Analysis of Thermal Comfort for Cycling Sport: A Case Study for Rio de Janeiro Olympic Games

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Abstract: As well known the meteorological and the environmental parameters (as wind, air temperature, rain, humidity, altitude, location, etc…) affect strongly the sport performance. Considering the recent literature on this topic, it is evident how the evaluation of the thermal comfort in the athletes is a crucial subject that has to be studied. In fact the thermal comfort of the athletes is not only linked with the sport performance but also with the safety of the athletes themselves. For these reasons in this research it is presented an innovative methodology to evaluate the thermal comfort of cycling athletes at the next Rio de Janeiro Olympic Games. This analysis is carried out for the Rio de Janeiro area considering the two venues for the cycling sport and for the two disciplines (Time Trial and Road Race). The meteorological data of two stations representative of the racing areas have been collected for a period of 20 years. They have been analyzed to produce the wind roses and to calculate two thermal indices: Predicted Mean Vote (PMV) and Physiological Equivalent Temperature (PET). The results of this research show the importance of the climatological analysis for optimizing the training and nutrition plans of the athletes.

1 INTRODUCTION

As shown in a previous paper (Pezzoli et al., 2015), the assessment of bio-climatological conditions and of thermal comfort in endurance sports, particularly in road cycling, is essential not only for a proper planning of the training program and the nutritional plan, but also for a better evaluation of the racing strategy or for the correct development and choice of the materials.

Among the meteorological variables that strongly influence the sport activity the most important ones are temperature, wind, precipitation, fog, atmospheric pressure and relative humidity.

In fact Brocherie et al. (2014) suggest how an integration of the combination of all relevant multidisciplinary data (i.e. thermal physiology, mathematical modelling, occupational medicine, biometeorology) would generate better application in an ecological sport science setting with potential impact on heat stress guideline management.

A deeper review about the emerging environmental and weather challenges in outdoor sports was held by Brocherie et al. (2015). The Authors show how the Universal Thermal Climate Index, also indicated by the abbreviation UTCI (Jendritsky et al., 2002), promises to be, in the next future, useful for the sport practitioners.

In fact the the operational UTCI procedure, classified into ten categories of thermal stress ranging from “extreme cold stress” to “extreme heat stress” (Brode et al., 2012), appears useful. It promises to assess the outdoor sport participants’ physiological responses to humidity and radiative loads in hot environments, as well as to wind in the cold.

Nevertheless Blazejczyk et al. (2012) illustrated how, in a comparison between UTCI and other bioclimatic indices, values most similar to those of UTCI were found for indices derived from human heat balance models as Physiological Equivalent Temperature (PET). Similarly to the UTCI, PET also is related to the equivalent temperature. The differences between the specific values of these two indeces result from the various structures of heat balance models and different definitions of reference conditions.

However Pezzoli et al. (2012) and Brocherie and Millet (2015) show how also the Predicted Mean

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Vote (PMV) can be used to characterize the thermal comfort in sport activities (respectively for cycling and tennis).

As shown by Brocherie and Millet (2015) the WBGT is indicated by numerous leading sports federations (e.g., Fédération Internationale de Football Association [FIFA], International Association of Athletics Federations [IAAF], International Tennis Federation [ITF]) as the index to be used to evaluate the thermal comfort during the sports activities. It is important to remember that this empirical index is computed from the reading of the dry-bulb temperature and two derived measures: the natural wet-bulb temperature and the black-globe temperature.

Moreover the same Authors, based on previous researches, denoted that incorporating newly available bioclimatic indices such as PMV instead of WBGT would considerably improve sport-specific heat stress modeling and current guidelines.

The main goal of this paper is to present an innovative methodology to evaluate the thermal comfort of the athletes considering PET and PMV indices for cycling sport. The analysis will be carried out for the Rio de Janeiro area considering the two venues for the cycling sport and for the two disciplines (Time Trial and Road Race).

This analysis will be developed considering the men's races. The developed statistical analysis will demonstrate how it is possible to characterize the thermal conditions of an athlete involved in a race. Finally this analysis can be used to develop the strategy's assessment of the race.

2 MATERIAL AND METHODS

2.1 Research Design

The research is developed analyzing:

- The geographical data of the race area with a particular focus on the tracks. For this analysis Google Earth is used as Open Access map system, as well as the free information available on Internet;
- The meteorological data (wind direction, wind speed, air temperature, relative humidity, cloud coverage). This computer supported analysis has been performed using the WindRose PRO3 software (Enviroware, 2015);
- The PET and the PMV thermal comfort indices. This part of research is also computer-supported through the RayMan software (Matzarakis et al. 2007, 2010).

2.2 Material

2.2.1 Geographical Data

To analyze the geographical data, the first step is searching the tracks that will be used for the two disciplines (Time Trial and Road Race) during Rio de Janeiro 2016 Olympic Games.

This information is provided by Union Cycliste International – International Cycling Union (UCI, 2015). In the UCI web-page it is possible to find the tracks for the two disciplines.

Then the tracks are georeferenced using Google Earth as Open Access map system (Figure 1).

2.2.2 Meteorological Data

The meteorological variables, needed for the analysis described in this study, are wind direction, wind speed, air temperature and relative humidity. The meteorological observations at surface have been obtained from the Jacarepagua and Santos Dumont weather stations, whose locations are shown in Figure 1. The distance between the two stations is about 22 km.

Weather data have been collected for the time period 1994-2014 (20 years). The meteorological data have been analysed filtering out all the values that were not measured in August, because the Olympic Games will be held in Rio de Janeiro between 5th and 21st August 2016.

Figure 1: Positions of the two meteorological stations. In the red box the zone of competence for the road races is indicated.

2.2.3 The WindRose PRO3 Software

A wind rose is a chart which gives a view of how wind speed and wind direction are distributed at a particular location over a specific period of time. This representation allows summarizing in a single plot a large quantity of data; therefore it is a very useful tool.

The wind roses presented in this work have been produced with the WindRose PRO3 software (Enviroware, 2015).

A time filter option allows analysing the wind data and produce wind roses only for particular years, months, days of the week or hours of the day. It is also possible to produce wind roses only for day or night hours, which are determined by the software itself starting from the geographical position and the time zone of the meteorological station. Monthly, hourly and three-hourly wind roses are automatically created by the software.

The WindRose PRO3 software has been used in many sectors: meteorology, architecture, air quality, oceanography, veterinary medicine, veterinary epidemiology, wind energy, climate, aquatic botany and agriculture. It has also been used for the analysis of sport performances (Pezzoli et al., 2013; Pezzoli and Bellasio, 2014).

2.2.4 The RayMan Software

The RayMan software (Matzarakis et al. 2007, 2010) is widely employed in bioclimatological studies applied to tourism activities and sport practices. Such software combines many heat transfer models with the heat sensation perceived in the human body. It generates universal scales of thermal sensation, which have large application in the outdoor sports like road cycling (Matzarakis et al. 1999; Brandenburg et al., 2007; Pezzoli et al., 2012). The input variables needed by the RayMan software are:

- Date, hour and location (longitude and latitude, altitude and time zone);
- Environmental and meteorological data like air temperature (°C), pressure (hPa), relative humidity (%), wind speed (m/s) and cloud covering (octas);
- Personal data about the subject (weight, height, age and sex);
- The heat transfer resistance of the clothing, according with UNI EN ISO 9920/2004 and the internal heat production (W), consequential to the physical activity of the subject.

The outputs of the model are the two bioclimatological indices (PMV and PET) which provide the thermal perception and the grade of physiological stress, as reported in Table 1.

The PMV predicts the normalized value of the thermal comfort of a large group of people exposed to similar environmental conditions, while the PET has detailed thermo-physiological basis taking into account the energy balance of the human body in relationship with climatic conditions.

Table 1: Thermal sensations according to PMV and PET values.

PMV	PET [°C]	Thermal perception	Grade of physiological stress
< -3.5	< 4	Very cold	Extreme cold stress
-3.5 - -2.5	4 - 8	Cold	Strong cold stress
-2.5 - -1.5	8 - 13	Cool	Moderate cold stress
-1.5 - -0.5	13 - 18	Slightly cool	Slight cold stress
-0.5 – 0.5	18 - 23	Comfortable	No thermal stress
0.5 – 1.5	23 - 29	Slightly warm	Slight heat stress
1.5 – 2.5	29 - 35	Warm	Moderate heat stress
2.5 – 3.5	35 - 41	Hot	Strong heat stress
> 3.5	> 41	Very hot	Extreme heat stress

2.3 Methods

2.3.1 The Evaluation of Meteorological Conditions for Cycling Sport

As well described by Pezzoli et al. (2012) the cycling sport is strongly influenced by the meteorological variables. The wind direction, as well as the wind speed, strongly influences the performance in the cycling sport.

A correct climatological analysis, taking into account this meteorological variable (wind), can be fruitfully used by the coaches and the athletes to:

- Decide the training program (physical and mental);
- Decide about the training site;
- Decide about the nutrition planning;
- Develop the material.

For what concerns the analysis of the wind direction, it is decided to analyse the "True Wind Direction" (TWD) failing to take into account the apparent wind generated by the speed of the bicycle. The TWD is measured in degrees considering the Geographical North. The wind roses (Section 3.2) are drawn considering a wind direction range of 30°.

Of course it is evident that also the air temperature and the relative humidity influence the performance in the cycling sport. In fact, as mentioned before, the thermal comfort indices are function of these two meteorological variables.

The typical day of each meteorological variable has been evaluated by using the WindRose PRO3 software. The hourly average wind direction, hourly average wind speed, hourly average air temperature and hourly average relative humidity as well as the hourly standard deviation for all of these meteorological variables are calculated in the typical day.

Finally the rain, evaluated in term of cloud coverage, is analysed and used as input in the RayMan model for the evaluation of the PET and PMV thermal indices.

2.3.2 The Evaluation of Thermal Comfort Conditions for Cycling Sport

The analysis of the thermal comfort was carried out considering the men's category.

The thermal comfort indices (PET and PMV) are evaluated for a target of athletes that represents an average professional "climbing and trialist" cyclist's categories (age: 27, height: 1,75m, weight: 65kg as suggested by Lucia et al., 2000).

It was decided to calculate the thermal comfort indices for each hour for a time interval included between 09.00LT ÷ 16.00LT. The input, for what concerns the meteorological variables, are the average of the meteorological variables corrected using the standard deviation.

Moreover the indices are calculated for two different conditions: restore and effort period. The internal heat production (W) is considered equal to 80W for the restore period and equal to 300W for the effort period (Pezzoli et al., 2012).

The heat transfer resistance of the clothing is considered equal to 0.6clo (corresponding to a light gym suit with a t-shirt) for the restore period and equal to 0.3clo (corresponding to a t-shirt and short pants) for the effort period.

3 RESULTS AND DISCUSSION

3.1 Analysis of the Venues for Cycling Sports in Rio de Janeiro 2016 Olympic Games

The venues for cycling sports are localized in two areas of Rio de Janeiro named Barra (Time Trial) and Copacabana (Road Race) as illustrated in Figure 2.

A more detailed geographical representation of the two different circuits is provided by UCI. Figure 3 illustrates the circuit of the Time Trial, for a total length of 54.5 km, while Figure 4 represents the circuit of the Road Race, for a total length of 241.5 km.

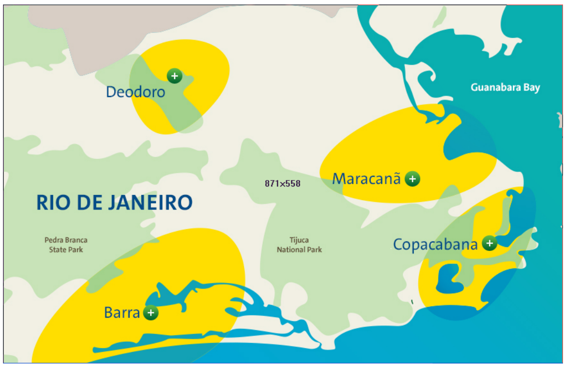

Figure 2: Location of the two areas for cycling sports in Rio de Janeiro (courtesy: Rio 2016 Organising Committee).

Comparing Figure 3 and Figure 4 with Figure 1 it is possible to observe that the selected weather stations are representative of both the circuits. Specifically the weather station of Santos Dumont is the reference for Copacabana area and the weather station of Jacarepagua is representative for Barra area.

It is also evident how the Time Trial race will be carried out in Barra region, while the Road Race will be held both in Copacabana (start and arrival) and in Barra region.

Figure 3: Time Trial circuit (courtesy: UCI).

Figure 4: Road Race circuit (courtesy: UCI).

3.2 Analysis of Meteorological Conditions in Rio de Janeiro in August

The wind roses are shown in Figure 5a, 5b, 5c, 5d and Figure 6a, 6b, 6c, 6d, respectively for the stations Jacarepagua and Santos Dumont. For each station the wind roses have been produced for the period 5-21 August and for four time intervals of the day: 09.00LT ÷ 11.00LT, 12.00LT ÷ 14.00LT, 15.00LT ÷ 17.00LT and 18.00LT ÷ 20.00LT.

At the Jacarepagua station the prevailing wind comes from the north eastern sector in the time interval 09.00LT ÷ 11.00LT, from the southern sector in the time periods 12.00LT ÷ 14.00LT and 15.00LT ÷ 17.00LT, and from the south western sector in the time interval 18.00LT ÷ 20.00LT. In all the time intervals wind speed from 1m/s to 3m/s interests about 40% of the observations, while wind speed greater than 5m/s interests about 5% ÷ 7% of the observations, with the exception of the time period 18.00LT ÷ 20.00LT where it is 2.3%. This last time interval is also characterized by a high value of calms (43%).

At the Santos Dumont station the prevailing wind comes from the northern sector in the time interval 09.00LT ÷ 11.00LT, and from the southern sector in the remaining time intervals.

In the first time interval wind speeds from 1m/s to 3m/s interest about 44% of the observations, in the second and fourth time intervals they interest about 25% of the observations, while in the third time interval they interest about the 10% of the observations. The third time interval is also characterized by the higher percentage of wind speeds greater than 5m/s (more than 30%) and by the lower presence of calms (3.5%).

Considering the positions of the weather stations (Figure 1), the pattern described by the wind roses is typical of the breeze regimes, with wind blowing from land to sea in the first hours of the morning, and in the opposite direction during the afternoon.

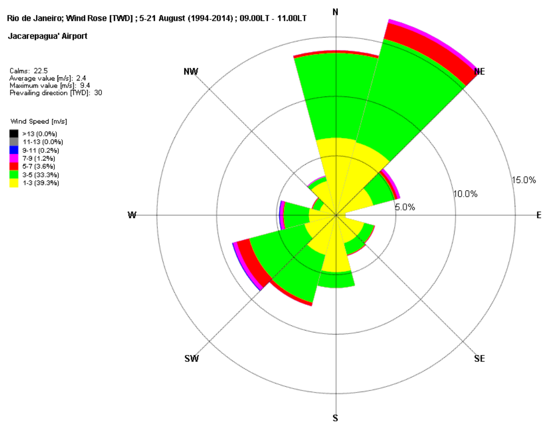

Figure 5a: Wind roses of the Jacarepagua station. Time interval: 09.00LT ÷ 11.00LT.

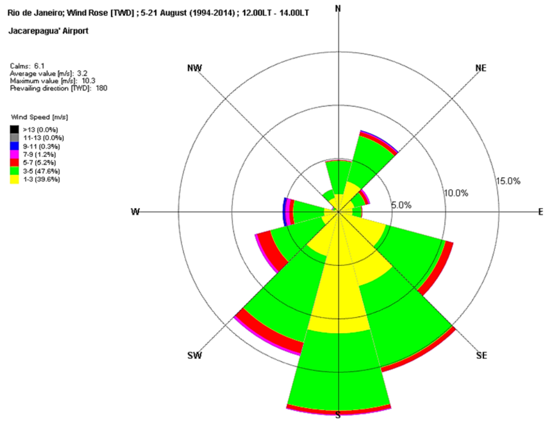

Figure 5b: Wind roses of the Jacarepagua station. Time interval: 12.00LT ÷ 14.00LT.

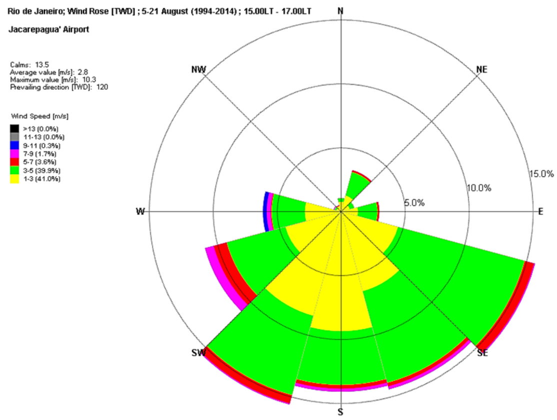

Figure 5c: Wind roses of the Jacarepagua station. Time interval: 15.00LT ÷ 17.00LT.

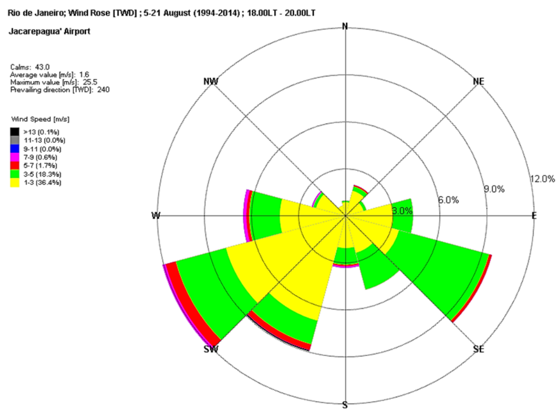

Figure 5d: Wind roses of the Jacarepagua station. Time interval: 18.00LT ÷ 20.00LT.

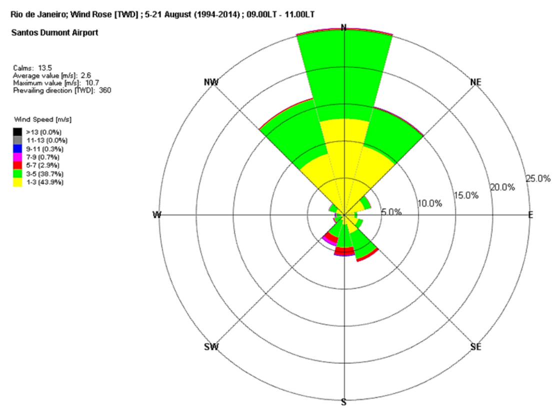

Figure 6a: Wind roses of the Santos Dumont station. Time interval: 09.00LT ÷ 11.00LT.

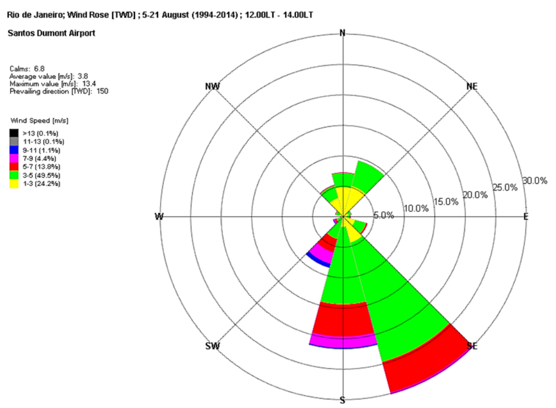

Figure 6b: Wind roses of the Santos Dumont station. Time interval: 12.00LT ÷ 14.00LT.

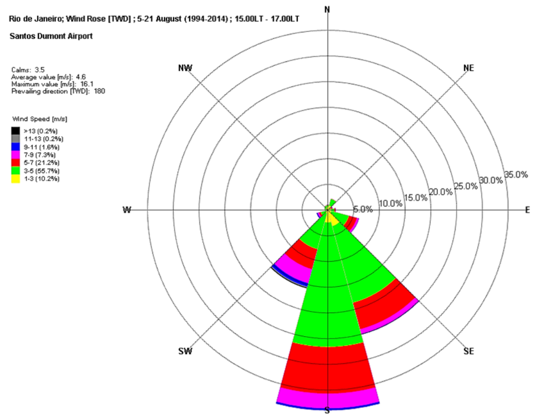

Figure 6c: Wind roses of the Santos Dumont station. Time interval: 15.00LT ÷ 17.00LT.

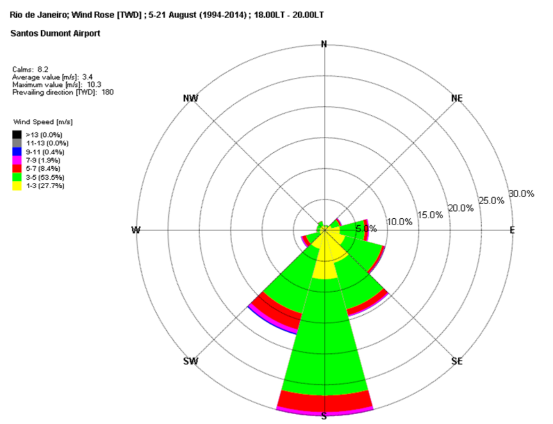

Figure 6d: Wind roses of the Santos Dumont station. Time interval: 18.00LT ÷ 20.00LT.

3.3 Analysis of Thermal Comfort in Rio de Janeiro in August for the Athletes of Cycling Sports

To analyze the thermal comfort in Rio de Janeiro the two tables, presented by Blazejczyk et al. (2012) and Brocherie and Millet (2015), are the reference. These tables show the heat-stress indices' temperature limits in reference to thermal sensation, alert description and recommended sporting activity.

Table 2 summarizes the above mentioned tables.

Figure 7 and Figure 8 illustrate the PET and PMV in the restore period for Copacabana and Barra areas (Section 2.3.2).

Observing Figure 7 and Figure 8, it is possible to note that around 12.00LT the thermal indices reach high values (PET = 27 ÷ 31°C ; PMV = 1.1 ÷ 1.7) for both the areas. It is also important to note that in Copacabana the values of the thermal comfort indices are lower than those obtained in the Barra area.

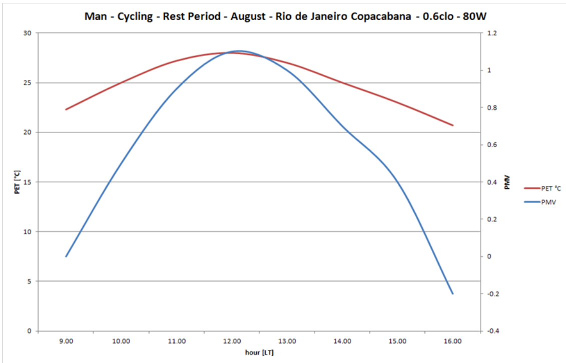

Figure 7: PET and PMV thermal indices in the restore period for Rio de Janeiro Copacabana area.

The maximum values of PET and PMV observed in Figure 7 and Figure 8 correspond to a warm thermal sensation and an alert description, as recommended for sporting activity for WBGT, equal to "caution".

Table 2: Selected heat—stress indices', temperature limits [°C] in reference to thermal sensations, alert description and recommended sporting activity. Modification of the tables of Blazejczyk et al. (2012) and of Brocherie and Millet (2015).

Thermal sensation	**Alert description[a]**	**Reccomended sporting activity[a]**	**Index**			
			WBGT[°C]	PET [°C]	PMV	UTCI[°C]
Neutral	Generally safe	Unlimited/normal activity	<18	18 ÷ 23	-0.5 ÷ 0.5	9 ÷ 26
Warm	Caution	Increase exercise-to-rest ratio. Decrease intensity and total duration of activity	18 ÷ 24[d]	23 ÷ 35	0.5 ÷ 2.5	26 ÷ 32
Hot	Extreme caution	Activity of unfit, unacclimatized, high-risk[b,c] subjects should be curtailed	24 ÷ 28	35 ÷ 41	2.5 ÷ 3.5	32 ÷ 38
Very hot	Danger	Activity for all except well acclimatized should be stopped	28 ÷ 30	>41	>3.5	38 ÷ 46
Sweltering	Extreme danger	Cancel or stop all practice and competition	>30[e]			>46

[a] Alert description/recommended sport activity for WBGT
[b] While wearing shorts, t-shirt, ankle socks and sneakers
[c] Internal heat production exceeds heat loss and core body temperature rises continuously without a plateau
[d] Threshold (WBGT = 21°C) recommended by marathon organization in northern latitutdes
[e] Threshold (WBGT > 30°C) recommended by most sporting governing bodies (i.e.: American College of Sport Medicine [ACSM], International Tennis Federation [ITF], Women's Tennis Association [WTA] and Fédération Internationale de Football Association [FIFA])

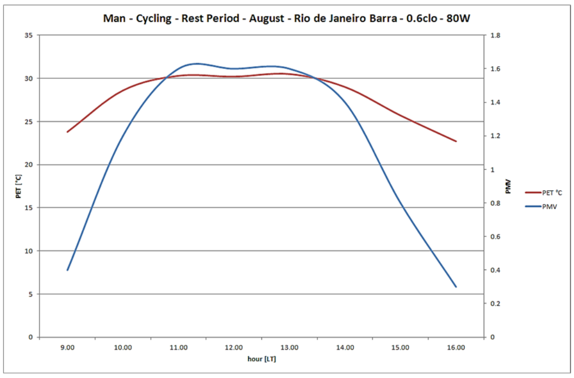

Figure 8: PET and PMV thermal indices in the restore period for Rio de Janeiro Barra area.

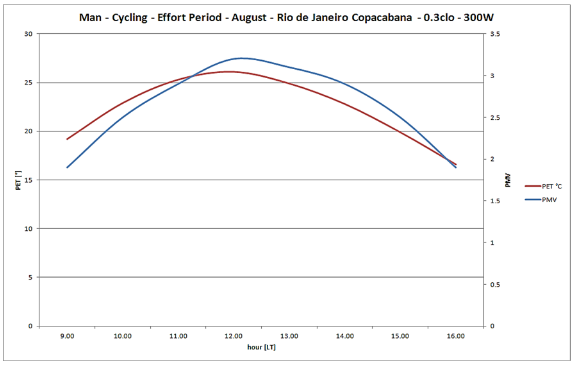

Figure 9: PET and PMV thermal indices in the effort period for Rio de Janeiro Copacabana area.

In the early morning, as well as in the afternoon, the indices show a comfortable situation from a thermal comfort point of view.

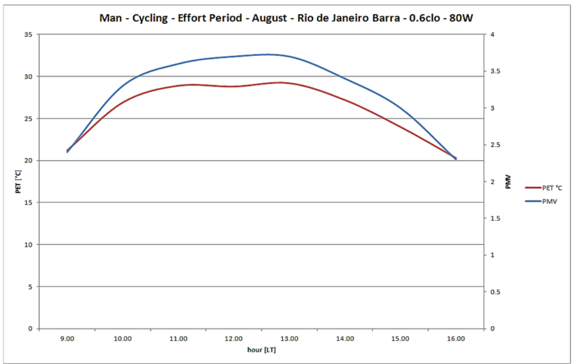

Figure 10: PET and PMV thermal indices in the effort period for Rio de Janeiro Barra area.

The values obtained in this analysis show that, in the restore period, the clothing suites are to be changed during the day moving from light gym suit with a t-shirt to t-shirt and short pants.

Finally, the PET and the PMV values in the effort period for Copacabana and Barra areas (Section 2.3.2) are shown in Figure 9 and Figure 10.

Also for the effort period, the maximum values of the PET and the PMV are confirmed between 12.00LT ÷ 13.00LT (PET = 27 ÷ 30°C; PMV = 3.2 ÷ 3.7).

It is possible to note as the PET values during the effort period are similar to the PET values during the restore period. These results are function of a correct choice of clothing that the athletes have to use during the race and the restore period (Section 2.3.2).

However the PMV values in the effort period are higher than the PMV values of the restore period. Generally it is possible to observe as the maximum values of the PET and PMV indices correspond to a "caution – extreme caution" alert description recommended for sporting activity for WBGT.

The same recommendations show that, in these conditions, it is important to increase the exercise-to-rest ratio as well as to decrease the intensity and the total duration of activity. In the same time it is very important that the athletes are well acclimatized and that they prepare a correct plan and strategy for nutrition and hydration (pre-event, event, post-event).

4 CONCLUSIONS

The analysis of the thermal comfort of the athletes during the next Rio de Janeiro Olympic Games, made with an innovative methodology, is presented in this research. The calculations have been carried out for the men's category of the cycling sport. The meteorological data of a 20-year long period have been collected for two monitoring stations that are representative for the race areas (Time Trial and Road Race). The data of the months of August have been analyzed in order to create the wind roses and the typical days of the main variables. Two thermal comfort indices (PET and PMV) have then been calculated considering also the clothing type and the power generated during the exercise. They have been determined for the time period 09-16 LT and for the resting and effort phases of both races.

It is important to note how the presented methodology can be generalized to other sport as well as to other venues. In fact the presented RayMan model takes into account the personal data about the subject (weight, height, age and sex) as well as the internal heat production (W) consequential to her/his physical activity.

Then it will be possible to change these reference data to adapt the methodology and the model to the analysed sport.

Finally, in the future, it will be interesting to quantify the thermal comfort of the athletes measuring directly the skin's temperature and the skin's humidity of the athletes (Pezzoli et al., 2012). This innovation in the research will help to quantify correctly the thermal comfort and to improve the alert description and the recommended sporting activity (Table 2).

For these reasons, the procedure described in this study gives useful information about the most suitable clothing type for affording the race. The results are also useful for defining pre, during and post-race nutrition and hydration plans.

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