) للسيناريوهات باستخدام BIOMET، وهي أداة داخل ENVI–met، ومقارنة درجة حرارة الهواء الخارجي حيث تبين ان زيادة النسبة المئوية للعلاجات المختلفة ساعدت في تعزيز مستوى الراحة الحرارية ولكن بتأثير مختلف، فالسيناريوهات التي تستخدم نسبًا مختلفة للأشجار مع النجيلة تأثيرها تراوح بين ٣,١٦ و ١,٧٣، وحالة للأشجار مع النجيلة، تراوحت درجة حرارة الهواء بين ٢٧,٦ و٣٤,٣٨ درجة مئوية وتراوح التغيير بين ١,٠٠ درجة مئوية الساعة ١٠:٠٠ و ٠,٣٦ درجة مئوية الساعة ١٤:٠٠.