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Thermal comfort investigation of an outdoor air-conditioned area in a hot and arid environment

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Thermal comfort in hot and arid outdoor environments is an industrial challenging field. An outdoor air-conditioned area was designed and built to host sport and social events during summers 2014 and 2015 in Qatar. This article presents a thermal comfort analysis of the outdoor air-conditioned area using computational fluid dynamics, on-site spectators surveys, and on-spot climatic measurements. The study utilized computational fluid dynamics to develop a thermal comfort model of the outdoor air-conditioned area to predict the thermal comfort of the occupants. Five different thermal comfort indices; mean comfort vote, cooling power index, wet-bulb globe temperature index, Humidex, discomfort index, were utilized to assess the thermal comfort of spectators within the conditioned space. The indices utilized different on site measurements of meteorological data and on-site interviews. In comparison to the mean comfort vote of the sampled survey, all thermal comfort indices underestimated the actual thermal comfort percentage except the wet-bulb globe temperature index that overestimated the comfort percentage. The computational fluid dynamics results reasonably predicted most of the thermal comfort indices values. The computational fluid dynamics results overestimated the comfort percentage of mean comfort vote, wet-bulb globe temperature index, and discomfort index, while the thermal comfort percentage was underestimated as indicated by the cooling power index, and Humidex.

Introduction

Thermal comfort in hot and arid environments

The human perception of thermal comfort is a challenging field since many factors contribute to the final estimation. Multiple environments lead to multiple thermal sensations because of the variety of microclimatic data. Wan et al. (2008) highlighted the dynamics of the environmental factors affecting thermal comfort. Indraganti (2010a) argued that the individual is an active member of the environment. Therefore, an individual thermal comfort can be determined by two factors. Namely, the body and its surrounding environment. Once one factor is altered, then an adjustment should be made to preserve the thermal equilibrium (Alahmer et al. 2011). Humphreys and Nicol (2002) and Nicol and Humphreys (2002) suggested that "if a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort" (p. 992). Although, this adaption may be conscious or unconscious (Holopainen et al. 2014). Clothing insulation also affects thermal comfort since garments and the body are in a continuously dynamic condition (Huang 2006). Choi et al. (2012) suggested that since these two factors affect thermoregulation, an individuals' heart rate can be considered as an additional index for thermal comfort. Gender subjective thermal comfort was shown by Parsons (2002) to be related to their clothing styles, fabrics, and trends. The author noticed that women generally evaluate their thermal sensation cooler than men in cold environments. The Arabian traditional garments can provide adequate insulation for optimal thermal comfort under hot and arid conditions (Al-ajmi et al. 2008).

During the summer season, optimal comfort sensation is achieved when the ambient dry-bulb air temperature is between 22.5°C–26°C and the wet bulb is at 20°C (ANSI/ASHRAE 55 1995). For the Mediterranean coastal climate of Tel Aviv in Israel, Cohen et al. (2013) argued

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that neutral thermal sensation ranges within 20°C–25°C of the physiologically equivalent temperature (PET). In Hungary, Kántor et al. (2012a) calculated the neutral PET range to be 18°C–23°C with visitors prefer the climate to become cooler when PET measured higher than 29°C. For tropical and humid climates, there is an important shifting of the PET range toward higher values. Indraganti (2010b) defined a comfort range ambient air temperature of 26°C–32.45°C for the humid climate of India, setting the temperature of neutral thermal comfort at 29.23°C. In other tropical countries, such as Bangladesh, where humidity is normally higher than 70%, the thermal comfort range included high ambient air temperatures 28.5°C and 32°C (Ahmed 2003). In Colombo, Sri Lanka, the PET comfort range was found to be 27.5°C–32.5°C (Johansson and Emmanuel 2006). For Taiwan, three different studies revealed similar findings. Kántor et al. (2012b) determined the comfort range to be 21.3°C–29.8°C PET and Lin and Matzarakis (2007) at 24.2°C–32.8°C PET for 85% acceptability with neutral temperature set at 27.2°C. Lin (2009) investigated the same region for both cold and hot season during April 2007 through February 2008 and determined the thermal acceptable range to be 21.3°C–28.5°C PET. Neutral PET temperatures were calculated to be 23.7°C for the cool period and 25.6°C for the hot period.

Researches also highlighted the importance of the climate background of the individual for describing the personal thermal acceptability. Knez and Thorsson (2006) interviewed individuals from Sweden and Japan for describing their thermal sensation under the same range of PET (18°C–23°C). Results showed that Japanese participants addressed their thermal sensation to be warmer than the Swedish participants, indicating higher thermal discomfort. Similar findings regarding different thermal comfort were assessed by Nikolopoulou and Lykoudis (2006). The authors argued that neutral temperature was calculated to be 23°C for Athens (Greece) and 13°C for Fribourg (Switzerland).

Outdoor thermal comfort, apart from climate conditions and clothing, is also affected by the urban planning of the region. For outdoor conditions, humans are exposed to different thermal aspects such as Urban Heat Island effect (UHI; Santamouris 2014). Arid regions are characterized by low precipitation (Shepherd 2006) and elevated rates of evaporation (Razo et al. 2004). Le Houérou (1996) determined the maximum mean rainfall to be 150–450 mm per year while (Martin 2006) argued that there are periods where the amount can be less than 50 mm for 2 years. Qatar has an arid desert-like climate, characterized by hot summers, scarce precipitation, and warm winters with mean relative humidity (RH) ranging from 43% in June to 72% in December (Ghani et al. 2017). Highest historical recorded values of rainfalls vary from 0–155.4 mm for June and December, respectively (CAA 2013). In arid environments, Shashua-Bar et al. (2011) investigated how vegetation affects the sense of comfort neutrality concluding that shade and grass irrigation contributes to advanced thermal acceptability. In China, Xi et al. (2012) argued that specific design of campuses facilities can lower ambient temperature by 3°C, setting the thermal comfort temperature at 24°C standard equivalent temperature (SET). To enhance outdoor thermal comfort utilization of shaded areas from plantation or buildings are recommended. Cheng et al. (2012) set neutral outdoor air temperature under shade to be 28°C for high levels of RH (80%) for subtropical Hong Kong.

Semi-outdoor environments can be considered as outdoor areas where the environmental parameters can be partially controlled by roof constructions for insulation from solar radiation, partitions for wind protection or supplementary HVAC supply (Nakano and Tanabe 2004). The authors investigated neutral SET for nonHVAC and HVAC areas. For the summer period, the temperatures were found to be 26.9°C and 25.6°C, respectively, indicating that individuals are more tolerant and have lower expectations from non-mechanically controlled environments. Such lower neutral temperature in colder outdoor or semi-outdoor areas can be explained by thermal adaption (Hwang and Lin 2007). The tolerance toward neutral temperature depends on additional reasons. Fiala et al. (1999) simulated Australia's main Olympic Stadium and revealed that lack of air circulation and ventilation in shaded seating areas can cause higher thermal discomfort than well-ventilated unshaded seating areas. Bouyer et al. (2007) underlines the segregation of the convective heat transfer between standing and seating positions when simulating stadia, because of the contact of the plastic chair with the body that can be considered as an extra clothing insulation factor. The authors visualized through virtual reality platform "EVE" two stadia, Stade de France in France and the Atatürk Olympic stadium in Turkey. Higher PET values where noticed during the afternoon period rather than noon period, mainly due to the heat trapped under the stadium roof. The authors concluded that the perceived thermal comfort in such structures mainly depends on the roof shape and the thermal inertia and properties of the stadium, rather than the incident solar radiation.

This study is divided into two parts. The first part describes the utilization of computational fluid dynamics (CFD) to develop a thermal comfort model of the outdoor air-conditioned area (FANZONE) suitable for hot and arid environment to predict the thermal comfort of the occupants. The second part refers to the FANZONE thermal comfort assessment by utilizing five different indices that describe and define thermal comfort. The indices utilize different on-site measurements of meteorological data such as temperature, RH, and wind speed. To define optimal outdoor conditions, subjective levels of thermal sensation such as thermal comfort and personal satisfaction were defined. In addition, objective thermal indices including mean comfort vote (MCV), cooling power index, wet-bulb global temperature (WBGT) index, Humidex, and discomfort index (DI) were analyzed. Finally, the CFD results were validated against thermal comfort survey analysis.

Thermal comfort indices

Five different thermal comfort indices based on microclimate data; namely MCV, cooling power index, WBGT, Humidex, and DI; were used to gauge atmospheric environment effects on human body heat regulating mechanisms. Table 1 summarizes the indices and their thermal sensation categories. On-spot measurements, such as air temperature, humidity, and wind speed, were recorded to calculate these factors.

Table 1. Thermal comfort indices and description.

Discomfort index (°C)		Cooling power index (mcal/cm²s)		Humidex °C		WBGT (°C)		MCV	
<21	No discomfort	<5	Hot	$H < 27$	Comfortable	<24°C	No risk	−3	Cold
21–24	Under 50% of the population feels discomfort	5–10	Mild	$27 \le H < 30$	Some discomfort	24°C–29.3°C	Moderate	−2	Cool
24–27	Over 50% of population feels discomfort	11–15	Cool	$30 \le H < 40$	Great discomfort	29.4°C–32.1°C	High	−1	Slightly cool
27–29	Most of population suffers discomfort	16–22	Cold	$40 \le H < 55$	Dangerous	≥32.2°C	Extreme	0	Neutral
29–32	Everyone feels stress	23–30	Very cold	$H \ge 55$	Heat stroke imminent			1	Slightly warm
>32	State of medical emergency	>30	Extreme cold					2	Warm
								3	Hot

Therefore, these factors represent a suitable quantitative determination of the stress level.

MCV index

Thermal comfort is directly related to the predicted mean vote index (PMV) which is a 7-point ASHRAE scale that describes the thermal sensation of the individual in a given environment. Namely, neutral sensation as 0 level,+3 as hot, +2 as warm, +1 as slightly warm, −1 as slightly cool, −2 as cool, and, finally, −3 as cold. D'Ambrosio Alfano et al. (2011, 2013), categorized the six parameters that affect PMV index into subjective (clothing thermal insulation and the metabolic rate) and physical (air temperature, mean radiant temperature, air speed, and air humidity). Consequently, the physical factors that define PMV are related to the local climate. Fabbri (2013) measured the predicted percentage of Dissatisfied (PPD) using questionnaires specially designed to gauge children's personal assumptions.

MCV, as shown in Equation 1, is related to the individual's thermal sensation (Adunola 2014). To calculate the daily MCV, the summation of the product of the thermal sensation votes and the number of responses is divided by the total number of respondents. The classification of the participants' comfort votes were based on PMV as proposed by ASHRAE.

$$\mathrm{MCV} = \frac{\sum thermalSensation \times votes}{\mathrm{Re}spondents}. \tag{1}$$

Cooling power index

Landsberrg (1972) defined the cooling power index, as shown in Equation 2, as an evaluation of human comfort sensation in means of dry-bulb temperature and wind speed. Balaras et al. (1993) used Vinje's formula to calculate the dry cooling power and defined its range. Although, according to Aynsley (1990), the wind speed factor is not dominant. Nevertheless, the wind speed still affects the thermometer data and more analytical relations should be applied to define outdoor thermal comfort. The author determined cooling power index range as "hot" when values are below five, "mild" when the index is between 5–10, "cool" for 11–15 values, "cold" for 16–22, "very cold" for the range of 23–30, and "extreme cold" when values exceed 30 mcal/cm^2 s.

$$H = (0.37 + 0.51 * V^{0.63}) * (36.5 - T), \tag{2}$$

where H = cooling power index (mcal/cm^2 s), V = wind speed (m/s), and T = dry-bulb temperature (°C).

WBGT index

Introduced by Yaglou and Minaed (1957) to investigate deaths related to heat illnesses in U.S. Military Training Centers, since then, WBGT met wide acceptance by researchers (Bernard et al. 2005; Buonanno et al. 2001; Lemke and Kjellstrom 2012; Montain et al. 1999; O'Connor and Bernard 1999). WBGT is officially adopted by the U.S. Army, the World Health Organization (WHO) and the National Institute for Occupational Safety and Health (NIOSH 1986). In 1982, it was approved by the ISO organization as an international standard for heat load assessment. The index was adopted for assessing heat stress levels in Brazil World Cup 2014 (Nassis et al. 2015). Rowlinson et al. (2014) described the WBGT index as the measurement of how hot the environment is according to the individual's senses. Sakoi and Mochida (2013) described the index as the heat storage rate of the human body. Evaluation of WBGT index must take into account activities and clothing of the individuals (Budd 2008). Burr (1991) described the equations to calculate WBGT with and without solar radiation (Equations 3–4).

$$\mathrm{WBGT} = 0.7\mathrm{T_w} + 0.2\mathrm{T_G} + 0.1\mathrm{T_a}, \tag{3}$$

$$\mathrm{WBGT} = 0.7\mathrm{T_w} + 0.3\mathrm{T_G}, \tag{4}$$

where WBGT = wet-bulb globe temperature (°C), $\mathrm{T_w}$ = wet-bulb temperature (°C), $\mathrm{T_G}$ = global temperature (°C), and $\mathrm{T_a}$ = dry-bulb temperature (°C).

In this research, Equation 4 was applied since the FANZONE occupancy time was at evening. $\mathrm{T_{globe}}$ was estimated as the dry-bulb temperature as proposed by Lemke and Kjellstrom (2012). Kolokotsa et al. (2009) defined the comfort categories of the WBGT index concluding to the higher limit of the WBGT index as 26.6°C, under which the population generally feels comfort. If the index exceeds 32°C, occupants may face health hazards. Football players whose metabolic rate is higher than six (Constantinou et al. 2009) are considered for a high risk of thermal injury when WBGT is over 29.3°C. Similar methodology was applied to working environments by Hyatt et al (2010) for indoor or outdoor conditions under shade in Australia for metabolic rate more than two.

Humidex

Humidex is an index introduced by Canadian meteorologists in order to quantify the perceived thermal discomfort of a person for outdoor climate conditions and activities (Crowe 1975). It has been applied to heat waves studies (Anderson and Bellb 2009; Conti et al. 2005, 2007; Giannopoulou et al. 2014). The combined effect of temperature and humidity leads to representative assumptions about thermal discomfort conditions. Rana et al. (2013) utilized the index to measure indoor thermal comfort and concluded its reliability of prediction in environments with high humidity. Researchers combined Humidex with the mortality rates (Barnett et al. 2010; Barnett and Astrom 2012; Rainham and Smoyer-Tomic 2003). The Humidex is used to assess children's health in outdoor areas as they are more easily affected by extreme values of ambient climate conditions (Vanos 2015).

Humidex is expressed in °C, and is always higher than ambient temperatures. Equation 5a and 5b was developed by the Canadian Center for Occupational Health and Safety to calculate Humidex. Humidex values ranges were determined by Masterton and Richardson (1979) to be 20°C–29°C as comfortable, 30°C–39°C as some discomfort, 40°C–45°C as great discomfort and over 45°C as dangerous with high possibility of heat strokes.

$$H = T + \frac{5}{9} * (e - 10) \tag{5a/5b}$$

where H = Humidex, T = dry-bulb temperature (°C), and e = atmospheric pressure of water vapor (mm Hg).

DI

As proposed by Thom (1959), DI is used for measuring and evaluating the effective temperature (Kandjov et al. 2003). The DI advantage over other indices lies in its simple calculation equation (Tselepidaki et al. 1992), as shown in Equation 6, since it only depends on temperature and humidity. The DI values can be combined with increased air pollution which lead to assess rates of mortality (Katsouyanni et al. 1993). Its maximum values are observed during summer months at daytime (Poupkou et al. 2011). When DI is calculated less than 21 "no discomfort" is observed to the population. For values between 21–24 "under 50% of the population feels discomfort," for DI between 24–27 "over 50% of population feels discomfort," for 27–29 "most of population suffers discomfort," between 29 and 32 "everyone feels stress," and for values over 32 there is "state of medical emergency."

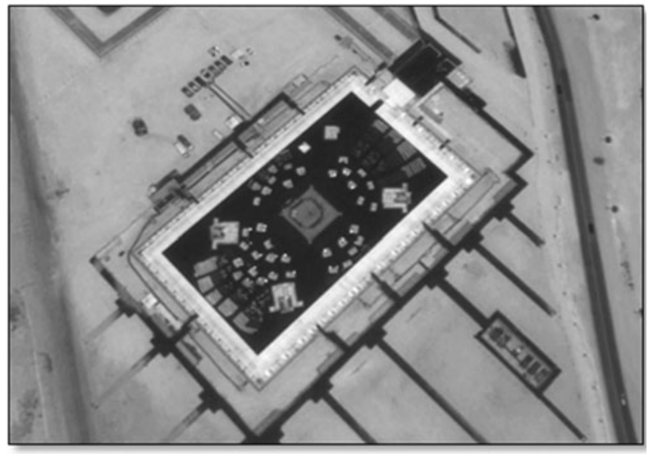

Fig. 1. ASPIRE FANZONE satellite location (longitude 25.271932, latitude: 51.459758).

$$\mathrm{DI} = T - (0.55 - 0.005 * \mathrm{RH}) * (T - 14.5) \tag{6}$$

where DI = discomfort index (°C), RH = relative humidity (%), T = dry-bulb temperature (°C).

Aspire FANZONE

Located in the state of Qatar, Aspire FANZONE is an outdoor cooled area that was specially developed and built to provide spectators with the chance to watch 2014 FIFA World Cup Brazil (Figure 1). As shown in Figure 2, the FANZONE is a rectangular shaped area of 126 × 74 m^2 surrounded by a 7 m fiberglass reinforced plastic (GRP) walls. The area is completely uncovered and has multiple access points for spectators and services.

Four large LED screens were placed on a 1 m height stage at the center of the pitch area surrounded by chairs, sofas and traditional seating, various food stalls, and shops as shown in Figure 3. Hybrid DX and evaporative cooling units were used to provide cold air through air discharge nozzles placed

Fig. 2. FANZONE inside view.

Fig. 3. ASPIRE FANZONE activities.

internally around the FANZONE perimeter as shown in Figure 4.

The study was conducted for a period of two summers, 2014 and 2015, covering two large events. The FANZONE was utilized for the public to watch the 2014 FIFA World Cup Brazil between the 4th and the 13th of July 2014 where it received around 7000 spectators at the final game. It was then utilized in the following summer for a longer period, between June 22 and July 5, 2015, during "Fereej Aspire" event, where it received more than 22,000 visitors during the course of the event. This period is described as the "hot season" with an average local dry-bulb temperature of 34°C and 46% RH recorded at the FANZONE occupancy time.

Developing the FANZONE CFD thermal comfort model

FANZONE computational domain

As shown in Figure 5, the FANZONE geometry of 126 × 74 m^2 with barrier height of 7 m was positioned in a computational domain of 560 × 200 × 350 m^3. A stage of 1 m height supporting four big LED screens was located at the center of the cooled area. Conditioned air was supplied at 14°C and 13 m/s by 263 ball jet nozzles of 200 mm diameter placed on

Fig. 4. FANZONE air discharge nozzles.

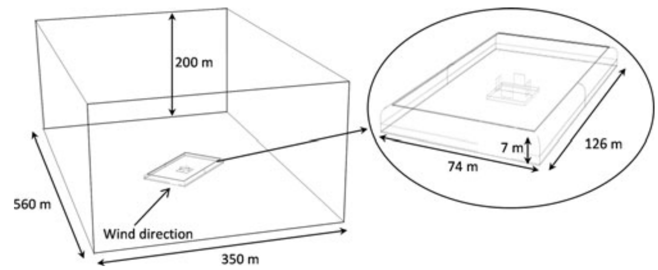

Fig. 5. FANZONE CFD model.

the inner surrounding barrier at a height of 0.275 m from the ground. The simulated walls material was GRP which represents the actual configuration of the walls properties.

FANZONE computational mesh

More than 8,000,000 tetrahedral cells with a growth rate function of 1.1 were used to model the FANZONE. A fine mesh was utilized near the discharge air nozzles and a coarser mesh was utilized further away as shown in Figure 6. The total number of cells was selected according to a mesh independency study to ensure that the numerical solution results do not depend on the model mesh size, quantity, or type.

FANZONE numerical model

The developed computational FANZONE model is accurately mimicking the structure and features of the designed FANZONE. CFD code ANSYS Fluent version 14.0 was used in order to examine the flow field and the distribution of temperature and RH within and around the FANZONE. The energy equation and species transport models were considered in the CFD model to reflect the actual heat transfer and RH levels, respectively. Moreover, the standard k-ε model was

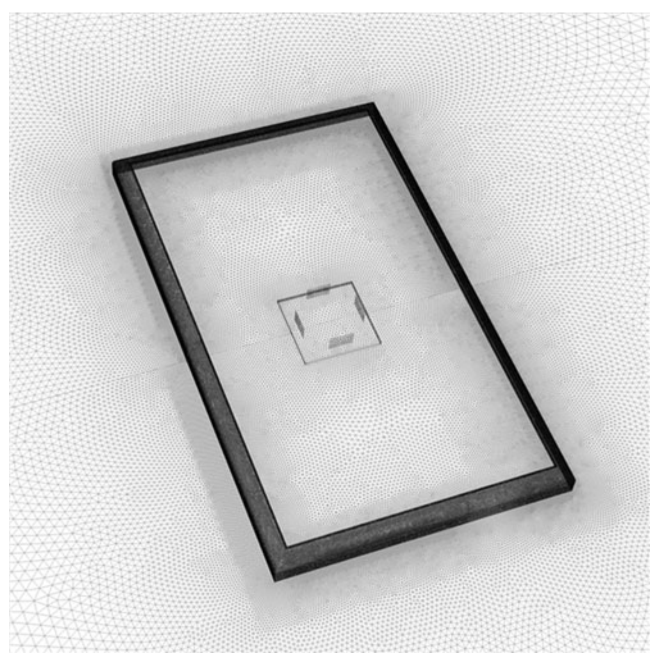

Fig. 6. FANZONE computational mesh using growth function starting from the air discharge nozzles.

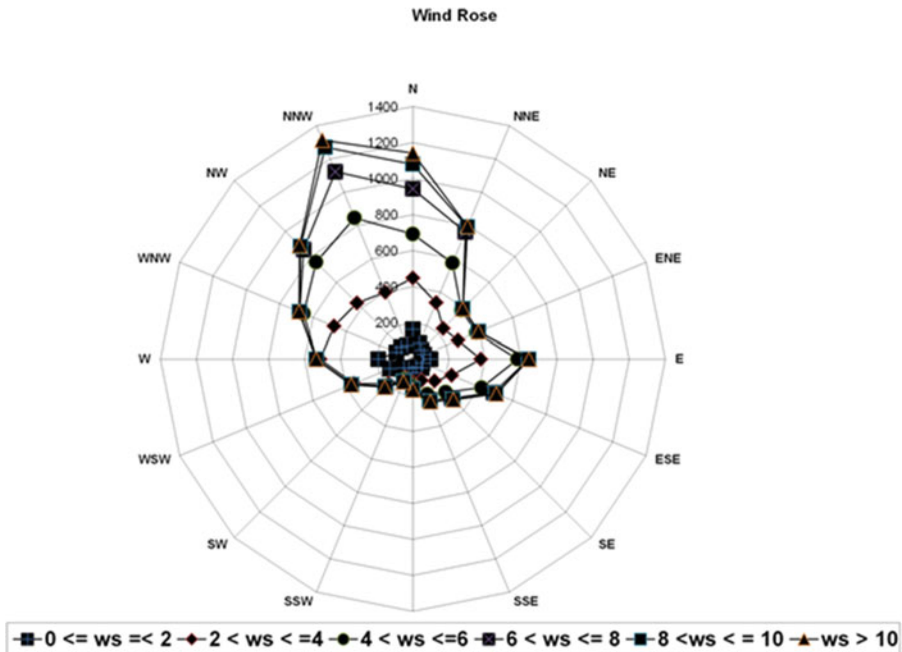

Fig. 7. Wind rose at the FANZONE location.

used to analyze the airflow characteristics within the FANZONE. It was developed by Launder and Spalding (1974) to compound the large gradients in the solution variables at the near wall region with the wall bounded flow. Since it represents a good compromise for a realistic description of turbulence and computational efficiency (Jones and Whittle 1992), standard k-ε was used for comparative parametric studies comparison. The reliability of the standard k-ε model was examined for the prediction of natural ventilation by (Linden 1999) and was evaluated in real size systems by (Drori et al. 2005; Drori and Ziskind 2004; Ziskind et al. 2002).

Boundary conditions

For the purpose of the CFD simulation, the FANZONE barrier was set in the solver to have a zero heat flux. The air supply discharge nozzles were simulated as velocity inlet boundary condition with 13 m/s air speed, 14°C air discharge temperature, and 13% RH. These values were measured during the on-site measurements of the utilized air-conditioning system. The turbulence intensity was assumed to be 5% which is relevant to different industrial applications. Figure 7 shows Qatar typical frequency of occurrence (wind rose) for each of the 16 wind directions as provided by Qatar Meteorological Department. The maximum value of different months' average wind speed was measured to be 3.5 m/s in the prevailing wind direction of NNW. Furthermore, the maximum ambient temperature of the summer season was recorded at 45°C.

CFD thermal comfort prediction

Prediction of weather conditions

Ambient dry-bulb temperature, wind speed, and RH have dominant effect on outdoor microclimate. The CFD model was used to calculate the temperature and relative humidty contours within the FANZONE. Table 2 shows three different cases that were investigated by the FANZONE CFD model. The three cases utilized the maximuim recoreded ambient dry-bulb temperature, maximuim on-site recoreded ambient dry-bulb temperature RH, and the prevailing wind speed to describe the weather conditions. The ambient dry-bulb temperature values were varied between the maximum recorded ambient temperature of 45°C, as obtained from Qatar historical measured weather data, and the maximum FANZONE on-site ambient temperture of 35°C. The prevailing incident wind speed was varied between a maximum value of 5.5 m/s and an average value of 2 m/s, respectively.The RH values varied in respect to each case. As the second case utilizes the maximum measured on-site ambient temperature during the FANZONE occupancy period on the August 28, 2015, it was considered the benchmark case. Hence, the five thermal comfort indices were only calculated for this case.

Case A: Boundary conditions of maximum recorded ambient dry-bulb temperature and wind speed

An ambient dry-bulb temperature of 45°C, 40% RH, and incident wind speed of 5.5 m/s were simulated in this case. The temperature and RH contours within the FANZONE are shown in Figures 8 and 9, respectively. Both contours are displayed on a horizontal plane covering the FANZONE at height of 1 m above the ground.

Figure 8 shows the indoor ambient temperature contours in the air-conditioned FANZONE under the effect of the highest recorded outdoor ambient temperature and wind speed obtained from Qatar historical measured weather conditions of 45°C and 5.5 m/s, respectively. As shown in Figure 8, the temperatures inside the FANZONE ranged between 20°C near the discharge nozzles and 42°C within the stage area. Similarly, the average RH within the FANZONE

Table 2. Simulated FANZONE CFD cases.

CFD case	Ambient dry-bulb temperature (°C)	Relative humidity (%)	Wind speed (m/s)	Remarks
CASE A: Maximum recorded ambient dry-bulb temperature and wind speed.	45	40	5.5	
CASE B: Maximum on-site measured ambient dry-bulb temperature during FANZONE occupancy period.	35	27	5.5	Benchmark case
CASE C: Maximum recorded ambient dry-bulb temperature and average wind speed.	45	40	2	

was approximately 66%. The high temperature zones near the stage area are expected as the stage is positioned at the furthest distance from the cold-air discharge nozzles.

Case B: Boundary conditions of maximum on-site ambient dry-bulb temperature during FANZONE occupancy period

During the FANZONE occupancy at the two consequent summers, the maximumx outdoor dry-bulb temperature measured on site was 35°C (Table 3). Figures 10 and 11, respectively show the temperature and RH contours in a horizontal plane covering the FANZONE at height of 1 m above the ground. Ambient indoor temperatures ranged from 19°C to 23°C in 70% of the FANZONE area as depicted by the temperature contours. RH had an overall average value of 65% within the FANZONE. The highest values of temperature were generally recorded within the stage area since it was furthest away from the cold-air discharge nozzles.

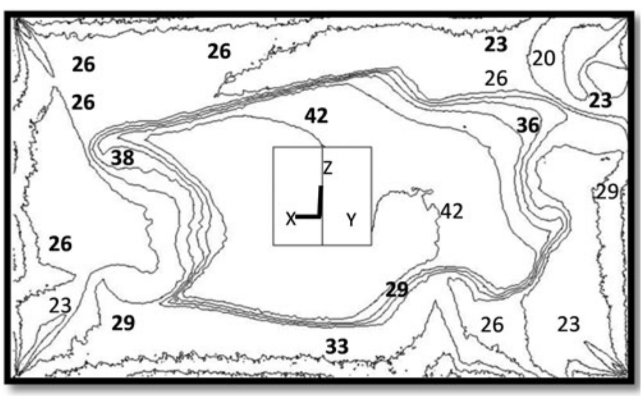

Fig. 8. Temperature (°C) contours at the FANZONE.

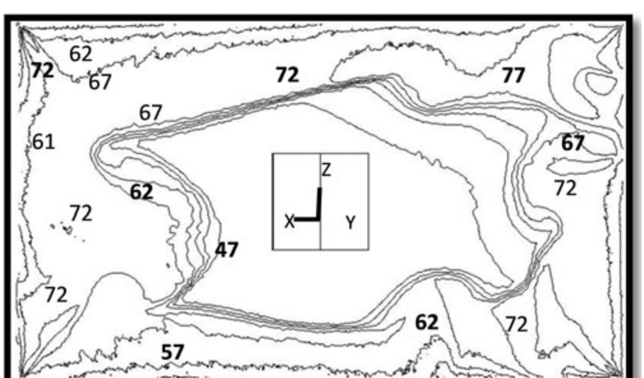

Fig. 9. Relative humidity (%) contours at the FANZONE.

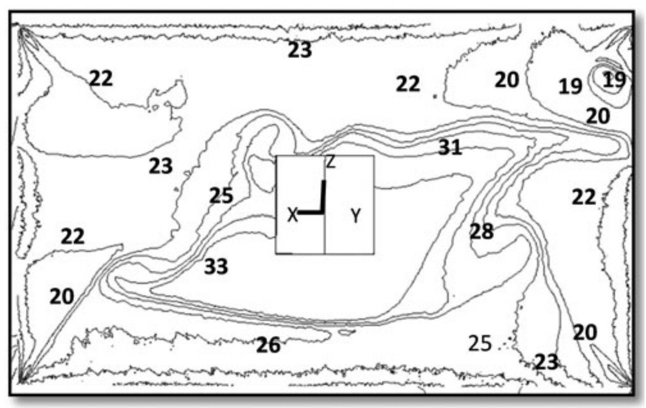

Fig. 10. Temperature (°C) contours at the FANZONE.

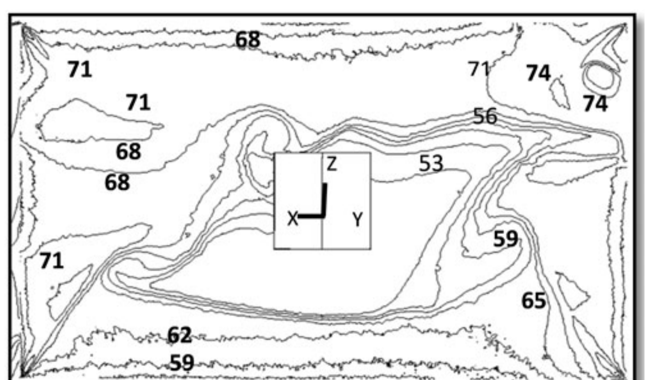

Fig. 11. Relative humidity (%) contours at the FANZONE.

Table 3. Microclimate data.

	Dry-bulb temperature		Wet-bulb temperature		Wind speed		Humidity	
Days	FANZONE	Outdoor	FANZONE	Outdoor	FANZONE	Outdoor	FANZONE	Outdoor
4/7/14	24.74	35.05	19.7	28.89	1.23	1.71	63.09	46
5/7/14	31.25	33.63	27.7	30.99	1.6	1.98	76.41	76.7
9/7/14	22.65	34	16.79	26.47	1.78	2.04	55.62	35.4
10/7/14	22.86	33.6	16.2	25.12	3.85	1.41	50.53	26.8
12/7/14	28.63	32.75	23.24	27.72	2.05	2.43	63.62	54.3
13/7/14	23.31	34.7	17.14	26.5	2.24	1.69	54.27	31.4
25/6/15	25.73	37	20.55	25.55	0.05	3.9	42.22	12
26/6/15	24.75	34.67	20.3	25.29	0.24	1.56	48.51	22
27/6/15	24.14	34.67	20.6	26.05	0.35	1.67	58.01	28
28/6/15	32.92	35	25.57	26.49	3.61	1.39	34.72	29.5
30/6/15	28.86	34	23.93	26.67	0.2	3.61	49.77	37
1/7/15	27.84	33.5	23.83	26.16	0.33	2.5	57.59	36
2/7/15	25.4	32.3	21.91	29.09	0.19	1.58	60.16	70
3/7/15	32.24	32.8	29.24	29.64	0.05	1.76	71.86	71
4/7/15	32.43	32.5	29.93	30.14	0.4	1.94	76.65	78
5/7/15	32.22	33.3	27.64	30.74	0.46	1.94	58	77

Case C: Maximum recorded ambient dry-bulb temperature and average wind speed

For the case of average recorded wind speed of 2 m/s and highest recorded temperature of 45°C, the temperature and RH contours are shown in Figures 12 and 13, respectively. As shown in Figure 12, the temperature distribution within the FANZONE is nearly uniform with an average temperature of 21°C. Similarly, an average RH value of 73% was calculated by the CFD under the same conditions. This shows the determintal effect of wind infiltration in disturbing the microclimate conditions of the FANZONE.

Prediction of thermal comfort indicies by CFD

The utilization of CFD in thermal comfort analysis helped to predict the thermal comfort of the FANZONE occupants. In this study, the CFD results were used to calculate five different thermal comfort indices. Namely, MCV, WBGT index, Humidex, cooling power index, and DI. The predicted thermal comfort indices were validated against survey results collected from attendees. As the weather parameters were measured on site, Case B boundary conditions were used for all the CFD indices prediction studies. The CFD is used to calculate the values of the thermal comfort indices by utilizing a user defined function (UDF) for each index. On-site surveys only covered limited zones of the entire FANZONE area. By utilizing the CFD study, more than 216,000 measuring points in the CFD model were used to calculate the average indices values compared to the number of surveyed participants.

CFD predicted the MCV index

CFD was used to predict MCV for the FANZONE occupants by utilizing the simplified PMV equation that was developed by Fanger in 1970 and is presented by García (2010):

$$\mathrm{PMV} = \left(0.303 \cdot e^{-0.036 \cdot M} + 0.028\right) L, \tag{7}$$

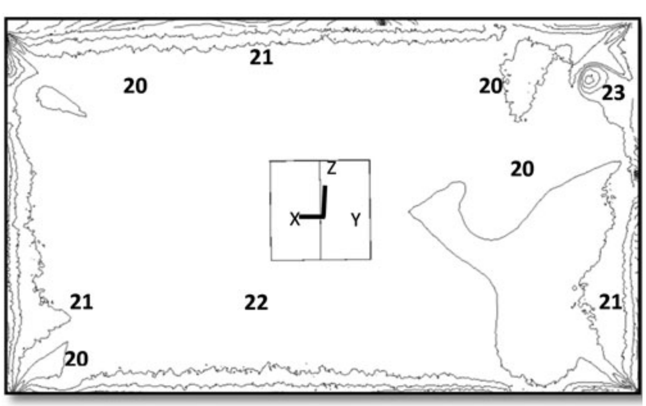

Fig. 12. Temperature contours (°C) at the FANZONE.

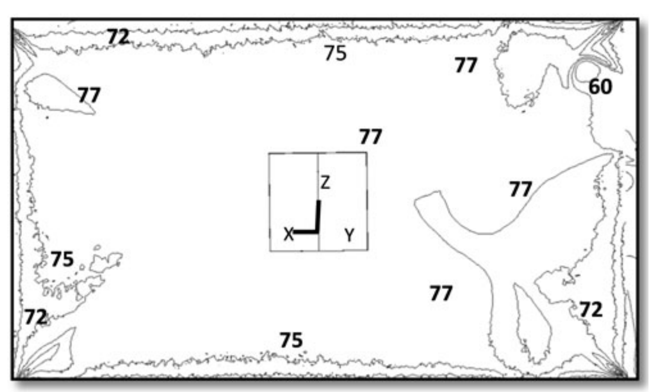

Fig. 13. Relative humidity (%) contours at the FANZONE.

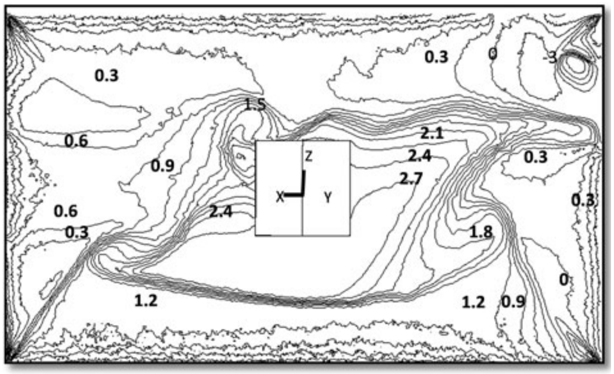

Fig. 14. MCV contours at a horizontal plane at $Y = 1$ m.

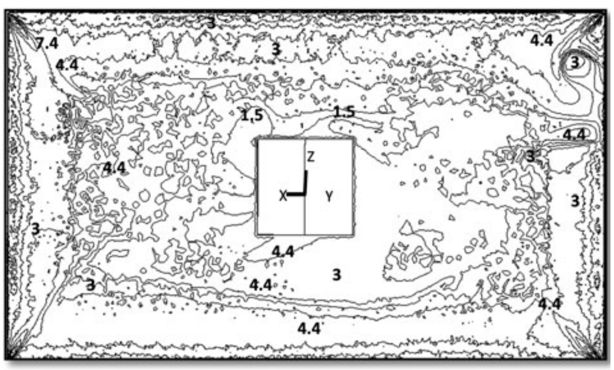

Fig. 15. Cooling power index (mcal/cm^{2}s) contours at the FANZONE.

where M = rate of metabolic heat production (W/m^2) and L = heat load (W/m^2).

The average values of metabolic rates are found in ASHRAE Handbook of Fundamentals or in the published literature such as (Bradshaw 2006) based on occupants activity. Similarly, heat load by occupants in the conditioned areas are obtained from ASHRAE pocket guide for air-conditioning, heating, ventilation, refrigeration. As shown in Figure 14, the average value of MCV index within the FANZONE is 2, indicating a warm thermal sensation. The maxiumum and minimum MCV values were 3.3 and −0.85, respectively. These values are refered as hot and cool thermal sensation, respectively. Higher values of MCV were generally located within the stage area reflecting a general feeling of discomfort. In contrast, lower values of MCV were generally recorded in the cooler areas near the vicinity of the cold-air discharge nozzles, especially around the FANZONE corners.

CFD predicted cooling power index

Cooling power index indicates the coldness of a zone. Equation 2 was embeded in the CFD model as a UDF in order to calculate the cooling power index. As shown in Figure 15, the colder areas around the FANZONE corners were noticed to have the higest cooling power index of 7.4 mcal/cm^{2}s indicating a mild coldness thermal sensation. On the other hand, the relatively hotter centeral stage area was shown to have the minimum cooling power index of 0.37 mcal/cm^{2}s, indicating a hot thermal sensation.

CFD predicted WBGT index

Several WBGT index calculation methods were reviewed by Lemke and Kjellstrom (2012). A simpler approach used by Dimiceli et al. (2011) and Burr (1991) showed that for outdoor conditions with no solar load, WBGT can be calculated using Equation 4. In order to estimate the value of the wet-bulb temperature in Equation 4, the empirical inverse solution developed by (Stull 2011) was used. Similarly, the method of (Dimiceli et al. 2013) was used to calculate an estimated value of the black globe temperature. A UDF was embedded in the CFD model to calculate and display the WBGT contours. As shown in Figure 16, the WBGT values ranged from a minimum of 27°C near the cold-air discharge nozzles to a maximum of 32°C within the stage area. The average predicted value was 31°C. Higher values of WBGT give a general feeling of discomfort as it indicates an increase in both wet-bulb temperature and globe temperature.

CFD predicted Humidex

Equation 5 was embedded in the CFD model to calculate and display the Humidex contours. Predicted Humidex values as shown in Figure 17, vary notably within the FANZONE. The average predicted Humidex value of 29°C indicates a small discomfort thermal sensation. Colder areas near the cold-air discharge nozzles were shown to have the minimum Humidex value of 16.1°C indicating a comfort state. In contrast, the relatively hotter centeral area recorded a maximum Humidex value of 35°C which is considerd to be within the discomfort zone.

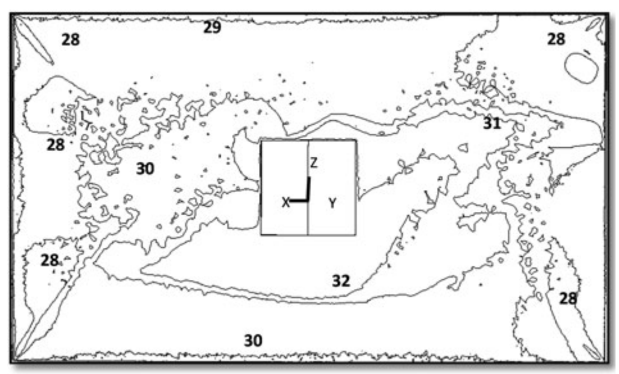

Fig. 16. WBGT contours (°C) at the FANZONE.

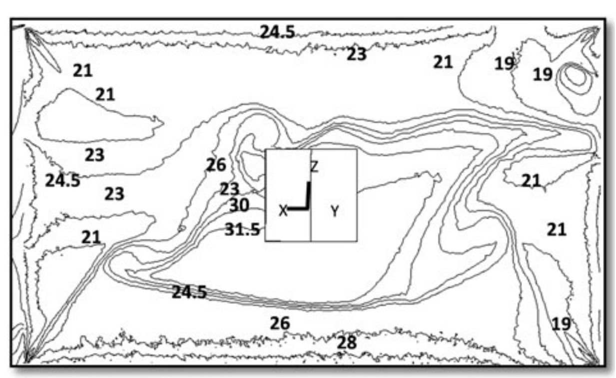

Fig. 17. Humidex contours at the FANZONE.

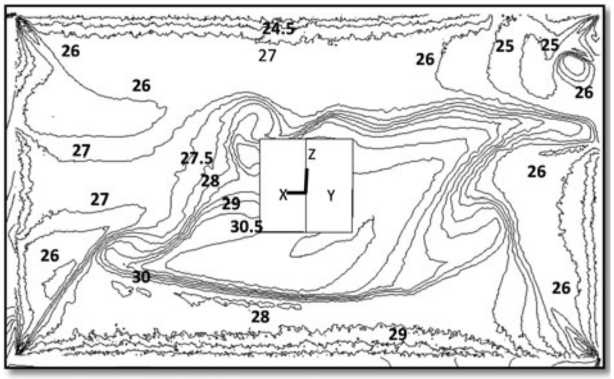

Fig. 18. Discomfort index (°C) contours at the FANZONE.

Table 4. Age and gender distribution.

Age	Male	Female	Total	%
<18	10	18	28	6.8
18–25	73	40	113	27.8
26–35	94	75	169	41.5
36–45	41	35	76	18.7
46–55	7	7	14	3.5
56–65	5	2	7	1.7
66–75	0	0	0	0
>76	0	0	0	0
Total	230	177	407	100

CFD predicted DI

The DI equation of Thom (1959) was used as a UDF in the CFD model to calculate the FANZONE DI. Predicted DI shown in Figure 18 is a thermos-hydrometric index for discomfort. The average recorded value of DI was recorded to be 29°C which is referred within the discomfort zone. The cooler areas next to the cold-air discharge nozzles have the minimum value of DI of 24.2°C indicating a higher comfort rate. On the other hand, maximum DI value of 31°C was predicted in the hotter area next to the central stage indicating a higher percentage of occupants under thermal stress.

Measured data analysis

Field survey and measuring tools

An overall of 407 participants were interviewed as 192 during summer 2014 and 215 during summer 2015. The surveys were focused on nonathletes adults sitting for approximately 2 h and did not perform any physical exercise prior to taking the survey. Thus, the exposure to the specific environmental conditions was long enough to define their thermal comfort condition. The main objective is to combine temperature and relative humidity in terms of population's comfort zone. The vast majority of the sample (over 95%) indicated no health problems such as asthma or recent surgeries. Thus, it is assumed that the recorded thermal sensation was not affected by any medical factors. The clothing insulation of men was 0.36–0.61 clo and for those wearing the traditional Arab cloth (Thob) was 1.05–1.23 clo while for women, the thermal clothing insulation is 0.57–0.61 clo and for those wearing the traditional women dress (Abaya) was 1.19–1.24 clo (Al-ajmi et al. 2008; ASHRAE 55:2004 2004). The survey selected a representative sample that accurately reflects the entire residents in Qatar. A total of 407 participants were interviewed face-to-face. The participants were 230 men and 177 women with the percentage distribution to be 56% and 44%, respectively. Eight out of ten of the participants for 2014/2015 summers were from the Middle East and North Africa (MENA) region and Asia which are considered to be relatively familiar with the local hot and arid climatic conditions. The rest of the individuals came from different climatic backgrounds such as Europe, North America, and Africa. Gender and age distribution of the survey's sample is presented in Table 4. The dominant age group among both genders was 26–35-years-old with the 18–25-year-old age group following. At the time of conducting each survey, a simultaneous on spot measurement of dry-bulb temperature, humidity, and wind speed was carried out close to the interviewees at a height of 1.7 m from the ground. The utilization of bilingual survey language (English and Arabic), allowed a better audience participants and assessment. All data collected, both physical and microclimatic, were examined through survey analysis and analytically compared with previous researches. Each face-to-face interview lasted approximately 2 min, to answer 12 questions divided in two parts. In order to define the demographic data and the thermal insulation of respondents, the first part consisted of personal questions. This included age, gender, nationality, and type of clothing. The second part included individuals' perception about thermal comfort according to ASHRAE 55:2004 and McIntyre scale (Ogoli 2007), the acceptance of a potential climate change and their level of satisfaction at different zones in the FANZONE. Participants were also asked to state any recent activities performed before their presence at the FANZONE, such as meal consumption within the previous 2 h, exercise (gym, swimming pool), and/or smoking. Exercise can affect human thermal sensation due to an increased metabolic rate (Ashley et al. 2008). The selection and the structure of the questionnaire was in line with published research in the field (Cheong et al. 2003; Ealiwa et al. 2001; Fountain et al. 1996; Noh et al. 2007; Sharples and Malama 1997; Zhang and Zhao 2008). The English version of the questionnaire can be found in Appendix 1.

Measured microclimatic data

The microclimate data of the study area and ambient conditions were defined by temperature, RH, and wind speed. Microclimate data outside the FANZONE were obtained from eight meteorological stations situated at the perimeter. On-site dry-bulb temperature measurements were obtained from a hand-held airflow meter. Wet-bulb temperature is the adiabatic saturation temperature and was calculated according to Thom (1959). All climatic data are included in Table 3 and the statistical description is presented in Table 5.

Table 5. Statistical analysis of microclimate data.

	Mean	SD	Min	Max	CoV %
Dry-bulb temperature °C	27.5	3.76	22.6	32.9	13.7
Wet-bulb temperature °C	22.8	4.4	16.2	27.9	19.2
Humidity %	57.56	11.43	34.7	76.7	19.8
Wind speed (m/s)	1.16	1.24	0.05	3.85	

As illustrated in Table 5, the coefficient of variation (CoV) in the FANZONE is 13.7% and 19.8% for dry-bulb temperature and humidity, respectively, and are described by high heterogeneity. According to Musat and Helerea (2009), the optimal thermal sensation is achieved when humidity is about 50%. Ng and Cheng (2012) claimed that a wind speed of 1–1.5 m/s is needed for humans to remain at a neutral thermal comfort in hot and humid climates. Dry-bulb temperature, wet-bulb temperature, and humidity inside and outside the FANZONE are depicted in Figures 19 and 20.

Results and discussion

Results analysis

The results are divided in two categories. Namely, participants survey results and calculated thermal comfort indices.

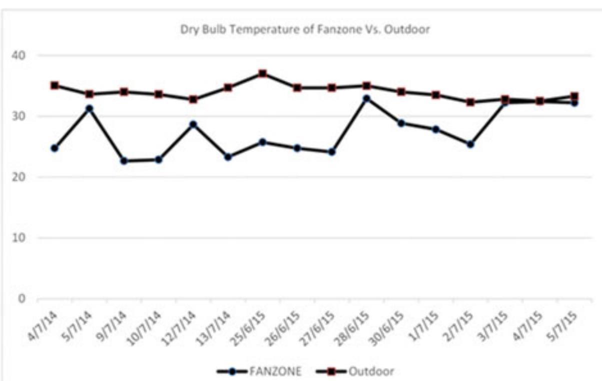

Fig. 19. Dry-bulb temperature (°C) FANZONE versus outdoor.

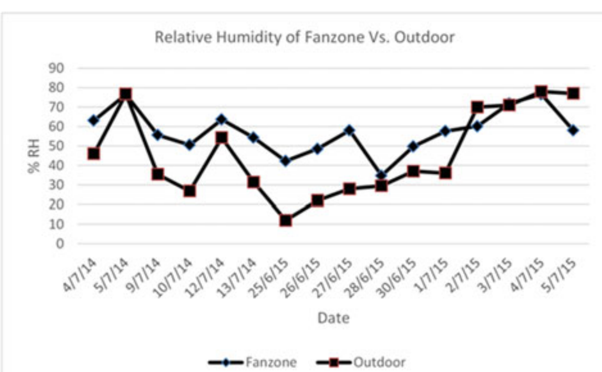

Fig. 20. Relative humidity (%) FANZONE versus outdoor.

Survey results

The surveys' thermal sensation description and microclimate change preference results are depicted in Figure 21. More than 70% of the participants stated that they felt neutral, indicating no climate change. Approximately 95% of those who were feeling hot wanted the climate to become cooler. This is in line with published literature as people tend to restore their thermal comfort (Humphreys and Nicol 2002; Nicol and Humphreys 2002; Zhang and Zhao 2008).

As shown in Figure 22, the FANZONE was divided into four zones identify the locations of potential dissatisfaction by the participants.

Distribution of the satisfaction votes by zones is shown in Figure 23. The second zone has approximately similar positive satisfaction votes compared to Zone 3, but Zone 3 presents more negative votes especially on the dissatisfied level. Zone 1 has the maximum satisfaction level ("very satisfied") with Zone 4 following, as the infiltration wind shielded the cold air inside the FANZONE.

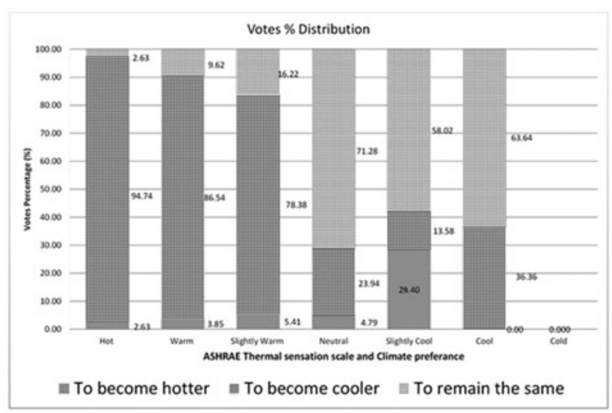

Fig. 21. Thermal comfort and climate change distribution.

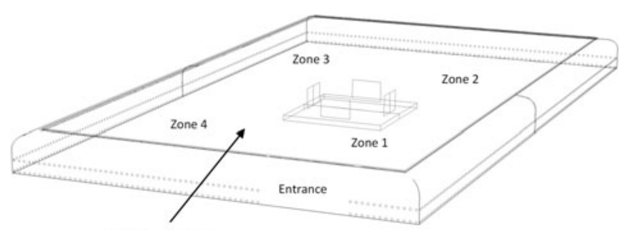

Fig. 22. FANZONE zoning scheme.

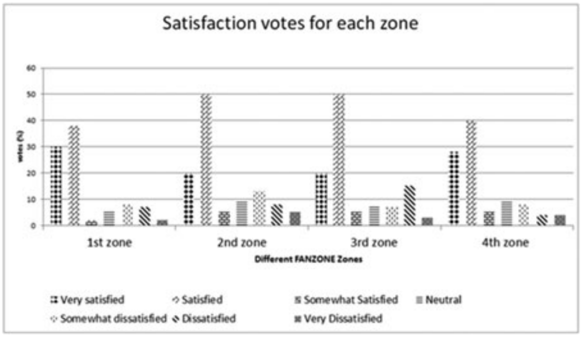

Fig. 23. Distribution of satisfaction votes per zone.

Thermal comfort indices

Table 6 summarizes the values and the categories of the calculated five thermal comfort indices.

Calculated MCV index. Equations relating outdoor temperature and RH with MCV as proposed by (Adunola 2014) were calculated as in Equations 8 and 9, respectively. R^2 values indicate stronger relation of MCV with temperature rather than humidity. The results are in line with literature (Humphreys 1976) where comfort votes present higher weightiness with temperature, rather than RH.

$$\mathrm{MCV_T} = 0.1875 \times \mathrm{T} - 4.6691 \left(R^2 = 0.553\right), \quad (8)$$

$$\mathrm{MCV_{R.H}} = 0.0575 \times \mathrm{RH} - 2.821 \left(R^2 = 0.481\right), \quad (9)$$

where T = dry-bulb temperature (°C), RH = relative humidity (%).

By setting 0 to MCV in Equations 7 and 8, neutral temperature and humidity were calculated to be 24.9°C and 49.01%, respectively. Neutral temperature indicates the temperature which individuals state their thermal sensation as neutral (Fountain et al. 1996). The findings agreed with previous researches. Giannopoulou et al. (2014) set the range of comfortability at 21°C–27.5°C dry-bulb temperature and 30%–65% for RH and ASHRAE (2004) set the range at 20°C–26°C of effective temperature. Neutral sensation equal to 0 though, is indicative, since for thermal sensation outside the three central categories of the ASHRAE scale can still reflect comfort sensation (Brager et al. 1993). As a result, human's optimal thermal sensation is not mandatory to be set at 0 point indicating the importance of individual's special adaption.

In the presented sample, the dominant thermal sensation was described as "slightly warm" for 7 days of the research (43.75%) following with "slightly cool" descriptions for 4 days (25%). "Warm" and "hot" thermal sensation were referred as 2 days (12.5%) with only 1 day (June 26, 2015) to be "neutral." Average thermal sensation was described as "slightly warm" (MCV = 0.49).

Calculated cooling power index. The cooling power index was calculated to be "mild" for 7 days (43.75%), with "hot" description following with 5 days (31.25%). "Cool" and "cold" days were two (12.5%) with the lowest value on July 4th (2.67) described as "hot." The highest cooling power index was on July 10, 2014 (21.31) described as "cold." The average value of the cooling power index was 7.92 mcal/cm²s with "mild" description.

Calculated WBGT index. Out of a total of 16 days of the study, 50% were described as "no risk" with July 10, 2014 being the day with the lower WBGT value. Six days (37.5%) were of "moderate" risk the highest value to be measured on July 5, 2015 (29.01°C). The two rest days (12.5%), presented the highest WBGT values of the research, 30.14°C on July 3, 2015 and 30.68°C on July 4, 2015, and were described with "high risk." Average WBGT value was calculated to be 24.19°C with "no risk" description.

Calculated Humidex. Out of a total of 16 days of the study, 6 days (37.5%) were referred as comfortable for the spectators, with the lowest value to be measured on July 10, 2014 (25.11°C). Five days (31.25%) were described as days with "some discomfort," 2 days (18.75%) with "great discomfort," while "dangerous" was 3 days (18.75%) with the highest value of 47.57°C measured on July 4, 2015. The average value was 31.08°C classified as "some discomfort."

Calculated DI. Three of the days were described as "no discomfort" and 5 days (31.25%) where less than half of the population was feeling discomfort. At 4 days (25%), more than 50% of the respondents were feeling discomfort, with the same percentage of days where most of the population was feeling discomfort. Lowest DI value was measured on July 10th (20.37°C) and the highest one on July 4th (29.44°C). The average value was 24.15°C and described as "less than half of the population was feeling discomfort."

Since the utilized five thermal comfort indices are based on different thermal comfort scales, they present different comfort and discomfort classification ranges. In order to create a common thermal comfort description, only two criteria were considered. Namely, comfort criterion and discomfort criterion. Table 7 shows the selected comfort and discomfort scale for each thermal comfort index.

Using the categorization criteria presented in Table 7, the percentage of thermal comfort acceptance was calculated for the five indices. As the MCV is directly obtained from the on-site surveyed participants, it was considered as the benchmark index to compare the other four mathematically calculated indices, as shown in Figure 24.

Figure 23 shows that cooling power index, Humidex, and DI underestimated the thermal comfort acceptance by 38%, 25%, and 25%, respectively. On the other hand, WBGT index overestimated the thermal comfort acceptance by 6%. The comparison presented in Figure 23, shows a difference between the thermal description concluded by the thermal comfort indices and by the on-site survey results. This can be justified by the high influence of personal factors such as metabolic rate, clothing, and gender on subjective preferences such as thermal satisfaction which are not taken into consideration by the thermal comfort indices. Furthermore, most of the utilized thermal comfort indices empirical equations do not include the effect of wind speed for thermal comfort assessment. That, if considered, affects the comfort feeling, which in turn, increases the general climate acceptance to the occupants. This was noticed by Bady (2014) who used Robaa index which accounts for the combined effects of the

Table 6. Summary of thermal comfort indices.

Date	WBGT description	Cooling power description	Humidex description	Discomfort index description	MCV ASHRAE description
7/4/14	21.21 No risk	11.18 Cool	30.09 Some discomfort	22.34 (°C) < 50% of population discomfort	− 0.43 Slightly cool
7/5/14	28.76 Moderate	5.538 Mild	45.00 Dangerous	28.44 (°C) Most of population suffers discomfort	1.15 Warm
7/9/14	18.55 No risk	15.27 Cool	25.59 Comfortable	20.43 (°C) No discomfort	−0.26 Slightly Cool
7/10/14	18.2 No risk	21.313 Cold	25.11 Comfortable	20.37 (°C) No discomfort	−0.68 Slightly cool
7/12/14	24.85 Moderate	9.23 Mild	36.90 Great discomfort	25.35(°C) >50% of population discomfort	0.55 Slightly warm
13/7/14	18.99 No risk	16.05 Cold	26.37 Comfortable	20.86 (°C) No discomfort	0.24 Slightly warm
25/6/15	22.1 No risk	4.82 Hot	27.9 Comfortable	21.92 (°C) <50% of population discomfort	−0.40 Slightly cool
26/6/15	21.64 No risk	6.79 Mild	28 Comfortable	21.60 (°C) <50% of population discomfort	0.09 Neutral
27/6/15	21.66 No risk	7.83 Mild	28.26 Comfortable	21.63 (°C) <50% of population discomfort	0.40 Slightly warm
28/6/15	27.78 Moderate	5.42 Mild	37 Some discomfort	25.99 (°C) >50% of population discomfort	0.14 Slightly warm
30/6/15	25.41 Moderate	4.24 Hot	34.26 Some discomfort	24.54(°C) >50% of population discomfort	0.14 Slightly warm
1/7/15	25.03 Moderate	5.40 Mild	34.24 Some discomfort	24.34 (°C) >50% of population discomfort	0.35 Slightly warm
2/7/15	22.96 No risk	6.10 Mild	30.67 Some discomfort	22.68 (°C) <50% of population discomfort	0.30 Slightly warm
3/7/15	30.14 High	1.91 Hot	45.9 Dangerous	28.86 (°C) Most of population suffers discomfort	2.73 Hot
4/7/15	30.68 High	2.67 Hot	47.57 Dangerous	29.44 (°C) Most of population suffers discomfort	2.31 Hot
5/7/15	29.01 Moderate	2.92 Hot	42.1 Great discomfort	27.61(°C) Most of population suffers discomfort	1.28 Warm
Average values	24 No risk	7.92 Mild	31.08 Some discomfort	24.15 >50% of population discomfort	0.49 Slightly warm

three weather elements; ambient dry-bulb temperature, RH, and wind speed; when assessing thermal human comfort.

Validation of the CFD model

For validation, a comparison between thermal comfort indices obtained from the survey results and CFD simulations were compared. The thermal comfort indices obtained from the CFD simulations are independent from the survey results as they were only calculated by the CFD governing equations. Similarly, thermal comfort indices obtained from survey analysis were calculated based on the on-site measurements during the collection of questionnaires.

Table 7. Thermal indices categorization criteria.

Thermal comfort index	Comfort criterion	Discomfort criterion
MCV	Slightly cool, neutral, slightly warm	Cold, cool, warm, hot
WBGT	No risk	High risk
cooling power index	Mild, cool	Cold, hot
Humidex	Comfortable	Some discomfort, great discomfort, dangerous, heat stroke imminent
Discomfort index	No discomfort, less than half of the population feels discomfort	More than half of the population feels discomfort, most of the population suffers discomfort, everyone feels severe stress, state of medical emergency.

The comfort levels of each thermal index of the previous section were compared against the survey data. Considering the second benchmark CFD case of the maximum on site temperature during occupancy period, thermal comfort results were compared against the days which recorded maximum ambient temperature within the FANZONE. The average comfort percentage of each index was calculated based on the thermal indices scale provided in Table 7. In addition, the average comfort percentage of the survey data was based on the average comfort percentage of each index at the same days. Figure 25 shows the comfort percentage comparison between the CFD simulations and survey results.

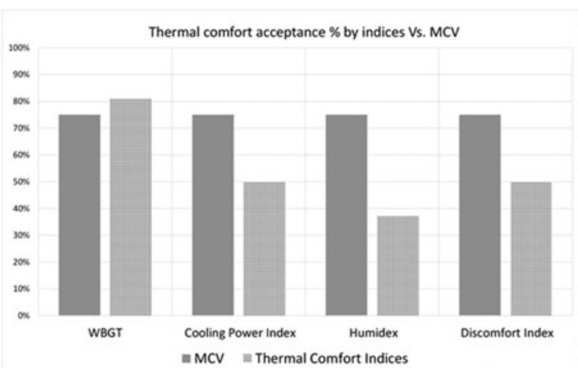

Fig. 24. Thermal comfort acceptance by indices versus MCV.

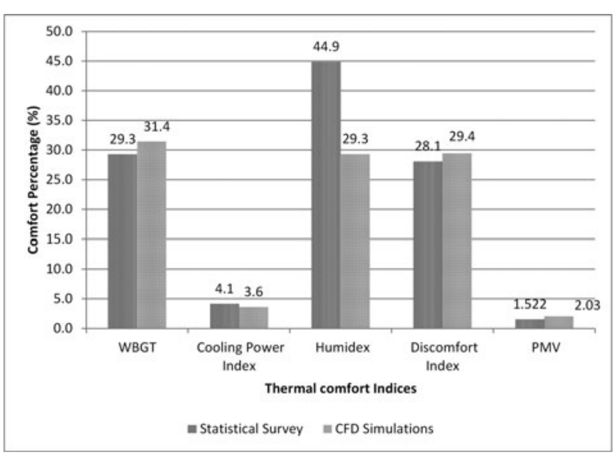

Fig. 25. Comfort percentages by CFD versus survey results.

CFD was shown to give reasonable predictions of most of the thermal comfort indices. It was shown to overestimate the comfort percentage for WBGT, DI, and MCV by 6.8%, 4.5%, and 25%, respectively. On the other hand, CFD was shown to underestimate the thermal comfort percentage indicated by the cooling power index, and Humidex by 14.9% and 54.1%, respectively. The variation in the CFD results can be attributed to different reasons. The subjective data on which Fanger's model is based on were obtained exclusively from climate chamber studies where a steady state had been reached when the subjects had been in steady state conditions in the chamber for 3 h. Furthermore, the required values of clothing insulation and metabolic rate were obtained from tables in which clothing insulation is listed against descriptions of items or ensembles of clothing. Furthermore, the activities of the survey participants must be known in addition to the activities in which they were engaged.

Conclusion

In the current article, five different thermal comfort indices were used to assess the thermal comfort of spectators within an FANZONE. The collected comfort votes were gathered from surveys taken during two consecutive summers along with on-site climatic measurements. Maximum values of measured ambient temperature and RH were noticed on July 4, 2015 (32.43°C, 76.65%), respectively. Neutral feeling dry-bulb temperature and RH within the FANZONE were calculated to be 24.9°C and 49.01%, respectively. In total, 50% of the spectators were satisfied from the climate within the study area.

Compared to the MCV of the sampled survey, all thermal comfort indices underestimated the thermal comfort percentage except WBGT index. The WBGT index overestimated the spectators' thermal comfort by 6% while Humidex, cooling power index, and DI underestimated the thermal comfort by 25%, 38%, and 25%, respectively.

CFD was shown to give reasonable predictions of most of the thermal comfort indices. By utilizing the CFD thermal model, it was shown that CFD predictions overestimated the comfort percentage of the WBGT index, DI, and MCV by 6.8%, 4.5%, and 25%, respectively. On the other hand, it was shown to underestimate the thermal comfort percentage indicated by the cooling power index and Humidex by 14.9% and 54.1%, respectively.

Nomenclature

ASHRAE	=	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
CFD	=	computational fluid dynamics
CV	=	coefficient of variation (%)
LES	=	large eddy simulation
MCV	=	mean comfort vote
PET	=	physiological equivalent temperature
PMV	=	predicted mean vote
RH	=	relative humidity (%)
SD	=	standard deviation
SET	=	standard equivalent temperature
TS	=	thermal sensation
WBGT	=	wet-bulb global temperature (°C)
DI	=	discomfort index (°C)

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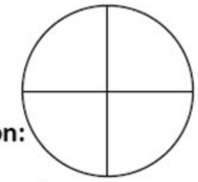
Appendix 1

Questionnaire Fanzone 2015

Date: **Time:** **Location:**



On Spot Fanzone Temperature: **On Spot Humidity:** **On Spot Wind Speed:**

- **Gender:** Male ☐ Female ☐ **Nationality:**
- **Age**

<18	18-25	26-35	36-45	56-65	66-75	>76

- **Health condition**
  a) Surgeries /recent illness
  b) Asthma
  c) Healthy

- **Type of clothing**
  A)Thob (men local dress) B) Abayas (ladies local dress)
  C) Short Sleeved Blouse D) Bermudas
  E)Long Sleeved Blouse F) Trousers
  G)Shoes H)Jacket

- **Best description of your thermal Sensation inside FANZONE (ASHRAE)**

  A)Hot
  B)Warm
  C)Slightly Warm
  D)Neutral
  E)Slightly Cool
  F)Cool
  G)Cold

- **Best description of your thermal preference, for the climate to**

  A) become hotter
  B)remain the same
  C)become cooler

- How would you describe your typical level of thermal acceptability:

  A)Highly Acceptable
  B)Acceptable
  C)Unacceptable
  D)Highly Unacceptable

- How would you describe your typical level of thermal comfort?

  A) Comfortable
  B) Slightly uncomfortable
  C) Uncomfortable
  D) Very uncomfortable

- **Best description of your satisfaction level**

3	Very satisfied
2	Satisfied
1	Somewhat dissatisfied
0	Neutral
1-	Somewhat dissatisfied
2-	Dissatisfied
-3	Very dissatisfied

- **Recent activities in the last 2 hours**

  a) Meal consumption
  b) Exercise (gym, swimming pool)
  c) Smoking