IMPROVING THE WEATHER INFORMATION AVAILABLE TO SIMULATION PROGRAMS

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ABSTRACT

Developers of building simulation tools have been continuously improving their programs and adding new capabilities over the last thirty years. Time steps of less than an hour are now common and even necessary to properly simulate the complex interactions of building components and systems. For example, some control issues, such as daylighting, require much shorter time steps of minutes—more traditional hourly time steps have been shown to introduce errors as large as 40% in illumination calculations.

Despite these increased capabilities, many simulation programs are still using the same limited set of hourly climatic/weather data they started with—temperature, humidity, wind speed and cloud cover or solar radiation. This often forces users to find or calculate missing weather data such as illuminance, solar radiation, and ground temperature from other sources or developers to calculate it within their program.

In this paper, we describe a generalized weather data format developed for use with two energy simulation programs. We also compare the new format with previous data sets in use in the US and UK.

INTRODUCTION

All building simulation programs employ some means of representing local climatic conditions relative to the building models. For example, Radiance (Ward 1996) needs a description of sky conditions and illuminance values to calculate solar distribution through a window and within a space. Three of the widely used energy simulation programs in the UK and US, ESP-r (ESRU 1999), BLAST (UI 1998), and DOE-2 (Winkelmann et al. 1993) also use weather conditions to simulate the response of a building. But even after 30 years of significant development advances in simulation capabilities, these programs use the same climate representations as in the past—a simple set of hourly temperature, humidity, wind speed and direction, and atmospheric pressure and solar radiation or cloud cover data. These data are often 'typical' data derived from hourly observations at a specific location by the national weather service or meteorological office. Examples of these typical data include TMY2 (NREL 1995) and WYEC2 (ASHRAE 1997) in the United States and Canada and TRY (CEC 1985) in Europe. The TMY2 and WYEC2 typical weather years contain more solar radiation and illumination data than older formats such as TMY (NCDC 1983), WYEC (ASHRAE 1985), and TRY (NCDC 1981) in the U.S. Crawley (1998) demonstrated that the methods used to select data for the TMY2 and TRY data sets better fit the long-term climate patterns.

Radiation and illumination data are becoming increasingly necessary in simulation programs. Anyone who has ever attempted to measure daylight factors will be familiar with the fluctuations in lighting levels under partly cloudy conditions. The expansion and contraction of lightweight building components also shares sensitivity to rapid fluctuations in solar radiation. Single-sided ventilation is dependant on wind pressure fluctuations and pedestrians in many cities are acquainted with the disarming tendency of the wind to guest and change direction. It is increasingly the case that design questions touch on such issues.

In a research context, the advent of tools such as LabVIEW (National Instruments Corporation 1999) have made it possible for increasing numbers of researchers to acquire and process test-cell data. The increasing use of building energy management systems (BEMS) has also provided high frequency information from which simulation could be used as a predictive tool for future control strategies. Other issues of control, particularly of advanced daylighting control require sub-hourly illumination data to ensure that possible control regimes are tested under realistic conditions. Janak (1997) observed that the differences between 5 minute and hourly illumination data could result in prediction variations approaching 40%.

Thus far, projects that mix empirical and simulation-based work have had to store and access such data via temporal database facilities (ESRU 1999). As the number of high quality datasets increases so does the need to encapsulate such information in a form that can be broadly distributed. The simulation community must also consider the uncertainty in high frequency performance predictions that are based on boundary conditions that have been sampled at one or two magnitudes less temporal resolution.

The simulation community must also consider practitioner demands and issues of quality assurance. Someone who is not a native of Copenhagen may not know that there are three or four recognizable patterns of winter weather that should be included in detailed assessments. A data set that lacks documentation or is dependent on separately held lists of assumptions can be effectively useless.

In the absence of data within the weather data format, the simulation programs must calculate these data often with older calculation methods. As the simulation programs have become more capable, data at hourly resolution is no longer enough—interpolating between hourly observations does not accurately represent weather conditions that change much more frequently such as illumination.

We have developed a new, generalized weather data format for use by energy simulation programs has been developed and adopted by both ESP-r (in the UK) and EnergyPlus (in the US). Anticipating the need for data at time steps less than one hour, the format includes a minute field to facilitate the use of sub hourly data. The data include basic location identifiers such as location name, data source, latitude, longitude, time zone, elevation, peak design conditions, holidays, daylight savings period, typical and extreme periods, ground temperatures, period(s) covered by the data and space for descriptive comments. The time step data include dry bulb and dew point temperature, relative humidity, station pressure, solar radiation (global, extraterrestrial, horizontal infrared, direct, and diffuse), illuminance, wind direction and speed, sky cover, and current weather.

NEW WEATHER FORMAT FOR SIMULATION PROGRAMS

For these reasons, we developed a new generalized weather data format for use with two major simulation programs—ESP-r and EnergyPlus (Crawley et al. 1999). All the data are in SI units. The format is simple, text-based with comma-separated data. It is based on the data available within the TMY2 weather format but has been rearranged to facilitate visual inspection of the data. The TMY2 data are a strict, position-specific format—filling missing data with nines and zero values with zeroes. The new weather data format contains commas to facilitate data reading and analysis with spreadsheet programs. By eliminating redundant 'fill' values, the size of each file is only slightly larger than the original TMY2 format.

The traditional distribution of data source and uncertainty flags within the raw data fields carries with it not only the need for many field separators, it obfuscates the relationships between non-numerical data. In a set of minute data, which could easily require hundreds of thousands of records, the space penalty is considerable. In the E/E file format, all data source and uncertainty fields have been clumped together as a single field immediately following the day and time stamp. For applications where uncertainty is not an issue such data can be easily ignored. When it is important, a single text field is conceptually and computationally easy to parse.

Another difference between the EnergyPlus/ESP-r (E/E) format and TMY2 is the addition of two new data fields—minute and infrared sky. The minute field facilitates use of data observed at intervals of less than one hour such as measured data from a research study of energy efficiency for a particular building. This will allow easier and more accurate calibration of a simulation model to measured data than possible in the past. The infrared sky field allows the programs to calculate the effective sky temperature for re-radiation during nighttime.

The last difference is that a full year of data (such as 8760 hours) is not required—subsets of years are acceptable. Which periods are covered by the data is described in the files. Periods of typical weather patterns based on analysis of the data are also included within the format. A side-by-side comparison of data included in the E/E weather format with data previously used by ESP-r, DOE-2, and BLAST is shown in Table 1. A deficiency noted within ESP-r for example is the lack of correcting air volumes for elevation change—many of the users of ESP-r are in relatively low elevations. For DOE-2 and BLAST, neither program used illumination data in daylighting calculations or infrared sky temperatures—it was always recalculated at time of use.

By including the uncertainty and data source information found in TMY2, users now can evaluate the potential impact of weather variability on the performance of the building.

Table 1. Comparison of E/E with ESP-r, DOE-2, and BLAST Weather Data Formats

Data Element	DOE-2	BLAST	ESP-r	E/E
Location (name, latitude, longitude, elevation, time zone)	X	X	X	X
Data source				X
Commentary			X	X
Design conditions				X
Typical/extreme periods				X
Data periods				X
Holiday/Daylight Savings		X		X
Solar Angles/Equation of Time Hours		X		
Degree Days		X		X
Year	X	X	X	X
Month	X	X	X	X
Day	X	X	X	X
Hour	X	X	X	X
Minute				X
Data source and uncertainty flags				X
Dry bulb temperature	X	X	X	X
Wet bulb temperature	X	X		X
Dew point temperature	X			X
Atmospheric station pressure	X	X		X
Humidity ratio	X	X		X
Relative humidity			X	X
Enthalpy	X			
Density	X			
Wind Speed	X	X	X	X
Wind Direction	X	X	X	X
Infrared Sky Temperature		X		X
Solar Radiation (global, normal, diffuse)	X	X	X	X
Illuminance (global, normal, diffuse)				X
Sky cover (cloud amount)	X			X
Opaque sky cover				X
Visibility				X
Ceiling height				X
Clearness (monthly)	X			
Ground temperatures (monthly)	X			X
Present weather observation and codes (rain, snow)		X		X
Precipitable water				X
Aerosol optical depth				X
Snow depth				X
Days since last snowfall				X

McDonald and Strachan (1998) are introducing uncertainty analysis into ESP-r.

We use the EnergyPlus data dictionary format to describe the E/E weather data set in Table 2. Each line in the format is preceded by a keyword such as LOCATION, DESIGN CONDITIONS, followed by a list of variables beginning either with A or N and a number. A stands for alphanumeric; N for numeric. The number following A/N is the sequence of that number in the keyword list. Commas separate data. The description of each variable follows inside square brackets '[ ]' with units inside braces '{ }'. The header information consists of eight lines (keywords): LOCATION, DESIGN CONDITIONS, TYPICAL/EXTREME PERIODS, GROUND TEMPERATURES, HOLIDAYS/DAYLIGHT SAVINGS, COMMENTS 1, COMMENTS 2, and DATA PERIODS. This is followed by the time step data.

The first eight lines or header within each E/E weather file define basic location information such as longitude, latitude, time zone, elevation, annual design conditions, monthly average ground temperatures, typical and extreme periods, holidays/daylight savings periods, and data periods included. There is also space for users to document any special features or information about the file such as sources of data. The data then follows—8760/8784 lines if hourly data for a year. The specific data elements in the E/E format include:

- Location (City, State Province Region, Country, Data Source, WMO Number, Latitude, Longitude, Time Zone, Elevation)
- Design Conditions (Annual Extreme Daily Mean, Mean Maximum Dry Bulb Temperature and Standard Deviation, Mean Minimum Dry Bulb Temperature and Standard Deviation, Heating Dry Bulb Temperature (99.6%, 99%, 98%), Cooling Dry Bulb Temperature/Mean Coincident Web Bulb Temp (0.4%, 1.0%, 2.0%), Cooling Dew Point Temperature, Mean Coincident Dry Bulb Temp (0.4%, 1.0%, 2.0%), Coincident Humidity Ratio and Relative Humidity (0.4%, 1.0%, 2.0%), Daily Range of Dry Bulb Temperature, Heating Degree Days Base Temperature, Heating Degree Days, Cooling Degree Days Base Temperature, Cooling Degree Days)
- Typical/Extreme Periods (Number of Typical/Extreme Periods (up to 8), Description of each Typical/Extreme Period, Start Month/Day, End Month/Day)
- Ground Temperatures (Number of Ground Temperature Depths (up to 3), Depth for each Ground Temperature set, Soil Conductivity, Soil Density, Soil Specific Heat, Monthly Average Ground Temperatures)

Table 2. EnergyPlus/ESP-r Weather Data Format Definition

LOCATION, A1 [City], A2 [State Province Region], A3 [Country], A4 [Data Source], N1 [WMO Number], N2 [Latitude {+N –S: -90.0 to +90.0:degrees minutes in decimal}], N3 [Longitude {-W +E: -180.0 to +180.0:degrees minutes in decimal}], N4 [Time Zone {-12.00 to +12.00: GMT-12 to GMT+12: partial hours in decimal}], N5 [Elevation {m: -1000.0 to +9999.9}]
DESIGN CONDITIONS, N1 [Annual Extreme Daily Mean Maximum Dry Bulb Temp {C}],
N2 [Annual Extreme Daily Mean Minimum Dry Bulb Temp {C}],
N3 [Annual Extreme Daily Standard Deviation Maximum Dry Bulb Temp {C}],
N4 [Annual Extreme Daily Standard Deviation Minimum Dry Bulb Temp {C}],
N5 [99.6% Heating Dry Bulb Temp {C}], N6 [99% Heating Dry Bulb Temp {C}], N7 [98% Heating Dry Bulb Temp {C}],
N8 [0.4% Cooling Dry Bulb Temp {C}], N9 [0.4% Mean Coincident Wet Bulb Temp {C}],
N10 [1.0% Cooling Dry Bulb Temp {C}], N11 [1.0% Mean Coincident Wet Bulb Temp {C}],
N12 [2.0% Cooling Dry Bulb Temp {C}], N13 [2.0% Mean Coincident Wet Bulb Temp {C}],
N14 [0.4% Cooling Dew Point Temp {C}], N15 [0.4% Mean Coincident Dry Bulb Temp {C}],
N16 [0.4% Humidity Ratio {g/kg}], N17 [0.4% Relative Humidity],
N18 [1.0% Cooling Dew Point Temp {C}], N19 [1.0% Mean Coincident Dry Bulb Temp {C}],
N20 [1.0% Humidity Ratio {g/kg}], N21 [1.0% Relative Humidity],
N22 [2.0% Cooling Dew Point Temp {C}], N23 [2.0% Mean Coincident Dry Bulb Temp {C}],
N24 [2.0% Humidity Ratio {g/kg}], N25 [2.0% Relative Humidity],
N26 [Daily Range of Dry Bulb Temp {C}],
N27 [Heating Degree Days Base Temp {C}], N28 [Heating Degree Days],
N29 [Cooling Degree Days Base Temp {C}], N30 [Cooling Degree Days]
TYPICAL/EXTREME PERIODS, N1 [Number of Typical/Extreme Periods],
A1 [Typical/Extreme Period 1], A2 [Period 1 Start Day], A3 [Period 1 End Day],
A4 [Typical/Extreme Period 2], A5 [Period 2 Start Day], A6 [Period 2 End Day],
A7 [Typical/Extreme Period 3], A8 [Period 3 Start Day], A9 [Period 3 End Day],
A10 [Typical/Extreme Period 4], A11 [Period 4 Start Day], A12 [Period 4 End Day],
A13 [Typical/Extreme Period 5], A14 [Period 5 Start Day], A15 [Period 5 End Day],
A16 [Typical/Extreme Period 6], A17 [Period 6 Start Day], A18 [Period 6 End Day],
A19 [Typical/Extreme Period 7], A20 [Period 7 Start Day], A21 [Period 7 End Day],
A22 [Typical/Extreme Period 8], A23 [Period 8 Start Day], A24 [Period 8 End Day]
GROUND TEMPERATURES, N1 [Number of Ground Temp Depths],
N2 [Ground Temp Depth 1 {m}], N3 [Depth 1 Soil Conductivity {W/(mK)}],
N4 [Depth 1 Soil Density {kg/m3}], N5 [Depth 1 Soil Specific Heat {kJ/(kgK)}],
N6 [Depth 1 January Average Ground Temp {C}], N7 [Depth 1 February Average Ground Temp {C}],
N8 [Depth 1 March Average Ground Temp {C}], N9 [Depth 1 April Average Ground Temp {C}],
N10 [Depth 1 May Average Ground Temp {C}], N11 [Depth 1 June Average Ground Temp {C}],
N12 [Depth 1 July Average Ground Temp {C}], N13 [Depth 1 August Average Ground Temp {C}],
N14 [Depth 1 September Average Ground Temp {C}], N15 [Depth 1 October Average Ground Temp {C}],
N16 [Depth 1 November Average Ground Temp {C}], N17 [Depth 1 December Average Ground Temp {C}],
N18 [Ground Temp Depth 2 {m}], N19 [Depth 2 Soil Conductivity {W/(mK)}],
N20 [Depth 2 Soil Density {kg/m3}], N21 [Depth 2 Soil Specific Heat {kJ/(kgK)}],
N22 [Depth 2 January Average Ground Temp {C}], N23 [Depth 2 February Average Ground Temp {C}],
N24 [Depth 2 March Average Ground Temp {C}], N25 [Depth 2 April Average Ground Temp {C}],
N26 [Depth 2 May Average Ground Temp {C}], N27 [Depth 2 June Average Ground Temp {C}],
N28 [Depth 2 July Average Ground Temp {C}], N29 [Depth 2 August Average Ground Temp {C}],
N30 [Depth 2 September Average Ground Temp {C}], N31 [Depth 2 October Average Ground Temp {C}],
N32 [Depth 2 November Average Ground Temp {C}], N33 [Depth 2 December Average Ground Temp {C}],
N34 [Ground Temp Depth 3 {m}], N35 [Depth 3 Soil Conductivity {W/(mK)}],
N36 [Depth 3 Soil Density {kg/m3}],N37 [Depth 3 Soil Specific Heat {kJ/(kgK)}],
N38 [Depth 3 January Average Ground Temp {C}], N39 [Depth 3 February Average Ground Temp {C}],
N40 [Depth 3 March Average Ground Temp {C}], N41 [Depth 3 April Average Ground Temp {C}],
N42 [Depth 3 May Average Ground Temp {C}], N43 [Depth 3 June Average Ground Temp {C}],
N44 [Depth 3 July Average Ground Temp {C}], N45 [Depth 3 August Average Ground Temp {C}],
N46 [Depth 3 September Average Ground Temp {C}], N47 [Depth 3 October Average Ground Temp {C}],
N48 [Depth 3 November Average Ground Temp {C}], N49 [Depth 3 December Average Ground Temp {C}]
HOLIDAYS/DAYLIGHT SAVINGS, A1 [Day of Week], A2 [Daylight Savings Start Day], A3 [Daylight Savings End Day],
N1 [Number of Holidays, A4 [Holiday 1 Name], A5 [Holiday 1 Day], … , Ax [Holiday N Name], Ay [Holiday N Day]
COMMENTS 1, A1 [Comments 1]
COMMENTS 2, A1 [Comments 2]
DATA PERIODS, N1 [Number of Data Periods], A1 [Data Period 1 Name/Description], A2 [Data Period 1 Start Day], A3 [Data Period 1 End Day],
A4 [Data Period 2 Name/Description], A5 [Data Period 2 Start Day], A6 [Data Period 2 End Day],
A7 [Data Period 3 Name/Description], A8 [Data Period 3 Start Day], A9 [Data Period 3 End Day],
A10 [Data Period 4 Name/Description], A11 [Data Period 4 Start Day], A12 [Data Period 4 End Day],
A13 [Data Period 5 Name/Description], A14 [Data Period 5 Start Day], A15 [Data Period 5 End Day],
A16 [Data Period 6 Name/Description], A17 [Data Period 6 Start Day], A18 [Data Period 6 End Day],
A19 [Data Period 7 Name/Description], A20 [Data Period 7 Start Day], A21 [Data Period 7 End Day],
A22 [Data Period 8 Name/Description], A23 [Data Period 8 Start Day], A24 [Data Period 8 End Day],
A25 [Data Period 9 Name/Description], A26 [Data Period 9 Start Day], A27 [Data Period 9 End Day],
A28 [Data Period 10 Name/Description], A29 [Data Period 10 Start Day], A30 [Data Period 10 End Day],
A31 [Data Period 11 Name/Description], A32 [Data Period 11 Start Day], A33 [Data Period 11 End Day],
A34 [Data Period 12 Name/Description], A35 [Data Period 12 Start Day], A36 [Data Period 12 End Day]
N1 [Year], N2 [Month {1-12}], N3 [Day {1-31}], N4 [Hour {0-23}], N5 [Minute {0-59}], A1 [Data Source and Uncertainty Flags], N6 [Dry Bulb Temp {C}],
N7 [Dew Point Temp {C}], N8 [Relative Humidity {0.0 to 1.0}], N9 [Atmospheric Station Pressure {mb}],
N10 [Extraterrestrial Horizontal Radiation {Wh/m2}], N11 [Extraterrestrial Direct Normal Radiation {Wh/m2}],
N12 [Horizontal Infrared Radiation from Sky {Wh/m2}], N13 [Global Horizontal Radiation {Wh/m2}], N14 [Direct Normal Radiation {Wh/m2}],
N15 [Diffuse Horizontal Radiation {Wh/m2}], N16 [Global Horizontal Illuminance {lux}], N17 [Direct Normal Illuminance {lux}],
N18 [Diffuse Horizontal Illuminance {lux}], N19 [Zenith Luminance {Cd/m2}], N20 [Wind Direction {degrees}], N21 [Wind Speed {m/s}],
N22 [Total Sky Cover], N23 [Opaque Sky Cover], N24 [Visibility {km}], N25 [Ceiling Height {m}], N26 [Present Weather Observation],
A2 [Present Weather Codes], N27 [Precipitable Water {mm}], N28 [Aerosol Optical Depth {thousandths}],
N29 [Snow Depth {cm}], N30 [Days Since Last Snowfall]

- Daylight Savings Periods, Holidays
- Comments
- Time Step Data Periods ((up to 12), Description, Start Month/Day, End Month/Day)
- Time Step (Year, Month, Day, Hour, Minute), Data Source and Uncertainty Flags
- Time Step Data (Dry Bulb Temperature, Dew Point Temperature, Relative Humidity, Atmospheric Station Pressure, Radiation (Extraterrestrial Horizontal, Extraterrestrial Direct Normal, Horizontal Infrared Radiation from Sky, Global Horizontal, Direct Normal, Diffuse Horizontal), Illuminance (Global Horizontal, Direct Normal, Diffuse Horizontal, Zenith Luminance), Wind (Direction, Speed), Sky Cover (Total, Opaque, Visibility, Ceiling Height), Present Weather (Observation, Codes), Precipitable Water, Aerosol Optical Depth, Snow (Depth, Days Since Last Snowfall))

Tables 3, 4, 5, 6, and 7 describe the codes for the sixth field in the time step data—Data Source and Uncertainty Flags. Table 3 describes the flags in order they are presented within the sixth data field—each flag is a single letter or number. Tables 4, 5, 6 and 7 provide a description of each of the codes. An example header and first and last days of an E/E data file for Washington, DC (Dulles Airport, Sterling, Virginia) is shown in Table 8.

As noted in Table 2, the E/E format allows up to 8 Typical/Extreme periods, and 12 Data Periods—users are not required to fill or use all of the data space allocated. The E/E Weather Utility automatically generates the Typical/Extreme periods. daylight savings periods and number of holidays and holiday dates are country- and site-specific. The number of holidays is variable and entered by the user. We included daylight savings and holidays in the format so that users will only have to find those data once, not each time they run the simulation program. In both EnergyPlus and ESP-r, these design conditions, holiday, daylight savings, other data are defaults and can be overridden by user input.

UTILITY

We developed a utility for the E/E format to read standard weather service file types such as TD1440 and DATSAV2 and newer ‘typical year’ weather files such as TMY2 and WYEC2.

The utility translates and extends typical weather data into the E/E format. The processor makes the calculations necessary for interpolating data (when data is missing) and calculates the illumination data—not typically currently an observed value reported by the meteorological offices through the world. The utility also prepares an interactive summary of the weather data set that the user can browse and save.

Table 3. Key to Data Source and Uncertainty Flags

Data Flag	Flag Values
Dry Bulb Temperature Data Source	A-F
Dry Bulb Temperature Data Uncertainty	0-9
Dew Point Temperature Data Source	A-F
Dew Point Temperature Data Uncertainty	0-9
Relative Humidity Data Source	A-F
Relative Humidity Data Uncertainty	0-9
Atmospheric Station Pressure Data Source	A-F
Atmospheric Station Pressure Data Uncertainty	0-9
Horizontal Infrared Radiation Data Source	A-H, ?
Horizontal Infrared Radiation Data Uncertainty	0-9
Global Horizontal Radiation Data Source	A-H, ?
Global Horizontal Radiation Data Uncertainty	0-9
Direct Normal Radiation Data Source	A-H, ?
Direct Normal Radiation Data Uncertainty	0-9
Diffuse Horizontal Radiation Data Source	A-H, ?
Diffuse Horizontal Radiation Data Uncertainty	0-9
Global Horizontal Illuminance Data Source	I, ?
Global Horizontal Illuminance Data Uncertainty	0-9
Direct Normal Illuminance Data Source	I, ?
Direct Normal Illuminance Data Uncertainty	0-9
Diffuse Horizontal Illuminance Data Source	I, ?
Diffuse Horizontal Illuminance Data Uncertainty	0-9
Zenith Luminance Data Source	I, ?
Zenith Luminance Data Uncertainty	0-9
Wind Direction Data Source	A-F
Wind Direction Data Uncertainty	0-9
Wind Speed Data Source	A-F
Wind Speed Data Uncertainty	0-9
Total Sky Cover Data Source	A-F
Total Sky Cover Data Uncertainty	0-9
Opaque Sky Cover Data Source	A-F
Opaque Sky Cover Data Uncertainty	0-9
Visibility Data Source	A-F, ?
Visibility Data Uncertainty	0-9
Ceiling Height Data Source	A-F, ?
Ceiling Height Data Uncertainty	0-9
Precipitable Water Data Source	A-F
Precipitable Water Data Uncertainty	0-9
Broadband Aerosol Optical Depth Data Source	A-F
Broadband Aerosol Optical Depth Data Uncertainty	0-9
Snow Depth Data Source	A-F, ?
Snow Cover Data Uncertainty	0-9
Days Since Last Snowfall Data Source	A-F, ?
Days Since Last Snowfall Data Uncertainty	0-9

Table 4. Solar Radiation and Illuminance Data Source Flag Codes

Flag Code	Definition
A	Post-1976 measured solar radiation data as received from NCDC or other sources
B	Same as "A" except the global horizontal data underwent a calibration correction
C	Pre-1976 measured global horizontal data (direct and diffuse were not measured before 1976), adjusted from solar to local time, usually with a calibration correction
D	Data derived from the other two elements of solar radiation using the relationship, global = diffuse + direct ´ cosine (zenith)
E	Modeled solar radiation data using inputs of observed sky cover (cloud amount) and aerosol optical depths derived from direct normal data collected at the same location
F	Modeled solar radiation data using interpolated sky cover and aerosol optical depths derived from direct normal data collected at the same location
G	Modeled solar radiation data using observed sky cover and aerosol optical depths estimated from geographical relationships
H	Modeled solar radiation data using interpolated sky cover and estimated aerosol optical depths
I	Modeled illuminance or luminance data derived from measured or modeled solar radiation data
?	Source does not fit any of the above categories. Used for nighttime values and missing data

Table 5. Solar Radiation and Illuminance Data Uncertainty Flag Codes

Flag	Uncertainty Range (%)
1	Not used
2	2 - 4
3	4 - 6
4	6 - 9
5	9 - 13
6	13 - 18
7	18 - 25
8	25 - 35
9	35 - 50
0	Not applicable

Table 6. Meteorological Data Source Flag Codes

Flag	Definition
A	Data as received from NCDC, converted to SI units
B	Linearly interpolated
C	Non-linearly interpolated to fill data gaps from 6 to 47 hours in length
D	Not used
E	Modeled or estimated, except: precipitable water, calculated from radiosonde data; dew point temperature calculated from dry bulb temperature and relative humidity; and relative humidity calculated from dry bulb temperature and dew point temperature
F	Precipitable water, calculated from surface vapor pressure; aerosol optical depth, estimated from geographic correlation
?	Source does not fit any of the above. Used mostly for missing data

Table 7. Meteorological Uncertainty Flag Codes

Flag	Definition
1- 6	Not used
7	Uncertainty consistent with NWS practices and the instrument or observation used to obtain the data
8	Greater uncertainty than 7 because values were interpolated or estimated
9	Greater uncertainty than 8 or unknown.
0	Not definable.

CONCLUSIONS

We have developed a generic weather format for use by EnergyPlus and ESP-r. The new data set covers data that are increasingly needed for simulations of complex building designs such as sub-hourly data and illumination data. By extending the weather data available to developers of energy simulation models, we believe that the new format will also encourage developers to actually use the data available rather than forcing them to create data within their modules. Several advantages for this weather data format include:

- Measured data with time-steps of less than one hour can be easily translated into the format
- Data are easily shared among major energy simulation programs
- Specialized weather data sets, e.g., hot sunny, cold cloudy, high wind, etc—can be developed for the same location
- Uncertainty associated with global climate change can be evaluated

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WEB RESOURCES

Building Energy Tools Directory, a directory of information on more than 160 energy tools from around the world.

http://www.eren.doe.gov/buildings/tools_directory/

Energy Systems Research Unit, University of Strathclyde, authors of ESP-r, up-to-date information on ESP-r and other energy systems research and software development.

http://www.strath.ac.uk/Departments/ESRU

EnergyPlus, up-to-date information on the current status of EnergyPlus and working with the team, and documentation such as input data structure, output data structure, and licensing opportunities. A more detailed description of the EnergyPlus/ESP-r weather format is also included with sample weather files.

http://www.eren.doe.gov/buildings/energy_tools/energyplus.htm

Table 8. Example EnergyPlus/ESP-r Weather Data for Washington, D.C. (Dulles Airport)

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LOCATION,Washington (Dulles Airport),DC,United States,TMY2 93738,724030,38.95, -77.45,-5,82
DESIGN CONDITIONS,26,1 5,4,5,-12.8,-10.2,-9.3,34,24,32,23,31,23,24,28,19,.40,23,27,18,.37,22,27,17,.35,11.7,18,1823,18,940
TYPICAL/EXTREME PERIODS,4,Winter,01/29,02/06,Spring,03/17,03/24,Summer,07/14,07/22,Fall,09/13,09/20
GROUND TEMPERATURES, 1,3,0.04,34,0.9,0,3,5,6,7,9,10,15,1 4,12,9,5
HOLIDAYS/DAYLIGHT SAVINGS,Friday,04/04,10/31,10,New Years Day,01/01,Martin Luther King Birthday,01/18,Presidents Day,02/15,Memorial Day,05/31,Independence Day,07/05,Labor Day,09/06,Columbus Day,10/11,Veterans
Day,11/11,Thanksgiving,11/25,Christmas,12/24
COMMENTS, TMY2 data Sterling Virginia United States WBAN 93738
COMMENTS, Design conditions from ASHRAE Fundamentals 1997
DATA PERIODS, 1,TMY2 Year,1,365
1976,01,01,01,0,A7A7A7A7?9?0?0?0?0?0?0A7A7A7A7A7A7F8F8A7E7,1.1,1.1,100,990,0,0,9999,0,0,0,0,0,0, 0,340,5.2,10,10,6.4,122,0,909099099,23,0.056,0,0
1976,01,01,02,0,B8E7B8B8?9?0?0?0?0?0?0B8B8B8B8?0?0F8F8A7E7,0.7,0.5,99,991,0,0,9999,0,0,0,0,0,0,0,340,5.2,10,10,9999,99999,0,999999999,23,0.056,0,0
1976,01,01,03,0,B8E7B8B8?9?0?0?0?0?0?0B8B8B8B8?0?0F8F8A7E7,0 .4,0.0,97,993,0,0,9999,0,0,0,0,0,0,0,330,5.2,10,10,9999,99999,0,999999999,23,0.056,0,0
1976,01,01,04,0,A7A7A7A7?9?0?0?0?0?0?0A7A7A7A7A7A7F8F8A7E7,0.0,-0.6,96,995,0,0,9999,0,0,0,0,0,0,0,330,5.2,10,10,1.6,91,0,999099099,23,0.056,0,0
1976,01,01,05,0,B8E7B8B8? 9?0?0?0?0?0?0B8B8B8B8?0?0F8F8A7E7,0.0,-0.5,96,997,0,0,9999,0,0,0,0,0,0,0,320,5.0,10,10,9999,99999,0,999999999,24,0.056,0,0
1976,01,01,06,0,B8E7B8B8?9?0?0?0?0?0?0B8B8B8B8?0?0F8F8A7E7,0.0, -0.5,96,999,0,0,9999,0,0,0,0,0,0,0,320,4.8,10,10,9999,99999,0,99999999 9,24,0.056,0,0
1976,01,01,07,0,A7A7A7A7?9?0?0?0?0?0?0A7A7A7A7A7A7F8F8A7E7,0.0,-0.6,96,1000,0,0,9999,0,0,0,0,0,0,0,310,4.6,10,10,8.0,213,0,999099099,24,0.056,0,0
1976,01,01,08,0,B8E7B8B8?9F6F6F6I6I6I6B8B8B8B8?0?0F8F8A7E7,0.4, -0.7,92,1002,59,637,9999,11,17,9 ,0,0,0,0,310,4.8,7,7,9999,99999,0,999999999,24,0.056,0,0
1976,01,01,09,0,B8E7B8B8?9F6F6F6I6I6I6B8B8B8B8?0?0F8F8A7E7,0.7, -0.8,89,1004,225,1415,9999,88,315,38,9100,21600,5700,690,300,5.0,4,4,9999,99999,0,999999999,25,0.056,0,0
1976,01,01,10,0,A7A7A7A7?9E4E4E 5I4I4I5A7A7A7A7A7A7F8F8A7E7,1.1,-1.1,85,1006,421,1415,9999,257,637,67,26900,55500,10400,1270,300,5.2,1,1,32.2,77777,0,999999999,25,0.056,0,0
1976,01,01,11,0,B8E7B8B8?9F4F4F5I4I4I5B8B8B8B8?0?0F8F8A7E7,1.7, -1.1,81,1006,565,1415,9999,356,745,59,38200,71600,96 00,1280,310,5.5,2,2,9999,99999,0,999999999,25,0.056,0,0
1976,01,01,12,0,B8E7B8B8?9F4F4F5I4I4I5B8B8B8B8?0?0F8F8A7E7,2.2, -1.2,77,1006,647,1415,9999,430,800,64,45800,78200,10000,1420,320,5.9,2,2,9999,99999,0,999999999,25,0.056,0,0
1976,01,01,13,0,A7A7A7A7?9E5E4E5I5I4I5A7A7A7A7A7A7F8F8A7E7,2.8,-1.7,73,1006,662,1415,9999,394,564,130,41200,54000,15900,2610,330,6.2,3,3,32.2,77777,0,999999999,25,0.056,0,0
1976,01,01,14,0,B8E7B8B8?9F4F4F5I4I4I5B8B8B8B8?0?0F8F8A7E7,3.0, -1.5,71,1007,608,1415,9999,385,722,74,40700,6980 0,10600,1530,320,6.2,2,2,9999,99999,0,999999999,26,0.056,0,0
1976,01,01,15,0,B8E7B8B8?9F4F4F5I4I4I5B8B8B8B8?0?0F8F8A7E7,3.1, -1.8,69,1008,489,1415,9999,299,749,40,32200,70300,7800,1030,320,6.2,1,1,9999,99999,0,999999999,26,0.056,0,0
1976,01,01,16,0,A7A7A7A7?9E5E4E5I5I4I5A7A7A7A7A7A7F8F8A7E7,3.3,-2.2,67,1009,313,1415,9999,177,671,28,19100,57200,6400,730,310,6.2,0,0,32.2,77777,0,999999999,26,0.056,0,0
1976,01,01,17,0,B8E7B8B8?9F5F4F5I5I4I5B8B8B8B8?0?0F8F8A7E7,1.8, -2.2,73,1009,111,1226,9999,47,348,16,4500,20300 ,2900,330,320,5.0,0,0,9999,99999,0,999999999,27,0.056,0,0
1976,01,01,18,0,B8E7B8B8?9?0?0?0?0?0?0B8B8B8B8?0?0F8F8A7E7,0.4, -2.5,79,1010,0,0,9999,0,0,0,0,0,0,0,330,3.8,0,0,9999,99999,0,999999999,27,0.056,0,0
1976,01,01,19,0,A7A7A7A7?9?0?0?0?0?0?0A7A7A7A7A7A7F8F8A7E7,-1.1,-3.3,85,1011,0,0,9999,0,0,0,0,0,0,0,340,2.6,0,0,24.1,77777,0,999999999,27,0.056,0,0
1976,01,01,20,0,B8E7B8B8?9?0?0?0?0?0?0B8B8B8B8?0?0F8F8A7E7, -2.0,-3.7,87,1011,0,0,9999,0,0,0,0,0,0,0,340,2.6,0,0,9999,99999,0,999999999,26,0.056,0,0
1976,01,01,21,0,B8E7B8B8?9?0?0?0?0?0?0B8B8B8B8?0?0F8F8A7E7, -3.0,-4.2,90,1011,0,0,9999,0,0,0,0,0,0,0,350,2.6,0,0,9999,99999,0,999999999,25,0.056,0,0
1976,01,01,22,0,A7A7A7A7?9?0?0?0?0?0?0A7A7A7A7A7A7F8F8A7E7,-3.9,-5.0,92,1012,0,0,9999,0,0,0,0,0,0,0,350,2.6,0,0,24.1,77 777,0,999999999,24,0.056,0,0
1976,01,01,23,0,B8E7B8B8?9?0?0?0?0?0?0B8B8B8B8?0?0F8F8A7E7, -4.3,-5.3,92,1012,0,0,9999,0,0,0,0,0,0,0,340,1.7,0,0,9999,99999,0,999999999,23,0.056,0,0
1976,01,01,24,0,B8E7B8B8?9?0?0?0?0?0?0B8B8B8B8?0?0F8F8A7E7, -4.6,-5.6,92,1013,0,0,9999,0,0,0,0,0,0,0,330,0.9,0,0,9999,99999,0,999999999,22,0.056,0,0
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1981,12,31,01,0,A7A7A7A7?9?0?0?0?0?0?0A7A7A7A7A7A7F8F8A7E7,-5.6,-8.9,78,1021,0,0,9999,0,0,0,0,0,0,0,120,2.1,5,2,11.3,77777,0,999999999,4,0.056,0,0
1981,12,31,02,0,A7A7A7A7?9?0?0?0?0?0?0A7A7A7A7A7A7F8F8A7E7,-6.1,-10.0,74,1020,0,0,9999,0,0,0,0,0,0,0,0,0.0,0,0,8.0,77777,0,999999919,4,0.056,0,0
1981,12,31,03,0,A7A7A7A7?9?0?0?0?0?0?0A7A7A7A7A7A7F8F8A7E7,-6.7,-9.4,81,1020,0,0,9999,0,0,0,0,0,0,0,0,0.0,0,0,9.7,77777,0,999999919,4,0.056,0 ,0
1981,12,31,04,0,A7A7A7A7?9?0?0?0?0?0?0A7A7A7A7A7A7F8F8A7E7,-6.1,-9.4,78,1020,0,0,9999,0,0,0,0,0,0,0,0,0.0,0,0,9.7,77777,0,999999929,4,0.056,0,0
1981,12,31,05,0,A7A7A7A7?9?0?0?0?0?0?0A7A7A7A7A7A7F8F8A7E7,-6.1,-10.0,74,1019,0,0,9999,0,0,0,0,0,0,0,90,2.1,2 ,0,9.7,77777,0,999999929,4,0.056,0,0
1981,12,31,06,0,A7A7A7A7?9?0?0?0?0?0?0A7A7A7A7A7A7F8F8A7E7,-5.0,-8.9,74,1020,0,0,9999,0,0,0,0,0,0,0,0,0.0,6,2,9.7,77777,0,999999919,4,0.056,0,0
1981,12,31,07,0,A7A7A7A7?9?0?0?0?0?0?0A7A7A7A7A7A7F8F8A7E7,-3.3,-6.7,78,1020,0,0,9999,0,0,0,0,0,0,0,150,3.1,6,2,9.7,77777,0,999999919,4,0.056,0,0
1981,12,31,08,0,A7A7A7A7?9A4A4A5I4I4I5A7A7A7A7A7A7F8F8A7E7, -2.8,-6.7,75,1020,60,637,9999,5,0,5,0,0,0,0,150,2.1,10,6,9.7,7620,0,999999919,4,0.056,0,0
1981,12,31,09,0,A7A7A7A7?9A4A4A5I4I4 I5A7A7A7A7A7A7F8F8A7E7,-0.6,-4.4,75,1019,225,1415,9999,51,0,54,6000,0,6000,1820,120,1.5,10,7,11.3,7620,0,999999999,4,0.056,0,0
1981,12,31,10,0,A7A7A7A7?9A3A2A4I3I2I4A7A7A7A7A7A7F8F8A7E7,1.1, -4.4,67,1019,421,1415,9999,208,146,165,22300,12600,18500,3690,130, 1.5,10,5,11.3,77777,0,999999999,5,0.056,0,0
1981,12,31,11,0,A7A7A7A7?9A3A2A4I3I2I4A7A7A7A7A7A7F8F8A7E7,2.2, -3.9,64,1018,564,1415,9999,229,163,175,26100,15400,20000,4100,100,3.1,10,8,11.3,7620,0,999999999,5,0.056,0,0
1981,12,31,12,0,A7A7A7A7?9A3A2A4I3I2I4A7 A7A7A7A7A7F8F8A7E7,4.4,-3.9,55,1016,646,1415,9999,283,233,180,30700,22800,20300,3920,120,3.1,10,10,11.3,7620,0,999999999,5,0.056,0,0
1981,12,31,13,0,A7A7A7A7?9A3A2A4I3I2I4A7A7A7A7A7A7F8F8A7E7,4.4, -3.3,57,1015,660,1415,9999,408,540,164,44000,51900,19800,338 0,140,2.6,10,10,11.3,1524,0,999999999,6,0.056,0,0
1981,12,31,14,0,A7A7A7A7?9A3A2A4I3I2I4A7A7A7A7A7A7F8F8A7E7,4.4, -2.8,60,1013,606,1415,9999,386,735,84,41600,70600,11300,1640,130,2.6,10,10,11.3,1280,0,999999999,6,0.056,0,0
1981,12,31,15,0,A7A7A7A7?9A3A2A4I3 I2I4A7A7A7A7A7A7F8F8A7E7,4.4,-2.8,60,1012,486,1415,9999,298,714,65,32500,66100,9600,1270,130,1.5,10,10,4.0,1097,0,999909999,6,0.056,0,0
1981,12,31,16,0,A7A7A7A7?9A3A3A4I3I3I4A7A7A7A7A7A7F8F8A7E7,2.8, -1.7,73,1011,310,1415,9999,168,608,45,18500,50000,7400,85 0,340,1.5,10,10,1.6,853,0,999099999,6,0.056,0,0
1981,12,31,17,0,A7A7A7A7?9A4A4A5I4I4I5A7A7A7A7A7A7F8F8A7E7,2.2, -1.1,79,1010,111,1203,9999,34,232,17,3700,11600,2800,320,20,1.5,10,10,1.6,549,0,909999999,6,0.056,0,0
1981,12,31,18,0,A7A7A7A7?9?0?0?0?0?0?0A7A7A7A7A7A7F8F8A7E7,2.2,-0.6,82,1009,0,0,9999,0,0,0,0,0,0,0,50,3.1,10,10,1.6,518,0,909999999,7,0.056,0,0
1981,12,31,19,0,A7A7A7A7?9?0?0?0?0?0?0A7A7A7A7A7A7F8F8A7E7,2.8,0.6,85,1008,0,0,9999,0,0,0,0,0,0,0,90,2.6,10,10,1.6,183,0,909999099,7,0.056,0,0
1981,12,31,20,0,A7A7A7A7?9?0?0?0?0?0?0A7A7A7A7A7A7F8F8A7E7,5.0,2.2,82,1006,0,0,9999,0,0,0,0,0,0,0,90,3.1,10,10,1.6,183,0,909999099,8,0.056,0,0
1981,12,31,21,0,A7A7A7A7?9?0?0?0?0?0?0A7A7A7A7A7A7F8F8A7E7,6.1,3.9,86,1005,0,0,9999,0,0,0,0,0,0,0,120,4.1,10,10,1.6,183,0,909 999099,9,0.056,0,0
1981,12,31,22,0,A7A7A7A7?9?0?0?0?0?0?0A7A7A7A7A7A7F8F8A7E7,7.2,3.9,80,1004,0,0,9999,0,0,0,0,0,0,0,100,3.1,10,10,4.0,183,0,909999099,10,0.056,0,0
1981,12,31,23,0,A7A7A7A7?9?0?0?0?0?0?0A7A7A7A7A7A7F8F8A7E7,7.8,5.6,86,1003,0,0,9999,0,0,0,0, 0,0,0,100,3.6,10,10,8.0,213,0,909999999,11,0.056,0,0
1981,12,31,24,0,A7A7A7A7?9?0?0?0?0?0?0A7A7A7A7A7A7F8F8A7E7,8.3,6.1,86,1001,0,0,9999,0,0,0,0,0,0,0,90,5.7,10,10,8.0,213,0,909999999,12,0.056,0
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