ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology
Vol. 2, Issue 7, July 2013

SEASONAL DISTRIBUTION OF COMFORTABILITY: A REGIONAL BASED STUDY OVER KALYANI, WEST BENGAL, INDIA

R. Bhattacharya[1], S. Pal[2], G. Biswas[3], S. Karmakar[4], G. Saha[5]

Associate Professor, Department of Environmental Science, University of Kalyani, Kalyani 741235, India[1]

Research Scholar, Department of Environmental Science, University of Kalyani, Kalyani 741235, India[2,3,4]

Associate Professor, Department of Agricultural Meteorology and Physics, Bidhan Chandra Krishi Vishwavidyalaya, Mohanpure 741252, India[5]

Abstract: Seasonal changes of weather parameters are the factors in urban environments which affect thermal comfort. It was reported that solar radiation may change the ambient temperature upto 4°C. Annual variation of temepration and global radiation follow similar pattern. Object of our work is to point out the seasonal distribution of thermal stress over Kalyani. Thermohygrometric index, Wet bulb globe temperature and Relative strain index are estimated for the period 1994 to 2012 with some data gap. WBGT and RSI are widely used for outdoor workers. A regional based scale of WBGT and RSI are developed with reference to THI over Kalyani. However an integrated approach including the behavioral adjustment and clothing insulation of a person along with other parameters to compute stress indices may give better results to identify zone of thermal comfort.

Keywords: Heat stress; Thermohygrometric index; Wet bulb globe temperature; Relative strain index

I. INTRODUCTION

Outdoor workers are frequently exposed to solar radiation causing severe environmental heat stress which can deteriorate work efficiency and threaten health [1]-[4]. Air temperature, relative humidity, direct solar radiation and air flow are the four major variables of human thermal comfort which is defined as "condition of mind which expresses satisfaction with the thermal environment'' [5]. In addition it also depends on heat exchange between body and the surrounding environment and clothing insulation [6].

Thermal comfort is different for different seasons. In winter the comfort temperature ranges from 20°C-25°C whereas in summer 23°C-27°C. However comfort depends on both climatic parameters and behavioral adjustment of human. Mathematically it is expressed by the following equation

$$(M+Q) + R \pm C - E = \pm S \qquad \text{...(i)}$$

M = Metabolic rate, Q = Incoming solar irradiance, R = Terrestrial radiation, C = Convection, E = Evaporation, S = Body temperature, for thermal comfort S = 0

Moreover indices of thermal discomfort of human are the result of the superposition of several components and are based on heat balance equation which integrate all environmental parameters. However it is practically impossible to record all the necessary variables of the heat balance. In reality the prevailing conditions are same at various working places. According to WMO discomfort starts provided ambient air temperature = 24°C, Wet bulb temperature = 24°C *i.e.* relative humidity = 100%.

Researches over the globe are continuing to express the heat stress and comfort zone from weather parameters [7]-[15]. Meteorologists, Agronomists, Physiologists and Biologists have proposed more than 40 heat stress indices starting from 1905 to 2005 that will give us zone of comfort within and outside the built area in relation to environmental heat stress [4], [16]. There is a need to apply these indices on regional basis. Hence for the present analysis widely used three indices are estimated to give the seasonal pattern of heat stress and also to develop regional based scales of WBGT and RSI to quantify the degree of comfortability over Kalyani in the district Nadia of West Bengal.

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology
Vol. 2, Issue 7, July 2013

II. METHODOLOGY

Study Area

Our study area Kalyani (22.58 ^{o}N, 88.26^{o}E) is situated in the Nadia district of West Bengal and only 60km away from Tropic of Cancer. The area has sub tropical humid climate. The daily temperature over the year ranges from 11.9^{o}C (minimum) to 36.9^{o} C (maximum). Rainy season lasts from June to October and peak in September (274 mm). Winter lasts only for two months. Here different habits are present. The area has good cover of greeneries in addition to residential zones.

Data

Daily weather data of AICRP on Agro Meteorology, Bidhan Chandra Krishi Vishwavidyalaya, Kalyani for the period 1994 to 2012 and global radiation data of the Department of Environmental Science, University of Kalyani during 2009 to 2012 are used in our analysis.

Heat Stress Indices

Thermohygrometric Index (THI), one of the simple indices used by India Meteorological Department [17] and was developed by Thom [18], [19].

$$THI = 0.72\ (Ta + Tw) + 40.6 \qquad \ldots(ii)$$

where Ta and Tw are respectively the ambient air temperature and wet bulb temperature in ˚C
Wet Bulb Globe Temperature (WBGT) was developed to account the heat related injuries during field training [20]

$$WBGT = 0.1\ Ta + 0.7\ Tw + 0.2\ Tg \qquad \ldots(iii)$$

where Tg is the globe temperature in ˚C. For indoor work Tg may be replaced by Ta. WBGT index is recommended by many international organizations and was adapted as NISOH, 1972 [21].
Relative strain index (RSI) was developed for a healthy people dressed with business suit at a place not acclimatized to direct heat in order to take into account the clothing insulation [22].

$$RSI = (Ta - 21) / (58 - e) \qquad \ldots(iv)$$

where e is the water vapour pressure.
THI, WBGT and RSI are computed from the available daily weather data of Kalyani with some data gap during the years 1994 to 2012. There are on an average 5.79 thunderstorm days per year [23]. We have excluded these days from the analysis. During winter wind chill must be consider as outdoor parameter and most commonly used cold index [24]

$$W = 13.12 + 0.6215 \times T - 11.37 \times K^{0.16} + 0.3965 \times T \times K^{0.16}\ ^{\circ}C \quad \ldots(v)$$

Based on a good number of observations or surveys on a population under different climatic conditions and thermal sensations a five graded discomfort scale was developed [4], [25], [26]. THI values between 65 to 75, no heat stress is encountered by most of the population (>90%). Between 75 to 80, mild sensation of heat is felt but between 80 to 85 heat loads is moderate. Above 85 people engaged in physical work are at increases risk [27]. Table I illustrates five graded scale with required skin wettedness.

TABLE I
Discomfort scale

Category	Degree of Comfort	THI (Range)	Required SW
I	Comfortable	65≤ THI <75	0
II	Partial discomfort	75≤ THI <80	20%
III	Discomfort	80≤ THI <85	20%-40%
IV	Severe stress	85≤ THI <90	40%-60%
V	Very severe stress	≥90	≥80%

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology
Vol. 2, Issue 7, July 2013

III. DATA ANALYSIS AND DISCUSSION

The variation of air temperature and global radiation over Kalyani follows the same pattern as shown Fig. 1. For outdoor exposure, shading is also an important factor that may affect thermal environment [28], [29]. It was reported that strong sunlight can change the effective temperature by 3.6˚C whereas low wind can reduce the temperature by 1.9˚C.

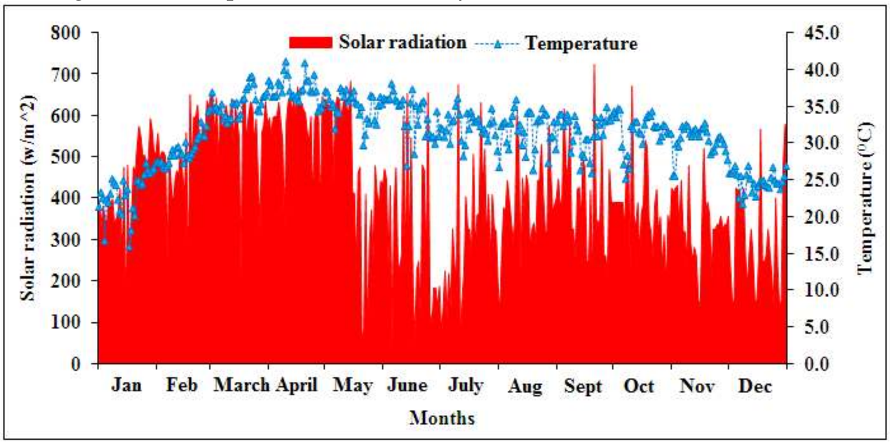

Fig. 1: Monthly variations of solar irradiance and ambient temperature

Heat indices THI, WBGT and RSI are computed from the daily weather data at 12:00 hrs, IST. Average values of THI for the months January, February, March, April, May, June, July, September, October, November and December are found to be 70.81^{0}C, 75.21^{0}C, 80.92, 84.62, 85.88, 84.61^{0}C, 83.31^{0}C, 83.43^{0}C, 82.86^{0}C, 81.83^{0}C, 78.14^{0}C and 72.74^{0}C respectively.

Average monthly weather parameters *viz.* ambient temperature, wet bulb temperature, vapour pressure and relative humidity during the analysis period over Kalyani are given in Table II. The temperature is found lowest in January and maximum in April-May over Kalyani. Temperature remains almost same during monsoon and post monsoon months.

Fig. 2(a) to 2(d) represents the relative departure of THI from their respective normal values. It is observed that days having positive relative departure from normal values during summer (March –May), monsoon (June-September), post-monsoon (October-November) and winter (December-February) seasons are 42.51%, 45.97%, 50.47% and 49.44% respectively.

The frequency distribution of comfortability scale is depicted in Fig. 3. It has been noted that 44.73% days fall in severe stress categories in summer whereas 27.35% and 5.03% sever stressful days fall in monsoon and post monsoon season respectively.

It is interesting to note that 3.83% days of winter are fall in discomfort zone. This may be due to the fact that winter at Kalyani actually persists from mid of December to first week of February. 85.62% days of the year lies within ±5% relative departure from their respective normal values.

TABLE II

Weather parameters (1994 to 2012)

Months	Dry bulb temperature (^{0}C)	Wet bulb temperature (^{0}C)	Vapour pressure (hPa)	Relative humidity (%)
January	24.2	17.8	1.54	53.58
February	28.0	20.1	1.72	46.54
March	32.7	23.3	2.13	43.18
April	34.7	26.6	2.83	52.19
May	34.7	28.3	3.25	59.91
June	32.9	28.5	3.53	73.11
July	31.2	28.1	3.55	79.09
August	31.5	28.0	3.54	79.91
September	31.0	27.7	3.45	78.13
October	31.0	26.3	3.01	69.17
November	29.1	23.1	2.24	55.93
December	25.6	19.1	1.68	52.00

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology
Vol. 2, Issue 7, July 2013

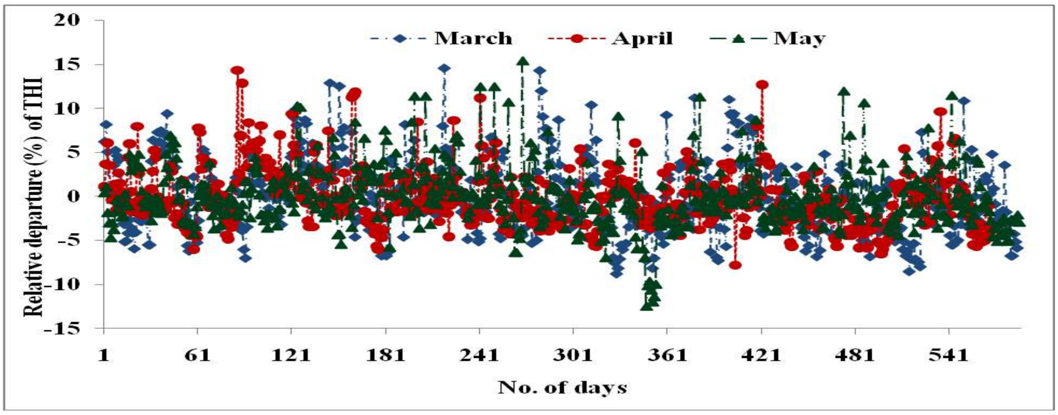

Fig. 2(a): Relative departure (%) of THI during summer months

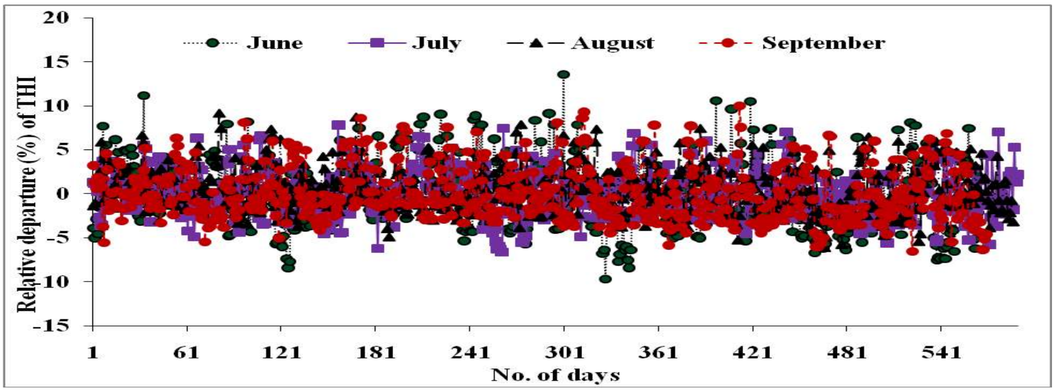

Fig. 2(b): Relative departure (%) of THI during monsoon months

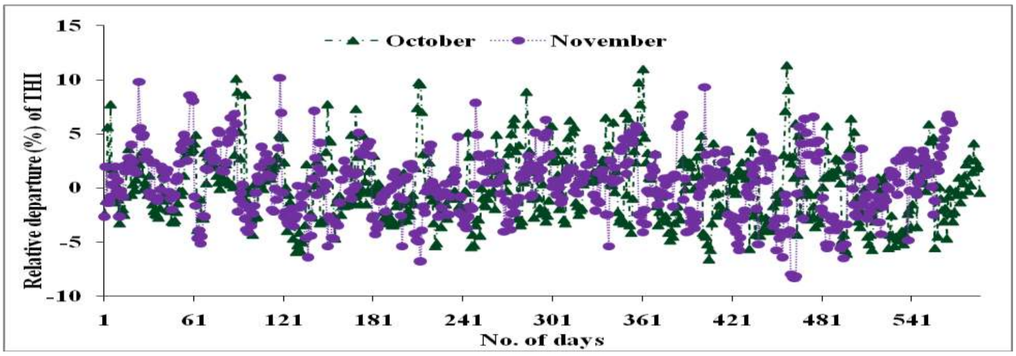

Fig. 2(c): Relative departure (%) of THI during post monsoon months

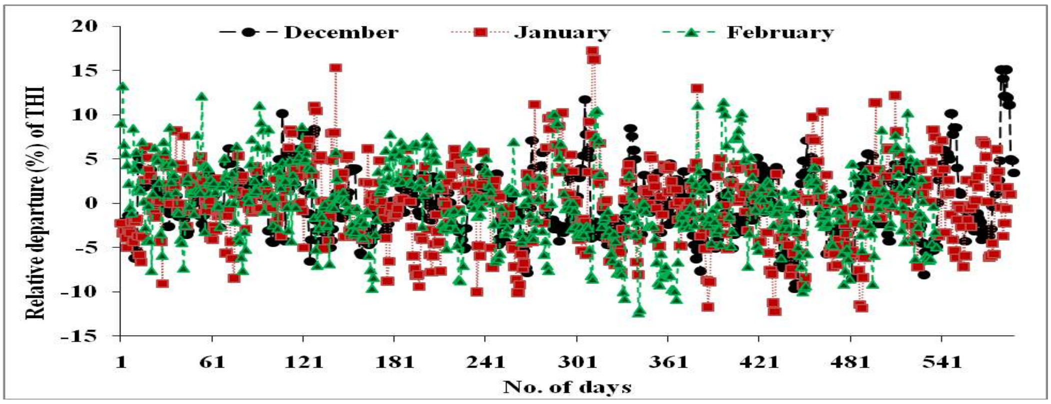

Fig. 2(d): Relative departure (%) of THI during winter months

ISSN: 2319-8753

IJIRSET

International Journal of Innovative Research in Science, Engineering and Technology

Vol. 2, Issue 7, July 2013

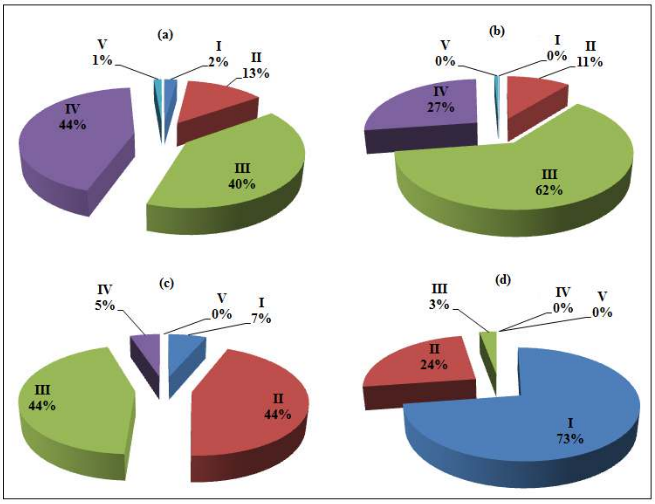

Fig. 3: Frequency distribution of THI during (a) summer months, (b) monsoon months, (c) post monsoon months and (d) winter months

Though the discomfort starts from 24^{0}C having relative humidity 100%, but days are practically hot when the ambient temperature is ≥34^{0}C. It is observed that hot conditions dominate for nearly 76.57 days per year. Highest hot days (category IV and V) is found in the year 2010 and lowest in 1994. An increasing trend of hot days per year is observed (Fig. 4).

WBGT and RSI are still the index adopted for a board range of environment. THI are highly correlated with WBGT and RSI (Fig. 5 and Fig. 6) with R^2 values ranges from 0.94 to 0.97 and 0.75 to 0.95 respectively. Since THI is the discomfort index that is in use over than five decades, we developed a regional based scale for WBGT and RSI with reference to THI as given in Table III.

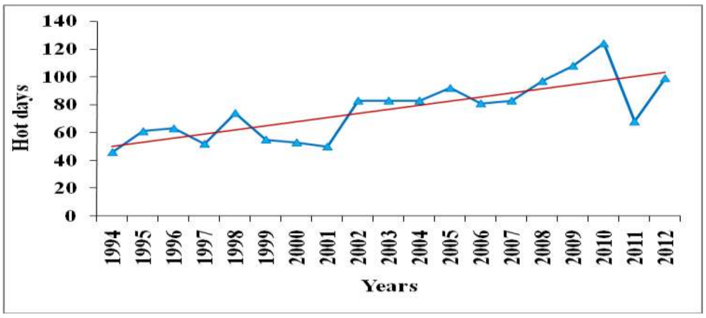

Fig. 4: Trends of hot days (1994 to 2012)

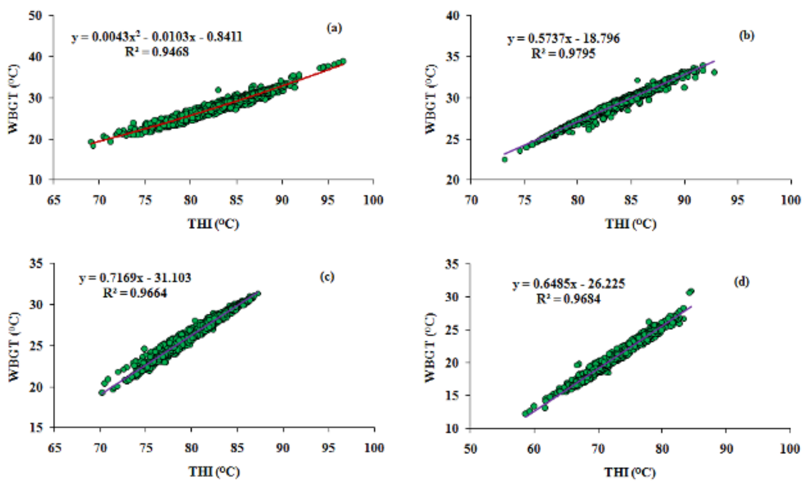

Fig. 5: Correlation between THI and WBGT during (a) summer months, (b) monsoon months, (c) post monsoon months and (d) winter months

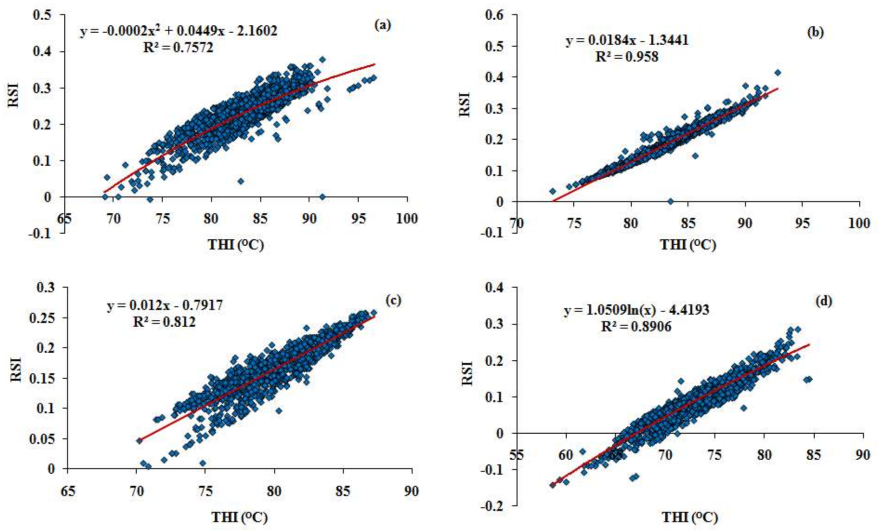

Fig. 6: Correlation between THI and RSI during (a) summer months, (b) monsoon months, (c) post monsoon months and (d) winter months

TABLE III
Regional based scale of WBGT and RSI

THI	WBGT	RSI
75≥ to >65	15.86 – 24.65	0.068
80≥ to >75	24.66 to 27.33	0.137
85≥ to >80	27.34 to 31.87	0.195
90≥ to >85	31.87 to 34.2	0.261
>90	>34.2	0.322

IV. CONCLUSIONS

There are many indices used by agronomists, agriculturists, meteorologist, physiologist and engineers that represent accurately heat stress and the comfortability zones. But for suggesting safety work rate, clothing and behavioral adjustment of a person should include in the index. Integrated approach may give better results. Other environmental parameters such as sweat evaporation, metabolic rate, wind speed, clothing insulation, relative humidity, solar radiation has both positive and negative feedback on the heat load.

Based on WBGT index, ACGIH (American Conference of Government Industrial Hygienists) published permissible heat exposure threshold limits values. In addition work-rest cycle and fluid replacement volumes will sustain the performance of the worker (Table IV). However fluid need may vary on individual and exposure to open sky or shaded area. Prevailing heat load is highly needed for biometeorological perspective.

TABLE IV
The guidelines of working under different heat load levels [30]

Work demands	**Acclimated**				**Non-acclimated**			
	L	M	H	VH	L	M	H	VH
100% work	29.5	27.5	26.0		27.5	25.0	22.5	
75% work; 25% rest	30.5	28.5		27.5	29.0	26.5	24.5	
50% work; 50% rest	31.5	29.5	28.5	27.5	30.0	28.0	26.5	25.0
25% work; 75% rest	32.5	31	30	29.5	31.0	29.0	28	26.5

Work demands: L = light work; M = moderate work; H = heavy work; VH = very heavy work.
WBGT additions for clothing type are as follows: summer work uniform = 0; woven material overalls = +3.5; double-cloth overall = +5

ACKNOWLEDGEMENTS

Financial support of University Grants Commission, New Delhi and PURSE Programme of Kalyani University, West Bengal are thankfully acknowledged.

REFERENCES

[1] Y. Epstein, G. Keren, J. Moisseiev, O. Gasko, and S. Yachin, "Psychomotor determination during exposure to heat". Aviat Space Environ. Med., vol. 51, pp. 607-610, 1980.
[2] P. A. Bell, "Physiological, comfort, performance and social effects of heat stress" J. Soc. Issues, vol. 37, pp. 71-94, 1981.
[3] K. Parsons, Human thermal environments, 2nd Ed., Taylor & Francis, London, pp. 258-292, 2003.
[4] Y. Epstein, and D. S. Moran, "Thermal comfort and the heat stress indices", Industrial Health, vol. 44, pp. 388-398, 2006.
[5] J. F. Wing, "Upper thermal tolerance limits for unimpaired mental performance", Aerospace Med., vol. 36, pp. 960-964, 1965.
[6] Y. Shapiro, and Y. Epstein, "Environmental physiology and indoor climate-thermoregulation and thermal comfort", Energy Build, vol. **7**, pp. 29-34, 1984.
[7] K. K. Chakrabarty, "An usual cold day in Calcutta in the third week of April", Vayumandal, vol. 12, pp. 29-31, 1982.
[8] D. R. Sikka, and S. M. Kulshrestha, "Climate and health studies: status and scopes in India", India Institute of Tropical Meteorology, Pune., Tech. report 5, 2003.
[9] D. S. Pai, V. Thapliyal, and P. D. Kotate, "Decadal variation in the heat and cold waves over India during 1971-2000", Mausam, vol. 55 (2), pp. 281-292, 2004.
[10] R. F. Wallace, D. Kriebel, L. Punnett, D. H. Weghman, C. B. Wenger, J. W. Gardner, and R. R. Gonzales, "The effects of continuous hot weather training on risk of exertional heat illness", Med. Sci. Sports Exerc., vol. 37, pp. 84-90, 2005.
[11] S. Miller, and G. P. Bates, "The thermal work limit is a simple reliable heat index for the protection of workers in thermally stressful environment", Ann. Occup. Hyg., vol. 51, pp. 553-561, 2007.
[12] T. Kjellstrom, and B. Lemke, "Estimating heat stress indices from routine weather station data; an important tool to support adaption planning", IOP Conf. Series: Earth and Environmental Science, 2009, 6, pp. 39-40.
[13] Bhattacharya R. and Biswas G. "Physiological stress during hot weather months over Kolkata, West Bengal", Proc. Biodiversity, Water Resources and Climate Change Issues, Kalyani University, 2010, pp. 110-115.
[14] R. Bhattacharya, G. Biswas, R. Guha, S. Pal, and S. S. Dey, "On the variation of summer thermal stress over Kolkata from 1995 to 2009", Vayumondal, vol. 36, pp. 16-21, 2010.
[15] R. Bhattacharya, S. Pal, G. Biswas, S. Karmakar, and R. Banik, "An estimation of heat stress in tropics", Int. J. Eng. Sci. Tech., vol. 4, pp. 4302-4307, 2012.
[16] E. Angouridakis, and T. J. Makrogiannis, "The discomfort-index in Thessaloniki", International Journal of Biometeor, vol. 26, pp. 53-59, 1982.
[17] K. K. Chakrabarty, A. K. Nath, and S. Sengupta, "Nor'wester over West Bengal and comfortability", Mausam, vol. 58, pp. 177-188, 2007.
[18] E. C. Thom, "A new concept for cooling degree days", Air Condit. Heat and Ventil., vol. 54, pp. 73-80, 1957.
[19] E. C. Thom, "The discomfort index", Weatherwise, vol. 12, pp. 57-60, 1959.
[20] C. P. Yaglou, and D. Minard, "Control of heat causalties at military training centers", Am. Med. Ass. Arch. Ind. Hlth., vol. 16, pp. 302-316, 1957.
[21] NIOSH, "Occupational exposure to hot environment", National Institute for Occupational safety and Health, HSM 72-10269, Department of Health, Education and Welfare, Washington DC, 1972.
[22] Y. Shapiro, K. B. Pandolf, and R. F. Goldman, "Predicting sweat loss response to exercise, environment and clothing", Eur. J. Appl. Physiol., vol. 48, pp. 83-96, 1982.
[23] G. K. Manohar, and A. P. Kesarkar, "Climatology of thunderstom activity over the Indian region: Spatial distribution", Mausam, vol. 55, pp. 31- , 2004.
[24] http://www.nws.noaa.gov/os/windchill/windchillfaq.shtml
[25] S. K. Prasad, and B. C. Power, "Discomfort over Bombay during winter", Vayumandal, vol. 12, pp. 53-54, 1982.
[26] H. Mayer, and P. Hoppe, "Thermal comfort of man in different urban environments", Theor. Appl. Climatol., vol. 38, pp. 43-49, 1987.
[27] Y. Shapiro, and D. S. Seidman, "Field and clinical observations of exertional heat stroke patients", Med. Sci. Sports Exerc., vol. 22, pp. 6-14, 1990.
[28] S. Thorsson, T. Honjo, F. Lindberg, I. Eliasson, and E. M. Lim, "Thermal comfort and outdoor activity in Japanese urban public places", Environment and Behavior, 39, pp. 660-684, 2007.
[29] R. L. Hwang, T. P. Lin, and A. Matzarakis, "Seasonal effect of urban street shading on long-term outdoor thermal comfort", Building and Environment, pp. 1-8, 2010.
[30] ACGIH, "TLVs and BELs. Threshold limit values for chemical substances and physical agents and biological exposure indices", ACGIH Signature Publications, Cincinnati, pp. 168-176, 2004.