A STATISTICALLY-BASED HOURLY WEATHER DATA GENERATOR FOR DRIVING ENERGY SIMULATION AND EQUIPMENT DESIGN SOFTWARE FOR BUILDINGS

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ABSTRACT

This paper describes an operating hourly weather simulation model which is utilized to drive building energy simulation and equipment design software. The model contains both deterministic and probabilistic portions that perform sun angle calculations, sky opacity, dry-bulb temperatures, dewpoint temperatures, wind speed, and barometric pressures. Sample summary statistics have been shown to give good agreement with means, extremes, and distributions of real weather data records. A sample energy analysis is also included to illustrate the model's flexibility for different applications. The model is also useful for creating synthetic hourly weather data files in TRY or TMY formats for use in a variety of energy calculation software or other applications.

A special data compression feature of the program permits it to simulate less than full months and still maintain its statistical integrity for energy calculations. This feature enables the energy simulations to run in one-quarter the time required by other simulation approaches. In the compressed mode, the model has been especially useful for material selection and daylighting evaluations during the early architectural design stage when quick turn around is desired.

The current database contains weather statistics for 194 U.S. cities, but this can be expanded to include additional cities at the will of the user. Input of new cities can be in either Inch-Pound or SI units. The program runs on most MS-DOS microcomputers.

INTRODUCTION

Building energy calculation programs typically rely on hourly weather data to drive the thermal models within the software. The need for reliable weather data has resulted in several efforts to make these data available to researchers and engineers. Currently used formats are WYEC (Weather Year for Energy Calculations) [Crow 1983, 1984], TRY (Test Reference Year) [TRY. 1976], and TMY (Typical Meteorological Year) [TMY. 1981]. This total resource represents weather records for over 230 cities and is available on 9-track magnetic tapes from the National Climatic Center [TMY. 1981].

Notwithstanding the weather data that are available in magnetic media for numerous cities, it is still often difficult to obtain the proper weather data information for a specific site. Hourly weather records are only collected for first order weather stations; therefore, weather tapes are not available for many small and medium sized cities. Even when weather tapes are available, access to the data is sometimes difficult.

This paper describes a model that is used to generate hourly weather data when only the daily maximum and mean temperatures, average wind speeds and mean daily horizontal insolation are known. The model can also be used to generate data for a site where no weather data are collected, if the site is near to another city that collects the data and the elevations of both sites are known.

A software implementation of the model is

```
                                                      WBAN   Lat.  Long.   STM.   Elev
NASHVILLE, TENNESSEE **                              13897   36.1   86.7   90.0    590
           Jan    Feb    Mar    Apr    May    Jun    Jul    Aug    Sep    Oct    Nov    Dec
DB ave    38.3   41.0   48.7   60.1   68.5   76.6   79.6   78.5   72.0   60.9   48.4   40.4
Ave std    8.6    9.2    7.9    6.0    4.7    5.1    6.5    6.3    6.0    6.5    7.7    8.3
DB Max    47.6   50.9   59.2   71.3   79.8   87.5   90.2   89.2   83.5   73.2   59.0   49.6
Max std    9.8   10.7    8.6    6.0    5.5    6.0    5.4    4.8    6.9    6.7    8.1    8.5
DP Ave    32.0   33.0   37.0   47.0   57.0   65.0   68.0   67.0   60.0   49.0   38.0   32.0
DP std     9.2    9.9    8.3    6.0    5.1    5.5    6.0    5.5    6.5    6.6    7.9    8.4
SOLAR      580    824   1130   1544   1825   1963   1891   1737   1398   1114    711    521
WIND       9.2    9.5   10.0    9.5    7.6    7.0    6.3    6.1    6.3    6.6    8.4    8.9


** SOLMET Corrected Station
```

Fig. 1 Sample WETHRGEN input data

available under the name, WETHRGEN [Degelman 1990b]. The hourly data output files generated by the program will vary in size from 170-k to around 1.1 Megabytes, so plenty of disk space needs to be available. Minimum system requirements are 384-K RAM, a math coprocessor chip, DOS 2.1 or higher, and a hard disk. On-screen displays operate best with color graphics adapters and color monitors. CGA, EGA, and VGA driver boards are all suitable, but not mandatory. Output from the program is sent to user-selected files on the hard disk. Printing of the results and/or use in other energy analysis software are left to the discretion of the user.

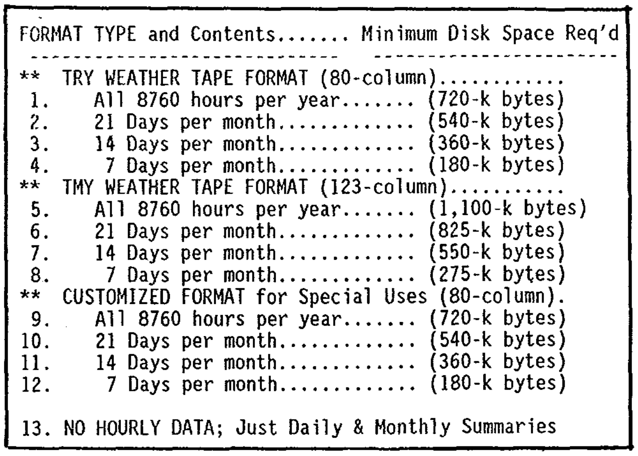
SOFTWARE INPUT/OUTPUT FEATURES

The hourly variables that WETHRGEN produces are dry-bulb, wet-bulb, and dewpoint temperatures; sun altitude and azimuthal angles; direct normal and diffuse horizontal insolation; cloud cover fraction; wind speed; and barometric pressure. These are normally the variables required for input to hourly energy calculations for buildings, though the user may wish to use these data for heating and cooling load calculations as well.

During the input stage, the program gives choices for performing several functions. A user-friendly routine in the front-end program permits browsing and automatically selecting any of the 194 U.S. weather stations contained in the standard database. These are most of the first order weather stations that have 30 years of weather records, and were obtained from NOAA publications. Each weather site is identified by a station number known as the **WBAN** number.

As an alternative to selecting a city already in the database, the user may choose to add a new city's weather data. The user needs to only provide city name, latitude, longitude, local time meridian, elevation above sea level, and monthly values for eight (8) weather parameters. These include: (1) average dry-bulb temperatures and OPTIONAL standard deviations, (2) average maximum dry-bulb temperatures and OPTIONAL standard deviations (or mean of annual extremes or extreme ever recorded), (3) average dewpoint temperatures and OPTIONAL standard deviations, (4) mean daily horizontal insolation, and (5) mean wind speeds. (See Fig. 1 for sample input data.) Input may be in SI or Inch-Pound units (or a mixture of both). The WETHRGEN software permits the user to save any number of additional cities to the database for later use.

The user's output choices are shown in Fig. 2. Files may be written in either of the two popular formats, TRY or TMY (ASHRAE's WYEC tapes also use TRY format), or a "text-like format" referred to as the CUSTOMIZED FORMAT. The latter is the easiest to read visually (see Fig. 3), ant it is intended for those persons who would be writing other software that could be customized to read this file in its current format, or for those persons who simply wish to examine the data for use in hand calculations. The data can be perused visually, for selecting data under any number of criteria and for a variety of applications.



```
FORMAT TYPE and Contents....... Minimum Disk Space Req'd
-----------------------------   ------------------------
**  TRY WEATHER TAPE FORMAT (80-column)...........
 1.     All 8760 hours per year....... (720-k bytes)
 2.     21 Days per month............. (540-k bytes)
 3.     14 Days per month............. (360-k bytes)
 4.      7 Days per month............. (180-k bytes)
**  TMY WEATHER TAPE FORMAT (123-column)..........
 5.     All 8760 hours per year....... (1,100-k bytes)
 6.     21 Days per month............. (825-k bytes)
 7.     14 Days per month............. (550-k bytes)
 8.      7 Days per month............. (275-k bytes)
**  CUSTOMIZED FORMAT for Special Uses (80-column).
 9.     All 8760 hours per year....... (720-k bytes)
10.     21 Days per month............. (540-k bytes)
11.     14 Days per month............. (360-k bytes)
12.      7 Days per month............. (180-k bytes)

13. NO HOURLY DATA; Just Daily & Monthly Summaries
```

Fig. 2 Choices of output file formats for hourly data

Sample output from the TRY and TMY runs are shown in Figs. 4 and 5.

In regard to subsequent use of the weather data, if the user anticipates that the computer run time will be inconveniently long for the planned energy calculations, the weather data simulation period may be performed for as few as seven days per month (2016 hours per year). This abbreviated simulation period will still yield statistically correct weather averages and extremes for both design load and energy calculations. Regardless of the output format requested or the simulation period specified, the program will always produce a summary file. This file contains daily and monthly weather statistics as well as a validity check on the simulation results. This comparison between input and simulated results is reported after the end of each month.

ENERGY SIMULATION APPLICATIONS

The primary intent of the WETHRGEN model is to produce weather data input to hourly energy programs. This weather data input has permitted energy software to produce annual and monthly energy consumption, peak demand charges, peak heating and cooling loads, solar heating fraction, and energy reductions from the thermal mass effect in the structure. Design data, tabulated by zones, can also show heating and cooling loads, duct sizes, and electric power requirements. An example of one such application are shown in Fig. 6 from the ENERCALC software [Degelman 1990a]. In this case the weather simulator is an embedded part of the energy calculation program. Other available detailed energy calculation software -- e.g., DOE-2 [LBL. 1979], BLAST [CERL 1986], as well as several others -- could utilize the results from WETHRGEN through the TRY and TMY formats.

The ENERCALC software currently accommodates the abbreviated simulation mode

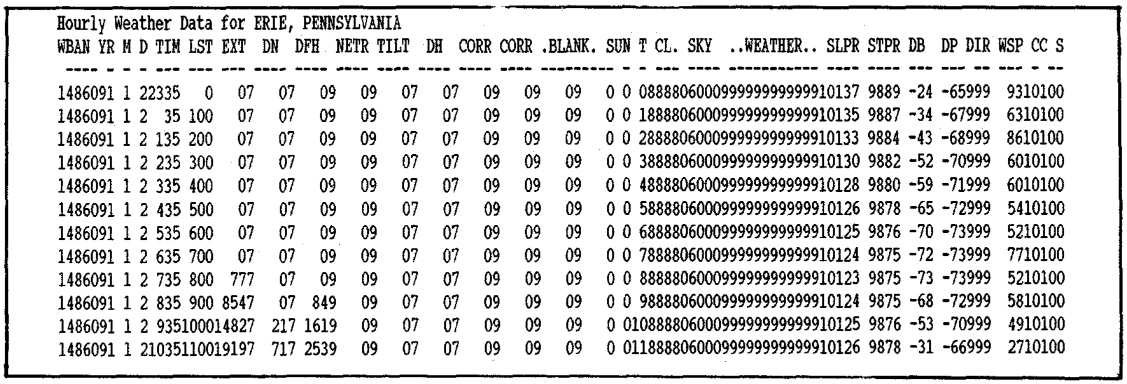
```
Hourly Weather Data for AUSTIN, TEXAS
WBAN Station Number: 13958
                              *Solar Angles, Radiation & Sky Cover*
Mon/Day/Time   DB   WB   DP    Sun  Sun Direct Diff. Total  Cloud  Wind   Station
      (hrs.) temp temp temp    alt  az. normal horiz horiz  cover speed   press.
______________(°F)_(°F)_(°F)____________(Btu per sq ft)_____(%)__(mph)__("Hg.)_

  1/ 2/ 0:00   51.  43.  35.    0.    0.    0.    0.    0.    82   15.3    29.43
  1/ 2/ 1:00   49.  42.  35.    0.    0.    0.    0.    0.    82   10.4    29.42
  1/ 2/ 2:00   46.  41.  35.    0.    0.    0.    0.    0.    82   14.0    29.41
  1/ 2/ 3:00   44.  40.  35.    0.    0.    0.    0.    0.    82    9.8    29.39
  1/ 2/ 4:00   42.  39.  35.    0.    0.    0.    0.    0.    82    9.8    29.38
  1/ 2/ 5:00   40.  38.  35.    0.    0.    0.    0.    0.    82    8.8    29.37
  1/ 2/ 6:00   39.  37.  35.    0.    0.    0.    0.    0.    82    8.5    29.36
  1/ 2/ 7:00   38.  37.  35.    0.    0.    0.    0.    0.    82   12.5    29.36
  1/ 2/ 8:00   38.  37.  35.    5.  121.    0.    0.    0.    82    8.5    29.35
  1/ 2/ 9:00   40.  38.  35.   16.  130.    8.   17.   19.    82    9.6    29.36
  1/ 2/10:00   44.  40.  35.   25.  141.   31.   43.   56.    82    8.0    29.36
  1/ 2/11:00   49.  43.  35.   32.  154.   52.   63.   91.    82    4.5    29.37
  1/ 2/12:00   56.  46.  35.   36.  170.   64.   72.  110.    82    9.1    29.38
  1/ 2/13:00   61.  48.  35.   36.  187.   65.   73.  111.    82    8.0    29.39
  1/ 2/14:00   65.  50.  35.   33.  204.   55.   65.   95.    82   11.0    29.41
  1/ 2/15:00   67.  51.  35.   26.  218.   35.   47.   62.    82    8.0    29.42
  1/ 2/16:00   67.  51.  35.   17.  229.   11.   21.   24.    82   10.4    29.43
  1/ 2/17:00   66.  51.  36.    7.  238.   47.   14.   20.    82   11.3    29.44
  1/ 2/18:00   66.  50.  36.    0.    0.    0.    0.    0.    82    6.6    29.45
  1/ 2/19:00   65.  50.  37.    0.    0.    0.    0.    0.    82    6.9    29.46
  1/ 2/20:00   64.  50.  38.    0.    0.    0.    0.    0.    82   10.1    29.46
  1/ 2/21:00   63.  50.  39.    0.    0.    0.    0.    0.    82    5.5    29.46
  1/ 2/22:00   62.  50.  40.    0.    0.    0.    0.    0.    82    9.1    29.45
  1/ 2/23:00   61.  51.  42.    0.    0.    0.    0.    0.    82   14.0    29.44
```

Fig. 3 Customized format from WETHRGEN

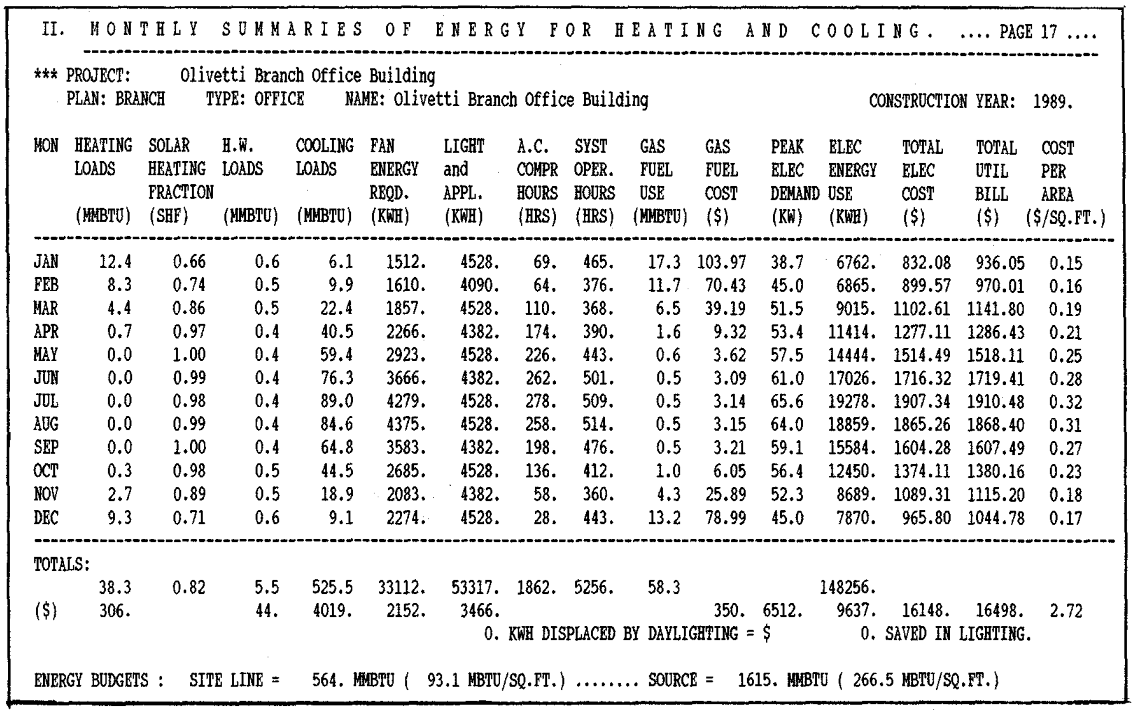
```
Hourly Weather Data for SAN JUAN (ISLA VERDE), PUERTO RICO
 WBAN DB WB DP .. WS SPB CC .......Missing Data....... SOLR ..Blank..Year M D TS
----- -- -- --  ---- --- -- --- -------------------- ----- ------- ----- - - --
11641 75 69 66999 1429960 59999999999999999999999999999   0          1991 1 2 09
11641 74 69 66999 1029950 59999999999999999999999999999   0          1991 1 2 19
11641 73 68 66999 1329940 59999999999999999999999999999   0          1991 1 2 29
11641 72 68 66999  929940 59999999999999999999999999999   0          1991 1 2 39
11641 71 68 66999  929930 59999999999999999999999999999   0          1991 1 2 49
11641 70 67 66999  829920 59999999999999999999999999999   0          1991 1 2 59
11641 70 67 66999  829920 59999999999999999999999999999   0          1991 1 2 69
11641 70 67 66999 1229910 59999999999999999999999999999   0          1991 1 2 79
11641 69 67 66999  829910 59999999999999999999999999999 124          1991 1 2 89
11641 70 67 66999  929910 59999999999999999999999999999 310          1991 1 2 99
11641 72 68 66999  729920 59999999999999999999999999999 225          1991 1 2109
11641 75 69 66999  429920 59999999999999999999999999999 326          1991 1 2119
11641 77 69 66999  829930 59999999999999999999999999999 377          1991 1 2129
11641 80 70 66999  729940 59999999999999999999999999999 375          1991 1 2139
11641 82 71 66999 1029940 59999999999999999999999999999 595          1991 1 2149
11641 83 71 66999  729950 59999999999999999999999999999 217          1991 1 2159
11641 82 71 66999 1029960 59999999999999999999999999999 299          1991 1 2169
11641 82 71 66999 1129970 59999999999999999999999999999 111          1991 1 2179
11641 82 71 66999  629970 59999999999999999999999999999   0          1991 1 2189
11641 81 71 66999  629970 59999999999999999999999999999   0          1991 1 2199
11641 81 71 66999  929970 59999999999999999999999999999   0          1991 1 2209
11641 80 71 67999  529970 59999999999999999999999999999   0          1991 1 2219
11641 79 71 67999  829970 59999999999999999999999999999   0          1991 1 2229
11641 78 70 67999 1329970 59999999999999999999999999999   0          1991 1 2239
11641 77 70 67999 1729870 09999999999999999999999999999   0          1991 1 7 09
11641 76 70 68999 1529770 09999999999999999999999999999   0          1991 1 7 19
11641 75 70 68999 1229670 09999999999999999999999999999   0          1991 1 7 29
11641 75 70 68999  929640 09999999999999999999999999999   0          1991 1 7 39
11641 74 70 68999  629640 09999999999999999999999999999   0          1991 1 7 49
```

Fig. 4 WETHRGEN output in TRY format



```
Hourly Weather Data for ERIE, PENNSYLVANIA
WBAN YR M D TIM LST EXT  DN  DFH  NETR TILT  DH  CORR CORR .BLANK. SUN T CL. SKY  ..WEATHER.. SLPR STPR DB  DP DIR WSP CC S
 ---- - - - --- --- --- ---- ---- ---- ---- ---- ---- ---- --------- - - --- ---- ---------- ---- ---- --- --- -- --- - --
1486091 1 22335   0  07   07   09   09   07   07   09   09   09   0 0 0888806000999999999999910137 9889 -24 -65999  9310100
1486091 1 2  35 100  07   07   09   09   07   07   09   09   09   0 0 1888806000999999999999910135 9887 -34 -67999  6310100
1486091 1 2 135 200  07   07   09   09   07   07   09   09   09   0 0 2888806000999999999999910133 9884 -43 -68999  8610100
1486091 1 2 235 300  07   07   09   09   07   07   09   09   09   0 0 3888806000999999999999910130 9882 -52 -70999  6010100
1486091 1 2 335 400  07   07   09   09   07   07   09   09   09   0 0 4888806000999999999999910128 9880 -59 -71999  6010100
1486091 1 2 435 500  07   07   09   09   07   07   09   09   09   0 0 5888806000999999999999910126 9878 -65 -72999  5410100
1486091 1 2 535 600  07   07   09   09   07   07   09   09   09   0 0 6888806000999999999999910125 9876 -70 -73999  5210100
1486091 1 2 635 700  07   07   09   09   07   07   09   09   09   0 0 7888806000999999999999910124 9875 -72 -73999  7710100
1486091 1 2 735 800  777  07   09   09   07   07   09   09   09   0 0 8888806000999999999999910123 9875 -73 -73999  5210100
1486091 1 2 835 900 8547  07  849   09   07   07   09   09   09   0 0 9888806000999999999999910124 9875 -68 -72999  5810100
1486091 1 2 935100014827  217 1619  09   07   07   09   09   09   0 010888806000999999999999910125 9876 -53 -70999  4910100
1486091 1 21035110019197  717 2539  09   07   07   09   09   09   0 011888806000999999999999910126 9878 -31 -66999  2710100
```

Fig. 5 WETHRGEN output in TMY format



```
 II.  MONTHLY  SUMMARIES  OF  ENERGY  FOR  HEATING  AND  COOLING.  .... PAGE 17 ....
     ------------------------------------------------------------------------------------------------------
*** PROJECT:     Olivetti Branch Office Building
    PLAN: BRANCH    TYPE: OFFICE    NAME: Olivetti Branch Office Building                 CONSTRUCTION YEAR:  1989.

MON  HEATING SOLAR    H.W.    COOLING FAN     LIGHT   A.C.  SYST   GAS     GAS    PEAK   ELEC    TOTAL   TOTAL  COST
     LOADS   HEATING  LOADS   LOADS   ENERGY  and     COMPR OPER.  FUEL    FUEL   ELEC   ENERGY  ELEC    UTIL   PER
             FRACTION                 REQD.   APPL.   HOURS HOURS  USE     COST   DEMAND USE     COST    BILL   AREA
     (MMBTU) (SHF)    (MMBTU) (MMBTU) (KWH)   (KWH)   (HRS) (HRS)  (MMBTU) ($)    (KW)   (KWH)   ($)     ($)   ($/SQ.FT.)
-----------------------------------------------------------------------------------------------------------------------
JAN   12.4    0.66     0.6      6.1   1512.   4528.    69.  465.    17.3  103.97  38.7    6762.  832.08  936.05  0.15
FEB    8.3    0.74     0.5      9.9   1610.   4090.    64.  376.    11.7   70.43  45.0    6865.  899.57  970.01  0.16
MAR    4.4    0.86     0.5     22.4   1857.   4528.   110.  368.     6.5   39.19  51.5    9015. 1102.61 1141.80  0.19
APR    0.7    0.97     0.4     40.5   2266.   4382.   174.  390.     1.6    9.32  53.4   11414. 1277.11 1286.43  0.21
MAY    0.0    1.00     0.4     59.4   2923.   4528.   226.  443.     0.6    3.62  57.5   14444. 1514.49 1518.11  0.25
JUN    0.0    0.99     0.4     76.3   3666.   4382.   262.  501.     0.5    3.09  61.0   17026. 1716.32 1719.41  0.28
JUL    0.0    0.98     0.4     89.0   4279.   4528.   278.  509.     0.5    3.14  65.6   19278. 1907.34 1910.48  0.32
AUG    0.0    0.99     0.4     84.6   4375.   4528.   258.  514.     0.5    3.15  64.0   18859. 1865.26 1868.40  0.31
SEP    0.0    1.00     0.4     64.8   3583.   4382.   198.  476.     0.5    3.21  59.1   15584. 1604.28 1607.49  0.27
OCT    0.3    0.98     0.5     44.5   2685.   4528.   136.  412.     1.0    6.05  56.4   12450. 1374.11 1380.16  0.23
NOV    2.7    0.89     0.5     18.9   2083.   4382.    58.  360.     4.3   25.89  52.3    8689. 1089.31 1115.20  0.18
DEC    9.3    0.71     0.6      9.1   2274.   4528.    28.  443.    13.2   78.99  45.0    7870.  965.80 1044.78  0.17
-----------------------------------------------------------------------------------------------------------------------
TOTALS:
      38.3    0.82     5.5    525.5  33112.  53317.  1862. 5256.    58.3                 148256.
($)   306.              44.   4019.   2152.   3466.                        350.  6512.    9637.  16148.  16498.  2.72
                                              0. KWH DISPLACED BY DAYLIGHTING = $         0. SAVED IN LIGHTING.

ENERGY BUDGETS :  SITE LINE =   564. MMBTU (  93.1 MBTU/SQ.FT.) ....... SOURCE =   1615. MMBTU ( 266.5 MBTU/SQ.FT.)
```

Fig. 6 Monthly summaries of energy consumption driven by simulated weather data

in which as few as 2016 hours are simulated annually. The other popular brand programs, mentioned above, require all 8760 hours to be simulated annually, but it may be possible to modify these packages to utilize the 2016-hour simulations as well. The advantage of the abbreviated simulations is that the computer run time is reduced by 75 percent, and this is highly desirable during preliminary building design phases when energy concepts are still in their exploratory phases.

The user often has the dilemma of choosing between the available energy analysis software packages. Some programs use <u>simplified energy calculations</u> (degree hour or bin data methods), while other programs use <u>detailed energy calculations</u> (hour-by-hour load and energy simulations). Simplified methods are always faster, but they are unable to account for intricacies of the building's shape or mass effect or complex occupancy patterns. Detailed energy calculation software would, therefore, always be preferred over simplified methods if run times could be improved. The WETHRGEN model output provides the opportunity for this to occur through its inherent 4-to-1 speed advantage. Yet, when desired, the model will still provide a full 8760-hour annual simulation.

Another important part of energy calculations is that of daylight contribution and the resultant savings in electric lighting and air conditioning. Daylight levels have been able to be estimated in the software by applying a "luminous efficacy" equation to the hourly values of solar irradiance data. Since the solar incidence angles are known along with solar luminance values, shadow angles and sun penetration through windows can be computed to assess the daylighting potential in buildings during design [Degelman and Boyer 1986].

WEATHER DATA GENERATION METHODS

Most of the concepts surrounding the weather simulation model and data compression techniques can be found in previous publications [Degelman 1970, 1976, and 1981]. Below is a brief summary of the algorithms involved:

Earth-Sun Geometry

The position of the sun in the sky is specified by the altitude angle (angle above the horizon) and the azimuth angle (the compass direction measuring from North as zero degrees azimuth). These equations have appeared elsewhere [ASHRAE 1989 and Degelman 1976] and are in widespread use today. These algorithms do make adjustments for differences in longitude location and the earth's equation of time.

Solar Radiation Prediction

Once the sun position is determined the solar radiation values can also be calculated. The direct normal insolation utilizes a well-known equation:

$$I_{DN}=I_o*\exp[-a/\sin(\beta)] \;\ldots\ldots\ldots\ldots\ldots\ (1)$$

where, I_{DN}=Direct normal insolation,
I_o=Apparent solar constant,
β=Sun altitude angle, and
a=Atmospheric extinction coeff.,

The apparent solar constant varies a small amount throughout the year, so an equation is fit to the published values in the ASHRAE Handbook of Fundamentals to establish this value once per month.

$$I_o \text{ (in Btu/hr}\cdot\text{ft}^2\text{)}=369.6+ 24.5245*\cos(\Omega)+0.9219*\cos^2(\Omega)\ldots\ (2)$$

The largest portion of work in generating results from Eq. (1) is the establishment of a value for "a", the atmospheric extinction coefficient. This variable sets the amount of atmospheric obscuration that the sun ray has to penetrate. The higher the "a" (cloudier sky), the less the radiation that passes through. ASHRAE publishes monthly values for "a", but these are of little value because they are only for clear days. In the simulation process, it was necessary to prescribe an entire series of "a's" so that the sky conditions could be simulated through a full range of cloudy to clear days.

The solution to this came from the solar radiation curves published by Liu and Jordan [1960]. These curves (Fig. 7) show the distribution of daily clearness values (K_t) after the monthly overall clearness (K_t) is known. Of all the solar radiation data available, the monthly horizontal insolation values seem to be the most prevalent. This makes the Liu-Jordan curves most appropriate for simulation work. In effect, the simulation process works backward. First, the average daily horizontal insolation (H) is read from the weather records. Second, the extraterrestrial horizontal insolation (H_o) is computed for outside the atmosphere. The equation for this value is shown below:

$$H_o = (24/\pi)*I_{SC}*[\cos(\phi)*\cos(\delta)*\sin(RA)+ (\pi-RA)*\sin(\phi)*\sin(\delta)] \;\ldots\ldots\ldots\ (3)$$

where, H_o=Extraterrestrial horizontal daily insolation,
I_{SC}=Solar Constant, and
RA=Sunrise angle=π*(Sunrise time)/12 measured as compass bearing.

The third step, then, is to derive the monthly K_t value by use of the formula:

$$K_t = H/H_o \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (4)$$

The K_t value derived from Eq. (4) is then used to determine which K_t-curve to select from the Liu-Jordan graph. The K_t-curve defines the distribution of K_t values for all 31 days of a month. The 31 days are evenly distributed along the horizontal axis (between 0 and 1), and for each day a unique K_t value is selected. Of course, these days are never entered in a consecutive order; there is a

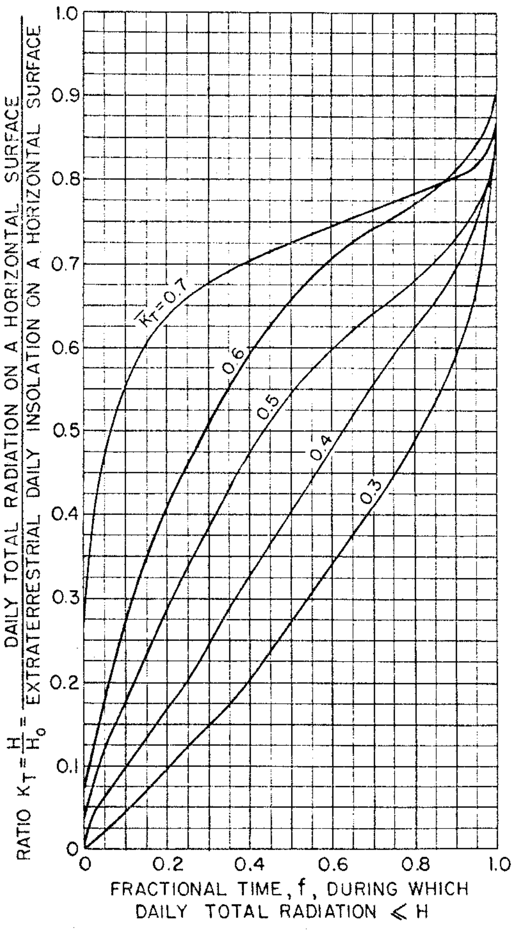


Fig. 7 The generalized K_t curves. (from Liu and Jordan [1960])

pattern imposed on the sequence of days that is discussed in another publication [Degelman 1981].

In effect, the establishment of the K_t value for any given day is to have established the solar radiation for that day before it really happens. The fourth step is to select an atmospheric extinction coefficient that will cause the hour-by-hour predictions to add up to this already established value. It important to have correct sky conditions established, so the breakdown of direct and diffuse radiation components can be done for each hour of the day.

Previous researchers [Liu and Jordan 1960 and Perez et al 1990] showed that there is a consistent relationship between daily direct and total global radiation. Their work concludes, therefore that both the direct and diffuse portions of solar irradiance can be estimated from the clearness factor (K_t).

Because the K_t value is simply the sum of the direct and diffuse portions, equations can be derived for both direct and diffuse fractions.

Equations that express these relationship shown are:

For clear days:
$K_D = 1.415*K_t - 0.384$ .... (5)

and for cloudy days:
$K_D = 1.492*K_t - 0.492$ .... (6)

when $K_t \geq 0.6$, and

$K_D = \exp(0.935*K_t^2) - 1.0$ .... (7)

when $K_t < 0.6$.

The K_D value is a weighted average of the sky transmissivity over all the daylight hours. Through examination of a spectrum of cloudy to clear type days, an empirical method was derived for estimating what the transmissivity for direct radiation would have to be at a known sun angle (say at noon). This work resulted in the formulation of Eq. (8) for derivation of "a".

$a = -\sin(\beta)*\ln[I_{sc}*\tau_D]$ .... (8)

where, τ_D=transmissivity of the atmosphere to direct solar.

$\tau_D = RATIO*K_D$ .... (9)

where, RATIO=empirically derived ratio.

After "a" is known, Eq. 1 is computed on an hourly basis throughout the daylight hours. The diffuse component is then added to the direct portion to obtain the total global irradiance. Other sources [Lui and Jordan 1960 and Threlkeld 1962] have been utilized to determine the correct amount of diffuse radiation falling on vertical and sloped surfaces.

Temperature Prediction

The simulation model predicts dry bulb and dewpoint temperatures from a normal distribution curve. So, input to the model requires averages and standard deviations on a monthly basis. What the program determines for each day is the dry bulb average and maximum temperatures and the dewpoint average temperature. This is one of the best defined portions of the simulation model and gives the best match between simulated and real data (typically less than 1% difference).

The range of the temperature fluctuations generally remains within plus and minus 2.11 standard deviations of the mean value. An array of 31 "normalized curve" values are permanently stored in the program and these are then simply multiplied by the standard deviations of the input temperatures. Each normalized value chosen has an equal probability of occurring, so each value represents one day of a 31-day month. This allows the program to derive the average and maximum temperatures on any given day.

After the average and maximum temperature has been chosen for one day, the minimum is computed. The minimum temperature is then assumed to occur at sunrise and the maximum is assumed to occur at 3:00 p.m. local standard time. The hourly values are then computed along two sine-wave segments -- one with the low at sunrise and the high at 3 p.m., and the next starting with the high at 3 p.m. and the low at sunrise on the next day.

The dewpoint temperatures are governed by their own means and standard deviations but also by the daily minimum dry bulb temperature and the amount of solar radiation on that day. These interdependencies are treated in a separate publication [Degelman 1981].

Wind Speed Prediction

Wind speeds are based on the input of only monthly averages. The fluctuations from day to day are estimated with a standard deviation equal to one-third of the monthly average speed. Hour-to-hour fluctuations are also based on standard deviations equal to one-third of the daily average. No simulation of wind direction was attempted, based on the assumption that wind direction would have little impact on a building's annual energy performance.

Barometric Pressure Calculations

Pressure calculations are based on the elevation above sea level and are then varied somewhat during each month based on certain trends which interrelate these with solar and temperature patterns. The barometric pressure influences the calculation of wet bulb temperatures and relative humidity. The significant variations, however, occur mostly with the elevation differences and not with the day-to-day pressure changes.

Psychrometric Calculations

Properties of air are calculated with the psychrometric models found in previous publications [ASHRAE. 1975 and Kusuda 1970]. The routines allow for fairly precise determination of wet bulb, relative humidity, enthalpy, and humidity ratio. Only the parameters directly affecting heating and cooling loads in buildings and certain equipment functions are calculated by WETHRGEN.

Methods of Weather Data Compression

The statistical methodology used by the weather simulator guarantees that a full spectrum of 31 types of days are simulated each month. It also guarantees that the average of these 31 days will equal the long-term average, and it guarantees that the maximum and minimum points will be encountered. The sequence of days is yet another important feature that enables the program to act like real weather conditions. The pattern cannot be left totally to random, so implied patterns were introduced into the daily simulation sequences. The statistical model will also permit the user to simulate less than 31 days per month. Any multiple of 7 days can be used. The 7-day simulation length was set as the minimum because it would allow for an appropriate mixture of work days and week end days and still permit a minimum, a maximum, an average, and four intermediate kind of days to be simulated. This permits a mix of solar, temperature, and humidity conditions that are necessary to evaluate energy use and design loads in most buildings. A full explanation of the weather data compression technique and sequencing can be found in one of the references [Degelman 1981].

MODEL VALIDATION

A certain degree of model validation is performed by the WETHRGEN program in each and every run that it performs. Summary statistics are reported at the end of each month, which shows both input and output values for means and standard deviations for temperatures and means for solar radiation, wind and barometric pressure. Also reported is the difference between the input and output, so the user has an instant reference as to how the means and extremes compare. Generally the monthly differences have fallen under 0.1°F for dry-bulb temperatures and under 0.15°F for dewpoint temperatures. For the other parameters, the average monthly error is 0.9% for wind and 0.7% for daily horizontal solar radiation. The maximum error in solar irradiance is 2% in one month, and the annual error is around 0.03%, which is the equivalent of missing about one hour of sunshine out of the year.

Some other efforts at model validation were reported in an ASHRAE symposium paper [Degelman 1981]. This paper showed almost a perfect agreement between generated degree day data and the actual recorded degree days (less than 1% difference in both heating and cooling degree days, see Figs. 8, 9, and 10). That analysis also showed less than a 2% difference in an office building's annual energy consumption when driven by simulated weather data vs. the actual weather data from a SOLMET tape. The data in Fig. 8, 9, and 10 are plots of monthly degree days and solar radiation as derived from a SOLMET tape for Dallas, Texas compared to the simulated weather data for the same period. It should be noted that the statistics put into the weather data simulator were actually derived from the same SOLMET tape. This indicates that the simulator is able to re-create at least the dry-bulb temperature and solar distribution with a high degree of accuracy when the proper statistics are entered.

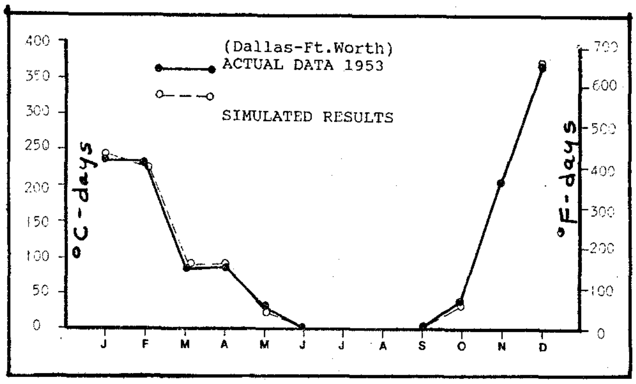


Fig. 8 Comparison of heating degree days from simulated vs. real weather data

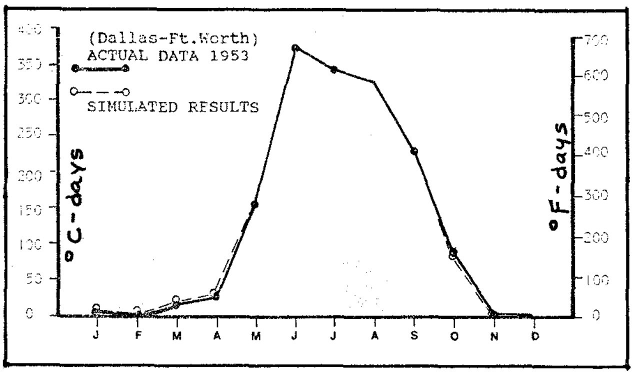


Fig. 9 Comparison of cooling degree days from simulated vs. real weather data

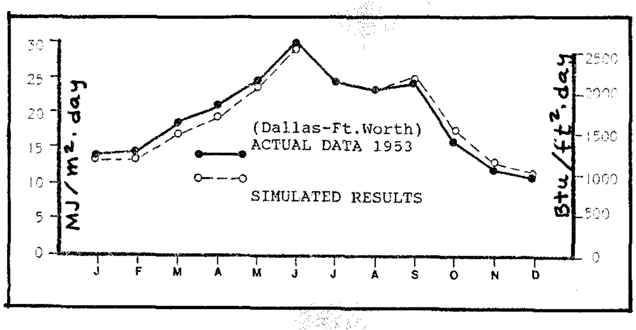


Fig. 10 Comparison of horizontal daily solar radiation from simulated vs. real data

SUMMARY AND CONCLUSIONS

A model and computer program have been developed for the purpose of generating synthetic weather data for input to building energy calculation software and as a sometimes replacement for real weather records when real data are hard to find (or are not collected). The model has been shown to reliably simulate the variables of temperature, humidity, wind, and solar radiation -- all important parameters in computing building heating and cooling loads. The model also permits a four-to-one compression of the simulation periods in order to save computer run time. In doing so, the simulation loses only up to 3% of its accuracy in the weather parameters.

The model testing has been carried out on the basic weather statistics and has been found to be an acceptable representation of real data for the parameters tested (mostly dry-bulb temperatures and solar radiation). More exhaustive testing needs to be done on wet-bulb and dewpoint distributions.

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