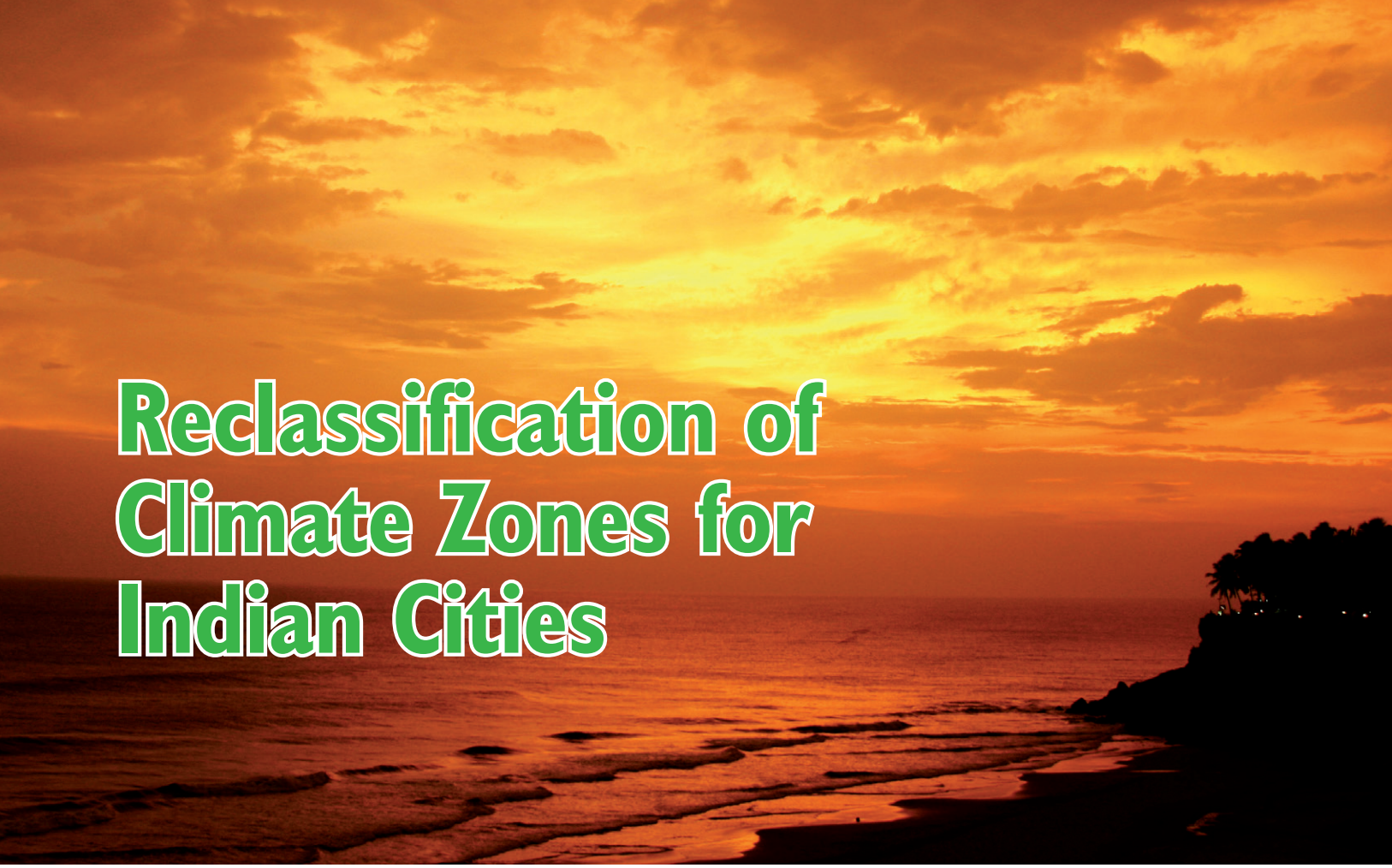

Reclassification of Climate Zones for Indian Cities

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Abstract
The development of building codes for energy efficiency depends on climate zones. Indian climate classification prescribes five climate zones in India. India has diversity in climates from severe cold to extremely hot conditions and the Indian climate classification does not consider fluctuation of outdoor conditions and its effect on indoor comfort conditions. Therefore, it is imperative to revisit the climate classification for Indian cities using other broader classification methods used globally.
This study introduces available international climate classification, a comparison with current Indian climate classification, the relevance of ASHRAE climate classification, and establishing a new classification for Indian cities based on ASHRAE climate classification. The ASHRAE classification divides Indian climate into 7 climate zones. This updated climate classification may improve the accuracy of the energy conservation codes and building design.
***Keywords**: Climate zone, building codes, climate classification*

Introduction

The weather of an area represents the state of the atmospheric environment over a brief time period. Integrated weather condition over several years is generally referred to as climate or, more specifically, as macro-climate. Regions having similar characteristic features of climate are grouped under one climatic zone. An analysis of the climate of a particular region can help in assessing the seasons or periods during which a person may experience comfortable or uncomfortable conditions. It further helps in identifying the climatic elements, as well as their severity, that cause discomfort. This information helps a designer to build a house that filters out adverse climatic effects, while simultaneously allowing those that are beneficial.[6]

In India *Bansal et al.* [1] had carried out detailed studies and reported that India can be divided into six climatic zones, namely, hot and dry, warm and humid, moderate, cold and cloudy, cold and sunny, and composite. The criteria of classification are described in *Table 1*. A place is assigned to one of the first five climatic zones only when the defined conditions prevail there for more than six months. In cases where none of the defined

categories can be identified for six months or longer, the climatic zone is marked as composite. [1]

Table 1: Bansal & Minke climate zone criteria

Climate Zone Categories	Mean Monthly Temperature (°C)	Relative Humidity (%)	Precipitation (mm)	No. of Clear Days
Hot & Dry	>30	<55	<5	>20
Warm & Humid	>30	>55	>5	<20
Moderate	25-30	<75	<5	>20
Cold & Cloudy	<25	>55	>5	<20
Cold & Sunny	<25	<55	<5	>20
Composite	When Six months or more do not fall within any of the above categories			

According to code of Bureau of Indian Standards *(National Building Codes, 2005 (NBC))* [9], the country may be divided into five major climatic zones. *Table 2* describes the criteria of this classification. It is seen that this modification in classification is not very different from the earlier one except that the cold and cloudy, and cold and sunny climates have been grouped together as cold climate. The moderate climate is renamed as temperate climate. [9]

Table 2: NBC 2005 climate zone criteria

Climate Zone Categories	Mean Monthly maximum Temperature (°C)	Mean Monthly Relative Humidity (%)
Hot & Dry	>30	<55
Warm & Humid	>30 >25	>55 >75
Temperate	25-30	<75
Cold	<25	All values
Composite	When six months or more do not fall within any of the above categories	

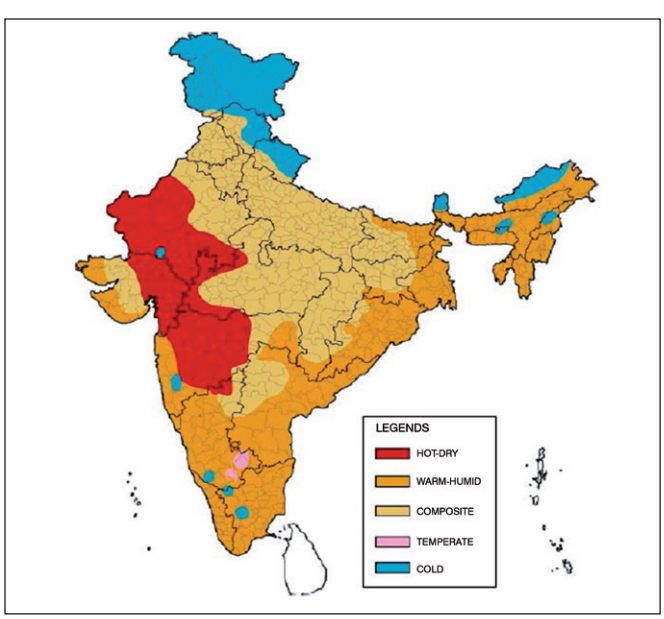

Figure 1: NBC climatic region [8,9]

However, due to the vast size of India and its complex geography, the climate in this part of the world has large spatial and temporal variations. *Dash et.al.* had carried out an analysis on climate change in India for 20th century and found that the mean temperatures during pre-monsoon and monsoon months have increased and the rainfall pattern indicates an increment in winter and pre-monsoon months, for example March and April. [13] Additionally, these climate classification systems are focused on outdoor conditions, which do not include building and occupant comfort parameters such as indoor temperature, relative humidity in categorization of climate zones. Therefore, there is a possibility of having more than five climate zones in India, which makes it necessary to revisit the climate classification for Indian cities based on globally accepted climate classifications.

For this study, we need to understand acceptable climate zone classification across the world. Various internationally acceptable climate classificationsare described in the following section.

Climate Classification

The initial contributors are astronomers and ancient Greeks who provided literature of consideration of climatic variation over the world. The ancient Greeks identified a three class, five zone system by knowledge of the Sun travel. These zones are – a torrid zone, two temperate zones and two frigid zones. This is the single variable climate classification. Several other attempts have been made in the field of climate classification. It is not possible to include all variations in this study. Some of them, which are widely spread over the world and used for classification of world climate, are discussed in this section.

Koppen-Geiger Classification

The first quantitative classification of world climates was presented by the German scientist Wladimir Koppen (1846-1940)

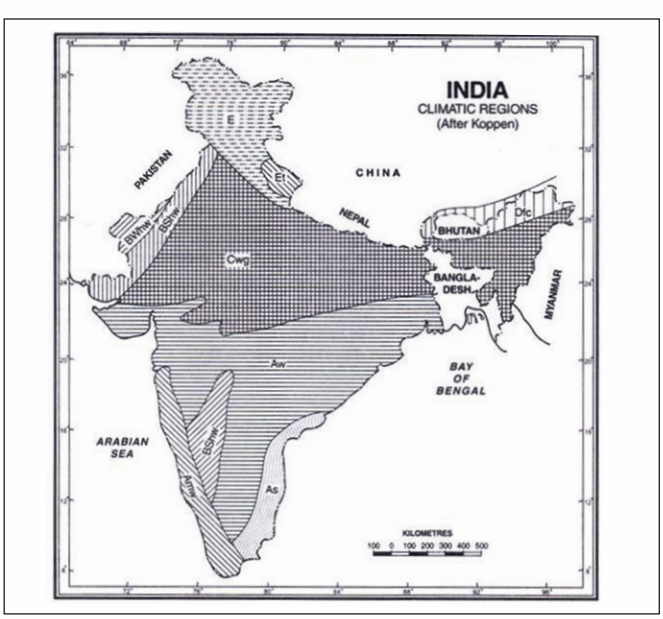

Figure 2: Koppen climatic regions of India [14]

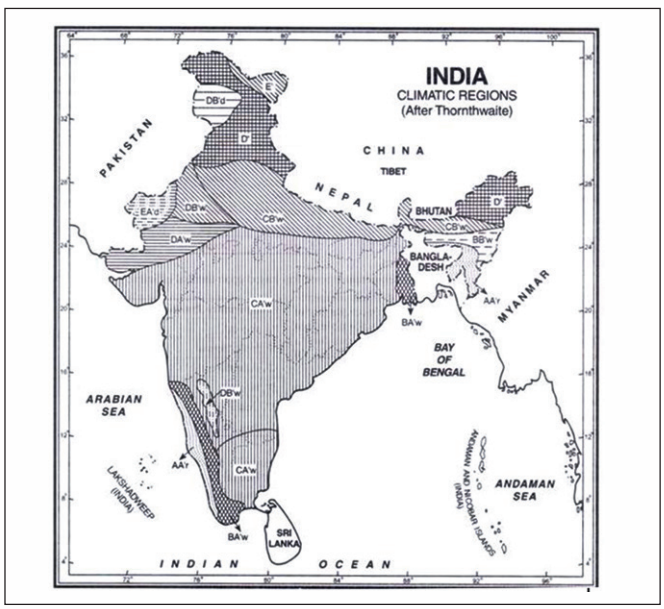

Figure 3: Thornwaite climatic regions of India [14]

in 1900; it has been available as a world map, later updated in 1954 and 1961 by Rudolf Gieger (1894-1981). His effective classification was constructed on the basis of five vegetation groups.[4] India has been classified into 9 climate zones. However, this classification is used specifically for agriculture and geographical research field.

Thornthwaite Climate Classification

An American scientist, C.W. Thornthwaite (1948), developed a well-known competitor to Koppen classification, although more complex and somewhat cumbersome to use. Thornwaite is credited with important contributions related to 'precipitation effectiveness' and 'thermal efficiency'. [2]

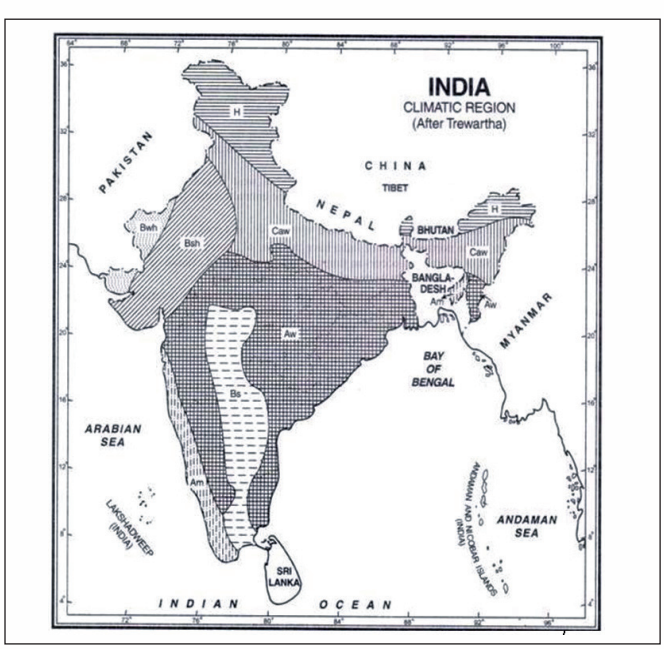

Figure 4: Trewartha climatic regions of India [14]

Thornthwaite defined 32 climatic types on the world map and out of these, only 12 climatic types are found in India.[14]

Strahler Climate Classification

A system for describing climates was devised in 1969 by A.N. Strahler, in which world climates are related to the main air masses that produce them, as (a) equatorial/tropical air masses, producing low-latitude climates; (b) tropical and polar air masses, producing mid-latitude climates; and (c) polar and arctic air masses, producing high latitude climates. Subsets of these are based on variations in temperature and precipitation to give 14 regional types, plus upland (highland) climates that are regarded as a separate category. [2,7]

G.T. Trewartha Climate Classification

The climate classification system devised by Trewartha represents a compromise between purely empirical and genetic methods. He classified the world climates into six climatic groups out of which five (A, C, D, E, F) are based on temperature and the sixth (B), the dry group, is based on precipitation.

The classification system proposed by Trewartha is for general purpose and mostly used for geographical and agriculture research work. [14]

Climate Classification through Energy Balance

Werner H. Terjung and Stella S-F Louie presented a generic climate classification of the world which is based on energy balance. The long and short wave inputs were abstracted into net radiation, whereas latent heat flux, vertical sensible heat flux and horizontal sensible heat flux (at interface level) were used as output components. This classification introduced six climatic groups and sixty-two climates. [15]

IEA (International Energy Agency)

In this model, the different climatic conditions are split into six climatic zones based on heating and cooling requirements. This classification system also takes into consideration cooling and heating degree day. However, the base temperature for both degree days is kept as 18°C. [5]

ASHRAE (American Society of Heating, Refrigeratiing and Air-conditioning Engineers)

Briggs et.al. [2] proposed a new climate classification in 2003 which was later included in ASHRAE Standard 169. This classification is based on two parameters: air temperature and precipitation. Air temperature is defined as Cooling Degree Day (CDD) and Heating Degree Day (HDD). The degree-day is essentially the summation of temperature differences over time, and hence they capture both the extremity and duration of outdoor temperatures. The temperature difference is between a reference (base) temperature and the outdoor air temperature. This system uses cooling criteria (CDD 10°C) for the cooling dominated climates and heating criteria (HDD 18°C) for heating-dominated climates for zone division. A mixed cooling and heating zone defined by both criteria falls in between. [11]

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Comparison of Different Climate Classifications

Table 3: Comparison of climate criteria for different classification systems

Classification Criteria/ Methodology	Mean Monthly Maximum Temperature (°C)	Mean Monthly Relative Humidity (%)	Precipitation (mm)	No. of Clear Days	Mean Monthly Temperature (°C)	Cooling Degree Days (10°C)	Cooling Degree Days (18°C)	Heating Degree Days (18°C)
Koppen	X	X	√	X	√	X	X	X
Bansal et.al.	√	√	√	√	X	X	X	X
NBC 2005	√	√	X	X	X	X	X	X
IEA	X	X	X	X	X	X	√	√
ASHRAE	X	X	√	X	√	√	X	√

ASHRAE classification provides a significant advantage over other methods that use daily mean outdoor temperature to calculate energy demand due to use of degree days.

Revisiting Climate Zone of Indian Cities

The methodology defined in ASHRAE Standard 169-2013 has been applied on the weather files of fifty-nine Indian cities. These files were developed by the Indian Society of Heating, Refrigerating and Air Conditioning Engineers (ISHRAE). For analysis, a Matlab program has been developed and validated by applying the data on the weather file of U.S. cities by defining different climate zones.

ASHRAE classification is defined by numeric numbers from 0 to 8 and letters A, B, and C. The definitions of numbers and letters are:[11]

Marine (C) Locations meet all four of the following criteria:

a) Mean temperature of coldest month between -3°C and 18°C;
b) Warmest month mean< 22°C;
c) At least four months with mean temperatures over 10°C;
d) Dry season in summer. The month with the heaviest precipitation in the cold season has at least three times as much precipitation as the month with the least precipitation in the rest of the year. The cold season is October through March in the Northern Hemisphere and April through September in the Southern Hemisphere. [11]

Dry (B) Locations meet the following criteria:

a) Not Marine (C);
b) If 70% or more of the precipitation, P, occurs during the high sun period, then the Dry/Humid threshold is

$$P < 2.0 \times (T + 14)$$

c) If between 30% and 70% of the precipitation, P, occurs during the high sun period, then the Dry/Humid threshold is

$$P < 2.0 \times (T + 7)$$

d) If 30% or less of the precipitation, P, occurs during the high sun period, then the Dry/Humid threshold is

$$P < 2.0 \times T$$

Where

P = annual precipitation in mm and

T = annual mean temperature in °C.

Summer or high sun period = April through September in the Northern Hemisphere, and October through March in the Southern Hemisphere.

Winter or cold season = October through March in the Northern Hemisphere and April through September in the Southern Hemisphere.[11]

Humid (A) Locations are those that are not marine and not dry. [11]

Table 4: ASHRAE standard 169-2013 climate zone criteria [11]

ASHRAE	Heating Degree Day (HDD 18°C)	Cooling Degree Day (CDD 10°C)	Climate Zone Number
Extremely Hot	-	6000<CDD	0
Very Hot	-	5000<CDD	1
Hot	-	3500<CDD<=5000	2
Warm	-	2500<CDD<3500	3
Warm-Marine	HDD<=2000	CDD<=2500	3C
Mixed	HDD<=3000	CDD<=2500	4
Mixed-Marine	2000<HDD<=3000	-	4C
Cool	3000<HDD<=4000	-	5
Cold	4000<HDD<=5000	-	6
Very Cold	5000<HDD<=7000	-	7
Subarctic	7000<HDD	-	8

India has been classified into seven climatic zones using ASHRAE Standard 169-2013 methodology. *Annexure 1* reports revised climate zones. ASHRAE Standard 169-2006 specified Indian cities in only one climate zone (Climate Zone-1). ASHRAE

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Standard 169-2013 (a revised version) specifies climate zones for 34 Indian cities based on World Meteorological Organization (WMO) data. A comparison of revised climate zones has been done with zones specified in Table A-6, ASHRAE Standard 169-2013 and NBC, 2005.

It is found that six cities (Aurangabad, Bikaner, Lucknow, Pune, Gwalior, and Hyderabad) have discrepancy in climate zones compared to Table A-6 of ASHRAE Standard 169-2013. The common discrepancy is dry-humid variation in climate type. This variation cannot be verified due to lack of data (precipitation in mm) in WMO weather file. Two cities (Bikaner and Hyderabad) have variation in climate zones (extreme hot or very hot), which is due to variation in CDD in WMO weather file and ISHRAE weather file.

Conclusion

The understanding of climatic features enables building designers to make energy efficient buildings that provide comfort to occupants and save energy. The energy codes define building envelope characteristics which rely on the clear definition of climate zones. These zones are used to define appropriate codes and standards. India has its own national energy code, Energy Conservation Building Code, 2007, which prescribed values for envelope parameters for five climate zones in India.

Indian cities are classified under five climate zones as per NBC, 2005. This study demonstrates the requirement to revise the climate zones using ASHRAE Standard 169-2013 methodology and compare with ASHRAE Standard 169-2013 and NBC, 2005 methodologies. The climate zones have been revised using latest weather data developed by ISHRAE using ASHRAE 169 and IEA methods.

The revised classification of climate zones for Indian cities is based on ASHRAE 169-2013 categories of seven climate zones, the highest number of categorization compared to other classification systems. ASHRAE and IEA both utilize HDD and CDD for classification. HDD and CDD lead to more realistic results in the context of building energy. However, the base temperature for the cooling degree is different: 10°C in ASHRAE and 18°C in IEA.

Annexure 1: Revised Climate Zones

Cities	Revised climate zones based on ASHRAE 169-2013 classification (ISHRAE 2014 Weather data)		ASHRAE 169-2013- (Table A-6) (WMO Weather data)		NBC, 2005
Ahmedabad	0B	Extreme Hot Dry	0B	Extreme Hot Dry	Hot & Dry
Akola	0A	Extreme Hot Humid	0B	Extreme Hot Dry	-
Allahabad	1A	Very Hot Humid	-		Composite
Amritsar	2B	Hot Dry	-		Composite
Aurangabad	1B	Very Hot Dry	1A	Very Hot Humid	Hot & Dry
Barmer	0B	Extreme Hot Dry	-	Extreme Hot Dry	Hot & Dry
Belgaum	1A	Very Hot Humid	1A	Very Hot Humid	Warm & Humid
Bengaluru	1A	Very Hot Humid	1A	Very Hot Humid	Temperate
Bhagalpur	1A	Very Hot Humid	-		Warm & Humid
Bhopal	1B	Very Hot Dry	1A		Composite
Bhubaneshwar	0A	Extreme Hot Humid	0A	Extreme Hot Humid	Warm & Humid
Bhuj	0B	Extreme Hot Dry	0B	Extreme Hot Dry	-
Bikaner	1B	Very Hot Dry	0B	Extreme Hot Dry	Hot & Dry
Chennai	0A	Extreme Hot Humid	-		Warm & Humid
Chitradurga	1B	Very Hot Dry	1B	Very Hot Dry	Warm & Humid
Dehradun	2A	Hot Humid	-		Composite
Dibrugarh	2A	Hot Humid	-		Warm & Humid
Gorakhpur	1A	Very Hot Humid	-		Composite
Guwahati	1A	Very Hot Humid	1A	Very Hot Humid	Cold
Gwalior	1B	Very Hot Dry	1A	Very Hot Humid	Composite
Hisar	1B	Very Hot Dry	1B	Very Hot Dry	Composite
Hyderabad	1B	Very Hot Dry	0A	Extreme Hot Humid	Composite
Imphal	2A	Hot Humid	-		Warm & Humid
Indore	1A	Very Hot Humid	1A	Very Hot Humid	Composite
Jabalpur	1A	Very Hot Humid	1A	Very Hot Humid	Composite
Jagdalpur	1A	Very Hot Humid	1A	Very Hot Humid	Warm & Humid
Jaipur	1B	Very Hot Dry	1B	Very Hot Dry	Composite

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Annexure 1: Revised Climate Zones (Contd.)

Jaisalmer	0B	Extreme Hot Dry	-		Hot & Dry
Jamnagar	1A	Very Hot Humid	-		Warm & Humid
Jodhpur	0B	Extreme Hot Dry	0B	Extreme Hot Dry	Hot & Dry
Jorhat	2A	Hot Humid	-		Warm & Humid
Kolkata	1A	Very Hot Humid	0A	Extreme Hot Humid	Warm & Humid
Kota	0B	Extreme Hot Dry	-		Hot & Dry
Kurnool	0B	Extreme Hot Dry	-		Warm & Humid
Lucknow	1B	Very Hot Dry	1A	Very Hot Humid	Composite
Mangalore	0A	Extreme Hot Humid	0A	Extreme Hot Humid	Warm & Humid
Mumbai	0A	Extreme Hot Humid	0A	Extreme Hot Humid	Warm & Humid
Nagpur	0A	Extreme Hot Humid	0A	Extreme Hot Humid	Composite
Nellore	0A	Extreme Hot Humid	0A	Extreme Hot Humid	Warm & Humid
New Delhi	1B	Very Hot Dry	1B	Very Hot Dry	Composite
Panjim	0A	Extreme Hot Humid	-		Warm & Humid
Patna	1A	Very Hot Humid	1A	Very Hot Humid	Composite
Pune	1A	Very Hot Humid	1B	Very Hot Dry	Warm & Humid
Raipur	0A	Extreme Hot Humid	-		Composite
Rajkot	0B	Extreme Hot Dry	0B	Extreme Hot Dry	Composite
Ramagundam	0A	Extreme Hot Humid	-		Warm & Humid
Ranchi	2A	Hot Humid	-		Composite
Ratnagiri	0A	Extreme Hot Humid	-		Warm & Humid
Raxaul	1A	Very Hot Humid	-		Warm & Humid
Saharanpur	2A	Hot Humid	-		Composite
Shillong	3C	Warm Marine	-		Warm & Humid
Solapur	0B	Extreme Hot Dry	0B	Extreme Hot Dry	Hot & Dry
Surat	0A	Extreme Hot Humid	0A	Extreme Hot Humid	Hot & Dry
Tezpur	2A	Hot Humid	-		Warm & Humid
Thiruvanan-thapuram	0A	Extreme Hot Humid	0A	Extreme Hot Humid	Warm & Humid
Tiruchirappalli	0A	Extreme Hot Humid	0A	Extreme Hot Humid	Warm & Humid
Varanasi	1B	Very Hot Dry	-		-
Veraval	0B	Extreme Hot Dry	0B	Extreme Hot Dry	Warm & Humid
Vishakhapatnam	0A	Extreme Hot Humid	-		Warm & Humid

Further, the dry humid boundary is based on precipitation and annual mean temperature in ASHRAE classification and on the relative humidity in NBC, 2005. This leads to future study on evaluation of appropriate base temperature and suitable parameter (precipitation or relative humidity) for a dry humid boundary.

References

1) Bansal, N.K., and G. Minke. Climatic zones and rural housing in India. Kernforschungsanlage, Juelich, Germany, (1988).
2) Briggs, RobertS., Robert G. Lucas, and Z.T Taylor. "Climate classiffication for Building Energy Codes and Standards: Part 1-Development Process." ASHRAE, (2003): 109-121.
3) Erbs, D, S Klien, and W Beckman. "Sol-air heating and cooling degree days." Solar Energy, (1984), 605-612.
4) Kottek, M, J. Grieser, C Beck, B Rudolph, and F Rubel. "World Map of the Koppen-Gieger climate classification updated." Meteorologische Zeitschrift 15, no. 3 (2006): 259-263.
5) Lausten, J. Energy Efficiency requirements in Building Codes, Energy Efficiency Policies for New Buildings. Information Paper, Paris: International Energy Agency,)2008).
6) Papakostas, K, and N. Kyriakis. "Heating and cooling degree-hours for Athens and Thessaloniki, Greece." Renewable Energy , (2005), 1873-1880.
7) Strahler, A. N. Physical Geography- III edition. New York: John Wiley and Sons Inc., (1969).
8) Energy Conservation Building Code (ECBC) - Revised Version May 2008. New Delhi, India: Bureau of Energy Efficiency, Ministry of Power, Government of India, (2007).
9) SP 7:2005, National Building Code of India 2005, Bureau of Indian Standards, New Delhi, (2005).
10) "Degree-days: theory and application" The chartered Instittution of Building Services Engineers, (2006),
11) "Climate Data for Building Design standard, ANSI/ASHRAE standard 169-2013, ASHRAE, (2013).
12) "Rain fall statistics" Indian Meteorological Department, Ministry of Earth and Science, Government of India,http://www.imd.gov.in/section/hydro/dynamic/rfmaps/datamain.html (accessed September 25, 2014).
13) Dash, S.K., Jenamani, R.K., Kalsi, S.R. and Panda, S.K.."Some evidence of climate change in twentieth century India." Science+Business Media, (2007).
14) NegiM.,"Climate of India: 2 Major Climatic Regions of Indian Climate." Your Article Library.May 2014. http://www.yourarticlelibrary.com/geography/climate-of-india-2-major-climatic-regions-of-indian-climate/13851 (accessed April 12, 2015).
15) Werner H.T., Stella S-F.L., " Energy input-output climates of the world: A preliminary attempt", ArchivfürMeteorologie, Geophysik und Bioklimatologie, Serie B,20, (1972), 129-166.