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SHORT COMMUNICATION

Sport events and climate for visitors—the case of FIFA World Cup in Qatar 2022

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Abstract The effect of weather on sport events is not well studied. It requires special attention if the event is taking place at a time and place with extreme weather situations. For the world soccer championship in Qatar (Doha 2022), human biometeorological analysis has been performed in order to identify the time of the year that is most suitable in terms of thermal comfort for visitors attending the event. The analysis is based on thermal indices like Physiologically Equivalent Temperature (PET). The results show that this kind of event may be not appropriate for visitors, if it is placed during months with extreme conditions. For Doha, this is the period from May to September, when conditions during a large majority of hours of the day cause strong heat stress for the visitors. A more appropriate time would be the months November to February, when thermally comfortable conditions are much more frequent. The methods applied here can quantify the thermal conditions and show limitations and possibilities for specific events and locations.

Keywords Qatar 2022 · Sport events · Physiologically Equivalent Temperature · Thermal stress · RayMan

Introduction

Big sport events often take place during summer seasons for several reasons. One reason might be that they are often originating from Europe, where the summer season is the one with the largest fraction of thermally comfortable hours. There are two points of view about the effect of meteorological conditions and factors (a) from the athletes view (e.g. Wong et al. 2013) and (b) from the point of view of visitors attending the events. The focus here is not lying on athletes' view, who are actively participating, but on visitors coming from different places all over the world (e.g., Europe), having different thermal perception and expressing different behavior. The analysis is performed for visitors from Central Europe. As climate in Doha is more extreme than in most other countries, results are expected to also hold for a large fraction of visitors from other parts of the world. Methodology for quantifying and assessing the effect of the thermal environment on humans by the use of thermal indices is well known, though often applied for other purposes apart from sporting event environments. Such applications include the analysis of the effect of open spaces or green areas on human thermal biometeorology (e.g., Lin et al. 2010) as well as heat waves in urban areas (e.g., Nastos and Matzarakis 2012). The effects depend on different factors of human thermal comfort that include different meteorological and nonmeteorological parameters (Höppe 1993, 1999). Some of these parameters are strongly influenced by the surroundings (e.g., wind speed and the different radiation fluxes that strongly influence human thermal comfort) (Matzarakis 2013). Sports grounds (like all types of areas) with their specific elements and configurations cause and modify the local meteorological conditions (Wong et al. 2013). The resulting local climate, the microclimate, may therefore be modified with reduction of heat load on humans attending sport events in scope.

The World Cup always takes place during the European off-season in June and July. For the Qatar 2022 FIFA World Cup, we analyzed the meteorological conditions in terms of human biometeorological assessment. During the analyzed period (March 1999 to January 2014), the daytime mean maximum air temperature (T_a) in most of June and July exceeded 50 °C and the average

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daily minimum air temperature did not drop below 30 °C.

There are many options about the construction of sport facilities. The organizers and FIFA state that it will take the help of technology to counter the harsh weather. Hence, a stadium with controlled air temperature is presented as the answer to the question. However, this will only help for the short time, the attendants spend inside the stadium and it will make things even worse as soon as they leave it.

The aim of this study is to give an assessment for the detection of appropriate or inappropriate time periods of the year in the context of human thermal comfort. The novelty of research presented here is that for instance it is not only relying on a quantification of the human biometeorological parameters, for example, air temperature and a thermal index (Physiologically Equivalent Temperature (PET)) on monthly values, but also for the analysis of temporal variability and sensitivity for a long period of meteorological data. The methodology was applied in order to get results that may assist in the organization and planning of sporting events not only in Qatar but also in other parts of the world. Therefore, the method is described in detail to enable organizers and planners to get detailed quantified results for a specific location. The results are presented graphically, in a way that can be easily understood by nonspecialists on the specific topic of thermal human biometeorology so they can be easily understood by the responsible people planning sport events.

Methodology and data

Study area

Qatar is a small peninsula that extends into the Persian Gulf on the eastern side of the Arabian Peninsula. Saudi Arabia is neighboring to the west and the United Arab Emirates to the south. The country is mainly barren. Doha (the capital) has a hot desert climate (Köppen climate classification *BWh*). The coordinates are 25° 17′ N and 51° 32′ W. The summer season is very long, ranging from May to September. Ten percent of all recorded values for T_a (see RayMan model) exceed 37.8 °C in the applied period. Humidity is usually least in May and June. Dewpoints may surpass 25 °C in summer. Throughout the summer, the city averages almost no precipitation and less than 20 mm during the other months (see Fig. 1). Rainfall is scarce, at a total of 75 mm per annum, falling on isolated days, mostly between October and March. The winters are warm. Air temperature only drops below 13.4 °C in 1 % of the recorded values (for information about the data, refer to section Input data for the RayMan calculations). An overview over the different meteorological parameters in Doha is provided by Table 1.

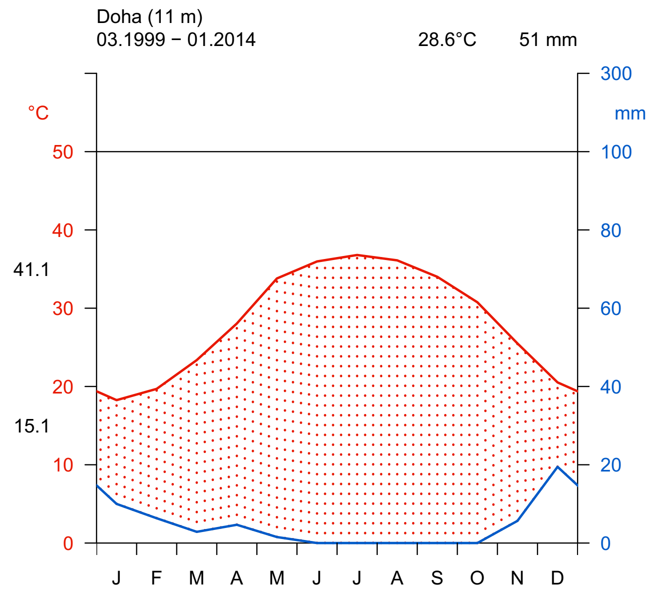

Fig. 1 Walter and Lieth Diagram (Walter and Lieth 1960) for Doha City for the period March 1999 to January 2014. Average monthly T_a (*left axis*, *red*) and average monthly sum of precipitation (*right axis*, *blue*). All months, where average monthly T_a is larger than two times the monthly sum of precipitation, are considered arid (*red dots*) (color figure online)

Physiologically Equivalent Temperature

PET, as applied in this study, is an index for the assessment of the changes in human thermal comfort. It is defined “as the air temperature at which, in a typical indoor setting (without wind and solar radiation), the energy balance of the human body is balanced with the same core and skin temperature as under the complex outdoor conditions to be assessed” (Höppe 1999; Mayer and Höppe 1987; Matzarakis et al. 1999). PET is one of the most commonly used indices for human thermal comfort, so results may be easily compared to those from other studies (Lin et al. 2010). Another big advantage of PET is the use of degree Celsius as a unit, facilitating interpretation by people without knowledge in the field of human biometeorology. As is the case with many other thermal bioclimatic indices, PET also bases on a human energy balance model. PET is based on the Munich Energy Balance Model for Individuals (MEMI) (Höppe 1984). One of the most important determining factors of PET is the mean radiant temperature (T_{mrt}) especially during summer (Herrmann and Matzarakis 2012). T_{mrt} is defined as the temperature of a perfect black and equal surrounding environment, which leads to the same energy balance, as the current environment (VDI 1998; Fanger 1972).

RayMan model

The RayMan model was applied for analyzing the long-term changes in thermal comfort conditions. RayMan is a micro-scale model developed to calculate radiation fluxes in simple and complex environments (Matzarakis et al. 2007, 2010).

Table 1 Overview of the meteorological input parameters air temperature, relative humidity, vapor pressure, wind velocity, and cloud cover recorded at the Doha Airport Station covering the period March 18, 1999 to January 10, 2014 in 3-h resolution

Parameter	Min	1st quantile	Mean	Median	3rd quantile	Max
Air temperature (°C)	1.4	22.0	28.3	29.0	34.0	59.1
Relative humidity (%)	4.7	38.2	54.3	56.2	71.0	100.0
Vapor pressure (hPa)	1.4	13.8	20.4	18.74	25.75	50.16
Wind velocity (m/s)	0.0	2.6	4.9	4.6	6.5	44.5
Cloud cover (octas)	0	0	1.2	0	2	8

This allows the calculation of T_{mrt}, which is an important input parameter in the calculation of thermal bioclimatic indices, e.g., PET. In this study, results in terms of the calculated PET were classified into nine classes of thermal stress (Table 2) (Matzarakis and Mayer 1996). The applied assessment scale for Qatar was extended by two new classes of 45–50 °C and above 50 °C to care for the higher heat loads, since the original scale was created for prevailing conditions of Central Europe.

Input data for the RayMan calculations

In order to get representative, basic, and comprehensive results, meteorological data for the period March 1999 to January 2014 in 3-hour resolution, recorded at the Doha Airport meteorological station (WMO station 41170) and provided by Ogimet (www.ogimet.com), was used. The airport is located directly at the city limits, so data is expected to be most representative. Wind speed at a height of 1.1 m above ground level was estimated based on a power-law profile approach applied in Matzarakis et al. (2009). The other parameters have been used without altitude correction as their measurement height of 2 m is close to the destination height and the error is therefore expected to be fairly small. Meteorological conditions in Doha are characterized by a high mean air temperature of 28.3 °C, as well as a high average wind speed (in 1.1 m) of 4.9 m/s during the examined period.

Table 2 Thermal stress classes for human beings (with an internal heat production of 80 W and a heat transfer resistance of the clothing of 0.9 clo (clothing value)).

PET (°C)	Thermal perception	Grade of physical stress
<4	Very cold	Extreme cold stress
4–8	Cold	Strong cold stress
8–13	Cool	Moderate cold stress
13–18	Slightly cool	Slight cold stress
18–23	Comfortable	No thermal stress
23–29	Slightly warm	Slight heat stress
29–35	Warm	Moderate heat stress
35–41	Hot	Strong heat stress
41–45	Very hot	Extreme heat stress
45–50	Very hot	Extreme heat stress
>50	Very hot	Extreme heat stress

Modified after Matzarakis and Mayer (1996). Two additional classes of 45–50 °C and above 50 °C have been added to meet the hot conditions in Doha. They can be found below the dashed line

Results

The results are presented in two sections: First, the frequencies of air temperature and PET are shown. They are presented in decade resolution. Each month is thus separated into three intervals to show the monthly conditions more precisely. The second section deals with the daily distribution of mean air temperature and PET over the year, which is presented as an average of a long period (March 1999 to January 2014).

Frequencies of air temperature and PET classes

Figure 2 shows the frequencies of air temperature classes in Doha City for the period 1999–2014 according to Table 2. It can be observed that classes lower than 8 °C did not occur at Doha. The highest frequency during winter is the class 18 to 23 °C followed by the 8 to 13 °C class. It is noted that the frequencies include day and nighttime situations. Therefore, cooler conditions mostly occur during nighttime. The classes 18–23 and 23–29 °C are the most frequently observed in spring and autumn. The classes with air temperature of 35 °C and above are limited to the months of April to October. The months of June and July, which will be the time of the FIFA Championship, are quite predominated by the classes of very high air temperature of about 35 °C. While they are only found in approximately 40 % of all hours in the first week of June, the probability of hours with high air temperature of 35 °C and above increases to more than 50 % at the end of June, rising to about 55 % for the whole month of July. Cooler conditions of lower than 29 °C can only be found in less than 10 % of all hours in the first week of June, declining to 0 % in July.

Generally, the PET values range from less than 4 °C to more than 50 °C (Fig. 3). The period with cooler conditions is limited to the period from the end of November to the end of March. The class indicating thermal comfort and acceptable

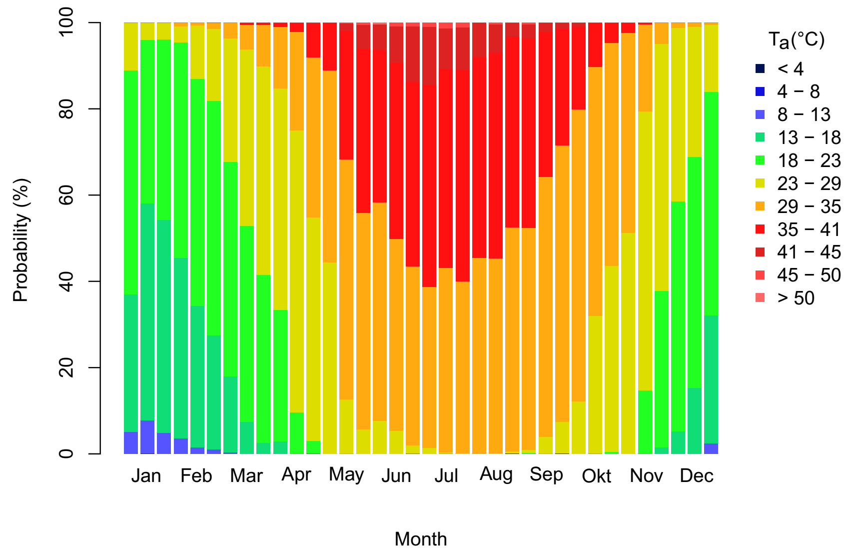

Fig. 2 Frequency diagram for T_a for Doha City for the period March 1999 to January 2014 in decade resolution. The reference height for the measurements is 2 m. Data was recorded in 3-hour resolution. The classes meet the extended thermal sensation classes stated in Table 2

conditions (18–29 °C) dominates during winter time and is prevalent only at nighttime in the summer. PET conditions (>41 °C) indicating thermal stress for Europeans are shown for the period end of April to end of October. Fifty percent of the time of the months May to middle of October are dominated by the classes of higher than 35 °C indicating strong heat stress for Europeans. These conditions are likely to occur more frequently during the time of the championship, possibly at about 50 % in the first week of June to above 55 % in July. Favorable thermal comfort conditions for Europeans are likely to occur at less than 5 % of all cases in June and almost none in July.

Daily distribution of mean air temperature and PET

The mean distribution of T_a (Fig. 4) and PET (Fig. 5) over daytime and year is analyzed to determine the periods with heat stress within each day of the year. Compared to the frequency diagrams, it can be observed that the hours of high air temperature as well as hot conditions under a human biometeorological point of view occur mostly during daytime. However, even at nighttime, conditions in Doha may cause heat stress for Europeans (Fig. 5).

Figure 4 indicates that hot conditions, represented by air temperature of 35 °C or above, may occur from May to October. Hours with air temperature of 35 °C and above are dominant from June to the end of September. From the end of July to August, mean air temperature of more than 41 °C is also calculated.

The distribution of mean PET over day and year (Fig. 5) shows a more significant pattern. Between the end of April and the end of October during daytime, the PET conditions are higher than 35 °C. In addition, these conditions take place during the day from sunrise to sunset. Conditions with the

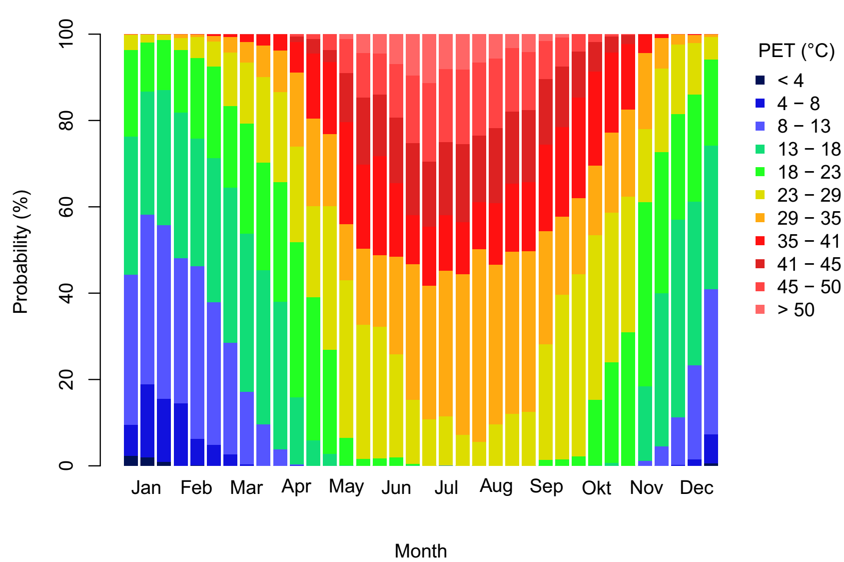

Fig. 3 Frequency diagram for PET for Doha City for the period March 1999 to January 2014 in decade resolution. The reference height is the gravity center of an average human of 1.1 m. PET is based on data that was recorded in 3-hour resolution. The classes meet the extended thermal sensation classes stated in Table 2

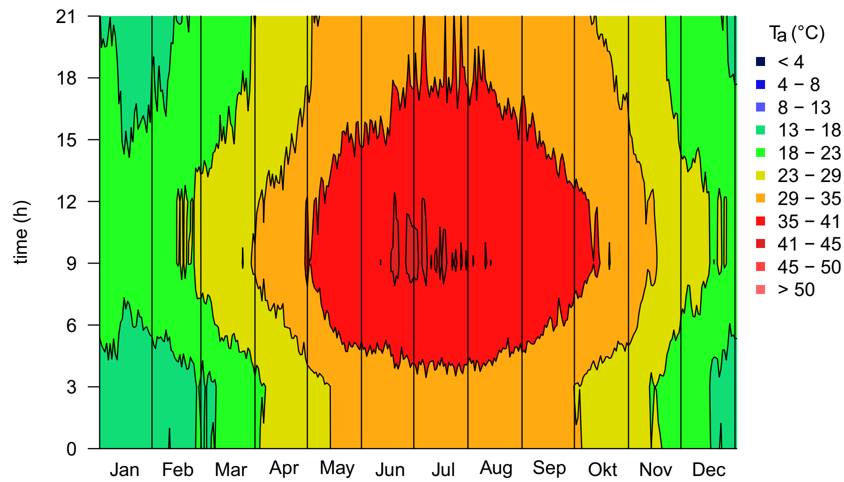

Fig. 4 Temporal diagram for T_a for Doha City for the period March 1999 to January 2014. The reference height for the measurements is 2 m. The variation over the day can be seen in y-direction, while the variation during the year is given in x-direction. The classes meet the extended thermal sensation classes stated in Table 2

strongest thermal stress (>41 °C) are found to occur from mid of May to the end of October.

Discussion and conclusion

Based on the results, it can be concluded that information based on monthly resolution and means do not deliver appropriate quantifications of meteorological conditions for the selection of periods, where sport events may take place over the year. There are several factors which have to be considered in this issue. First of all, it has to be stated that visitors and tourists are the groups which are affected the most by extreme meteorological conditions. Comparing Figs. 2, 3, 4, and 5, it can be seen that conditions with negative implications, namely heat stress, cannot be quantified based on air temperature alone (e.g., Nastos and Matzarakis 2012) because this is only one of the constituent environmental parameters affecting the human body's energy balance and therefore does not represent the whole human thermal perception (Fanger 1972; VDI 1998; Cohen et al. 2013). Humans perceive their thermal environment based on the integral effect of air temperature, air humidity, wind speed, and radiation fluxes (Fanger 1972; Höppe 1984). The applied thermal index (PET) allows this quantification (Höppe 1999; Matzarakis et al. 1999). In addition, the results' representation in terms of frequencies of thermal comfort classes facilitates a more appropriate description of the conditions during the day and year (Matzarakis and Mayer 1996). The thermal sensation classification for Central Europe therefore had to be extended to be able to distinguish within the high fraction of results above 41 °C.

While the study is concentrating on visitors from Central Europe, it should also hold for people originating from regions with similar thermal climatic conditions and could easily be applied to visitors from other parts of the world by just using different assessment scales, e.g., for Taiwan (Lin and Matzarakis 2008) or Israel (Cohen et al. 2013).

This study described an approach to determine possible negative implications on visitors attending sport events, quantitatively and based on human biometeorological methods. It is not the aim of this study to show that Doha City is

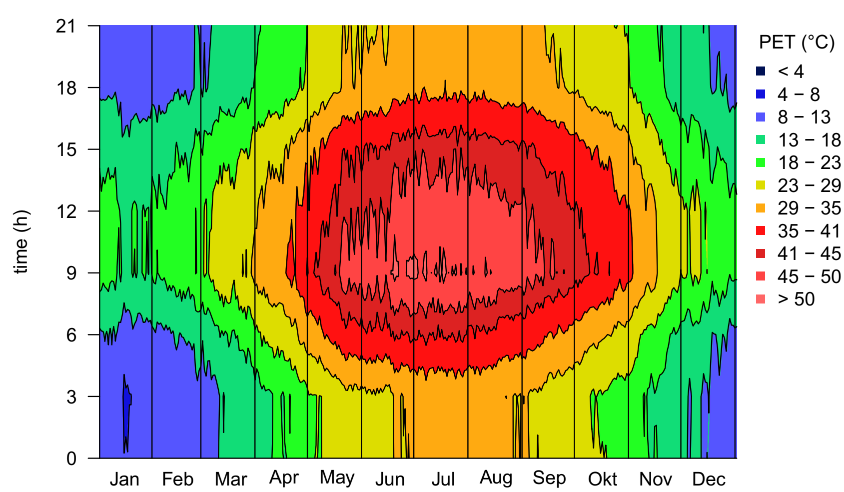

Fig. 5 Temporal diagram for PET for Doha City for the period March 1999 to January 2014. The reference height is the gravity center of an average human of 1.1 m. The variation over the day can be seen in y-direction, while the variation during the year is given in x-direction. The classes meet the extended thermal sensation classes stated in Table 2

inappropriate for the FIFA 2022 but to find a time period with the most suitable thermal conditions for visitors and tourists. According to the results, this is the time from November to February.

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