DEVELOPMENT OF TYPICAL YEAR WEATHER FILES FOR 59 INDIAN LOCATIONS

Yu Joe Huang[1], Jyotirmay Mathur[2], Vikram Murthy[3], Vishal Garg[4]
[1]White Box Technologies, Moraga CA, United States of America
[2]Centre for Energy and Environment, MNIT, Jaipur, India
[3]Univac Environment Systems Pvt Ltd, Mumbai;
[4]Centre for IT in Building Science, IIITH, Hyderabad, India

ABSTRACT

The Indian Society of Heating, Refrigerating, and Air Conditioning Engineers (ISHRAE) has worked in developing weather data for use in HVAC design and energy calculations since the 1990s. The increased use of building energy simulations in recent years has created a need for detailed hourly weather files for Indian locations. In 2005, ISHRAE released an initial set (ISHRAE1) of Typical Year weather files for 58 locations based on limited raw data. In 2009, ISHRAE started a 4-year effort to create a new set of Typical Year weather files, using raw weather data from 1993 through 2007 provided by the Indian Bureau of Energy Efficiency. Much of the software techniques to fill data gaps, calculate the solar radiation, and select the typical months making up the typical year were based on prior work done to create the IWEC2 weather files for ASHRAE. The main technical challenge is the calculation of global horizontal and direct normal solar radiation, which utilized the newly-available ASHRAE Clear Sky Model, and were in addition calibrated against satellite-derived solar radiation produced by the US National Renewable Energy Laboratory. Due to the limitations in the raw data, this second effort was able to produce new ISHRAE2 weather files for only 38 locations. Therefore, the decision was made to retain 21 of the ISHRAE1 weather files, but upgrade their solar radiation values using the same calculation method, ultimately resulting in 59 weather files in all. The paper will also briefly describe other sources of hourly weather files for Indian locations.

INTRODUCTION

For building energy simulation, a weather file is needed with information on the ambient conditions on an hour-by-hour basis for an entire year. Because of the stochastic variations in weather conditions, "typical year" weather files have been developed that are extracted from many years of historical weather data, most often from 15-30 years of historical weather data. For the US, the National Renewable Energy Laboratory (NREL) has developed TMY3 (Typical Meteorological Year Version 3) weather files for 1020 locations (Wilcox and Marion 2008). There are similar typical year data sets of 60 to over 300 locations for Canada, Western Europe, Australia, Japan, and China (Numerical Logics 1999, Lund 1991, DEWR 2006, Akasaka et al. 2000, CMB et al. 2005). Lastly, ASHRAE recently developed the International Weather for Energy calculations Version 2 (IWEC2) weather files for 3,012 locations outside of North America (Huang et al. 2013).

In India, the Indian Society of Heating, Refrigerating, and Air Conditioning Engineers (ISHRAE) has taken the lead in developing weather data for use in HVAC design and energy calculations. In 1996, ISHRAE and the Ministry of Non-conventional Energy Sources (MNES) contracted the Tata Energy Research Institute (TERI, now renamed The Energy and Resources Institute) for a project, "Weather Data and Design Conditions in India". In Phase One, TERI obtained from the India Meteorological Bureau (IMB) raw weather data for 92 locations with up to 10 years. However, it was found that most stations contained data for only 5-7 years, and that some were missing key climatic parameters such as dry-bulb temperature or relative humidity, and that only eight contained any data on solar radiation. After data analysis, TERI determined that only 52 locations had data of sufficient quality to calculate design conditions (TERI 1998).

Phase Two of the project was devoted to the creation of reference or "typical year" files from the same raw weather data, which was completed in 2003. This first set of ISHRAE weather files will be referred to in this paper as the ISHRAE1 files. In 2008, the lead author was contacted by ISHRAE to improve the solar radiation in the ISHRAE1 files using the method that was then being developed for an ASHRAE research project (RP-1477) to create the IWEC2 weather files.

In 2009, the authors agreed on a complete overhaul of the ISHRAE weather files with new weather data obtained from the IMB, as well as utilizing other data sources such as the US National Climatic Data Center (NCDC) and the weather processing software and techniques developed by the lead author for RP-1477. This effort took from 2009 through 2011, during which several incremental improvements were made to the solar radiation calculations, partly in response to the co-authors' review and critique of the results, and partly due to the serendipitous availability of satellite-derived solar radiation from the (US) National Renewable Energy Laboratory (NREL).

Despite the hope that the new raw weather data would be more plentiful and complete, they were found to have much the same limitations as the earlier raw data, i.e., empty files, partial records, and large amounts of missing data. Although new raw weather data were obtained for 50 locations, it was possible to create credible "typical year" weather files for only 38 locations. The final set of these new weather files, which will be referred to in this paper as the ISHRAE2 files, were provided to ISHRAE in Dec. 2011. Following a long review period, the files were approved in March 2013.

In February 2014, ISHRAE publicly announced the availability of the new "typical year" weather files in the form of a book titled "Indian Weather Data" (ISHRAE 2014). Since there are 21 locations in the ISHRAE1 files that do not appear in the ISHRAE2 files, ISHRAE decided to retain them, but asked Huang to reprocess their solar radiation data using the same procedure as the ISHRAE2 files, without any change to the other climatic parameters, which was completed in April 2014.

Since the development of the ISHRAE1 files predated the involvement of the lead author, this paper describes only the process behind the development of the ISHRAE2 weather files.

DESCRIPTION OF THE RAW DATA

The ISHRAE2 weather files were created using several different sources of weather data. The initial source were weather files provided by the IMB for 43 locations and 23 years (1985, 1987-2008). However, since many of these files contain missing data that's crucial for building energy simulations, the decision was made early on to supplement the IMB data with the Integrated Surface Hourly Database (ISD) that NCDC has made available on the Web since 2006.

Since the ISD raw data also contain many more parameters, e.g., Present Weather, Visibility, and Ceiling Height, it's estimated that 30-60% of the data in the final ISHRAE2 files are actually from the ISD rather than the IMB raw data files.

a. Indian Meteorological Bureau weather files

The IMB raw data files come in a standard CSV format with the following meteorological elements: temperature, humidity, pressure, wind speed, direct and diffuse solar radiation. However, only ten of the files (9 years for New Delhi, 1 year for Bangalore) contained data in all the fields, while of the rest, 33% were empty files, another 45% missing solar data, and another 21% missing wind speed. Table 1 lists the stations and data availability of the IMB data

Table 1. Status of IMB Raw Weather Files
(Numbers indicate years with more than 50% data for that climatic parameter)

City	WMO#	DBT	HR	Pres	Wind	Rain	DifS	DirS
Ahmedabad	42647	15	15	12	15	0	15	0
Allahabad	42475	15	15	8	15	0	0	0
Amritsar	42071	15	16	15	15	15	0	0
Aurangabad	43014	14	12	11	14	0	0	0
Babatpur	42479	16	14	15	14	0	0	0
Bangalore	43295	10	12	12	13	11	9	2
Barmer	42435	0	14	0	0	0	0	0
Belgaum	43198	10	12	11	11	0	0	0
Bhavnagar	42838	0	13	15	15	0	0	0
Bhubaneshwar	42971	11	14	13	12	0	0	0
Bhuj	42634	9	13	8	14	0	0	0
Bikaner	42165	0	0	0	9	0	0	0
Bombay Santacruz	43003	15	15	15	15	17	12	0
Calcutta	42809	11	11	11	11	0	13	0
Chitradurga	43233	11	12	11	11	0	0	0
Dehradoon	42111	14	13	17	15	0	0	0
Gorakhpur	42379	14	14	15	12	0	0	0
Hissar	42131	16	15	15	15	0	0	0
Hyderabad	43128	11	11	11	11	0	14	0
Jaipur	42348	15	15	15	14	0	9	7
Jaisalmer	42328	14	12	15	13	0	0	0
Jammu	42056	15	15	8	15	0	0	0
Jodhpur	42339	12	12	0	17	0	12	0
Kodaikanal	43339	15	15	15	15	15	0	0
Kurnool	43213	10	10	10	10	0	0	0
Lucknow	42369	11	14	15	15	0	0	0
Madras	43279	15	15	14	15	15	12	0
Mangalore	43285	11	12	11	11	0	0	0
Nagpur	42867	8	7	8	9	0	10	0
Nellore	43245	10	10	10	10	0	0	0
New Delhi	42182	15	17	11	17	16	12	6
Panjim	43192	15	15	15	15	0	14	0
Rajkot	42737	9	15	15	13	0	0	0
Ramgundam	43086	0	0	10	9	0	0	0
Ranchi	42701	0	0	0	8	0	10	0
Ratnagiri	43110	15	15	14	14	0	0	0
Shillong	42516	0	0	0	0	0	15	0
Sholapur	43117	15	15	15	14	0	0	0
Srinagar	42027	15	15	16	0	0	5	0
Tiruchchirapalli	43344	15	15	15	15	15	0	0
Trivandrum	43371	14	14	12	12	12	15	0
Varanasi	42483	0	0	0	0	0	6	0
Veraval	42909	11	14	15	15	0	0	0

note: the IMB files did not list WMO numbers; these were added by correlating location names and coordinates to the ISD.

There were several unexpected conditions in the data. Although there were hopes the new files would contain much more measured solar data, these were found to be problematic and not directly usable for the ISHRAE2 weather files. Only 16 stations out of the 43 contained any solar information, of which 13 contained only diffuse radiation and only three (Bangalore, Jaipur, and New Delhi) contained both diffuse and direct radiation. Consequently, the solar radiation in the ISHRAE2 files were modelled using the same technique as used in the ISHRAE1 files, although with numerous refinements as described later in this paper.

The decision was made to ignore all files that were missing either temperature or humidity data. For the remaining files, the ISD was queried and the data there used to fill unreported data fields, especially wind speed and cloud cover, as well as to fill gaps in the IMB.

b. The Integrated Surface Hourly Database

The ISD is a database of weather station reports from around the world maintained by the NCDC under a World Meteorological Organization (WMO) agreement (Lott and Baldwin 2001, NCDC 2007). NCDC made the ISD available through the Web in 2006. Up until 2012, access to the ISD was free for US governmental, educational, and other non-profit organizations, and at cost for commercial users, but in 2012 NCDC made it free to all (NCDC 2015). This database contains up to 28 years of weather data for nearly 20,000 locations around the world, of which up to 9,000 (2,100 US, and 100 in India for 2014) have data of sufficient resolution and period-of-record for developing “typical year” weather files.

The corresponding ISD weather files to the IMB were found by matching location names and station coordinates. For all IMB locations, it was possible to find an equivalent station and year in the ISD.

PROCESSING MISSING DATA

a. Temperature

To interpolate for missing dry-bulb temperatures, two separate equations have been used depending on the time of day. For hours from 5 to 20, the following Fourier Series is used:

$$\theta(t) = b_0 + \sum \{ b_n cos(n\frac{\pi}{12}t) + a_0 sin\,(n\frac{\pi}{12}t) \} \qquad (1)$$

where $b_0 = 1/8 \sum_{k=1}^{8} \theta(t)$

$$b_n = 1/4 \sum_{k=1}^{8} \theta(k)\ cos\,\frac{n\pi k}{4}$$

$$a_n = 1/4 \sum_{k=1}^{8} \theta(k)\ sin\,\frac{n\pi k}{4}$$

n = nth term of the Fourier series

k = sequential number of temperature from 1 to 8 at three-hour intervals

$\theta(k)$ = k^th observed temperature

t = local standard time

For hours from 20 to 5, the following empirical equation is used (Zhang and Asano 2000):

$$\theta_j = \theta_{j-1} - 0.3419 + 0.2449\,(\theta_{j+2} - \theta_{j-1}) + 0.2282 \cdot CC + 0.3243 \cdot CC^2 \qquad j=21,24,3$$

$$\theta_j = \theta_{j-2} - 0.5617 + 0.6900\,(\theta_{j+1} - \theta_{j-2}) + 0.07229 \cdot CC + 0.02331 \cdot CC^2 \qquad j=22,1,4 \qquad (2)$$

where CC = cloud cover in fractions

To interpolate for missing dewpoint temperatures, the same Fourier Series as Equation 1 is used for the daytime hours, but a simple linear interpolation is used for the nighttime hours from Hour 20 to 5.

b. Pressure

Many of the weather files have no or very infrequent recordings of atmospheric pressure. If pressure data are regularly recorded, linear interpolation is used for missing values. If pressure data is infrequent or nonexistent, values from a suitable nearby station with values are substituted. If no suitable station can be found, a constant pressure based on altitude is used.

c. Wind speed

To interpolate for missing wind speed data, linear approximations are used.

d. Wind direction

To interpolate for missing wind direction data, the last observed values are repeated.

e. Cloud cover

To interpolate for missing cloud cover data, linear approximations are used.

DERIVATION OF SOLAR RADIATION

Derivation of the solar radiation has always been the most challenging part of creating weather files from weather station data for use in building energy simulations. Simulations require hourly records of global horizontal and direct normal (beam) radiation, but these, especially the latter, are almost never recorded by weather stations. Although the authors had hoped the new IMB data would contain such solar data, it was found that only 4% of the files contain both direct and diffuse solar, while another 20% contain only diffuse solar radiation. Even in the three locations (Bangalore, Jaipur, and New Delhi) with both direct and diffuse solar, their time periods were considerably shorter than the total periods of record.

Since there has to be solar radiation on all the ISHRAE2 weather files, the authors decided to use the same basic technique as used for the ISHRAE1 and IWEC2 weather files (Huang et al. 2013), but to further improve the technique by better use of ASHRAE’s 2009 Clear Sky Model (Gueymard and Thevenard 2013) and calibrating the results against recently-available satellite-derived gridded solar data for India 2002-2008 (NREL 2010).

a. Global horizontal solar radiation

The key component of the procedure used by the lead author to derive global horizontal solar is an empirical solar model, often referred to as the Zhang-Huang Model (ZHM), that correlated total solar radiation to the cloud cover, change in dry-bulb temperature over the past three hours, relative humidity, and wind speed (Zhang et al. 2002):

$$
\begin{aligned}
I &= Io \bullet \sin h \bullet \{C0 + C1(CC) + C2(CC)2 \\
&\quad + C3(Tn - Tn\text{-}3) + C4\,\varphi + C5Vw\} + D \\
&\qquad \text{when } ET{*}0.10 > I > ET{*}0.90 \\
&= ET{*}0.90 \qquad \text{when } I > ET{*}0.90 \\
&= ET{*}0.10 \qquad \text{when } I < ET{*}0.10 \qquad (3)
\end{aligned}
$$

where I = predicted hourly solar radiation W/m^2
Io = solar constant, 1367.7 W/m^2
ET = extraterrestrial solar radiation
h = solar altitude angle, the angle between the horizontal and the line to the sun
CC = cloud cover in fractions
φ = relative humidity in %
T_n, T_{n-3} = dry-bulb temperature at hours n and n-3, respectively
Vw = wind speed in m/s.
C0,C1,C2,C3,C4,C5,D = regression coefficients

The ZHM has been constrained with maximum and minimum thresholds to prevent it from producing solar radiation outside of physical reality, i.e., either exceeding the clear sky or zero radiation when the sun is above the horizon. After discussions with solar experts, the maximum threshold has been set to 0.90**ET* and the minimum threshold to 0.10**ET*, where *ET* is the total extraterrestrial solar radiation for that hour (Gueymard 2008, Perez 2009).

The original ZHM contained a single set of coefficients based on regression analysis of 1993 measured solar data in two Chinese cities (Zhang et al. 2002). For the IWEC2, the lead author calculated regression coefficients for each Köppen-Geiger climate region using least-square analysis of Equation 3 against measured solar data from a site or sites within each region (Kottek et al. 2006, Huang et al. 2013). Figure 1 shows that India falls into 6 Köppen-Geiger regions. The regression coefficients for these six regions as calculated for the IWEC2 are listed in Table 2.

Table 2. Regression coefficients for Indian locations based on Köppen-Geiger climate regions

Region	C0	C1	C2	C3	C4	C5	D	L *
Am	0.71868	-0.11359	-0.07259	0.01038	-0.00285	0.00866	-8.42023	1.00
Aw	0.80890	0.07355	-0.40101	-0.00424	-0.00242	0.00342	-8.39500	1.00
BSh	0.68149	-0.04697	-0.28420	0.01726	-0.00081	0.00453	-8.91306	1.00
BWh	0.51315	0.15540	-0.42157	0.01427	-0.00035	0.00469	-9.55426	1.00
Cfa	0.67839	0.03646	-0.39075	0.01359	-0.00148	0.00730	-8.71373	1.00
ET	0.77029	0.00687	-0.35561	0.01849	-0.00149	-0.00278	-6.41702	1.00

* L is a scalar multiplier among locations in the same climate region and calculated during the calibration against satellite-derived solar

Source cities:

AM = Miami 1983-84
AW= Honolulu 1979-80
BSh= Phoenix 1988-90
BWh=Kuwait 2001, 2005
Cfa =Nashville 1988, Dodge City 1989, Montgomery 1990, Busan 2005-06
Eth=Davos 2001-2008, Ushuaia 1995-2008

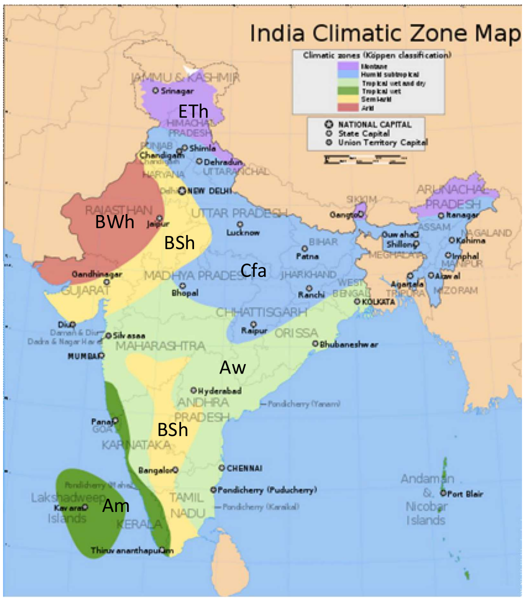

Figure 1. Köppen-Geiger Regions for India
(source for base map: en.wikipedia.org)

During the co-authors' review of the initial results, they found that the hourly solar profiles often peaked in the late morning, rather than at noon as would be expected. The explanation is that the ZHM is an statistical model with no knowledge of solar angles, so that the results when viewed as a time series will show random data noise.

To overcome this limitation in the ZHM, the ASHRAE 2009 Clear Sky Model (Gueymard and Thevenard 2013), or ACSM09 for brevity, is used to calculate the hourly distribution of global horizontal radiation under clear sky conditions with no clouds. The ZHM is then used twice, once with the reported cloud cover (CC) and again with the CC arbitrarily set to 0, i.e., no clouds, and the ratio between the two calculated as the Clearness Number (CN):

$$CN = Icc \,/\, I_{CC0} \qquad (4)$$

where CN = clearness number (non-dimensional fraction)
Icc = ZHM solar radiation at reported CC
I_{CCO} = ZHM solar radiation with CC set to 0

The net global horizontal radiation is then calculated as the clear sky solar times the clearness number:

$$I' = I_{ACSM09} * CN \qquad (5)$$

where I' = predicted hourly solar radiation combining ZHM and ACSM09, W/m^2
I_{ACSM09} = global solar radiation calculated by ACSM09

b. Direct normal solar radiation

In addition to the global horizontal solar, building energy simulations also need the direct normal solar radiation, i.e., the amount of beam radiation looking directly at the sun. The following model developed by Zhang et al. (2004) has been used to estimate the direct normal radiation using a sigmoidal Gompertz Function where growth is slowest at the start and end of the function (Parton and Innis 1972). Its general mathematical form is shown in Equation 5

$$y(x) = ae^{be^{cx}} \tag{5}$$

Zhang et al. (2004) have applied the Gompertz Function for estimating the direct solar radiation *Kn* as a function of the total horizontal global radiation *Kt*, both normalized by the extraterrestrial radiation (*Iosinh*):

$$K_n = A_1 A_2^{-A_3 A_2^{-A_4 K_t}} \tag{6}$$

where

$A1 \sim A4$ = coefficients, exponents as the function of sun angles

h = solar altitude angle, i.e., the angle between the horizontal and the line to the sun

I_d = diffuse horizontal radiation at the Earth's surface, W/m^2

IH = global horizontal radiation at the Earth's surface, W/m^2

In = direct normal at the Earth's surface, W/m^2

Kn = direct beam transmittance

Kt = clearness index

The four coefficients (A1 – A4) are expressed as equations of the solar angle obtained by least square fit to measured data from seven cities in China and Japan (Zhang et al. 2004):

$$A1 = -0.1556\sin 2h + 0.1028\sin h + 1.3748 \tag{7}$$

$$A2 = 0.7973\sin 2h + 0.1509\sin h + 3.035 \tag{8}$$

$$A3 = 5.4307\sin h + 7.2182 \tag{9}$$

$$A4 = 2.990 \tag{10}$$

The main reasons for using the Gompertz Function model are its simplicity and lack of discontinuities. The lead author had done most of the work using two other models (Watanabe et al. 1983, Perez et al. 1990), but gravitated to the Gompertz Function model because it worked better with the modification of the hourly solar profiles described earlier.

c. Calibration against satellite-derived solar data

As this project was winding down in 2011, the lead author learned from a colleague that NREL was making available satellite-derived solar data from 2002-2008 (now updated through 2011) on a 10-km grid for all of India (NREL 2010). Previous comparisons between satellite-derived and good-quality ground observations have indicated that satellite-derived solar were very accurate (Huang 2011b). Thus, the project quickly obtained the hourly data for all the ISHRAE2 locations and used them to calibrate the global horizontal radiation on the files. No attempt was done to calibrate the direct normal radiation. Comparison of the monthly totals found the relationship to be quite linear, i.e., that a single calibration factor was sufficient to remove the bias between them. Figure 2 is for three locations (Bangalore, Madras, and Lucknow) with good cloud cover data. Figure 3 is for three locations (Babatpur, Belgaum, and Dehradoon) where the cloud cover data is less good, thus causing more scatter.

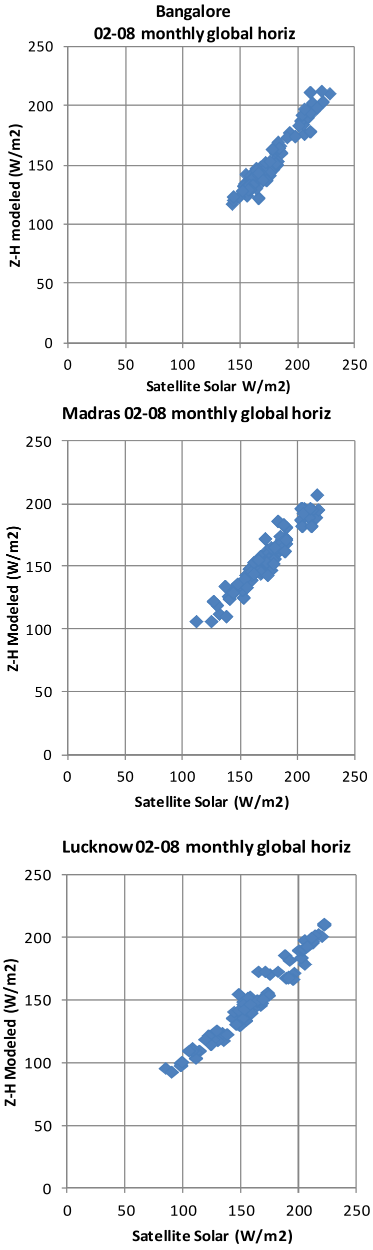

Figure 2. Comparison of calculated to satellite-derived monthly global horizontal radiation for locations with good cloud observations

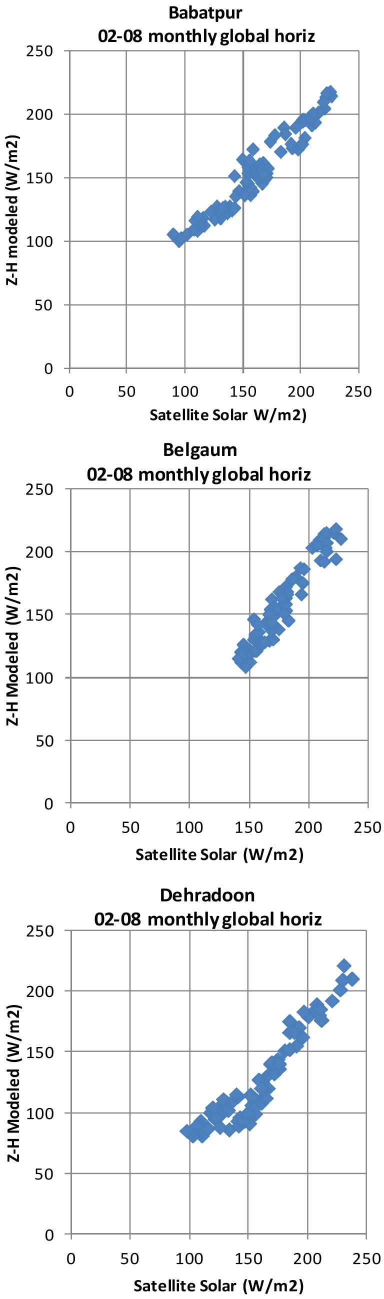

Figure 3. Comparison of calculated to satellite-derived monthly global horizontal radiation for locations with poor cloud observations

The IWEC2 project has shown that the ZHM produced estimates of total solar radiation that correlated well with measured results, although problems remained with the hourly solar profiles, which have been resolved in this project by coupling the ZHM with the ACSM09. The calibration against satellite-derived solar provides further evidence that the solar estimates in the ISHRAE1 and ISHRAE2 weather files are credible and reliable.

PRODUCTION OF HISTORICAL WEATHER FILES

The largest part of the work in creating “typical year” weather files is the production of the historical year weather files from which the “typical year” files are drawn. For the ISHRAE2 weather files, 489 historical weather files were created for 37 locations in India, some with as few as 4 and others with as many as 17 years. The number of years for each city are shown on the rightmost column of Table 3 on the next page. The ISHRAE1 weather files are also listed, although it’s unclear whether any of the historical weather files still exist.

PRODUCTION OF “TYPICAL YEAR” WEATHER FILES

For building energy analysis, it is often desirable to have a "typical year" weather file that replicates the long-term average conditions for a location. To produce the ISHRAE2 weather files, the TMY methodology developed by NREL has been followed (NCDC 1981). In this method, the selection is made by calculating the Cumulative Distribution Function (CDF) of each climate parameter (temperature, solar radiation, and wind speed) for each month of historical data, comparing these CDFs to the long-term CDF using the Finkelstein-Schafer (FS) statistic as a measure of the closeness of fit. The FS statistic is the sum of the differences between the individual and long-term CDFs, and can be visualized as the absolute area enclosed between the two curves.

Figure 4 shows an illustrative example of the CDFs for January daily average dry-bulb temperatures for January in New Delhi 1991-2006 (no 1998). The thick red line is the long-term CDF for the 15 year period of record. The thinner lines show the CDFs for the 15 individual years, with 2002 (thick orange line) having the smallest FS of 0.093. However, after considering the other climate parameters, 2001 (thick light blue line) was found to have the smallest cumulative FS and thus picked to represent January.

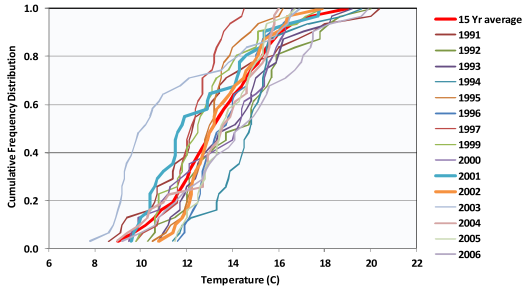

Figure 4. CDF for January daily average dry-bulb temperature in New Delhi 1991-2006

The FS statistic for each parameter is multiplied by its weight, and then added to produce a cumulative FS. The month having the smallest cumulative FS is selected as the typical month. For the ISHRAE2 files,

Table 3. List of Cities in ISHRAE Weather Data

City	Lat (N)	Lon (E)	Elev (m)	Num Yrs
Ahmedabad	23° 4'	72° 37'	55	15
Akola*	20° 42'	77° 1'	282	5
Allahabad*	25° 27'	81° 43'	98	4
Amritsar	31° 37'	74° 52'	234	16
Aurangabad	19° 51'	75° 24'	579	14
Barmer*	25° 45'	71° 22'	194	16
Belgaum	15° 51'	74° 37'	747	13
Bengaluru	12° 58'	77° 34'	921	12
Bhagalpur*	25° 13'	86° 56'	49	?
Bhopal	23° 16'	77° 20'	523	7
Bhubaneshwar	20° 15'	85° 49'	46	17
Bhuj	23° 15'	69° 40'	80	15
Bikaner*	28° 0'	73° 18'	224	?
Chennai	13° 0'	80° 10'	16	15
Chitradurga	14° 13'	76° 25'	733	13
Dehradun	30° 19'	78° 1'	682	17
Dibrugarh*	27° 28'	95° 1'	111	?
Gorakhpur*	26° 45'	83° 22'	77	15
Guwahati*	26° 6'	91° 34'	54	
Gwalior*	26° 13'	78° 15'	207	
Hissar	29° 10'	75° 43'	221	15
Hyderabad	17° 27'	78° 28'	545	11
Imphal*	24° 46'	93° 54'	781	
Indore*	22° 43'	75° 48'	567	10
Jabalpur*	23° 12'	79° 56'	393	7
Jagdelpur*	19° 4'	82° 1'	553	
Jaipur	26° 49'	75° 48'	390	15
Jaisalmer	26° 53'	70° 55'	231	12
Jamnagar*	22° 28'	70° 1'	20	
Jodhpur	26° 17'	73° 1'	224	14
Jorhat*	26° 43'	94° 10'	90	
Kolkata	22° 38'	88° 26'	6	11
Kota*	25° 8'	75° 50'	274	
Kurnool	15° 48'	78° 4'	281	
Lucknow	26° 45'	80° 52'	128	
Mangalore*	12° 31'	74° 31'	22	3
Mumbai	19° 7'	72° 50'	14	15
Nagpur	21° 6'	79° 3'	310	7
Nellore	14° 26'	79° 58'	20	11
New Delhi	28° 34'	77° 11'	216	17
Panjim	15° 28'	73° 49'	60	16
Patna*	25° 16'	85° 10'	53	
Pune*	18° 31'	73° 50'	559	5
Raipur*	21° 13'	81° 39'	298	5
Rajkot	22° 17'	70° 46'	138	16
Ramagundam*	18° 46'	79° 25'	156	
Ranchi*	23° 22'	85° 19'	655	
Ratnagiri	16° 58'	73° 19'	67	16
Raxaul*	26° 34'	84° 31'	1350	
Sharanpur*	29° 51'	77° 52'	274	
Shillong*	25° 34'	91° 52'	1500	?
Solapur	17° 40'	75° 54'	479	16
Surat*	21° 12'	72° 49'	12	
Tezpur*	26° 37'	92° 46'	79	
Thiruvananthapuram	8° 28'	76° 56'	64	14
Tiruchirapalli	10° 46'	78° 43'	88	10
Varanasi	25° 27'	82° 52'	85	
Veraval	20° 53'	70° 22'	8	5
Vishakhapatnam*	17° 43'	83° 13'	3	

*ISHRAE1 file, else ISHRAE2.

the same weights as used in the TMY (NCDC 1981) for the following nine climatic parameters have been applied:

- Maximum, average, and minimum daily dry-bulb temperature 1/24 each
- Maximum, average, and minimum daily dew-point temperature 1/24 each
- Average and max. daily wind speed 2/24 each
- Average daily solar radiation 12/24

Once the twelve "typical months" have been selected, creating the "typical year" weather file is a simple process of concatenating the months into a single file. For example, the ISHRAE2 weather file for New Delhi uses the following months: Jan. 2001, Feb. 2004, Mar. 1991, Apr. 1992, May 1994, Jun. 2000, Jul. 1998, Aug. 2004, Sep. 1996, Oct. 1999, Nov. 1994, and Dec. 1992.

AVAILABILITY OF THE WEATHER DATA

After extensive review by the co-authors, the ISHRAE2 weather files were approved in late 2013. Based on this review, a book, *Indian Weather Data*, was written, supported by the Bureau of Energy Efficiency and ISHRAE, describing the weather data and including the files on an attached CD (Mathur et al. 2014). There are also plans to make the weather files available online, although as of May 2015 the plans still have not been formalized.

CONCLUSION

This paper has described the procedure used to develop "typical year" weather files for 59 location in India. The "typical year" weather files are based on historical hourly weather data from 4 to 17 years in length, with each month taken from a historical month selected as the most representative of the long-term weather for that month over the historical period. Therefore, in order to create the "typical year" weather file, it was necessary first to create the historical weather files for those periods, or almost 500 station-years of data.

The methods used to fill missing data is described. Since only 4% of the weather files contained measured solar data, an empirical all-sky model is combined with an analytical clear-sky model to estimate the hourly amounts of solar radiation, which are then apportioned to direct normal beam and diffuse sky radiation using another empirical model. The results are then calibrated against satellite-derived solar radiation to further improve the results. Since this procedure relies only on standard weather station reports, and models that are universally applicable, it can also be applied to other locations in the world as long as the weather station reports are reliable.

The method used to select the "typical months" making up the "typical year" weather files is also described and illustrated, and information given on where the ISHRAE weather files can be obtained.

REFERENCES

Akasaka, H., H. Nimiya, K. Soga, S. Matsumoto, K. Emura, N. Miki, and E. Emura 2000. "Development of Expanded AMeDAS Weather Data for Building Energy Calculation in Japan", ASHRAE Transactions, Jan. 2000 , Minneapolis MN.

China Meteorological Bureau (CMB) Climate Information Center, Climate Data Office and Tsinghua University Department of Building Science and Technology 2005. China Standard Weather Data for Analyzing Building Thermal Conditions. China Architecture & Building Press, Beijing CHN. ISBN 7-112-07273-3 (13228,in Chinese), http://www.china-building.com.cn.

Dept. of the Environment and Water Resources (DEWR) 2006. "Australia Representative Meteorological Year Climate Files", Australia Greenhouse Office, Canberra ACT, AUS.

Gueymard, C. 2008, e-mail exchange.

Gueymard, C. and D. Thevenard 2013. "Revising ASHRAE Climatic Data for Design and Standards - Part II, Clear-Sky Solar Radiation Model (1613-RP)", ASHRAE Transactions, June 2013, Denver CO.

Huang, Y.J., Su, F.X., Seo, D.H., and Krarti, M. 2013. "Development of 3,012 IWEC2 weather files for international locations". ASHRAE Transactions, Jan. 2013, New York.

Huang, Y.J. 2011. "Use of Satellite-Derived Solar Radiation in Updating California Energy Commission's Standard Weather files", TC 4.2 Seminar on New High Quality Solar Data Sources and Analysis Methods for High Resolution Weather Applications, ASHRAE Annual Conference, Montreal June 26, 2011.

Kottek, M., J. Grieser, C. Beck, B. Rudolf, and F. Rubel 2006: "World Map of the Köppen-Geiger climate classification updated". Meteorol. Z., 15, 259-263. DOI: 10.1127/0941-2948/2006/0130, http://koeppen-geiger.vu-wien.ac.at/.

Lott, N. and R. Baldwin 2001. "The FCC Integrated Surface Hourly Database, a New Resource of Global Climate Data", Technical Report, National Climatic Data Center, Asheville NC.

Lund, H 1991. "The Design Reference Year", Proceedings of the 2nd International Building Performance Simulation Association Conference, Aug. 20-22 1991, Nice, FRA.

Mathur, J., V. Murthy, and V. Garg. 2014. *Indian Weather Data,* Indian Society of Heating, Refrigeration, and Air Conditioning Engineers.

National Climatic Center (NCC) 1981. "Typical Meteorological Year User's Manual TD-9374", Asheville NC.

National Climatic Data Center (NCDC) 2003. "Data Documentation for Data Set 3505 (DSI-3505), Integrated Surface Hourly Data", Asheville NC.

National Climatic Data Center (NCDC) 2007. http://www.ncdc.noaa.gov/oa/climate/isd/index.php (URL for data access, articles, papers, and reports)

National Climatic Data Center (NCDC) 2015. Link to the ISD : http:// www.ncdc.noaa.gov/isd

National Renewable Energy Laboratory (NREL) 2010. "India Solar Resource Data: Hourly". http://rredc.nrel.gov/solar/new_data/India/about.html (data now updated to 2011).

Parton, W.J. and G.S. Innis 1972. "Some Graphs and Their Functional Forms". Technical Report No. 153 p. 21, National Resources Ecology Laboratory, Colorado State University, Fort Collins, CO.

Perez, R. 2009. e-mail exchange.

Perez, R., P. Ineichen, R. Seals, J. Michalsky, and R. Stewart 1990. "Modeling Daylight Availability and Irradiance Components from Direct and Global Irradiance." Solar Energy, 44(5), pp. 271-289.

Tata Energy Resources Institute (TERI) 1998. "Weather Data and Design Conditions for India". Progress Report (June 1996 – May 1998), submitted to the Ministry of Non-conventional Energy Sources (MNES) and ISHRAE.

Watanabe, T., Y. Urano, and T. Hayashi 1983. "Procedures for Separating Direct and Diffuse Insolation on a Horizontal Surface and Prediction of Insolation on Tilted Surfaces" (in Japanese), Transactions, No. 330, Architectural Institute of Japan, Tokyo, JPN.

Wilcox, S. and W. Marion 2008. Users Manual for TMY3 Data Sets, NREL/TP-581-43156, National Renewable Energy Laboratory, Golden CO.

Zhang, Q.Y., C.Z. Lou, and H.X. Yang 2004. "A New Method to Separate Horizontal Solar Radiation into Direct and Diffuse Components", Proceedings, ISESAP 2004.

Zhang, Q.Y., Y.J. Huang, and S.W. Lang 2002 "Development of Typical Year Weather Data for Chinese Locations", LBNL-51436. ASHRAE Transactions, June 2002, Honolulu HI Mitchell, J.W., Beckman, W.A. 1995.