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EFFECTS OF PAVING MATERIALS ON THERMAL PROFILE OF OUTDOOR SPACES IN MEDITERRANEAN CONTEXT: CASE OF JIJEL, ALGERIA

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Abstract: Ensuring acceptable comfort conditions in quality outdoor spaces is nowadays one of the major concerns of urban design. Various paving materials contribute to this quality. Several studies have examined their optical and thermal properties, but few of them have addressed the negative impacts of a random choice of these materials on the thermal profile, especially in Jijel on the southern shore of the Mediterranean. This study aims to highlight the paving material's contribution to the emergence of microclimates that are not always favorable to users. The thermal environment of two outdoor spaces with different paving materials was simulated and evaluated using the physiological equivalent temperature index through the RayMan model. The simulation results, validated by measurements and a questionnaire survey conducted in winter and summer 2019, revealed large variability in air temperatures for the studied paving materials. Air temperatures do not systematically follow the surface temperature profile, let alone the corresponding sky opening factors. Slate recorded the highest surface temperature (50.3°C), with a difference of up to 14.8°C from marble. Grassed surfaces and shade dampened the impact of radiation three times more than tiled surfaces. The peak air temperature (33 °C) is recorded for the tiled surfaces. It is reduced by 1°C for grassy surfaces and by up to 3.1°C for marbled surfaces. These results can therefore alert decision-makers to the need for an appropriate choice of paving materials for outdoor spaces that can favorably impact their thermal profile.

Keywords: Public space, Outdoor comfort, Paving materials, Thermal profile, Surface temperature, PET index

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INTRODUCTION

Public spaces are used and enjoyed in a variety of ways by everyone as part of the city's recreational spaces. There, spatial and social forms collide. This is where the interest and complexity of their approach come from, as well as the challenges of their development. Architects, urban planners, and other city actors encourage outdoor activities and promote dynamic cities by offering numerous opportunities for socializing. Consequently, creating quality outdoor public spaces by ensuring conditions of comfort that are acceptable and accepted by users is one of the major concerns of urban design and development today. Several normative references are defined to establish the qualitative requirements during their design and implementation. However, several variables constrain the emergence of favorable thermal comfort conditions in outdoor public spaces. Climate is the most influential factor in determining this comfort level. Nevertheless, many urban development projects are elaborated within the framework of rehabilitation, renovation, or even new construction operations without taking into account the climatic parameters.

The variability of stimuli emanating as much from radiation as from the configuration of these spaces can generate significant changes in microclimatic parameters (Lai et al., 2014), which in turn greatly affect the psychological and behavioral aspects (Lin et al., 2013, Andrade et al., 2011, Lindner-Cendrowska & Błażejczyk, 2018, Lam et al., 2018). In this perspective and in the Mediterranean context, researchers have analyzed thermal comfort in urban spaces in Italy and Greece (Nikolopoulou & Lykoudis, 2007), and confirmed in their results the existence of a close relationship between microclimatic conditions and the use of outdoor spaces where air temperature and solar radiation are the most dominant parameters.

The city of Jijel (Algeria) is not left out. With the shift of seasons and sunny days becoming more and more intense, they expose pedestrians to high thermal loads. Some of its recreational spaces have been rehabilitated using different paving materials, favoring aesthetics at the expense of the environment and disregarding any comfortable thermal aspect that should be provided. This study focuses on the determination of surface temperatures and the degree of heating of a few materials commonly used for urban paving, notably rough slate. It examines the negative impact on the thermal profile and air temperature, particularly in summer. It aims to highlight the complex relationship between perceived comfort, variability of materials, and generated microclimates.

In the literature, we find similar studies on various aspects of the materiality of urban soils. The latter has become a primordial qualitative criterion for any development. The materials implemented absorb solar radiation and dissipate part of the heat accumulated by convective and radiative processes into the atmosphere, thus increasing the ambient temperature (Santamouris *et al.*, 2011). High albedo pavement materials contribute to the improvement of the urban climate (Akbari *et al.*, 2001) and can provide better thermal comfort conditions during the summer (Doulos *et al.*, 2004). Santamouris *et al.* (2011) conducted experimental analyses of a wide variety of urban materials. They highlighted the role of light-colored, smooth materials, classified as cool materials, in maintaining lower surface temperatures compared to dark, rough materials. Rahn *et al.* (2015) compared the summer day surface temperatures of nine different pavement surfaces and found that dark pavements were warmer, lighter, more reflective pavements were cooler, and grass was the coolest texture. This last finding is supported by the work of Talghani (Taleghani, 2018), who compared thermal conditions at three sites with different surface materials. The physiological equivalent temperature (PET), used as an index of thermal comfort, was lower in the park (grass covered) by 11°C compared to the parking lot (concrete paved) at 4:00 pm. It was also found that increasing the surface albedo by 0.1 resulted in a 1.2°C increase in mean radiant temperature and, consequently, a 0.8°C higher PET. Djekic *et al.* (2018) conducted measurements that stated that under the same conditions, various materials yield different maximum temperatures. It was also concluded that the type of material, color, roughness, and shading of an area affect the heating of pedestrian surfaces. Thus, the effect of paving is well proven in terms of its effect on albedo in urban areas with various geometric configurations. Its effect, however, remains to be established in outdoor spaces with heterogeneous pavements.

The properties of paving materials, such as the ability to absorb, propagate, or reflect solar radiation, affect the surface temperature and, consequently, the temperature of urban areas (Djekic *et al.*, 2018). The thermal balance of urban surfaces depends on their thermal characteristics, in particular their albedo and emissivity (Taleghani, 2018).

Research shows that these two factors have a large influence on the surface temperatures of materials (Ferguson *et al.*, 2008). Pavement materials used in urban areas generally have a lower albedo than areas with vegetation; they reflect less and absorb more solar radiation, which naturally leads to higher surface and air temperatures. Materials used for paving have a higher heat storage capacity than natural materials. Green surfaces and trees in particular are cooled by evapotranspiration, which not only helps provide shade but also lowers air temperatures (Morille & Musy, 2017). Unlike macadamized surfaces, they store the solar energy received in-depth and return it to the atmosphere at night in the form of heat. The choice of urban paving materials is very diverse, and it is very important to know their characteristics for a relevant and favorable choice in terms of thermoradiative behavior, maintenance, and aesthetics. Cortesão *et al.* (2016) reported that the nature of paving materials and the amount of vegetation are behind the different remarkable perceptions of thermal comfort and intensity of use of each space. Whether and when people decide to use these spaces depend on the outdoor microclimate, which itself is impacted by spatial characteristics and ground surface materials (Nikolopoulou & Lykoudis, 2007, Lin *et al.*, 2011, Chen *et al.*, 2015). This lends real complexity to the process of assessing comfort in these outdoor spaces.

Several indices are then used to evaluate the latter; however, some are better adapted than others to hot conditions. Most of these indices have been developed mainly for the steady state and, therefore, cannot represent the wide variety of urban microclimates to which users are often exposed. Their confrontation with subjective thermal perception has become a methodological issue to confirm their accuracy, applicability, and validation through comparison (Potchter *et al.*, 2018, Fang *et al.*, 2017, Fröhlich *et al.*, 2019, Zare *et al.*, 2018). These have led to adjustments and scale calibrations because their relationships with thermal sensations are not always clear and suggest the modification of thresholds for some stress categories for a better assessment of such environments (Pantavou *et al.*, 2014, Tsitoura *et al.*, 2014, Salata *et al.*, 2016, Fang et *al.*, 2019).

MATERIALS AND METHODS

In this research, we evaluate the microclimatic conditions of two public open spaces and their related comfort. The focus is on the spatial support of the problem, i.e., the floor surfaces with their variable materiality and the effects they have on the degree of user satisfaction with thermal comfort. The methodological approach in the analysis and evaluation of comfort is divided into four parts: (a) observation of the study area by counting the number of users present and identifying their preferred locations while conducting a questionnaire survey; (b) simulation and calculation of thermal comfort indices using the RayMan model, including the Physiological Equivalent Temperature (PET), to compare the values obtained with those presented in **Table 1** and with the survey results; and (c) validation of the simulation results by measuring the surface temperatures.

The general context of the study

With its position on the coastal strip of northeastern Algeria, the city of Jijel (latitude 36°49'N; longitude 5°46'E; altitude 9 m) offers all the climatological characteristics of the Mediterranean maritime regions (**Fig. 1**), with mild winters and hot and humid summers. It is considered one of the most watered areas in Algeria. This study is based on in situ meteorological measurements in a square and a public garden in the city center. Jijel has a Mediterranean climate with an average annual temperature of 18.1 °C. The hot season extends from June to September, with maximum temperatures of between 28.2°C and 31.8°C. The highest monthly daytime and nighttime temperatures are 26.3 °C, with a maximum of 31.8 °C and a minimum of 20.6 °C. The relatively cold (mild) season runs from October to April, with temperatures ranging from 16.2 °C to 20.9 °C.

In February, the coldest month, temperatures reach their minimum value with a monthly average of 11.5 °C, while the hottest month is July with a monthly average temperature of 26.4 °C. Several hot days are regularly recorded during the summer season, caused by the rising winds from the south (Sirocco).

Table 1. Thermal comfort ranges and corresponding perception index categories.

Classes Indices	PMV [-]	PET [°C]	SET* [°C]	Thermal Perception	Level of Physical stress
+4	> +3.5	> 41	> 37	Extremely hot	Extreme thermal Stress
+3	+2.5 - +3.5	35 - 41	34 - 37	Very hot	High thermal stress
+2	+1.5 - +2.5	29 - 35	30 - 34	Hot	Moderate thermal stress
+1	+0.5 - +1.5	23 - 29	25 - 30	Slightly warm	Slight thermal stress
0	-0.5 - +0.5	18 - 23	22 - 25	Confortable	No thermal stress
-1	-1.5 - -0.5	13-18	17 - 22	Slightly cold	Slight cold stress
-2	-2.5 - -1.5	8 -13	14 - 17	Cold	Moderate cold stress
-3	-3.5 - -2.5	4 - 8	10 - 14	Very cold	High cold stress
-4	< -3.5	< 4	< 10	Extremely cold	Extreme cold stress

Source: (Zare *et al.*, 2018) completed by the author

Fig. 1 Jijel's geographical position and the locations of the public areas under study

Surface temperatures of used paving materials in both studied spaces were measured during the months of February and July 2019. The two open spaces were chosen because they are on the same axis and occupy adjacent plots, which predispose them to have similar weather conditions, as well as the fact that they are the most popular. The Abbane Ramdane plaza is entirely mineralized and has granite tiles covering its ground, giving it a uniform appearance. A white-gray marble monument stands in the center of the square, with two kiosks on either side. Its edges are punctuated by a few ficus-like trees.

The peace garden, on the other hand, is heterogeneous with 70% grassy surfaces, tinted concrete pavers in the central paths, rough slate in the periphery, and granite tiles on the sidewalks. A water fountain occupies the center of this space. Palms are the most prevalent type of tree in this garden, aside from the ficus trees that border it **(Fig. 2)**. The diversity of materials in a single location and their proximity allowed us to measure the temperature of various surfaces exposed to identical microclimatic conditions. The measurement points were chosen far from any morphological constraints and were precisely exposed to the sun during most of the day, except for those intentionally chosen in partial or total shade, to determine the impact and measure the temperature variations between shaded and sunny surfaces.

Field instruments and data collection

Direct observation of users was adopted as an approach method on the day of the measurement campaign. It covered the entire area and made it possible to count the number of users every hour, identify the most used areas and draw up a profile of the use of the two areas under study. The measurements of air temperature, relative humidity, wind speed, and illumination are made with a portable multifunctional digital instrument LM 8000A with a type K probe. While for the temperatures of the horizontal surfaces and those of the external walls of the facades delimiting the premises, a ScanTemp 0-1353 laser thermometer has allowed reading instantaneously the different temperatures. The characteristics of the used instruments are reported in **Table 2**. Test measurements were carried out to calibrate the instruments compared to those of the meteorological station of the airport of Jijel. We ensured that the weather conditions were sunny with a clear sky and low wind speeds.

Table 2. Characteristics of the measuring instruments used in the field

Parameters	Symbol/Unit	Instrument	Range	Accuracy
Air Temperature	Ta [°C]		-100 to 1300 °C	±(1% rdg+1°C)
Relative Humidity	Hr [%]		10 to 95 %	< 70% RH : ±4% RH ≥70% RH : ±4% rdg+1.2% RH
Air Velocity	Va [m/s]	Multifunction 4 in 1 Meter Type LM-8000A	0.4 to 30 m/s	≤20 m/s : ± 3% >20 m/s : ±4%
Illumination	Lx [Lux]		200 to 20000 Lux	±5% rdg ± 8 dgt
Surface Temperature	Ts [°C]	 Laser Thermometer ScanTemp 0-1353	-32 to 600°C	> 23°C: ±1% rdg or ±1°C whichever is greater -18 to 23°C: ±2°C

Fig. 2 General views of (a) Abbane Ramdane Square and the Peace Garden (b) the Peace Garden Central path in tinted concrete pavers (c) Peripheral path in rough slate

Fig. 3 Location of measurement points in studied areas. Source: Google Earth completed by author

The measuring campaigns took place in the winter and summer of 2019 on two typical days. The measurements were taken at a height of 1.10 meters every hour during the day, from 9:00 a.m. to 4:00 p.m. in the winter and 6:00 p.m. in the summer, and lasted 15 to 20 minutes each. The typical days were obtained using statistical analysis of weather data from 2009 to 2018. The standard deviation and a ten-year average were determined. The daily data recorded during the analyzed period are then compared to these averages. For each physical parameter, only data with a standard deviation of less than or equal to 20% is selected.

First filtering brings out February as the coldest month and July as the warmest one. Then, the comparison between the hourly values of the different physical parameters recorded during the filtered years showed that the day of 12 February and 19 July have the lowest standard deviation from the mean and are adopted respectively as representative days of winter and summer. The measurement plan in **Fig. 3** encompasses different types of materials (tile, concrete pavers, slate, and grass) and four water bodies in the middle of the garden.

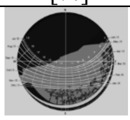
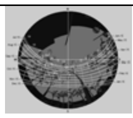
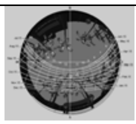
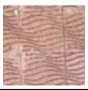
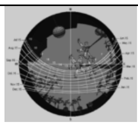
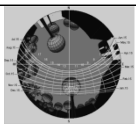
All measuring points were located within a radius of fewer than 100 meters and were therefore exposed to identical microclimatic conditions during the day. Three additional points, A, B, and C, were selected for the same material, i.e., rough slate, and are differently exposed to solar radiation with different values of the sky opening factor. **Table 3** summarizes the meteorological conditions of the two typical field days. The reference data were obtained from Jijel airport's local weather station, which is about 15 kilometers away from the study area.

Table 3. Characterization of the weather on fieldwork days

Typical day dates	Average daily values							Average monthly temperature [°C]	ΔT [°C]
	Air temperature [°C]		Relative humidity [%]		Air velocity [m/s]		Luminance [Cd/m²]		
	In situ	Meteo St.	In situ	Meteo St.	In situ	Meteo St.	In situ	Meteo St.	
Winter 12 February 2019	19.03	12.80	54.54	61.40	0.46	5.2	883.25	11.5	7.53
Summer 19 July 2019	30.56	28.0	53.60	56.40	0.18	2.4	2586.60	26.4	4.16

The differences between the average air temperatures of the field days and the monthly average temperature (ΔT) are also presented for comparison. Simulations were performed in Townscope (Teller & Azar, 2001) using 3D modeling of the two study spaces. From a sustainable urban design perspective, Townscope is based on a computer system to support solar access decision-making. The software consists of a three-dimensional urban information system coupled with solar energy assessment tools. Stereographic views were generated from the different measurement points along with their equivalent sky opening factors (SVF), corresponding to the main materials in place (**Table 4**).

Table 4. Thermo-physical properties of the main materials in place and equivalent sky view factors (SVF).

Pts	Materials	SVF [%]	Absorptivity $[m^{-1}]$	Albedo [-]	Emissivity [-]	Conductivity [W/m°C]	Diffusivity [m²/s]	Effusivity $[Wh^{1/2}\,m^{-1/2}.°C^{-1/2}]$
Pt1	Rough Slate 	 SVF=44.8%	0.67	0.33	0.85	2.10	0.0037	34.5
Pt2	Grass 	 SVF=64.7%	0.72	0.28	0.88	1.26	0.0044	19.1
Pt3	Concrete pavers 	 SVF=66.7%	0.55	0.45	0.90	1.51	0.0032	26.60
Pt4	Granite Tiles 	 SVF=76.6%	0.60	0.40	0.90	1.70	0.0039	27.30
Pt5	Marble 	 SVF=52.6%	0.44	0.56	0.95	2.91	0.0045	35.96

Source: Oke (1982), Lavigne *et al.* (1997), AND Izard & Lelong (2006).

Questionnaires and observations

There was no pre-defined sample before the survey was conducted; users were interviewed at random. We were careful to reduce the margin of error so that the results of the questionnaire could be validated. For this purpose, we assumed an infinite or very large study population. It includes not only permanent users (the local public) but also temporary users from other nearby communities. The sample size used in this study was determined based on the Cochran formula (Cochran, 2007). It gives the minimum sample size to ensure adequate coverage of the nominal 95% confidence interval.

$$N \geq (Z^2 P (1-P)) / E^2 \quad (1)$$

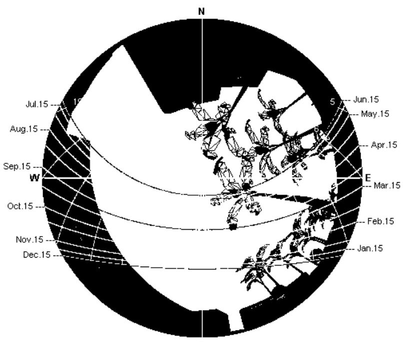
where N is the minimum sample size, Z is the critical value (Z-score), which depends on the confidence level (CL). For a CL of 95%, Z = 1.96. P is the proportion of the characterized population (degree of variability). For an unknown population, P = 0.5, which gives the maximum size of the population. E represents the margin of sampling error, which is less than 5% for this study. The questionnaire used is adopted by modifying those deployed in the literature according to the thermal environment stipulated in ASHRAE 55 (2004) and ISO 7726 (2003). It is divided into three components: a contextual signage component, a perceptual component, and a preference and acceptability component. The signaling component covers questions related to the demographics, age category, status, activities, and some visually noticeable signs of the interviewee. Some of the information collected relates to the identification of personal factors, perception and climatic appreciation of places, noting behaviors that indicate particular discomfort. The perceptual component highlights the unitary or fragmented vision that the user has of the space studied and whether the climatic parameters intervene in this unitary or partitioned perception of the space. We also seek to estimate if microclimatic variations are felt by the users and if this variation is important for them in the organization of their activities and to what extent they grant the elements of the climate importance in the evaluation of their thermal environment. We asked users to report their sensations of the thermal environment on a 9-point scale, ranging from extremely cold (-4) to extremely hot (+4), with neutral (0) in the middle. The questions in the preferences and acceptability component focus on the assessment of a few climate parameters according to the McIntyre scale to evaluate the actual sensation vote and the inherent expectations.

Simulation of thermal comfort

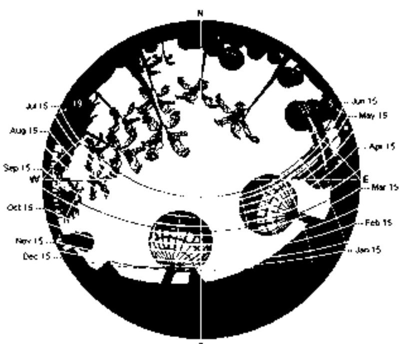
A first reading of the data from the surface temperature measurements showed that the greatest differences in surface temperatures are between the rough slate surfaces exposed to the sun all day and those shaded. Therefore, the thermal comfort simulation was performed specifically during the overheating period for three points with the same material in this case, slate. Point A (SVF = 67.6%) is exposed to the sun all day; point B (SVF = 58.2%) is in intermittent partial shade; and finally, point C (SVF = 46.6%) is under the tree canopy and shaded most of the day, as shown in **Fig. 4**.

Meteorological parameters, measured in the field for a typical summer day (19th July) and used for simulation in the RayMan model, are presented in **Table 5** below, and the results can be seen in a section later in **Table 6**.

Rayman (Matzarakis et al., 2007) is a micro-scale radiation diagnostic model developed at the university of freiburg. it is designed to calculate radiation fluxes in simple and complex environments. it calculates the thermal indices pmv, pet, and set* based on six given parameters for a specific time and location. these parameters include four meteorological and two thermo-physiological parameters: air temperature (°c), mean radiant temperature (°c), wind speed (m.s-1), relative air humidity (%), thermal resistance of clothing (clo), and activity level (w) for a person of height: 1.75 m, weight: 75 kg, age: 35 years, gender: male, clothing: 0.9 clo, and activity: 80 w in this research, physiological equivalent temperature (pet) was



Point **A** (SVF=67.6%)


Point **B** (SVF=58.2%)

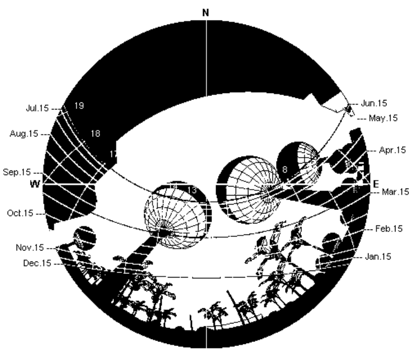

Point **C** (SVF= 46.6%)

Fig. 4 Stereographic projections of selected points with sun path and horizon constraints

Table 5. Meteorological parameters of the typical summer day – 19 July 2019

Parameters	9:00h	10:00h	11:00h	12:00h	13:00h	14:00h	15:00h	16:00h	17:00h	18:00h	19:00h
Air temperature [°C]	28.2	29.6	31.1	31.3	31.5	31.0	30.8	30.0	28.9	27.6	25.4
Relative humidity [%]	55.7	46.8	43.4	43.5	46.8	49.8	49.8	51.8	54.3	56.7	61.3
Air velocity [m/s]	0.5	0.6	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.3	0.1
Cloud cover [Octas]	0	0	0	0	0	0	0	0	0	0	0

chosen as the primary thermal index. it is defined as "equivalent to the air temperature that is necessary to reproduce in a standardized indoor environment and for a standardized person the core and skin temperatures that are observed under the conditions evaluated" (Höppe, 1999). In addition, the mean radiant temperature is considered equal to the air temperature Ta, the wind speed of 0.1 m/s, and a relative humidity of 50% for Ta=20 °C. It refers to the heat balance equation introduced by the Munich Individual Energy Balance Model (MEMI) (Höppe, 1999):

$$M+W_o+R+C+E_{sk}+E_{res}+E_{sw}+S = 0 \quad (2)$$

The research work based on the application of PET in the Mediterranean context was carried out mainly in Cairo, Egypt (Mahmoud, 2011), Crete (Tsitoura *et al.*, 2014), Athens (Tseliou *et al.*, 2017), Milan, Italy, and Thessaloniki, Greece (Nikolopoulou & Lykoudis, 2006), and Constantine, Algeria (Louafi *et al.*, 2017). But, very few published studies have been conducted in coastal environments on the southern shore of the Mediterranean in Algeria. This work therefore adds to this important area of research and extends the application of the PET thermal index to urban public recreation spaces in a Mediterranean environment that is hot and humid in summer and relatively mild in winter.

RESULTS

The results obtained concern the impact of surface temperature on ambient air, reflecting the effect of albedo variability on urban microclimates. They examine the contribution of shading to the attenuation of surface temperature and highlight the effect of the sky openness factor (SVF) on air temperature. They also explore the impact of the variability of materials used on thermal comfort.

Effect of surface temperature (Ts) on air temperature (Ta)

The results of the surface and air temperature measurements shown in **Fig. 5** correspond to specific points during the two typical days in winter and summer. The materials selected are among those usually used in outdoor spaces (concrete pavers, rough slate, tiles, marble, and grass). The rough black surface of slate, with an absorptivity of 0.67 m^{-1}, captures more radiation than smooth, clear surfaces such as marble. Its low emissivity of 0.85 considerably reduces radiation losses and it therefore remains the warmest material. In contrast, with an absorption coefficient of 0.44 m^{-1} and an emissivity of 0.95, marble remains the coldest material (**Fig. 5 (b)**). In summer, the air temperature ranged from 26.3 °C in the morning to 33 °C at 13:00, the hottest time of the day. The temperature of the hottest material (rough slate) ranged from 35.5 °C to 50.3 °C (**Fig. 5 (b)**). The smallest differences between the air temperature and the hottest surface temperature were observed in the early morning hours, while the largest differences were observed not at the hottest time of the day but at 3:00 pm, two hours out of phase with the air temperature, thus confirming the absorptive capacity of the rough slate. And it was in this precise slot (12:00 am-3:00 pm) that air and surface temperatures were the highest. In the middle of the day, the effect of paving materials on winter air temperature did not exceed the 2.1°C difference between the tiled and grassed surfaces (**Fig. 5 (a)**). In the summer, it is more important and fluctuated between 3.1 °C (between tiles and marble at 1:00 pm) and 3.4 °C (between slate and the marble at 11:00 am) marking a maximum difference of (3.8 °C between grass and marble at noon). And since the rough slate represents only 5% of the total surface of the garden, its air temperature dropped in summer from 11:00 am to 2:00 pm due to the effect of shade, combined with evaporative cooling of the grassy surfaces covering 70% of the garden. The lowest surface temperatures (27 °C) were reached by the marble, which is lower than the average maximum air temperature of 31.8 °C (**Fig. 5 (b)**).

In summer, marble remains the coldest material, mainly because of its high albedo and high Effusivity (**Table 4**). This resulted in the lowest local air temperatures compared to other materials in place. And it is at the tiled and grassed surface levels that we record the highest air temperatures, 33 °C and 32.6 °C, with a phase shift of one hour. we think that grassed surfaces, reaching a value of 39.5 °C at 10:00 am, are sufficiently warmed up to trigger the phenomenon of evapotranspiration, which lowers their temperatures by 1.7 °C until noon, then rises again to reach a maximum temperature of 46.8 °C at 3:00 pm, while the corresponding air temperature does not systematically follow these fluctuations. Grass diffusivity and very low inertia make it more sensitive to abrupt variations in radiation due to shade, recording a 5.9 °C decrease in surface temperature at 1:00 pm, reaching 8.6°c at the same hour as the slate. Marble, pavers, and tiles show different behaviors depending on the season (winter or summer) and on the time of day (morning or afternoon). Marble and tile show almost the same thermal profile in winter and cool down faster at the end of the day, while concrete pavers cause a slight phase shift and heat up gradually, but heat up longer.

In winter (**Fig. 5 (a)**), the effect of surface temperature on air temperature is not significant given the daily shape and trend of the surface temperature curves, except between 10:00 and 12:00 am, where the rise in surface temperature of tile and marble resulted in an average increase in air temperature of 2.5 °C and 1.9 °C respectively. The city's effect is more noticeable in winter than in summer, and more so at the beginning of the day. A difference in air temperature of more than 7 °C is noticed, compared to the local weather station, whereas, in summer, this difference is reduced by half. In **Table 6**, we see that the amplitudes of surface temperatures are relatively high in winter. It ranges between 7.9 °C and 11.8 °C at the tiled surface level, with a maximum amplitude of 17 °C in summer, and the slate records the highest temperature of the day (50.3 °C). In the winter, the grass had the lowest temperature range of 7.9 °C, compared to almost double in the summer. However, the nocturnal cooling had a noticeable influence on concrete pavers, tile, and marble, which had the lowest surface temperatures in the early morning, ranging from 6.9 to 8.5 °C. The average minimum surface temperature in the summer is 31.8 °C, which is very close to the average maximum air temperature of 31.9 °C.

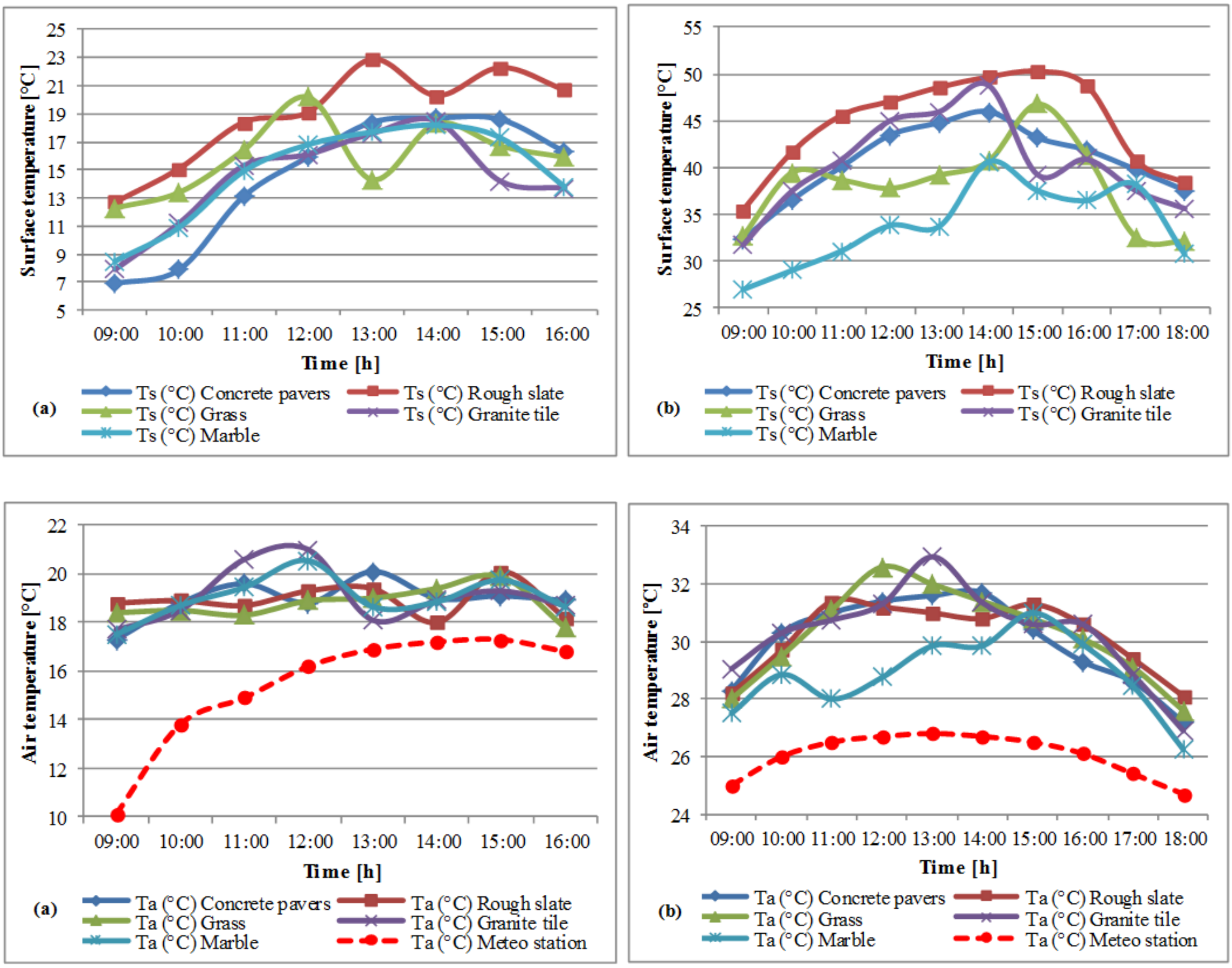


Fig. 5 Surface and air temperature variations at various materials in (a) winter and (b) summer

Table 6. A summary of the surface temperature amplitudes according to the used materials

Material Designation	Surface temperature (Ts) in [°C]						Air temperature (Ta) in [°C]					
	Winter			Summer			Winter			Summer		
	Ts max	Ts min	ΔTs	Ts max	Ts min	ΔTs	Ta max	Ta min	ΔTa	Ta max	Ta min	ΔTa
Rough slate	22,9	12,7	10,2	50,3	35,5	14,8	20,1	18,0	2,1	31,4	28,1	3,3
Grass	20,2	12,3	7,9	46,8	32,1	14,7	19,9	17,8	2,1	32,6	27,6	5,0
Concrete pavers	18,7	6,9	11,8	46,0	32,4	13,6	20,1	17,3	2,8	31,7	27,2	4,5
Granite tile	18,5	7,9	10,6	48,8	31,8	17,0	21,0	18,7	2,3	33,0	26,9	6,1
Marble	18,2	8,5	9,7	40,7	27,0	13,7	20,6	18,7	1,9	31,0	26,3	4,7

Impact of shade on surface temperature

To determine the effect of shading on surface temperature, the temperatures of slate and grass were measured at two points with different degrees of shading. Both Pt1 (slate) and Pt2 (grass) are exposed to direct sunlight almost all day, with Pt1' (slate) and Pt2' (grass) in full or partial shade almost all day in winter and much of the morning in summer. In winter, the measurement of the surface temperature of the slate over the whole day indicated that the temperatures of the points partially in the shade were between 6.3 °C and 19.3 °C, which was 1 to 10.4 °C lower than the temperature of the slate exposed to the sun all day (**Fig. 6 (a)**.

On the other hand, the daily measurements of the grassed areas indicated that the surface temperatures of the points in partial shade ranged from 7.6°C to 17.7°C, which was 0.6–4.6°C lower than the temperature of the grass exposed to the sun all day. Morning and evening measurements indicated that the temperatures of the points exposed to the sun throughout the day were higher than the temperatures of the points in the shade, both at the beginning and end of the day.

The disparities are more pronounced in the morning than in the afternoon, even more for the slate than for the grass. it should also be noted that in the case of sunny points, there is a sudden decrease in temperature with the return of shade at a certain time of day, as, for example, grass at Pt2, which decreased by 5.9 °C between 12:00 am and 1:00 pm, then started to rise again between 1:00 and 2:00 pm by increasing 4 °C, and began a gradual decline until the final temperature (**Fig. 6 (a)**). In the summer, the differences between Pt1 (sunny) and Pt1' (partially shaded) for slate are rather small, ranging from 0.4°C to 2°C in the morning, then the trend reverses at 1:00 pm (both points become sunny), with Pt1' recording a maximum difference of 2.4°C at 2:00 pm and equaling Pt1 at 4:00 pm (**Fig. 6b (b)**). In contrast, for the grass, the differences are larger in the early morning and decrease as the sun rises. The effect of color and texture is visible on the heating of the materials, especially in summer when solar radiation is more intense. Rough slate with black color and rough texture showed the highest temperatures, while light-colored marble with smooth texture recorded the lowest temperatures.

Impact of material variability on user comfort

The observation showed that some areas are occupied almost all day long. The sun's path seems to punctuate the occupation of the places. For older users and retirees, the best spot is the one on the central alley near the florist, but they deplore the lack of benches to sit on and the fact that those that do exist are far from comfortable and do not encourage long stays, a reason that is repeated by 8% of those questioned and dissuades more than one from staying there. The heat and the intensity of the radiation are mentioned in the first position (45%), in response to the question concerning the climatic conditions that can constitute an obstacle and prevent citizens from frequenting this public garden. The wind comes in second place with nearly 25% of responses, and only 22% of users do not feel accommodated by the heavy weather that characterizes the climate of the city of Jijel and see in the humidity of the air a factor accentuating the discomfort they feel, especially in summer. The diversity of materials that characterizes these two public spaces does not seem to attract their attention where the aesthetic aspect prevails over the thermal. The identification of rough slate as the warmest material motivated the choice of comfort simulation at three different points for the same material, as shown in **Fig. 4**.

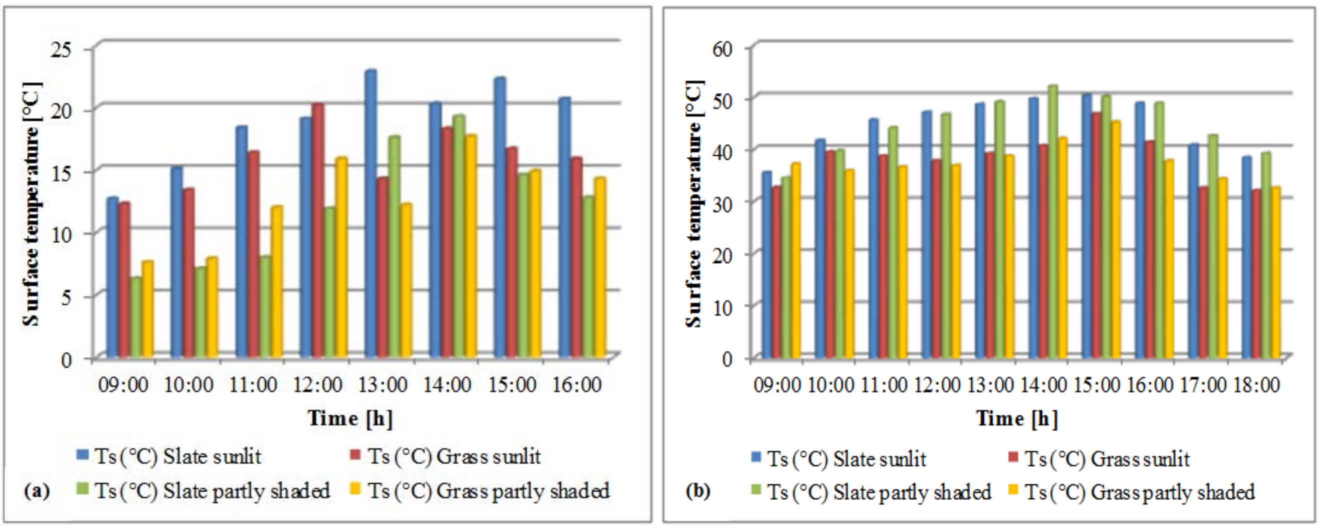


Fig. 6 Measured surface temperatures of slate and grass throughout the day in (a) winter (b) summer

Point A (SVF = 67.6%) is exposed to the sun almost all day, while point B (SVF = 58.2%) is partially shaded, and point C (SVF = 46.6%) is under the tree canopy and is shaded for most of the day.

The simulation results in **Table .7** show that the surface temperatures (Ts) at point A are higher than the surface temperatures at points B and C, which is consistent with the results of the measurement campaign. The largest difference in (Ts) is between points A and C, with an average difference of 17.1 °C while it is 13.1 °C between points A and B and 4 °C between B and C. At 11:00 h the maximum temperature difference between Point A and C is 26.3 °C, while the difference between Point A and B is 21.6 °C and the difference between Point B and C is only 4.7 °C. The difference in surface temperature decreases between points A and B as it is irradiated with sunlight. The difference is reduced from 20.7°C (1:00 pm) to 5.1°C (5:00 pm), while the difference between points A and C is doubled (10.7°C).This highlights the impact of the shadow and sky view factors on the surface temperature.

The results of the simulation in **Table 7** also show the difference in physiologically equivalent temperature (PET) for unshaded and shaded spaces. The PET values for the unshaded spaces exceed 41°C for most of the day (from 9:00 am to 4:00 pm), which indicates extreme thermal stress, while for the partially shaded spaces, a strong thermal stress is felt only in the time slot from 11:00 am to 1:00 pm, where the PET values are between 35°C and 41°C, with moderate thermal stress being felt the rest of the day. On the other hand, in the shaded areas, the sensation of thermal stress is moderate between 11:00 am and 3:00 pm and remains light during the rest of the day. The PET values for point C range between 17.7 and 20.2 °C, which are significantly lower than the values for point A at the same time. This is consistent with the survey results which indicate that users feel more comfortable in the shade than in sunny areas during the summer season and confirms the existence of daytime heat stress felt and expressed by almost 80% of users. From this point of view, and except for the month of February, the majority of users expressed themselves in favor of a microclimate described as "spring-like", acceptable and comfortable due to a shift upwards in the average air temperature values. It should be noted that during the month of July, the expression of the thermal sensation was rather disparate from the point of view of the acceptability of the general comfort conditions due to the adaptation and the time spent on the premises. Indeed, more than 38% of the subjects chose the sensation of heat (+2) in different places. About 27% of the subjects chose the sensation of heat (+3), while 15% found the weather suffocating and chose the sensation of extreme heat (+4). The remaining 20% expressed indifference and even found the weather comfortable. Furthermore, the results of the survey showed that the respondents do not feel small differences in surface temperature, such as those found between concrete paving and granite tiles, and that these do not affect their comfort. On the other hand, they do feel larger differences such as those between slate and grassy surfaces, reaching 9.4°C at 1:00 pm, even though

Table 7. Results of thermal comfort simulation in summer for selected points A, B, and C

Time	Points	Real global radiation [W/m²]	Real direct radiation W/m²]	Real diffuse radiation [W/m²]	Ts [°C]	Ta [°C]	T_{mrt} [°C]	PMV [-]	PET [°C]	SET* [°C]
	A	708	566	142	47.9	28.2	57.4	4.1	42.5	36.7
09:00	**B**	257	206	51	33.3	28.2	34.4	1.6	30.4	24.7
	C	123	98	25	28.9	28.2	26.6	0.9	26.7	20.9
	A	939	751	188	62.0	31.1	67.2	6.8	53.1	47.1
11:00	**B**	347	278	69	40.4	31.1	40.2	3.1	36.4	30.9
	C	224	179	45	35.7	31.1	33.9	2.3	32.9	27.3
	A	939	751	188	61.2	31.5	66.9	6.8	52.2	46.5
13:00	**B**	352	282	70	40.5	31.5	40.7	3.1	36.5	31.1
	C	223	178	45	35.8	31.5	34.2	2.3	33.1	27.4
	A	708	566	142	52.6	30.8	60.3	5.5	47.7	42.3
15:00	**B**	246	197	49	36.0	30.8	36.3	2.5	33.8	28.4
	C	120	96	24	31.4	30.8	28.9	1.7	30.0	24.3
	A	336	269	67	37.9	28.9	41.8	3.1	36.4	31.2
17:00	**B**	201	161	40	32.8	28.9	33.3	2.0	31.7	26.3
	C	52	42	10	27.2	28.9	23.3	0.9	26.4	20.9
	A	9	7	2	22.3	25.4	16.9	-0.2	21.5	16.4
19:00	**B**	2	2	0	22.2	25.4	16.4	-0.4	21.0	16.0
	C	6	5	1	22.2	25.4	16.7	-0.2	21.4	16.3

T_S - Surface Temperature; T_a - Air Temperature; T_{mrt} - Mean Radiant Temperature, PMV - Predicted Mean Vote; PET - Physiological Equivalent Temperature; SET* - Standard Effective Temperature.

they only result in a 1°C difference in air temperature. The greatest difference in surface temperature was between the warmest material (slate) and the coldest one (marble), which reached 14.8°C at the same time. However, the respondents seemed to be more affected by the reflection of the marble than by the energy emitted from it, and even less by the 1.1°C effect on the air temperature.

The simulation results also showed that the difference in (Ts) between shaded and unshaded surfaces reaches more than 20 °C in the middle of the day. Considering the temperature difference sensitivity determined by the survey and the measured differences in surface temperature, we can conclude that different paving materials significantly influence the thermal comfort of users. This research found that in summer, in a hot and humid Mediterranean climate, the combination of heat, low wind, and high humidity accentuated the perception of small temperature differences of less than 3.5 °C, especially for those over 65 years of age. The majority of respondents (85%) reported feeling "hot" and uncomfortable in the open in both public spaces surveyed, and almost a third (27%) felt "very hot" and found the thermal environment quite difficult to tolerate, although most were adequately clothed. The intermittence of shade on the premises and its unbalanced distribution, combined with the ubiquitous asphalt in the traffic lanes that bound the premises, was perceived by the majority of respondents as borderline uncomfortable during the hot summer days.

DISCUSSION

Based on the recorded results and the spatial distribution of the respondents, we find that in summer, visitors prefer to sit in shaded areas, while in winter, sunny areas are the most popular. The diurnal pattern of space use also reveals a strong dependence on meteorological parameters, in particular solar radiation, relative humidity, and wind speed. Low recorded air-speeds are one possible factor that accentuates the feeling of heat when the ambient air temperature exceeds 30 °C during the survey. However, because high air temperature contributes to discomfort, attendance and frequency are significantly reduced as air temperature rises.67% of respondents would have preferred a little less sun in the summer, a little more wind, and less humidity. The total of the percentages equivalent to +2, +3, and +4 on the ASHRAE scale is close to 80% and indicates the existence of day-long heat stress felt and expressed by the users. Younger people tolerate higher temperatures on the premises more easily, while sensitivity to summer heat appears for those over the age of 65 years. Forty-one percent said they were unable to tolerate such conditions. This has had an impact on attendance. Indeed, the maximum attendance is at the end of the day during the summer, while it is around 10:00 am in the winter. It was 2.5 times higher in the winter than it was in the summer. The survey revealed the predominance of the aesthetic aspect of the places and ignorance of the optical and thermal properties of the materials. The latter, when they are noticed, are identified only by their colors. The black color of the slate does not seem to bother them in any way, despite its less advantageous thermal properties. As for the water basins in the middle of the garden, their effect remains localized because of the lack of regular operation, even if the presence of water, especially in summer, is appreciated by 95% of the users who deplore, however, the lack of maintenance of these basins.

Comparison of the survey results with the simulation results showed a match between simulated and perceived thermal comfort. More than 67% of the respondents said that there was too much sun and reported feeling more comfortable in the shade. At the same time, the simulated PET values for partially shaded spaces were lower than those for unshaded spaces. Similar studies have shown that barely shaded locations with a high sky view factor are uncomfortable in summer (Lin *et al.*, 2010). Furthermore, although the impact of the sky view factor (SVF) on PET index values is proven (Mahmoud, 2011), this study showed that its effect on air warming remains unclear. The slate Pt1 point, with SVF = 44.8%, is the warmer point of the two spaces studied, while the granite tile Pt4 point, with SVF = 76.6%, showed a lower surface temperature of 2.6 °C at 13:00 h, but paradoxically, the impact on air temperature is 2°C in favor of the tile. The air temperatures are variable from one point to another and are impacted by the surface temperatures of the materials, but do not systematically follow their profiles. The phase shift is mainly due to the inertia of the materials and their emissivity.

The peak temperature of the air is noted at 1:00 pm on the tiled surfaces (33 °C). A reduction of about 1°C is recorded for the grassed surface at the same time, reaching up to 3.1 °C for the marble surface. We think that the impact of grassed surfaces could have been more significant if they were regularly watered.

CONCLUSION

Assessing comfort conditions in outdoor spaces is difficult because of the great subjectivity that characterizes the perception of microclimatic conditions and how they affect their uses. Meteorological measurements alone cannot provide information on the general level of comfort. Therefore, the field survey provided important insights into the validity of the combined method that compares both subjective data collected and objective, measurable ones.

In this study, rough slate was found to be the hottest material in field measurements. The results showed that the heating of slate walkways had a localized impact on the heating of the ambient air and on the thermal comfort of users relative to the 5% coverage rate they occupied. The color and rough texture of the slate contributed significantly to the increase in heat absorption and impacted surface and air temperatures. A large thermoradiative variability of the implemented paving materials is observed. It highlights the important effect of color and texture on the thermal and optical properties of materials used in urban paving. For this reason, particular attention should be paid to the choice of paving materials, and lighter colors are to be preferred. In this study, the temperature differences measured between the warmest material (rough slate) and the coldest material (marble) reached 14.8 °C, the warmest material and grass (9.4 °C), and the partially shaded and unshaded areas (10.4 °C). These differences are noticeable and affect the thermal comfort of users. In addition, the study shows that the allocation of materials, especially in the garden, giving it a heterogeneous character, seeming to respond to an aesthetic logic more than a thermal one. This choice harms the thermal environment and general comfort. The influence of the materials used is particularly noticeable because of the surfaces exposed to daily sunlight. The grassy surfaces covering 70% of the garden soil attenuated three times more radiation than the tiled surfaces. The increase in shade levels resulted in a significant cooling of the ambient air.

Grassed surfaces should be promoted in cities because of their low inertia and the cooling they provide if they are regularly watered. They contribute in a remarkable way to the microclimatic quality of the places. The choice of the vegetable species and trees should be doubly reflected. These results may alert decision-makers to the need for an appropriate choice of paving materials for outdoor spaces that can favorably impact their thermal profile.

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