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Predictive Capacity Analysis for Outdoor Thermal Comfort Assessments: A Case Study of Jijel City, Algeria

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ABSTRACT

Ensuring acceptable thermal comfort conditions in public spaces is nowadays a major concern of urban design. A number of indices have been proposed in the literature, namely PMV, PET, SET*, UTCI, PT, mPET and MOCI. The present study aims to find the most suitable index of the outdoor thermal comfort assessment in the city of Jijel by comparing the predictive capacities of these indices in terms of frequency occurrence and by relating them with the contextual responses of users. These indices are defined, their feature is analysed and finally explored. Thermal comfort based on these indices was evaluated using RayMan and Townscope softwares. The choice among these indices needs their comparison with data gathered from a survey by questionnaire. The findings indicate a slight agreement between these indices and the perceived sensation (PESV) values in the range of -1 and +1, especially with the indices SET* and mPET. However, for the classes +2 and +4, a significant disagreement is observed. For the class +3, however, only PET, PMV and SET* are more joined to the perceived sensation values. The disagreements may be related to the physical environment characteristics, the subjective perception, and the adaptation attitude of the users. Thus, further indices calibration investigation is needed for better prediction of comfort taking into account local specificities. Based on the indices which are relatively in agreement with PESV, a neutral air temperature of 19.8 °C in winter and 20.4 °C in summer for the city of Jijel is deduced. Also, a comfort zone of 17.3 to 22.4 °C in winter and 18 to 22.8 °C in summer is extrapolated.

Keywords:
Public space; microclimate; outdoor comfort; thermal indices; predictive capacity; Jijel

1. Introduction

Ensuring acceptable thermal comfort conditions in public spaces is nowadays a major concern of urban design. Like other countries, Algeria also suffers from the effects of global climate change, which disrupts the natural cycle of seasons and extends the summer period, further exposing pedestrians to very high heat loads especially in urban areas, causing them inexorably great thermal discomfort.

At this scope, several studies report on outdoor thermal comfort in dry and arid climate conditions where Gherraz *et al.,* [1] showed the main role of urban vegetation in improving thermal

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comfort by varying the sky view factor (SVF), reducing the radiation by more than 25%. The maximum Predict Mean Vote (PMV) level was decreased from 7.9 to 4.8 and the average radiant temperature also, from 52.9°C to 42.9°C. Hanafi and Alkama [2] highlighted the role of urban plant in improving thermal comfort, energy savings and generating ambience [3]. Matallah *et al.,* [4] assessed thermal comfort in the heart of Tolga Palm Grove and in different urban settlements and tested the validity of the “oasis effect” concept using Physiological Equivalent Temperature (PET) index. The performance of shaded areas was compared for five different types of trees, including an open area with no vegetation [5,6]. Their results indicate that the percentage of tree cover in a space is a very important measure for assessing outdoor comfort in a semi-arid climate and primarily influences the use of outdoor recreational spaces. In coastal cities with a Mediterranean climate, the impact of cultural referents on the use of outdoor spaces is explored as well, regardless of meteorological factors [7,8]. However, the materiality of places and its impact on outdoor comfort remain understudied. Kwong *et al.,* [9] suggested that biomass aggregate and fly ash are successfully used as partial replacement in producing sustainable green concrete. It allows improving the thermal behavior of some paving materials in urban areas. Many of these studies have incorporated thermal indices to estimate the degree of comfort in spaces visited by the public. Yet some of these indices appear to be less suitable for heat conditions than others, or cannot be applied in conditions other than those for which they were designed, or have not been validated for a wide range of climates. This case study, undertaken in two public spaces in Jijel, Algeria, attempts to provide guidelines for the selection of an appropriate index by describing the characteristics and underlying methods of the most frequently used indices. It attempts to extend the use of some comfort indicators to the Mediterranean context, by comparing their predictive capacities taking into account local microclimatic particularities. It highlights the way in which outdoor thermal comfort indices work effectively by an in-depth examination of comfort zones and neutral outdoor temperatures for the regions of the southern shore of the Mediterranean.

Various aspects of outdoor thermal comfort have been explored in different climates around the world, using different methods and a variety of instruments and affecting different urban configurations; plaza, park, courtyard, square, and public garden [8,10,11]. Bouchair [12] has developed an environmental temperature approach which allows for the inclusion of various factors of the external urban surrounding obstructions. Sebti *et al.,* [13] tried to understand the bioclimatic concept of adaptation of a Ksar (a vernacular fortified city without vegetation in the desert of Algeria) and assess to what extent its morphological transformation has impacted its microclimatic conditions. This assessment is made through a comparative study between two different areas: one untransformed and the other transformed. The effect urban morphology upon the air temperature variation of urban condition in hot and dry climate of Biskra city in the south east of Algeria was also investigated [14]. The results show that Urban Heat Island phenomenon is becoming the character of the urban micro-climate.

The variability of the stimuli emanating as much from the radiation as from the variation in the configuration of these spaces can generate significant modifications of the microclimate parameters [15,16], which in turn greatly affect the psychological and behavioural aspects [17,18]. All of these studies have apprehended the elements of urban morphology involved in microclimate variation. The most relevant aspects of comfort were examined too [19]. Furthermore, Nikolopoulou and Lykoudis [20] analysed outdoor thermal comfort in five countries in Europe and related microclimate conditions to the use of outdoor spaces, where air temperature and solar radiation were the most dominant parameters. Other investigations have focused on thermal variability in urban environments by analysing the relationship between urban morphology, microclimate, ground surface treatment, vegetation cover contribution and thermal comfort [21-23]. Indeed, the use of outdoor public spaces has become a qualitative indicator that should not be neglected for the determination of the most favourable environment and the establishment of seasonal usage profiles [24]. Trees and the shade have a major impact on comfort and usage [25]. They contribute to the improvement of the microclimate in urban areas and significantly reduce user discomfort by providing better conditions [1,2,5,26]. A recent study related to the influence of green spaces on human behaviour; not only in terms of quantity of greenery but also in terms of the configuration [27].

The subjectivity of perceptions and the multiplicity of sensations have led to numerous research efforts to evaluate thermal conditions by linking local microclimate conditions and personal thermal sensations and to classify the related thermal stress. Migliari *et al.,* [28] affirms the existence of at least 200 indices and models, among which four are widely used in outdoor thermal perception studies, namely PET, PMV, Universal Thermal Climate Index (UTCI), and Standard Effective Temperature (SET*) [29]. Whereas, for Staiger *et al.,* [30] only twelve are classified to be principally suitable for the human biometeorological evaluation of climate for urban and regional planning. Seven out of the twelve indices are fully suitable, of which three overlap with the others. Accordingly, the following four indices were selected as appropriate: UTCI, Perceived Temperature (PT), PET, and rational SET*.

Inaccurate predictions of the PMV index have been shown by several studies in hot-humid regions [31,32]. During the hot season, PMV tends to overestimate the thermal sensation and vice versa [31]. These findings were corroborated by ISO-PMV validation tests for the prediction of comfort voting, which revealed that PMV overestimates the sensation of heat at 27°C, with the overestimation becoming severe at higher degrees. On the other hand, a comparison of the human thermal load in PMV and SET* for the evaluation of outdoor thermal comfort in unsteady mode was carried out by Shimazaki *et al.,* [33], which resulted in more accurate predictions with PMV than with SET*. In practice, their use remains dependent on the time factor and the degree of expertise of professionals. However, methods of classifying these indices according to their applicability, adequacy, and suitability for a particular purpose will overcome this difficulty, on the one hand, by targeting the index that best meets the pre-established objectives, on the other hand, by searching for the best index to predict comfort in a particular outdoor environment [10,34-36]. A recent study by Migliari *et al.,* [28] respond to this concern, by producing a graphical methodology named Metamatrix of Thermal Comfort, developed and addressed to academicians and practitioners, that allows to rapidly comprehend and compare the specificities of 65 renowned thermal comfort indices and thermo-physiological models, explaining their mutual interactions. New indices continue to be proposed and are being introduced as possible predictive responses to specific local or regional conditions [11,37-39].

Nowadays, the confrontation of indices with subjective thermal perception has become a methodological issue to evaluate their accuracy, applicability, and validation through comparison [40-43]. This has led to adjustments and scale calibrations due to the fact that their relationships with thermal sensations are not always clear and suggest modification of thresholds for certain stress categories for better assessment of such environments [36,44-50]. On the other hand, many researchers have tried to define the high and low thresholds of some indices to estimate thermal comfort zones, to evaluate differences in terms of local climate specific to a country, or adapt them to different climate zones [51-56].

It is in this perspective that this research attempts to broaden the application of some of the most widely used indices to the climate of the southern shore of the Mediterranean, particularly the 36° north latitude, and to evaluate the thermal environment by comparing the predictive capacities of six indices in terms of frequency occurrence and by confronting them with the contextual responses of users, i.e., the number of times that the values of each thermal comfort index obtained by simulation belong to the same class of sensation reported to the total number of measurements of the day, and by confronting them with the contextual responses of users and the seventh index, the Mediterranean Outdoor Comfort index (MOCI), elaborated especially for Mediterranean areas [49].

2. Methods and Investigation Tools

2.1 Study Area

Jijel City is located on the southern shore of the Mediterranean Sea at latitude 36° 49'N, longitude 5° 46'E, and altitude of 9 m (Figure 1 Left). The study is based on meteorological measurements made in situ in a square and a public garden in Jijel City (Figure 1 Right). It has a population of 134,500 inhabitants and a Mediterranean climate with mild winters and hot, humid summers.

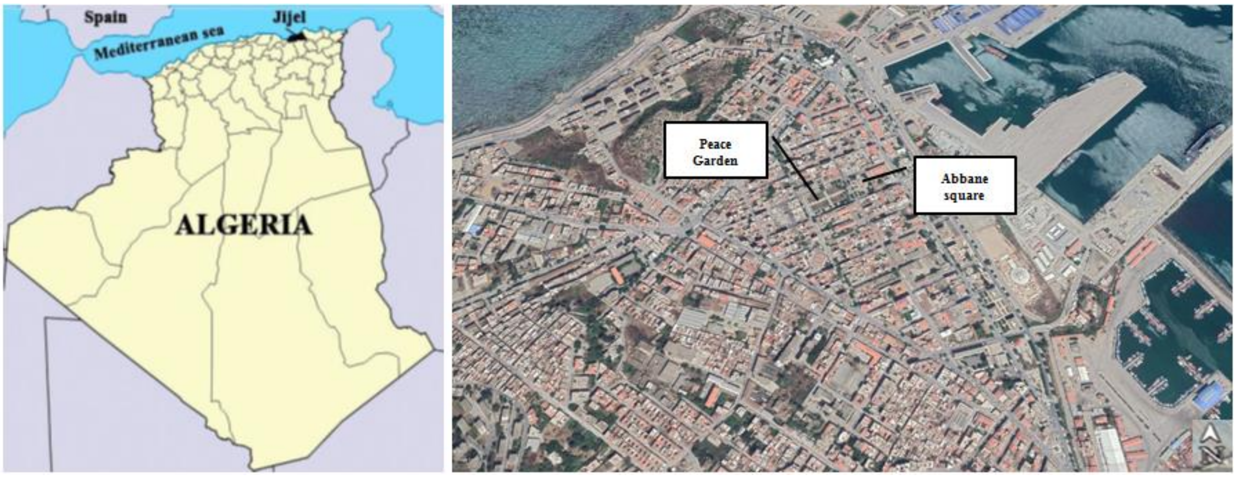

Fig. 1. Geographical situation of Jijel City (Left) and location of the studied public spaces (Right)

The choice of the two open spaces is motivated by their proximity since they occupy contiguous plots, which predisposes them to share the same weather conditions. Abbane Ramdane Square is completely mineralised and presents a homogeneous aspect with a granite tile covering. A white marble monument stands in the centre of the square, with two kiosks on either side. Its outside bounds are punctuated with ficus-type trees (Figure 2(d)). The Peace Garden, on the other hand, is diverse, with 70% grassed surfaces (Figure 2(a)), as well as tinted concrete pavers in the centre (Figure 2(b)) and rough slate in the periphery (Figure 2(c)). Palm trees, as well as the ficus trees that line the perimeter, are the most prominent trees in this area.

Fig. 2. General views on the studied spaces (a) Abbane Ramdane Square and the Peace Garden, (b) Central alley of the Peace Garden in tinted concrete paving stone, (c) Peripheral Alley in slate, (d) Tiled Abbane Ramdane square

2.2 Instruments and Data Acquisition

The measurements of air temperature, relative humidity, and wind speed are carried out using a portable digital instrument multifunction, type LM 8000A, with probe type K, whose characteristics are reported in Table 1. While for the temperatures of the horizontal surfaces and the external walls of the facades delimiting the places, a laser thermometer enabled instantaneous and precise temperature readings. The measurements were taken at a height of 1.10 m approximately every hour during the day, from 8:30 am to 5:30 pm in winter and 7:00 pm in summer, and lasted 15 to 20 minutes for all the selected points, which did not have a considerable impact on the variation of the measured data. Tests were carried out on site in order to calibrate the instruments with the meteorological station of Jijel airport, located approximately 15 km from the study area. We ensured that the meteorological conditions during the two measurement campaigns were sunny, with clear skies and low wind speeds.

Table 1
Characteristics of the measuring instruments used in the field

Variables	Symbol/Unit	Instruments		Interval	Accuracy
Air Temperature	Ta [°C]	Multifunction 4 in 1 Meter		-100 to 1300 °C	±(1% rdg+1°C)
Relative Humidity	Hr [%]	Type LM-8000A		10 to 95 %	< 70% RH : ±4% RH ≥70% RH : ±4% rdg+1.2% RH
Air Velocity	Va [m/s]			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]	Thermometer Laser ScanTemp 0-1353		-32 to 600°C	> 23°C: ±1% rdg or ±1°C whichever is greater -18 to 23°C: ±2°C

The measurement campaigns were conducted during two typical days in the winter and summer of 2019. The two representative days are obtained following the statistical processing of meteorological data recorded from 2009 to 2018. In both seasons, this data includes air temperature, relative humidity, wind speed, and global solar radiation. A ten-year average was evaluated as well as the standard deviation. The daily data collected during the analysis period is then compared to these averages. Only the data that had a standard deviation lower than or equal to 20% for each physical parameter simultaneously was selected. A first filtering brings out February as the coolest month and July as the hottest month. Then, the comparison between the hourly values of the different physical parameters recorded during the filtered years showed that the days of February 12 and July 19 have the lowest standard deviation from the mean and are adopted, respectively, as typical days representative of the winter and summer seasons. Table 2 summarises the weather conditions of the fieldwork days. The differences between the mean air temperatures of the fieldwork days and the monthly mean temperature (ΔT) are also presented for comparison.

Table 2
Characterisation of the weather on typical 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	19.03	12.80	54.54	61.40	0.46	5.2	883.25	11.5	7.53
Summer 19 July	30.56	28.0	53.60	56.40	0.18	2.4	2586.60	26.4	4.16

Six-time slots were set for the evaluation of microclimate parameters in winter and seven in summer. The values for each point and for each time slot are obtained by averaging two consecutive measurements taken throughout the day. The plan of the selected points is presented in two transverse profiles, each encompassing five points of measurement and passing through the Peace Garden (Profile 1) and Abbane Ramdane Square (Profile 2), as illustrated in Figure 3. A third longitudinal profile (Profile 3) includes eight measurement points and passes through the two studied spaces. It lets appreciating simultaneously the thermoradiative behaviour of the various coatings.

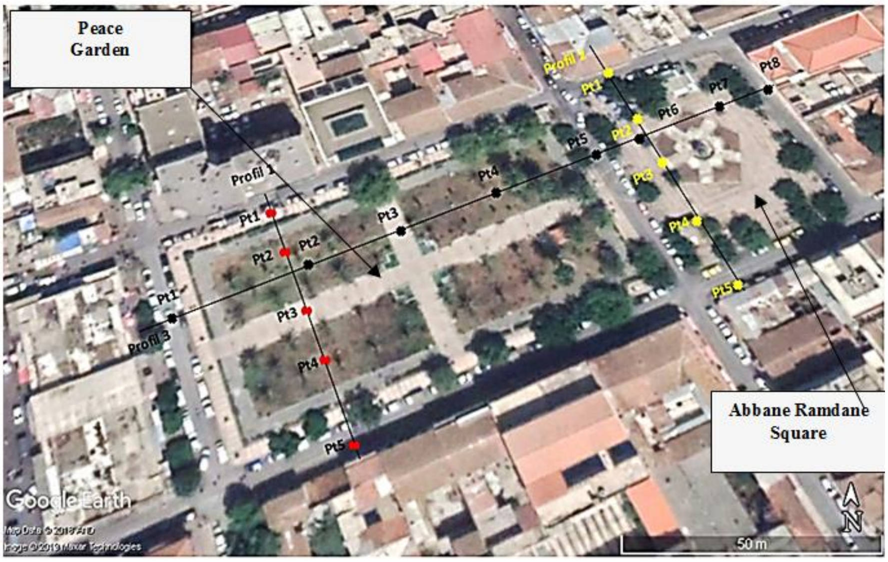

Fig. 3. Profiles location and related measurement points. Source: Adapted from Google Earth

2.3 Simulation of Solar Accessibility

The stereographic projections of the measurement points were made in Townscope, based on 3D modeling of the two study spaces [57]. Townscope is based on a computer system to support solar access decision-making from a sustainable urban design perspective. The software consists of a three-dimensional urban information system coupled with solar energy assessment tools. The obtained projections (Figure 4) allow appreciating the sky view factor (SVF) which is of prime importance in the accessibility of solar radiation at the selected points. It varies according to the profile and the position of the point between 41.6% and 76.6%.

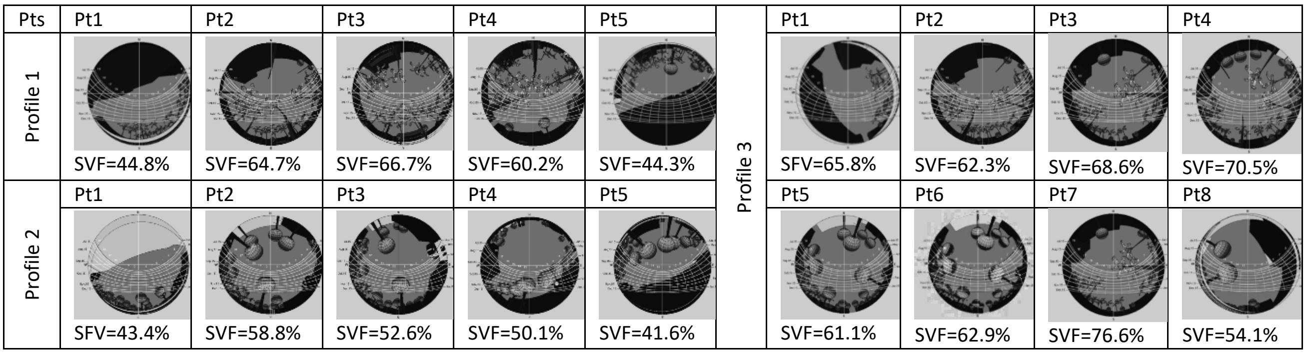

Fig. 4. Stereographic projections with sky view factors for profiles 1, 2 and 3

This simulation also allowed calculating in Wh/m² the energy emanating from the direct radiation, the energy diffused by the sky, the energy reflected by the surrounding surfaces and the duration of sunshine. Calculations are performed for the three above-mentioned profiles during the two typical days by entering the geolocalization data of the studied areas (latitude, longitude and altitude) and the nominal values of the meteorological data taken in the field such as air temperature, relative air humidity, air speed, global radiation and turbidity of the site. Townscope uses spherical projections to calculate scene masks that obstruct direct radiation.

2.4 Questionnaires and Observations

There was no pre-defined sample before the survey was conducted; 444 users were interviewed at random at the end of each measurement all day long in the Peace Garden since it is the most frequented. We were careful to reduce the margin of error so that the results of the questionnaire could be validated. For this purpose, we assumed a 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 [58]. 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 characterised 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 and ISO 7726 [59,60]. 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 behaviours that indicate particular discomfort. The perceptual component highlights the unitary or fragmented vision that the user has of the place 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 organisation 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.

Respondents are predominantly male. Indeed, more than 95% of users are men; the female junta is present in well-defined time slots, otherwise they only cross or transit to go to the market or cultural center. Of the respondents, 64% live or work in the Peace Garden district, and 36% are from other regions. The age profile of the subjects is very varied: 25% of adolescents, 40 % are between 20 and 55, and 35 % are over 55 years old. Except for the age categories 20–55 and 55 and older, there was no statistically significant variation in I_{cl} between genders or age groups. The mean I_{cl} in the 55+ age group was 0.08 clo greater than that in the 20-55 age group. Only 3.5% of respondents wore hats, with the highest rate in summer, while fewer wore scarves in winter. (17%) of people wore sunglasses. In general, people preferred wearing dark clothing (52%) regardless of the season.

2.5 Analytical Definition of the Used Thermal Indices

In this research we applied the most commonly used indices to assess thermal comfort and related stress levels, in this case PMV, PET, SET*, UTCI, PT and mPET obtained using the RayMan Pro model [61]. RayMan Pro is a microscale radiation diagnostic model developed at the University of Freiburg. It is designed to calculate radiation fluxes in simple and complex environments. It calculates these thermal indices based on six parameters given for a specific time and location. These parameters include four meteorological and two thermophysiological 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 in winter, 0.5 in summer, and activity: 80 W. The observed value of global radiation (W/m²) can be used to estimate the mean radiant temperature (T_{mrt}) which is an important input parameter for the calculation of thermo-meteorological indices. We integrate the obtained T_{mrt} in the calculation of the seventh index, the MOCI [49]. This subsection describes the characteristics of the above thermal comfort indices.

The PMV was one of the first indices introduced and was originally developed for indoor environments and then adapted to the more complex radiative conditions of the outdoor environment by Jendritzky and Nübler [63] through an approach known as the "Klima Michel Model" [62]

$$PMV = (0.303.e^{-0.036M} + 0.028).S \tag{2}$$

where M is the metabolic rate and S refers to the thermal balance of the human body. This index, based on the ASHRAE 7-point scale, requires for its evaluation two operational variables (metabolic rate M and thermal insulation of clothing I_{CL}) and four environmental variables (air temperature T_A, mean radiant temperature T_{MRT}, relative humidity R_H and wind speed W_S).

Physiological equivalent temperature (PET) is defined as "equivalent to the air temperature that is necessary to reproduce in a standardised indoor environment and for a standardised person the core and skin temperatures that are observed under the conditions evaluated" [64]. In addition, it considers the mean radiant temperature (T_{mrt}) to be equal to the air temperature Ta, the wind speed of 0.1 m/s and sets the water vapour pressure at 12 hPa (corresponding to a relative humidity of 50% for Ta=20 °C). It refers to the heat balance Eq. (3) introduced by the Munich Individual Energy Balance Model (MEMI) [64].

$$M + W_p + R + ED + E_{Re} + E_{SW} + S = 0 \tag{3}$$

The standard effective temperature (SET*) is defined as "the equivalent temperature of an isothermal environment at 50% relative humidity in which a subject, while wearing clothing standardised for the activity of interest, would have the same heat stress and thermoregulatory strain as in the actual test environment" [65,66]. The isothermal environment refers to an environment at sea level where the mean radiant temperature (Tmrt) and air temperature have the same value and the wind speed is 0. Its evaluation is performed based on Eq. (4)

$$SET^* = \left(wh_{s,e}\left(p_{s,sk} - 0.5p_{SET*}\right) + h_S T_{SK} - H_{SK}\right)/h_S \tag{4}$$

The Universal Thermal Climate Index (UTCI) is defined as "the isothermal air temperature of the reference condition that would elicit the same dynamic response (strain) of the physiological model" than the actual environment [67]. UTCI also follows the concept of an equivalent temperature. The meteorological conditions are compared to a reference environment with 50 % relative humidity, calm air and T_{mrt} being equal to Ta. In contrast to other indices, physiological parameters cannot be set in UTCI. Besides the self-adapting clothing insulation, a permanent walking speed of 4 km/h (1.11 m/s) and an internal heat production of 135 W/m² are assumed [67]. UTCI includes a clothing model that automatically adapts to the current conditions. Within the accepted range, UTCI is very sensitive to wind speed. Besides T_a, also T_{mrt} strongly influences UTCI [68,69].

The perceived temperature (PT) is an equivalent temperature for the assessment of outdoor human thermal comfort based on the human energy balance model “Klima-Michel model” [70]. PT assessment is based on a modification of the (indoor) thermal index PMV, and is defined as “the air temperature of a reference environment in which the thermal perception would be the same as in the actual environment”. The perceived temperature does consider a self-adapting clothing model that will automatically try to achieve thermally comfortable conditions. A simplified human heat balance Eq. (5) is applied

$$M - W_o = (C + R + E_{sk}) + (C_{res} + E_{res}) + S_{sk} + S_{cr} \tag{5}$$

The modified physiologically equivalent temperature (mPET), is a further development of PET adding a self-adapting or manual clothing model, as well as an improved consideration of humidity [71].

The Mediterranean Outdoor Comfort Index (MOCI) is the result of a study conducted in Rome (Italy), so it is specific for subjects used to the Mediterranean climate [49,72]. This is in fact the reason for wanting to test it in a coastal city on the southern shore of the Mediterranean. Like the PMV, it is able to predict thermal perception thanks to the ASHRAE 7-point scale. The analytical expression is given by Eq. (6) which includes wind speed (W_S), relative humidity (R_H), mean radiant temperature (T_{mrt}), air temperature (T_A) and cloak (I_{CL}).

$$MOCI = -4.068 - 0.272.W_S + 0.005.R_H + 0.083.T_{mrt} + 0.058.T_A + 0.264.I_{CL} \tag{6}$$

The classes of perception and sensation of these four thermal indices and the corresponding index categories are shown in Table 3.

Table 3
Thermal perception and the corresponding index categories

Classes Indices	PMV[73]/ MOCI[49] [-]	PET[74] [°C]	SET*[65] [°C]	UTCI[75] [°C]	PT[70] [°C]	mPET[71] [°C]	Thermal Perception	Level of Physical stress
+4	> +3.5	> 41	> 37	> +46	> +38	> 41	Extremely hot	Extreme thermal Stress
+3	+2.5 - +3.5	35 - 41	34 - 37	38 - 46	32 - 38	35 - 41	Very hot	High thermal stress
+2	+1.5 - +2.5	29 - 35	30 - 34	32 - 38	26 - 32	29 - 35	Hot	Moderate thermal stress
+1	+0.5 - +1.5	23 - 29	25 - 30	26 - 32	20 - 26	23 - 29	Slightly warm	Slight thermal stress
0	-0.5 - +0.5	18 - 23	22 - 25	9 - 26	0 - 20	18 - 23	Comfortable	No thermal stress
-1	-1.5 - -0.5	13-18	17 - 22	0 - 9	-13- 0	13-18	Slightly cold	Slight cold stress
-2	-2.5 - -1.5	8 -13	14 - 17	-13 - 0	-26- -13	8 -13	Cold	Moderate cold stress
-3	-3.5 - -2.5	4 - 8	10 - 14	-27 - -13	-39 - -26	4 - 8	Very cold	High cold stress
-4	< -3.5	< 4	< 10	< -27	< -39	< 4	Extremely cold	Extreme cold stress

3. Results and Discussion

3.1 Analysis and Interpretation of Microclimatic Measurements

The air temperature recorded a great variation within the same space, while disparities are found between the two studied spaces according to the seasonal profile (winter or summer), the period of the day (morning or afternoon) and within the same time slot, mainly due to the sun's path, the evolution of the shade and the nature of the ground surfaces.

In winter, the square showed that the air temperature was about 0.7 to 1.7 °C higher than in the garden, especially in the morning. At midday, the trend reverses in favour of the garden, where we record the peak of the day with 28.2 °C, a 2.1°C difference compared to the square. On average, the air temperature is relatively 1.0 °C higher than in the square during the morning, while in the afternoon, the garden was the warmer of the two spaces, with a difference of 1.2 °C. Figure 5 similar findings of the order of 1.1°C were reported by Thorsson *et al.,* [76].

In the median concrete paver walkway, point (Pt3) well exposed to radiations recorded an increase in air temperature of 2.1°C compared to point (Pt2) over the grass, especially in the first-time slot. The air temperature in this lane drops by 0.8°C as a result of natural cooling, which begins at 3:00 p.m. Maximum surface temperatures were comparatively higher at the square (+4.8°C on average) than at the garden, with variable differences of 2 to 9.9 °C from midday and during the afternoon. The highest value (29.8°C) was recorded during the 10-11:30 am period at Abbane Square at the point (Pt6). The point (Pt7) in the shade at that time saw its surface temperature drop by 11.6 °C. The point (Pt5) in the middle of the asphalt road, with a low albedo (0.07) and therefore little reflective, showed a remarkable sensitivity to the shade that had a significant impact on the inflection of the curves of the measured parameters (Figure 5).

On the other hand, in summer, the highest air temperature (33.6 °C) was recorded on the traffic lane (Pt5) during the 11:30–1:00 p.m. hourly period, dropping by 6.8°C at the end of the day and remaining above the daily average. The point (Pt1), in intermittent shade almost all day, recorded the lowest air temperatures, varying between 22.4 and 28.2 °C. The city's effect is remarkable, with average minimum temperatures above the average daily temperature of the weather station. The surface temperatures of the points (Pt3) in concrete pavement and (Pt6) in granite tile stand out from the other points. The latter (Pt6) records the maximum values of the day, varying on average from 38.25 °C to 48.9 °C. While the point (Pt3) in the Peace Garden begins its rise from noon to reach a maximum value of 45.4 °C, displaying differences between the two areas studied of about 3.08 °C on average.

The relative humidity is very variable in both studied spaces and varies in winter from 45 to 70%, and in summer between 37.8 and 58%. The amplitudes and fluctuations are, however, more pronounced in the winter than in the summer. At Abbane Square, the relative humidity is slightly higher in the morning, but with small changes that do not surpass 3% on average. It rises in the afternoon due to evapotranspiration, especially in the Peace Garden, and continues to rise until the end of the day, although it stays within permissible limits and does not exceed 58 %. We observe in the wooded area the influence of a high air temperature (28.2 °C) compared to the monthly average, which is reflected in an increase in relative humidity values at (Pt5), where evapotranspiration begins around 11:30 a.m.

The air velocities in the majority of the measurements were low, in the range of 0.1 to 1.5 m/s. Momentary accelerations were observed at different times and in different locations, but they had no effect on the expected cooling. These accelerations were recorded at the beginning and the end of the afternoon during both winter and summer.

The influence of soil material types is particularly noticeable in the Peace Garden, which is highly exposed to daily insolation. However, the increase in shading levels has resulted in a noticeable cooling of the ambient air. Slate with its high inertia, black colour and rough texture showed a lower thermoradiative performance than concrete paving and granite tiles with respect to insolation. It recorded the highest surface temperature of the day in summer (50.3 °C) in Peace Garden, but the high air temperature was recorded in Abbane square with granite tiles. It is partially consistent with the results reported by Taleghani and Berardi [77]. Although increasing pavement reflectivity reduces air temperature, it reduces pedestrian comfort as well. Darker albedos rise air temperature and surface temperature, but they improve thermal comfort by reducing solar re-radiation (lower mean radiant temperature). In this study, there was no significant increase in air temperature, probably due to the proximity and extent of the grassed areas. The improvement in thermal comfort, on the other hand, is not very clear as even users did not seem to be bothered by the dark color of the slate. This study has shown that the effect of shading can mitigate insolation effects on the increase in surface and air temperatures.

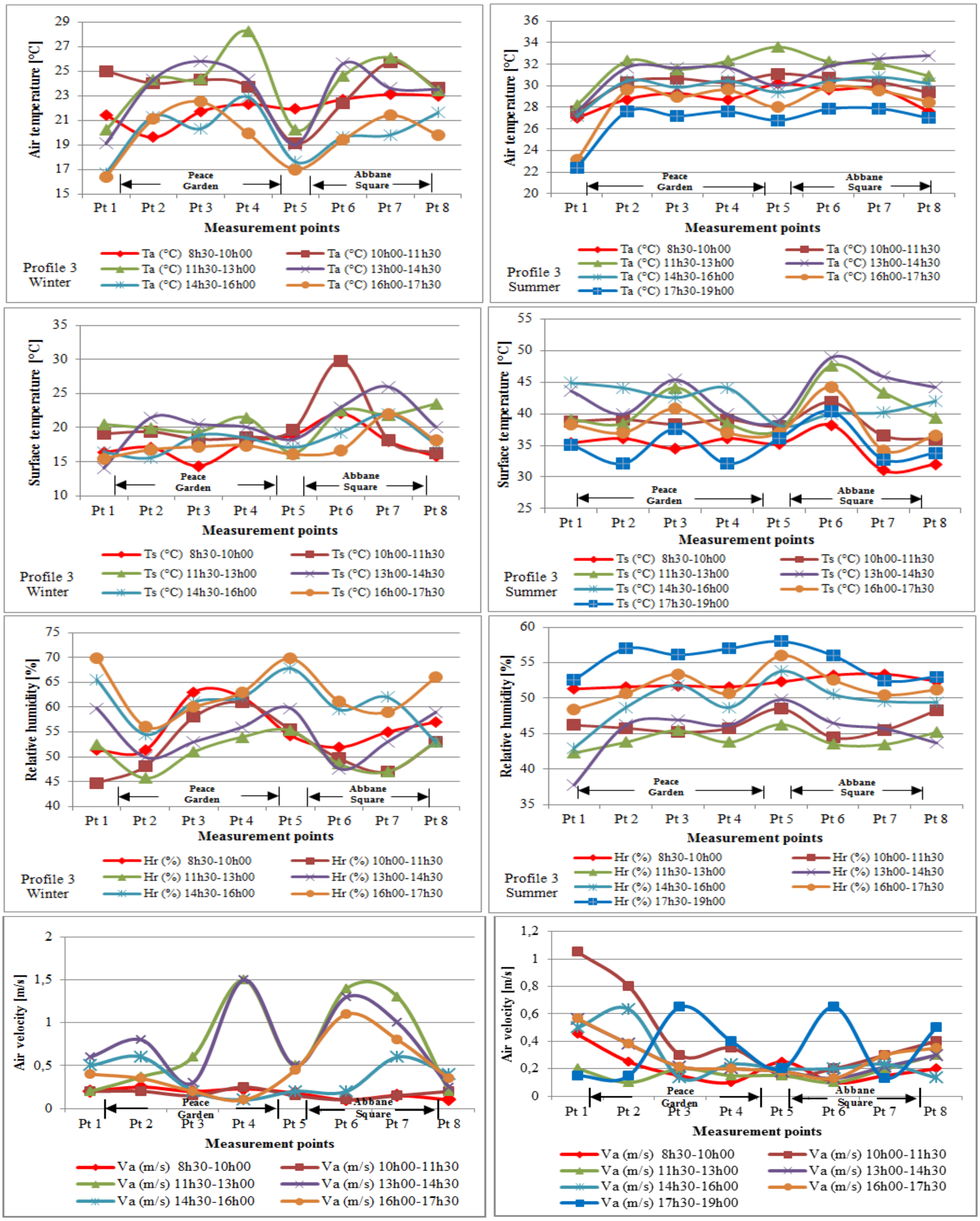

Fig. 5. Profile 3 showing the sequential variations of air and surface temperatures, relative humidity and air velocity in winter and summer

3.2 The Solar Accessibility Simulation Results

The simulation of solar accessibility according to the three profiles clearly shows, in Figure 6, the effect of the different measurement point's orientation and the induced shades by trees masks. This effect is manifested by a variation in the amount of energy received and emanating from the global radiation. As an indication, on July 19 at 12:00, it varies between 155 Wh/m² and 766 Wh/m².

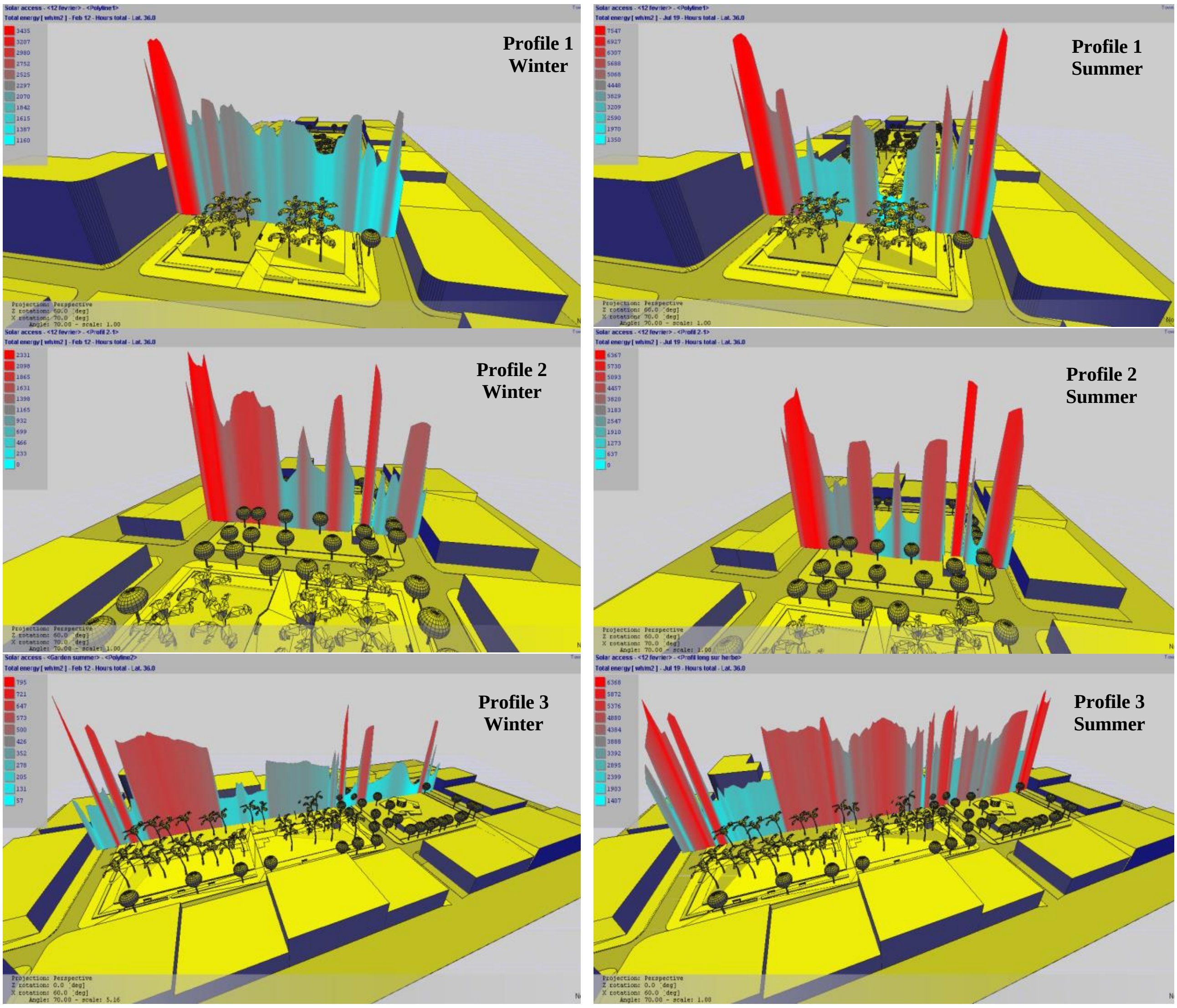

Fig. 6. Solar accessibility and total energy in Wh/m² for the three profiles in winter and summer

The greatest amount of energy received is noticed on the Abbane Square, the traffic lanes, and the bare surfaces in the Peace Garden. The wide profiles clearly show a difference of 158.5Wh/m² on average between the two areas studied. The Abbane square had a more radiating behavior than the Peace Garden due to its homogeneity. Because the grassy ground that comprises 70% of the surface of the Peace Garden is not consistently irrigated during the summer, the average albedo in the latter varies with the seasons and increases by more than 1.1% in the summer, becoming more reflecting. Its albedo varies from 0.12 in the winter to 0.25 in the summer, resulting in an unexpected thermal behaviour. Morning dew also darkens the slate in the winter and changes its hue in the summer, altering its absorption and reflection abilities.

The grassy and shaded surfaces have intercepted and minimised the sun's rays three times more than the tiled surfaces. The overall radiation is of the order of 1082 Wh/m² at 12:00, observed at the traffic lanes and on a large part of the granite tiles of Abbane Square, while it varies from 56 to 363 Wh/m² on the grassy surfaces. The optical properties of materials govern the storage of heat from direct solar radiation. This process will participate in the increase of the temperature of horizontal and vertical surfaces. We see it on the level of the R+5 brown hue of the housing block's exterior, which is quite sunny during the day. Its surface temperature reaches 31.8 °C during the hours of 8:30-10:00; however, the surface temperature of the light beige coloured facade is just 13.5 °C. This contributes to an increase in air temperature at the bottom of the building on the sidewalk, which translates to a thermal load of 431Wh/m^2 at 12:00 on the sidewalk and asphalt roadway (7547Wh/m^2 in cumulative hours) and between 165 and 298 Wh/m^2 on grassy surfaces (1350Wh/m^2 and 2590 Wh/m^2 in cumulative hours), as shown on profile 1 (Figure 6).

The combined effect of the heat emanating from the facade of the R+5 housing block in the form of infrared radiation, the granite tiled sidewalk and the asphalt, contributes to raising the air temperature by several degrees at the Pt1 point of profile 1. However, the impact of the sky openness factor of 10% more for the latter did not have the expected effect on the air temperature. Its impact on air warming remains unclear.

3.3 Results of the Survey

The observation showed that some places are occupied almost all day long. The sun's path seems to punctuate their occupation of the site. For the retired and older users, the best place is 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 was mentioned by 8% of those questioned and that dissuades more than one person from coming to this recreation area. The heat and the intensity of the radiation are mentioned in first position (45%) in response to the question about the climatic conditions that can constitute an obstacle and prevent citizens from using this public garden. The wind comes in second place at nearly 25% of responses and that only 22% of users do not feel accommodated to the heaviness of the weather that characterises the climate of the city of Jijel and see in the humidity of the air a major factor of the discomfort they feel especially in summer.

Concerning the evaluation of the thermal environment and on this precise point of view, we asked the users to report their sensations of the thermal environment through a scale of 9 points going from very cold (-4) to very hot (+4), with neutral (0) in the middle. For the month of February, the majority of users were in favour of a microclimate described as "spring-like", acceptable and comfortable due to an upward shift in average air temperature values. It should be noted that during the month of July, the expression of the thermal sensation was rather mixed and disparate from the point of view of acceptability of the general comfort conditions due to the adaptation and the time spent on the premises. Indeed, most subjects chose the sensation of warmth (+2), which was around 38% in all locations. About 16% of the subjects chose the sensation of heat (+3), while 15% found the weather suffocating and chose the sensation extremely hot (+4). The remaining 20% expressed indifference and even found the weather comfortable.

The low air velocities recorded are one of the possible factors that accentuate the feeling of heat when the ambient air temperature exceeded 30°C during the survey. The total of the percentages of +1, +2, +3 and +4 being close to 80%, which indicates the existence of heat stress all day long felt and expressed by the users. Young people tolerate more easily a higher temperature on the premises, while sensitivity to summer heat appeared for the age category above 65 years. Forty-one percent said they could not tolerate such conditions. The spatial distribution of the respondents shows that in summer visitors prefer to sit in shaded areas, while in winter sunny areas are the most popular. However, since high air temperature is a contributing factor to discomfort, attendance and visitation are significantly reduced as air temperature increases. The preference for sunlight differs from season to season, but it is most appreciated in winter. The diurnal pattern of space use also reveals a strong dependence on meteorological parameters, namely solar radiation, relative humidity and wind speed. 67% of respondents would have preferred a little less sun in summer, a little more wind and less humidity. As for the time of maximum use, it is at the end of the day during the summer, whereas it is around 10:00 am in winter. Daytime attendance was two and a half times higher in winter than in summer.

The questionnaire revealed a major concern for the aesthetics of the site and a lack of knowledge of the optical and thermal properties of the materials. The latter, when noticed, are identified by their colours. The black colour of the slate does not seem to bother them in anyway despite its less advantageous thermal properties. As for the water basins in the middle of the garden, their effect remains localised for 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.

3.4 Thermal Comfort Assessment and Predictive Capability Analysis

It should be noted that the prediction of the comfort level in the two spaces studied was supported firstly by their daily and seasonal profiles, secondly by the intensity of radiation and the degree of homogeneity of the spaces. The analysis refers to the ASHRAE nine-point scale. It places the comfort zone of the PMV and MOCI between (-0.5 and +0.5), the equivalent temperatures for PET and mPET (18-23°C), SET* (22.2-25.6°C), UTCI (9-26°C) and PT (0-20°C) corresponding to the absence of thermal stress. The Y axis in Figure 7, represents the frequency occurrence of each thermal condition. We note that Profile1 recorded the best predictions of favourable comfort in winter. UTCI, PT, mPET and PET show the same trend with differentiated frequencies on the neutrality axis. UTCI stands out with 57% followed by PT (50%), mPET (47%), PMV (40%), PET (33%), MOCI (30%) and finally SET* (27%).

The seven thermal indices display significantly different evaluations on thermal conditions in Jijel. The estimation of UTCI, PT and mPET* showed that fewer cold stress events occur in Jijel in winter compared to the evaluation of PMV, PET, SET* and MOCI. Only SET* leaded to 17% probability of occurrence of high cold conditions during February at Abbane square against 3% in Peace Garden. In addition, moderate to slight cold events occurred according to PMV, PET, SET* and MOCI assessments with different frequencies ranging from 4% to 37%. UTCI, PT, and mPET, on the other hand, gave at most slightly cold assessments during the winter. On the other hand, all the thermal indices used indicated to different degrees, the omnipresence of thermal stress, however weak, in the three categories of sensation class +1, +2 and +3. These predictions indicate the temperature shift upwards in early 2019.

In Profile 2, SET* and MOCI increased by 6% and 7% respectively in the neutrality axis. The MOCI showed more stability in favourable predictions. All the others indices showed a decline on average from 7 to 20%. A class shift (+1) was observed for PMV (43%) and PET (33%) indicating the occurrence of a slight thermal stress. This can be explained by the results of the measurements that give the place Abbane warmer than the Peace Garden.

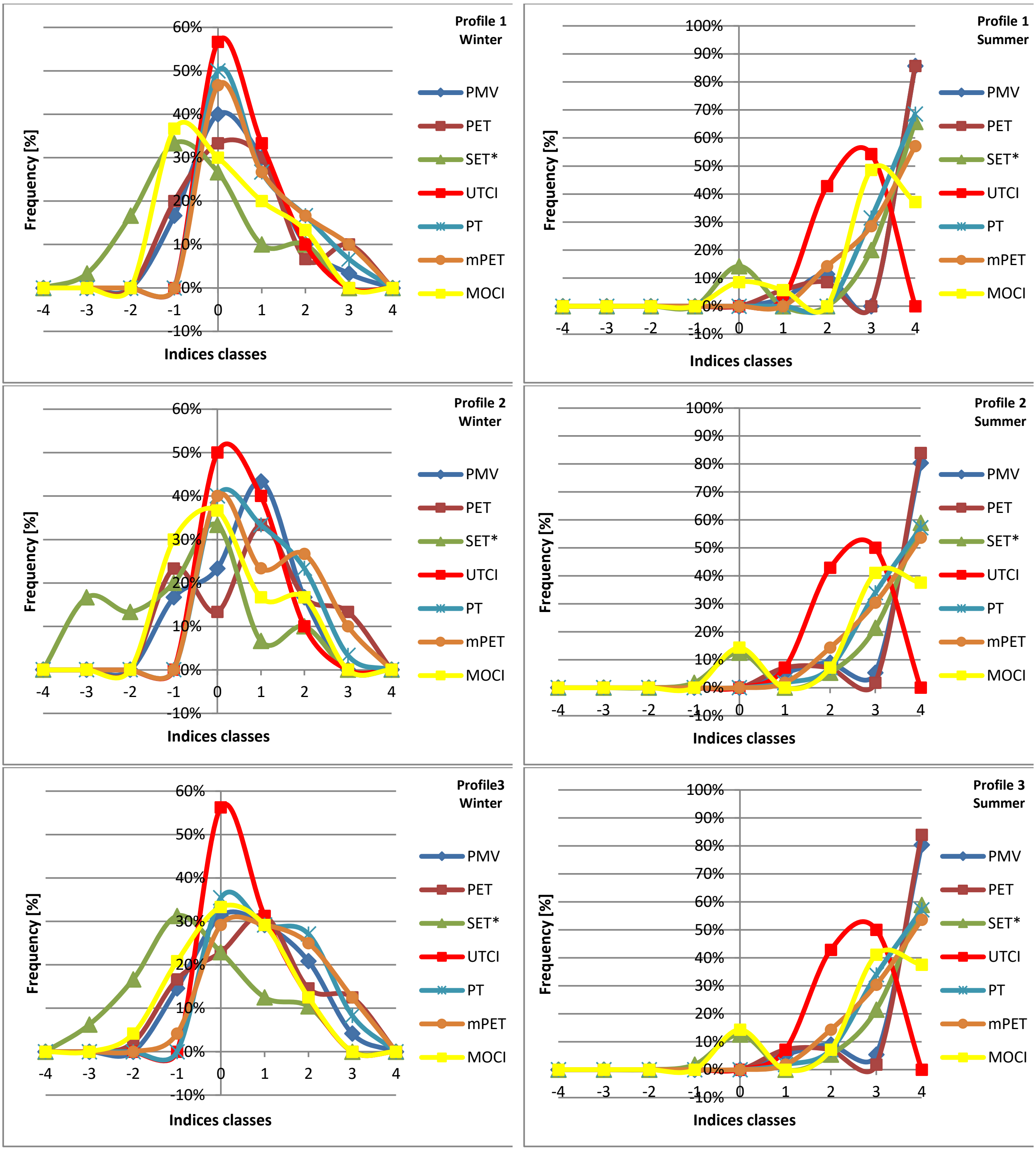

Fig. 7. Frequency occurrence for the used thermal indices according to the different profiles in winter and summer

The deterioration of the thermal environment in the summer, on the other hand, is quite noticeable, as even the air temperature recorded did not exceed 34.2°C. There are significant variations in the seven indices taken into account for the estimations of extreme heat events. All the used thermal indices indicated, to different degrees, the omnipresence of thermal stress in winter in the three categories of sensation class +1, +2 and +3. These predictions confirm the temperature shift upwards in early 2019. The UTCI estimate made no forecasts regarding extreme heat events. It suggested that moderate heat stress occurred just over 40% of the time and that severe heat stress occurred at most 50% of the time. On the other hand, PMV and PET indicated that more than 80% of

Jijel's summertime residents had extreme heat stress. Less severe heat stress was detected by SET*, PT, and mPET, with incidence rates ranging between 54 and 57%. Furthermore, only SET* and MOCI provide a likelihood of comfortable thermal conditions in the summer ranging from 9 to 14% on the neutral axis.

Figure 8 shows that the differences between PMV and MOCI rise proportionally with increasing air temperature. The linear regression showed a moderate correlation between air temperature and MOCI especially in winter with R^2=0.5594. The PMV showed more correlational dispositions with R^2=0.6884. On the other hand, MOCI showed strong correlational relationship with T_{mrt} than PMV, in winter (R^2=0,9476) and particularly in summer (R^2=0,9764). The two indices predicted different neutral temperatures, with slightly larger differences in winter than in summer (Table 4). When the air temperature is between 27 and 34,2°C, MOCI is concentrated in the ranges 1.5 to 5.2 while PMV extends over the intervals 2.5 to 7.5. Paradoxically, the correlation with air temperature is more significant in summer for PMV with R^2=0.7287. Hashim *et al.,* [78] had the same findings for Selangor amusement park, suggesting the need to reframe the PMV perception thresholds and related stress categories for the assessment of similar hot and humid environments in summer.

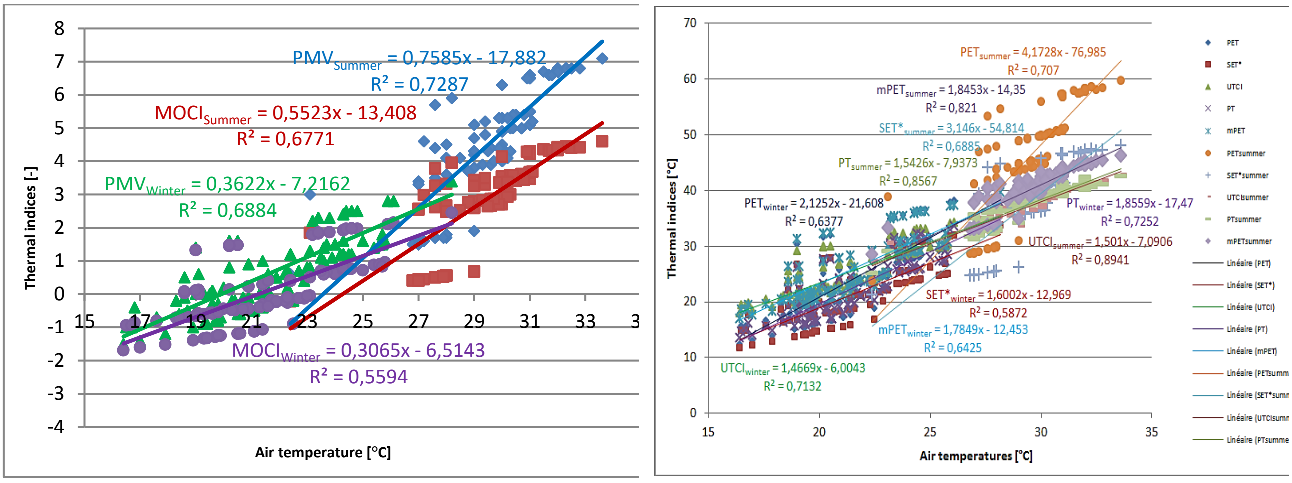

Fig. 8. Correlation between thermal indices and T_a for the studied spaces in winter and summer

PET has relatively strong performance with T_{mrt} in winter and summer. The mPET showed in summer a stronger correlational relationship with Ta than PET, with R^2=0.821 and a lower slope of 1.8453, even if in winter the correlation factors are very close. On the other hand, with T_{mrt}, mPET showed better correlational results than PET in winter and summer. But UTCI showed the best correlation with both T_a and T_{mrt} (Figure 9).

The intervals obtained from the linear regressions were compared to those found in previous studies conducted in Mediterranean cities. For the city of Rome for example, Nikolopoulou and Lykoudis [20] reported in their study, a neutral air temperature of 22.1°C in winter and 27.2°C in summer. These values are very close to PET, where a neutral temperature of 20.7°C is reported in winter, and a comfort range of 17.8-23.7°C. While in summer, we find that neutral PET (21.4°C) is below of winter neutral PET (22.1°C), placing the comfort interval between 18.6-24.1°C. The neutral values of UTCI seem very close to reported neutral air temperature in Rome, with 23.2°C in winter and 28.3°C in summer. The PET comfort range was defined for the city of Rome, between 21.1-29.2°C, based on the reference comfort range between -0.5 and +0.5 of the ASHRAE 7-point scale. The UTCI displayed a comfort range from 21.2- 29.3°C (all seasons) which is very close to mentioned values in Rome. Even the MOCI index, developed for Mediterranean areas, showed a narrower range between 22.9-25.2°C.

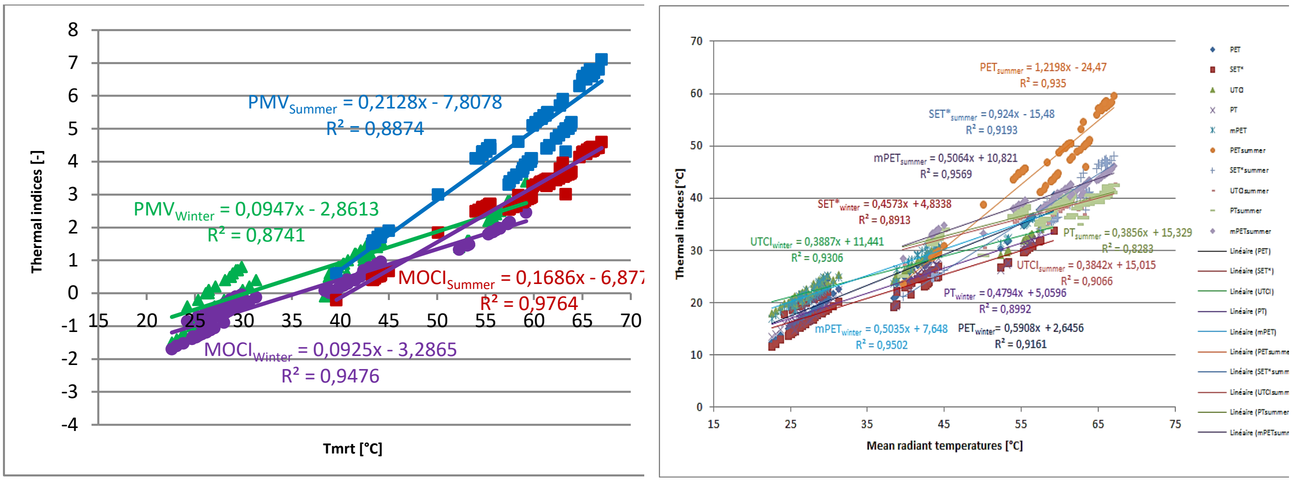

Fig. 9. Correlation between thermal indices and T_{mrt} for the studied spaces in winter and summer

Examining these results, we note two significant facts for the city of Jijel. The first relates to the neutral temperatures which seem to follow the profile of the average daily temperatures (21.6 °C for the measurements of February and 30.1°C for those of July). The second refers to the difference between the neutral air temperatures and the seasonal average temperatures (12.33 °C in winter and 25.06 °C in summer for our case study). The differences are significantly larger in winter than in summer and tend to increase as the seasonal average temperature decreases.

The present study defines different intervals for the city of Jijel on the same 9-point basis (Table 4). The degradation of the thermal conditions in this particular case occurs from 35.1°C PET onwards, 29.7°C SET*, 33.2°C UTCI, 33.5°C PT, 35.2°C mPET and 28.8°C MOCI, where the level of "moderate" thermal stress appears, announcing higher levels of "strong thermal stress" from 40.6°C PET onwards, 33.9°C SET*, 35.2°C UTCI, 35.5°C PT, 37.7°C mPET and 30.6°C MOCI.

Table 4
Neutral and comfort range for thermal indices proposed for Jijel's City

Winter							Summer						
Neutral [°C]													
PMV	PET	SET*	UTCI	PT	mPET	MOCI	PMV	PET	SET*	UTCI	PT	mPET	MOCI
19,9	20,7	18,9	23,2	19,5	23,1	21,3	23,6	21,4	19,4	28,3	28,4	29,2	24,3
Comfort range [°C]													
Winter							Summer						
18,5 - 21,3	17,8 - 23,7	16,7 - 21,1	21,2-25,2	16,9-22,1	20,6-25,6	22,9 - 24,2	19,6 - 22,9	18,6 - 24,1	17,3 - 21,4	27,3-29,3	27,4-29,4	27,9-30,4	23,4 - 25,2

The subjective data collected from the questionnaires carried out in the Peace Garden, which described the perceived and expressed sensation votes (PESV) according to satisfaction, acceptability and tolerance results, were then compared to the computed thermal indices, reported on a 9-points scale, ranging from extremely cold (-4) to extremely hot (+4), with neutral (0) in the middle (Figure 10). We note a large discrepancy between the used thermal indices and PESV.

The perceived and expressed thermal comfort graph trend seems to be lower than what is given by the computed thermal indices in the interval -1<PESV<+1. However, for the class +2 "moderate" level of stress, the PESV reaches nearly the value of 38% and approaches UTCI index. This is reasonable since the measured air temperature did not actually exceed 34.2°C on average, and the temperature feel is higher than air temperature but remains below the body temperature of 37°C. On the neutrality axis, UTCI had the highest prediction (38.50%) ahead of MOCI (31.98%), PMV

(29.37%), PT (28.71%), mPET (26.10%), PET (24.80%) and SET* (15.66%). In addition, the PESV (19.82%) seems to be close to SET* and PET. On the other hand, in the +3 subdivision where the stress level is "strong" equivalent to the sensation "very hot", the UTCI, MOCI, mPET and PT values are higher than PESV. The value of PESV agree with PET, PMV and SET* values. The responses given by the interviewees (about 17% of the subjects chose the sensation of heat (+3) "very hot", while nearly 14% found the weather suffocating and chose the sensation "extremely hot" (+4)). In the latter class, the MOCI predicts 30%, while the other indices vary from 43 to 70% (Figure 10). However, PESV displays lower values in relation to all indices, except UTCI index which, to some extent, agrees with it.

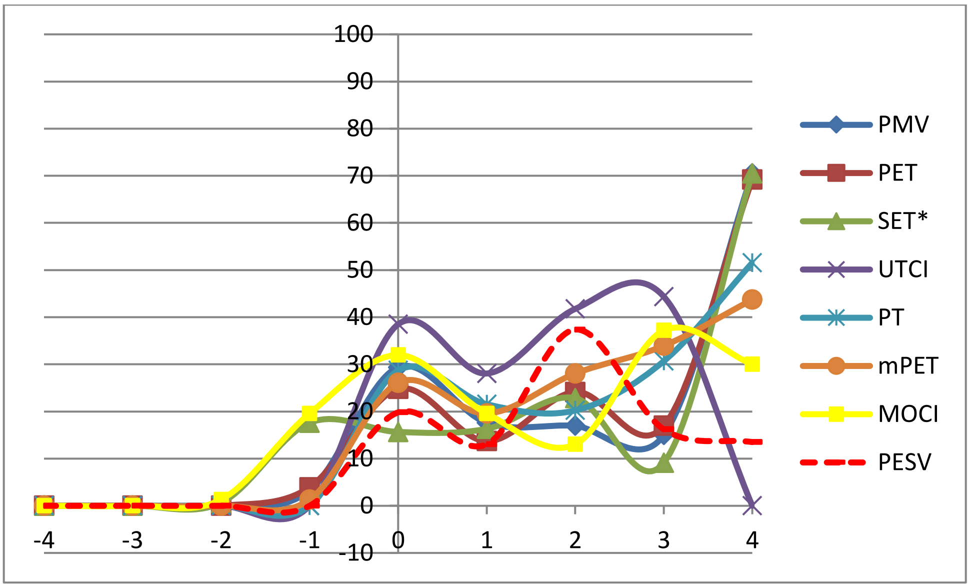

Fig. 10. Comparison between the Perceived and Expressed Sensation Votes (PESV) from the survey and the indices calculated from the mathematical model in RayMan

The MOCI index developed for the Mediterranean area does not seem to be the appropriate index for the evaluation of comfort in Jijel City as expected according to the subjective answers collected by the survey. While most indices predict an extreme sensation of heat (+4) in summer, however, PESV indicates less than 15%, which is not enough to pretend an extreme heat event. The disagreement between PESV and the rest of indices may be explained by the fact that some local parameters such as level of clothing, the metabolic activity, the adaptation of the people questioned and the time spent on the premises intervene. This implies further calibration investigation for better prediction of comfort thresholds.

4. Conclusion

This study aims to find the most suitable index to evaluate the outdoor thermal comfort in Jijel City by comparing the predictive capacities of seven indices (namely PMV, PET, SET*, UTCI, PT, mPET and MOCI) in terms of frequency occurrence and by confronting them with the contextual responses of users.

The perceived and expressed thermal comfort seems to be lower than what is given by studied thermal indices in the interval -1<PESV<+1. However, for the class +2 "moderate" level of stress, the PESV reaches nearly the value of 38% and approaches UTCI index. On the neutrality axis, UTCI had the highest prediction in relation all considered thermal comfort indices. In addition, the PESV seems to be close to SET* and PET. In the (+3) class, the UTCI, MOCI, mPET and PT values are higher than PESV. The value of PESV agree with PET, PMV and SET* values. In the (+4) class, the MOCI predicts 30%, while the other indices vary from 43 to 70%. However, PESV displays lower values in relation to all indices, except UTCI index which, to some extent, agrees with it.

The MOCI index developed for the Mediterranean area does not seem to be the appropriate index for the evaluation of comfort in Jijel City according to the subjective answers collected by the survey. While most indices predict an extreme sensation of heat (+4) in summer, however, PESV indicates less than 15%, which is not enough to pretend an extreme heat event. The disagreement between PESV and the rest of indices may be explained by the fact that some local parameters such as level of clothing, the metabolic activity, the adaptation of the people questioned and the time spent on the premises intervene. This implies further calibration investigation for better prediction of comfort thresholds.

It was found that microclimatic conditions directly influence the individual's perception of the thermal environment which is affected by the treatment of the ground surfaces and thermoradiative properties either in winter and summer. The highest variation was observed in the afternoon, given the impact of solar radiation on the different surface treatments, especially those with low albedo. The study showed the effectiveness of the grass cover in regulating surface and air temperatures. The study also pointed out the impact of surrounding buildings in terms of solar accessibility and heat trapping on the outdoor spaces.

For the city of Jijel, we defined a neutral air temperature of 19.8 °C in winter and 20.4 °C in summer. These values are calculated from the PET and SET* mean because PESV agrees, to a large extent, with these indices between -0.5 and +0.5 of the ASHRAE scale. Moreover, a comfort range of 16.8-21.6 °C in winter and 22.4-25.4 °C in summer has been proposed.

The limitation of our study is that only one case study for data collecting is considered. This will affect the generalisability of the results. The study could have been stronger if more cases outside the one studied were added, so we could get a balanced view of the subject.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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