Characteristics And Long-Term Trends of The Outdoor Thermal Comfort Indices in Aligarh City

Huma Matloob

Assistant Professor, Architecture Section
University Polytechnic, AMU, Aligarh

Abstract - *Outdoor Thermal Comfort Indices (THI, WBGT and RSI) were determined for the Aligarh city. It is found that climatic conditions lead to the uncomfortable conditions in (May –September). Long-term trends of annual kurtosis and skewness values indicate negative and positive trends respectively and maximum change is exhibited by THI. Long-term trends of Outdoor Thermal Indices indicated that lower range of indices have increased in last century. Among the indices, the RSI indicated continuous increase throughout the century, while THI and WBGT indicated sudden change in values since, 1980s.*

Key Words: Aligarh, Outdoor Thermal Indices, Climate Change

1.INTRODUCTION

Dramatic changes in land use/land cover is witnessed by developing country particular Indian and China. These changes impact on thermal regime of land especially over the city areas. Changes in urban climate is linked to the industrial output and also impact on health of urban population. Based on climatic parameters numbers of studies at various scales and indices have been developed for thermal comfort and heat stress which gives numerical relations or graphs for evaluating thermal comfort [1]. Based on cities, their climate type, indices used and comfort reporting was studied for selecting appropriate thermal comfort index. Each index has their own strength in terms of comprehensiveness, usability, validity and completeness [2]. PET (Physiological Equivalent Temperature) was observed as a widely used outdoor thermal comfort index in tropics. Other indices such as Thom's (DI) Discomfort Index [3] and Relative Strain Index (RSI) are commonly used in urban climate studies [4, 5]. Temperature Humidity Index (THI) is used to describe thermal sensations experienced by people as a result of modifications in the climatic conditions of the urban areas [6, 7] It is a more suitable index for the tropics [8]. WBGT index (Wet Bulb Global Temperature) is recommended by the International Organization for Standardization (ISO) and widely used in numbers of studies. A comparative formulas table for the various indices is present in table 1.

RSI allows the effect of clothing and net radiation to be considered along with the effects of temperature and humidity. The RSI for a healthy 25-year-old male, un acclimatized to heat and in a business clothing; with an internal heat production of 100 W/m2 and in the absence of direct solar radiation and a wind speed of 1 m/s [5]. Both indices, RSI and DI, use temperature and relative humidity (RH) meteorological parameters only to deduce the thermal comfort. Unlike PET and UTCI (Universal Thermal Climate Index), other factors such as variation in solar radiation, wind velocity, and clothing condition are not taken into account in these indices. At city level, local comfort assessment requires a large number of monitoring stations which account these parameters. Many studies often focus over temperature and RH data and extrapolate other parameters using Weather Research and Forecasting model (WRF) [9] or obstacle-resolving numerical models [10].

Present study is designed to determine the various outdoor thermal indices. Characteristics of the indices were analyzed for the Aligarh city. Indices similarity, monthly distribution, long trends have been discussed in detail.

2. AREA OF STUDY

The city is located in the plains between the Ganga and Yamuna rivers (Fig. 1). It is nearly a level plain and slight elevation is the central. Southern part of the city has old habitation and new urbanization is taking place all along the busy National Highways. The northern part of the city has less habitation and currently going under new urban developmental activity.

The Aligarh Muslim University, the prominent part of the city was once on the northern edge of the city, now it is surrounded by new urbanization and is currently in middle of the city [11]. Upper Ganga canal passes through in the Northern part of the city, while the southern part of the city has low lying area of the canal and this area is largely affected by saline soil. In the South eastern direction, the famous tourist cities Mathura and Agra are situated. Busy Delhi –Kanpur and other highway (Aligarh – Matura-Agra), National Highway and Railway passes through the main city.

3. CLIMATE

The area is located on the fringe area of the arid zone (Rajasthan) and falls under the semi-arid climatic conditions. Climate in the area can be marked with distinct five seasons winter, spring, summer, monsoon and autumn.. The winter prevails for three months (December – February). During this time, area is under influence of western disturbances and receive winter showers and foggy conditions prevails in the December and January. The spring season prevails hardly for two months (March –April) with moderate dryness and temperatures. The summer prevails for about three months (May – June) with high dryness and strong hot winds from South Western direction from arid land in Rajasthan. These winds bring dust and caused to high dust concentration in June - July. Monsoon season (July – September) in the area is characterized by high humidity and rainfall. Autumn season (October to November) in the area commence after retreat of monsoon. In one climatic year the atmosphere events show high concentration of dust in June and foggy conditions in December and January.

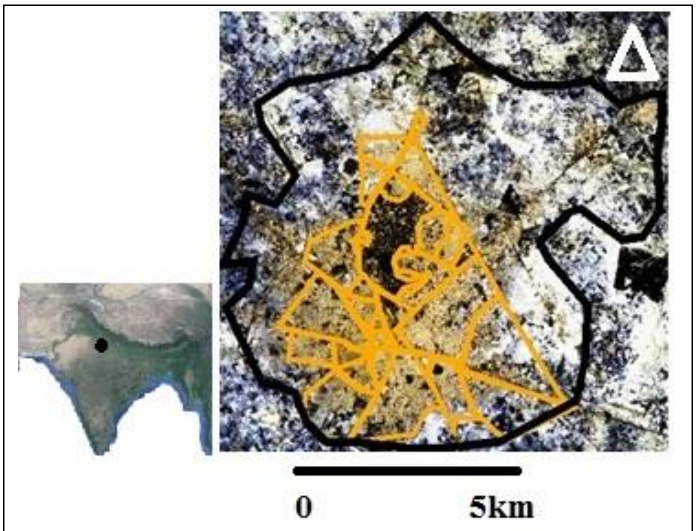

Figure 1: Location map of the study area showing major segments in the city

4. DATA AND METHODS

In this study the monthly mean temperature and vapor pressure of Aligarh city is download from http://www.cru.uea.ac.uk/cru/data/hrg/. The 4.04 release of the CRU TS dataset covers the period 1901-2019 and available with 0.5-degree global resolution [12].

The CRU TS (Climatic Research Unit gridded Time Series) dataset provides a high-resolution, monthly grid of land-based observations going back to 1901 and consists of ten observed and derived variables. Individual station series are animalized using their 1961–1990 observations, then gridded to a 0.5° regular grid using angular distance weighting (ADW). Present data for the study area is gridded based on 8 surrounding weather observatories.

The description of outdoor thermal comfort is present in table 1. Each index is described in separate along with values and corresponding comfort level for the RSI, THI and WBGT.

Table 1: Thermal Indices and their formulas

Thermal Comfort Index	Variables used
RSI= T-21/58-E	Ta= Average air Temperature (°C), E = vapor pressure (hpa)
THI = T – (0.55 – 0.00RH). (Ta-14.5)	Ta= Average air Temperature (°C), RH= Relative humidity (%)
WBGT = 0.567 × T*a* + 3.94 + 0.393 × *E*	Ta = Average air temperature (°C), RH = Relative humidity (%), E = water vapor pressure (hPa)

4.1 Relative Strain Index (RSI)

RSI index is used to assess the heat stress of outdoor environments. It is obtained from two variables of air temperature (°C) and water vapor pressure (hectopascal) (Equation 1). Due to the fact that at some stations there is no access to water vapor pressure variable, therefore this parameter is determined by using the two variables of air temperature and relative humidity, using [4] and [14]. A table of different level thermal comfort of Relative Strain Index (RSI) is presented in Table 2

RSI= T-21/58-E -- (1)

4.2 Wet Bulb Globe Temperature (WBGT)

Unfortunately, due to the lack of measurement of globe temperature (Tg) by meteorological stations, it is not possible to report the heat stress conditions based on the WBGT index provided by the International Organization for Standardization (ISO) (Equation 2). Therefore, the model presented by the Australian Bureau of Meteorology (ABM) was used in this study (Equation 2) used in [14]. This model has been used in several studies abroad [15, 16, 17, 18]

WBGT out = 0.7Tnw + 0.2Tg + 0.1Ta ----------------- (1)

Where, Tnw, Ta and Tg are natural wet temperature, dry temperature and globe temperature in terms of (°C) respectively [19]. The water vapor pressure in equation 5 is used directly from the data climate data set.

$WBGT = 0.567 \times ta + 3.94 + 0.393$ --------------------------(2)

Ta = Average air temperature (°C)
RH = Relative humidity (%)
E = water vapor pressure (hPa)

The classification of this index by the American College of Sports Medicine (ACSM) is presented in the WBGT table 3, which is categorized in four levels [20].

Table 2. Classification of the relative strain index levels (Błażejczyk, 2011).

Relative Strain Index	Interpretation of Index
RSI < 0.15	Discomfort for sensitive individuals such as the elderly and children
0.15 ≤ RSI < 0.25	Discomfort for all people
0.25 ≤ RSI < 0.35	The risk of exposure to excessive heat (heat stroke risk) for 50% of people and more
0.35 ≤ RSI < 0.45	The risk of hyperthermia for all people
RSI ≥ 0.45	Discomfort for sensitive individuals such as the elderly and children

Table 3. Risk Levels of the WBGT index.

Wet Bulb Globe Temperature	Risk Leve l Risk Level
<18	Low (down)
18-23	Medium
23-28	High
>28	Very high

4.3 Thermo-Hygrometric Index (THI)

The THI formula proposed by [4] was also used in the current study. This formula incorporates air temperature (T) and relative humidity (RH):

THI =T – (0.55 – 0.00RH) (Ta-14.5) ----------------------- (3)

Where T is air temperature (^{0}C) and RH is relative humidity (%). For comfort values, [21] delimited (21.1 ^{0}C) as a threshold separating comfort from hot discomfort (Table 4). The comfortable conditions range between 15 ^{0}C and 20 ^{0}C [5]. Eight THI categories were calculated (very cold, cold, cool, comfortable, hot, very hot and torrid). Water vapor pressure (hPa) data were derived from psychometric formula using monthly of relative humidity and temperature data.

Table 4. The categories of the THI.

THI Category	THI Values (^{0}C)
Extremely cold	-19.9 to -10.0
Very cold	-9.9 to -1.8
Cold	-1.7 to 12.9
Cool	13.0 to 14.9
Comfortable	15.0 to 19.9
Hot	20.0 to 26.4
Very Hot	26.5 to 29.9
Uncomfortable	<30

5. RESULTS AND DISCUSSION

Exposure to heat stress can cause a wide range of disorders and complications in people and in some cases can cause death [17, 22]. Moreover, it can reduce the productivity and performance of individuals [23]. Therefore, evaluation of this harmful factor in outdoor environments can be considered as a priority. In this regard, different indices are used to assess the heat stress and each of them has advantages and disadvantages [9].

In this study, the THI, RSI index along with the WBGT index offered by the Australian Meteorological agency were studied for Aligarh city. In the Aligarh city during the last 120 years, the maximum mean monthly air temperature was observed in June (34.07± 0.99 ^{0}C), the maximum vapor pressure in July (31.14 ± 1.13) hPA. While, minimum monthly temperature and vapor pressure were recorded in January (14± 0.95) and (9.8 ± 0.61) hPA. The long-term trends were determined for the mean atmospheric temperature ^{0}C and vapor pressure hPA on monthly basis. Slope analysis indicated highest increase is during autumn months and moderate increase in winter months. However, summer months show lowest increase (fig.2). Trend analysis in other studies in Indian continent also showed a continuous increase in lower temperature regime of winter and autumn and also impacted on trends of the thermal comfort indices (fig.3).

The monthly RSI, WBGT and THI indices are separately presented in figure 4. The RSI, WBGT and THI showed higher discomfort level during the months of May to September. However, discomfort levels were observed slight shorter by RSI compare to WBGT and THI. Trends of the skewness and kurtosis for the 120 yrs. (1900 -2019) are presented in fig. 4. It indicated negative and positive trends for the skewness and kurtosis respectively for the different indices. But the slopes of trends were different for each index. Trends of skewness and kurtosis of THI showed highest slope for the long-term trend of THI. It suggested that THI is most influenced by climate change in last century. Long term temporal distribution of annual RSI, WBGT and THI indicate rising trends with different degree of growth. It indicated sudden increase in THI started from 1980 onwards. But the growth pattern of RSI and WBGT indicate continuous increase in index values since 1900 (fig.5).

Monthly variation in indices shows similarity between WBGT and THI and slightly differ with RSI. A significant correlation between studied indices, shows appropriateness of using the RSI, THI and WBGT. Present study also indicated that bioclimatic indices WBGT and THI show very good exponential relation. However, RSI and THI, WBGT and RSI showed linear relation with high correlation coefficient (fig.5).

Regarding the advantage of using Thermal comfort indices, it should be noted that data measured by meteorological organizations can be used to predict and timely announce the state of heat stress in a region. If preventive management measures are taken by the relevant organizations, the occurrence of stressful conditions and its complications will reduce among exposed people. The low cost for measuring and easy interpretation of thermal index is one of its benefits. On the other hand, given the climate change phenomena and global warming in the coming decades, the amount of this index by considering different scenarios of climate change can be predicted. It is hoped that this way steps to maintain and protect the health of individuals can be taken, especially the manpower of outdoor work environments.

6. CONCLUSIONS

The long-term trends for the mean atmospheric temperature and vapor pressure on monthly basis indicated highest increase is in autumn and moderate increase in winter months, while summer months show minimum increase. These climatic trends also impact on trends of the thermal comfort indices. RSI, WBGT and THI showed higher discomfort level during the months of May to September. Trends of the skewness and kurtosis for the 120 yrs. (1900 -2019) indicate highest change for THI. It showed highest increase in Kurtosis and decrease in skewness indicated as result of climate change in the last century. Long term trends of annual RSI, WBGT and THI mean value indicating rising in indices values from 1980 onwards. But the long-term trends suggested that RSI showing a continuous increase since 1900 in index values.

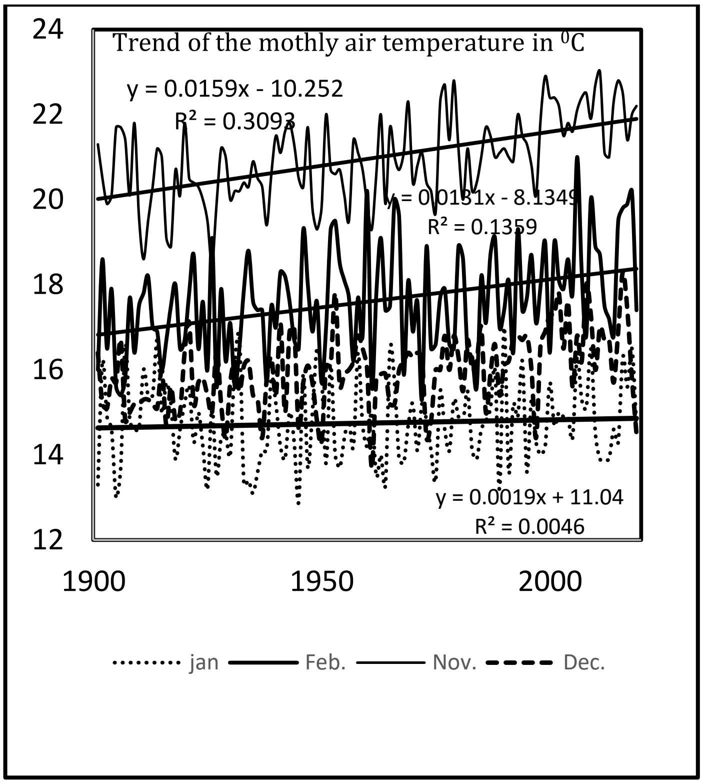

Figure 2: Long term trends of the monthly atmospheric temperature (^{0}C) for the last 120 (1900- 2020).

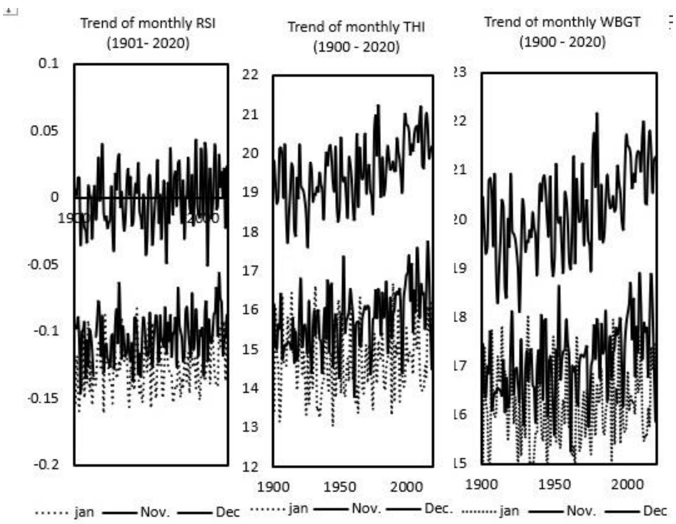

Figure 3: Long term trends of the outdoor thermal indices for the last 120 (1900- 2020) years in Aligarh.

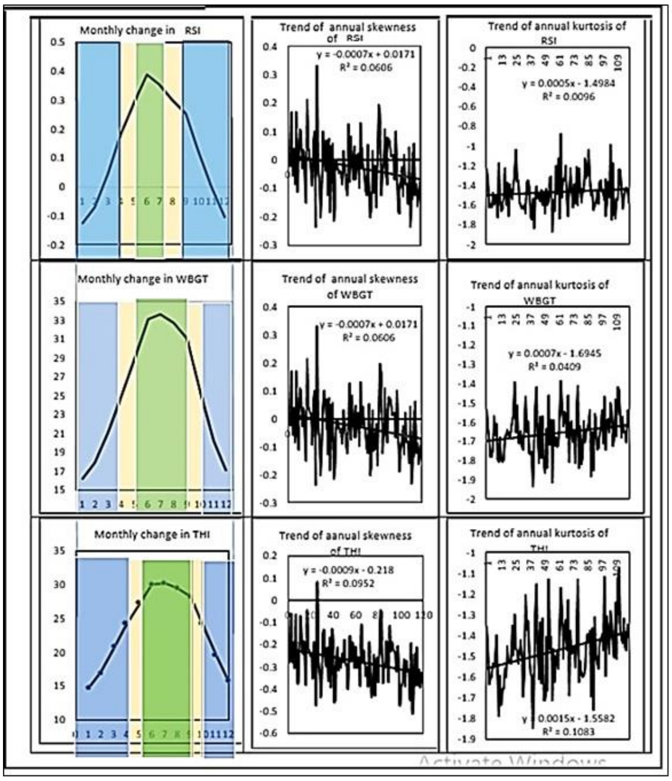

Figure 4: Monthly change in outdoor thermal indices (a), Long term annual skewness and kurtosis trends of the different bioclimatic Indices for the last 120 years (1901-2019)

lues.

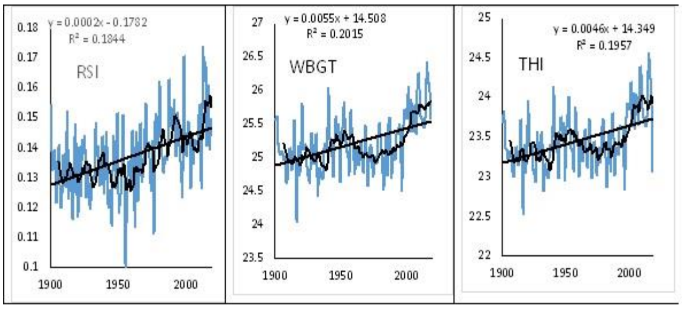

Figure 5: Temporal change in annual mean outdoor thermal indices (RSI, WBGT and THI). Black thick line indicated 6 year running average.

ACKNOWLEDGEMENT

The authors would like to express their sincere thanks to Principal, University Polytechnic, Aligarh Muslim University for providing the laboratory and library facilities.

REFERENCES

[1] A. Abdel-Ghany, I. Al-Helal and M. Shady, "Human Thermal Comfort and Heat Stress in an Outdoor Urban Arid Environment: A Case Study, " Advances in Meteorology, 2013, 1-7. doi:10.1155/2013/693541.

[2] C. Freitas and E. Grigorieva, "A comparison and appraisal of a comprehensive range of human thermal climate indices," Int. J. Biometeorol, 2017, 61(3), pp.487-512. [http://dx.doi.org/10.1007/s00484-016-1228-6]

[3] S. Nieuwolt, "Tropical climatology. An introduction to the climates of the low latitudes. John Wiley and Sons", 1977.

[4] W. Kyle, "Summer and winter patterns of human thermal stress in Hong Kong", In: Kyle, W., Chang, CP., (Eds.), Proceedings of the 2nd Int, Conference on east asia, and western pacific meteorology and climate, Hong Kong 557-83, 1992.

[5] J.Unger, "Comparisons of urban and rural bioclimatological conditions in the case of a Central European city," Int. J. Biometeorol. 1999, 43, 139–144.

[6] A. Polydoros and C.Cartalis, "Assessing thermal risk in urban areas - an application for the urban agglomeration of Athens", Advances in Building Energy Research, 2014, 8, 74-83. doi:10.1080/17512549. 2014.890536.

[7] M. Stathopoulou, C. Cartalis, and A. Andritsos, "Assessing the thermal environment of major cities in Greece" In 1st International Conference on Passive and Low Energy Cooling for the Built Environment, Santorini, Greece May 2005.

[8] R. Emmanuel, "Thermal comfort implications of urbanization in a warm-humid city: the Colombo Metropolitan Region (CMR), Sri Lanka. Building and Environment, 2005, 40(12), 1591-1601. doi:10.1016/j. buildenv.2004.12.004.

[9] I. Bajšanski, D. Milošević, and S. Savić, "Evaluation and improvement of outdoor thermal comfort in urban areas on extreme temperature days: Applications of automatic algorithms. Building and Environment", 2015, 94, 632-643. doi:10.1016/j. buildenv.2015.10.019 .

[10] J. Fischereit and K. Schlünzen, "Evaluation of thermal indices for their applicability in obstacle resolving meteorology models" International

journal of biometeorology, 2018, 62(10), 1887-1900. doi:10.1007/s00484-018-1591-6.

[11] S. Farooq and S. Ahmad, "Urban sprawl development around Aligarh city: a study aided by satellite remote sensing and GIS," Jour. Indian Soc. Remote Sensing, 2008, 36(1), pp. 77-88.

[12] I. Harris, T. Osborn, P. Jones, "Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset" Sci Data, 2020, 7, 109 https://doi.org/10.1038/s41597-020-0453-3.

[13] N. Ionac and S. Ciulache, "The bioclimatic stress in Dobrudja. Present Environment and Sustainable Development," 2007, 1, 168-78.

[14] B. Lemke and T. Kjellstrom, Calculating workplace WBGT from meteorological data: A tool for climate change assessment. Ind Health, 2012, 50(4), 267-78. [http://dx.doi.org/10.2486/indhealth.MS1352].

[15] T. Kakamu, K. Wada, D. Smith, S. Endo and T. Fukushima, "Preventing heat illness in the anticipated hot climate of the Tokyo 2020 Summer Olympic Games. Environ Health Prev Med, 2017, 22(1), 68. [http://dx.doi.org/10.1186/s12199-017-0675-y].

[16] S, Leroyer, S, Bélair, S, Spacek, L and I. Gultepe, "Modelling of radiation based thermal stress indicators for urban numerical weather prediction. Urban Climate, 2018, 25, 64-81. [http://dx.doi.org/10.1016/j.uclim.2018.05.003].

[17] S. Farhang, A. Mehri, F. Golbabaei and M. Beheshti, "Heat stress assessment in outdoor workplaces of a hot arid climate based on meteorological data: a case study in qom, Iran". Journal Mil Med, 2015, 17, 89-95.

[18] R. Hajizadeh, A. Mehri, S. Jafari, M. Beheshti, and H. Haghighatjou, "Feasibility of ESI index to assess heat stress in outdoor jobs. Journal Of Occupational And Environmental Health, 2016, 2, 18-26.

[19] P. Nassiri, M. Monazzam, F. Golbabaei, S. Dehghan, S. Rafieepour, A. Mortezapour, and M.Asghari, Application of Universal Thermal Climate Index (UTCI) for assessment of occupational heat stress in open-pit mines. Ind Health, 2017, 55(5), 437-43. [http://dx.doi.org/10.2486/indhealth.2017-0018].

[20] Y. Epstein, and D. Moran, "Thermal comfort and the heat stress indices", Ind Health, 2006, 44(3), 388-98. [http://dx.doi.org/10.2486/ind health.44.388.

[21] E. Thom, "The Discomfort Index. Weatherwise," 1959, 12, 57-60 http://dx.doi.org/10.1080/00431672.1959.992696

[22] M. Asghari, P. Nassiri, M. Monazzam, F. Golbabaei, A. Shamsipour, and H. Arabalibeik, "Provision of an empirical model to estimate the adaptive capacity of workers at risk of heat stress Health Scope", 2018, 7.

[23] A. Mazloumi, F. Golbabaei, S. Mahmood Khani, Z. Kazemi, M. Hosseini, M. Abbasinia, M. and S. Farhang Dehghan, "Evaluating effects of heat stress on cognitive function among workers in a hot industry", *Health Promot Perspect,* 2018, 4(2), 240-6.