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TECHNICAL THERMODYNAMICS

Property Library for Humid Air Calculated as Ideal Mixture of Real Fluids

FluidMAT
with **LibHuAir**
for Mathcad®

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Property Software for Humid Air Calculated as Ideal Mixture of Real Fluids

FluidMAT for Mathcad®

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0 Package Contents

English zip file "CD_FluidMAT_LibHuAir_Eng.zip" includes the following files:

FluidMAT_LibHuAir_Docu_Eng.pdf	- User's Guide
FluidMAT_LibHuAir_Setup.exe	- Self-extracting and self-installing program
LibHuAir.dll	- DLL with functions of the LibHuAir library
MAT_LibHuAir_EN.xml	- Function registration in the dialog window "Insert Function" for English Mathcad

German zip file "CD_FluidMAT_LibHuAir.zip" includes the following files:

FluidMAT_LibHuAir_Docu_Eng.pdf	- User's Guide
FluidMAT_LibHuAir_Setup.exe	- Self-extracting and self-installing program
LibHuAir.dll	- DLL with functions of the LibHuAir library
MAT_LibHuAir_EN.xml	- Function registration in the dialog window "Insert Function" for English Mathcad

1. Property Functions

1.1 Calculation Programs

Functional Dependence	Function Name	Call as Fortran Program	Property or Function	Unit of the Result	Source or Algorithm	Site Info
$a = f(p, t, x_w)$	a_ptxw_HuAir	= a_ptxw_HuAir(p,t,xw) or = C_a_ptxw_HuAir(a,p,t,xw)	Thermal diffusivity	m^2/s	[1-4], [6], [12], [14], [15]	3/1
$c_p = f(p, t, x_w)$	cp_ptxw_HuAir	= cp_ptxw_HuAir(p,t,xw), or = C_cp_ptxw_HuAir(cp,p,t,xw)	Specific isobaric heat capacity	$\text{kJ}/(\text{kg} \cdot \text{K})$	[1-4], [13], [14]	3/2
$\eta = f(p, t, x_w)$	Eta_ptxw_HuAir	= Eta_ptxw_HuAir(p,t,xw), or = C_Eta_ptxw_HuAir(Eta,p,t,xw)	Dynamic viscosity	$\text{Pa} \cdot \text{s}$	[7], [12], [15]	3/3
$h_l = f(p, t, x_w)$	hl_ptxw_HuAir	= hl_ptxw_HuAir(p,t,xw), or = C_hl_ptxw_HuAir(h,p,t,xw)	Air-specific enthalpy	$\text{kJ}/\text{kg}_{\text{Air}}$	[1-4], [13], [14], [18], [19]	3/4
$\lambda = f(p, t, x_w)$	Lambda_ptxw_HuAir	= Lambda_ptxw_HuAir(p,t,xw), or = C_Lambda_ptxw_HuAir(Lambda,p,t,xw)	Thermal conductivity	$\text{W}/(\text{m} \cdot \text{K})$	[6], [12], [15]	3/5
$\nu = f(p, t, x_w)$	Ny_ptxw_HuAir	= Ny_ptxw_HuAir(p,t,xw), or = C_Ny_ptxw_HuAir(Ny,p,t,xw)	Kinematic viscosity	m^2/s	[1-4], [7], [12], [14], [15]	3/6
$p_d = f(p, t, x_w)$	pd_ptxw_HuAir	= pd_ptxw_HuAir(p,t,xw), or = C_pd_ptxw_HuAir(pd,p,t,xw)	Partial pressure of steam	bar	[1-4], [16], [17], [25], [26]	3/7
$p_{ds} = f(p, t)$	pds_pt_HuAir	= pds_pt_HuAir(p,t), or = C_pds_pt_HuAir(pd,p,t)	Saturation pressure of water	bar	[1-4], [16], [17], [25], [26]	3/8
$\varphi = f(p, t, x_w)$	Phi_ptxw_HuAir	= Phi_ptxw_HuAir(p,t,xw), or = C_Phi_ptxw_HuAir(Phi,p,t,xw)	Relative humidity	%	[1-4], [16], [17], [25], [26]	3/9
$p_l = f(p, t, x_w)$	pl_ptxw_HuAir	= pl_ptxw_HuAir(p,t,xw), or = C_pl_ptxw_HuAir(pl,p,t,xw)	Partial pressure of air	bar	[1-4], [16], [17], [25], [26]	3/10
$Pr = f(p, t, x_w)$	Pr_ptxw_HuAir	= Pr_ptxw_HuAir(p,t,xw), or = C_Pr_ptxw_HuAir(Pr,p,t,xw)	PRANDTL-number	-	[1-4], [6], [7], [12-15]	3/11
$\psi_l = f(x_w)$	Psil_xw_HuAir	= Psil_xw_HuAir(xw), or = C_Psil_xw_HuAir(Psil,xw)	Mole fraction of air	kmol/kmol	-	3/12

Functional Dependence	Function Name	Call as Fortran Program	Property or Function	Unit of the Result	Source or Algorithm	Site Info
$\psi_w = f(x_w)$	Psiw_xw_HuAir	= Psiw_xw_HuAir(xw), or = C_Psiw_xw_HuAir(Psiw,xw)	Mole fraction of water	kmol/kmol	-	3/13
$\rho = f(p, t, x_w)$	Rho_ptxw_HuAir	= Rho_ptxw_HuAir(p,t,xw), or = C_Rho_ptxw_HuAir(Rho,p,t,xw)	Density	kg/m ³	[1-4], [14], [18], [19]	3/14
$s_l = f(p, t, x_w)$	sl_ptxw_HuAir	= sl_ptxw_HuAir(p,t,xw), or = C_sl_ptxw_HuAir(Rho,p,t,xw)	Air-specific entropy	kJ/(kg _{Air} K)	[1-4], [13], [14], [18], [19]	3/15
$t = f(p, h_l, x_w)$	t_phlxw_HuAir	= t_phlxw_HuAir(p,hl,xw), or = C_t_phlxw_HuAir(t,p,hl,xw)	Backward function: temperature from air-specific enthalpy and humidity ratio (absolute humidity)	°C	[1-4], [13], [14], [18], [19]	3/16
$t = f(p, s_l, x_w)$	t_pslxw_HuAir	= t_pslxw_HuAir(p,hl,xw), or = C_t_pslxw_HuAir(t,p,sl,xw)	Backward function: temperature from air-specific entropy and humidity ratio (absolute humidity)	°C	[1-4], [13], [14], [18], [19]	3/17
$t_f = f(p, t, x_w)$	tf_ptxw_HuAir	= tf_ptxw_HuAir(p,t,xw), or = C_tf_ptxw_HuAir(tf,p,t,xw)	Wet bulb temperature	°C	[1-4], [13], [14]	3/18
$t_\tau = f(p, x_w)$	tTau_pxw_HuAir	= tTau_pxw_HuAir(p,xw), or = C_tTau_pxw_HuAir(tTau,p,xw)	Dew point temperature	°C	[1-4], [16], [17]	3/19
$u_l = f(p, t, x_w)$	ul_ptxw_HuAir	= ul_ptxw_HuAir(p,t,xw), or = C_ul_ptxw_HuAir(ul,p,t,xw)	Air-specific internal energy	kJ/kg _{Air}	[1-4], [13], [14], [18], [19]	3/20
$v_l = f(p, t, x_w)$	vl_ptxw_HuAir	= vl_ptxw_HuAir(p,t,xw), or = C_vl_ptxw_HuAir(vl,p,t,xw)	Air-specific volume	m ³ /kg _{Air}	[1-4], [14], [18], [19]	3/21
$\xi_l = f(x_w)$	Xil_xw_HuAir	= Xil_xw_HuAir(xw), or = C_Xil_xw_HuAir(Xil,xw)	Mass fraction of air	kg/kg	-	3/22
$\xi_w = f(x_w)$	Xiw_xw_HuAir	= Xiw_xw_HuAir(xw), or = C_Xiw_xw_HuAir(Xiw,xw)	Mass fraction of water	kg/kg	-	3/23
$x_w = f(p, t, p_d)$	xw_ptpd_HuAir	= xw_ptpd_HuAir(p,t,pd), or = C_xw_ptpd_HuAir(xw,p,t,pd)	Humidity ratio (Absolute humidity) from partial pressure of steam	g _{water} /kg _{Air}	[1-4], [16], [17], [25], [26]	3/25
$x_w = f(p, t, \varphi)$	xw_ptPhi_HuAir	= xw_ptPhi_HuAir(p,t,Phi), or = C_xw_ptPhi_HuAir(xw,p,t,Phi)	Humidity ratio (Absolute humidity) from temperature and relative humidity	g _{water} /kg _{Air}	[1-4], [16], [17], [25], [26]	3/24

Functional Dependence	Function Name	Cal as Fortran Program	Property or Function	Unit of the Result	Source or Algorithm	Site Info
$x_w = f(p, t_r)$	xw_ptTau_HuAir	= xw_ptTau_HuAir(p,tTau), or = C_xw_ptTau_HuAir(xw,p,tTau)	Humidity ratio (Absolute humidity) from dew point temperature	g _{water} /kg _{Air}	[1-4], [16], [17], [25], [26]	3/26
$x_w = f(p, t, t_f)$	xw_pttf_HuAir	= xw_pttf_HuAir(p,t,tf), or = C_xw_pttf_HuAir(xw,p,t,tf)	Humidity ratio (Absolute humidity) from temperature and wet bulb temperature	g _{water} /kg _{Air}	[1-4], [13], [14]	3/27
$x_w = f(p, t, v_l)$	xw_ptvl_HuAir	= xw_ptvl_HuAir(p,t,vl), or = C_xw_ptvl_HuAir(xw,p,t,vl)	Backward function: Humidity ratio (Absolute humidity) from temperature and air-specific volume	g _{water} /kg _{Air}	[1-4], [16], [17], [25], [26]	3/28
$x_{ws} = f(p, t)$	xws_pt_HuAir	= xws_pt_HuAir(p,t), or = C_xws_pt_HuAir(xws,p,t)	Humidity ratio (Absolute humidity) of saturated humid air	g _{water} /kg _{Air}	[1-4], [16], [17], [25], [26]	3/29

Variable Types for Function Call

All functions <u>not</u> starting with C_ :	REAL*8
All functions starting with C_ :	INTEGER*4
All variables:	REAL*8

Composition of Dry Air (from Lemmon et al. [14], [15]) :

Component		Mole Fraction
Nitrogen	N ₂	0.7812
Oxygen	O ₂	0.2096
Argon	Ar	0.0092

Reference States

Property	Dry air	Water
Pressure	1.01325 bar	6.11657 mbar
Temperature	0 °C	0.01 °C
Enthalpy	0 kJ/ kg _{Air}	0.000611783 kJ/ kg _{Air}
Internal energy	- 78.37885533 kJ/ kg _{Air}	0 kJ/ kg _{Air}
Entropy	0.161802887 kJ/(kg _{Air} K)	0 kJ/ (kg _{Air} K)

Units

- p - Mixture pressure in bar
- t - Temperature in °C
- x_w - Humidity ratio (Absolute humidity) in g steam(water, ice)/kg dry air
- φ - Relative humidity in % (only defined for unsaturated and saturated humid air)

Range of Validity

- Temperature: $t = -143.15\text{ °C} \dots 1726.85\text{ °C}$
- Mixture pressure: $p = 6.112\text{ mbar} \dots 1000\text{ bar}$

Calculation Algorithm

Saturated and unsaturated air ($0 < x_w \leq x_{ws}$):

Ideal mixture of dry air and steam

- Dry air:
 - v_l, h_l, u_l, s_l, c_p from Lemmon et al. [14]
 - λ, η from Lemmon et al. [15]
- Steam:
 - v, h, u, s, c_p of steam from IAPWS-IF97 [1], [2], [3], [4]
 - λ, η for $0\text{ °C} \leq t \leq 800\text{ °C}$ from IAPWS-85 [6], [7]
 - for $t < 0\text{ °C}$ and $t > 800\text{ °C}$ from Brandt [12]

Supersaturated humid air (liquid fog or ice fog)

- Liquid fog ($x_w > x_{ws}$) and $t \geq 0.01\text{ °C}$
 - Ideal mixture of saturated humid air and water
 - Saturated humid air (see above)
 - v, h, u, s, c_p of liquid droplets from IAPWS-IF97 [1], [2], [3], [4]
 - λ, η of liquid droplets from IAPWS-85 [6], [7]
- Ice fog ($x_w > x_{ws}$) and $t < 0.01\text{ °C}$
 - Ideal mixture of saturated humid air and ice
 - Saturated humid air (see above)
 - v, h, s of ice crystals from IAPWS-06 [18], [19]
 - λ, c_p of ice crystals as constant value
 - η, κ, w of saturated humid air

$x_{ws}(p, t)$ from saturation pressure $p_{ds}(p, t)$ of water in gas mixtures

$p_{ds}(p, t)$ is the saturation vapor pressure from $p_{ds}(p, t) = f(p, t) \cdot p_s(t)$

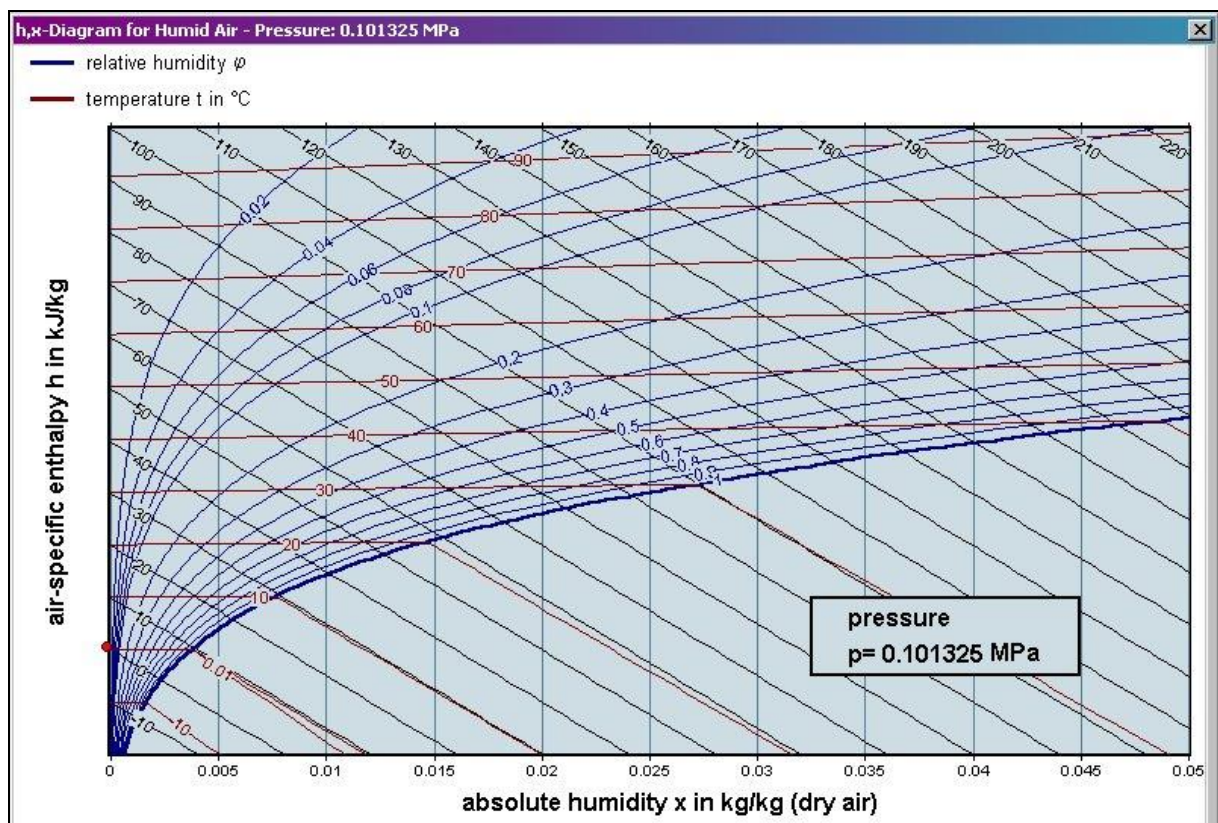
- $f(p, T)$ from Herrmann et al. [25], [26],
- $p_s(t)$ for $t \geq 273.16\text{ K}$ from IAPWS - IF97 [1], [2], [3], [4],
- $p_s(t)$ for $t < 273.15\text{ K}$ from IAPWS-08 [16], [17].

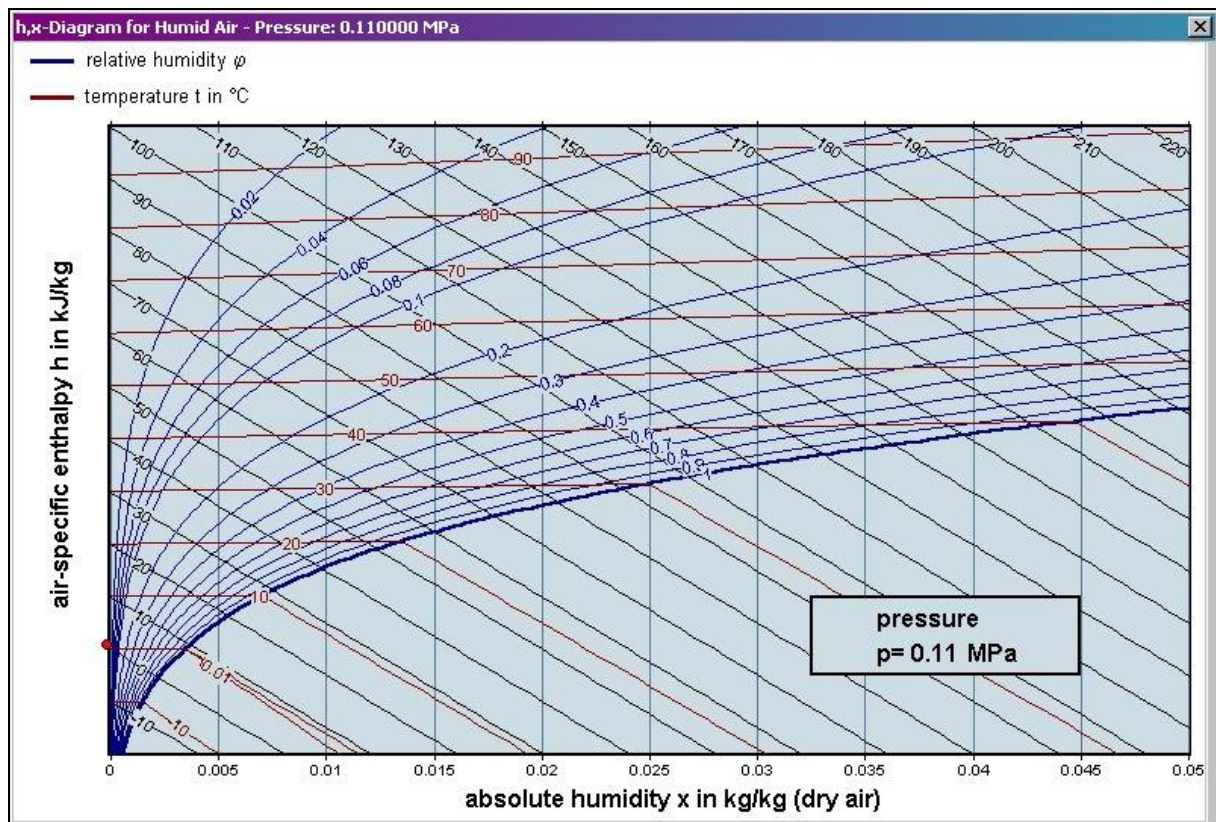
1.2 Thermodynamic Diagrams

FluidEXL^{Graphics} enables representation of the calculated property values in the following thermodynamic diagrams:

- h,x-Diagram $p = 0.101325 \text{ MPa}$
- h,x-Diagram $p = 0.11 \text{ MPa}$

The diagrams, in which the calculated state point will be represented are shown below.





2 Application of FluidMAT in Mathcad®

FluidMAT has been developed to calculate thermodynamic properties in Mathcad® more conveniently. Within Mathcad, it enables the direct call of functions relating to humid air from the LibHuAir property library.

2.1 Installing FluidMAT

In this section, the installation of FluidMAT LibHuAir is described.

Before you begin, it is best to close any Windows® applications, since Windows may need to be rebooted during the installation process.

After you have downloaded and extracted the zip-file "CD_FluidMAT_LibHuAir_Eng.zip", you will see the folder

CD_FluidMAT_LibHuAir_Eng	(for English version of Windows)
CD_FluidMAT_LibHuAir	(for German version of Windows)

in your Windows Explorer, Norton Commander etc.

Now, open this folder by double-clicking on it.

Within this folder you will see the following files:

- FluidMAT_LibHuAir_Docu_Eng.pdf
- FluidMAT_LibHuAir_Setup.exe
- LibHuAir.dll
- MAT_LibHuAir_EN.xml.

In order to run the installation of FluidMAT including the LibHuAir property library double-click the file

FluidMAT_LibHuAir_Setup.exe.

Installation may start with a window noting that all Windows programs should be closed.

When this is the case, the installation can be continued. Click the "Next >" button.

Now, you will be informed on the FluidMAT product in the "ReadMe-File" window. Click "Next >" to leave this window.

In the following dialog box, "Choose Destination Location" (see following figure), the default path where Mathcad has been installed will be shown

C:\Program Files\Mathcad\Mathcad 14\	(for English version of Windows)
C:\Programme\Mathcad\Mathcad 14\	(for German version of Windows).

By clicking the "Browse..." button, you can change the installation directory before installation.

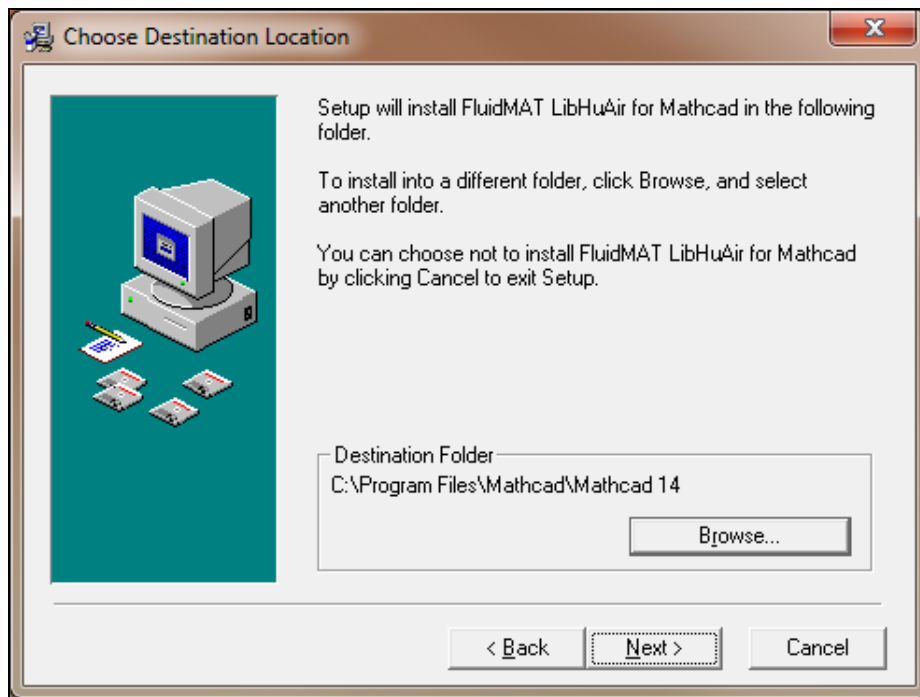


Figure 2.1: "Choose Destination Location" dialog window

The path will be displayed in the window.

Click on "Next >" in the window "Choose Destination Location".

Click on the "Next >" button in the "Start Installation" window.

After FluidMAT LibHuAir has been installed, the sentence "FluidMAT LibHuAir for Mathcad Professional has been successfully installed" will be shown.

Confirm this by clicking the "Finish >" button.

During the installation process the following files have been copied into the chosen destination folder (which is the folder, where Mathcad was installed):

advapi32.dll	Dynamic link library for use in Windows [®] programs
Dformd.dll	Dynamic link library for use in Windows [®] programs
Dforrt.dll	Dynamic link library for use in Windows [®] programs
INSTALL_MAT_LibHuAir.LOG	Installation log-file
LC.dll	Dynamic link library for use in Windows [®] programs
LibHuAir.dll	Property library for real moist air
msvcp60.dll	Dynamic link library for use in Windows [®] programs
msvcrt.dll	Dynamic link library for use in Windows [®] programs

The following files were installed into your Mathcad subdirectory \userEFI:

MAT_LibHuAir.dll	Function definition of LibHuAir
------------------	---------------------------------

The following files were installed into your Mathcad subdirectory \doc\funcdoc:

MAT_LibHuAir_DE.xml	Function registration in the dialog window "Insert Function" for LibHuAir (German Mathcad version 12 or higher)
MAT_LibHuAir_EN.xml	Function registration in the dialog window "Insert Function" for LibHuAir (English Mathcad version 12 or higher)
MAT_LibHuAir.xml	Function registration in the dialog window "Insert Function" for LibHuAir (Mathcad version 11 or lower)

Now, you have to overwrite the files

LibHuAir.dll
MAT_LibHuAir_EN.xml

in your Mathcad directory with the file of the same name provided on your CD with FluidMAT. To do this, open the CD in "My Computer" and press the Ctrl key and click on the files

LibHuAir.dll
MAT_LibHuAir_EN.xml

in order to highlight them. Then click on the "Edit" menu in your Explorer and select "Copy". Now, open your Mathcad directory (the standard being

C:\Program Files\Mathcad\Mathcad 14 (for English version of Windows)
C:\Programme\Mathcad\Mathcad 14 (for German version of Windows))

and insert the files by clicking the "Edit" menu in your Explorer and then select "Paste". Answer the question whether you want to replace the files by clicking the "Yes" button. You have overwritten the files "LibHuAir.dll" and "MAT_LibHuAir_EN.xml" successfully.

From within Mathcad you can now select the FluidMAT LibHuAir property functions.

2.2 Licensing the LibHuAir Property Library

The licensing procedure has to be carried out when you are calculating a function with LibHuAir in Mathcad® and a FluidMAT prompt message appears. In this case, you will see the "License Information" window for LibHuAir (see figure below).

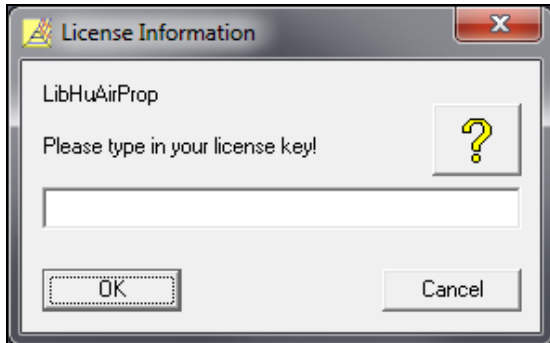


Figure 2.2: "License Information" window

Here you are asked to type in the license key which you have obtained from Zittau/Goerlitz University of Applied Sciences. If you do not have this, or have any questions, you will find contact information on the "Content" page of this User's Guide or by clicking the yellow question mark in the "License Information" window. Then the following window will appear:

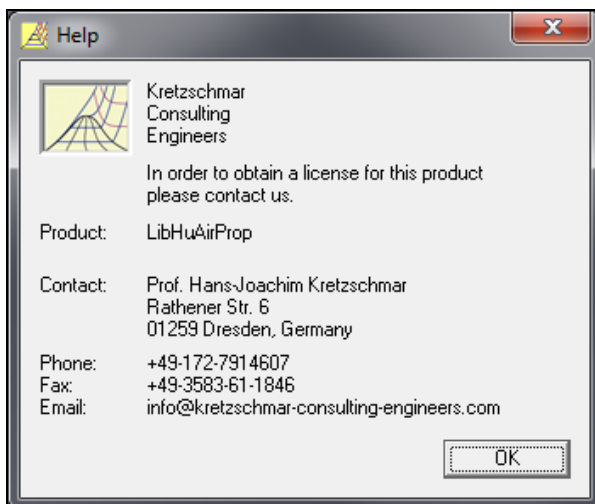


Figure 2.3: "Help" window

If you do not enter a valid license it is still possible to use Mathcad® by clicking "Cancel". In this case, the LibHuAir property library will display the result "-11111111" for every calculation.

The "License Information" window will appear every time you use FluidMAT LibHuAir until you enter a license code to complete registration. If you decide not to use FluidMAT LibHuAir, you can uninstall the program following the instructions given in section 2.4 of this User's Guide.

2.3 Example: Calculation of the Air-Specific Enthalpy $h_l = f(p, t, x_w)$ for Humid Air

Now we will calculate, step by step, the air-specific enthalpy h_l as a function of mixture pressure p , temperature t and humidity ratio (absolute humidity) x_w for humid air, using FluidMAT.

- Start Mathcad.
- Type "p:" and enter the value for the pressure p in bar.
(Range of validity: $p = 6.112 \text{ mbar} \dots 1000 \text{ bar}$)
e. g.: Enter "p:1.01325 " for the first operand
- Type "t:" and enter the value for the temperature t in $^{\circ}\text{C}$.
(Range of validity: $t = -143.15^{\circ}\text{C} \dots 1726.85^{\circ}\text{C}$)
e. g.: Enter "t:20" for the second operand
- Type "xw:" and enter the value for the humidity ratio x_w in $\text{g}_{\text{Water}}/\text{kg}_{\text{Air}}$ (dry Air).
(Range of validity: $x_w \geq 0 \text{ g/kgAir}$)
e. g.: Enter "xw:10" for the third operand
- Confirm your entry by pressing the "ENTER" key.
- Your Mathcad calculation window should look like Figure 2.4:

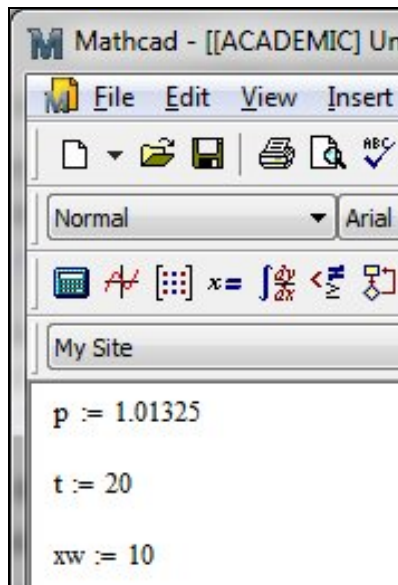


Figure 2.4: Example Mathcad[®] sheet after input of the given parameters

- Now, type "hl:" in the Mathcad window. Now, you will see **hl := ■**.
- Click on "Insert" in the upper menu bar and then click "Function...". Now, the "Insert function" window appears (see next figure).

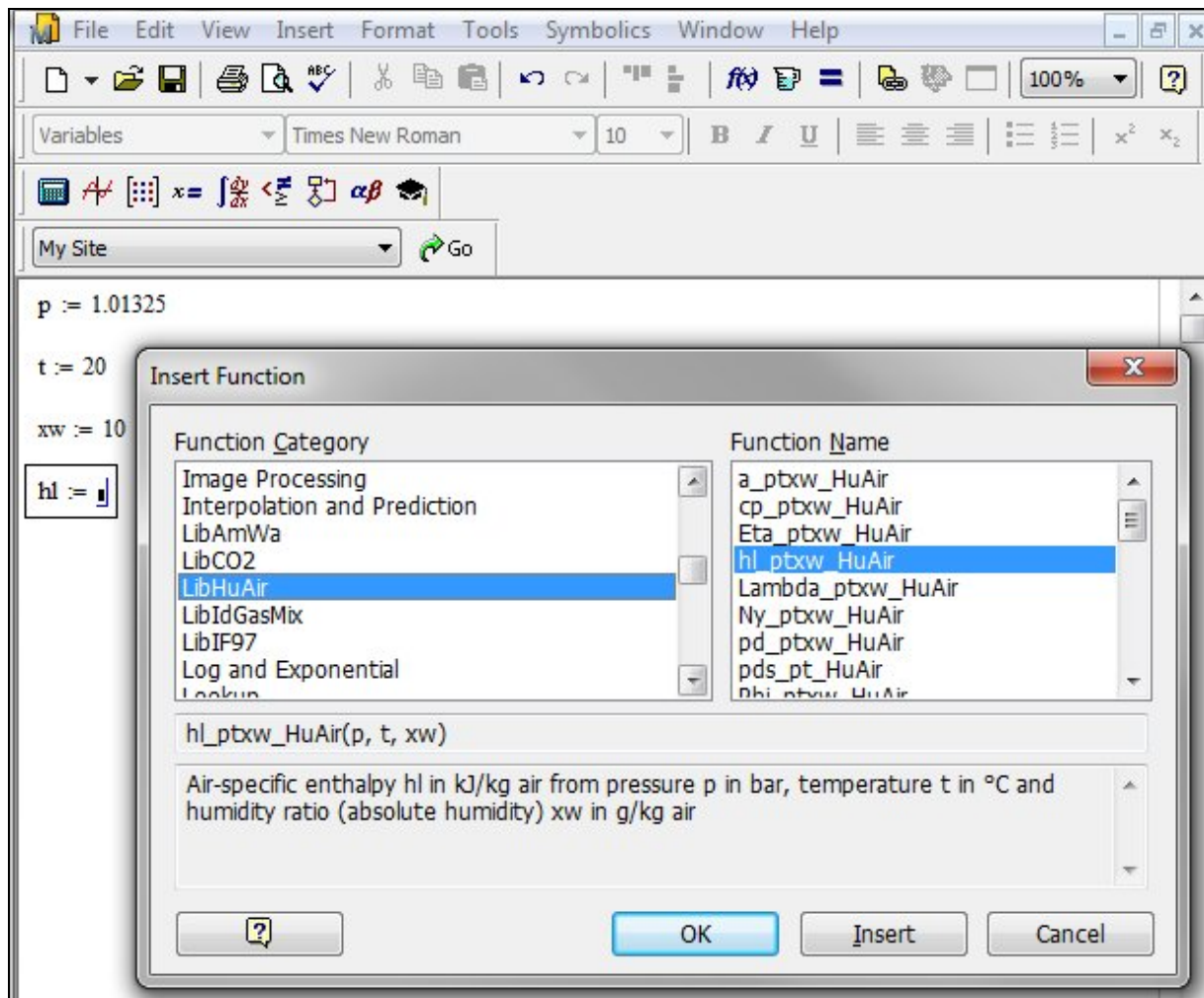


Figure 2.5: Choice of library and function name

- Search and click the "LibHuAir" library under "Function Category" in the left part of the window.
- Now, search and click the "hl_ptxw_HuAir" function under "Function Name" on the right hand side of the window.

The function category and the function name will be inverted, highlighted and furthermore the description of the function and the measuring units of the variables are shown.

- Now, click "OK" and you will see **hl := hl_ptxw_HuAir (■ , ■ , ■)** in the Mathcad window (see next figure).

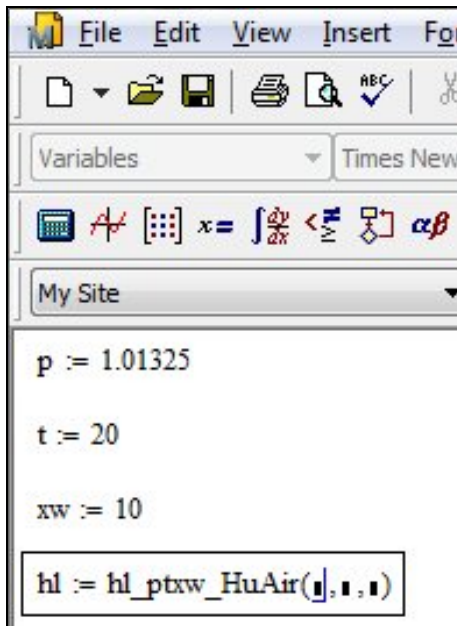


Figure 2.6: Example Mathcad® sheet with formula and placeholders

- The cursor is now situated on the first operand. You can now enter the value for p either by entering the value directly or by entering the name of the variable where the value was saved.
⇒ e.g.: Enter "p".
- Situate the cursor on the next placeholder. You can now enter the value for the temperature t either by entering the value for t directly or by typing the name of the variable in which the value of the temperature has been saved.
⇒ e.g.: Enter "t".
- Situate the cursor on the next placeholder. You can now enter the value for the humidity ratio xw either by entering the value for xw directly or by typing the name of the variable in which the value of the humidity ratio has been saved.
⇒ e.g.: Enter "xw".
- Close the input formula by pressing the "Enter"-Key.
- Your Mathcad calculation window should like the following figure:

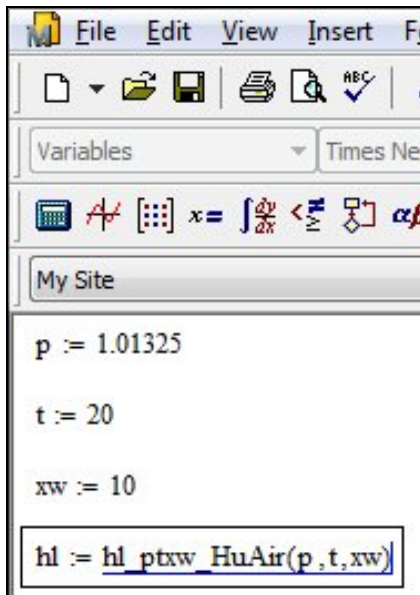


Figure 2.7: Example Mathcad® sheet with formula

- You can now go on working with the variable hl which we have just calculated.
- If you wish to see the result, you have to type the following command on the next line in the Mathcad window:
"hl =".

You will now see the result $hl = 45.5052$. The corresponding unit is kJ/kg (see table of the property functions in Chapter 1).

The representation of the result depends on the amount of places and decimal places which you have set before. In the next figure you can see that we have chosen the decimal number format and the amount of four decimal places.

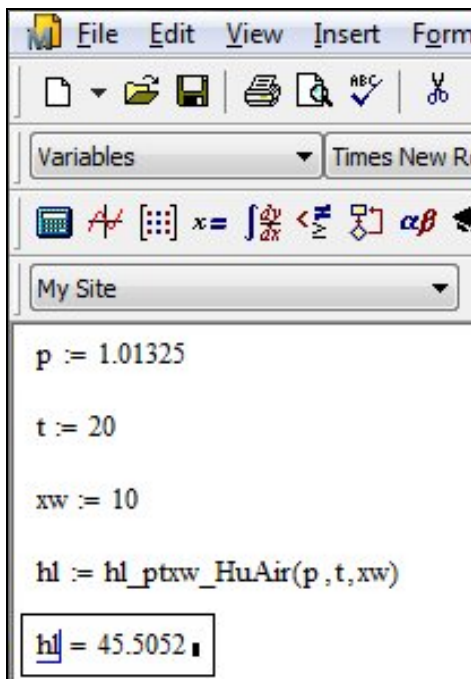


Figure 2.8: Example Mathcad® sheet with finished calculation

2.4 Removing FluidMAT

To remove FluidMAT from Mathcad® and from your hard drive, carry out the following steps:

- Click "Start" in the lower task bar of your desktop, then "Settings" and then "Control Panel".
- Now, double click on "Add or Remove Programs".
- In the list box of the "Add or Remove Programs" window that appears select "FluidMAT LibHuAir for Mathcad Professional" by clicking on it and click the "Add/Remove..." button.
- In the following dialog box click "Automatic" and thereafter "Next >".
- Click "Finish" in the "Perform Uninstall" window.
- Finally, close the "Add or Remove Programs" and "Control Panel" windows.

Now FluidMAT has been removed.

3 Program Documentation

Thermal Diffusivity $a = f(p, t, x_w)$

Function Name:

a_ptxw_HuAir

Fortran Programs:

REAL*8 FUNCTION a_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw

INTEGER*4 FUNCTION C_a_ptxw_HuAir(a,p,t,xw), REAL*8 a,p,t,xw

Input Values:

p - Mixture pressure p in bar
 t - Temperature t in °C
 x_w - Absolute humidity x_w in g/kg_{Air}

Result:

a_ptxw_HuAir, a - Thermal diffusivity in m²/s

Range of Validity:

Temperature t : from -73.15°C to 1726.85°C
 Mixture pressure p : from 6.112 mbar to 165.29 bar
 Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

- Thermal diffusivity $a = \frac{\lambda}{\rho \cdot c_p}$
- Model of ideal mixture of real fluids

Results for wrong input values:

a_ptxw_HuAir, a = - 1

References:

Dry Air:

λ from *Lemmon* et al. [15]
 c_p from *Lemmon* et al. [14]
 ρ from *Lemmon* et al. [14]

Steam in humid air and liquid droplets in fog:

λ for 0°C ≤ t ≤ 800°C from IAPWS-85 [6]
 for t < 0°C and t > 800°C from *Brandt* [12]
 c_p from IAPWS-IF97 [1], [2], [3], [4]
 ρ from IAPWS-IF97 [1], [2], [3], [4]
 for t < 0.01 °C from IAPWS-06 [18], [19]

Specific Isobaric Heat Capacity $c_p = f(p, t, x_w)$
Function Name:

cp_ptxw_HuAir

Fortran Programs:

REAL*8 FUNCTION cp_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw

INTEGER*4 FUNCTION C_cp_ptxw_HuAir(cp,p,t,xw), REAL*8 cp,p,t,xw

Input Values:

p - Mixture pressure p in bar
t - Temperature t in °C
 x_w - Absolute humidity x_w in g/kg_{Air}

Result:

cp_ptxw_HuAir, cp - Specific isobaric heat capacity in kJ/(kg K)

Range of Validity:

Temperature t : from -143.15°C to 1726.85°C
Mixture pressure p : from 6.112 mbar to 165.29 bar
Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

- For unsaturated and saturated humid air ($x_w \leq x_{ws}$), calculation as ideal mixture of real gases (dry air and steam)
- For supersaturated humid air ($x_w \geq x_{ws}$), calculation is not possible
- For temperatures greater than 500°C, the dissociation is taken into consideration

Results for wrong input values:

cp_ptxw_HuAir, cp = -1

References:

Dry Air:
from Lemmon et al. [14]
Steam in humid air and liquid droplets in fog:
from IAPWS-IF97 [1], [2], [3], [4]
Dissociation:
from VDI Guideline 4670 [13]

Dynamic Viscosity $\eta = f(p, t, x_w)$
Function Name:

Eta_ptxw_HuAir

Fortran Programs:

REAL*8 FUNCTION Eta_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw

INTEGER*4 FUNCTION C_Eta_ptxw_HuAir(Eta,p,t,xw), REAL*8 Eta,p,t,xw

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C
 x_w - Absolute humidity x_w in g/kg_{Air}

Result:

Eta_ptxw_HuAir, Eta - Dynamic viscosity in Pa s

Range of Validity:

Temperature t : from -73.15°C to 1726.85°C
Mixture pressure p : from 6.112 mbar to 165.29 bar
Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

- Model of ideal mixture of real fluids
- Neglect of ice crystals in ice fog ($t < 0.01^\circ\text{C}$ and $x_w > x_{ws}$)

Results for wrong input values:

Eta_ptxw_HuAir, Eta = -1

References:

Dry Air:
from *Lemmon* et al. [15]
Steam in humid air and liquid droplets in fog:
for $0^\circ\text{C} \leq t \leq 800^\circ\text{C}$ from IAPWS-85 [7]
for $t < 0^\circ\text{C}$ and $t > 800^\circ\text{C}$ from *Brandt* [12]

Air-Specific Enthalpy $h_l = f(p, t, x_w)$
Function Name:

hl_ptxw_HuAir

Fortran Programs:

```
REAL*8 FUNCTION hl_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw
INTEGER*4 FUNCTION C_hl_ptxw_HuAir(hl,p,t,xw), REAL*8 hl,p,t,xw
```

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C
 x_w - Absolute humidity x_w in g/kg_{Air}

Result:

hl_ptxw_HuAir, hl - Air-specific enthalpy in kJ/kg_{Air}

Range of Validity:

Temperature t : from -143.15°C to 1726.85°C
Mixture pressure p : from 6.112 mbar to 165.29 bar
Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

- For unsaturated and saturated humid air ($x_w \leq x_{ws}$), calculation as ideal mixture of real gases (dry air and steam)
- For fog ($x_w > x_{ws}$), calculation as ideal mixture of saturated humid air and water, ice
- For temperatures greater than 500°C, the dissociation is taken into consideration

Result for wrong input values:

hl_ptxw_HuAir, hl = -1000

References:

Dry Air:
from Lemmon et al. [14]
Steam in humid air and liquid droplets in fog:
from IAPWS-IF97 [1], [2], [3], [4]
Ice crystals in fog:
according to IAPWS-06 [18], [19]
Dissociation:
from VDI Guideline 4670 [13]

Thermal Conductivity $\lambda = f(p, t, x_w)$
Function Name:

Lambda_ptxw_HuAir

Fortran Programs:

```
REAL*8 FUNCTION Lambda_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw
INTEGER*4 FUNCTION C_Lambda_ptxw_HuAir(Lambda,p,t,xw),
REAL*8 Lambda,p,t,xw
```

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C
 x_w - Absolute humidity x_w in g/kg_{Air}

Result:

Lambda_ptxw_HuAir, Lambda - Heat conductivity in W/(m K)

Range of Validity:

Temperature t : from -73.15°C to 1726.85°C
Mixture pressure p : from 6.112 mbar to 165.29 bar
Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

- Model of ideal mixture of real fluids

Result for wrong input values:

Lambda_ptxw_HuAir, Lambda = -1

References:

Dry Air:
from *Lemmon* et al. [15]
Steam in humid air and humid droplets in fog:
for $0^\circ\text{C} \leq t \leq 800^\circ\text{C}$ from IAPWS-85 [6]
for $t < 0^\circ\text{C}$ and $t > 800^\circ\text{C}$ from *Brandt* [12]

Kinematic Viscosity $\nu = f(p, t, x_w)$
Function Name:

Ny_ptxw_HuAir

Fortran Programs:

```
REAL*8 FUNCTION Ny_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw
INTEGER*4 FUNCTION C_Ny_ptxw_HuAir(Ny,p,t,xw), REAL*8 Ny,p,t,xw
```

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C
 x_w - Absolute humidity x_w in g/kg_{Air}

Result:

Ny_ptxw_HuAir, Ny - Kinematic viscosity in m²/s

Range of Validity:

Temperature t : from -73.15°C to 1726.85°C
Mixture pressure p : from 6.112 mbar to 165.29 bar
Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

- Kinematic viscosity $\nu = \frac{\eta}{\rho} = \eta \cdot \nu$
- Model of ideal mixture of real fluid

Result for wrong input values:

Ny_ptxw_HuAir, Ny = -1

References:

Dry Air:

η from *Lemmon* et al. [15]
 ρ from *Lemmon* et al. [14]

Steam in humid air and liquid droplets in fog:

η for $0^\circ\text{C} \leq t \leq 800^\circ\text{C}$ from IAPWS-85 [7]
 for $t < 0^\circ\text{C}$ and $t > 800^\circ\text{C}$ from *Brandt* [12]
 ρ from IAPWS-IF97 [1], [2], [3], [4]
 for $t < 0.01^\circ\text{C}$ from IAPWS-06 [18], [19]

Partial Pressure of Steam $p_d = f(p, t, x_w)$

Function Name:

pd_ptxw_HuAir

Fortran Programs:

```
REAL*8 FUNCTION pd_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw
INTEGER*4 FUNCTION C_pd_ptxw_HuAir(pd,p,t,xw), REAL*8 pd,p,t,xw
```

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C
 x_w - Absolute humidity x_w in g/kg_{Air}

Result:

pd_ptxw_HuAir, pd - Partial pressure of steam in bar

Range of Validity:

Temperature t : from -143.15°C to 1726.85°C
Mixture pressure p : from 6.112 mbar to 165.29 bar
Absolute humidity x_w : from 0 g/kg_{Air} to $x_{ws}(p, t)$

Comments:

- Partial pressure of steam $p_d = \frac{x_w}{\frac{R_l}{R_w} + x_w} \cdot p$ for $x_w \leq x_{ws}(p, t)$
- For $x_w > x_{ws}(p, t)$ result $p_d = p_{ds}(p, t)$
- Saturation vapor pressure at saturation $p_{ds} = f \cdot p_s(t)$
with $p_{ds}(p, t)$ for $t \geq 0.01^\circ\text{C}$ - vapor pressure of water
 for $t < 0.01^\circ\text{C}$ - sublimation pressure of water
- Result for pure steam, liquid water and water ice: $p_d = 0$

Result for wrong input values:

pd_ptxw_HuAir, pd = -1

References:

$f(p, t)$ Herrmann et al. [25], [26]
 $p_s(t)$ if $t \geq 0.01^\circ\text{C}$ from IAPWS-IF97 [1], [2], [3], [4]
 if $t < 0.01^\circ\text{C}$ from IAPWS-08 [16], [17]

pds_pt_HuAir

Fortran Programs:

```
REAL*8 FUNCTION pds_pt_HuAir(p,t), REAL*8 p,t
INTEGER*4 FUNCTION C_pds_pt_HuAir(pds,p,t), REAL*8 pds,p,t
```

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C

Result:

pds_pt_HuAir, pds - Saturation vapor pressure of water in humid air in bar

Range of Validity:

Temperature t : from -143.15°C to $t_s(p, p_d)$
(boiling temperature of water in gas mixtures)

Mixture pressure p : from 6.112 mbar to 165.29 bar

Comments:

Saturation pressure at saturation $p_{ds} = f \cdot p_s(t)$

$p_{ds}(p, t)$ for $t \geq 0.01^\circ\text{C}$ - vapor pressure of water
 for $t < 0.01^\circ\text{C}$ - sublimation pressure of water

Result for wrong input values:

pds_pt_HuAir, pds = -1

References:

f(p,t)	Herrmann et al. [25], [26]
p _S (t)	if t ≥ 0.01 °C from IAPWS-IF97 [1], [2], [3], [4] if t < 0.01 °C from IAPWS-08 [16], [17]

Relative Humidity $\varphi = f(p, t, x_w)$
Function Name:

Phi_ptxw_HuAir

Fortran Programs:

REAL*8 FUNCTION Phi_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw

INTEGER*4 FUNCTION C_Phi_ptxw_HuAir(Phi,p,t,xw), REAL*8 Phi,p,t,xw

Input values:

p - Mixture pressure p in bar

t - Temperature t in °C

x_w - Absolute humidity x_w in g/kg_{Air}

Result:

Phi_ptxw_HuAir, Phi - Relative humidity in %

Range of Validity:

Temperature t : from -143.15°C to $t_{\text{critical}} = 373,946^\circ\text{C}$ (critical temperature of water)

Mixture pressure p : from 6.112 mbar to 165.29 bar

Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

$$\text{Relative humidity } \varphi = \frac{x_w}{\frac{R_l}{R_w} + x_w} \frac{p}{p_{ds}(p, t)} \cdot 100 \%$$

Saturation vapor pressure at saturation $p_{ds} = f \cdot p_s(t)$

with $p_{ds}(p, t)$ for $t \geq 0.01^\circ\text{C}$ - vapor pressure of water

for $t < 0.01^\circ\text{C}$ - sublimation pressure of water

Result for wrong input values:

Phi_ptxw_HuAir, Phi = - 1

References:

$f(p, t)$ Herrmann et al. [25], [26]

$p_s(t)$ if $t \geq 0.01^\circ\text{C}$ from IAPWS-IF97 [1], [2], [3], [4]

if $t < 0.01^\circ\text{C}$ from IAPWS-08 [16], [17]

Partial Pressure of Air $p_l = f(p, t, x_w)$
Function Name:

pl_ptxw_HuAir

Fortran Programs:

```
REAL*8 FUNCTION pl_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw
INTEGER*4 FUNCTION C_pl_ptxw_HuAir(pl,p,t,xw), REAL*8 pl,p,t,xw
```

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C
 x_w - Absolute humidity x_w in g/kg_{Air}

Result:

pl_ptxw_HuAir, pl - Partial pressure of air in bar

Range of Validity:

Temperature t : from -143.15°C to 1726.85°C
Mixture pressure p : from 6.112 mbar to 165.29 bar
Absolute humidity x_w : from 0 g/kg_{Air} to $x_{ws}(p, t)$

Comments:

$$\text{Partial pressure of air } p_l = p \left(1 - \frac{x_w}{\frac{R_l}{R_w} + x_w} \right)$$

when $x_w > x_{ws}(p, t)$ result $p_l = p - p_{ds}(p, t)$

Saturation vapor pressure at saturation $p_{ds} = f \cdot p_s(t)$

with $p_{ds}(p, t)$ for $t \geq 0.01^\circ\text{C}$ - vapor pressure of water in gas mixtures
 for $t < 0.01^\circ\text{C}$ - sublimation pressure of water in gas mixtures

Result for wrong input values:

pl_ptxw_HuAir, pl = -1

References:

$f(p, t)$ Herrmann et al. [25], [26]
 $p_s(t)$ if $t \geq 0.01^\circ\text{C}$ from IAPWS-IF97 [1], [2], [3], [4]
 if $t < 0.01^\circ\text{C}$ from IAPWS-08 [16], [17]

Prandtl-Number $Pr = f(p, t, x_w)$
Function Name:

Pr_ptxw_HuAir

Fortran Programs:

REAL*8 FUNCTION Pr_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw

INTEGER*4 FUNCTION C_Pr_ptxw_HuAir(Pr,p,t,xw), REAL*8 Pr,p,t,xw

Input values:

- p - Mixture pressure p in bar
- t - Temperature t in °C
- x_w - Absolute humidity x_w in g/kg_{Air}

Result:

Pr_ptxw_HuAir, Pr - *Prandtl*-number

Range of Validity:

- Temperature t : from -73.15°C to 1726.85°C
- Mixture pressure p : from 6.112 mbar to 165.29 bar
- Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

- Prandtl-number $Pr = \frac{\nu}{a} = \frac{\eta \cdot c_p}{\lambda}$
- Model of ideal mixture of real fluids

Result for wrong input values:

Pr_ptxw_HuAir , Pr = - 1

References:

Dry Air:

- λ from *Lemmon* et al. [15]
- η from *Lemmon* et al. [15]
- c_p from *Lemmon* et al. [14]

Steam in humid air and liquid droplets in fog:

- λ for $0^\circ\text{C} \leq t \leq 800^\circ\text{C}$ from IAPWS-85 [6]
for $t < 0^\circ\text{C}$ and $t > 800^\circ\text{C}$ from *Brandt* [12]
- η for $0^\circ\text{C} \leq t \leq 800^\circ\text{C}$ from IAPWS-85 [7]
for $t < 0^\circ\text{C}$ and $t > 800^\circ\text{C}$ from *Brandt* [12]
- c_p from IAPWS-IF97 [1], [2], [3], [4]

Dissociation:

from VDI Guideline 4670 [13]

Mole Fraction of Air $\psi_I = f(x_w)$
Function Name:

Psil_xw_HuAir

Fortran Programs:

```
REAL*8 FUNCTION Psil_xw_HuAir(xw), REAL*8 xw
INTEGER*4 FUNCTION C_Psil_xw_HuAir(Psil, xw), REAL*8 Psil, xw
```

Input values:

x_w - Absolute humidity x_w in g/kg_{Air}

Result:

Psil_xw_HuAir, Psil - Mole fraction of air in kmol / kmol

Range of Validity:

Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

Mole fraction of dry air $\psi_I = 1 - \frac{R_w \cdot x_w}{R(1 + x_w)}$

Result for wrong input values:

Psil_xw_HuAir, Psil = - 1

Mole Fraction of Water $\psi_w = f(x_w)$
Function Name:

Psiw_xw_HuAir

Fortran Programs:

REAL*8 FUNCTION Psiw_xw_HuAir(xw), REAL*8 xw

INTEGER*4 FUNCTION C_Psiw_xw_HuAir(Psiw,xw), REAL*8 Psiw, xw

Input values:

x_w - Absolute humidity x_w in g/kg_{Air}

Result:

Psiw_xw_HuAir, Psiw - Mole fraction of water in kmol / kmol

Range of Validity:

Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

$$\text{Mole fraction of water } \psi_w = \frac{R_w \cdot x_w}{R(1 + x_w)}$$

Result for wrong input values:

Psiw_xw_HuAir , Psiw = - 1

Density $\rho = f(p, t, x_w)$
Function Name:

Rho_ptxw_HuAir

Fortran Programs:

```
REAL*8 FUNCTION Rho_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw
INTEGER*4 FUNCTION C_Rho_ptxw_HuAir(Rho,p,t,xw), REAL*8 Rho,p,t,xw
```

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C
 x_w - Absolute humidity x_w in g/kg_{Air}

Result:

Rho_ptxw_HuAir, Rho - Density in kg/m³

Range of Validity:

Temperature t : from -143.15°C to 1726.85°C
Mixture pressure p : from 6.112 mbar to 165.29 bar
Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

- For unsaturated and saturated humid air ($x_w \leq x_{ws}$), calculation as ideal mixture of real gases (dry air and steam)
- For fog ($x_w > x_{ws}$), calculation as ideal mixture of saturated humid air and water, ice

Result for wrong input values:

Rho_ptxw_HuAir, Rho = -1

References:

Dry Air:
from Lemmon et al. [14]
Steam in humid air and liquid droplets in fog:
from IAPWS-IF97 [1], [2], [3], [4]
Ice crystals in fog:
from IAPWS-06 [18], [19]

Air-Specific Entropy $s_l = f(p, t, x_w)$
Function Name:

sl_ptxw_HuAir

Fortran Programs:

```
REAL*8 FUNCTION sl_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw
INTEGER*4 FUNCTION C_sl_ptxw_HuAir(sl,p,t,xw), REAL*8 sl,p,t,xw
```

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C
 x_w - Absolute humidity x_w in g/kg_{Air}

Result:

sl_ptxw_HuAir, sl - Air-specific entropy in kJ/(kg_{Air} K)

Range of Validity:

Temperature t : from -143.15°C to 1726.85°C
Mixture pressure p : from 6.112 mbar to 165.29 bar
Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

- For unsaturated and saturated humid air ($x_w \leq x_{ws}$), calculation as ideal mixture of real gases (dry air and steam)
- For fog ($x_w > x_{ws}$), calculation as ideal mixture of saturated humid air and water, ice
- For temperatures greater than 500°C, the dissociation is taken into consideration

Result for wrong input values:

sl_ptxw_HuAir, sl = - 1000

References:

Dry Air:
from *Lemmon et al.* [14]
Steam in humid air and liquid droplets in fog:
from IAPWS-IF97 [1], [2], [3], [4]
Ice crystals in fog:
from to IAPWS-06 [18], [19]
Dissociation:
from VDI Guideline 4670 [13]

Backward Function: $t = f(p, h_l, x_w)$
Function Name:

t_phlxw_HuAir

Fortran Programs:

REAL*8 FUNCTION t_phlxw_HuAir(p,hl,xw), REAL*8 p,hl,xw

INTEGER*4 FUNCTION C_t_phlxw_HuAir(t,p,hl,xw), REAL*8 t,p,hl,xw

Input values:

p - Mixture pressure p in bar

h_l - Air-specific enthalpy in kJ/kg_{Air}

x_w - Absolute humidity x_w in g/kg_{Air}

Result:

t_phlxw_HuAir, t - Temperature in °C

Range of Validity:

Temperature t : from -143.15°C to 1726.85°C

Mixture pressure p : from 6.112 mbar to 165.29 bar

Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

Iteration from t of $h_l(p, t, x_w)$

Calculation of $h_l(p, t, x_w)$:

- For unsaturated and saturated humid air ($x_w \leq x_{ws}$), calculation as ideal mixture of real gases (dry air and steam)
- For fog ($x_w > x_{ws}$), calculation as ideal mixture of saturated humid air and water, ice
- For temperatures greater than 500°C, the dissociation is taken into consideration

Result for wrong input values:

t_phlxw_HuAir , t = - 1000

References:

Dry Air:

from Lemmon et al. [14]

Steam in humid air and liquid droplets in fog:

from IAPWS-IF97 [1], [2], [3], [4]

Ice crystals in fog:

from to IAPWS-06 [18], [19]

Dissociation:

from VDI Guideline 4670 [13]

Backward Function: $t = f(p, s_l, x_w)$
Function Name:

t_pslxw_HuAir

Fortran Programs:

REAL*8 FUNCTION t_pslxw_HuAir(p,sl,xw), REAL*8 p,sl,xw

INTEGER*4 FUNCTION C_t_pslxw_HuAir(t,p,sl,xw), REAL*8 t,p,sl,xw

Input values:

- p - Mixture pressure p in bar
- s_l - Air-specific entropy in $\text{kJ}/(\text{kg}_{\text{Air}} \text{ K})$
- x_w - Absolute humidity x_w in $\text{g}/\text{kg}_{\text{Air}}$

Result:

t_pslxw_HuAir, t - Temperature in °C

Range of Validity:

- Temperature t : from -143.15°C to 1726.85°C
- Mixture pressure p : from 6.112 mbar to 165.29 bar
- Absolute humidity x_w : $\geq 0 \text{ g}/\text{kg}_{\text{Air}}$

Comments:

Iteration from t of $s_l(p, t, x_w)$

Calculation of $s_l(p, t, x_w)$:

- For unsaturated and saturated humid air ($x_w \leq x_{ws}$), calculation as ideal mixture of real gases (dry air and steam)
- For fog ($x_w > x_{ws}$), calculation as ideal mixture of saturated humid air and water, ice

From 500°C influence because of dissociation taken into consideration.

Result for wrong input values:

t_pslxw_HuAir, t = -1000

References:

Dry Air:

from Lemmon et al. [22]

Steam in humid air and liquid droplets in fog:

from IAPWS-IF97 [1], [2], [3], [4]

Ice crystals in fog:

from IAPWS-06 [18], [19]

Dissociation:

from VDI Guideline 4670 [13]

Wet Bulb Temperature $t_f = f(p, t, x_w)$
Function Name:

tf_ptxw_HuAir

Fortran Programs:

```
REAL*8 FUNCTION tf_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw
INTEGER*4 FUNCTION C_tf_ptxw_HuAir(tf,p,t,xw), REAL*8 tf,p,t,xw
```

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C
 x_w - Absolute humidity x_w in g/kg_{Air}

Result:

tf_ptxw_HuAir, tf - Wet bulb temperature in °C

Range of Validity:

Temperature t : from 0.01°C to 1726,85 °C
Mixture pressure p : from 6.112 mbar to 165.29 bar
Absolute humidity x_w : from 0 g/kg to $x_{ws}(p,t)$

Comments:

- Iteration from t_f of $h_l^{\text{unsaturated}}(p, t, x_w) = h_l^{\text{fog}}(p, t_f, x_w)$
- For temperatures greater than 500°C, the dissociation is taken into consideration

Result for wrong input values:

tf_ptxw_HuAir, tf = - 1000

References:

Dry Air:
from *Lemmon et al.* [22]
Steam in humid air and liquid droplets in fog:
from IAPWS-IF97 [1], [2], [3], [4]
Dissociation:
from VDI Guideline 4670 [13]

Dew Point Temperature $t_\tau = f(p, x_w)$
Function Name:

tTau_pxw_HuAir

Fortran Programs:

REAL*8 FUNCTION tTau_pxw_HuAir(p,xw), REAL*8 p,xw

INTEGER*4 FUNCTION C_tTau_pxw_HuAir(tTau,p,xw), REAL*8 tTau,p,xw

Input values:

p - Mixture pressure p in bar

x_w - Absolute humidity x_w in g/kg_{Air}

Result:

tdew_pxw_HuAir, tdew - Dew point temperature in °C

Range of Validity:

Mixture pressure p : from 6.112 mbar to 165.29 bar

Absolute humidity x_w : $\geq x_{ws}(p, -30^\circ\text{C})$

Comments:

Dew point temperature $t_\tau = t_s(p, p_d)$ for $t \geq 0.01^\circ\text{C}$
(boiling temperature of water in gas mixtures)

$t_\tau = t_{\text{sub}}(p, p_d)$ for $t < 0.01^\circ\text{C}$
(sublimation temperature from water in gas mixtures)

$$\text{with } p_d = \frac{x_w}{\frac{R_l}{R_w} + x_w} p$$

Result for wrong input values:

tdew_pxw_HuAir, tdew = - 1000

References:

$t_{ds}(p, p_d)$ for $t_\tau \geq 0.01^\circ\text{C}$ from IAPWS-IF97 [1], [2], [3], [4]

$t_{\text{sub}}(p, p_d)$ for $t_\tau < 0.01^\circ\text{C}$ from IAPWS-08 [16], [17]

$t_s(p)$ from IAPWS-IF97 [1], [2], [3], [4]

Air-Specific Internal Energy $u_l = f(p, t, x_w)$
Function Name:

ul_ptxw_HuAir

Fortran Programs:

REAL*8 FUNCTION ul_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw

INTEGER*4 FUNCTION C_ul_ptxw_HuAir(ul,p,t,xw), REAL*8 ul,p,t,xw

Input values:

p - Mixture pressure p in bar

t - Temperature t in °C

x_w - Absolute humidity x_w in g/kg_{Air}

Result:

ul_ptxw_HuAir, ul - Air-specific internal energy in kJ/kg_{Air}

Range of Validity:

Temperature t : from -143.15°C to 1726.85°C

Mixture pressure p : from 6.112 mbar to 165.29 bar

Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

Calculation: $u_l = h_l - p \cdot v_l$

- For unsaturated and saturated humid air ($x_w \leq x_{ws}$), calculation as ideal mixture of real gases (dry air and steam)
- For fog ($x_w > x_{ws}$), calculation as ideal mixture of saturated humid air and water, ice
- For temperatures greater than 500°C, the dissociation is taken into consideration

Result for wrong input values:

ul_ptxw_HuAir, ul = - 1000

References:

Dry Air:

h, v from *Lemmon* et al. [14]

Steam in humid air and liquid droplets in fog:

h, v from IAPWS-IF97 [1], [2], [3], [4]

Ice crystals in fog:

h, v according to IAPWS-06 [18], [19]

Dissociation:

from VDI Guideline 4670 [13]

Air-specific Volume $v_l = f(p, t, x_w)$
Function Name:

vl_ptxw_HuAir

Fortran Programs:

```
REAL*8 FUNCTION vl_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw
INTEGER*4 FUNCTION C_vl_ptxw_HuAir(vl, p, t ,xw), REAL*8 vl,p,t,xw
```

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C
 x_w - Absolute humidity x_w in g/kg_{Air}

Result:

vl_ptxw_HuAir, vl - Air-specific volume in m³/kg_{Air}

Range of Validity:

Temperature t : from -143.15°C to 1726.85°C
Mixture pressure p : from 6.112 mbar to 165.29 bar
Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

- For unsaturated and saturated humid air ($x_w \leq x_{ws}$), calculation as ideal mixture of real gases (dry air and steam)
- For fog ($x_w > x_{ws}$), calculation as ideal mixture of saturated humid air and water, ice

Result for wrong input values:

vl_ptxw_HuAir, vl = -1

References:

Dry Air:
from Lemmon et al. [14]
Steam in humid air and liquid droplets in fog:
from IAPWS-IF97 [1], [2], [3], [4]
Ice crystals in fog:
from IAPWS-06 [18], [19]

Mass Fraction of Air $\xi_l = f(x_w)$
Function Name:

Xil_xw_HuAir

Fortran Programs:

```
REAL*8 FUNCTION Xil_xw_HuAir(xw), REAL*8 xw
INTEGER*4 FUNCTION C_Xil_xw_HuAir(Xil,xw), REAL*8 Xil,xw
```

Input values:

x_w - Absolute humidity x_w in g/kg_{Air}

Result:

Xil_xw_HuAir, Xil - Mass fraction of air

Range of Validity:

Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

Mass fraction of dry air $\xi_l = 1 - \frac{x_w}{1 + x_w}$

Result for wrong input values:

Xil_xw_HuAir , Xil = - 1

Mass Fraction of Water $\xi_w = f(x_w)$
Function Name:

`Xiw_xw_HuAir`

Fortran Programs:

```
REAL*8 FUNCTION Xiw_xw_HuAir(xw), REAL*8 xw
INTEGER*4 FUNCTION C_Xiw_xw_HuAir(Xiw,xw), REAL*8 Xiw,xw
```

Input values:

x_w - Absolute humidity x_w in g/kg_{Air}

Result:

`Xiw_xw_HuAir, Xiw` - Mass fraction of water

Range of Validity:

Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

Mass fraction of water $\xi_w = \frac{x_w}{1 + x_w}$

Result for wrong input values:

`Xiw_xw_HuAir, Xiw = - 1`

Absolute Humidity from Relative Humidity $x_w = f(p, t, \varphi)$
Function Name:

xw_ptPhi_HuAir

Fortran Programs:

```
REAL*8 FUNCTION xw_ptPhi_HuAir(p,t,Phi), REAL*8 p,t,Phi
INTEGER*4 FUNCTION C_xw_ptPhi_HuAir(xw,p,t,Phi), REAL*8 xw,p,t,Phi
```

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C
Phi - Relative humidity in %

Result:

xw_ptPhi_HuAir, x_w - Absolute humidity from temperature and relative humidity
in g/kg_{Air}

Range of Validity:

Temperature t : from -143.15°C to $t_{\text{critical}} = 373,946^\circ\text{C}$ (critical temperature of water)
Mixture pressure p : from 6.112 mbar to 165.29 bar
Relative Humidity φ : from 0 % to 100 %

Comments:

Absolute humidity:
$$x_w = \frac{R_l}{R_w} \frac{\varphi \cdot p_{ds}(p, t)}{p - \varphi \cdot p_{ds}(p, t)}$$

Saturation vapor pressure at saturation $p_{ds} = f \cdot p_s(t)$

with $p_{ds}(p, t)$ for $t \geq 0.01^\circ\text{C}$ - Vapor pressure of water

 for $t < 0.01^\circ\text{C}$ - Sublimation pressure of water

Result for wrong input values:

xw_ptPhi_HuAir, $x_w = -1$

References:

$f(p, t)$ Herrmann et al. [25], [26]

$p_{ds}(p, t)$ if $t \geq 0.01^\circ\text{C}$ from IAPWS-IF97 [1], [2], [3], [4]
 if $t < 0.01^\circ\text{C}$ from IAPWS-08 [16], [17]

Absolute Humidity from Partial Pressure of Steam $x_w = f(p, t, p_d)$
Function Name:

xw_ptpd_HuAir

Fortran Programs:

REAL*8 FUNCTION xw_ptpd_HuAir(p,t,pd), REAL*8 p,t,pd

INTEGER*4 FUNCTION C_xw_ptpd_HuAir(xw,p,t,pd), REAL*8 xw,p,t,pd

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C
p_d - Partial pressure of steam in bar

Result:

xw_ptpd_HuAir, x_w - Absolute humidity from partial pressure in g/kg_{Air}

Range of Validity:

Temperature t : from -143.15°C to 1726.85°C
Mixture pressure p : from 6.112 mbar to 165.29 bar
Partial pressure of steam p_d : from 6.112 mbar to p_{ds}(p,t) for t ≤ 373,946°C,
to 165.29 bar for t > 373,946°C

Comments:

$$\text{Absolute humidity} \quad x_w = \frac{R_l}{R_w} \frac{p_{ds}(p, t)}{p - p_{ds}(p, t)}$$

Saturation vapor pressure at saturation $p_{ds} = f \cdot p_s(t)$

with $p_{ds}(p, t)$ for t ≥ 0.01°C - Vapor pressure of water

for t < 0.01°C - Sublimation pressure of water

Result for wrong input values:

xw_ptpd_HuAir, $x_w = -1$

References:

f(p, t) Herrmann et al. [25], [26]

p_{ds}(p, t) if t ≥ 0.01°C from IAPWS-IF97 [1], [2], [3], [4]
 if t < 0.01°C from IAPWS-08 [16], [17]

xw_ptTau_HuAir

Fortran Programs:

```
REAL*8 FUNCTION xw_ptTau_HuAir(p,tTau), REAL*8 p,tTau
INTEGER*4 FUNCTION C_xw_ptTau_HuAir(xw,p,tTau), REAL*8 xw, p,tTau
```

Input values:

p - Mixture pressure p in bar
t_T - Dew point temperature in °C

Result:

xw_ptTau_HuAir, x_w - Absolute humidity from temperature and dew point temperature in g/kg_{Air}

Range of Validity:

Dew point temperature t_{τ} : from -143.15°C to $t_{\text{ds}}(p, p_d)$
(boiling temperature of water in gas mixtures)

Mixture pressure p : from 6.112 mbar to 165.29 bar

Comments:

$$\text{Absolute humidity} \quad x_w = \frac{R_l}{R_w} \frac{p_{ds}(p, t)}{p - p_{ds}(p, t)}$$

Saturation vapor pressure at saturation $p_{ds} = f \cdot p_s(t)$

with $p_{ds}(p, t)$ for $t \geq 0.01^\circ\text{C}$ - Vapor pressure of water
for $t < 0.01^\circ\text{C}$ - Sublimation pressure of water

Result for wrong input values:

xw_ptTau_HuAir, xw = - 1

References:

$f(p, t)$	Herrmann et al. [25], [26]
$p_{ds}(p, t)$	if $t \geq 0.01^\circ\text{C}$ from IAPWS-IF97 [1], [2], [3], [4] if $t < 0.01^\circ\text{C}$ from IAPWS-08 [16], [17]

Absolute Humidity from Wet Bulb Temperature $x_w = f(p, t, t_f)$
Function Name:

xw_pttf_HuAir

Fortran Programs:

```
REAL*8 FUNCTION xw_pttf_HuAir(p,t,tf), REAL*8 p,t,tf
INTEGER*4 FUNCTION C_xw_pttf_HuAir(xw,p,t,tf), REAL*8 xw,p,t,tf
```

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C
t_f - Wet bulb temperature in °C

Result:

xw_pttf_HuAir, x_w - Absolute humidity from temperature and wet bulb temperature in g/kg_{Air}

Range of Validity:

Temperature t : from 0.01°C to 1726.85°C
Wet bulb temperature t_f : from 0.01°C to the given temperature t,
 to t_s(p,p_d) (boiling temp. of water in gas mixtures)
Mixture pressure p : from 6.112 mbar to 165.29 bar

Comments:

Iteration of x_w from $h_l^{\text{unsaturated}}(p, t, x_w) = h_l^{\text{fog}}(p, t_f, x_w)$
- For temperatures greater than 500°C, the dissociation is taken into consideration

Result for wrong input values:

xw_pttf_HuAir, $x_w = -1$

References:

Dry Air:
from *Lemmon et al.* [14]
Steam in humid air and liquid droplets in fog:
from IAPWS-IF97 [1], [2], [3], [4]
Dissociation:
from VDI Guideline 4670 [13]

Backward Function: $x_w = f(p, t, v_l)$
Function Name:

xw_ptvl_HuAir

Fortran Programs:

```
REAL*8 FUNCTION xw_ptvl_HuAir(p,t,vl), REAL*8 p,t,vl
INTEGER*4 FUNCTION C_xw_ptvl_HuAir(xw, p,t,vl), REAL*8 xw,p,t,vl
```

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C
 v_l - Air-specific volume in $\text{m}^3/\text{kg}_{\text{Air}}$

Result:

xw_ptvl_HuAir, x_w - Absolute humidity in $\text{g}/\text{kg}_{\text{Air}}$

Range of Validity:

Temperature t : from -143.15°C to 1726.85°C
Mixture pressure p : from 6.112 mbar to 165.29 bar

Comments:

Iteration of x_w from $v_l(p, t, x_w)$

Calculation from $v_l(p, t, x_w)$:

- For unsaturated and saturated humid air ($x_w \leq x_{ws}$), calculation as ideal mixture of real gases (dry air and steam)
- For fog ($x_w > x_{ws}$), calculation as ideal mixture of saturated humid air and water, ice

Result for wrong input values:

xw_ptvl_HuAir, $x_w = -1$

References:

Dry Air:
from Lemmon et al. [14]
Steam in humid air and liquid droplets in fog:
from IAPWS-IF97 [1], [2], [3], [4]
Ice crystals in fog:
according to IAPWS-06 [18], [19]
Dissociation:
from VDI Guideline 4670 [13]

Absolute Humidity of Saturated Humid Air $x_{ws} = f(p,t)$
Function Name:

xws_pt_HuAir

Fortran Programs:

```
REAL*8 FUNCTION xws_pt_HuAir(p,t), REAL*8 p,t
INTEGER*4 FUNCTION C_xws_pt_HuAir(xws,p,t), REAL*8 xws,p,t
```

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C

Result:

xws_pt_HuAir, x_{ws} - Absolute humidity of saturated air in g/kg_{Air}

Range of Validity:

Temperature t : from -143.15°C to $t_s(p,p_d)$ (boiling temp. from water in gas mixtures)
Mixture pressure p : from 6.112 mbar to 165.29 bar

Comments:

Absolute humidity $x_w = \frac{R_l}{R_w} \frac{p_{ds}(p,t)}{p - p_{ds}(p,t)}$

with $p_{ds}(p,t)$ for $t \geq 0.01^\circ\text{C}$ - Vapor pressure of water
 for $t < 0.01^\circ\text{C}$ - Sublimation pressure of water

Result for wrong input values:

xws_pt_HuAir, $x_{ws} = -1$

References:

$f(p,t)$ Herrmann et al. [25], [26]
 $p_{ds}(p,t)$ if $t \geq 0.01^\circ\text{C}$ from IAPWS-IF97 [1], [2], [3], [4]
 if $t < 0.01^\circ\text{C}$ from IAPWS-08 [16], [17]



4. Property Libraries for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

Water and Steam

Library LibIF97

- Industrial Formulation IAPWS-IF97 (Revision 2007)
- Supplementary Standards
 - IAPWS-IF97-S01
 - IAPWS-IF97-S03rev
 - IAPWS-IF97-S04
 - IAPWS-IF97-S05
- IAPWS Revised Advisory Note No. 3 on Thermodynamic Derivatives (2008)

Library LibSBTL_IF97 Library LibSBTL_95

Extremely fast property calculations using IAPWS Guideline 2015 Spline-based Table Look-up Method (SBTL) applied to the Industrial Formulation IAPWS-IF97 or to the Scientific Formulation IAPWS-95 for CFD and non-stationary heat cycle calculations

Humid Combustion Gas Mixtures

Library LibHuGas

Model: Ideal mixture of the real fluids:
CO₂ - Span, Wagner H₂O - IAPWS-95
O₂ - Schmidt, Wagner N₂ - Span et al.
Ar - Tegeler et al.
and of the ideal gases:
SO₂, CO, Ne
(Scientific Formulation of Bucker et al.)
Consideration of:
Dissociation from VDI 4670 and Poynting effect

Humid Air

Library LibHuAir

Model: Ideal mixture of the real fluids:
• Dry air from Lemmon et al.
• Steam, water and ice from IAPWS-IF97 and IAPWS-06
Consideration of:
• Condensation and freezing of steam
• Dissociation from VDI 4670
• Poynting effect from ASHRAE RP-1485

Carbon Dioxide Including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1996)

Seawater

Library LibSeaWa

IAPWS Industrial Formulation 2013

Ice

Library LibICE

Ice from IAPWS-06, Melting and sublimation pressures from IAPWS-08, Water from IAPWS-IF97, Steam from IAPWS-95 and -IF97

Ideal Gas Mixtures

Library LibIdGasMix

Model: Ideal mixture of the ideal gases:

Ar	NO	He	Propylene
Ne	H ₂ O	F ₂	Propane
N ₂	SO ₂	NH ₃	Iso-Butane
O ₂	H ₂	Methane	n-Butane
CO	H ₂ S	Ethane	Benzene
CO ₂	OH	Ethylene	Methanol
Air			

Consideration of:

- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

Humid Air

Library ASHRAE LibHuAirProp

Model: Virial equation from ASHRAE Report RP-1485 for real mixture of the real fluids:
- Dry air
- Steam

Consideration of:

- Enhancement of the partial saturation pressure of water vapor at elevated total pressures

www.ashrae.org/bookstore

Dry Air Including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth et al. (1993)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of Bucker and Wagner (2006)

n-Butane

Library LibButane_n

Formulation of Bucker and Wagner (2006)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

IAPWS Guideline 2001 of Tillner-Roth and Friend (1998)

Helmholtz energy equation for the mixing term (also useable for calculating the Kalina Cycle)

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

C ₂ H ₆ O ₂	Ethylene glycol
C ₃ H ₈ O ₂	Propylene glycol
C ₂ H ₅ OH	Ethyl alcohol
CH ₃ OH	Methyl alcohol
C ₃ H ₈ O ₃	Glycerol
K ₂ CO ₃	Potassium carbonate
CaCl ₂	Calcium chloride
MgCl ₂	Magnesium chloride
NaCl	Sodium chloride
C ₂ H ₃ KO ₂	Potassium acetate

Formulation of the International Institute of Refrigeration (1997)

Ethanol**Library LibC2H5OH**

Formulation of Schroeder
(2012)

Methanol**Library LibCH3OH**

Formulation of
de Reuck and Craven (1993)

Propane**Library LibPropane**

Formulation of
Lemmon et al. (2009)

Siloxanes as ORC Working Fluids

Octamethylcyclotetrasiloxane $C_8H_{24}O_4Si_4$ **Library LibD4**

Decamethylcyclopentasiloxane $C_{10}H_{30}O_5Si_5$ **Library LibD5**

Tetradecamethylhexasiloxane $C_{14}H_{42}O_6Si_6$ **Library LibMD4M**

Hexamethyldisiloxane $C_6H_{18}OSi_2$ **Library LibMM**

Formulation of Colonna et al. (2006)

Dodecamethylcyclohexasiloxane $C_{12}H_{36}O_6Si_6$ **Library LibD6**

Decamethyltetrasiloxane $C_{10}H_{30}O_3Si_4$ **Library LibMD2M**

Dodecamethylpentasiloxane $C_{12}H_{36}O_4Si_5$ **Library LibMD3M**

Octamethyltrisiloxane $C_8H_{24}O_2Si_3$ **Library LibMDM**

Formulation of Colonna et al. (2008)

Nitrogen**Library LibN2**

Formulation of
Span et al. (2000)

Hydrogen**Library LibH2**

Formulation of
Leachman et al. (2009)

Helium**Library LibHe**

Formulation of Arp et al. (1998)

Hydrocarbons

Decane $C_{10}H_{22}$ **Library LibC10H22**

Isopentane C_5H_{12} **Library LibC5H12_ISO**

Neopentane C_5H_{12} **Library LibC5H12_NEO**

Isohexane C_6H_{14} **Library LibC6H14**

Toluene C_7H_8 **Library LibC7H8**

Formulation of Lemmon and Span (2006)

Further Fluids

Carbon monoxide **CO** **Library LibCO**

Carbonyl sulfide **COS** **Library LibCOS**

Hydrogen sulfide **H₂S** **Library LibH2S**

Dinitrogen monoxide **N₂O** **Library LibN2O**

Sulfur dioxide **SO₂** **Library LibSO2**

Acetone **C₃H₆O** **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

For more information please contact:

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Fax.: +49-3583-61-1846

The following thermodynamic and transport properties can be calculated^a:**Thermodynamic Properties**

- Vapor pressure p_s
- Saturation temperature T_s
- Density ρ
- Specific volume v
- Enthalpy h
- Internal energy u
- Entropy s
- Exergy e
- Isobaric heat capacity c_p
- Isochoric heat capacity c_v
- Isentropic exponent κ
- Speed of sound w
- Surface tension σ

Transport Properties

- Dynamic viscosity η
- Kinematic viscosity ν
- Thermal conductivity λ
- Prandtl number Pr

Backward Functions

- $T, v, s(p, h)$
- $T, v, h(p, s)$
- $p, T, v(h, s)$
- $p, T(v, h)$
- $p, T(v, u)$

Thermodynamic Derivatives

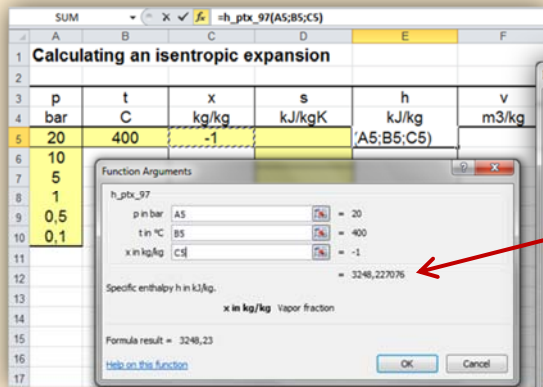
- Partial derivatives can be calculated.

^a Not all of these property functions are available in all property libraries.

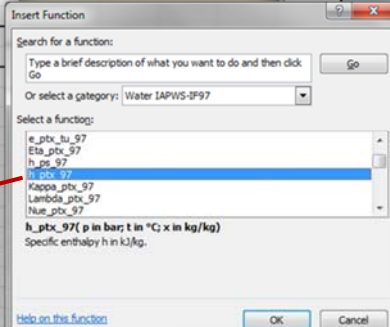


Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

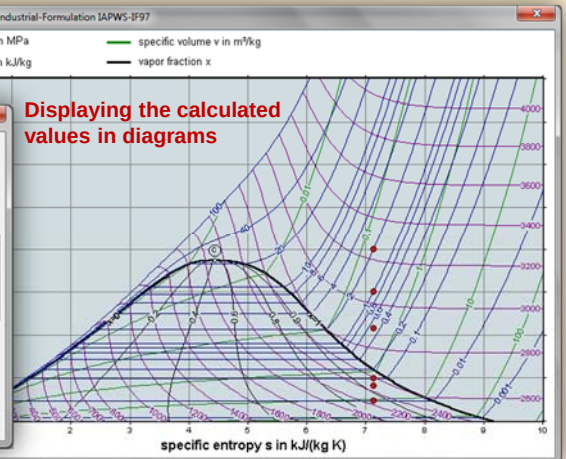
Add-In FluidEXL^{Graphics} for Excel[®]



Choosing a property library and a function



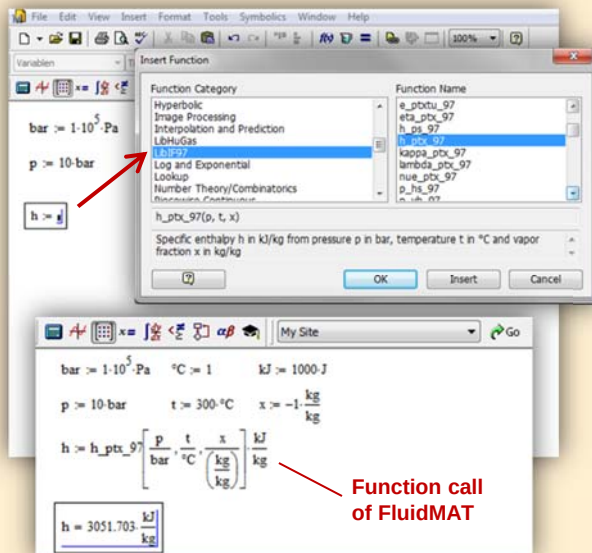
Displaying the calculated values in diagrams



Menu for the input of given property values

Add-In FluidMAT for Mathcad[®]

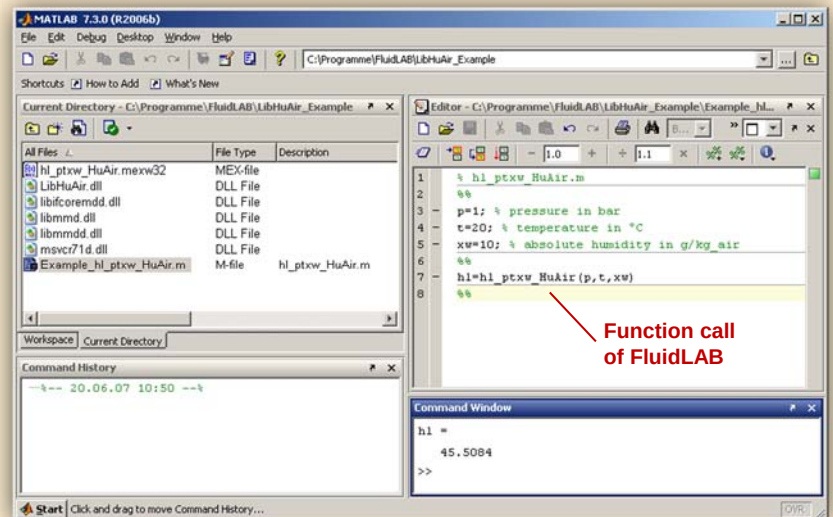
The property libraries can be used in Mathcad[®].



Function call of FluidMAT

Add-In FluidLAB for MATLAB[®]

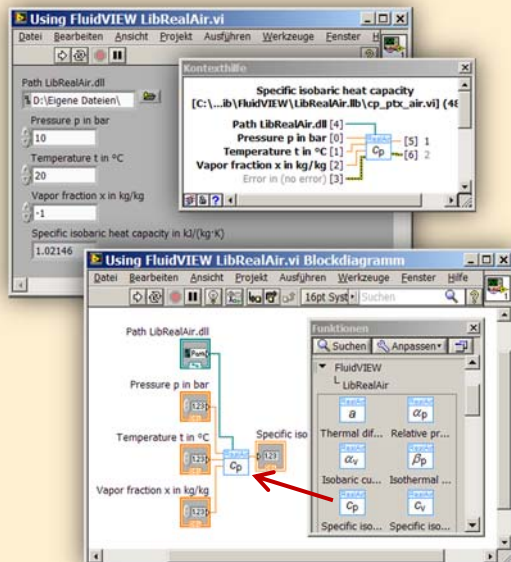
Using the Add-In FluidLAB the property functions can be called in MATLAB[®].



Function call of FluidLAB

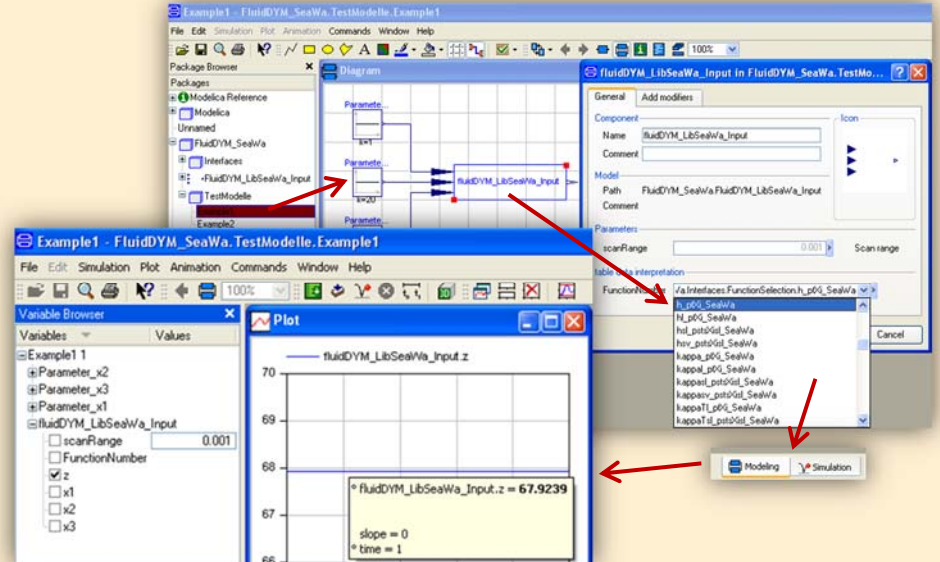
Add-On FluidVIEW for LabVIEW[®]

The property functions can be calculated in LabVIEW[®].

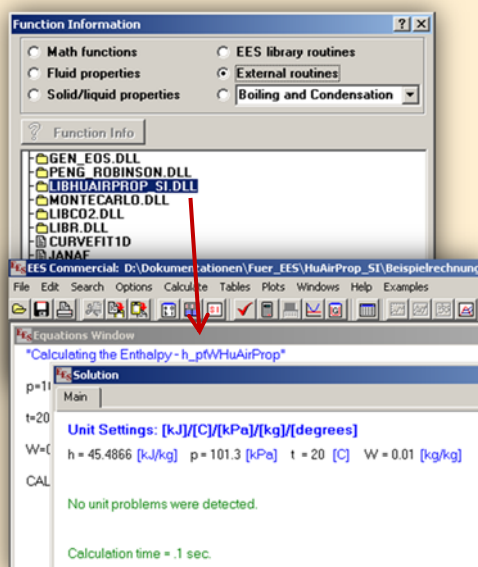


Add-In FluidDYM for DYMOLA[®] (Modelica) and SimulationX[®]

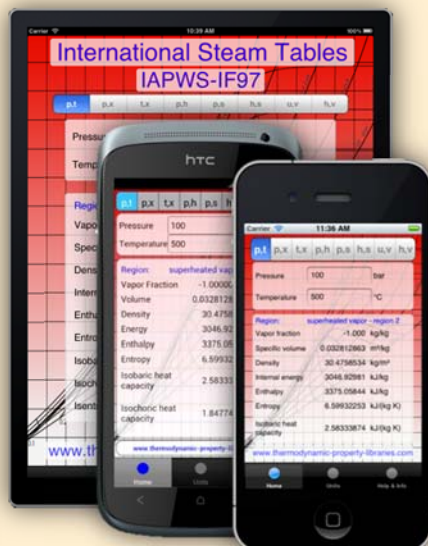
The property functions can be called in DYMOLA[®] and SimulationX[®].



Add-In FluidEES for Engineering Equation Solver®



App International Steam Tables for iPhone, iPad, iPod touch, Android smart phones and tablets



Online Property Calculator at www.thermodynamics-zittau.de

Zittau's Fluid Property Calculator

Fluid:

Function:

Unit System:

Enter given values: [Range of validity](#)

Pressure p: bar

Temperature t: °C

Vapor fraction x: kg/kg

Calculate / Recalculate

Result:

Specific enthalpy h = 3097.38 kJ/kg

For further information on property libraries available for EXCEL®, MATLAB®, Mathcad®, Engineering Equation Solver®, DYMOLA® (Modelica), SimulationX®, and LabView® click [here](#)

An App for calculating steam properties on iPhone, iPad, and iPod touch can be found [here](#)

PDF with the [description](#)

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The following thermodynamic and transport properties^a can be calculated in Excel®, MATLAB®, Mathcad®, Engineering Equation Solver® EES, DYMOLA® (Modelica), SimulationX®, and LabVIEW®:

Thermodynamic Properties

- Vapor pressure p_s
- Saturation temperature T_s
- Density ρ
- Specific volume v
- Enthalpy h
- Internal energy u
- Entropy s
- Exergy e
- Isobaric heat capacity c_p
- Isochoric heat capacity c_v
- Isentropic exponent κ
- Speed of sound w
- Surface tension σ

Transport Properties

- Dynamic viscosity η
- Kinematic viscosity ν
- Thermal conductivity λ
- Prandtl number Pr

Backward Functions

- $T, v, s(p, h)$
- $T, v, h(p, s)$
- $p, T, v(h, s)$
- $p, T(v, h)$
- $p, T(v, u)$

Thermodynamic Derivatives

- Partial derivatives can be calculated.

^a Not all of these property functions are available in all property libraries.

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6. Satisfied Customers

Date: 04/2014

The following companies and institutions use the property libraries

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- FluidEES for Engineering Equation Solver[®] EES
- FluidDYM for Dymola[®] (Modelica) and SimulationX[®]
- FluidVIEW for LabVIEW[®]:

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HEW-Kraftwerk, Tiefstack	06/2004
h s energieanlagen, Freising	07/2004
FCIT, Stuttgart	08/2004
Physikalisch Technische Bundesanstalt (PTB), Braunschweig	08/2004
Mainova Frankfurt	08/2004
Rietschle Energieplaner, Winterthur, Switzerland	08/2004
MAN Turbo Machines, Oberhausen	09/2004
TUEV Sued, Dresden	10/2004
STEAG Kraftwerk, Herne	10/2004, 12/2004
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Rietschle Energieplaner, Winterthur, Switzerland	02/2003
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LG, Annaberg-Buchholz	10/2003
FZR Forschungszentrum, Rossendorf/Dresden	10/2003
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VEO Vulkan Energiewirtschaft Oderbruecke, Eisenhuettenstadt	11/2003
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SaarEnergie, Saarbruecken	11/2003
Fraunhofer-Gesellschaft, Munich	12/2003
Erfurt University of Applied Sciences, Department of Supply Engineering	12/2003
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SCA Hygiene Products, Munich	10/1998
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