THE CIBSE EXAMPLE WEATHER YEAR

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This paper summarises the work of the CIBSE Example Year Task Group. Its main task has been to develop a methodology for the selection of representative weather data. This data is required as input to the various procedures available for the estimation of the energy performance of buildings and their engineering systems. As a further aid to applying a consistent set of meteorological data as input to energy calculations, the Task Group's work has extended to the preparation of a set of algorithms for calculating psychrometric properties .

1. INTRODUCTION

One of the major purposes of buildings is to act as a climate modifier, to make the internal environment acceptable for human comfort, and to shield us from the vagaries of the British weather. Acceptable environmental conditions can only be provided in UK conditions by using energy to heat and/or cool the building, and the amount of energy to be used can only be predicted on the basis of an understanding of the applied external and internal thermal loads. External loads are defined by the prevailing weather conditions, and it is important to appreciate that the parameters of importance are more than just dry-bulb temperature. Temperature related parameters like seasonal mean temperatures and degree-days have been used to characterise climate as an input to the estimation of seasonal heating requirements. However it is clear that such approaches are simplifications of the real pattern of thermal energy flows within buildings, since they ignore (or at best simplify) the effects of radiation and convective heat flows. The trend to increasing use of passive solar design features and the use of natural ventilation techniques make the proper accounting of these energy flows more important if reasonable estimates of energy use are to be made.

The above trends in building design have been paralleled by the development and increasing acceptance of detailed thermal and energy simulation models. These models calculate the performance of the building not on a seasonal basis, but on a timestep of an hour or even less. The procedures allow all the energy flows to be calculated, and their nett effect on space temperatures, plant performance etc to be predicted. It is clear that if these models are to be used at all, they need data input which is of a comparable temporal resolution to the simulation. It has been this impetus which has led to the development by CIBSE of the Example Weather Year.

2. THE CONCEPT OF THE EXAMPLE WEATHER YEAR

The unforseen hurricanes of October 1987 are indicative of the problems of forecasting weather patterns even on a short time scale, let alone the future life of a building. We are therefore forced to use historical weather data as a basis for predicting the future performance of both new and existing buildings. It is also clear from experience that our weather varies from year to year - a comparison of the summers of 1976 and 1987 indicates the type of variation seen in the UK. We are therefore forced to be selective in our choice of an historical weather sequence, and the first choice that should be made is the length of the historical period. The obvious choice is a period of one year as this is the minimum period containing all the major seasonal weather patterns. However it must be stressed that by selecting a 12 month period of weather for a given location, the chances o that same pattern of weather recurring exactly are essentially zero. Therefor estimates of energy use based on an historical weather year cannot be used as th basis of making absolute predictions of future energy consumption, they can only b used as the basis of making comparisons of building/system options (e.g. wil double glazing offer significant energy savings over single glazing etc).

It is also important to remember that the CIBSE Example Weather Year has bee selected to provide the basis of comparing annual energy consumptions of differen design options. Therefore sample periods from the year should **NOT** be used as th basis for making design decisions, estimates of the frequency or severity of summe overheating etc. The Example Years were not selected with these types of analyse in mind, and so different types of weather data may be more suited to those needs By way of illustration consider table 1 reproduced from Letherman (ref 1). Thi table shows the frequency distributiuon of temperature data for the Example Weathe Year for Kew, and indicates that the temperature dropped below -3 deg.C for only hours in the entire year, and only rose above 24 deg.C for 14 hours.

A further point to bear in mind is the regional variations in weather patterns Because of its maritime situation, the UK weather varies both in time and space and a year characterising the weather for S.E. England will not be full representative of conditions in, say, Northern Ireland. To that end, th objectives of the CIBSE Example Year Task Group are to select appropriate weathe years for a number of different sites within the UK.

3. THE FORM AND CONTENT OF THE EXAMPLE WEATHER YEAR

In setting out to choose an example weather year, the first major decision whether to choose a real year of recorded data, or to synthesise an aritificia year based on long term weather patterns. The latter approach can be used produce a weather tape which statistically is a better representation of the lo term average weather condition. However, this approach presents one very maj problem, namely that of the interdependance of the various weather parameters. O could envisage a statistical technique which could generate a profile of dry-bul temperatures for January which was the average of say a 20 year period. The sa exercise could then be carried out for the global solar radiation. The probl that arises is that the answers obtained might give coincident temperature a radiation values which were never observed in practice. It was primarily for th reason that the Task Group decided to use a single real years weather selected fr the years of available data, and thus preserve the real patterns of weather, su as the very cold but bright sunny days often seen in winter.

The next question that needs to be addressed is the start and finish date of th typical years weather. The obvious choice is a calendar year, but this would mea that if one were predicting the heating energy consumption of a building, one wou use the October to December weather data for, say, 1965, and the earlier January April data for the same year. This is a major drawback in that there would be discontinuity in the data at the transition from December 31 to January 1, which during the period of maximum heating demand. Consequently it was decided that would be most appropriate to start the year at a period of minimum heating deman where the effect of this discontinuity in the data would be minimised. To this e an October 1st start date was used, as this marks a convenient transition betwe the cooling and heating seasons.

The final detail on the specification of the form and content of the Examp Weather Year is the number of parameters that should be recorded on the tape. has been agreed that each Example Year should contain 8760 hourly records of th following parameters:-

Dry bulb temperature (^{o}C)
Wet bulb temperature (^{o}C)
Wind speed (m/s)
Wind direction (deg from N)
Direct solar radiation (W/m^2)
Diffuse solar radiation (W/m^2)
Radiation balance (W/m^2)
Atmospheric pressure (mbar)
Precipitation (rainfall) (mms)
Illuminance (lux)

There are certain problems in obtaining all this data, since for example, the Met Office only measures solar radiation at a relatively few sites in the UK, and nett radiation balance and illuminance values at even fewer. Although the coverage of solar intensity measurements is increasing, in many cases records are only available for the recent past, certainly insufficient to provide enough data to determine an appropriate example year (see section 4). It is also clear that the above list of parameters is not exhaustive in the data needs of thermal models, and this point is covered in sections 5 and 6 of the paper.

4. THE SELECTION PROCEDURE

The selection procedure has been described in some detail in reference 2, but for completeness, the broad outline is presented here. The Task Group decided that the selection procedure should be reasonably simple involving the analysis of readily accessible data, and not requiring computers to perform the necessary calculations (albeit their availability may make the task simpler to carry out!). This makes the selection technique readily available to all. The selection procedure developed by Holmes and Hitchin involves the analysis of the mean monthly values of various weather parameters; these figures are readily available from the 'Monthly Weather Summaries' published by the Met Office. These parameters are usually global and diffuse radiation, daily mean wind speed, mean maximum and minimum dry bulb temperatures, and mean dry bulb. In addition, a combined parameter is used, namely the Infiltration Number (windspeed x (18.0-dry bulb). This will cover all energy flows where temperature and windspeed appear as multiples, e.g. infiltration, convective heat loss etc. Having obtained the data, the selection procedure involves the rejection of years which contain months where the mean value of a parameter is significantly different from the long term average. The stages in the procedure are as follows:-

a) For each month, calculate the long term average and the standard deviation about that average for each parameter.

b) For each possible year in the period under consideration (which must be at least 20 years), begin at the start month for the year (October) and calculate the difference between the actual parameter for that month and the long term average for that parameter and that month.

c) If that difference is more than 2 standard deviations, reject that year as it will contain a parameter which for that month is too far removed from the long term average. A filter of 2 standard deviations is chosen since if all the weather parameters are normally distributed about the mean, 95 percent of the values would pass through the filter.

d) Repeat for all 12 months and all parameters. If all the months in a given year with all their individual parameters pass through the filter, then that year is marked as a potential example year.

e) If more than 1 year passes test d) above, then that year which has the minimum total deviation of all parameters is selected as the CIBSE Example Weather Year for that location.

The only problem with this technique of rejecting extreme means is that the selected year may well not itself contain any extreme weather data, as demonstrated in section 2. However as highlighted earlier, the Example Year is a yardstick for comparision of energy consumptions, not as an aid for making design decisions like boiler sizing etc.

The above technique has been applied to the selection of an Example Year for a number of sites in the UK, as shown in figure 1. The selections to date are:-

Kew	Oct 64 - Sep 65
Aldergrove	Oct 77 - Sep 78
Eskdalemuir	Oct 70 - Dep 71
Bracknell	Oct 66 - Sep 67
Aberporth	Oct 72 - Sep 73
Watnall	Oct 76 - Sep 77 (provisional)

5. PSYCHROMETRIC DATA

The basic weather parameters that are available from the Met Office are essential but insufficient for all the computations that may be needed in carrying out an energy calculation. For example, in air conditioning applications in particular, there is a need to be able to determine moisture contents, relative humidities, enthalpies etc. The Task Group has been preparing a consistent set of algorithms which can be used to calculate any of the properties of moist air, provided that dry-bulb temperature, atmospheric pressure and either wet-bulb or moisture content are known. These algorithms are presented in the form of FORTRAN functions in appendix 1, and are based largely on information available in references 3 to 5.

It is worthy of comment that there are some unnecessary inconsistencies existing in the currently published section C-1 of the Guide. One area to note is that if the equations published in the Guide are used, then it is impossible to reproduce the tabulated figures in the same Guide. It seems that the reason for this is that the tabulated values are reproduced from an earlier edition, with the units changed to S.I. These earlier tables were calculated on a different basis, using the so called Magnus formula for the calculation of saturated vapour pressure SATVP (mbar), viz:-

$$\log(\mathrm{SATVP}) = 7.5\ \mathrm{TD}/(273.3+\mathrm{TD}) + 0.78571$$

where TD is the dry-bulb temperature (^{o}C)

The Guide now recommends a more detailed formula for this calculation,

$$\log(\mathrm{SATVP}) = 31.59051 - 8.2\log(T) + 0.0024804\,T - 3142.31/T$$

where T is the dry bulb temperature (^{o}K)

$= \mathrm{TD} + 273.15$

Although the differences in the answers from the two equations is of negligible practical significance, it can be disconcerting to use published equations and find that they disagree with data published in the same document.

Of more significance is the fact that the published adiabatic saturation temperatures below 0 deg.C appear to be wrong. For a given adiabatic saturation temperature, the enthalpy must always be the same. Table 2 shows there are inconsistencies below 0 deg.C. The reason for this is not clear, but is probably due to an error in the original calculation of the tables; in the vapour pressure calculation, the latent heat of vapourisation of water may have been used rather than the latent heat of fusion of ice for values of wet bulb temperature below 0 ^{o}C.

One final point of clarification is in the way that some of the equations are represented in C-1. For example, the specific volume v, is given as:-

$$v = \frac{82.0567\,T}{28966\ (101.325-p_v)/101.325} + \text{correction terms.}$$

In essence this is a manipulation of the familiar ideal gas law, usually written as:-

$$v = \frac{R\,T}{m\,p_a} + \text{correction terms}$$

where R is the Universal Gas constant - 8.31441 kJ/kmol ^{o}K
m is the relative molecular mass of dry air - 28.966 kg/kmol
p_a is the partial pressure of air (kPa)

Again the confusion has arisen out of a change in units. The 82.0567 in equation C1-5 is the value of R in atm.cm /gm mol ^{o}K. In order to convert this into S.I units, it has to be multiplied by:-

101.325 kPa/atm
10^{-6} m^3/cm^3

10^3gm mol/kg mol

Thus it is that the 101.325 appears beneath the partial pressure term in equation C1-5, and the molecular mass term has been multiplied by 1000. It then also becomes apparent that in C1-5, one of the 101.325 terms is a constant conversion factor, but the other is a particular value of the variable term representing the atmospheric pressure. This is of particular importance if wanting to calculate psychrometric properties at non-standard conditions. The equation should therefore more usefully be written as

$$v = \frac{8.31441\ T}{28.966\ (P - p_v)}$$

where P is the atmospheric pressure (kPa) and p_v is the vapour pressure (kPa)

6. SOLAR ALGORITHMS

In the same way that data available from the Met Office is not sufficient to calculate all the necessary properties of air, so additional information is required to determine all the relevant factors affecting solar radiation falling on any given surface of a building. The Task Group is currently working on the production of a second set of algorithms which can be used for determining such essential parameters as:-

solar altitude
solar azimuth
the split between direct and diffuse solar intensities assuming global radiation values are known
solar radiation falling on surfaces of any given slope and orientation

The results of this work will be published in due course.

7. THE AVAILABILITY OF THE EXAMPLE WEATHER YEARS

The information required to make up a CIBSE Example Weather Year can be purchased from the Met Office. Unfortunately at the present time it is not possible to obtain an appropriately formatted tape containing all the relevant data, since the solar data is supplied by one Met Office department (Met O1C), and the other measurements by another (Met O3), both located at Eastern Road, Bracknell, Berkshire, RG12 2UR. These two data sets then have to be merged to produce a single tape, taking care that the two sets are consistent in their timings. For example, temperatures are usually recorded on the hour, whereas solar data is often integrated over an hour, and is thus effectively centred about the half-hour.

In order to overcome these difficulties, discussions are currently underway to try and establish CIBSE or one of its representatives as an agent of the Met Office in preparing and distributing at a reasonable price, standard weather tapes containing properly formatted and consistent weather data for use by the industry.

8. CONCLUDING COMMENTS

The paper has described the philosophy of the CIBSE Example Weather Years, and given some more detail on the selection procedures, and the necessary supporting technical information. The preparation and adoption of such Example Weather Years is the only realistic way to achieve the desired end of providing a consistent basis of calculation in the estimation of annual energy consumption for buildings in the UK. Of course, weather data is only one of the many sub-sets of data required for an energy calculation, and other initiatives are in hand to help promote standards in other areas. The Modellers Club (BEPAC) being promoted primarily by the Performance Prediction Section at BRE is most notable in this respect.

9. REFERENCES

1. K.M.Letherman 'Condensed Statistics on the CIBS Example Weather Year' BSER&T 1, 157-1159, 1980
2. E.R.Hitchin et al 'The CIBS Example Weather Year', BSER&T, 4, 119-124 1983
3. CIBSE Guide, sections C1 and C2
4. 'Some fundemental data used by building services engineers', IHVE 1973
5. 'The Change to Metric', IHVE, 1968

10. ACKNOWLEDGEMENTS

The author would like to acknowledge the fact that the material described in this paper is the work of the CIBSE Task Group, of which he is but one member. The others are Mike Holmes (chairman), Barry Hutt, Dushan Nevrala, Martin Liddament and Roger Hitchin (part time). The Group would also like to acknowledge the work done by John Quick in assembling the psychrometric algorithms given as appendix 1.

KEY
Ab = Aberporth
Al = Aldergrove
B = Bracknell
E = Eskdalemuir
K = Kew
W = Watnall

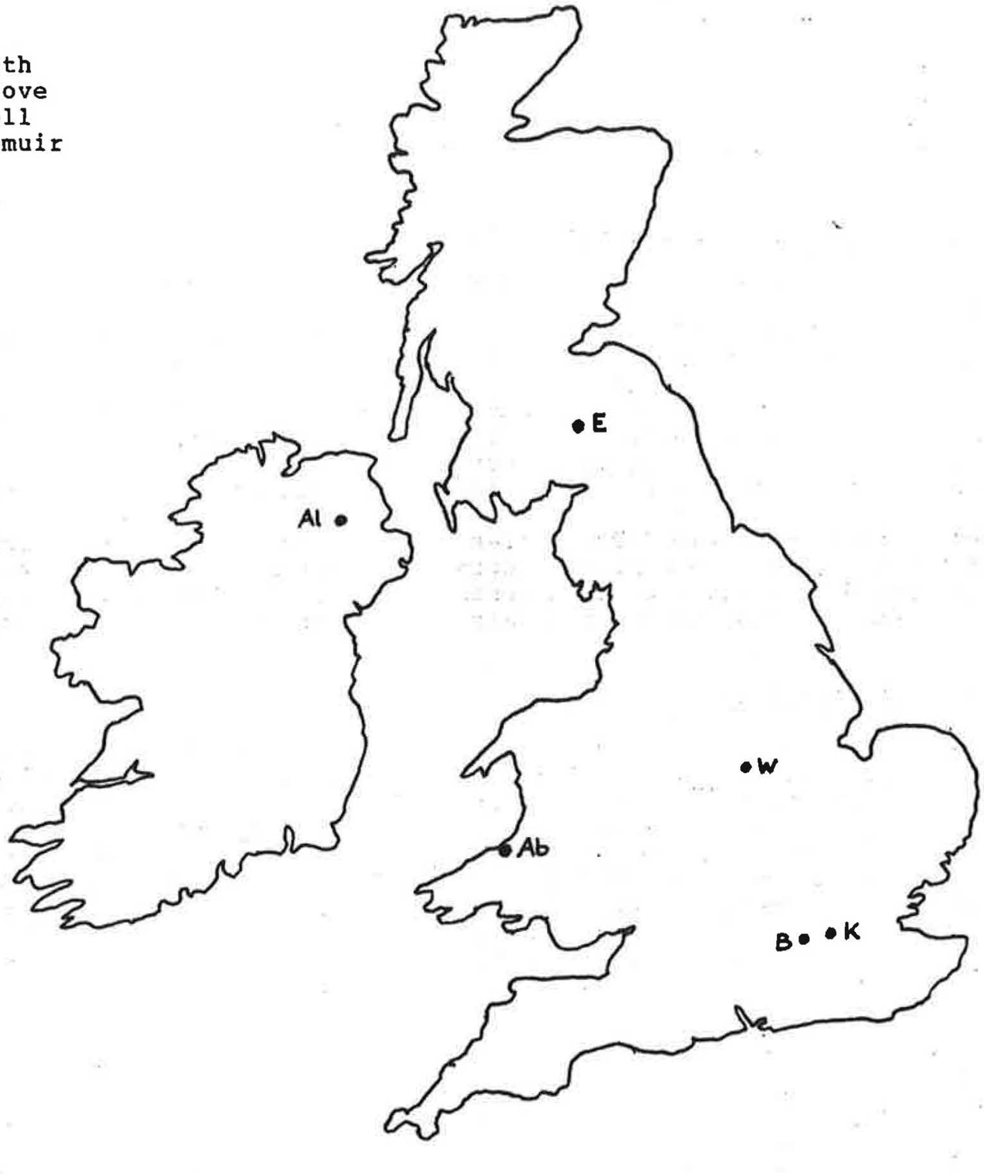

Fig 1 Map of UK showing location of sites for which Example Years have been chosen

TABLE 1 - Frequency distribution of data in Kew Example Year (from ref 1)

From deg.C	To deg.C	Hourly Temp hours at	From deg.C	To deg.C	Hourly Temp hours at
-6	-5	1	11	12	603
-5	-4	4	12	13	596
-4	-3	8	13	14	553
-3	-2	24	14	15	459
-2	-1	39	15	16	477
-1	0	63	16	17	387
0	1	270	17	18	292
1	2	321	18	19	218
2	3	320	19	20	150
3	4	323	20	21	98
4	5	424	21	22	77
5	6	449	22	23	64
6	7	459	23	24	22
7	8	419	24	25	7
8	9	572	25	26	4
9	10	536	26	27	3
10	11	518	27	28	0
					8670

TABLE 2 - Comparison of Guide C1 tabulated values showing inconsistency in adiabatic saturation temperatures and enthalpies.

Dry bulb deg.C	Percent Sat %	Enthalpy kJ/kg	Ad.Sat Temp deg.C
-10.0	100	-6.065	-10.0
-9.0	72	-5.908	-10.0
-8.0	46	-5.851	-10.0
-7.0	26	-5.685	-10.0
-6.0	8	-5.578	-10.0
-5.5	0	-5.530	-10.0

APPENDIX 1 FORTRAN routines based on Task Group psychrometric algorithms.

```
C SERIES OF FUNCTIONS FOR EVALUATING PSYCHROMETRIC PROPERTIES
C
C TD IS DRY BULB TEMP (deg.C)
C TW IS WET BULB TEMP (deg.C)
C GS IS MOISTURE CONTENT (kg/kg)
C PATMOS IS ATMOSPHERIC PRESSURE (mbars)
C IOPT IS INDICATOR FOR WET BULB   =1 FOR SLING
C                                   2 FOR SCREEN
C
      REAL FUNCTION TSATH1(TDINP,TWINP,PATMOS,IOPT)
C
C  FUNCTION ESTIMATES SATURATION TEMP FOR CONSTANT ENTHALPY COOLING
C
      INTEGER     IERR,IOPT
      REAL        TDINP,TD,TWINP,PATMOS,TW,H,ENTHP1,TSATHO
      EXTERNAL    TDCHEK,ERMESS,TWCHEK,ENTHP1,TSATHO
C
C - ENSURE THAT DRY & WET BULB TEMPS ARE VALID.
      CALL TDCHEK(TDINP,TD,IERR)
      CALL ERMESS(IERR,TD,1,TD,'TSATH1',6)
      CALL TWCHEK(TD,TWINP,PATMOS,IOPT,TW,IERR)
      CALL ERMESS(IERR,TW,1,TW,'TSATH1',6)
C - DETERMINE ENTHALPY OF AIR BEFORE PROCESS
      H = ENTHP1(TD,TW,PATMOS,IOPT)
C
      TSATH1 = TSATHO(H,PATMOS)
      RETURN
      END
C -----------------------------------------------------------------------------
```

```
C
      REAL FUNCTION TSATH2(TDINP,GSINP,PATMOS)
C
C   FUNCTION ESTIMATES SATURATION TEMP FOR CONSTANT ENTHALPY COOLING
C
      INTEGER      IERR
      REAL         TDINP,TD,GSINP,PATMOS,GS,H,ENTHP2,TSATHO
      EXTERNAL     TDCHEK,ERMESS,GSCHEK,ENTHP2,TSATHO
C
C - ENSURE THAT DRY BULB TEMP & MOISTURE CONTENT ARE VALID.
      CALL TDCHEK(TDINP,TD,IERR)
      CALL ERMESS(IERR,TD,1,TD,'TSATH2',6)
      CALL GSCHEK(TD,GSINP,PATMOS,GS,IERR)
      CALL ERMESS(IERR,GS,1,GS,'TSATH2',6)
C - DETERMINE ENTHALPY OF AIR BEFORE PROCESS
      H = ENTHP2(TD,GS)
C
      TSATH2 = TSATHO(H,PATMOS)
      RETURN
      END
C
C ---------------------------------------------------------------------------
C
      REAL FUNCTION DEWPT1(TDINP,TWINP,PATMOS,IOPT)
C
C   FUNCTION ESTIMATES DEW POINT TEMP.(CONSTANT MOISTURE CONTENT COOLING)
C
      INTEGER      IERR,IOPT
      REAL         TDINP,TD,TWINP,PATMOS,TW,GS,HUMRAT,DEWPTO
      EXTERNAL     TDCHEK,ERMESS,TWCHEK,HUMRAT,DEWPTO
C
C - ENSURE THAT DRY & WET BULB TEMPS ARE VALID.
      CALL TDCHEK(TDINP,TD,IERR)
      CALL ERMESS(IERR,TD,1,TD,'DEWPT1',6)
      CALL TWCHEK(TD,TWINP,PATMOS,IOPT,TW,IERR)
      CALL ERMESS(IERR,TW,1,TW,'DEWPT1',6)
C - DETERMINE MOISTURE CONTENT OF AIR BEFORE PROCESS
      GS = HUMRAT(TD,TW,PATMOS,IOPT)
C
      DEWPT1 = DEWPTO(GS,PATMOS)
      RETURN
      END
C
C ---------------------------------------------------------------------------
C
      REAL FUNCTION DEWPT2(TDINP,GSINP,PATMOS)
C
C   FUNCTION ESTIMATES DEW POINT TEMP.(CONSTANT MOISTURE CONTENT COOLING)
C
      INTEGER      IERR
      REAL         TDINP,TD,GSINP,PATMOS,GS,DEWPTO
      EXTERNAL     TDCHEK,ERMESS,GSCHEK,DEWPTO
C
C - ENSURE THAT DRY BULB TEMP & MOISTURE CONTENT ARE VALID.
      CALL TDCHEK(TDINP,TD,IERR)
      CALL ERMESS(IERR,TD,1,TD,'DEWPT2',6)
      CALL GSCHEK(TD,GSINP,PATMOS,GS,IERR)
      CALL ERMESS(IERR,GS,1,GS,'DEWPT2',6)
C
      DEWPT2 = DEWPTO(GS,PATMOS)
      RETURN
      END
C
C ---------------------------------------------------------------------------
```

```
C
      SUBROUTINE TWCHEK(TD,TW,PATMOS,IOPT,TWVALD,IERR)
C
C  ROUTINE CHECKS THAT WET BULB TEMP IS WITHIN A VALID RANGE.
C  IF OK THEN IERR RETURNED AS ZERO.  IF NOT, IERR IS NON-ZERO AND
C  TWVALD IS RETURNED WITH THE NEAREST VALID VALUE.
C
      INTEGER       IERR,IOPT
      REAL          TWVALD,TW,GS,TD,PATMOS,HUMRAT,WETBLB
      EXTERNAL      HUMRAT,WETBLB
C
      TWVALD = TW
      IERR = 0
      GS = HUMRAT(TD,TW,PATMOS,IOPT)
C
      IF(GS.LT.0.0001) GOTO 100
      IF(TW.GT.TD)  GOTO 200
      GOTO 500
C - WET BULB TOO LOW - GIVES A NEGATIVE MOISTURE CONTENT.
100   TWVALD = WETBLB(TD,0.0001,PATMOS,IOPT)
      IERR = 5
      GOTO 500
C - WET BULB TOO HIGH - GREATER THAN DRY BULB.
200   TWVALD = TD
      IERR = 6
C
500   RETURN
      END
C
C ----------------------------------------------------------------------------
C
      REAL FUNCTION WETBLB(TD,GS,PATMOS,IOPT)
C
C  FUNCTION ESTIMATES WET BULB TEMP.(deg.C) FROM MOISTURE CONTENT
C
      INTEGER       IOPT
      REAL          H,TD,GS,T1,PATMOS,TINC,GS1,ENTHP2,TSATHO,HUMRAT
      EXTERNAL      ENTHP2,TSATHO,HUMRAT
      INTRINSIC     ABS
C
      H = ENTHP2(TD,GS)
C  FIRST GUESS IS ADIABATIC SATURATION TEMPERATURE
      T1 = TSATHO(H,PATMOS)
      TINC = 0.5
C
10    GS1 = HUMRAT(TD,T1,PATMOS,IOPT)
      IF(GS1.GE.GS.AND.TINC.GT.0.0) TINC = -0.5*TINC
      IF(GS1.LE.GS.AND.TINC.LT.0.0) TINC = -0.5*TINC
      T1 = T1 + TINC
      IF(ABS(TINC).GT.0.005) GOTO 10
C
      WETBLB = T1
      RETURN
      END
C
C ----------------------------------------------------------------------------
C
      SUBROUTINE GSCHEK(TD,GS,PATMOS,GSVALD,IERR)
C
C  ROUTINE CHECKS THAT MOISTURE CONTENT IS WITHIN VALID RANGE.
C  IF OK THEN IERR RETURNED AS ZERO. IF NOT THEN IERR IS NON-ZERO AND
C  GSVALD IS RETURNED AS TEH NEAREST VALID VALUE.
C
      INTEGER       IERR
      REAL          GSVALD,GS,GSS,TD,PATMOS,HUMRAT
      EXTERNAL      HUMRAT
C
      GSVALD = GS
      IERR = 0
      GSS = HUMRAT(TD,TD,PATMOS,1)
```

```
C
      IF(GS.LT.0.00005) GOTO 100
      IF(GS.GT.(GSS+0.0001)) GOTO 200
      GOTO 500
C - MOISTURE CONTENT TOO LOW
100   GSVALD = 0.00005
      IERR = 7
      GOTO 500
C - MOISTURE CONTENT TOO HIGH
200   GSVALD = GSS
      IERR = 8
C
500   RETURN
      END
C
C ----------------------------------------------------------------------------
C
      SUBROUTINE TDCHEK(TD,TDVALD,IERR)
C
C  ROUTINE CHECKS VALUE OF DRY BULB TEMP.IS WITHIN VALID RANGE.
C  IERR RETURNED AS ZERO IF VALUE IS OK.
C  IERR RETURNED NON-ZERO IF VALUE IS NOT. NEAREST OK VALUE IN TDVALD.
C
      INTEGER      IERR
      REAL         TD,TDVALD
C
      TDVALD = TD
      IERR = 0
      IF(TD.LT.-10.0) GOTO 100
      IF(TD.GT.60.0)  GOTO 200
      GOTO 500
C - TEMPERATURE IS TOO LOW
100   TDVALD = -10.0
      IERR = 1
      GOTO 500
C - TEMPERATURE IS TOO HIGH
200   TDVALD = 60.0
      IERR = 2
C
500   RETURN
      END
C
C ----------------------------------------------------------------------------
C
      SUBROUTINE PACHEK(PATMOS,PAVALD,IERR)
C
C  ROUTINE CHECKS THAT ATMOSPHERIC PRESSURE IS WITHIN THE VALID RANGE.
C  IERR RETURNED AS ZERO IF OK. NON-ZERO IF NOT OK, & PAVALD IS SET TO
C  NEAREST VALID VALUE.
C
      INTEGER      IERR
      REAL         PATMOS,PAVALD
C
      PAVALD = PATMOS
      IERR = 0
C
      IF(PATMOS.LT.800.0) GOTO 100
      IF(PATMOS.GT.1030.0)GOTO 200
      GOTO 500
C - ATMOSPHERIC PRESSURE TOO LOW
100   PAVALD = 800.0
      IERR = 3
      GOTO 500
C - ATMOSPHERIC PRESSURE TOO HIGH
200   PAVALD = 1030.0
      IERR = 4
C
500   RETURN
      END
C ----------------------------------------------------------------------------
```

```
C
      SUBROUTINE ERMESS(IERR,VALUE,IRESET,VALID,NAMSUB,LEN)
C
C  ROUTINE PRINTS AN ERROR MESSAGE AT THE TERMINAL IF IERR HAS BEEN
C  RETURNED FROM ONE OF THE PSYCHROMETRIC CHECK ROUTINES AS NON-ZERO.
C  IF IERR & IRESET ARE NON-ZERO THEN VALUE IS RESET TO VALID.
C
      INTEGER     IERR,IRESET,LEN,J
      REAL        VALUE,VALID
      CHARACTER*(*) NAMSUB
C
      IF(IERR.EQ.0) GOTO 500
C
      GOTO (10,20,30,40,50,60,70,80), IERR
      WRITE(*,1000)
1000  FORMAT(' INVALID ERROR CODE IN SUBR.ERMESS (PSYCHROMETRICS)')
      GOTO 500
C
10    WRITE(*,1010) NAMSUB
1010  FORMAT(' DRY BULB TEMPERATURE BELOW -20 deg.C',5X,'- ',A)
      GOTO 400
20    WRITE(*,1020) NAMSUB
1020  FORMAT(' DRY BULB TEMPERATURE ABOVE 60 deg.C',5X,'- ',A)
      GOTO 400
30    WRITE(*,1030) NAMSUB
1030  FORMAT(' ATMOSPHERIC PRESSURE BELOW 800 mbar',5X,'- ',A)
      GOTO 400
40    WRITE(*,1040) NAMSUB
1040  FORMAT(' ATMOSPHERIC PRESSURE ABOVE 1030 mbar',5X,'- ',A)
      GOTO 400
50    WRITE(*,1050) NAMSUB
1050  FORMAT(' WET BULB TEMP GIVES NEGATIVE MOISTURE',5X,'- ',A)
      GOTO 400
60    WRITE(*,1060) NAMSUB
1060  FORMAT(' WET BULB TEMP ABOVE DRY BULB TEMP',5X,'- ',A)
      GOTO 400
70    WRITE(*,1070) NAMSUB
1070  FORMAT(' MOISTURE CONTENT BELOW ZERO',5X,'- ',A)
      GOTO 400
80    WRITE(*,1080) NAMSUB
1080  FORMAT(' MOISTURE CONTENT ABOVE SATURATION',5X,'- ',A)
C
400   IF(IRESET.EQ.0) GOTO 500
      VALUE = VALID
      WRITE(*,1400)
1400  FORMAT(' VALUE HAS BEEN RESET TO NEAREST VALID VALUE')
C
500   RETURN
      END
C
C ----------------------------------------------------------------------------
C
      REAL FUNCTION TSATHO(H1,PATMOS)
C
C APPLIES POLYNOMIAL CURVE FITS TO DETERMINE SATURATION TEMP FROM ENTHALPY
C THIS IS REQUIRED WHEN FOLLOWING ADIABATIC COOLING PROCESSES. THEN, USING
C CURVE FIT VALUE AS THE FIRST GUESS IT ITERATES TO MORE EXACT SOLUTION.
C
      INTEGER     I
      REAL        A,H1,H2,H3,H4,T1,TINC,PATMOS,HGUESS,ENTHP1
      EXTERNAL    ENTHP1
      INTRINSIC   ABS
C
C SET UP POLYNOMIAL COEFFS
      DIMENSION A(5,3)
      DATA A/-5.80119,6.64782E-1,-5.01455E-3,2.49725E-5,-5.50151E-8,
     +-3.70951,5.50403E-1,-2.90194E-3,8.83702E-6,-1.0862E-8,
     +1.78663E1,1.72699E-1,-2.47968E-4,1.69221E-7,-2.95851E-11/
```

```
C CHECK VALID RANGE
      IF(H1.LT.-10.0) GOTO 500
      IF(H1.GT.600.0) GOTO 510
C
C FIND RANGE FOR RELEVANT CURVE
      I=1
      IF(H1.GT.75.) I=2
      IF(H1.GT.250.) I=3
      H2=H1*H1
      H3=H1*H2
      H4=H2*H2
      T1=A(1,I)+A(2,I)*H1+A(3,I)*H2+A(4,I)*H3+A(5,I)*H4
      GOTO 550
500   T1=-13.4
      GOTO 550
510   T1=65.0
C
C FOR THE FOLLOWING ITERATION SET SIZE OF STEP (TINC) ACCORDING TO PATMOS
C
550   TINC = ABS(PATMOS-1013.25)/50.0
      IF(TINC.LT.0.02) TINC = 0.02
      IF(TINC.GT.5.0)  TINC = 5.0
C
C NOW USE T1 AS THE FIRST GUESS IN AN ITERATION
C
600   HGUESS = ENTHP1(T1,T1,PATMOS,1)
      IF(HGUESS.GE.H1.AND.TINC.GT.0.0) TINC = -0.5*TINC
      IF(HGUESS.LE.H1.AND.TINC.LT.0.0) TINC = -0.5*TINC
      T1 = T1 + TINC
      IF(ABS(TINC).GT.0.005) GOTO 600
C
      TSATHO = T1
      RETURN
      END
C
C -------------------------------------------------------------------------------
C
      REAL FUNCTION DEWPTO(G1,PATMOS)
C
C FUNCTION MAKES CRUDE STARTING ESTIMATE OF DEW POINT BASED ON MOISTURE CONTENT
C USING CURVE FIT. USING THIS ESTIMATE IT ITERATES TO A MORE EXACT SOLUTION.
C
      INTEGER      I
      REAL         A,G1,G2,G3,T1,TINC,PATMOS,GUESS,HUMRAT
      EXTERNAL     HUMRAT
      INTRINSIC    ABS
      DIMENSION    A(4,3)
      DATA A/-1.97465E1,7.19837E3,-5.99776E5,2.17091E7,
     +-4.05519,2.21854E3,-4.63971E4,4.03557E5,
     +1.5746E1,6.568E2,-3.80307E3,9.18275E3/
C
      IF(G1.LT.0.0) GOTO 500
      IF(G1.GT.0.16) GOTO 510
      G2=G1*G1
      G3=G1*G2
C
C FIND RANGE FOR POLYNOMIAL
      I=1
      IF(G1.GT.0.01) I=2
      IF(G1.GT.0.035) I=3
      T1=A(1,I)+A(2,I)*G1+A(3,I)*G2+A(4,I)*G3
      GOTO 550
500   T1=-50.0
      GOTO 550
510   T1=60.0
C
C FOR THE ITERATION SET SIZE OF STEP (TINC) ACCORDING TO PATMOS
C
550   TINC = ABS(PATMOS-1013.25)/50.0
      IF(TINC.LT.0.02) TINC = 0.02
```

```
      IF(TINC.GT.5.0)  TINC = 5.0
C
C NOW USE T1 AS FIRST GUESS IN ITERATION
C
600   GUESS = HUMRAT(T1,T1,PATMOS,1)
      IF(GUESS.GE.G1.AND.TINC.GT.0.0) TINC = -0.5*TINC
      IF(GUESS.LE.G1.AND.TINC.LT.0.0) TINC = -0.5*TINC
      T1 = T1 + TINC
      IF(ABS(TINC).GT.0.005) GOTO 600
C
      DEWPTO = T1
      RETURN
      END
C
C -----------------------------------------------------------------------------
C
      REAL FUNCTION DENS1(TD,TW,PATMOS,IOPT)
C
C  FUNCTION RETURNS THE DENSITY OF AIR kg/cu.m
C
      INTEGER     IOPT
      REAL        TD,TW,PATMOS,SPVOL1
      EXTERNAL    SPVOL1
C
      DENS1 = 1.0 / SPVOL1(TD,TW,PATMOS,IOPT)
      RETURN
      END
C
C -----------------------------------------------------------------------------
C
      REAL FUNCTION DENS2(TD,GS,PATMOS)
C
C  FUNCTION RETURNS THE DENSITY OF AIR kg/cu.m
C
      REAL        TD,GS,PATMOS,SPVOL2
      EXTERNAL    SPVOL2
C
      DENS2 = 1.0 / SPVOL2(TD,GS,PATMOS)
      RETURN
      END
C
C -----------------------------------------------------------------------------
C
      REAL FUNCTION SPVOL1(TD,TW,PATMOS,IOPT)
C
C FUNCTION CALCULATES SPECIFIC VOLUME cu.m/kg DRY AIR
C
      INTEGER     IOPT
      REAL        TD,TW,PATMOS,GS,HUMRAT,SPVOL2
      EXTERNAL    HUMRAT,SPVOL2
C
      GS=HUMRAT(TD,TW,PATMOS,IOPT)
C
C EQN C1.14 IHVE(1975) - 0.1 TO CONVERT MBAR TO KPA
      SPVOL1=SPVOL2(TD,GS,PATMOS)
      RETURN
      END
C
C -----------------------------------------------------------------------------
```

```
C
      REAL FUNCTION SPVOL2(TD,GS,PATMOS)
C
C FUNCTION CALCULATES SPECIFIC VOLUME cu.m/kg DRY AIR
C
C
      INTEGER        I
      REAL           TD,GS,PATMOS,GASCON,AAFACS(2,3),WWFACS(2,7),AAA,AAW,
     &               AWW,XA,ONEMXA,VAPRS2
      EXTERNAL       VAPRS2
      INTRINSIC      IFIX
C########################################################################
C GASCON HAS THE VALUE 2.8704 WHICH IS MADE UP OF THREE FACTORS
C              UNIVERSAL GAS CONSTANT - 8.31441 kJ/kmol K
C divided by   MOLECULAR MASS OF AIR - 28.966 kg/kmol
C divided by   CONVERSION FACTOR - 0.1 kPa/mbar
      DATA GASCON /2.8704/
C##################DATA FOR EXTRA ACCURACY TERM##########################
C - VALUES FOR Aaa,Aaw & Aww FROM FUNDAMENTAL DATA FOR B.S.ENGINEERS
      DATA AAFACS/4.56E-4,8.3E-6,4.43E-4,6.9E-6,4.084E-4,5.7E-6/
      DATA WWFACS/6.318,0.1622,6.318,0.1105,6.076,0.0863,5.634,0.0642,
     &            5.262,0.0518,4.862,0.0418,4.462,0.0338/
      I = 1
      IF(TD.GT.10.0) I = 2
      IF(TD.GT.30.0) I = 3
      AAA = AAFACS(1,I) - TD*AAFACS(2,I)
C
      AAW = (1.45-0.0097*TD+0.32*(TD/100.0)*(TD/100.0)) * 0.001
C
      I = IFIX((TD+20.0)/10.0)
C IFIX IS A FORTRAN FUNCTION WHICH TRUNCATES A REAL NUMBER TO AN INTEGER
C THE FUNCTION NAME MAY VARY FROM MACHINE TO MACHINE
      IF(I.LT.1) I = 1
      IF(I.GT.7) I = 7
      AWW = (WWFACS(1,I) - TD*WWFACS(2,I)) * 0.01
C
      XA = 0.62197 / (0.62197 + GS)
      ONEMXA = 1.0 - XA
C###########IDEAL GAS LAW################################################
      SPVOL2=GASCON*(TD+273.15)/(PATMOS-VAPRS2(TD,GS,PATMOS))
C###########EXTRA TERM FOR IMPROVED ACCURACY#############################
     & - (XA*XA*AAA + XA*ONEMXA*2.0*AAW + ONEMXA*ONEMXA*AWW)
C########################################################################
      RETURN
      END
C
C ---------------------------------------------------------------------------
C
      REAL FUNCTION HUVOL1(TD,TW,PATMOS,IOPT)
C
C FUNCTION EVALUATES HUMID VOLUME cu.m/kg
C
      INTEGER        IOPT
      REAL           TD,TW,PATMOS,PS,VAPRS1
      EXTERNAL       VAPRS1
C
      PS=VAPRS1(TD,TW,PATMOS,IOPT)
C
C EQUN IHVE CHANGE TO METRIC APP C, P28
      HUVOL1=(2.87*(273.15+TD))/(PATMOS-PS)
C
C EXTRA FACTOR OF 100 IS FOR mbar TO Pa
      RETURN
      END
C
C ---------------------------------------------------------------------------
```

```
C
      REAL FUNCTION HUVOL2(TD,GS,PATMOS)
C
C FUNCTION EVALUATES HUMID VOLUME cu.m/kg
C
      REAL        TD,GS,PATMOS,PS,VAPRS2
      EXTERNAL    VAPRS2
C
      PS=VAPRS2(TD,GS,PATMOS)
C
C EQUN IHVE CHANGE TO METRIC APP C, P28
      HUVOL2=(2.87*(273.15+TD))/(PATMOS-PS)
C
C EXTRA FACTOR OF 100 IS FOR mbar TO Pa
      RETURN
      END
C
C -----------------------------------------------------------------------------
C
      REAL FUNCTION PCSAT1(TD,TW,PATMOS,IOPT)
C
C  FUNCTION EVALUATES PERCENT SATURATION
C
      INTEGER     IOPT
      REAL        TD,TW,PATMOS,HUMRAT
      EXTERNAL    HUMRAT
C
      PCSAT1=100.0*HUMRAT(TD,TW,PATMOS,IOPT)/HUMRAT(TD,TD,PATMOS,IOPT)
      RETURN
      END
C
C -----------------------------------------------------------------------------
C
      REAL FUNCTION PCSAT2(TD,GS,PATMOS)
C
C  FUNCTION EVALUATES PERCENT SATURATION
C
      REAL        TD,GS,PATMOS,HUMRAT
      EXTERNAL    HUMRAT
C
      PCSAT2 = 100.0 * GS / HUMRAT(TD,TD,PATMOS,1)
      RETURN
      END
C
C -----------------------------------------------------------------------------
C
      REAL FUNCTION PCRH1(TD,TW,PATMOS,IOPT)
C
C  FUNCTION EVALUATES RELATIVE HUMIDITY
C
      INTEGER     IOPT
      REAL        TD,TW,PATMOS,VAPRS1,SATVP
      EXTERNAL    VAPRS1,SATVP
C
      PCRH1 = 100.0 * VAPRS1(TD,TW,PATMOS,IOPT) / SATVP(TD)
      RETURN
      END
C
C -----------------------------------------------------------------------------
C
      REAL FUNCTION PCRH2(TD,GS,PATMOS)
C
C  FUNCTION EVALUATES RELATIVE HUMIDITY
C
      REAL        TD,GS,PATMOS,VAPRS2,SATVP
      EXTERNAL    VAPRS2,SATVP
C
      PCRH2 = 100.0 * VAPRS2(TD,GS,PATMOS) / SATVP(TD)
      RETURN
      END
```

```
C
      REAL FUNCTION SPHTC1(TD,TW,PATMOS,IOPT)
C
C  FUNCTION RETURNS THE SPECIFIC HEAT CAPACITY OF AIR kJ/kg deg.C
C
      INTEGER     IOPT
      REAL        TD,TW,PATMOS,GS,HUMRAT,SPHTC2
      EXTERNAL    HUMRAT,SPHTC2
C
      GS = HUMRAT(TD,TW,PATMOS,IOPT)
      SPHTC1 = SPHTC2(TD,GS)
      RETURN
      END
C
C ---------------------------------------------------------------------
C
      REAL FUNCTION SPHTC2(TD,GS)
C
C  FUNCTION RETURNS THE SPECIFIC HEAT CAPACITY OF AIR kJ/kg deg.C
C
      REAL        TD,GS,TD1,TD2,ENTHP2
      EXTERNAL    ENTHP2
C
      TD1 = TD + 0.5
      TD2 = TD - 0.5
      SPHTC2 = ENTHP2(TD1,GS) - ENTHP2(TD2,GS)
      RETURN
      END
C
C ---------------------------------------------------------------------
C
      REAL FUNCTION ENTHP1(TD,TW,PATMOS,IOPT)
C
C FUNCTION CALCULATES ENTHALPY OF MOIST AIR KJ/KG
C
      INTEGER     IOPT
      REAL        TD,TW,PATMOS,GS,HUMRAT,ENTHP2
      EXTERNAL    HUMRAT,ENTHP2
C
      GS=HUMRAT(TD,TW,PATMOS,IOPT)
C
      ENTHP1 = ENTHP2(TD,GS)
      RETURN
      END
C
C ---------------------------------------------------------------------
C
      REAL FUNCTION ENTHP2(TD,GS)
C
C FUNCTION CALCULATES ENTHALPY OF MOIST AIR kJ/kg
C
      INTEGER     ISW
      REAL        TD,GS,HA,HG
      INTRINSIC   IFIX
C
C NOW FIND RELEVANT EQUN FOR ENTHALPY OF AIR & WATER VAPOUR
C EQUN BASED ON FUNDEMENTAL DATA FOR B.S. ENGINEERS,SECTION 8,EQS 7-20
      ISW=IFIX((TD+20.0)/10.0)
C IFIX IS A FORTRAN FUNCTION WHICH TRUNCATES A REAL NUMBER TO AN INTEGER
C THE FUNCTION NAME MAY VARY FROM MACHINE TO MACHINE
      IF(ISW.LT.1) ISW=1
      IF(ISW.GT.7) ISW=7
      GOTO (100,200,300,400,500,600,700), ISW
100   HA=1.0054*TD
      HG=2500.822+1.8375*TD
      GOTO 800
200   HA=1.00597*TD
      HG=2500.92+1.84*TD
      GOTO 800
300   HA=1.00597*TD
```

```
      HG=2519.32+1.83*(TD-10.)
      GOTO 800
400   HA=1.0062*TD-0.0045
      HG=2537.62+1.82*(TD-20.0)
      GOTO 800
500   HA=1.00676*TD-0.0213
      HG=2555.82+1.8*(TD-30.)
      GOTO 800
600   HA=1.00707*TD-0.0337
      HG=2573.82+1.77*(TD-40.)
      GOTO 800
700   HA=1.00778*TD-0.0692
      HG=2591.52+1.76*(TD-50.)
800   CONTINUE
      ENTHP2=HA+GS*HG
      RETURN
      END
C
C -----------------------------------------------------------------------
C
      REAL FUNCTION HUMRAT(TD,TW,PATMOS,IOPT)
C
C FUNCTION CALCULATES HUMIDITY RATIO kg/kg
C
      INTEGER     IOPT
      REAL        TD,TW,PATMOS,PS,FS,VAPRS1
      EXTERNAL    VAPRS1
C
      PS=VAPRS1(TD,TW,PATMOS,IOPT)
C
C EQUN C1.3 IHVE(1975)
C VALUES OF FS FROM FUNDEMENTAL DATA FOR B.S ENGINEERS
C N.B. FS DEPENDS ON ATMOSPHERIC PRESSURE -
C   SEE W.P.JONES AIR CONDITIONING ENGINEERING, SECOND EDITION.
C   PAGE 34 TABLE 2.1.
C   ALSO ASHRAE HANDBOOK OF FUNDAMENTALS 1981 PAGE 5.4 TABLE 2.
      FS = -7.3E-6*TD + 1.00444
      IF(TD.GE.11.0.AND.TD.LT.26.0) FS = 1.32E-5*TD + 1.004205
      IF(TD.GE.26.0) FS = 4.05E-5*TD + 1.003497
      HUMRAT=0.62197*FS*PS/(PATMOS-FS*PS)
      RETURN
      END
C
C -----------------------------------------------------------------------
C
      REAL FUNCTION VAPRS1(TD,TW,PATMOS,IOPT)
C
C FUNCTION EVALUATES VAPOUR PRESSURE (mbar)
C
      INTEGER     IOPT,I
      REAL        TD,TW,PATMOS,FACTOR(2,2),SATVP
      EXTERNAL    SATVP
C
C  N.B. FACTOR MAY DEPEND ON ATMOSPHERIC PRESSURE. SEE W.P.JONES
C  AIR CONDITIONING ENGINEERING, SECOND EDITION, PAGE 29 SECTION 2.17
      DATA FACTOR/6.66E-4,5.94E-4,7.99E-4,7.2E-4/
C
C CHECK FOR TW GREATER OR LESS THAN ZERO
      I=1
      IF(TW.LT.0.0) I=2
C
C EQNS C1.7 & C1.8 IHVE (1975)
      VAPRS1=SATVP(TW)-FACTOR(I,IOPT)*PATMOS*(TD-TW)
      RETURN
      END
C
C -----------------------------------------------------------------------
```

```
C
      REAL FUNCTION VAPRS2(TD,GS,PATMOS)
C
C FUNCTION EVALUATES VAPOUR PRESSURE (mbar)
C
      REAL        TD,GS,PATMOS,FS
C
C EQUN C1.3 IHVE(1975)
C VALUES OF FS FROM FUNDAMENTAL DATA FOR B.S ENGINEERS
C N.B. FS DEPENDS ON ATMOSPHERIC PRESSURE -
C   SEE W.P.JONES AIR CONDITIONING ENGINEERING, SECOND EDITION.
C   PAGE 34 TABLE 2.1.
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      FS = -7.3E-6*TD + 1.00444
      IF(TD.GE.11.0.AND.TD.LT.26.0) FS = 1.32E-5*TD + 1.004205
      IF(TD.GE.26.0) FS = 4.05E-5*TD + 1.003497
      VAPRS2 = (GS*PATMOS) / (FS*(0.62197+GS))
      RETURN
      END
C
C -----------------------------------------------------------------------------
C
      REAL FUNCTION SATVP(TD)
C
C FUNCTION EVALUATES SATURATED VAPOUR PRESSURE (mbar)
C
      REAL        TD
      DOUBLE PRECISION T,X
C CONVERT TEMP TO ABSOLUTE
      T=TD+273.15
C
C CHECK FOR ABOVE ICE/WATER
      IF(TD.LT.0.0) GOTO 100
C###############################1975 EQUATION################################
C$$$$$ WATER -EQUN IHVE C1.9 (1975)
C$$$$$ NOT RECOMMENDED FOR COMPUTER APPLICATIONS
C$$$$$      X=3.159051D1-8.2*DLOG10(T)+2.4804D-3*T-3.14231D3/T
C
C NOTE FIRST TERM IS 31., C1.9 GIVES 30. - THIS CORRECTS UNITS FROM kPa TO mbar
C#######################ALTERNATIVE VERSION - MAGNUS EQTN####################
C WATER - EQUN IHVE C2.6 (1965)      MAGNUS FORMULA
      X = 7.5*TD / (237.3+TD) + 7.8571D-1
C############################################################################
      SATVP=1.0D1**X
      RETURN
100   CONTINUE
C
C ICE IHVE C.10 (1975)
      X=1.05380997D1-2.66391D3/T
C
C NOTE FIRST TERM 10., NOT 9. - AS ABOVE
      SATVP=1.0D1**X
      RETURN
      END
C
C -----------------------------------------------------------------------------
```