Climate-Tourism Information Scheme (CTIS) for Sport Events from Past: Analysis of Cases of 1980 Summer Olympics (Moscow) and 2018 FIFA World Cup

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ABSTRACT

This article provides a quantitative analysis of local climate-related factors that may influence the organization of large sport events in Moscow, Russia, and its graphic representation in form of CTIS (Climate-Tourism Information Scheme) with decade resolution for 1991-2021. The individual CTIS for two historical sport events with daily resolution were also done, and then compared to meteorological data recorded during two large sport events to assess the agreement between averaged and actual conditions, which was found to be good enough for CTIS to serve as basic evaluation method. The CTIS-difference with sport events in Moscow compared with cases of Doha and Tokyo seem to be more about identifying the time period with biggest thermal comfort frequencies, instead of looking for occurrences of heat stress conditions. According to 1980 Summer Olympics and 2018 FIFA World Cup events it can be noted that time period was planned satisfactorily.

Introduction

Climate change is an issue that has complex consequences for many facets of human life, including people's health (Townsend et al., 2003; Schneider & Mücke, 2021). It is especially relevant to sport, as it is directly impacted by natural environment and exhibits climate vulnerability at different levels: from the process of organizing the event itself to the condition of individual athletes (Orr & Inoue, 2019). The most common concerns for such events seem to be the heat impact on athlete and spectator health, the heat impact on the athletic performance, and suitability of various cities for sport events hosting (Orr et al., 2021).

Sport-specific health risks caused by the climate change may be direct and indirect (Schneider & Mücke, 2021). In case of direct health risks, the main cause of

damage is the prolonged exposure to very high temperatures. Generally, physical exercise combined with high temperature and air humidity imposes a significant strain on human body system and compromises thermoregulation system (Brotherhood, 2008; Hanna et al., 2011), as high humidity levels prevent cooling of the body through sweat evaporation thus causing the heat to remain in the body (Maloney & Forbes, 2011). Even though the well-trained athletes have an individual tolerance to increases in core body temperature (Hanna et al., 2011), they still may be vulnerable to exertional heat illnesses (EHI) and exertional heat strokes, the latest listed as the third highest cause of death of athletes during physical activities (Mallen et al., 2022), while the number of reg-

istered EHI deaths has significantly increased in the last three decades (Gamage et al., 2020).

Therefore, information about meteorological and climate conditions, including the ones that influence the level of the thermal stress experienced by human body, is highly relevant for the participants and spectators of sport events. With the latest large sport events, such as 2020 Summer Olympics and 2022 FIFA World Cup, being held in location with high probabilities of extreme daytime temperatures (Japan and Quatar respectively), this problem came to the forefront of biometeorological research. The general climatological conditions of Tokyo Olympics expected to be hottest ever were evaluated in (Gerret et al., 2019; Kakamu et al., 2017; Matzarakis et al., 2018), as well as heat exposure at some Olympic event venues, such as the marathon (Honjo et al., 2018; Vanos et al. 2019). Similar research was conducted for Doha, where the 2022 FIFA World Cup was held (Sofotasiou et al., 2015; Matzarakis & Frohlich, 2015). Some of them, for example, (Olya, 2019), made calls for a change in approach to planning sport mega events as part of adaptive strategy toward climate change.

In recent years, the effective methodology for such evaluation, employing mean an extreme climate conditions of the area, was developed (Matzarakis, 2014). It allows to identify the most appropriate period of the year, as well as to present it in the easily accessible way for interpretation by non-experts in terms of climatology, which usually serve as decision-makers on different administrative levels. It requires appropriate data series with high temporal resolution, which can illustrate the patterns of change of all relevant parameters throughout the year.

This methodology had been applied to the Tokyo Olympic Games (Matzarakis et al., 2018, 2019), which were held at open air in summer, as well as to the case of FIFA World Cup of 2022 in Doha (Matzarakis & Frohlich, 2015), which originally had been planned for summer too. Similar analysis was also conducted for the upcoming Paris Olympic Games in 2024 (Matzarakis & Graw, 2022).

Therefore, the aim of this paper is to assess suitability of background meteorological conditions for outdoor sport events, including human thermal comfort, for Moscow, Russia. Specific attention was paid to summer thermal comfort conditions in the city, for the increase in surface temperature of this season and the frequency of heatwaves in European Russia is well-documented (Vyshkvarkova & Sukhonos, 2023). Additionally, Moscow is a largest megacity in Europe, made more vulnerable to heat wave events by the urban heat island effect (Kislov & Konstantinov, 2011; Kuznetsova et al., 2017; Varentsov et al., 2019). The previous research on bioclimatic conditions in Russia (Vinogradova, 2021) and its largest cities (Konstantinov et al., 2021) also indicates the increase on frequency of thermal stress conditions in summer months.

The detailed results presented in accessible graphic form may be employed in long-term planning concerning organization of different open-air events in that specific location. This assessment methodology has also been applied to the large sport events held previously in the city: Moscow 1980 Olympic Games, and FIFA World Cup of 2018. The comparison of the most appropriate time periods according to chosen method and existing dates of events was conducted.
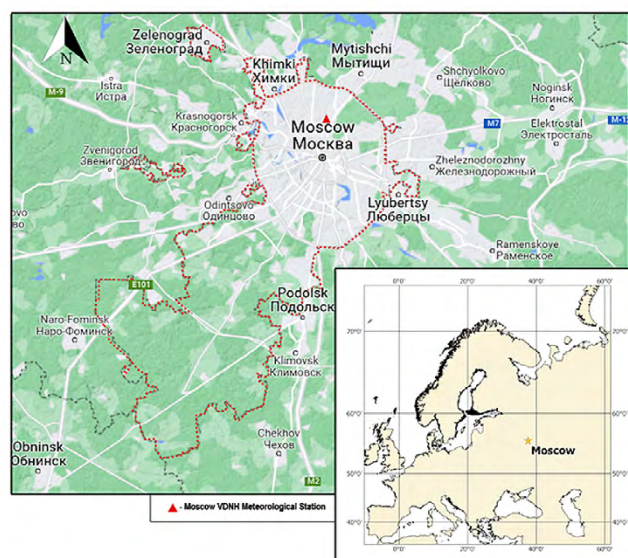
Data and methods

Moscow-VDNH meteorological station (WMO station ID 27612) is located in the northern part of Moscow (55.8°N, 37.6°E, 156 m).

The city itself has the area of 2511 km², and the population of 13,1 million inhabitants within its administrative borders. The climate of Moscow is continental and characterized by warm and humid summer with cold, dryer winter (Dfb Köppen climate zone) (Peel, 2007). The annual average temperature is 5.5 °C, and the annual sum of precipitation is 690 mm (Figure 2). The warmest month is July, when average temperature reaches 18.2 °C, and the coldest month is January with an average temperature of -9.3 °C. Monthly average of precipitation is highest in July (94 mm), and the driest month of the year is March (34 mm).

The assessment of human thermal comfort requires the calculation of thermal indices (Matzarakis et al, 2007). There are more than 170 such indices (de Freitas & Grigorieva, 2017), and most of them require data on air temperature and air humidity for calculation. Studies like (Grundstein et al., 2013,
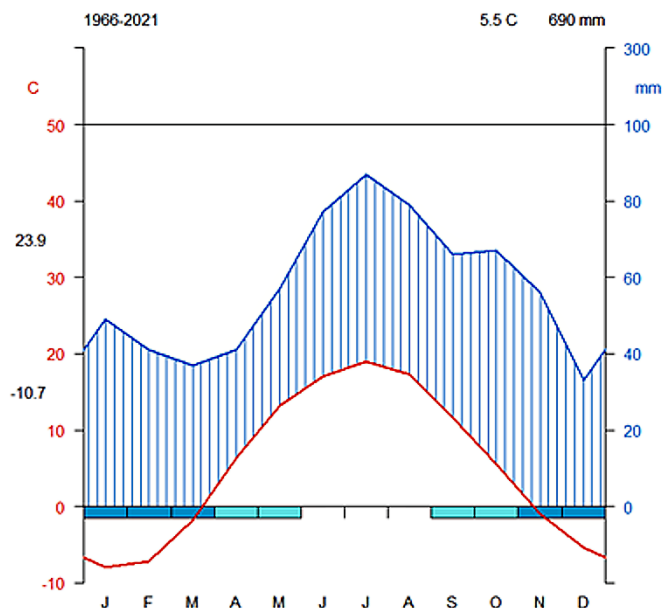

Figure 1. Location of Moscow

Figure 2. Walter and Lieth diagram for Moscow. Red line represents mean monthly averages of air temperature, blue line – mean monthly sum of precipitation for the period 1966-2021. Blue vertical lines exhibit humid conditions

2023; Gerret et al, 2019) have suggested to use wet-bulb globe temperature (WBGT) index for evaluation of thermal stress during sport activities. WBGT values demonstrate the cooling rate of human skin through surface evaporation. However, to better account for the complexity of heat exchanges in the human body – environment system, thermal comfort indices based on human energy balance model (Höppe, 1993) were used in this study. They combine the physiological aspects of the human body with appropriate meteorological parameters, such as air and surface temperature, humidity, wind speed and cloudiness which influences radiation fluxes in the environment. For evaluation of overall thermal comfort, the Physiological Equivalent Temperature (PET) was calculated (Höppe, 1999).

PET 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; Matzarakis et al, 2007). This index has many advantages; however, one particular is that degrees Celsius (ºC) are used as a unit of measurement for PET, which makes it easily digestible for non-professionals, and allows the comparison to similar studies.

The RayMan model was applied for the analysis of thermal comfort conditions throughout the year. It is a micro-scale model developed for calculation of radiation fluxes in different environments (Matzarakis et al, 2007, 2010). The resulting PET was divided into nine well-known classes of thermal perception.

In this research, meteorological data with standard 3-hour resolution (WMO station 27612) was used, except for sums of precipitation and for snow cover with daily resolution. In order to get more relevant results, the data utilized was mainly for the period from 1991–2021, which represents current climate of the area. However, for evaluation of the meteorological conditions during Moscow Summer Olympics in 1980, additional data for 1961–1990 was separately included to get information on mean and extreme climate conditions of the previous 30-year period.

Climate information was presented using CTIS (Climate-Tourism Information Scheme) (Matzarakis, 2014), which provides frequency of extreme weather conditions (including thermal comfort) that exceed chosen threshold criteria throughout the year with appropriate frequency classes. CTIS may have different resolution, depending on the characteristics of available data. For purposes of this study, yearly conditions were presented in decades. The selection of factors included in CTIS was based on climate of the study area.

Threshold criteria have been selected according to literature references. For thermal Moscow, the following threshold criteria have been used: thermal comfort (13ºC < PET ≤ 29ºC), heat stress (PET > 35ºC) cold stress (PET ≤ 8ºC), foggy days (relative humidity > 93 % between 6 and 18 h., local time), wet days (daily precipitation sum > 5 mm), dry days (daily precipitation sum <1 mm), sultry days (water vapor pressure > 18 hPa) (Matzarakis, 2007). The criteria for sunny days (cloud cover < 5 oktas between 6 and 18 h., local time) and stormy days (wind speed > 8 m/s) were chosen according to (Gómez-Martín, 2004). Threshold criteria for snow days was snow cover exceeding 10 cm, which is considered enough for cross-country skiing in non-alpine regions (OECD, 2007; Neuvonen et al., 2015).

However, several of these factors give positive contribution to overall comfort, and some – negative. Therefore, to get one suitability scale, all rows save for frequencies of thermal comfort conditions and sunny days have been inverted. The frequencies of extreme weather conditions were expressed via color-coded 5 % probability classes that range from "unsuitable" (red on the diagram) to "ideal" (green on the diagram).

Results

Thermal conditions in Moscow throughout the year have been described mainly using PET thermal index, which provides averaged thermal perception and grade of thermal stress in decade resolution for 1991-2021. Same has been done for precipitation, which is another important factor for open-air events. The annual distribution of both has been visualized on frequency-distribution plots that show the probability of each class of PET and daily precipitation throughout the year.

In general, year in Moscow is dominated by classes of PET <13ºC, which indicates high probability of cold stress conditions. The probability of PET ≤4ºC (extreme cold stress) exceeds 90 % from mid-November to the second decade of March, and the probability of extreme cold stress conditions occurring is close to zero only in late July and early August. Classes of PET that indicate cold stress conditions, from strong to moderate, occur throughout all year. Thermal comfort conditions can be found in summer
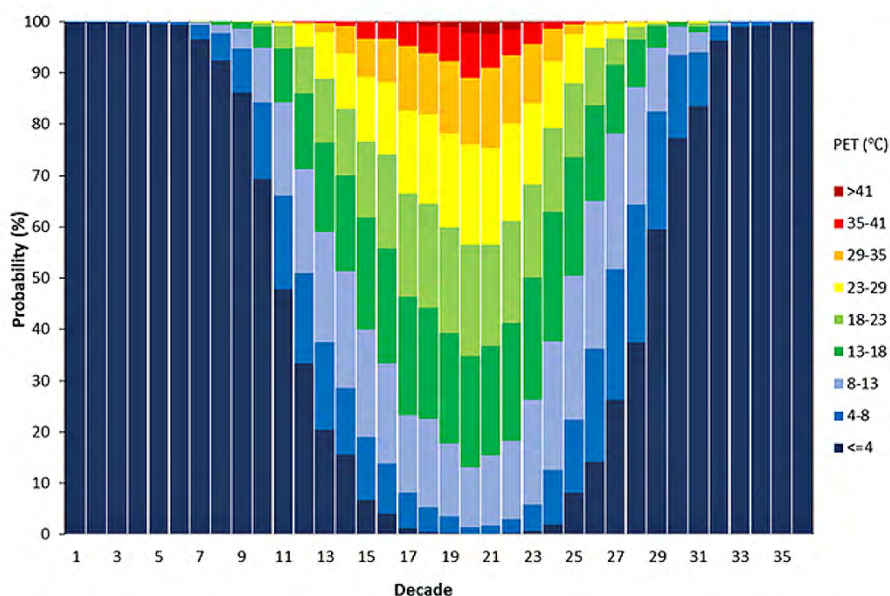

Figure 3. Frequency diagram for the occurrence of PET classes for Moscow in each decade in 1991-2021 (3-hour resolution)
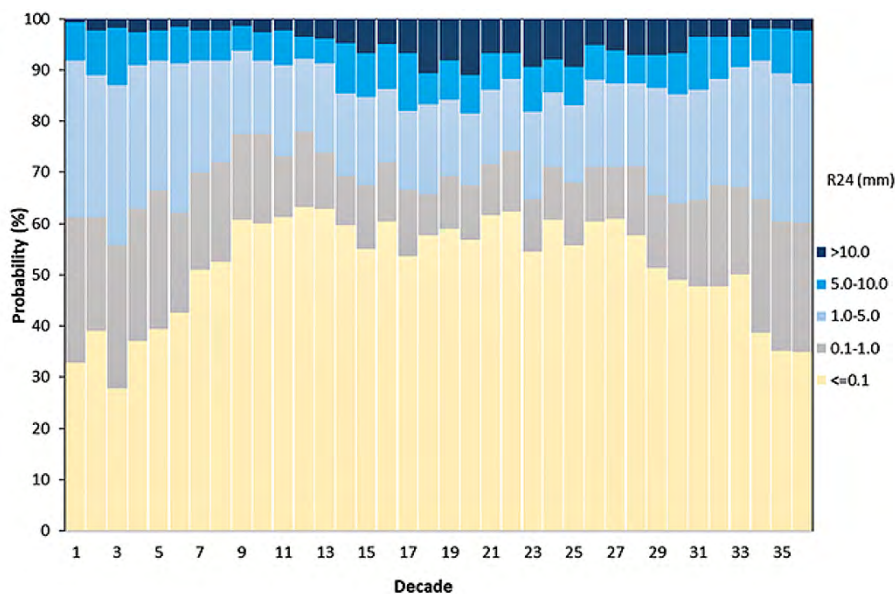

Figure 4. Frequency diagram for the occurrence of precipitation classes for Moscow in each decade in 1991-2021 (daily resolution)

months, from early June to the second decade of August. Its probability is highest in the second decade of July (22 %). Heat stress conditions (PET > 35°C) mostly occur from late May to the end of August, and their probability barely exceeds 10 %. Maximum heat stress is characteristic for July and first decade of August, and probability of PET > 41°C in that period ranges from 1.5 to 3 %.

Precipitation in Moscow is regular throughout the year. Winter months are distinguished by the higher probability of light precipitation. Dry days occur more frequently in summer months, and the heavy rain evens follow similar pattern. Probability of such events reaches 10 % in that period, mainly due to more intense daytime convection.

The Climate-Tourism/Transfer-Information-Scheme created for Moscow reveals a few interesting patterns. In terms of thermal comfort (the first row on Figure 5), the most suitable conditions mainly confined to the period from June to August, and throughout July and early September the conditions are in "suitable" range (frequency > 55 %). Their frequency is also up to 40 % in May and first decade of June. The cold stress conditions are characteristic for period from October to April, and since 21.10 to

20.03 the frequency of their occurrence is close 100 %, and it renders these months less suitable for holding open-air events. On the other hand, heat stress conditions occur most frequently in summer months, especially in mid-July (13 %).

Sunny conditions are quite rare throughout the year in Moscow. The most suitable conditions can be found from middle of July to the end of August, with probability reaching 45 %. Least favorable are months from November to January. Consequently, foggy days are characteristic to colder season, and warm season is dominated by dry days instead. Wet days are also more frequent in June-August due to higher probability of convective precipitation. Stormy days are rare throughout all seasons and do not demonstrate any digestible patterns. Finally, snow days occur with highest probability from November to March.

The 1980 Summer Olympics and FIFA World Cup were the large sport evens that were used to assess the agreement between CTIS diagrams and meteorological data from the station.

The 1980 Summer Olympics were held in Moscow from July 19th to August 3rd, 1980 (Figure 6). For the specific time
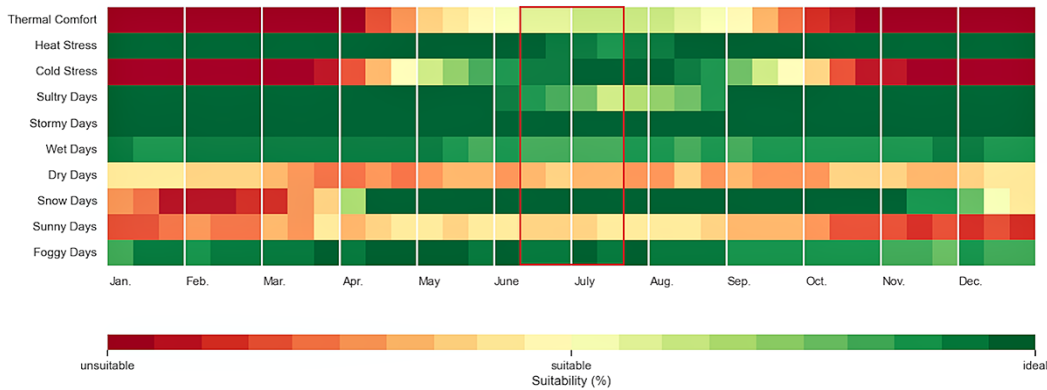

Figure 5. CTIS (Climate-Tourism/Transfer-Information-Scheme) demonstrating averaged frequency of occurrence by decades for relevant parameters in Moscow for the period 1991-2021. The red box highlights time of FIFA World Cup, 2018
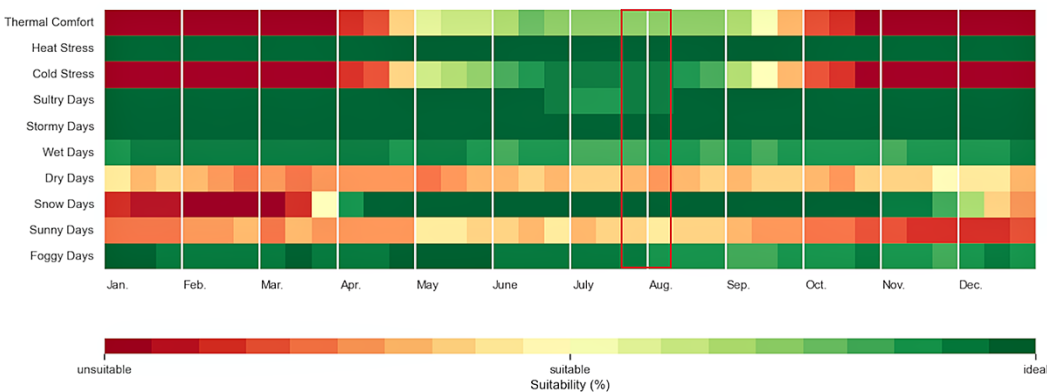

Figure 6. CTIS (Climate-Tourism/Transfer-Information-Scheme) demonstrating averaged frequency of occurrence by decades for relevant parameters in Moscow for the period 1961-1990. The red box highlights time of the Moscow Olympics, 1980
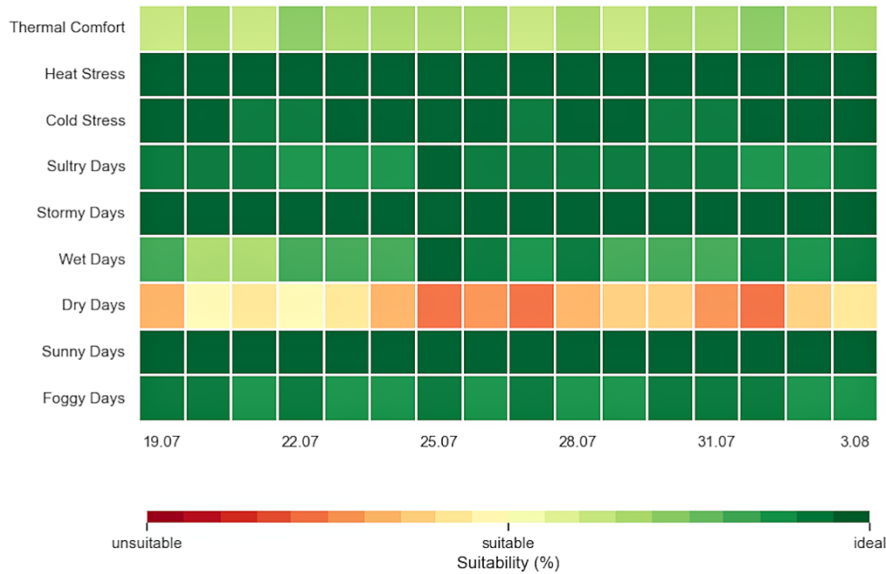
Figure 7. CTIS (Climate-Tourism/Transfer-Information-Scheme) demonstrating averaged frequency of occurrence by individual days of the year (19.07-3.08) for relevant parameters in Moscow for the period 1961-1990

of the Olympic Games, CTIS indicates a well-selected period in terms of heat and cold stress, as well as snow and stormy days. Probability of thermal comfort conditions occurring is within "suitable" range too. Sunny days are less frequent in the chosen period; however, it is characteristic for Moscow throughout the entire year. In terms of frequencies of wet and sultry days, the decades also may be considered suitable, and the probability of thermal comfort conditions worsening due to air humidity is not high.

CTIS with daily resolution for specific days of Moscow 1980 Olympics (Figure 7) indicates similar patterns, with

all parameters except for dry days (row 8) being in "suitable" or "ideal" range.

For specific days of the Olympics, daily distributions of PET and precipitation classes were also illustrated (Figure 8, 9). The daily distribution of PET is dominated by slight cold stress, thermal comfort, and slight heat stress conditions, which occur in that order from nighttime to daytime. Probabilities of moderate or strong cold stress conditions does not exceed 10 %, and for moderate and strong heat stress the frequency of occurrence is less than 15 % too. For precipitation classes, frequency of days with sum
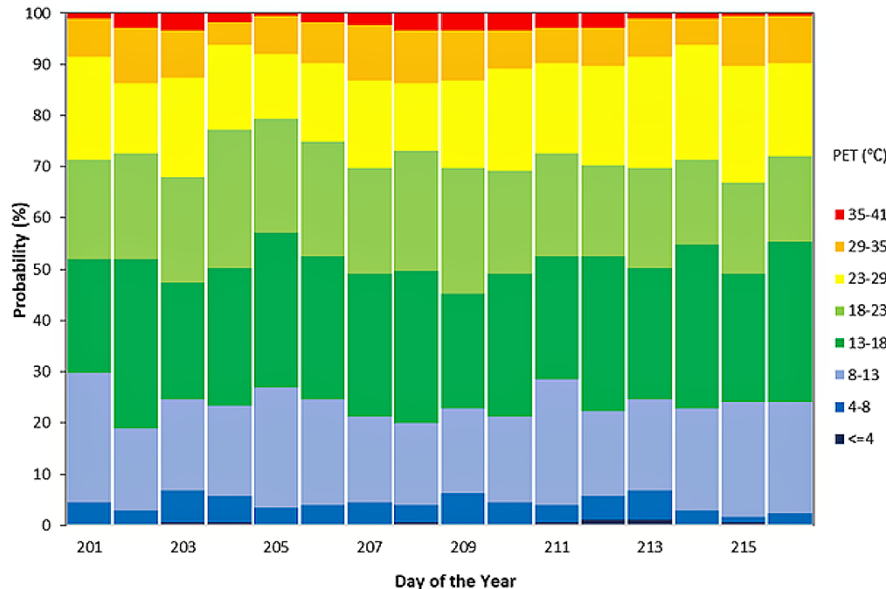

Figure 8. Frequency diagram for the occurrence of PET classes for Moscow by individual days of the year (19.07-3.08) for the period 1961-1990
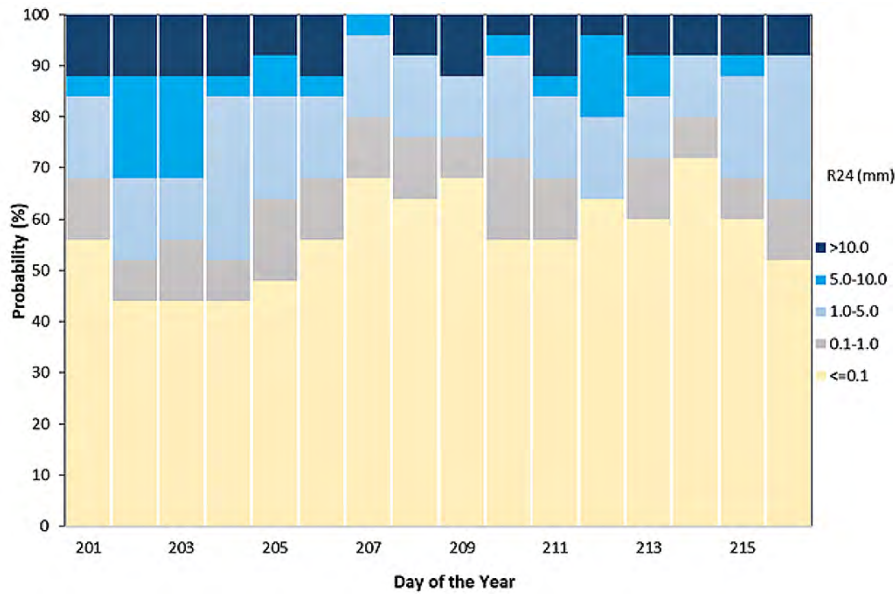
Figure 9. Frequency diagram for the occurrence of precipitation classes for Moscow by individual days of the year (19.07-3.08) for the period 1961-1990

of precipitation less than 1 mm is highest and reaches more than 70 %.

When analyzing the observed meteorological conditions during 1980 Olympics, the days in which threshold criteria were exceeded in general are consistent with CTIS for the same period (Figure 7). For example, it reflects the higher probability of precipitation on 20.07, as well as more likely occurrence of sultry conditions on 24.07. However, there seem to be inaccuracy in evaluation of the parameter of cloudiness which may be attributed to the methodology of the research.

In recent years, Moscow had also been a host of FIFA World Cup which took place from June 14th to July 15th, 2018 (Figure 5). Despite the observed climate change, CTIS also indicates a well-selected time period for the World Cup, similar in its basic characteristics for the time period of the summer Olympics described above, although

the probability of cold stress conditions occurring in June is slightly higher, and the probability of thermal comfort conditions, therefore, lower.

CTIS with daily resolution for relevant days also demonstrates a similar pattern of all evaluated parameters being in "suitable" or higher range, except for dry days probability which in the "unsuitable" range of several occasions.

Daily distribution of PET and precipitation classes for FIFA World Cup of 2018 are demonstrated on Figures 11, 12. PET daily distribution consists mostly of slight cold stress, thermal comfort, slight heat stress and moderate heat stress conditions, the latter becoming noticeably more frequent in comparison to the 1966-1990. Probability of strong heat stress conditions, mostly confined to afternoon hours, on some days of July exceed 10 %, and the probability of extreme heat stress conditions (extreme-
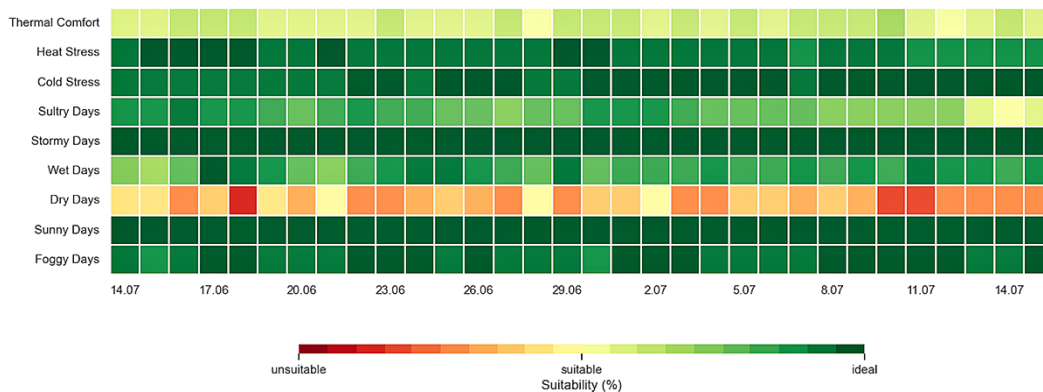

Figure 10. CTIS (Climate-Tourism/Transfer-Information-Scheme) demonstrating averaged frequency of occurrence by individual days of the year (14.06-15.07) for relevant parameters in Moscow for the period 1991-2021
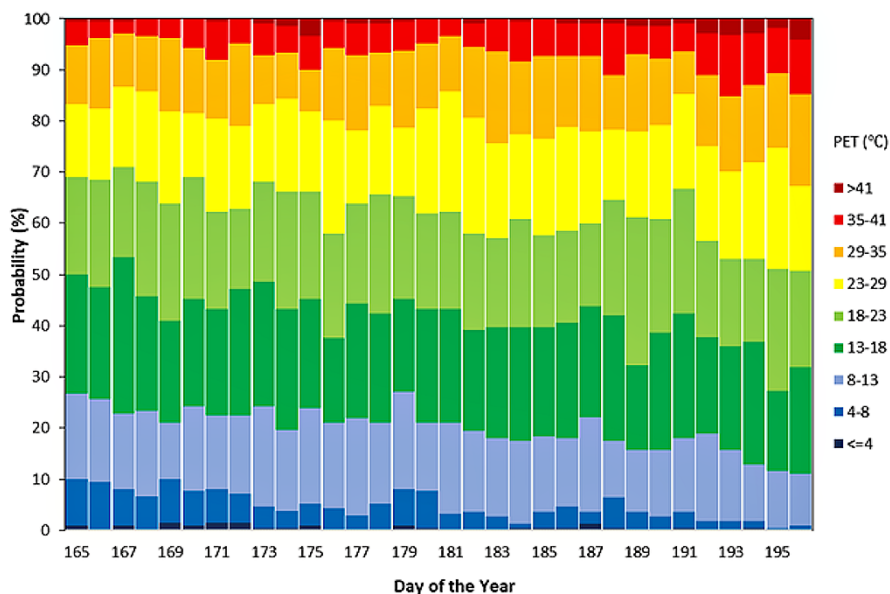
Figure 11. Frequency diagram for the occurrence of PET classes for Moscow by individual days of the year (14.06-15.07) for the period 1991-2021
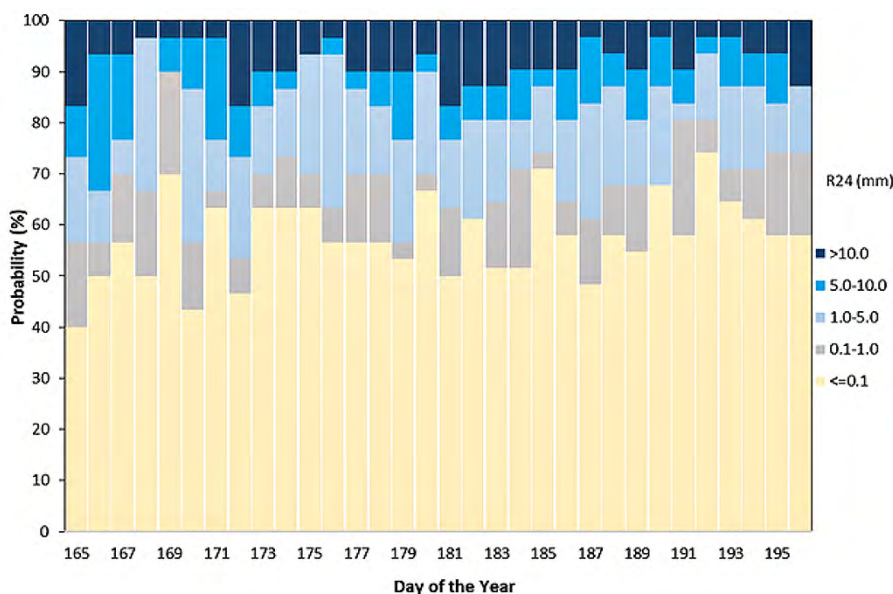

Figure 12. Frequency diagram for the occurrence of precipitation classes for Moscow by individual days of the year (14.06-15.07) for the period 1991-2021

ly rare for previous 30-year period) occurring also exceed 2 %. The daily distribution of frequency for different precipitation classes is dominated by dry conditions with less than 0.1 mm of precipitation and precipitation in range from 1.0 to 5.0 mm per day.

CTIS (Figure 5) in general reflects the observed meteorological conditions during 2018 FIFA World Cup. As with Moscow Olympics described above, CTIS describes the precipitation probability most accurately, reflecting the actual occurrences of it with daily resolution. Cloudiness evaluation remains the least accurate of the parameters.

Discussion

Comprehensive evaluation of meteorological conditions for open-air events, including sports, is impossible without methods of biometeorology and tourist climatology (Matzarakis, 2014), which can be used to quantify data on thermal stress and to combine it with other parameters that influence perception of comfort of the environment (Top et al., 2020; Geletic et al., 2018; Giannaros et al., 2018). The selection of these should include thermal comfort index (PET, UTCI, mPET) and other individual parameters that describe, for example, distribution of precipitation throughout the year in accordance with specifics of the local climate (Pochter et al., 2018). However, the application of this research requires a presentation of the findings in intuitively understandable and easily assessable way (Matzarakis & Frohlich, 2015; Matzarakis & Graw, 2022; Milosevic et al., 2023).

Therefore, the CTIS schemes with different time resolution, which require only highly available meteorological data from on-site stations, appear to be the most practical way of doing so. It can provide information for all kinds of tourist activities in the area, including large events which require throughout strategic planning, especially in relation to possible risks and negative impact of different conditions, including climate.

Results for Moscow for period 1991-2021 show the expected rise in the probability of thermal comfort conditions in summer months and its decline in the cold season, as well as quite high frequency of occurrence of cold stress conditions throughout the year, with heat stress conditions being confined mostly to July and August. The CTIS also accurately represents the higher probability of dry days in warm season and wet days in cold, which is a characteristic feature of Moscow climate.

Time periods chosen for 1980 Moscow Olympics and FIFA World Cup demonstrate suitable conditions in terms of thermal comfort availability back then (Figure 4, 5, 6, 9). The frequency of heat and cold stress conditions occurrence in these periods was also low. The probability of the sunny weather, another limiting factor for open-air events, is close to ideal too. The most probable cause of discomfort could have been the combination of heat stress conditions with sultriness and heavy precipitation; however, the observation data reports that it wasn't the case. The CTIS diagrams with daily resolution for both events demonstrate good agreement with observation results, accurately predicting possibility of wet and sultry conditions on specific days.

Compared to the cases of Doha (Matzarakis & Frohlich, 2015) and Tokyo (Matzarakis et al., 2018) CTIS for sport events in Moscow seem to be more about identifying the time period with biggest thermal comfort frequencies, instead of looking for occurrences of heat stress conditions, as the city's geographical location accounts for far colder climate. Therefore, even in summer period, the frequencies of cold stress conditions surpass them for heat stress and may present a bigger obstacle, although the one with less severe consequences for health in May-September.

This research provides an easily digestible results which can be applied to many sectors of the economy, not only management of sport. The frequency-based approach also helps to minimize the distortions which may appear in case of approach based on calculation of average for a variable. The assessment of thermal comfort through PET allows the incorporation of many meteorological parameters that may influence human health. The comparison of CTIS frequencies to observation data also indicates the agreement between them which validates this approach for planning of future sport events. However, CTIS diagrams are based on the data of representative meteorological station, therefore the evaluation for specific locations of sport events still requires more computationally expensive methods such as microscale modelling. As described above, the accuracy of CTIS relative to observation data differs for different meteorological parameters.

Conclusions

Proposed variant of CTIS provides the easily accessible information on basic climatological conditions in the research area, making it a valuable asset for decision making on different administrative levels. The inclusion of the biometeorological facet using thermal comfort indices specifically, allows for planning which addresses negative impact heat or cold stress may have on participants, especially athletes. The comparison of CTIS frequencies with meteorological observation data indicates the agreement between them, which proves it to be a good baseline for assessment of climate conditions when it comes to planning major events. In terms of managing future sport events, CTIS provides a tool for micro-managing their time frames, which generally tend to be well-placed in terms of combination of climate factors (due to familiarity with local conditions) and require assessment in 10-days or less resolution. These diagrams may also be adapted by local communities for tourism management purposes as they show the most favorable conditions for potential visitors.

Acknowledgments

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