

# **A comparative study of topography controlled temperature distribution of the hill and plain stations in North East India in associated with thermal comfort**

## **Abstract:**

This study investigates the role of topography in controlling temperature distribution across hill and plain stations in North-East India using Indian Meteorological Department (IMD) climatological normal data for the period 1991–2020. The analysis is based on key thermal parameters, including mean daily maximum and minimum temperatures, wet bulb and dry bulb temperatures, and extreme temperature indices. Selected stations of North-East India representing contrasting topographic settings—such as Shillong, Aizawl and Kohima (hill stations), and Guwahati, Silchar and Agartala (plain stations)—have been comparatively examined. The study evaluates spatial variation in temperature, diurnal temperature range (DTR), and thermal comfort conditions influenced by elevation and terrain characteristics. Statistical techniques such as mean, standard deviation, correlation, and regression analysis have been applied to establish the relationship between elevation and temperature variables. The results reveal a significant inverse relationship between elevation and temperature, with hill stations exhibiting lower mean temperatures and reduced diurnal variation compared to plains. Furthermore, higher wet bulb temperatures in lowland areas indicate increased humidity and thermal discomfort. The findings highlight the dominant role of topography in shaping regional thermal regimes and provide valuable insights for climate assessment, environmental planning, and regional development in North-East India.

**Keywords:** Topography, Temperature Distribution, Elevation, Diurnal Temperature Range (DTR), Thermal Comfort.

## **1. Introduction**

Temperature is one of the most fundamental elements of climate, significantly influencing environmental processes, human comfort, agriculture, and regional development. The spatial distribution of temperature is controlled by several factors, among which topography plays a dominant role, particularly in regions with complex terrain. Variations in elevation, slope, and aspect directly affect the receipt and distribution of solar radiation, atmospheric circulation, and moisture conditions, thereby shaping local and regional thermal regimes.

North-East India represents a unique geographical setting characterized by diverse physiographic features, including high hills, plateaus, and low-lying plains. The region experiences a humid subtropical to montane climate, strongly influenced by the southwest monsoon. Due to its varied

topography, significant spatial heterogeneity in temperature distribution is observed across the region. Hill stations such as Shillong, Aizawl, and Kohima generally exhibit lower temperatures and reduced diurnal variation, whereas plain stations like Guwahati, Silchar, and Agartala experience relatively higher temperatures and greater thermal stress.

One of the key mechanisms governing temperature variation with altitude is the environmental lapse rate, which indicates a decrease in temperature with increasing elevation. In addition, factors such as cloud cover, humidity, and vegetation further modify temperature conditions, especially in monsoon-dominated regions like North-East India. The presence of high moisture content in the atmosphere often leads to lower diurnal temperature range (DTR) in hill regions, while plains tend to experience higher DTR due to greater heating during the day and relatively slower cooling at night.

Despite the importance of topographic control on temperature distribution, comprehensive comparative studies focusing on hill and plain stations in North-East India using long-term climatological data remain limited. The use of standardized climatological normals provides a reliable basis for understanding long-term thermal characteristics and spatial variability.

In this context, the present study aims to examine the role of topography in controlling temperature distribution across selected hill and plain stations of North-East India using IMD climatological normal data for the period 1991–2020. The study further seeks to analyse variations in mean temperature, diurnal temperature range, and thermal comfort conditions, and to establish the statistical relationship between elevation and temperature parameters.

## **2. Literature Review**

The relationship between topography and temperature distribution has been widely studied in climatology and physical geography. It is well established that elevation plays a critical role in controlling temperature patterns through the environmental lapse rate, which indicates a general decrease in temperature with increasing altitude. Early climatological studies have demonstrated that mountainous regions tend to experience lower temperatures and reduced thermal variability compared to adjacent lowland areas due to differences in atmospheric pressure, radiation balance, and air density.

Several global studies have highlighted that topographic factors such as elevation, slope, and aspect significantly influence local and regional climates. Mountain environments often exhibit complex microclimatic conditions, where temperature distribution is further modified by cloud cover, vegetation, and moisture availability. In humid regions, particularly those influenced by monsoonal circulation, high atmospheric moisture tends to reduce the diurnal temperature range (DTR) by limiting daytime heating and nighttime cooling.

In the Indian context, numerous studies have examined the spatial variability of temperature across different physiographic regions, including the Himalayas, the Western Ghats, and the North-East. These studies consistently report an inverse relationship between elevation and temperature, with

hill stations experiencing cooler climates compared to plains. Research conducted in monsoon-dominated regions has also emphasized the role of humidity in moderating temperature extremes and influencing thermal comfort conditions.

With specific reference to North-East India, existing literature primarily focuses on rainfall patterns, monsoon dynamics, and general climatic characteristics. While some studies have addressed temperature variability, comprehensive analyses comparing hill and plain stations using long-term standardized climatological data remain limited. Moreover, the role of thermal comfort indicators, particularly wet bulb temperature, has not been adequately explored in the regional context.

Therefore, a clear research gap exists in terms of a systematic comparative assessment of temperature characteristics between hill and plain stations in North-East India using recent climatological normals. The present study seeks to address this gap by utilizing IMD climatological data (1991–2020) to analyse spatial temperature variation, diurnal temperature range, and the influence of elevation on thermal conditions

### **3. Data and Methodology**

#### **3.1 Data Source**

The present study is based on secondary data obtained from the climatological normals published by the India Meteorological Department (IMD) for the period 1991–2020. The dataset provides long-term averaged values of key meteorological parameters, ensuring reliability and consistency in climatic analysis.

Temperature-related variables considered in this study include mean daily maximum temperature (Tmax), mean daily minimum temperature (Tmin), mean wet bulb temperature, mean dry bulb temperature, mean highest maximum temperature, and mean lowest minimum temperature. These parameters are essential for understanding both average thermal conditions and extreme temperature behaviour.

#### **3.2 Data Processing and Analysis**

The data were processed using MS Excel. Diurnal Temperature Range (DTR) was calculated as the difference between Tmax and Tmin, while the wet–dry bulb difference was derived to assess atmospheric moisture conditions.

Descriptive statistics such as mean, standard deviation, and coefficient of variation were used to examine variability. Pearson’s correlation and simple linear regression analyses were applied to evaluate the relationship between elevation and temperature parameters.

Graphical presentation bar graphs used to illustrate the spatial and seasonal variation of the Discomfort Index (DI) across selected hill and plain stations in Northeast India.

### 3.3 Analytical Framework

A comparative approach was adopted to analyse differences between hill and plain regions, with emphasis on temperature distribution, diurnal variation, and the influence of topography.

### 3.5 Study area

The study area comprises selected hill and plain stations located in North-East India (Table 1), a region known for its diverse topography and climatic heterogeneity. The hill stations—Shillong, Aizawl, and Kohima—are situated in elevated terrains of the Khasi, Mizo, and Naga Hills, respectively. These areas experience relatively cooler temperatures, higher rainfall, and reduced thermal extremes due to altitudinal influence and orographic effects.

On the other hand, the plain stations—Guwahati, Silchar, and Agartala—are located in the Brahmaputra and Barak valley systems and adjacent lowlands. These regions are marked by higher temperatures, increased humidity, and greater diurnal temperature variation. The entire study area falls under a humid subtropical climatic regime influenced by the southwest monsoon, which significantly affects temperature and moisture distribution.

The clear physiographic contrast between hill and plain stations makes the region highly suitable for examining the role of topography in controlling temperature distribution and thermal comfort conditions.

**Table 1: Description of the Study Area ( Hill and Plain Stations of North-East India)**

Station	Type	State	Latitude (N)	Longitude (E)	Elevation (m)	Physiographic Characteristics
Shillong	Hill	Meghalaya	25.57°N	91.88°E	1496	Located on Khasi Hills; moderate climate, high rainfall
Aizawl	Hill	Mizoram	23.73°N	92.72°E	1132	Situated on Mizo Hills; undulating terrain and humid conditions
Kohima	Hill	Nagaland	25.67°N	94.11°E	1444	Mountainous terrain with moderate temperature variation
Guwahati	Plain	Assam	26.18°N	91.73°E	55	Brahmaputra valley; low elevation, humid subtropical climate
Silchar	Plain	Assam	24.83°N	92.78°E	22	Barak valley; high humidity and rainfall
Agartala	Plain	Tripura	23.83°N	91.28°E	40	Low-lying plain; warm

#### 4. Result and Discussion

The following table 2 presents the seasonal variation of temperature (maximum and minimum) across selected hill and plain stations of North-East India. The data highlights the influence of elevation on temperature distribution and allows a comparative analysis between different topographic regions.

**Table 2: Mean Seasonal Maximum and Minimum Temperature along with Elevation for Selected Hill and Plain Stations in North-East India:**

Station	Type	Elevation (m)	Jan Max	Apr Max	Jul Max	Oct Max	Jan Min	Apr Min	Jul Min	Oct Min
Shillong	Hill	1496	15.2	23.4	24.2	21.9	5.7	14.1	17.9	14.2
Aizawl	Hill	1132	23.3	28.8	27	27.2	11.3	17.5	20.2	19.1
Kohima	Hill	1444	16.1	25.2	25.8	24.2	5.1	13.3	17.2	13.5
Guwahati	Plain	55	23.9	31.2	32.8	31.3	10.8	20.3	25.9	22.3
Silchar	Plain	22	25.2	31.6	32.8	31.9	12.3	21.2	25.5	23.2
Agartala	Plain	40	24.9	33.3	32.1	31.8	10.8	22.5	25.6	23.1

Source: IMD Climatological Data (1991–2020)

We have studied the Elevation–Temperature Relationship. A clear inverse relationship is observed between elevation and temperature. Stations at higher elevations record lower temperatures compared to low-lying stations. High-altitude stations such as Shillong, Kohima, and Aizawl consistently show lower maximum and minimum temperatures. The cooler conditions are evident across all selected months (January, April, July, October).

Low-altitude stations like Guwahati, Silchar, and Agartala exhibit significantly higher temperatures. Both maximum and minimum temperatures remain higher throughout the year. The elevation-based temperature difference is consistent in all seasons. Even during cooler months (January), plains remain warmer than hill stations.

The difference in temperature between hill and plain stations is more pronounced during warmer months (April and July). This suggests stronger heating effects in lowland areas. Night-time (minimum) temperatures are also lower in hill stations, indicating cooler nocturnal conditions at higher elevations. Plains retain more heat, leading to higher minimum temperatures. The observed pattern confirms that elevation plays a key role in controlling temperature distribution. The variation is influenced by altitude-related factors such as lapse rate and atmospheric conditions.

During winter, temperatures remain lowest across all stations, but a clear elevation effect is observed. High-altitude stations such as Shillong and Kohima experience significantly lower maximum and minimum temperatures. Low-lying stations like Guwahati and Silchar remain comparatively warmer. The temperature contrast highlights strong cooling effects associated with higher elevation.

A rapid increase in temperature is observed across all stations during the pre-monsoon period. Plain stations such as Agartala and Guwahati record significantly higher temperatures compared to hill stations. Hill stations maintain relatively moderate temperatures despite seasonal warming. The temperature gap between hill and plain stations becomes more pronounced during this season.

During the monsoon season, temperatures remain high but relatively stable due to cloud cover and rainfall. Plain stations such as Silchar and Guwahati continue to experience higher temperatures. Hill stations show comparatively lower temperatures due to elevation and orographic effects. The influence of altitude remains evident despite the moderating effect of monsoon conditions.

A gradual decline in temperature is observed after the monsoon season. Hill stations again exhibit cooler conditions compared to plains. Plain stations such as Agartala retain relatively higher temperatures due to residual heat. The elevation-controlled temperature pattern continues to persist.

Hill stations (Shillong, Aizawl, Kohima) record comparatively lower dry and wet bulb temperatures. Plain stations (Guwahati, Silchar, Agartala) show higher temperature values. This clearly reflects the influence of altitude (environmental lapse rate).

As evident from the table 3, the lowest temperature is observed at Shillong (Dry: 17.9°C, Wet: 14.5°C). The highest temperature is recorded at Agartala (Dry: 25.0°C, Wet: 22.5°C). This indicates significant spatial variation controlled by topography. At all stations, dry bulb temperature is higher than wet bulb temperature. This difference represents the moisture condition of the atmosphere. A smaller difference indicates higher humidity levels.

**Table 3: Average Dry Bulb and Wet Bulb Temperature (°C) based on 03UTC & 12 UTC  
[ (January, April, July and October) (1991–2020)]**

Station	Type	Dry Bulb Temp(°C)	Wet Bulb Temp (°C)
Shillong	Hill	17.9	14.5
Aizawl	Hill	21 .2	1 9.0
Kohima	Hill	20.5	17.2
Guwahati	Plain	23.9	21 .7
Silchar	Plain	23.9	22.4
Agartala	Plain	25	22.5

Source: IMD Climatological Data (1991–2020)

Plain stations show a smaller difference between dry and wet bulb temperatures. For example, Silchar shows a difference of about 1.5°C. This suggests higher relative humidity in plain areas. Hill stations show a relatively larger difference, indicating comparatively drier conditions. Hill stations experience a relatively cool and moderate climate. Plain stations are characterized by warmer thermal conditions. Temperature distribution is strongly influenced by topography. An increase in elevation leads to a decrease in temperature. Shillong, being a high-altitude station, records the lowest temperature. Plain areas retain more heat due to lower elevation. The table clearly demonstrates that hill stations experience lower dry and wet bulb temperatures compared to plain stations due to the influence of altitude. The smaller difference between dry and wet bulb temperatures in plains indicates higher humidity, whereas hill stations exhibit relatively drier and cooler conditions.

Relative humidity values remain moderately high to high across all stations. This indicates a moist atmospheric condition in the study region throughout the selected months. Plain stations generally exhibit slightly higher relative humidity compared to hill stations. This is due to low elevation, higher moisture retention, and proximity to valley systems. Hill stations show relatively lower humidity, especially during non-monsoon months. Table 4 shows Average Relative Humidity for different stations from 1991 to 2020.

**Table 4: Average Relative Humidity (%) based on 03 UTC and 12 UTC Observations**

Station	Type	Jan (%)	Apr (%)	Jul (%)	Oct (%)
Shillong	Hill	72.5	68	85.5	80.5
Guwahati	Plain	80	68	82.5	80.5
Silchar	Plain	79.5	77	85.5	83.5
Agartala	Plain	79	70.5	82	82

Source: IMD Climatological Data (1991–2020)

Relative humidity tends to be highest during the monsoon season (July). It is comparatively lower during winter (January). This reflects the seasonal influence of monsoon circulation and moisture availability.

Humidity is generally higher at 12 UTC (evening) than at 03 UTC (morning). This is associated with lower temperature and increased moisture retention in the evening. Stations like Silchar and Agartala tend to show consistently higher humidity levels, indicating stronger moisture influence. Shillong shows relatively moderate humidity, reflecting its elevated terrain.

### **Relation with Thermal Comfort**

High relative humidity reduces the rate of evaporation of sweat, leading to thermal discomfort. Even moderate temperatures can feel warmer and more oppressive in humid

conditions. In plain stations, the combination of high temperature + high humidity leads to low thermal comfort. This results in hot and humid conditions, especially during summer and monsoon. Hill stations experience lower temperatures, which partly offsets the effect of humidity.

Therefore, thermal conditions are more comfortable compared to plains, despite moderate humidity. During July, very high humidity levels significantly reduce comfort levels across all stations. The effect is more severe in plains due to higher temperatures.

The analysis of relative humidity indicates consistently high moisture conditions across both hill and plain stations, with slightly higher values observed in plains. Seasonal variation highlights peak humidity during the monsoon months.

Thermal comfort assessment has been evaluated using the Discomfort Index (DI), which integrates the combined effects of air temperature and humidity on human comfort levels. The DI was calculated using the mean dry bulb temperature and relative humidity for the selected months (January, April, July, and October) during the period 1991–2020.

The Discomfort Index (DI) is expressed as, where  $T$  represents the dry bulb temperature ( $^{\circ}\text{C}$ ) and  $\text{RH}$  denotes the relative humidity (%). In cases where relative humidity data were not directly available, it was approximated based on the relationship between dry bulb and wet bulb temperatures.

Based on the computed DI values, thermal comfort conditions were classified into four categories: comfortable ( $\text{DI} < 21^{\circ}\text{C}$ ), slight discomfort ( $21\text{--}24^{\circ}\text{C}$ ), moderate discomfort ( $24\text{--}27^{\circ}\text{C}$ ), and severe discomfort ( $\text{DI} > 27^{\circ}\text{C}$ ). This classification helps in understanding the spatial and seasonal variation of thermal stress across hill and plain stations. The analysis enables a comparative assessment of thermal comfort conditions and highlights the role of topography in influencing human-perceived climate in North-East India.

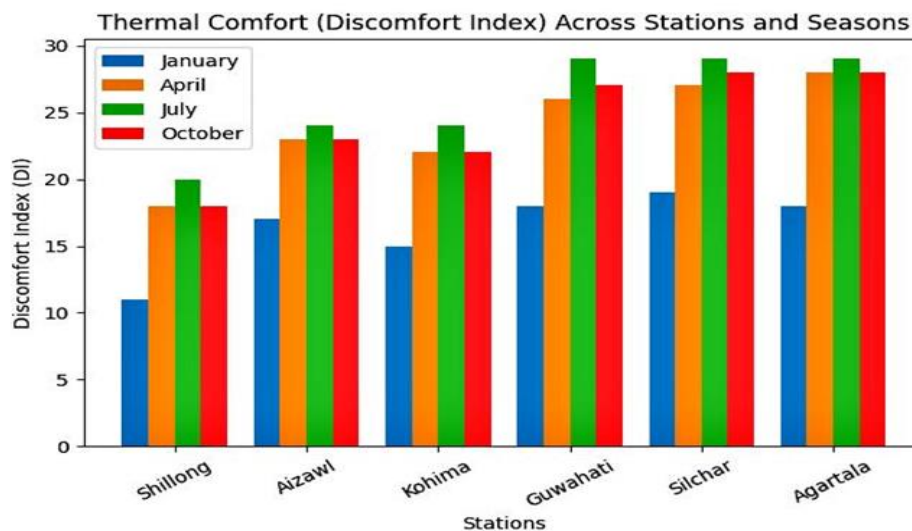


Fig-1 Source: IMD Climatological Data (1991–2020)

The bar diagram illustrates the spatial and seasonal variation of the Discomfort Index (DI) across selected hill and plain stations in Northeast India. A clear distinction is observed between hill stations (Shillong, Aizawl, and Kohima) and plain stations (Guwahati, Silchar, and Agartala), highlighting the influence of topography on thermal comfort.

Among the hill stations, Shillong consistently records the lowest DI values in all seasons, remaining within the comfortable to slightly uncomfortable range. Aizawl and Kohima exhibit moderate DI values, with a gradual increase from January to July, indicating rising discomfort during the warmer and wetter months. However, their DI values remain comparatively lower than those of the plain stations, suggesting relatively favorable thermal conditions.

In contrast, the plain stations show significantly higher DI values throughout the year. Guwahati, Silchar, and Agartala experience a sharp increase in DI from January to July, reaching peak values close to 29°C during the monsoon season, which indicates severe thermal discomfort. This pattern reflects the combined effect of high temperature and humidity in the plains. Even in October, the DI values remain high, indicating persistent discomfort.

### Diurnal Temperature Range (DTR)

The diurnal temperature range (DTR) varies from 14.7°C to 17.1°C across the stations. This indicates a moderate level of day–night temperature variation in the study region. Hill stations (Shillong, Aizawl, Kohima) generally exhibit lower to moderate DTR. Plain stations (Guwahati, Silchar, Agartala) show slightly higher DTR values. This reflects stronger heating and cooling contrasts in the plains.

Shillong records the lowest DTR (14.7°C). This is due to high elevation, greater cloud cover and higher moisture content. These factors reduce both daytime heating and nighttime cooling. Agartala shows the highest DTR (17.1°C). This indicates strong daytime heating, significant nighttime cooling and typical of lowland plain environments.

**Table 4: Diurnal Temperature Range (DTR) (°C) Derived from Mean Highest Maximum and Mean Lowest Minimum Temperatures (1991–2020)**

Station	Type	Highest Temp(°C)	Lowest Temp(°C)	DTR(°C)
Shilong	Hill	24.6	9.9	14.7
Aizawl	Hill	30.4	13.9	16.5
Kohima	Hill	26.1	9.5	16.6
Guwahati	Plain	33.5	16.9	16.6
Silchar	Plain	34	17.8	16.2
Agartala	Plain	33.9	16.8	17.1

Source: IMD Climatological Data (1991–2020)

### **Elevation plays a key role in controlling DTR**

- Higher altitude → lower DTR
- Lower altitude → higher DTR

Hill regions experience a moderated thermal regime, whereas plains show greater variability. Lower DTR indicates thermal stability and reduced variability. Higher DTR reflects greater climatic variability and stronger diurnal contrasts. Cloud cover and humidity tend to reduce DTR by: Limiting solar heating during the day Reducing heat loss at night. These effects are more pronounced in hill regions.

The analysis of diurnal temperature range (DTR) reveals that hill stations experience relatively lower thermal variability compared to plain stations. The reduced DTR in elevated regions highlights the moderating influence of altitude, cloud cover and humidity, whereas the higher DTR in plains reflects stronger diurnal heating and cooling. These variations have significant implications for regional climate and thermal comfort conditions.

### **5. Conclusion**

The present study provides a comprehensive assessment of the role of topography in modulating temperature distribution across hill and plain stations in Northeast India, based on long-term climatological observations (1991–2020). The analysis reveals a clear altitudinal control on thermal conditions, with hill stations such as Shillong, Aizawl and Kohima consistently exhibiting lower dry bulb and wet bulb temperatures compared to their plain counterparts, namely Guwahati, Silchar and Agartala. This inverse relationship between elevation and temperature conforms to the established environmental lapse rate and underscores the dominant influence of physiography on regional climate.

The study further demonstrates that atmospheric moisture, as reflected by relative humidity and wet bulb temperature, plays a critical role in shaping thermal characteristics. Plain stations, characterized by lower elevation and enhanced moisture retention, exhibit a narrower dry–wet bulb temperature difference, indicating persistently humid conditions. In contrast, hill stations display relatively larger differences, suggesting comparatively drier atmospheric conditions despite overall high humidity levels in the region.

The evaluation of diurnal temperature range (DTR) highlights moderate spatial variability, with relatively lower values observed in elevated terrains and higher values in the plains. This pattern reflects the combined influence of altitude, cloud cover and moisture availability, which act to suppress diurnal thermal amplitude in hill regions while allowing greater heating and cooling contrasts in lowland areas. Such differences in thermal regimes are indicative of the complex interaction between topography and atmospheric processes.

From a bioclimatic perspective, the findings suggest that thermal comfort conditions vary significantly across the region. The coexistence of high temperature and high humidity in plain

areas contributes to increased thermal stress, particularly during the pre-monsoon and monsoon seasons. Conversely, the relatively cooler and thermally stable conditions in hill stations offer a more favourable environment for human comfort.

In conclusion, the study establishes that topography, in conjunction with atmospheric moisture and cloud dynamics, exerts a fundamental control over temperature patterns and thermal variability in Northeast India. The integration of temperature indices, humidity parameters and DTR provides a nuanced understanding of regional climate behaviour. These insights have important implications for climate-sensitive planning, sustainable development and the assessment of human-environment interactions in diverse physiographic settings.

### References:

1. Barry, R. G., R. G., & Chorley, R. J. (2009). *Atmosphere, Weather and Climate* (9<sup>th</sup> ed.). Routledge.
  2. Critchfield, H. J. (1983). *General Climatology* (4<sup>th</sup> ed.). Prentice Hall.
  3. Lal, D. S. (2012). *Climatology*. Sharda Pustak Bhawan.
  4. India Meteorological Department (2020). *Climatological Tables (1991–2020)*. Government of India.
  5. World Meteorological Organization (2018). *Guide to Climatological Practices* (WMO-No. 100).
  6. Oke, T. R. (1987). *Boundary Layer Climates*. Routledge.
  7. Geiger, R., Aron, R. H., & Todhunter, P. (2009). *The Climate Near the Ground*. Rowman & Littlefield.
  8. Thom, E. C. (1959). The Discomfort Index. *Weatherwise*, 12(2), 57–61.
  9. Singh, S. (2013). *Climatology*. Prayag Pustak Bhawan.
- Government of India (various years). *Indian Climate Data Reports*.
10. Ahrens, C. D. (2015). *Meteorology Today: An Introduction to Weather, Climate, and the Environment* (11<sup>th</sup> ed.). Cengage Learning.
  11. Strahler, A. N., & Strahler, A. H. (2008). *Modern Physical Geography* (4<sup>th</sup> ed.). Wiley.
- Pidwirny, M. (2006). *Fundamentals of Physical Geography*. University of British Columbia.
12. Karl, T. R., Kukla, G., & Razuvayev, V. (1991). Global warming: Evidence for asymmetric diurnal temperature change. *Geophysical Research Letters*, 18(12), 2253–2256.

13. Dai, A., Trenberth, K. E., & Karl, T. R. (1999). Effects of clouds, soil moisture, precipitation, and water vapor on diurnal temperature range. *Journal of Climate*, 12, 2451–2473.
14. Vose, R. S., Easterling, D. R., & Gleason, B. (2005). Maximum and minimum temperature trends for the globe. *Journal of Geophysical Research*, 110.
15. Wallace, J. M., & Hobbs, P. V. (2006). *Atmospheric Science: An Introductory Survey* (2<sup>nd</sup> ed.). Academic Press.
16. Ramanathan, V. et al. (2001). Aerosols, climate, and the hydrological cycle. *Science*, 294(5549), 2119–2124.
17. Fanger, P. O. (1970). *Thermal Comfort: Analysis and Applications in Environmental Engineering*. McGraw-Hill.
18. American Society of Heating, Refrigerating and Air-Conditioning Engineers (2017). *ASHRAE Handbook—Fundamentals*.
19. Steadman, R. G. (1979). The assessment of sultriness. *Journal of Applied Meteorology*, 18(7), 861-873
20. Raghavan, S. (2012). *Monsoon Climatology*. Springer.
21. Yaglou, C. P., C. P., & Miller, D. R. (1925). Effective temperature with clothing. *Journal of the American Society of Heating and Ventilating Engineers*.
22. Gagge, A. P., A. P., Stolwijk, J. A. J., J. A. J., & Nishi, Y. (1967). An effective temperature scale based on a simple model of human physiological regulation. *ASHRAE Transactions*.
23. Fanger, P. O. (1970). *Thermal Comfort: Analysis and Applications in Environmental Engineering*. Copenhagen: Danish Technical Press.