Operation manual, Air State Calculation Tool

Shigeru Suzuki

Apr. 4, 2024 (original release Oct. 30, 2021)

Version02 Update

Following changes are made to previous release:

1. Bug fix. Calculation results were not printed while RH=100%.
2. Calculation results are automatically recorded to A15:K15. Former calculation results are shifted down.
3. Calculation values are shown in 2nd decimal place (actual precision is float).
4. Wrong input condition is detected and notes are shown when input values are not appropriate.

   (Additional logic)

   (1) If input temperature values do not satisfy DBT≥WBT≥Dewpoint, then input values are corrected and comment is shown.

   (2) Condition 0%≤RH≤100% is applied. If RH<0% then RH is set to 0%, and if RH>100%, then RH is set to 100%.

   (3) Calculation range of −10℃≥DBT≥50℃ is applied. Any condition outside of this temperature range stops calculation with error message.
5. V2 to V2.1
   When WBT was user-set, WBT was shown as 0.00. This bug was fixed.

[1] Preface

This program calculates air state values if DBT (dry bulb temperature) and one of WBT (wet bulb temperature), RH (relative humidity), DP (dewpoint), or AH(absolute humidity) are indicated.
Users may refer to programme code writen in OpenOffice BASIC.
This manual explains how to read the source code.

OpenOffice BASIC is a programming language that reads information on LibreOffice spreadsheet and execute calculation procedure.
Calculation equations used in each procedure (Sub) and function (Function) are general logics.
Reference of each procedure is documented at the end of this manual.

Report any bug if you found, then the original developer will fix the bug and publish new release. This program is distributed in compliance with General Public License (GPL). Any user can use and modify this program. Any user can redistribute original or modified program. On the other hand, no one is allowed to distribute the program for commercial use. Modified program shall be shown if requested by someone.
Copyright Act is as well applied to the program and this document. Calculation formula reside in public domain. This program developer does not guarantee right results. You shall use the program at your own risk.
Verify the calculation results with other program if you find any questionable results.
Calculation equations may not be exactly accurate and includes some amount of errors.

[2] Operation

This program consists of one spreadsheet and BASIC program. The spreadsheet is equipped with execution buttons.
Input DBT to C4, and *ONLY* one of WBT, RH%, DP or AH, then click "CALCULATE" button.
Values need to be in indicated units in D4:D8. Calculated results are shown in 2-digit after the decimal point. You may modify the program module or change numerical format on the spreadsheet if any other digits are desired.
Calculated results are recorded. Latest calculation results are shown in A15:K15. J15:K15 are provided for the user to write comments.
Clicking "CLEAR" button will erace calculation results with the user's comments.

[3] Program description

Calculation program consists of procedures (Sub) and functions (Function). Input and output is done through LibreOffice Calc spreadsheet.
Table 1 gives list of functions and procedures.
Table 3 gives description of each procedure.

Table 1 Procedures and Functions

Procedure or Function	Process	Output (variable name)
Main	Read input variables and error processing Write calculation results and error messages	Absolute humidity(AH) (some AH values are processed by AHI module) Specific enthalpy of air (h) Discomfort index
RHI	Calculation procedure where relative humidity (RH) is indicated	Saturated water vapor pressure (ps) Partial water vapor pressure(pw) Dewpoint(dpe) Wet bulb temperature(tw)
DWI	Calculation procedure where wet bulb temperature (WBT) is indicated	Saturated water vapor pressure(ps) Partial water vapor pressure(pw) Relative humidity(rh) Dewpoint(dpe)
DPI	Calculation procedure where dewpoint (DP) is indicated	Saturated water vapor pressure (ps) Partial water vapor pressure(pw) Relative humidity(rh) Wet bulb temperature(tw)
AHI	Calculation procedure where absolute humidity (AH) is indicated	Saturated water vapor pressure (ps) Partial water vapor pressure(pw) Relative humidity(rh) Wet bulb temperature(tw)
WH (Function)	Calculate saturated water vapor pressure Wexler-Hyland's formula	Saturated water vapor pressure(ps)
WHD (Function)	Discrete delivative calculation of saturated vapor pressure	Discrete delivative by temperature (used for dewpoint calculation)
TWEST	Calculate wet bulb temperature (WBT) (It calculates square error valu per each	Wet bulb temperature(tw)

	estimated value, decreasing estimated value. Square error decreases at each step until estimated value passes true value. When square error increased at certain step, previous estimated value is considerd right value.	
DPEST	Calculate dewpoint (DP) (Newton's algorithm)	Dewpoint(dpe)
Param	Read parameter values	Constants of Wexler-Hyland formula {wha0(0) - wha0(6), whb0(0) - whb0(6)} psychrometer coefficient (cdw) atmospheric pressure(p0) molecular massof water(mw) equivalent molecular mass of air(ma)
Cancellare	Erace calculation result records.	Inut values remain
Spostare	Insert cells to show and record calculated results and error/warning messages. Values are shown in 2 digits after floating point.	Insert cells to A15:K15 while previous values shift down.

Table 2 Principal variables

tc	air temperature (DBT)[℃]	h	specific enthalpy of air@tk[K](tc[℃]) [kJ/kg]
td	DBT[℃]	mw	molecular mass of water=18.0153[g/mol]
tk	absolute DBT[K]	ma	equivalent molecular mass of air=28.9645[g/mol]
tw	WBT[℃]	p0	atmospheric pressure = 101.3 [kPa]
rh	relative humidity [-] (not in % in the program)	cdw	psychrometer coefficient(tc<0.01 then 0.000583, else 0.00062)
ah	absolute humidity[g/kg]	dp	user-specified dewpoint[℃]
ps	saturated water vapor pressure@tk [kPa]	dpe	estimated value of dewpoint[℃]
psl_wk	ln(ps)	twe	estimated value of WBT[℃]
ps	saturated water vapor pressure@tk[K](tc[℃])	ps_error	error value for WBT estimation
pw	saturated water vapor pressure@tk[K](tc[℃]) [kPa]		

About each procedure

Table 3-1 Main Program

Program	Comments
Dim dbs, wbs, rhs, dps, ahs As String	Declare variables
errore1="" errore2=""	These are variables to store messages. Initial values are empty.
cbook=ThisComponent csheet=cbook.CurrentController.ActiveSheet	Object variable definitions
dbs=csheet.getCellByPosition(2,3).string wbs=csheet.getCellByPosition(2,4).string rhs=csheet.getCellByPosition(2,5).string dps=csheet.getCellByPosition(2,6).string ahs=csheet.getCellByPosition(2,7).string	Read input variables as string. These variables are used to detect if the cell is blank or not.
td=csheet.getCellByPosition(2,3).value	Read DBT.

If td<-10 or td>50 Then
errore1="Range error."
foglio_a.getCellByPosition(9,14).string=errore1
Goto Z9999
EndIf
	Error processing if DBT is not in [−10,50].

Call Param	Call parameter reading procedure.

If dbs="" Then
MsgBox("DBT shall not be blank.",1)
Goto Z9999
End If
If wbs="" AND rhs="" AND dps="" AND ahs="" Then
MsgBox("Input one of WBT, RH, DewPoint or Absolute Humidity.",1)
Goto Z9999
End If
	If following one of condition is applied, program generates message and stop process.
	
	(1) DBT cell is blank.
	(2) Necessary condition is not given.(DBT, RH, DP and AH are all blank)

If wbs="" AND rhs<>"" Then
Call RHI
Goto Z9980
End If
	Case#1 RH is indicated
	Execute procedure RHI then return to AH calculation step.

If wbs<>"" Then
Call DWI
Goto Z9980
End If
	Case#2 WBT is specified
	Execute procedure DWI then return to AH calculation step.

If wbs="" AND rhs="" AND dps<>"" Then
CALL DPI
GOTO Z9980
End If
	Case#3 DP is indicated
	Execute procedure DPI then return to AH calculation step.

If wbs="" AND rhs="" AND dps="" AND ahs<>"" Then
CALL AHI
GOTO Z9970
End If
	Case#4 AH is indicated.
	Execute procedure AHI, skipping AH calculation step, then return to specific enthalpy calculation step.

Z9980: ah=mw/ma*pw/(p0-pw)	AH[g/kg] calculation step
Z9970: h=1.006*td+(1.86*td+2501)*ah di=0.81*td+0.01*rh*100*(0.99*td-14.3)+46.3	air specific enthalpy calculation step disconfort index calculation step
foglio_a.getCellByPosition(0,14).value=td foglio_a.getCellByPosition(1,14).value=twe foglio_a.getCellByPosition(2,14).value=rh*100 foglio_a.getCellByPosition(3,14).value=ah*1000 foglio_a.getCellByPosition(4,14).value=tc foglio_a.getCellByPosition(5,14).value=h foglio_a.getCellByPosition(6,14).value=di foglio_a.getCellByPosition(7,14).value=ps	Write calculation results to A15:K15 cells. errore1, errore2: error message variables, written to J15:K16 cells. User may write own comments to J15:K15. If block: If WBT has not been indicated, calculated WBT value is written to indicated cell.

foglio_a.getCellByPosition(8,14).value=pw
foglio_a.getCellByPosition(9,14).string=errore1
foglio_a.getCellByPosition(10,14).string=errore2
If wbs="" then
foglio_a.getCellByPosition(1,14).value=twe
Else
Goto Z9999
End If	

Z9999:	End of error handling process.

Table 3-2 RHI : 'Case#1' Calculation Procedure if RH is indicated

Sub RHI	
rh=foglio_a.getCellByPosition(2,5).value/100	Read RH value

If rh>1.0 Then
rh=1.0
errore2="Humidity set to 100%"
ElseIf rh<0.0 Then
rh=0.0
errore2="Humidity set to 0%"
End If
	If RH is outside of the range [0%,100%], then RH value is set to 0% (if RH<0%) or 100% (if RH>100%). This correction is shown as message in Humidity modified：湿度修正

If rh=100.0 Then
dpe=td
tw=td
Goto Z0100
End If
	If relative humidity is indicated as 100%, then dew point and wet bulb temperature are set to dry bulb temperature, and skip those calculation step.

If rh=1.0 Then
tc=td
twe=td
pw=WH(td)
ps=pw
Goto Z0100
End If
	If relative humidity is 100%, then dew point and wet bulb temperature are set to dry bulb temperature.

ps=WH(td) pw=ps*rh	ps :saturated water vapor pressure pw :water vapor pressure at DBT

If rh=0.0 Then
tc=-273.15
Goto Z0110
EndIf
	If relative humidity is 0%, dewpoint is set 0K.

Call DPEST Z0110: Call TWEST Z0100:	DPEST :dewpoint calculation module TWEST :WBT calculation module

Table 3-3 DWI: 'Case#2' Calculation Procedure if WBT is indicated

tw=csheet.getCellByPosition(2,4).value
If tw>td Then
twe=td
tw=td
errore2="WBT is set to DBT"
End If
ps=WH(td)
pw=WH(tw)-cdw*p0*(td-tw)
rh=pw/ps
csheet.getCellByPosition(2,16).value=tw
twe=tw
Call DPEST
	Read wet bulb temperature
	
	If WBT>DBT, then
	let WBT=DBT

Table 3-4 DPI 'Case#3' Calculation Procedure if Dewpoint is indicated

dp=csheet.getCellByPosition(2,6).value
 	
If dp>td Then
  dp=td
  errore2="dewpoint is set to DBT"
End If
 	
rh=WH(dp)/WH(td)
dpe=dp
ps=WH(td)
pw=WH(dp)
	Read dewpoint
	
	If dewpoint > DBT, then
	let dewpoint is DBT.
	In this case, relative humidity is set 100%.
	Message "dewpoint is set to DBT" is written to a remark cell.

Call TWEST	

Table 3-5 AHI 'Case#4" Calculation Procedure if absolute humidity is indicated

ah=csheet.getCellByPosition(2,7).value/1000	Read absolute humidity
ps=WH(td) pw=ma*p0*ah/(mw+ma*ah) rh=pw/ps	ps : saturated water vapor pressure pw :vapor pressure at DBT rh :relative humidity

If rh>1.0 Then
  rh=1.0
  ah=mw/ma*WH(td)/(p0-WH(td))
  errore2="input value modified"
EndIf
	Process if RH>100%

Call DPEST	Dewpoint calculation module
Call TWEST	WBT calculation module

Table 3-6 DPEST Dewpoint calculation module

If rh=0 Then
  tc=-273.15
  GOTO Z0020
End If
pwdp=WH(td)*rh
spwmpw=WH(td)-pwdp
	If absolute humidity is zero, let dewpoint is 0K (-273.15℃).
	spwmpw: saturated vapor pressure - actual vapor pressure

tc=td	Begin with DBT(td) as initial estimate.

i=0
Z0010:
  i=i+1
  dpe=tc-(WH(tc)-pwdp)/WHD(tc)
	i: iteration counter
	Z0010: itteration start point
	dpe: estimated value of dewpoint

ps_error=WH(dpe)-pwdp	Vapor pressure error at estimated dewpoint

If i>100 OR ps_error<1.0E-6 Then
  goto Z0020
Else
  tc=dpe
  goto Z0010
End If
Z0020:
	Condition to stop iteration
	(1)Max iteration is 102.
	(2)Target error value (1/1 000 000).
	Because Newton algorithm generally becomes convergent within several iteration steps, 102 iteration is considered something wrong.

Table 3-7 TWEST　WBT calculation procedure

Dim delta_t As Double	Value increase size for every step
twe=dpe ps_error_p=(rh*WH(td)-WH(twe)+cdw*p0*(td-twe))^2	Because DP≤WBT≤DBT, first estimate is set to DP, then increase estimated value and calculate error of each step. ps_error_p: previous estimation error
i=0 delta_t=0.02 Z0030:	initial counter value Increase value is resolution. If accuracy allowance value is less than 0.1, then delta_t shall be 0.4 or smaller. We set delta_t = 0.02 for enough accuracy.

i=i+1
twe=twe+delta_t
ps_error=(rh*WH(td)-WH(twe)+cdw*p0*(td-twe))^2
 	
If ps_error>ps_error_p Then
foglio_a.getCellByPosition(2,16).value=twe-delta_t
Goto Z0040
End If
 	
If twe>td Then
Goto Z0040
End If
 	
ps_error_p = ps_error
 	
Goto Z0030
 	
Z0040:
	Add delta_t in each error calculation step.
	Update ps_error.
	
	If ps_error is smaller than ps_error_p (error of precious step), then newer value is more accurate. If ps_error≥ps_error_p, then previous value is more accurate. Therefore previous estimation is considered the best of all.
	
	If estimation exceeds DBT, then it is considered something wrong, so stop the process.

Refer to source code and comments (in Japanese) for other functions and procedures.

[4] Calculation equations and their algorithms

Symbols

	Unit	Description	Variable in the program code
p_s	kPa	saturated water vapor pressure at T_d	ps
p_w	kPa	partial water vapor pressure at T_d	pw
r_H	no dimension	relative humidity (calculation results are shown in % value)	rh
T_d	℃	DBT: dry bulb temperature	td
T_w	℃	WBT: wet bulb temperature	tw
T_{dp}	℃	DP: Dewpoint	dpe, dp
x	g/kg(DA)	AH: absolute humidity	ah
h	kJ/kg(DA)	unit mass enthalpy of air	h
T	K	dry bulb temperature	tk
I_d	no dimension	Discomfort index	di

Saturated water vapor pressure at DBT

Wexler-Hyland formula were used.
Refer to Handbook of The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan.
Ps=saturated water vapor pressure (Pa)
T = 273.15 + DBT(℃)[K]

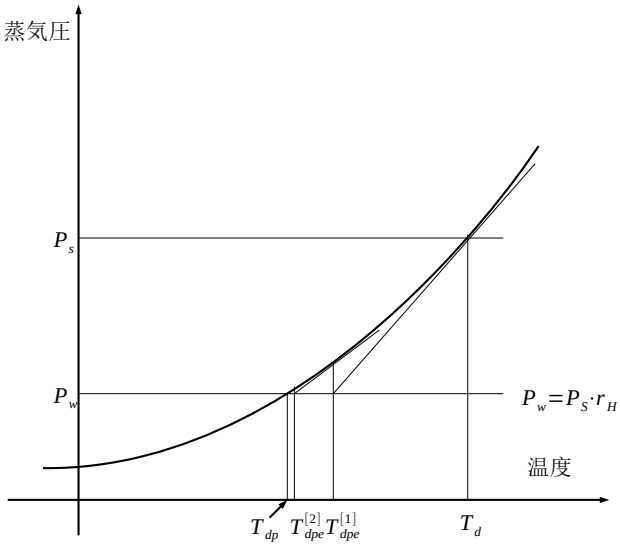
$$\ln(P_S)=a_{-1}T^{-1}+a_0+a_1T+a_2t^2+a_3T^3+a_4T^4+a_L\ln(T)$$
$$P_S=\exp[a_{-1}T^{-1}+a_0+a_1T+a_2t^2+a_3T^3+a_4T^4+a_L\ln(T)]$$

Coefficient schedule

Coefficient	Value	
	$T_d<0.01$	$T_d\geq 0.01$
a_{-1}	−0.56745 359E4	−0.58002 206E4
a_0	6.3925247	1.3914993
a_1	−0.96778 430E-2	−0.48640 239E-1
a_2	0.62215 701E-6	0.41764 768E-4
a_3	0.20747 825E-8	−0.14452 093E-7
a_4	−0.94840 240E-12	0
a_L	4.1635019	6.5459673

Dewpoint

Dewpoint is calculated using Newton's algorithm.
DBT is set initial estimation, then repeat estimation until error value becomes within preset error value.
Here are details.



Newton's algorithm

In saturated water vapor pressure curve, tangential line at DBT T_d crosses P_w. The crossing point is set first estimation value $T_{dpe}^{[1]}$. Then begin with $T_{dpe}^{[1]}$ then calculate next estimation point, then second estimation value is set $T_{dpe}^{[2]}$.
Repeat this process until error value becomes preset error allowance value.
Discrete differential value calculation procedure is made as Function "WHD".

Function WH Saturated water vapor pressure calculation
Function WHD Derivative calculation of WH

<u>If dewpoint is indicated by a user then:</u>

$$p_s(T_{dp})=r_H\,p_s(T_d)$$

$$r_H=\frac{p_s(T_{dp})}{p_s(T_d)}$$

<u>Wet bulb temperature (WBT)</u>

Use Sprung's formula.

P_w : partial water vapor pressure (kPa)
P_s : saturated water vapor pressure at indicated DBT (kPa)
C_{dw} : psychrometer coefficient,
p_0 : atmospheric pressure (kPa)
T_d : dry bulb temperature DBT (℃)
T_w : wet bulb temperature WBT (℃)
※C_{dw} : $C_{dw}=0.000662$ if $T_w \geq 0.01$, $C_{dw}=0.000583$ if $T_w<0.01$

$$P_w=P_s(T_w)-C_{dw}\cdot p_0(T_d-T_w)$$

$$P_w=r_H P_s(T_d)$$

We define error function as follows:

$$E_p=\left[P_w-P_s(T_w)+C_{dw}\,p_0(T_d-T_w)\right]^2$$

Because of the relationship $T_{dp}\leq T_w \leq T_d$, first estimation og T_w is set to T_{dp} (dewpoint). Then add increasing value, and calculate error value δt at next estimation point. Error value decreases until estimated value exceeds actual T_w . When error value increased, stop the calculation and previous estimation is determined the best estimate.
It is noted that δt<0.04, if you want to know the value until 1st digit below floating point. In this program, δt=0.02. δt is user-indicated value.
On the other hand, increasing calculation accuracy to 3rd or 4th digits below floating point may not make sense, because used formula and equations involve error and uncertainty.

<u>Absolute humidity</u>

Handbook of The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan uses the following formula.

$$x=\frac{m_w}{m_a}\frac{p_w}{p_0-p_w}$$

Where,

x	absolute humidity[kg/kg]
m_w	molecular mass of water(=18.0153[g/mol])
m_a	equivalent molecular mass of air(=28.9645[g/mol])
p_0	total air pressure[kPa]
p_w	partial water vapor pressure [kPa]

Following equations are used in the program. These equations are same as the formula above.

$$p_w=\frac{m_a\,p_0\,x}{m_w+m_a\,x}$$

$$p_w=r_H\,p_s$$

$$r_H=\frac{p_0}{p_s}\frac{m_a\,x}{m_w+m_a\,x}$$

Discomfort index

Calculated with J.F.Bosen's formula.
T_d: dry bulb temperature DBT(℃)、r_H: relative humidity(%)

$$I_d = 0.81 T_d + 0.01 r_H (0.99 T_d - 14.3) + 46.3$$

Air enthalpy per unit mass

Handbook of The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan uses the following formula.
h: air enthalpy per unit mass (kJ/kg(DA))、Td: DBT(℃)、x: absolute humidity(kg/kg')

$$h = 1.006 T_d + (1.86 T_d + 2501) x$$

Bug Reports, Questions, and Requests

Bug reports are appreciated.
If you have any questions or requests, write email to "webmaster@mcap-cr.com".

No information below