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Sea Breeze Climate and Human Thermal Comfort over Gaza, Palestine

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Abstract

The purpose of this study is to examine the sea breeze climate and thermal human comfort in Gaza, Palestine. Analyses are based on weather data gathered at Gaza weather station. Considering the limitation of meteorological observation, the meteorological data used to represent the outdoor environment were obtained from the Palestinian meteorological department over 12 years periods (1995-2006). Summarizing the results, the average starting and ending times of sea breeze found between 09:00 and 15:00 UTC. Starts from March to October, with mean velocity of 3 m/s reaching a maximum at about 1500 UTC with 4.2 m/s. Spring and summer months have the most sea breeze, while nil in winter months. Lifted condensation level (LCL) at spring and summer of about 742 m and 650 m respectively. The LCL is less than the limits required for inland distance penetration of the sea breeze according to the depth of the unstable layer. Physiologically equivalent temperature (PET) observed to varied between (34.9°C) during summer months, while (15.7 °C) during winter. Universal Thermal Climate Index (UTCI) indicated strong thermal stress during July and August months, while at the rest of the year felt under no thermal stress to moderate thermal stress. The study was suggested that, the better comfortable level found during sea breeze hours at summer months.

Keywords: Sea Breeze; Comfort Index; Outdoor Environment; PET; UTCI; Gaza Strip; Palestine.

1. Introduction

The coastal sea breeze has a long history. When the day's heating by the sun radiation reaches a maximum at the afternoon, the air heats up and expands, causing the surface air pressure to decrease. Over water, the surface air pressure did not vary because the high specific heat capacity of the water maintained heating of the air over water. The air pressure over water would then be greater than the air pressure over land. This difference in pressure forces air to flow from high to low pressure on a circulating path that has cool, moist air flowing off the water onto the shoreline. At night, land cools faster than offshore waters. This cooling increases the surface air pressure overland making it higher than the surface air pressure over offshore waters. This pressure gradient forces the surface wind to flow from land to coastal areas in a reversed sea breeze circulation generally called a land breeze. The land breeze circulation is generally weaker than the sea breeze. The land surface air temperature increases more rapidly in the morning than the sea surface air temperature, producing a sharper thermal gradient over the land than over the sea in the lower level of the atmosphere. This drives a cooling breeze known as a sea breeze which blows from sea toward the land (Simpson, 1994). The sea breeze passing across the sea carries large amount of humidity and as it penetrates over the land it increases the relative humidity there. The invasion of the sea breeze is followed by a drop in the surface air temperature of the land (Kala *et al*.,, 2010). The inland penetration of the sea breeze in mid latitudes can reach to maximum of 50 km, while in the tropical and subtropical zones it has been observed to extend to 150 km (Abbs and Physick, 1992). Bigot and Planchon (2003) reported that a strong confronting synoptic wind with a speed greater than 6 to 8 m/s can disrupt sea breeze generation. Sea breeze have been observed to influence precipitation (Baker *et al*., 2001) and coastal processes (Masselink and Pattiaratchi, 2001). The interaction of urban heat island and sea land breeze circulation has been observed to affect the sea land circulation pattern. It can change the sea breeze wind speed and the timing of its arrival (Yoshikado, 1992). Several models and indices were developed to calculate the extent of thermal stress during the last decade. Recent models, based on the human energy balance equation to evaluate the thermal stress and thermal comfort on the human body.

The different microclimates condition influence also on outdoor human comfort. The perception for comfort of human beings depends on conditions for the thermal balance between the body and the environment; the factors affecting thermal comfort are both environmental factors (air temperature, radiant temperature, wind speed and relative humidity) and personal factors (Clothing insulation and Metabolic of the body). Recently, the heat related effects in cities, such as the urban heat island (UHI) and the thermal comfort came to the focus of urban environmental research (Potchter and Ben-Shalom, 2013), especially in the region between the Jordan and the Mediterranean coast that is among the most vulnerable regions.

This paper aim to analysis the sea breeze climate of Gaza. Also this research discussed the influence of sea breeze on human thermal comfort. So far, no studies dealing with sea breeze climatic have been conducted in Gaza Strip, Palestine.

2. Material and Methods

The longest meteorological data for a coastal weather station were collected. The data include air temperature (°C), relative humidity (%) and 3- hourly wind speed (m/s) and direction (degree) during the period from 1995 to 2006 which provided by Palestinian Meteorology. Air temperatures were measured by dry bulb mercury thermometers sheltered from direct solar radiation 2m above ground level with an accuracy of 0.1°C. Hygrometers

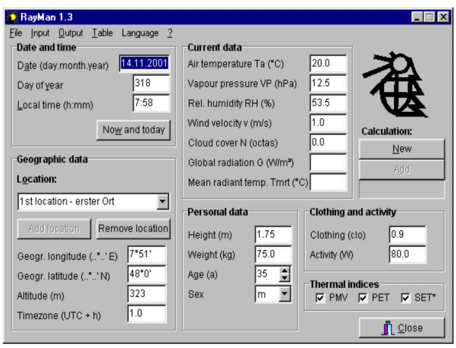

Figure 1. Input window of RayMan 1.3.

Table 1. Ranges of the Physiological Equivalent Temperature (PET) with an internal heat production of 80 W and a heat transfer resistance of the clothing of 0.9 clo. (According to Matzarakis and Mayer, 1996).

PET	Thermal Perception	Grade of physical stress
< 4	Very cold	Extreme cold stress
4 – 8	Cold	Strong cold stress
8 – 13	Cool	Moderate cold stress
13 – 18	Slightly cool	Slight cold stress
18 – 23	Comfortable	No thermal stress
23 – 26	Slightly warm	Slight heat stress
29 – 35	Warm	Moderate heat stress
35 – 41	Hot	Strong heat stress
> 41	Very hot	Extreme heat stress

registered relative humidity. Wind speeds were recorded by anemometers (standard height 10m). The seasonal difference of the height of Lifted Condensation Level (LCL) were calculated. The main method used in this study is discussing the sea breeze climate. The next methods are the calculation of the thermal human comfort indices which assessed by two indicators:

Physiologically Equivalent Temperature (PET), based on the numerical radiation model RayMan (Matzarakis *et al*.,, 2007), (as seen in Figure 1 and Table 1).

And Universal Thermal Climate Index (UTCI) (According to Glossary of Terms for Thermal Physiology (2003), Journal of Thermal Biology 28, 75-106) (Cooperation in Science and Technical Development) (www.utci.org). The different values of the UTCI are categorized in terms of thermal stress. UTCI values between 18 and 26°C may comply closely with definition of the thermal comfort zone supplied in the Glossary of terms for thermal physiology (IUPS 2003) as: the range of ambient temperature, associated with mean radiant temperature, humidity and wind speed.

3. Study areas

Palestine is located in the Middle East between 29°and 33° North Latitude and between 35° and 39°East Longitude at the eastern south ends of the Mediterranean Sea in south – west of Asia (see Figure 2). It is bounded to the north by Lebanon, the northeast by Syria, the east by Jordan, and to the southwest by Egypt. The Gaza Strip is an exclave region of the State of Palestine on the eastern coast of the Mediterranean Sea that borders Egypt on the southwest for 11 kilometers (6.8 mi) and Israel on the east and north, Gaza is part of the Palestinian National Authority , which also includes the West Bank and are claimed by the State of Palestine. The Gaza strip is 41 kilometers (25 mi) long, and from 6 to 12 kilometers (3.7 to 7.5 mi) wide, with a total area of 365 square kilometers (141 sq. mi). With around 1.9 million Palestinians on some 360 square kilometers, Gaza is among the regions with the highest population density in the world. The Gaza Strip is located in the Middle East at 31°25'N 34°20'E. Gaza weather station has a Mediterranean climate with dry hot summers and mild winters (Köppen climate classification Csa), located on the country's Mediterranean coastal plain at the distance of nearly 200m from the shoreline, 14m above sea level.

4. Results and Discussion

4.1 Sea Breeze Climate

Gaza weather station located on the eastern coast of the Mediterranean sea. In this study, we consider the westerly component as sea breeze. Generally, sea breeze start from March to October, with mean velocity of 3 m/s.

The percentage of sea breeze cases in each season are shown in Table 2. For the period

Figure 2. The location of study area

Table 2. Seasonal percentage of sea breeze at Gaza station from 1995 to 2006.

Seasons	Wind Direction (degree)	Annual Percentage
Winter	-	0 %
Spring	Mar, Apr, May	25 %
Summer	Jun, Jul, Aug	25 %
Autumn	Sep, Oct	16 %

of study, 66 % of the year were identified as sea breeze. As expected, spring and summer months have the most sea breeze, while nil in winter months.

The morning wind (from 00am to 06am at UTC time) blows in summer months from the south-east direction (land breeze), there is not any dominant direction for the 21pm winds, when temperatures are at their minimum, air pressures over water and the neighboring land are equal, consequently variable wind speed.

The explore indicated that on average, during the 12 years period, the sea breeze can be expected to found between 09:00 and 15:00 UTC, the average wind speed being 3 m/s reaching a maximum at about 1500 UTC with 4.2 m/s (Figure 4). That's because of the greatest temperature differences between the sea and nearby land, take place in the afternoon when the land is at maximum heating from the sun. The lighter land breeze is most likely to begin at 0000 UTC, blow at about 1.7 m/s.

As shown in Figure 5, The land absorbs much of the sun's energy as well. However, the warm air over the land will ascend throughout the day, generating low pressure at the surface. Over the water, high surface pressure will form because of the colder air. The wind will blow from the higher pressure over the water to lower pressure over the land causing the sea breeze. The sea breeze strength will vary depending on the temperature difference between the land and the sea surface. This breeze occurs most often in the spring and summer months because of the greater temperature differences between the sea and nearby land, particularlyin the afternoon when the landis at maximum heating from the sun. Bradbury (1989) stated that sea breezes peak during the early summer when thermal gradients between the land and sea are the greatest.

Analysis of annual wind speed (in Figure 6), from 1995 to 2005 shows that, fluctuation of wind speed from high at 1996 with 4.1 m/s to low at 1999 with 2.2 m/s. The study suggest that, these fluctuation related to oscillation in pressure between land and sea surface .

Bradbury (1989) and Riehl (1979) suggest that due to the Coriolis force, in middle latitudes the sea breeze is deflected to the right and to the left in the northern and southern hemispheres, respectively, to the point that the wind, in time, blows parallel to the coast, thus limiting sea breeze penetration to about 20 to 50 kilometers

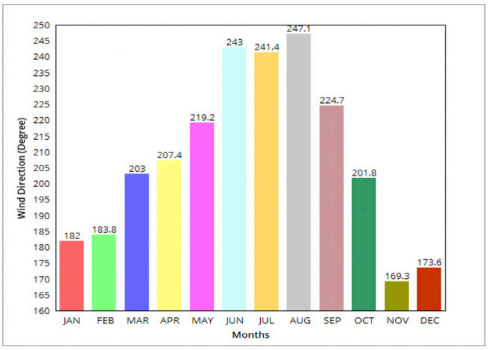

Figure 3. Mean monthly wind direction (in degree) at Gaza station from 1995 to 2006

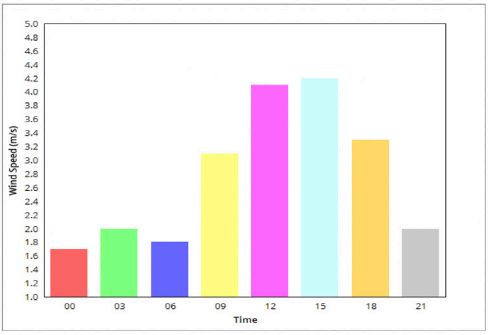

Figure 4. Mean 3-hourly wind speed (in m/s) during the day at Gaza station from 1995 to 2006

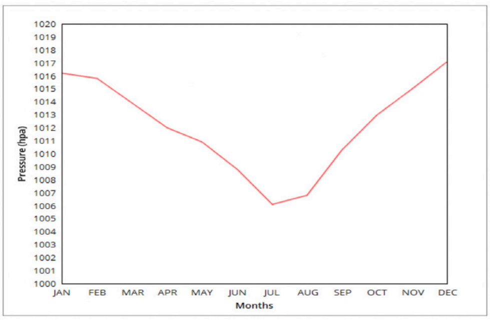

Figure 5. Mean monthly air pressure at station level from 1995 to 2006

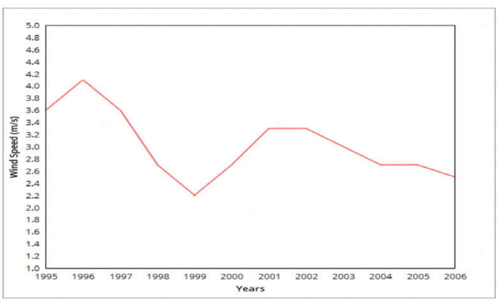

Figure 6. Mean annual wind speed (in m/s) at Gaza station from 1995 to 2006

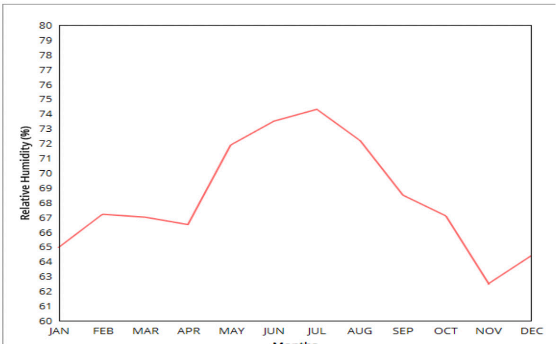

Figure 7. Mean monthly relative humidity over Gaza station during 1995 to 2006

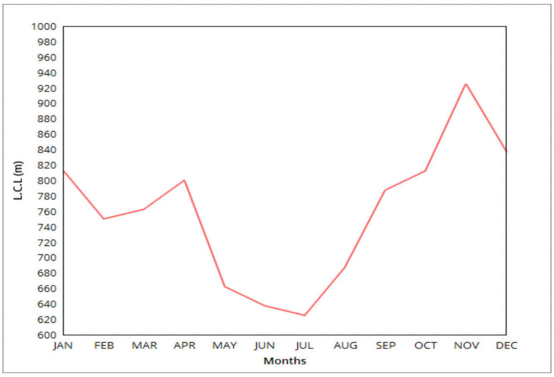

Figure 8. Mean monthly Lifted Condensation Level(LCL) over Gaza station during 1995 to 2006

Table 3. Seasonal Lifted Condensation Level (LCL) at Gaza station from 1995 to 2006

Seasons	LCL (m)
Winter	800
Spring	742
Summer	650
Autumn	842

inland. Approaching the equator the magnitude of the Coriolis force eventually diminishes to zero. This means that near the equator the wind follows the direction of the pressure gradient and this allows the sea breezes to penetrate further inland in the tropics. Eager *et al.* (2005) found that the sea breeze can penetrate up to 130 km inland, while Zhu and Atkinson (2004) found that landward penetration along the UAE coast is over 250 km. The extent of the circulation varies according to different sources. It may extend about 20 kilometers seaward and 60 to 70 kilometers inland, or not more than 50 kilometers according to Critchfield (1974), while Hsu (1988) defines the vertical extent as being up to 700 hPa.

The depth of the inversion layer has an effect on the distance of inland penetration of the sea breeze. Bradbury (1989) suggest that the best penetration occurs with dry convection from 1830 to 2740 meters, while the UKMO Source book to the forecaster's reference book (1997) specifies dry convection up to 1500 meters. In the mid latitudes, these sea breezes usually travel from 5 to 50 Km inland (Atkinson, 1981). It goes on to add that if there is a very shallow convection layer, there will be virtually no inland penetration of the sea breeze regardless of the land and sea temperature difference. with a surface temperature of 27.4°C, on either day at Gaza station, it was not hot enough for dry air to convection up to a lifted condensation level (LCL) at summer of about 650meters (Table 3). This is considerably less than the limits required for inland penetration of the sea breeze as specified by Bradbury (1989) and the UKMO (1997).

4.2 Thermal Human Comfort

Different degrees of cold stress (PET < 18 °C) occurred mostly from January to March in Gaza station; while PET values over 30 °C, indicating at least moderate heat stress, can be found during the 4-months period from June to September. Highest PET values were observed during summer months (34.9°C), while lowest PET we find during winter (15.7°C).

International Union of Physiological Sciences-IUPS (2003) categorized the different values of Universal Thermal Climate Index (UTCI) (degrees Celsius) in term of thermal stress: no thermal stress to moderate heat stress (UTCI=9-26°C), strong heat stress (UTCI=26-32°C), very strong heat stress (UTCI=38-46°C) and extreme heat stress (UTCI= above 46°C). In our study, the UTCI value in the months July and August indicated strong thermal stress, while at the rest of the year felt under no thermal

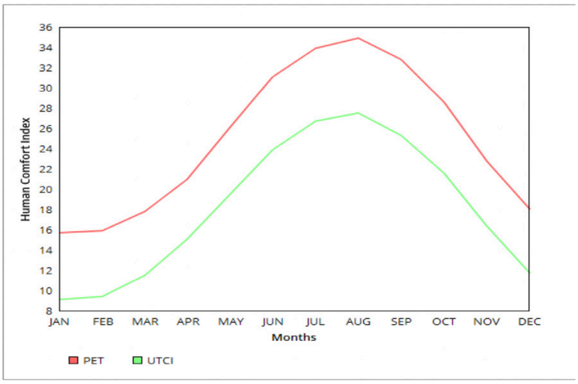

Figure 9. Mean monthly pattern of Physiologically Equivalent Temperature (PET) and Universal Thermal Climate Index (UTCI) (in °C) at Gaza station for the years 1995 - 2006

Table 4. Mean monthly PET(°C) and UTCI (°C) for Gaza station during the period from 1995 to 2006.

Months	PET(°C)	UTCI(°C)
Jan	15.7	9.1
Feb	15.9	9.4
Mar	17.8	11.5
Apr	21.0	15.1
May	26.1	19.5
Jun	31.1	23.9
Jul	33.9	26.7
Aug	34.9	27.5
Sep	32.8	25.3
Oct	28.6	21.6
Nov	22.8	16.4
Dec	18.1	11.8

stress to moderate thermal stress (as seen in Table 4 and Figure 9).

5. Conclusions

In conclusion, there is a significant change of the frequency of sea breeze events for the period of the study, however the sea breeze vary with time during the day. There is a greater tendency of intensification in the late afternoon easterly wind speed, which is land breeze, especially from June to August. The temperature difference between the land and sea is the essential factor of a sea breeze circulation. Increasing of the afternoon sea breeze intensity, might be related to a possible increase in the temperature of land surface or decrease of sea surface temperature as a result of urbanization or tele-connection of pressure oscillation around the equator.

During the analyzed periods, the sea breeze hours can have better levels of thermal comfort during summer months.

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