



ThermoFluidProperties

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

**FluidEXL *Graphics*  
with LibHuAir  
for Excel<sup>®</sup>**

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**Software for the Calculation of the Properties  
of Ideal Mixtures of Real Fluids  
Including DLL and Add-In for Excel®  
FluidEXL *Graphics*  
LibHuAir**

## **Contents**

0. Package Contents
  - 0.1 Zip-files for 32-bit Office®
  - 0.2 Zip-files for 64-bit Office®
1. Property Functions
2. Application of FluidEXL in Excel®
  - 2.1 Installing FluidEXL
  - 2.2 Registering FluidEXL as Add-In in Excel®
  - 2.3 Licensing the LibHuAir Property Library
  - 2.4 Example calculation
  - 2.5 Representation of Calculated Properties on Thermodynamic Diagrams
  - 2.6 The FluidEXL Help System
  - 2.7 Removing FluidEXL
3. Program Documentation
4. Property Libraries for Calculating Heat Cycles, Boilers, Turbines, and Refrigerators
5. References
6. Satisfied Customers

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## 0 Package Contents

### 0.1 Zip files for 64-bit Office®

The following zip file has been delivered for your computer running a 64-bit Office® version:

CD\_FluidEXL\_Graphics\_Eng\_LibHuAir\_x64.zip

including the following folders and files:

\FLUFT\

\Formulation97\

FluidEXL\_Graphics\_LibHuAir\_Docu\_Eng.pdf.pdf

FluidEXL\_Graphics\_Eng.xla

LC.dll

LibHuAir.dll

LibHuAir.chm.

### 0.2 Zip files for 32-bit Office®

The following zip file has been delivered for your computer running a 32-bit Office® version:

CD\_FluidEXL\_Graphics\_Eng\_LibHuAir.zip

including the following folders and files:

\FLUFT\

\Formulation97\

FluidEXL\_Graphics\_LibHuAir\_Docu\_Eng.pdf.pdf

FluidEXL\_Graphics\_Eng.xla

LC.dll

LibHuAir.dll

LibHuAir.chm.

# 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)	Thermal diffusivity	m <sup>2</sup> /s	[1-4], [6], [8], [10], [11]	3/1
$c_p = f(p, t, x_w)$	cp_ptxw_HuAir	= CP_PTXW_HUAIR(p,t,xw)	Specific isobaric heat capacity, related to mass of humid air	kJ/(kg K)	[1-4], [9], [10]	3/2
$c_v = f(p, t, x_w)$	cv_ptxw_HuAir	= CV_PTXW_HUAIR(p,t,xw)	Specific isochoric heat capacity, related to mass of humid air	kJ/(kg K)	[1-4], [9], [10]	3/3
$\eta = f(p, t, x_w)$	Eta_ptxw_HuAir	= ETA_PTXW_HUAIR(p,t,xw)	Dynamic viscosity	Pa s	[6], [8], [11]	3/4
$h_l = f(p, t, x_w)$	hl_ptxw_HuAir	= HL_PTXW_HUAIR(p,t,xw)	Air-specific enthalpy	kJ/kg <sub>Air</sub>	[1-4], [9], [10], [14], [15]	3/5
$\kappa = f(p, t, x_w)$	Kappa_ptxw_HuAir	= KAPPA_PTXW_HUAIR(p,t,xw)	Isentropic exponent	-	[1-4], [9], [10]	3/6
$\lambda = f(p, t, x_w)$	Lambda_ptxw_HuAir	= LAMBDA_PTXW_HUAIR(p,t,xw)	Thermal conductivity	W/(m K)	[5], [8], [11]	3/7
$\nu = f(p, t, x_w)$	Ny_ptxw_HuAir	= NY_PTXW_HUAIR(p,t,xw)	Kinematic viscosity	m <sup>2</sup> /s	[1-4], [6], [8], [10], [11]	3/8
$p_d = f(p, t, x_w)$	pd_ptxw_HuAir	= PD_PTXW_HUAIR(p,t,xw)	Partial pressure of steam	bar	[1-4], [12], [13], [16], [17]	3/9
$p_{ds} = f(p, t)$	pds_pt_HuAir	= PDS_PT_HUAIR(p,t)	Saturation pressure of water	bar	[1-4], [12], [13], [16], [17]	3/10
$\varphi = f(p, t, x_w)$	Phi_ptxw_HuAir	= PHI_PTXW_HUAIR(p,t,xw)	Relative humidity	%	[1-4], [12], [13], [16], [17]	3/11
$p_l = f(p, t, x_w)$	pl_ptxw_HuAir	= PL_PTXW_HUAIR(p,t,xw)	Partial pressure of air	bar	[1-4], [12], [13], [16], [17]	3/12
$Pr = f(p, t, x_w)$	Pr_ptxw_HuAir	= PR_PTXW_HUAIR(p,t,xw)	PRANDTL-number	-	[1-4], [5], [6], [8-11]	3/13
$\psi_l = f(x_w)$	Psil_xw_HuAir	= PSIL_XW_HUAIR(xw)	Mole fraction of air	kmol <sub>Air</sub> /kmol	-	3/14

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)	Mole fraction of water	kmol <sub>Water</sub> /kmol	-	3/15
$\rho = f(p, t, x_w)$	Rho_ptxw_HuAir	= RHO_PTXW_HUAIR(p,t,xw)	Density, related to mass of humid air	kg/m <sup>3</sup>	[1-4], [10], [14], [15]	3/16
$s_l = f(p, t, x_w)$	sl_ptxw_HuAir	= SL_PTXW_HUAIR(p,t,xw)	Air-specific entropy	kJ/(kg <sub>Air</sub> K)	[1-4], [9], [10], [14], [15]	3/17
$t = f(p, h_l, x_w)$	t_phlxw_HuAir	= T_PHLXW_HUAIR(p,h_l,xw)	Backward function: temperature from air-specific enthalpy and humidity ratio (absolute humidity)	°C	[1-4], [9], [10], [14], [15]	3/18
$t = f(p, s_l, x_w)$	t_pslxw_HuAir	= T_PSLXW_HUAIR(p,h_l,xw)	Backward function: temperature from air-specific entropy and humidity ratio (absolute humidity)	°C	[1-4], [9], [10], [14], [15]	3/19
$t = f(p, t_f, x_w)$	t_ptfxw_HuAir	= T_PTFXW_HUAIR(p,t_f,xw)	Temperature	°C	[1-4], [9], [10]	3/20
$t_f = f(p, t, x_w)$	tf_ptxw_HuAir	= TF_PTXW_HUAIR(p,t,xw)	Wet bulb temperature	°C	[1-4], [9], [10]	3/21
$t_r = f(p, x_w)$	tTau_pxw_HuAir	= TTAU_PXW_HUAIR(p,xw)	Dew point temperature	°C	[1-4], [12], [13]	3/22
$u_l = f(p, t, x_w)$	ul_ptxw_HuAir	= UL_PTXW_HUAIR(p,t,xw)	Air-specific internal energy	kJ/kg <sub>Air</sub>	[1-4], [9], [10], [14], [15]	3/23
$v_l = f(p, t, x_w)$	vl_ptxw_HuAir	= VL_PTXW_HUAIR(p,t,xw)	Air-specific volume	m <sup>3</sup> /kg <sub>Air</sub>	[1-4], [10], [14], [15]	3/24
$\xi_l = f(x_w)$	Xil_xw_HuAir	= XIL_XW_HUAIR(xw)	Mass fraction of air	kg <sub>Air</sub> /kg	-	3/25
$\xi_w = f(x_w)$	Xiw_xw_HuAir	= XIW_XW_HUAIR(xw)	Mass fraction of water	kg <sub>Water</sub> /kg	-	3/26
$x_w = f(p, t, p_d)$	xw_ptpd_HuAir	= XW_PTPD_HUAIR(p,t,p_d)	Humidity ratio (Absolute humidity) from partial pressure of steam	g <sub>Water</sub> /kg <sub>Air</sub>	[1-4], [12], [13], [16], [17]	3/27
$x_w = f(p, t, \varphi)$	xw_ptPhi_HuAir	= XW_PTPHI_HUAIR(p,t,Phi)	Humidity ratio (Absolute humidity) from temperature and relative humidity	g <sub>Water</sub> /kg <sub>Air</sub>	[1-4], [12], [13], [16], [17]	3/28

Functional Dependence	Function Name	Cal as Fortran Program	Property or Function	Unit of the Result	Source or Algorithm	Site Info
$x_w = f(p, t, t_r)$	xw_ptTau_HuAir	= XW_PTTAU_HUAIR(p,tTau)	Humidity ratio (Absolute humidity) from dew point temperature	$g_{\text{Water}}/kg_{\text{Air}}$	[1-4], [12], [13], [16], [17]	3/29
$x_w = f(p, t, t_f)$	xw_pttf_HuAir	= XW_PTTF_HUAIR(p,t,tf)	Humidity ratio (Absolute humidity) from temperature and wet bulb temperature	$g_{\text{Water}}/kg_{\text{Air}}$	[1-4], [9], [10]	3/30
$x_w = f(p, t, v_l)$	xw_ptvl_HuAir	= XW_PTVL_HUAIR(p,t,vl)	Backward function: Humidity ratio (Absolute humidity) from temperature and air-specific volume	$g_{\text{Water}}/kg_{\text{Air}}$	[1-4], [12], [13], [16], [17]	3/31
$x_{ws} = f(p, t)$	xws_pt_HuAir	= XWS_PT_HUAIR(p,t)	Humidity ratio (Absolute humidity) of saturated humid air	$g_{\text{Water}}/kg_{\text{Air}}$	[1-4], [12], [13], [16], [17]	3/32
$z = f(p, t, x_w)$	z_ptxw_HuAir	= Z_PTXW_HUAIR(p,t,xw)	Compression factor	-	[1-4], [9], [10]	3/33

### 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. [10], [11]) :

Component		Mole Fraction
Nitrogen	N <sub>2</sub>	0.7812
Oxygen	O <sub>2</sub>	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 <sub>Air</sub>	0.000611783 kJ/kg <sub>Water</sub>
Internal energy	-78.37885533 kJ/kg <sub>Air</sub>	0 kJ/kg <sub>Water</sub>
Entropy	0.161802887 kJ/(kg <sub>Air</sub> K)	0 kJ/(kg <sub>Water</sub> 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
- $\varphi$  - 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.* [10]
- $\lambda, \eta$  from *Lemmon et al.* [11]

- Steam:

- $v, h, u, s, c_p$  of steam from IAPWS-IF97 [1], [2], [3], [4]
- $\lambda, \eta$  for  $0 \text{ °C} \leq t \leq 800 \text{ °C}$  from IAPWS-85 [5], [6]
- for  $t < 0 \text{ °C}$  and  $t > 800 \text{ °C}$  from *Brandt* [9]

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]
- $\lambda, \eta$  of liquid droplets from IAPWS-85 [6],

- 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 [14], [15]
- $\lambda, c_p$  of ice crystals as constant value
- $\eta, \kappa, w$  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  $p_{ds}(p, t) = f(p, t) \cdot p_s(t)$

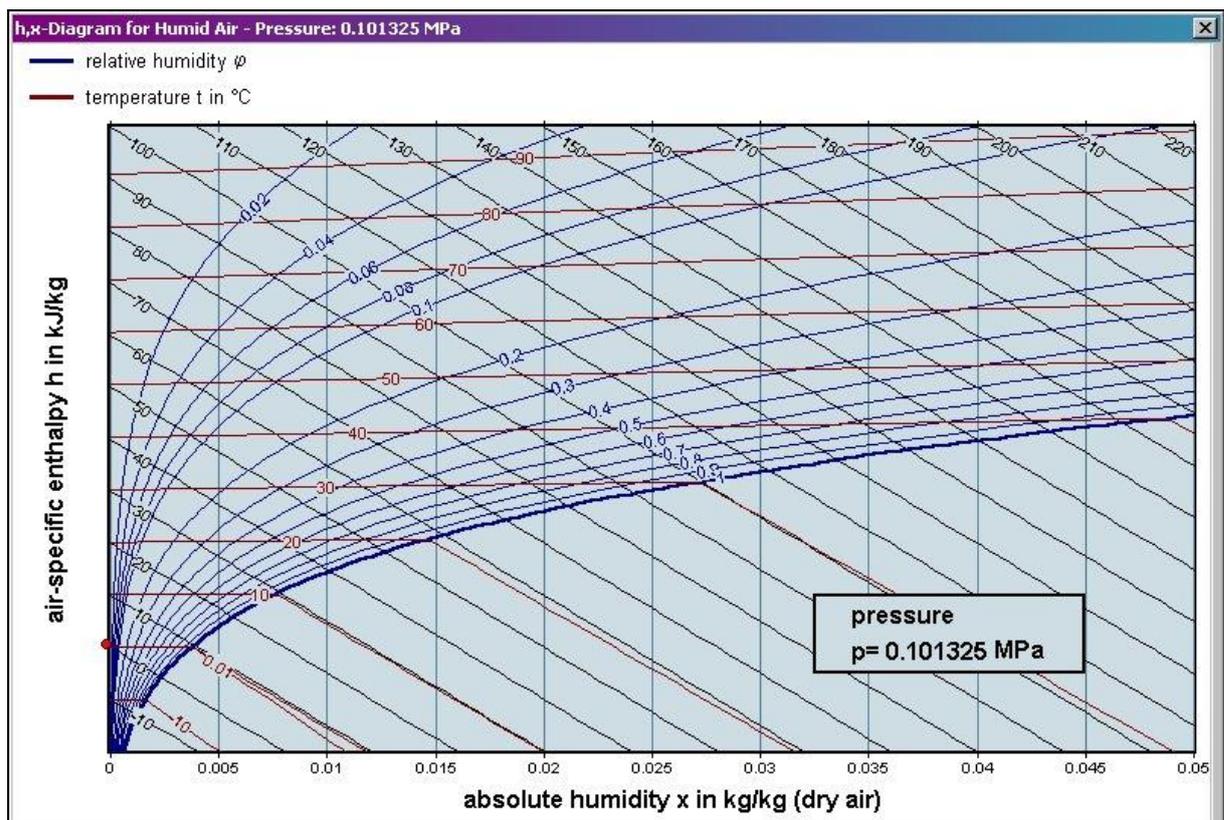
- $f(p, T)$  from *Herrmann et al.* [16], [17],
- $p_s(t)$  for  $t \geq 273.15 \text{ K}$  from IAPWS-IF97 [1], [2], [3], [4],
- $p_s(t)$  for  $t < 273.15 \text{ K}$  from IAPWS-08 [12], [13].

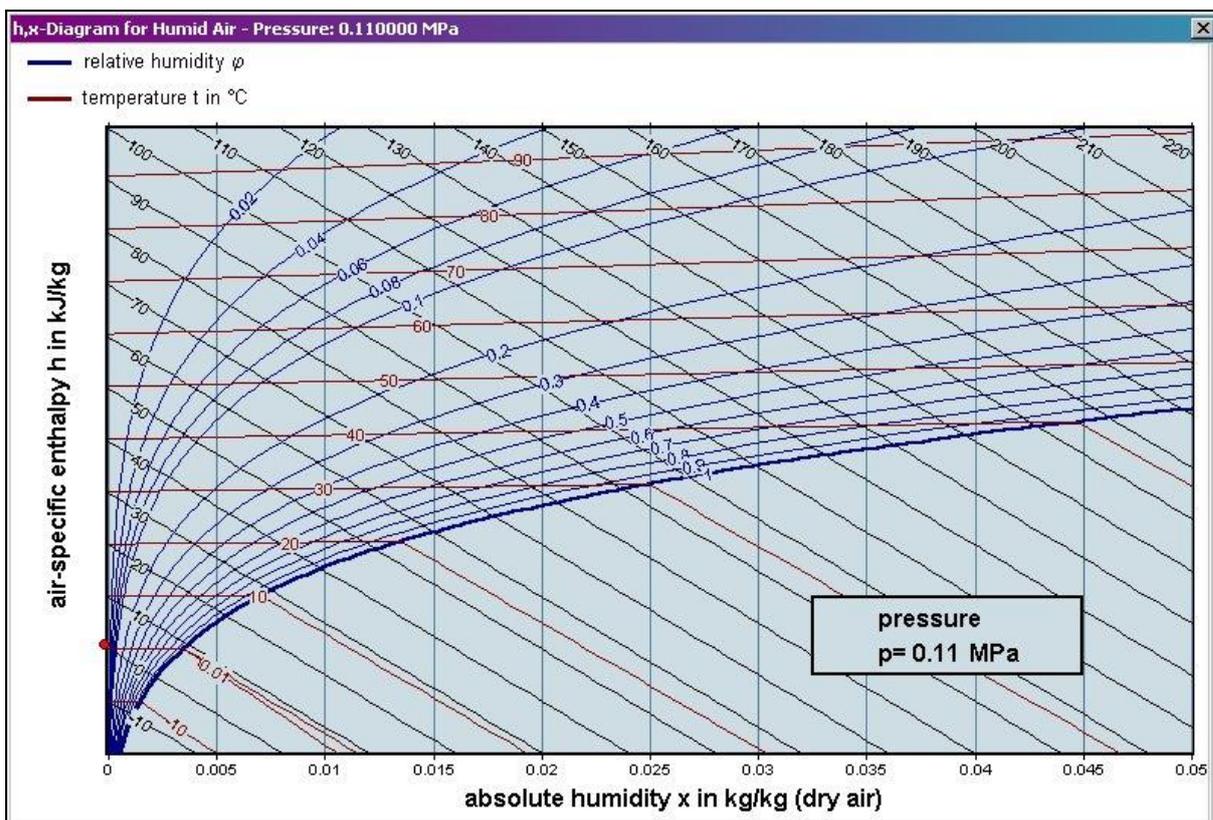
## 1.2 Thermodynamic Diagrams

FluidEXL *Graphics* enables representation of the calculated property values in the following thermodynamic diagrams:

- $h,x$  Diagram  $p = 0.101325$  MPa
- $h,x$  Diagram  $p = 0.11$  MPa

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





## 2. Application of FluidEXL *Graphics* in Excel®

The FluidEXL *Graphics* Add-In has been developed to calculate thermodynamic properties in Excel® more conveniently. Within Excel®, it enables the direct call of functions relating to Water and Steam from the LibHuAir property program library.

### 2.1 Installing FluidEXL *Graphics*

Complete the following steps for initial installation of FluidEXL *Graphics*.

Before you begin, it is best to uninstall any older version of FluidEXL *Graphics*.

The installation routine for 32-bit and 64-bit versions of Excel is similar. The following instructions are valid for both versions.

After you have downloaded and extracted the zip-file:

CD\_FluidEXL\_Graphics\_LibHuAir\_x64\_Eng.zip (for 64 bit version)

or

CD\_FluidEXL\_Graphics\_LibHuAir\_Eng.zip" (for 32 bit version).

you will see the folder

\CD\_FluidEXL\_Graphics\_LibHuAir\_x64\_Eng\ (for 64 bit version)

or

\CD\_FluidEXL\_Graphics\_LibHuAir\_Eng\ (for 32 bit version)

in your Windows Explorer, Total Commander etc.

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

Within this folder you will see the following folders and files:

\FLUFT\  
 \Formulation97\  
 FluidEXL\_Graphics\_Eng.xla  
 FluidEXL\_Graphics\_LibHuAir\_Docu\_Eng  
 LC.dll  
 LibHuAir.dll  
 LibHuAir.chm  
 Reg\_.reg

Now, please copy the following folders and files

\FLUFT\  
 \Formulation97\  
 FluidEXL\_Graphics\_Eng.xla  
 LibHuAir.dll  
 LibHuAir.chm  
 LC.dll

into the folder

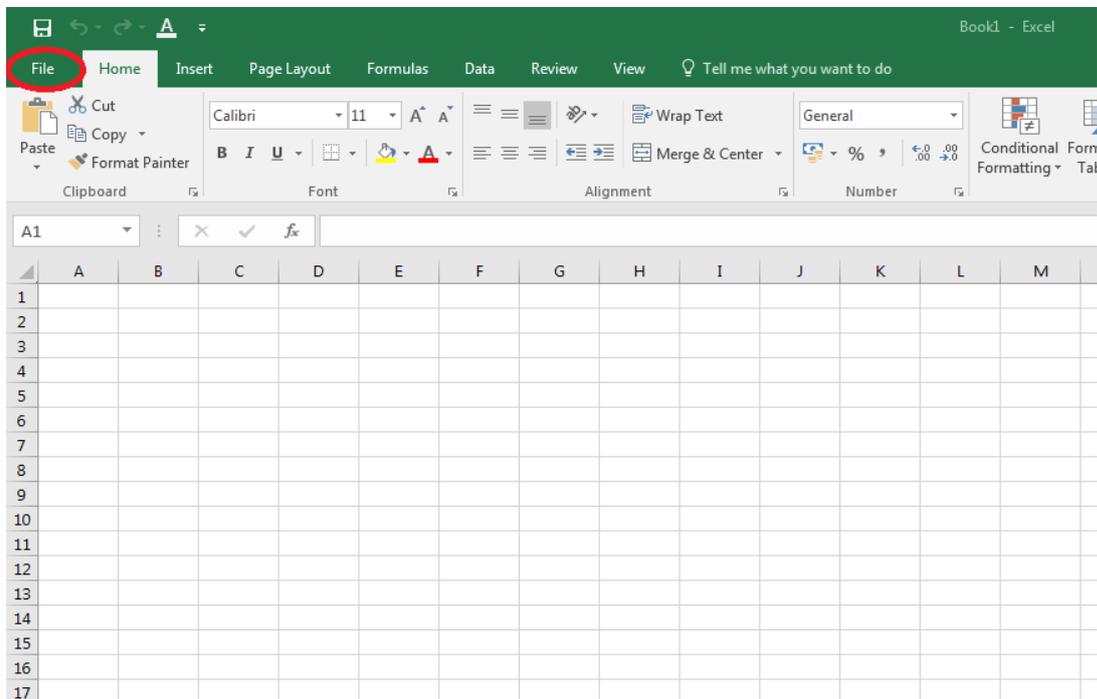
C:\Users\[your name]\AppData\Roaming\Microsoft\AddIns\  
 where [your name] is your name in the Windows system.

If this folder is not found, follow the next section anyway.

## 2.2 Registering FluidEXL *Graphics* as Add-In in Excel®

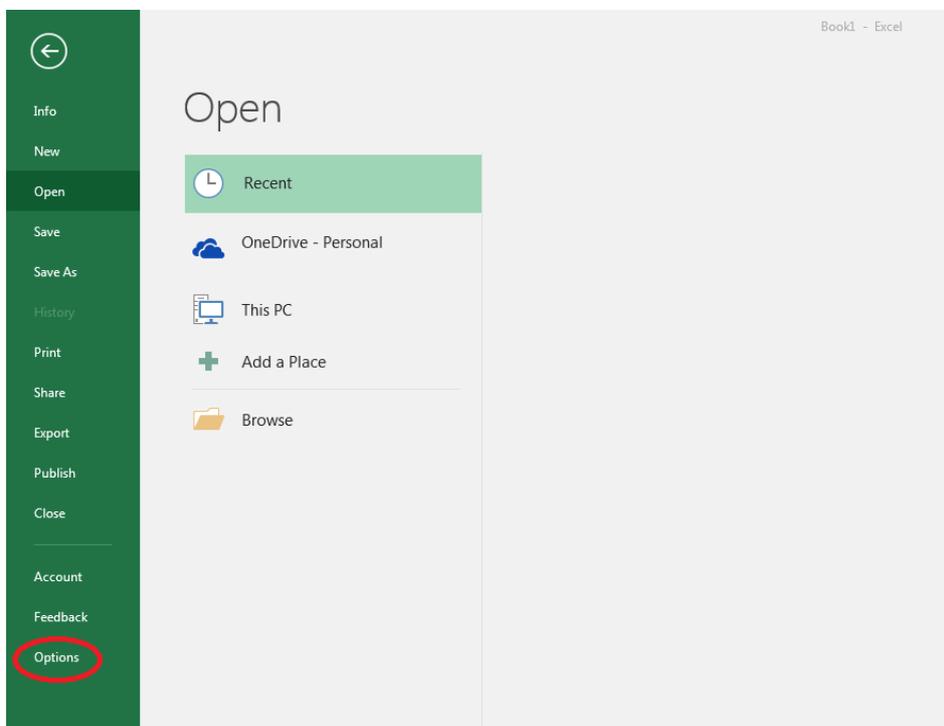
After installation in Windows®, FluidEXL *Graphics* must be registered in Excel® as an Add-In. To do this, start Excel® and carry out the following steps:

- Click the "File" button in the upper left hand corner of Excel® (see Fig. 2.1)



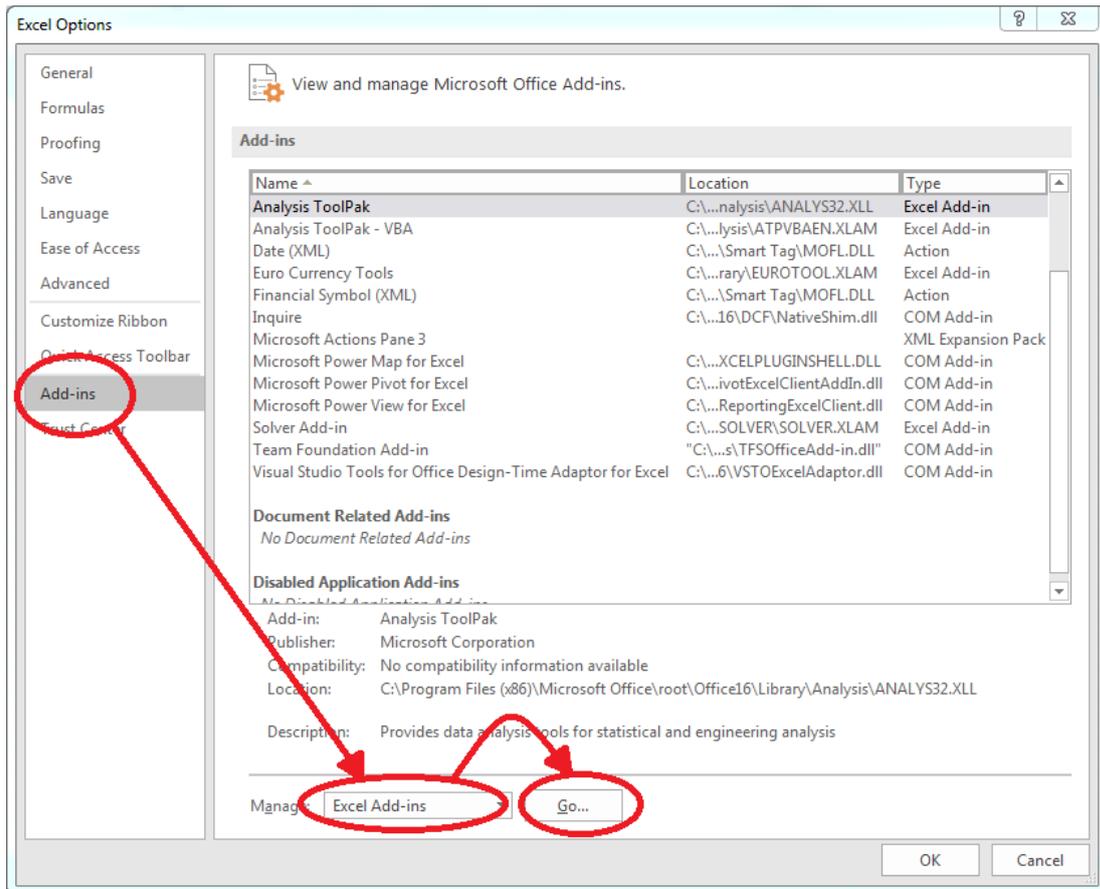
**Figure 2.1:** Registering FluidEXL *Graphics* as Add-In in Excel® 2016

- Click on the "Options" button in the menu which appears (see Fig. 2.2)



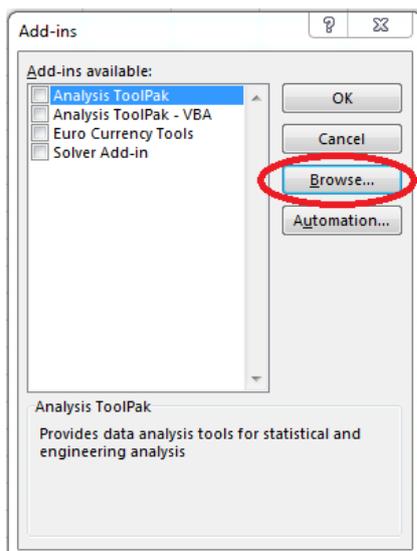
**Figure 2.2:** Registering FluidEXL *Graphics* as Add-In in Excel® 2016

- Click on "Add-Ins" in the next menu (Fig. 2.3)



**Figure 2.3:** Dialog window "Excel Options"

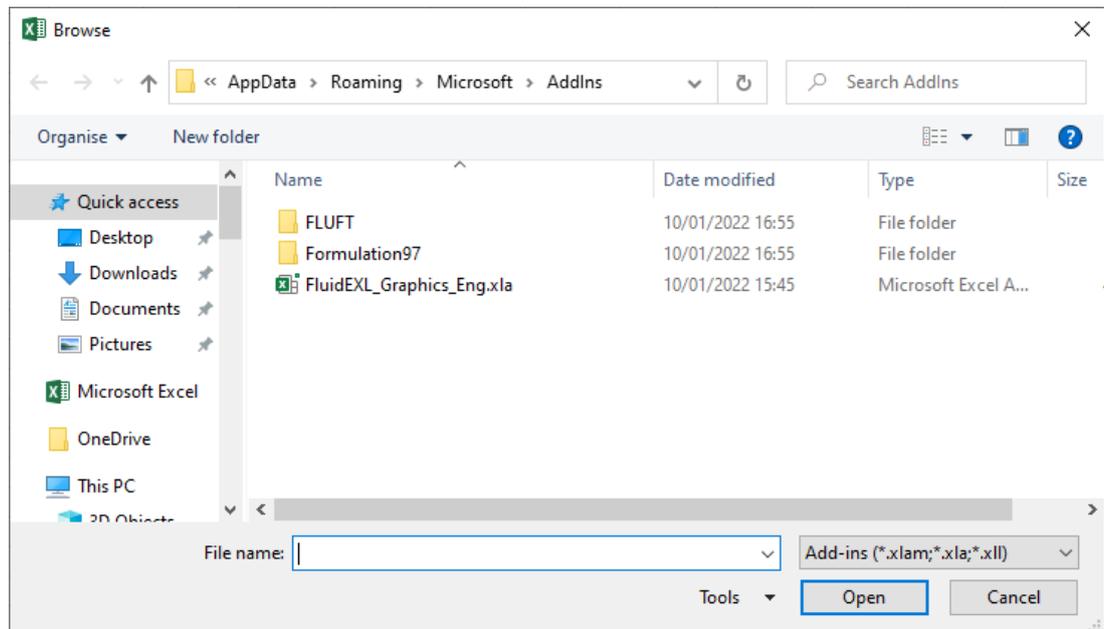
- Select "Excel Add-ins" next to "Manage:" in the lower area of the menu
- Then click the "Go..." button
- Click "Browse" in the following window (Fig. 2.4)



**Figure 2.4:** Dialog window "Add-ins"

- Excel opens the AddIns folder. This is usually  
C:\Users\[your name]\AppData\Roaming\Microsoft\AddIns\.
- If the FluidEXL files have already been copied to this directory in section 2.1, please skip the following indented section. If not, follow the indented instructions to successful paste the needed files for the FluidEXL Add-In:

In the upper part of the "Browse" window the correct Add-In path is displayed (see Figure 2.5). Please note that not the entire path is displayed.



**Figure 2.5:** "Browse"-Window

Please copy this path and paste it into your file manager.

Now, please copy the following directories and files:

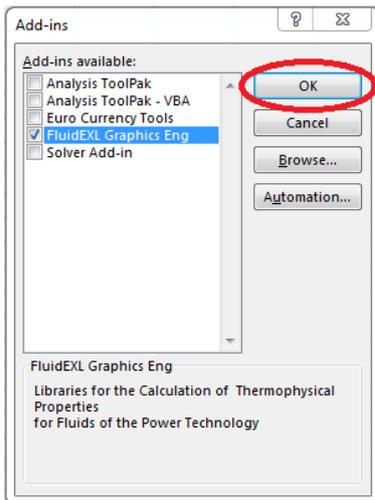
```

\FLUFT\
\Formulation97\
LC.dll
FluidEXL_Graphics_Eng.xla
LibHuAir.dll
LibHuAir.chm

```

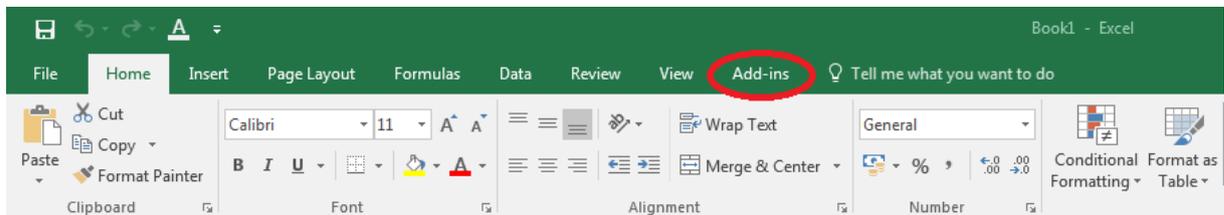
from the delivered CD-folder into this folder.

- Click "FluidEXL\_Graphics\_Eng.xla" in this folder (see Fig. 2.5) and click "OK."
- Now, "FluidEXL Graphics Eng" will be shown in the list of Add-ins (see Fig. 2.6).  
(If a checkmark is in the box next to the name "FluidEXL Graphics Eng", this Add-In will automatically be loaded whenever Excel starts. This will continue to occur unless the checkmark is removed from the box by clicking on it.)
- In order to register the Add-In click the "OK" button in the "Add-ins" window (see Fig. 2.6).



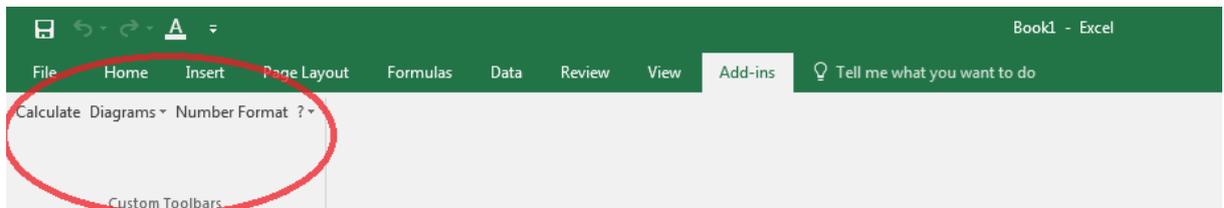
**Figure 2.6:** Dialog window "Add-Ins"

In order to use FluidEXL *Graphics* in the following example, click on the menu item "Add-Ins" shown in Fig. 2.7.



**Figure 2.7:** Menu item "Add-Ins"

In the upper menu region of Excel®, the FluidEXL *Graphics* menu bar will appear as marked with the red circle in Fig. 2.8.



**Figure 2.8:** FluidEXL *Graphics* menu bar

The Installation of FluidEXL *Graphics* in Excel® is now complete.

An example calculation of "LibHuAir" DLL library property functions can be found in chapter 2.4.

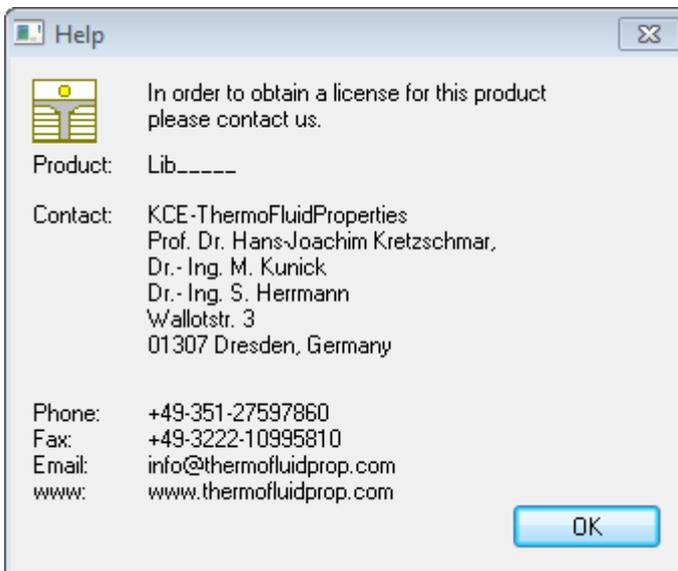
### 2.3 Licensing the LibHuAir Property LibHuAarray

The licensing procedure has to be carried out when Excel® starts up and a FluidEXL *Graphics* prompt message appears. In this case, you will see the "License Information" window (see figure below).



**Figure 2.12:** "License Information" window

Here you will have to type in the license key. You can 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 2.13:** "Help" window

If you do not enter a valid license it is still possible to start Excel® by clicking "Cancel" twice. In this case, the LibHuAir property library will display the result "-11111111" for every calculation. The "License Information" window will appear every time you start Excel® unless you uninstall FluidEXL<sub>Graphics</sub> according to the description in section 2.6 of this User's Guide.

Should you not wish to license the LibHuAir property library, you have to delete the files

LibHuAir.dll  
LibHuAir.chm

in the installation folder of FluidEXL<sub>Graphics</sub> (the standard being)

C:\Program Files\FuildEXL\_Graphics\_Eng  
using an appropriate program such as Explorer® or Norton Commander.

**Note:**

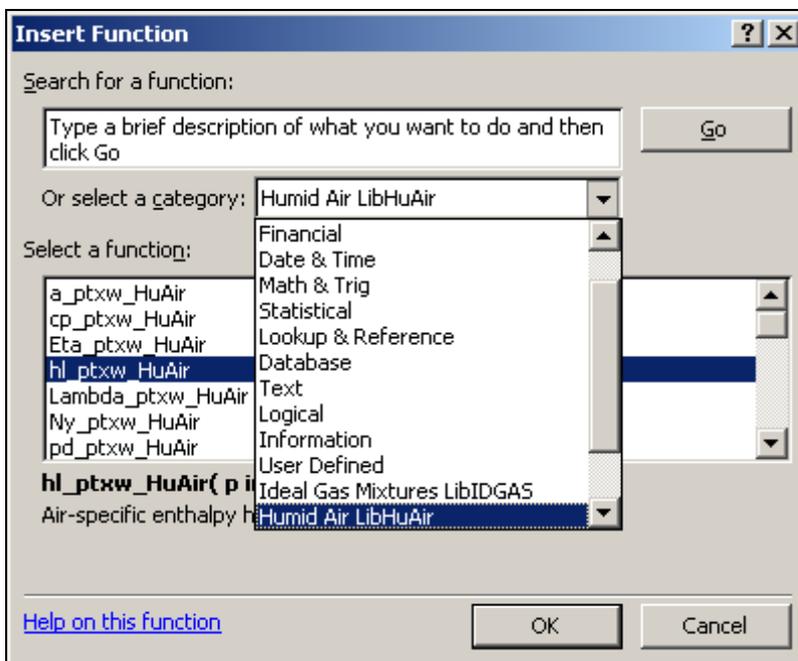
*The product name "LibHuAir\_ \_ \_ \_" in Figure 2.12 and 2.13 stands for the LibHuAir library you are installing. In this case it is the LibHuAir library.*

## 2.4 Example calculation

Now we will calculate, step by step, the air-specific enthalpy  $h_1$  as a function of mixture pressure  $p$ , temperature  $t$  and absolute humidity  $x_w$ , using FluidEXL *Graphics*. The following description relates to Excel<sup>®</sup> 97. The procedure is analogous for Excel<sup>®</sup> 2000 and XP.

Carry out the following steps:

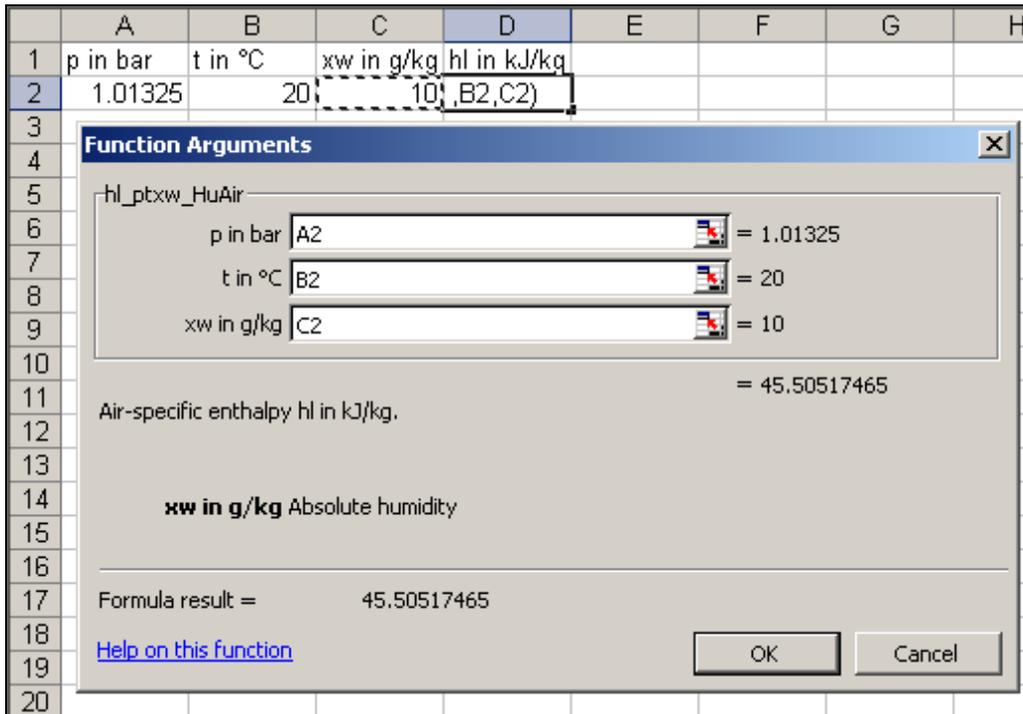
- Start Excel<sup>®</sup>
- Enter the value for  $p$  in bar into a cell  
(Range of validity:  $p = 6.112 \text{ mbar} \dots 1000 \text{ bar}$ )  
⇒ e.g.: Enter the value 1.01325 into cell A1
- Enter the value for  $t$  in °C into cell  
(Range of validity:  $t = -143.15^\circ\text{C} \dots 1726.85^\circ\text{C}$ )  
⇒ e.g.: Enter the value 20 into cell B1
- Enter the value for  $x_w$  in  $\text{g}_{\text{Water}}/\text{kg}_{\text{Air}}$  (dry Air) into a cell  
(Range of validity:  $x_w \geq 0 \text{ g}/\text{kg}_{\text{Air}}$ )  
⇒ e.g.: Enter the value 10 into cell C1
- Click the cell in which the air specific enthalpy  $h_1$  in  $\text{kJ}/\text{kg}_{\text{Air}}$  is to be displayed  
⇒ e.g.: click on the cell D1
- Click "Calculate" in the menu bar of FluidEXL *Graphics*.  
The "Insert Function" window appears as shown in the next figure



**Figure 2.9:** Choice of library and function name

- Search and click the "Humid Air LibHuAir" library next to "Or select a category:" in the upper part of the window.
- Search and click the "hl\_ptxw\_HuAir" function under "Select a function:" right below.
- Click the "OK" button

The "Function Arguments" menu for the "hl\_ptxw\_HuAir" function, as shown in figure 2.10, appears.



**Figure 2.10:** Input menu for the function

- The cursor is now situated on the line next to "p in bar". You can now enter the value for the mixture pressure  $p$  either by clicking the cell which contains the value for  $p$  or by typing the number of the cell or by entering the value for  $p$  directly into the window.  
⇒ e. g.: [Click the cell A1](#)
- Situate the cursor on the line next to "t in °C". You can now enter the value for the temperature either by clicking the cell which contains the value for  $t$  or by typing the number of the cell or by entering the value for  $t$  directly into the window.  
⇒ e. g.: [Type B1 into the line next to "t in °C"](#)
- Situate the cursor on the line next to " $x_w$  in g/kg". You can now enter the value for the absolute humidity  $x_w$  either by clicking the cell which contains the value for  $x_w$  or by typing the number of the cell or by entering the value for  $x_w$  directly into the window.  
⇒ e. g.: [Click the cell C1](#)
- Click the "Finish" button

The result for  $h_l$  in  $\text{kJ/kg}_{\text{Air}}$  appears in the cell selected above.

⇒ The result in our sample calculation here is:  $h_l = 45.50517465$ .

The calculation of  $h_l = f(p, t, x_w)$  has thus been completed.

You can now arbitrarily change the values for  $p$ ,  $t$  or  $x_w$  in the appropriate cells. The enthalpy  $h_l$  is recalculated and updated every time you change the data. This shows that the Excel<sup>®</sup> data flow and the DLL calculations are working together successfully.

**Hint:**

*If the input values entered are located outside the range of validity or if they do not fit together the result for the calculated function will always be -1 or -1000.*

For further property functions calculable in FluidEXL *Graphics* see the function table in Chapter 1.

## Number Formats

When using FluidEXL *Graphics* you have the option of choosing special number formats in advance.

Changes can be made as follows:

- Click the cell or select and click on the cells you wish to format.  
(In empty cells the new format will be applied once a value has been entered.)
- Click "Number Format" in the FluidEXL *Graphics* menu bar.
- Select the desired number format in the dialog box which appears:
  - "STD – Standard": Insignificant zeros behind the decimal point are not shown.
  - "FIX – Fixed Number of Digits": All set decimal places are shown, including insignificant zeros.
  - "SCI – Scientific Format": Numbers are always shown in the exponential form with the set number of decimal places.
- Set the "Number of decimal places" by entering the number into the appropriate window.
- Confirm this by clicking the "OK" button.

As an example, the table below shows the three formats for the number 1.230 adjusted for three decimal places:

STD	1.23
FIX	1.230
SCI	1.230E+00

This formatting can also be applied to cells which have already been calculated.

## 2.5 Calculated of Calculated Properties on Thermodynamic Diagrams

In the following section, the calculated state point is to be represented in thermodynamic diagrams with the help of FluidEXL *Graphics*. Calculations can be represented in the following diagrams:

- $h$ - $x$  Diagram  $p = 0.101325$  MPa
- $h$ - $x$  Diagram  $p = 0.11$  MPa

In order to represent the calculated values in a  $h$ - $x$  diagram for  $p = 0.101325$  MPa, for example, the absolute humidity and specific entropy values for the point to be represented must be marked.

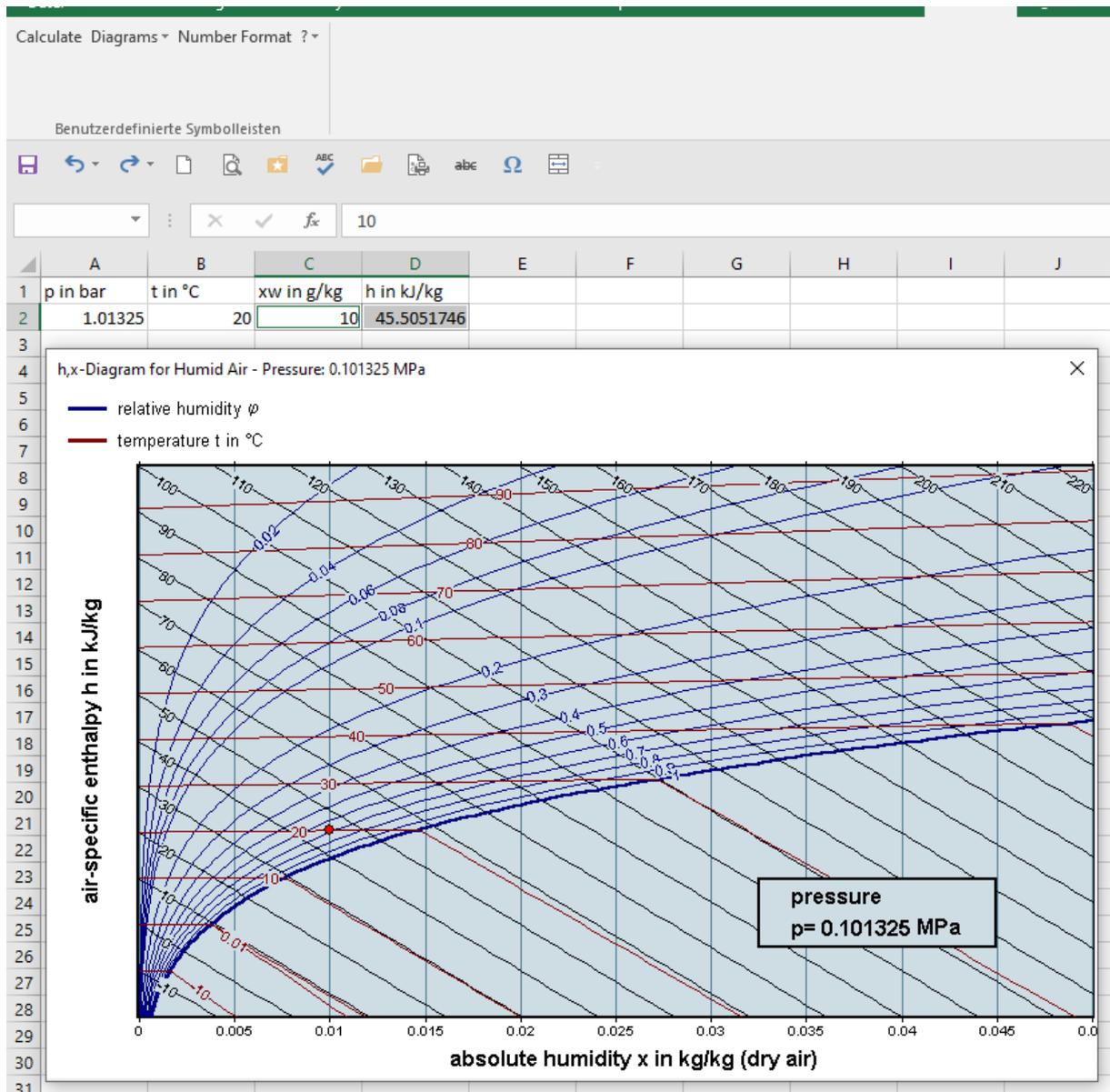
- Click on the cell with the value for  $h$  (as  $h$  is the ordinate in the diagram)  
⇒ e. g.: [Click the cell D1](#)
- Hold down the "Ctrl" key and simultaneously click the cell with the value for  $x_w$  (as  $x_w$  is the abscissa in the diagram)  
⇒ e. g.: [Hold down the "Ctrl" key and click the cell C1](#)

**Note:**

*The value pairs to be depicted ( $Y, X$ ) here ( $h, x_w$ ) must always be located in the same row or column.*

- As displayed in the next figure, click "Diagrams" in the FluidEXL *Graphics* menu bar and choose "h-x Diagram 0.101325 MPa" in the drop-down menu.

The  $h$ - $x$  diagram shown in the figure below will appear. The calculated state point is marked as a red point.



**Figure 2.11:**  $h$ - $x$  Diagram including the state point

**Note - Diagrams with various state points:**

If you calculate various state points, they can be represented in one selected diagram. To do this, first mark with the cursor those values which are to represent the values of  $y$  in the diagram. Afterwards, hold down the "Ctrl" key and mark the corresponding values which are to represent the values of  $x$  in the diagram. Note once more that all value pairs which should be represented ( $Y, X$ ) must be located in one row in Excel®. Proceed as described above.

**Note - Diagrams without any state points:**

If you wish to have a look at a diagram without performing a calculation, mark two empty cells located in one row and select a diagram.

**Printing the Diagrams**

The state diagrams can be printed with the help of Word<sup>®</sup>, which also belongs to the Office suite<sup>®</sup>.

- When the selected diagram is on the screen, hold down the "Alt" key and press the "Print" key briefly.  
(This keyboard shortcut copies the current window, e.g., the diagram, into the Windows clipboard where it is ready to be pasted into other Windows<sup>®</sup> application programs.)
- Start Word by clicking "Start" in the Windows task bar, then "Programs", and then "Microsoft Word".
- As the diagram is to be printed in landscape format, change the (now loaded) Word application window into the landscape format.  
In order to do so, click "File" in the upper menu bar of Word, and then "Page Setup". Click "Margins" in the window which now appears, then "Landscape". Confirm this change by clicking "OK".
- In order to paste the diagram out of the Windows clipboard, click "Edit" in the upper menu bar of Word, and then "Paste".  
The diagram out of FluidEXL *Graphics* appears in the Word application window and is ready to save and/or print.
- Start the printing process by clicking "File" in the upper menu bar of Word, and then "Print". Proceed as usual in the "Print" window which appears.

The diagram will be printed in the A4 landscape format, if you do not change the preferences.

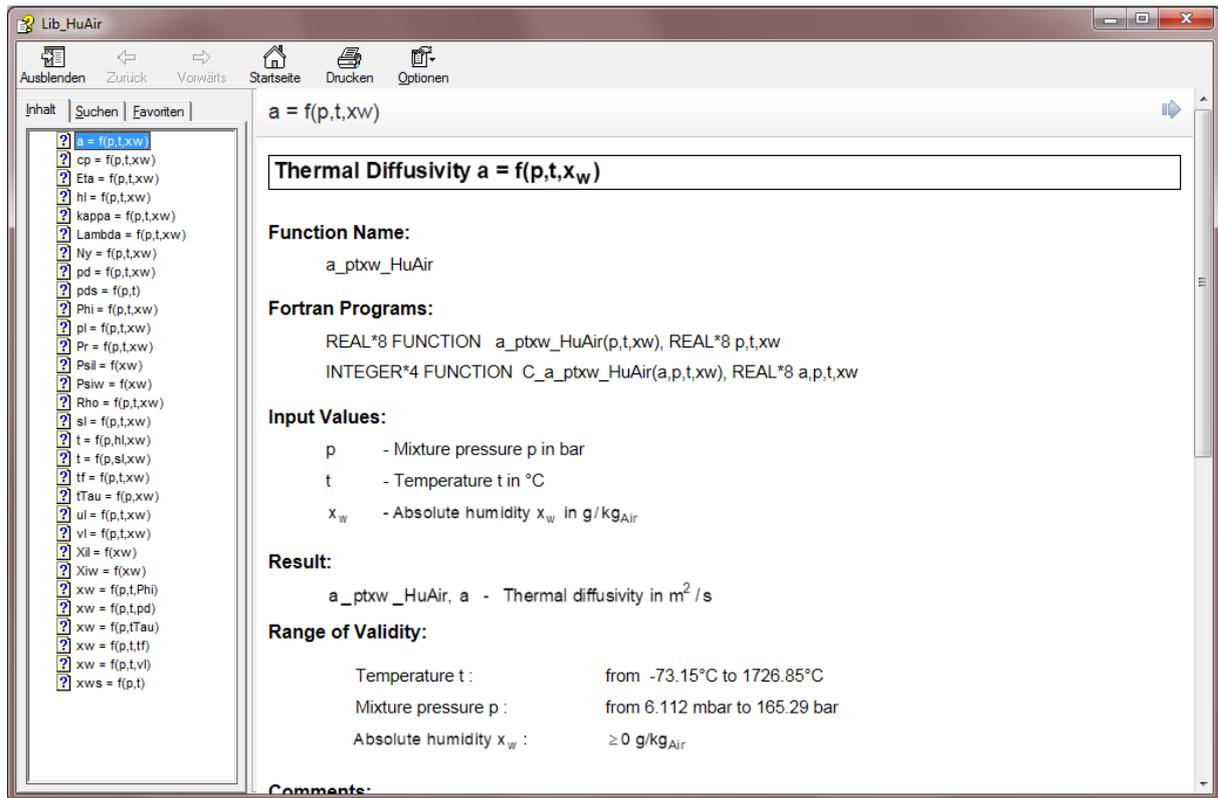
In order to continue working in Excel<sup>®</sup>, click "Microsoft Excel - ..." in the Windows task bar. Proceed in the same way to print further diagrams.

## 2.6 The FluidEXL *Graphics* Help System

As mentioned earlier, FluidEXL *Graphics* also provides detailed help functions.

Information on individual property functions may be accessed via the following steps:

- Click "Calculate" in the FluidEXL *Graphics* menu bar.
- Click on the "LibHuAir" library under "Or select a category:" in the "Insert Function" window which will appear.
- Click the "Help on this function" button in the lower left-hand edge of the "Insert Function" window.



**Figure 2.12:** Help Window

If the LibHuAir.chm function help cannot be found, you will be redirected to a Microsoft® help website by your standard browser. In this case, the LibHuAir.chm file has to be copied into the folder of FluidEXL *Graphics*, in the standard case

C:\Program Files\FuildEXL\_Graphics\_Eng

to use the help system.

## 2.7 Removing FluidEXLGraphics

### 2.7.1 Removing LibHuAir Library

Should you wish to remove only the LibHuAir library, delete the files

LibHuAir.dll  
LibHuAir.chm

in the directory selected for the installation of FluidEXL *Graphics*, in the standard case,

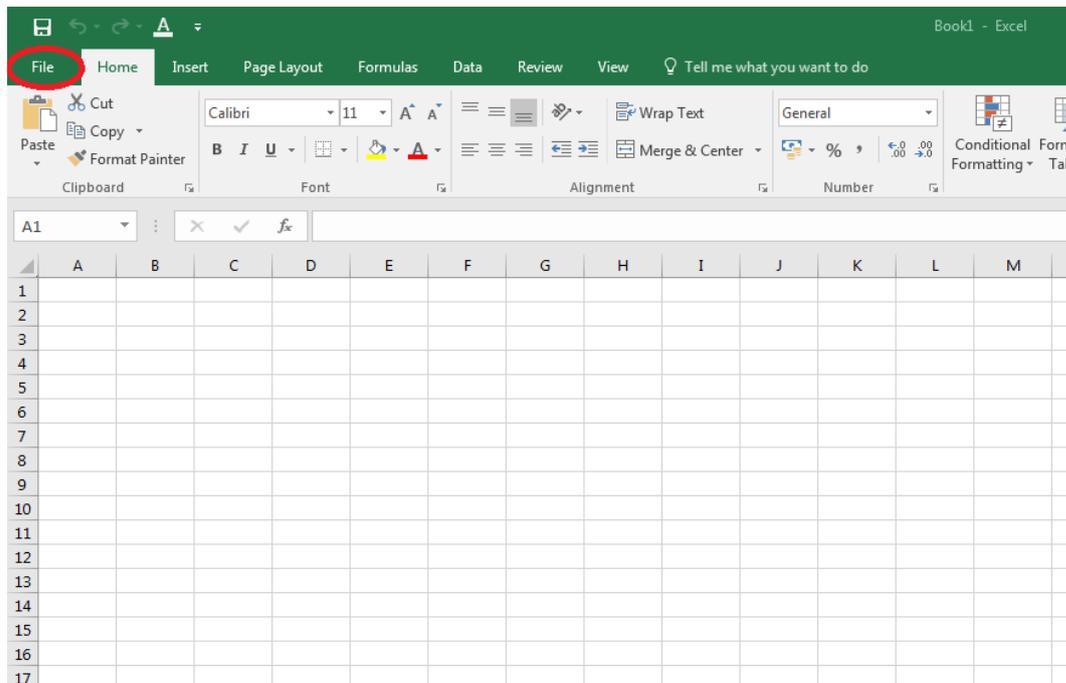
C:\Program Files\FuildEXL\_Graphics\_Eng

by using an appropriate program such as Explorer® or Norton Commander.

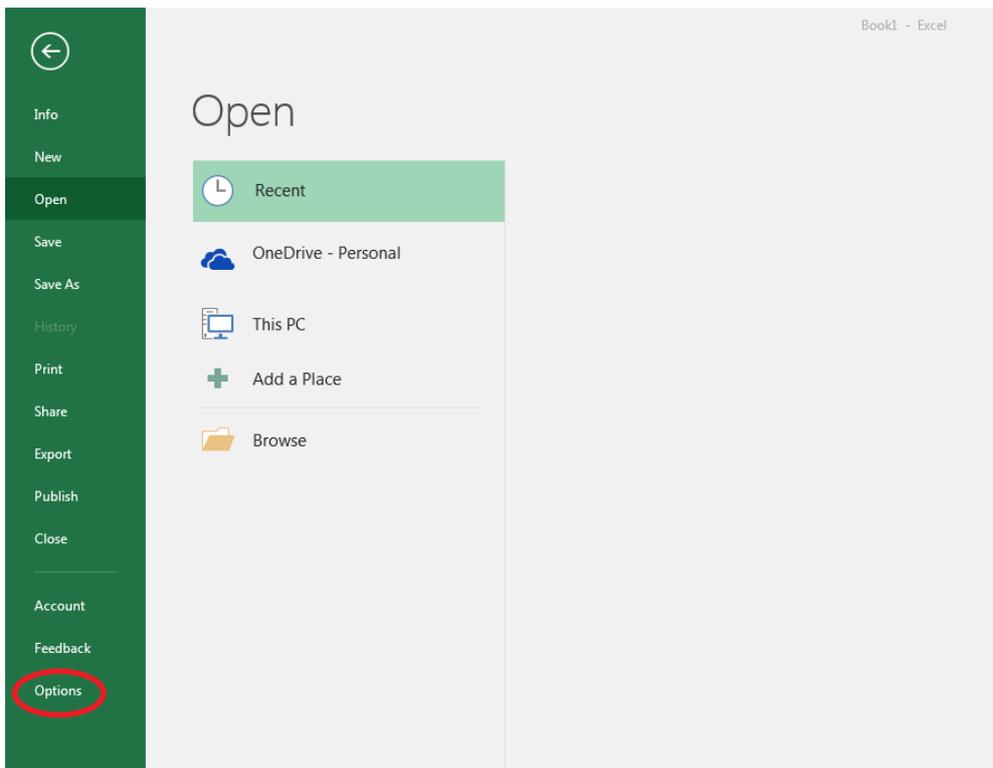
### 2.7.2 Unregistering and uninstalling FluidEXL *Graphics* as Add-In in versions of Excel® from 2007 onwards (for earlier versions see 2.6.3)

In order to unregister the FluidEXL *Graphics* Add-In in versions of Excel® from 2007 onwards start Excel® and carry out the following commands:

- Click the "File" button in the upper left corner of Excel®
- Click on the "Options" button in the menu which appears

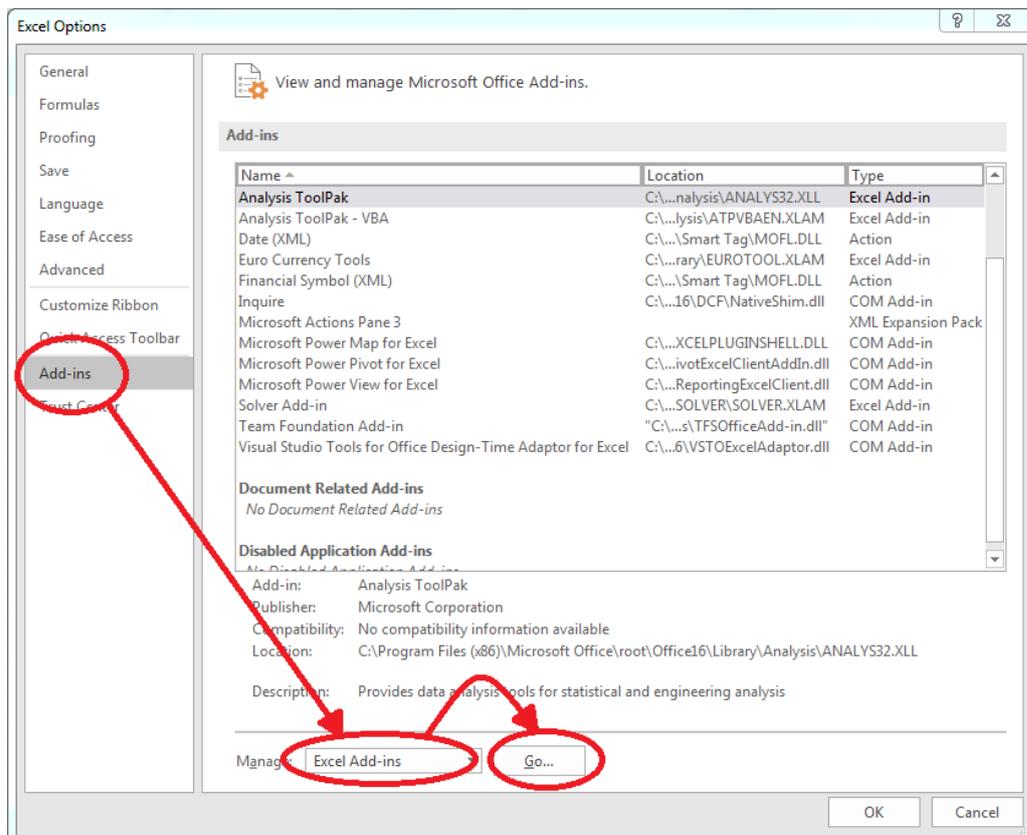


**Figure 2.13:** Unregistering FluidEXL *Graphics* as Add-In in Excel® 2016



**Figure 2.14** Unregistering FluidEXL *Graphics* as Add-In in Excel® 2016

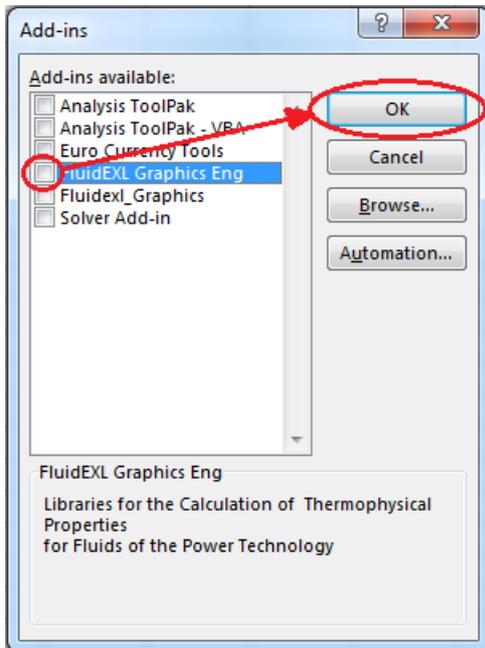
- Click on "Add-Ins" in the next menu (Figure 2.15)



**Figure 2.15:** Dialog window "Add-Ins"

- If it is not shown in the list automatically, chose and click "Excel Add-ins" next to "Manage:" in the lower area of the menu

- Afterwards click the "Go..." button
- Remove the checkmark in front of "FluidEXL Graphics Eng" in the window which now appears. Click the "OK" button to confirm your entry.



**Figure 2.16:** Dialog window "Add-Ins"

In order to remove FluidEXL *Graphics* from Windows and the hard drive, click "Start" in the Windows task bar, select "Settings" and click "Control Panel."

Now, double click on "Add or Remove Programs."

In the list box of the "Add or Remove Programs" window that appears, select "FluidEXL Graphics Eng"

by clicking on it and then clicking the "Add/Remove..." button.

Click "Automatic" in the following dialog box and then the "Next >" button.

Click "Finish" in the "Perform Uninstall" window.

Answer the question of whether all shared components should be removed with "Yes to All." Finally, close the "Add or Remove Programs" and "Control Panel" windows.

Now FluidEXL *Graphics* has been completely removed from your computer.

### 2.7.3 Unregistering and uninstalling FluidEXL *Graphics* as Add-In in Excel®, versions 2003 or earlier

To remove FluidEXL *Graphics* completely, proceed as follows: First the registration of FluidEXL\_Graphics\_Eng.xla has to be cancelled in Excel®.

In order to do this, click "Tools" in the upper menu bar of Excel® and here "Add-Ins...". Untick the box on the left-hand side of

"FluidEXL Graphics Eng"

in the window that appears and click the "OK" button. The additional menu bar of FluidEXL *Graphics* disappears from the upper part of the Excel® window. Afterwards, we

recommend closing Excel®.

If the FluidEXL *Graphics* menu bar does not disappear, take the following steps:

Click "View" in the upper menu bar of Excel®, then "Toolbars" and then "Customize..." in the list box which appears.

"FluidEXL Graphics Eng"

is situated at the bottom of the "Toolbars" entries, which must be selected by clicking on it. Delete the entry by clicking "Delete". You will be asked whether you really want to delete the toolbar – click "OK".

Within the next step delete the files

LibHuAir.dll

LibHuAir.chm

in the directory selected for the installation of FluidEXL *Graphics*, in the standard case,

C:\Program Files\FuildEXL\_Graphics\_Eng

using an appropriate program such as Explorer® or Norton Commander.

In order to remove FluidEXL *Graphics* from Windows and the hard drive, click "Start" in the Windows task bar, select "Settings" and click "Control Panel". Now double-click on "Add or Remove Programs". In the list box of the "Add/Remove Programs" window that appears select

"FluidEXL Graphics Eng"

by clicking on it and click the "Add/Remove..." button. In the following dialog box, click "Automatic" and then "Next >". Click "Finish" in the "Perform Uninstall" window. Answer the question whether all shared components shall be removed with "Yes to All". Finally, close the "Add/Remove Programs" and "Control Panel" windows.

Now FluidEXL *Graphics* 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

#### Input Values:

p - Mixture pressure p in bar  
 t - Temperature t in °C  
 x<sub>w</sub> - Absolute humidity x<sub>w</sub> in g/kg<sub>Air</sub>

#### Result:

a\_ptxw\_HuAir, a - Thermal diffusivity in m<sup>2</sup>/s

#### Range of Validity:

Temperature t : from -143.15°C to 1726.85°C  
 Mixture pressure p : from 6.112 mbar to 1000.0 bar  
 Absolute humidity x<sub>w</sub> : ≥ 0 g/kg<sub>Air</sub>

#### 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. [11]  
 c<sub>p</sub> from *Lemmon* et al. [10]  
 ρ from *Lemmon* et al. [10]

Steam in humid air and liquid droplets in fog:

λ for 0°C ≤ t ≤ 800°C from IAPWS-85 [5]  
 for t < 0°C and t > 800°C from *Brandt* [8]  
 c<sub>p</sub> from IAPWS-IF97 [1], [2], [3], [4]  
 ρ from IAPWS-IF97 [1], [2], [3], [4]  
 for t < 0.01 °C from IAPWS-06 [14], [15]

## 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
```

### Input Values:

p - Mixture pressure p in bar  
 t - Temperature t in °C  
 x<sub>w</sub> - Absolute humidity x<sub>w</sub> in g/kg<sub>Air</sub>

### 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 1000.0 bar  
 Absolute humidity x<sub>w</sub> : ≥ 0 g/kg<sub>Air</sub>

### 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. [10]  
 Steam in humid air and liquid droplets in fog:  
 from IAPWS-IF97 [1], [2], [3], [4]  
 Dissociation:  
 from VDI Guideline 4670 [9]

## Specific Isochoric Heat Capacity $c_v = f(p, t, x_w)$

### Function Name:

cv\_ptxw\_HuAir

### Fortran Programs:

```
REAL*8 FUNCTION cv_ptxw_HuAir(p,t,xw), REAL*8 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<sub>Air</sub>

### Result:

cv\_ptxw\_HuAir,  $c_v$  - Specific isochoric 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 1000.0 bar  
Absolute humidity  $x_w$  :     $\geq 0$  g/kg<sub>Air</sub>

### 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:

cv\_ptxw\_HuAir,  $c_p = -1$

### References:

Dry Air:  
from *Lemmon et al.* [10]  
Steam in humid air and liquid droplets in fog:  
from IAPWS-IF97 [1], [2], [3], [4]  
Dissociation:  
from VDI Guideline 4670 [9]

## 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
```

### Input values:

p - Mixture pressure p in bar  
 t - Temperature t in °C  
 x<sub>w</sub> - Absolute humidity x<sub>w</sub> in g/kg<sub>Air</sub>

### Result:

Eta\_ptxw\_HuAir, Eta - Dynamic viscosity in Pa s

### Range of Validity:

Temperature t : from -143.15°C to 1726.85°C  
 Mixture pressure p : from 6.112 mbar to 1000.0 bar  
 Absolute humidity x<sub>w</sub> : ≥ 0 g/kg<sub>Air</sub>

### Comments:

- Model of ideal mixture of real fluids
- Neglect of ice crystals in ice fog ( t < 0.01°C and x<sub>w</sub> > x<sub>ws</sub> )

### Results for wrong input values:

Eta\_ptxw\_HuAir, Eta = -1

### References:

Dry Air:  
 from *Lemmon et al.* [11]  
 Steam in humid air and liquid droplets in fog:  
 for 0°C ≤ t ≤ 800°C from IAPWS-85 [7]  
 for t < 0°C and t > 800°C from *Brandt* [8]

## 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
```

### Input values:

p        - Mixture pressure p in bar  
t        - Temperature t in °C  
 $x_w$     - Absolute humidity  $x_w$  in g/kg<sub>Air</sub>

### Result:

hl\_ptxw\_HuAir, hl - Air-specific enthalpy in kJ/kg<sub>Air</sub>

### Range of Validity:

Temperature t :            from -143.15°C to 1726.85°C  
Mixture pressure p :        from 6.112 mbar to 1000.0 bar  
Absolute humidity  $x_w$  :     $\geq 0$  g/kg<sub>Air</sub>

### 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. [10]  
Steam in humid air and liquid droplets in fog:  
from IAPWS-IF97 [1], [2], [3], [4]  
Ice crystals in fog:  
according to IAPWS-06 [14], [15]  
Dissociation:  
from VDI Guideline 4670 [9]

## Isentropic Exponent $\kappa = f(p,t,x_w)$

### Function Name:

Kappa\_ptxw\_HuAir

### Fortran Programs:

REAL\*8 FUNCTION kappa\_ptxw\_HuAir(p,t,xw), REAL\*8 p,t,xw

### Input Values:

p - Mixture pressure p in bar  
 t - Temperature t in °C  
 x<sub>w</sub> - Absolute humidity x<sub>w</sub> in g/kg<sub>Air</sub>

### Result:

kappa\_ptxw\_HuAir, kappa - Isentropic exponent

### Range of Validity:

Temperature t : from -143.15°C to 1726.85°C  
 Mixture pressure p : from 6.112 mbar to 1000.0 bar  
 Absolute humidity x<sub>w</sub> : ≥ 0 g/kg<sub>Air</sub>

### Comments:

- For unsaturated and saturated humid air ( $x_w \leq x_{ws}$ ), calculation as ideal mixture of real gases (dry air and steam)
 
$$\kappa = -\frac{v}{p} \cdot \left( \frac{\partial p}{\partial v} \right)_t \cdot \frac{c_p}{c_v}$$
- For liquid fog ( $x_w > x_{ws}$ ), calculation as ideal mixture of saturated humid air and water
- For ice fog ( $x_w > x_{ws}$ ), calculation of saturated humid air
- For temperatures greater than 500°C, the dissociation is taken into consideration

### Results for wrong input values:

kappa\_ptxw\_HuAir, kappa = -1

### References:

Dry Air:  
 from *Lemmon et al.* [10]  
 Steam in humid air and liquid droplets in fog:  
 from IAPWS-IF97 [1], [2], [3], [4]  
 Dissociation:  
 from VDI Guideline 4670 [9]

**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
```

**Input values:**

p - Mixture pressure p in bar  
 t - Temperature t in °C  
 x<sub>w</sub> - Absolute humidity x<sub>w</sub> in g/kg<sub>Air</sub>

**Result:**

Lambda\_ptxw\_HuAir, Lambda - Heat conductivity in W/(m K)

**Range of Validity:**

Temperature t : from -143.15°C to 1726.85°C  
 Mixture pressure p : from 6.112 mbar to 1000.0 bar  
 Absolute humidity x<sub>w</sub> : ≥ 0 g/kg<sub>Air</sub>

**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. [11]  
 Steam in humid air and humid droplets in fog:  
 for 0°C ≤ t ≤ 800°C from IAPWS-85 [5]  
 for t < 0°C and t > 800°C from *Brandt* [8]

## 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
```

### Input values:

$\rho$  - Mixture pressure p in bar  
 t - Temperature t in °C  
 $x_w$  - Absolute humidity  $x_w$  in g/kg<sub>Air</sub>

### Result:

Ny\_ptxw\_HuAir, Ny - Kinematic viscosity in m<sup>2</sup>/s

### Range of Validity:

Temperature t : from -143.15°C to 1726.85°C  
 Mixture pressure p : from 6.112 mbar to 1000.0 bar  
 Absolute humidity  $x_w$  :  $\geq 0$  g/kg<sub>Air</sub>

### 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:

$\eta$  from *Lemmon* et al. [11]

$\rho$  from *Lemmon* et al. [10]

Steam in humid air and liquid droplets in fog:

$\eta$  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* [8]

$\rho$  from IAPWS-IF97 [1], [2], [3], [4]

for  $t < 0.01^\circ\text{C}$  from IAPWS-06 [14], [15]

## 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
```

### Input values:

p - Mixture pressure p in bar  
t - Temperature t in °C  
 $x_w$  - Absolute humidity  $x_w$  in g/kg<sub>Air</sub>

### 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 1000.0 bar  
Absolute humidity  $x_w$  : from 0 g/kg<sub>Air</sub> 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 [12], [13]

**Saturation Pressure of Water  $p_{ds} = f(p,t)$** 
**Function Name:**

pds\_pt\_HuAir

**Fortran Programs:**

REAL\*8 FUNCTION pds\_pt\_HuAir(p,t), REAL\*8 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 1000.0 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  $t \geq 0.01^\circ\text{C}$  from IAPWS-IF97 [1], [2], [3], [4]

if  $t < 0.01^\circ\text{C}$  from IAPWS-08 [12], [13]

**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

**Input values:**

p - Mixture pressure p in bar  
 t - Temperature t in °C  
 x<sub>w</sub> - Absolute humidity x<sub>w</sub> in g/kg<sub>Air</sub>

**Result:**

Phi\_ptxw\_HuAir, Phi - Relative humidity in %

**Range of Validity:**

Temperature t : from -143.15°C to t<sub>critical</sub> = 373,946°C (critical temperature of water)  
 Mixture pressure p : from 6.112 mbar to 1000.0 bar  
 Absolute humidity x<sub>w</sub> : ≥ 0 g/kg<sub>Air</sub>

**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<sub>ds</sub> = f · p<sub>s</sub>(t)

with p<sub>ds</sub>(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:**

Phi\_ptxw\_HuAir, Phi = - 1

**References:**

f(p,t) Herrmann et al. [25], [26]  
 p<sub>s</sub>(t) if t ≥ 0.01 °C from IAPWS-IF97 [1], [2], [3], [4]  
 if t < 0.01 °C from IAPWS-08 [12], [13]

**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

**Input values:**

p - Mixture pressure p in bar  
 t - Temperature t in °C  
 x<sub>w</sub> - Absolute humidity x<sub>w</sub> in g/kg<sub>Air</sub>

**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 1000.0 bar  
 Absolute humidity x<sub>w</sub> : from 0 g/kg<sub>Air</sub> to x<sub>ws</sub>(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<sub>s</sub>(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 [12], [13]

**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

**Input values:**

p - Mixture pressure p in bar  
 t - Temperature t in °C  
 x<sub>w</sub> - Absolute humidity x<sub>w</sub> in g/kg<sub>Air</sub>

**Result:**

Pr\_ptxw\_HuAir, Pr - Prandtl-number

**Range of Validity:**

Temperature t : from -143.15°C to 1726.85°C  
 Mixture pressure p : from 6.112 mbar to 1000.0 bar  
 Absolute humidity x<sub>w</sub> : ≥ 0 g/kg<sub>Air</sub>

**Comments:**

- Prandtl-number  $Pr = \frac{v}{a} = \frac{\eta \cdot c_p}{\lambda}$
- 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. [11]  
 η from Lemmon et al. [11]  
 c<sub>p</sub> from Lemmon et al. [10]

Steam in humid air and liquid droplets in fog:

λ for 0°C ≤ t ≤ 800°C from IAPWS-85 [5]  
 for t < 0°C and t > 800°C from Brandt [8]  
 η for 0°C ≤ t ≤ 800°C from IAPWS-85 [7]  
 for t < 0°C and t > 800°C from Brandt [8]  
 c<sub>p</sub> from IAPWS-IF97 [1], [2], [3], [4]

Dissociation:

from VDI Guideline 4670 [9]

**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

**Input values:** $x_w$  - Absolute humidity  $x_w$  in g/kg<sub>Air</sub>**Result:**

Psil\_xw\_HuAir, Psil - Mole fraction of air in kmol/kmol

**Range of Validity:**Absolute humidity  $x_w$  :  $\geq 0$  g/kg<sub>Air</sub>**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

**Input values:** $x_w$  - Absolute humidity  $x_w$  in g/kg<sub>Air</sub>**Result:**

Psiw\_xw\_HuAir, Psiw - Mole fraction of water in kmol/kmol

**Range of Validity:**Absolute humidity  $x_w$  :  $\geq 0$  g/kg<sub>Air</sub>**Comments:**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
```

**Input values:**

p - Mixture pressure p in bar  
t - Temperature t in °C  
 $x_w$  - Absolute humidity  $x_w$  in g/kg<sub>Air</sub>

**Result:**Rho\_ptxw\_HuAir, Rho - Density in kg/m<sup>3</sup>**Range of Validity:**

Temperature t : from -143.15°C to 1726.85°C  
Mixture pressure p : from 6.112 mbar to 1000.0 bar  
Absolute humidity  $x_w$  :  $\geq 0$  g/kg<sub>Air</sub>

**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. [10]  
Steam in humid air and liquid droplets in fog:  
from IAPWS-IF97 [1], [2], [3], [4]  
Ice crystals in fog:  
from IAPWS-06 [14], [15]

## 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
```

### Input values:

p        - Mixture pressure p in bar  
t        - Temperature t in °C  
 $x_w$     - Absolute humidity  $x_w$  in g/kg<sub>Air</sub>

### Result:

sl\_ptxw\_HuAir, sl - Air-specific entropy in kJ/(kg<sub>Air</sub> K)

### Range of Validity:

Temperature t :            from -143.15°C to 1726.85°C  
Mixture pressure p :        from 6.112 mbar to 1000.0 bar  
Absolute humidity  $x_w$  :     $\geq 0$  g/kg<sub>Air</sub>

### 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.* [10]  
Steam in humid air and liquid droplets in fog:  
from IAPWS-IF97 [1], [2], [3], [4]  
Ice crystals in fog:  
from to IAPWS-06 [14], [15]  
Dissociation:  
from VDI Guideline 4670 [9]

**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

**Input values:**

p - Mixture pressure p in bar  
 h<sub>l</sub> - Air-specific enthalpy in kJ/kg<sub>Air</sub>  
 x<sub>w</sub> - Absolute humidity x<sub>w</sub> in g/kg<sub>Air</sub>

**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 1000.0 bar  
 Absolute humidity x<sub>w</sub> : ≥ 0 g/kg<sub>Air</sub>

**Comments:**Iteration from t of h<sub>l</sub>(p,t,x<sub>w</sub>)Calculation of h<sub>l</sub>(p,t,x<sub>w</sub>):

- 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. [10]

Steam in humid air and liquid droplets in fog:

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

Ice crystals in fog:

from to IAPWS-06 [14], [15]

Dissociation:

from VDI Guideline 4670 [9]

**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

**Input values:**

- p - Mixture pressure p in bar  
 s<sub>l</sub> - Air-specific entropy in kJ/(kg<sub>Air</sub> K)  
 x<sub>w</sub> - Absolute humidity x<sub>w</sub> in g/kg<sub>Air</sub>

**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 1000.0 bar  
 Absolute humidity x<sub>w</sub> : ≥ 0 g/kg<sub>Air</sub>

**Comments:**Iteration from t of s<sub>l</sub>(p,t,x<sub>w</sub>)Calculation of s<sub>l</sub>(p,t,x<sub>w</sub>):

- 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 [14], [15]

Dissociation:

from VDI Guideline 4670 [9]

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

t\_ptfxw\_HuAir

**Fortran Programs:**

```
REAL*8 FUNCTION t_ptfxw_HuAir(p,tf,xw), REAL*8 p,tf,xw
```

**Input values:**

p - Mixture pressure p in bar  
 tf - Temperature t in °C  
 x<sub>w</sub> - Absolute humidity x<sub>w</sub> in g/kg<sub>Air</sub>

**Result:**

t\_ptfxw\_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 1000.0 bar  
 Absolute humidity x<sub>w</sub> : from 0 g/kg to x<sub>ws</sub>(p,t)

**Comments:**

- For temperatures greater than 500°C, the dissociation is taken into consideration

**Result for wrong input values:**

t\_ptfxw\_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]  
 Dissociation:  
 from VDI Guideline 4670 [9]

**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
```

**Input values:**

p - Mixture pressure p in bar  
 t - Temperature t in °C  
 x<sub>w</sub> - Absolute humidity x<sub>w</sub> in g/kg<sub>Air</sub>

**Result:**

tf\_ptxw\_HuAir, tf - Wet bulb temperature in °C

**Range of Validity:**

Temperature t : from -143.15°C to 1726,85 °C  
 Mixture pressure p : from 6.112 mbar to 1000.0 bar  
 Absolute humidity x<sub>w</sub> : from 0 g/kg to x<sub>ws</sub>(p,t)

**Comments:**

- Iteration from t<sub>f</sub> 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 [9]

**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

**Input values:**

p - Mixture pressure p in bar

 $x_w$  - Absolute humidity  $x_w$  in g/kg<sub>Air</sub>**Result:**

tdew\_pxw\_HuAir, tdew - Dew point temperature in °C

**Range of Validity:**

Mixture pressure p : from 6.112 mbar to 1000.0 bar

Absolute humidity  $x_w$  :  $\geq x_{ws}(p, -143.15^{\circ}\text{C})$ **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

### Input values:

p        - Mixture pressure p in bar  
 t        - Temperature t in °C  
 x<sub>w</sub>    - Absolute humidity x<sub>w</sub> in g/kg<sub>Air</sub>

### Result:

ul\_ptxw\_HuAir, ul - Air-specific internal energy in kJ/kg<sub>Air</sub>

### Range of Validity:

Temperature t :            from -143.15°C to 1726.85°C  
 Mixture pressure p :      from 6.112 mbar to 1000.0 bar  
 Absolute humidity x<sub>w</sub> :    ≥ 0 g/kg<sub>Air</sub>

### 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.* [10]

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 [14], [15]

Dissociation:

from VDI Guideline 4670 [9]

## 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
```

### Input values:

p        - Mixture pressure p in bar  
t        - Temperature t in °C  
 $x_w$     - Absolute humidity  $x_w$  in g/kg<sub>Air</sub>

### Result:

vl\_ptxw\_HuAir, vl - Air-specific volume in m<sup>3</sup>/kg<sub>Air</sub>

### Range of Validity:

Temperature t :            from -143.15°C to 1726.85°C  
Mixture pressure p :        from 6.112 mbar to 1000.0 bar  
Absolute humidity  $x_w$  :     $\geq 0$  g/kg<sub>Air</sub>

### 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. [10]  
Steam in humid air and liquid droplets in fog:  
from IAPWS-IF97 [1], [2], [3], [4]  
Ice crystals in fog:  
from IAPWS-06 [14], [15]

**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

**Input values:** $x_w$  - Absolute humidity  $x_w$  in g/kg<sub>Air</sub>**Result:**

Xil\_xw\_HuAir, Xil - Mass fraction of air

**Range of Validity:**Absolute humidity  $x_w$  :  $\geq 0$  g/kg<sub>Air</sub>**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
```

**Input values:**

$x_w$  - Absolute humidity  $x_w$  in g/kg<sub>Air</sub>

**Result:**

Xiw\_xw\_HuAir, Xiw - Mass fraction of water

**Range of Validity:**

Absolute humidity  $x_w$  :  $\geq 0$  g/kg<sub>Air</sub>

**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

**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<sub>Air</sub>

**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 1000.0 bar

Relative Humidity  $\varphi$ : from 0 % to 100 %**Comments:**

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

Saturation vapor pressure at saturation  $p_{\text{ds}} = f \cdot p_s(t)$ with  $p_{\text{ds}}(p, t)$  for  $t \geq 0.01^\circ\text{C}$  - Vapor pressure of waterfor  $t < 0.01^\circ\text{C}$  - Sublimation pressure of water**Result for wrong input values:**xw\_ptPhi\_HuAir,  $x_w = -1$ **References:**

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

 $p_{\text{ds}}(p, t)$  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
```

**Input values:**

p - Mixture pressure p in bar  
 t - Temperature t in °C  
 p<sub>d</sub> - Partial pressure of steam in bar

**Result:**

xw\_ptpd\_HuAir, x<sub>w</sub> - Absolute humidity from partial pressure in g/kg<sub>Air</sub>

**Range of Validity:**

Temperature t : from -143.15°C to 1726.85°C  
 Mixture pressure p : from 6.112 mbar to 1000.0 bar  
 Partial pressure of steam p<sub>d</sub> : from 6.112 mbar to p<sub>ds</sub>(p,t) for t ≤ 373,946°C,  
 to 165.29 bar for t > 373,946°C

**Comments:**

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

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

with p<sub>ds</sub>(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<sub>w</sub> = - 1

**References:**

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

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

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

xw\_ptTau\_HuAir

**Fortran Programs:**

```
REAL*8 FUNCTION xw_ptTau_HuAir(p,tTau), REAL*8 p,tTau
```

**Input values:**

p - Mixture pressure p in bar  
 $t_\tau$  - Dew point temperature in °C

**Result:**

xw\_ptTau\_HuAir,  $x_w$  - Absolute humidity from temperature and dew point temperature in g/kg<sub>Air</sub>

**Range of Validity:**

Dew point temperature  $t_\tau$  : from -143.15°C to  $t_{ds}(p, p_d)$   
 (boiling temperature of water in gas mixtures)  
 Mixture pressure p : from 6.112 mbar to 1000.0 bar

**Comments:**

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

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,  $x_w = -1$

**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 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
```

### Input values:

p        - Mixture pressure p in bar  
t        - Temperature t in °C  
t<sub>f</sub>     - Wet bulb temperature in °C

### Result:

xw\_pttf\_HuAir, x<sub>w</sub> - Absolute humidity from temperature and wet bulb temperature in g/kg<sub>Air</sub>

### Range of Validity:

Temperature t :                from -143.15°C to 1726.85°C  
Wet bulb temperature t<sub>f</sub> :    from 0.01°C to the given temperature t,  
   to t<sub>s</sub>(p,p<sub>d</sub>) (boiling temp. of water in gas mixtures)  
Mixture pressure p :         from 6.112 mbar to 1000.0 bar

### Comments:

Iteration of x<sub>w</sub> from  $h_i^{\text{unsaturated}}(p, t, x_w) = h_i^{\text{fog}}(p, t_f, x_w)$

- For temperatures greater than 500°C, the dissociation is taken into consideration

### Result for wrong input values:

xw\_pttf\_HuAir, xw = - 1

### References:

Dry Air:  
from *Lemmon et al.* [10]  
Steam in humid air and liquid droplets in fog:  
from IAPWS-IF97 [1], [2], [3], [4]  
Dissociation:  
from VDI Guideline 4670 [9]

**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

**Input values:**

- p - Mixture pressure p in bar  
 t - Temperature t in °C  
 v<sub>l</sub> - Air-specific volume in m<sup>3</sup>/kg<sub>Air</sub>

**Result:**xw\_ptvl\_HuAir, x<sub>w</sub> - Absolute humidity in g/kg<sub>Air</sub>**Range of Validity:**

- Temperature t : from -143.15°C to 1726.85°C  
 Mixture pressure p : from 6.112 mbar to 1000.0 bar

**Comments:**Iteration of x<sub>w</sub> from v<sub>l</sub>(p,t,x<sub>w</sub>)Calculation from v<sub>l</sub>(p,t,x<sub>w</sub>):

- 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<sub>w</sub> = - 1**References:**

Dry Air:

from *Lemmon* et al. [10]

Steam in humid air and liquid droplets in fog:

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

Ice crystals in fog:

according to IAPWS-06 [14], [15]

Dissociation:

from VDI Guideline 4670 [9]

**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

**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<sub>Air</sub>**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 1000.0 bar

**Comments:**

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

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

## Compression factor $z = f(p, t, x_w)$

### Function Name:

`z_ptxw_HuAir`

### Fortran Programs:

```
REAL*8 FUNCTION z_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw
```

### Input values:

`p` - Mixture pressure  $p$  in bar  
`t` - Temperature  $t$  in °C  
`xw` - Absolute humidity  $x_w$  in g/kg<sub>Air</sub>

### Result:

`z_ptxw_HuAir, vl` - Compression factor

### Range of Validity:

Temperature  $t$  : from -143.15°C to 1726.85°C  
 Mixture pressure  $p$  : from 6.112 mbar to 1000.0 bar  
 Absolute humidity  $x_w$  :  $\geq 0$  g/kg<sub>Air</sub>

### 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:

`z_ptxw_HuAir, vl` = -1

### References:

Dry Air:  
 from *Lemmon et al.* [10]  
 Steam in humid air and liquid droplets in fog:  
 from IAPWS-IF97 [1], [2], [3], [4]  
 Ice crystals in fog:  
 from IAPWS-06 [14], [15]

## 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, -S03rev, -S04, and -S05
- IAPWS Revised Advisory Note No. 3 on Thermodynamic Derivatives (2008)

#### Library LibIF97\_META

- Industrial Formulation IAPWS-IF97 (Revision 2007) for metastable steam

### Humid Combustion Gas Mixtures

#### Library LibHuGas

- Model: Ideal mixture of the real fluids:  
 CO<sub>2</sub> - Span, Wagner H<sub>2</sub>O - IAPWS-95  
 O<sub>2</sub> - Schmidt, Wagner N<sub>2</sub> - Span et al.  
 Ar - Tegeler et al.  
 and of the ideal gases:  
 SO<sub>2</sub>, CO, Ne  
 (Scientific Formulation of Bückler et al.)  
 Consideration of:
- Dissociation from VDI 4670
  - 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

### Extremely Fast Property Calculations

- Spline-Based Table  
 Look-up Method (SBTL)  
**Library LibSBTL\_IF97**  
**Library LibSBTL\_95**  
**Library LibSBTL\_HuAir**  
 For steam, water, humid air, carbon dioxide and other fluids and mixtures according IAPWS Guideline 2015 for Computational Fluid Dynamics (CFD), real-time and non-stationary simulations

### 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 <sub>2</sub> O	F <sub>2</sub>	Propane
N <sub>2</sub>	SO <sub>2</sub>	NH <sub>3</sub>	Iso-Butane
O <sub>2</sub>	H <sub>2</sub>	Methane	n-Butane
CO	H <sub>2</sub> S	Ethane	Benzene
CO <sub>2</sub>	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](http://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 Bückler and Wagner (2006)

#### n-Butane

#### Library LibButane\_n

Formulation of Bückler 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 <sub>2</sub> H <sub>6</sub> O <sub>2</sub>	Ethylene glycol
C <sub>3</sub> H <sub>8</sub> O <sub>2</sub>	Propylene glycol
C <sub>2</sub> H <sub>5</sub> OH	Ethanol
CH <sub>3</sub> OH	Methanol
C <sub>3</sub> H <sub>8</sub> O <sub>3</sub>	Glycerol
K <sub>2</sub> CO <sub>3</sub>	Potassium carbonate
CaCl <sub>2</sub>	Calcium chloride
MgCl <sub>2</sub>	Magnesium chloride
NaCl	Sodium chloride
C <sub>2</sub> H <sub>3</sub> KO <sub>2</sub>	Potassium acetate
CHKO <sub>2</sub>	Potassium formate
LiCl	Lithium chloride
NH <sub>3</sub>	Ammonia

Formulation of the International Institute of Refrigeration (IIR 2010)

### Ethanol

#### Library LibC2H5OH

Formulation of Schroeder et al. (2014)

### 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 and Oxygen

#### Libraries LibN2 and LibO2

Formulations of Span et al. (2000) and Schmidt and Wagner (1985)

### 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 **H<sub>2</sub>S** **Library LibH2S**

Nitrous oxide **N<sub>2</sub>O** **Library LibN2O**

Sulfur dioxide **SO<sub>2</sub>** **Library LibSO2**

Acetone  $C_3H_6O$  **Library LibC3H6O**

Formulation of Lemmon and Span (2006)



### For more information please contact:

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Mobile: +49-172-7914607  
Fax: +49-3222-1095810

### The following thermodynamic and transport properties can be calculated<sup>a</sup>:

#### Thermodynamic Properties

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

#### Transport Properties

- Dynamic viscosity  $\eta$
- Kinematic viscosity  $\nu$
- Thermal conductivity  $\lambda$
- Prandtl number  $Pr$
- Thermal diffusivity  $a$

#### Backward Functions

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

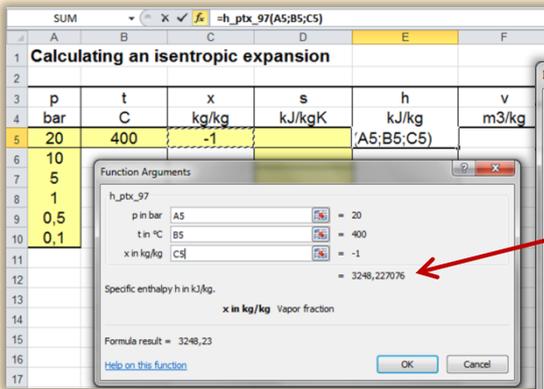
#### Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

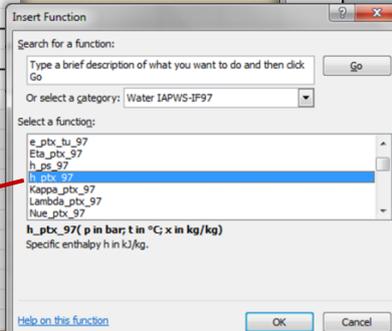
<sup>a</sup> Not all of these property functions are available in all property libraries.

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

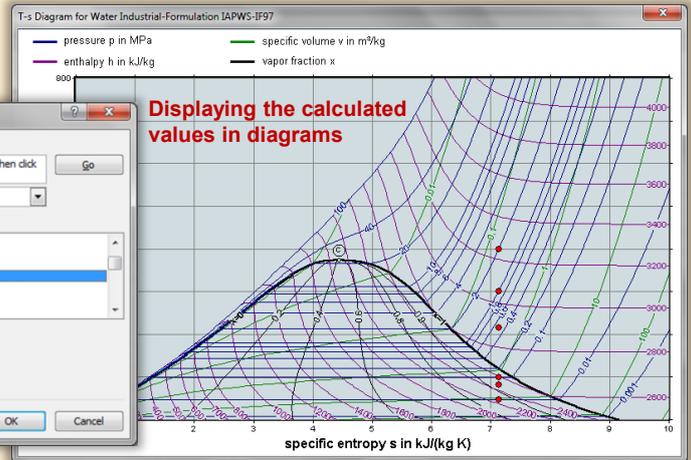
**Add-In FluidEXL<sup>Graphics</sup> for Excel<sup>®</sup>**



Choosing a property library and a function



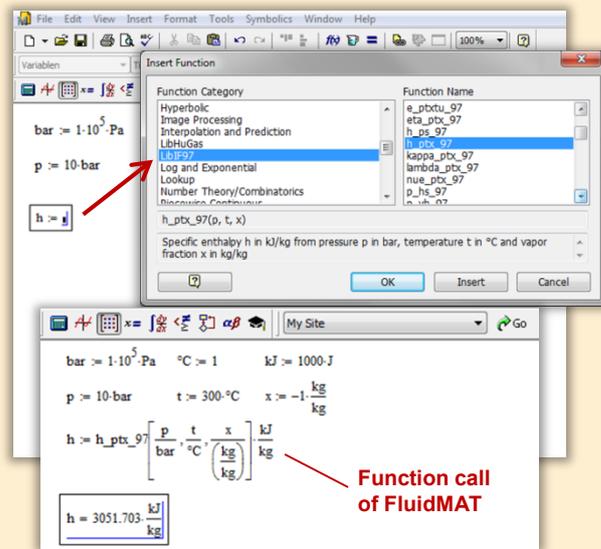
Displaying the calculated values in diagrams



Menu for the input of given property values

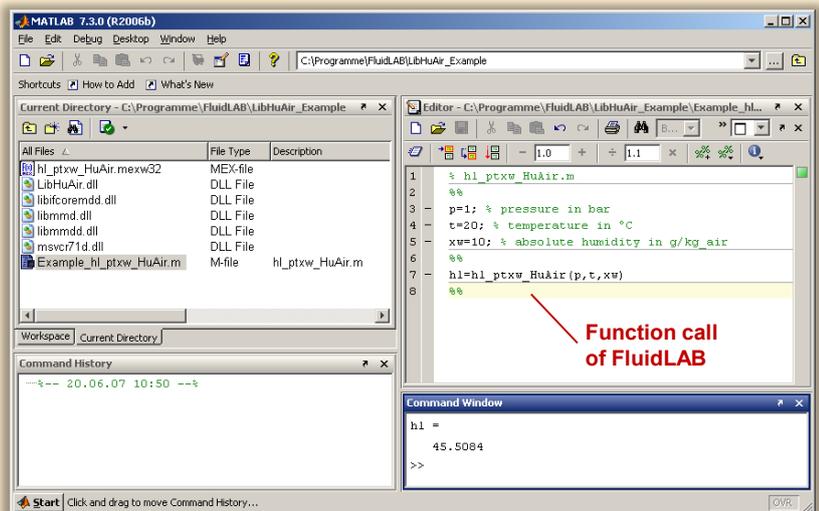
**Add-On FluidMAT for Mathcad<sup>®</sup>**  
**Add-On FluidPRIME for Mathcad Prime<sup>®</sup>**

The property libraries can be used in Mathcad<sup>®</sup> and Mathcad Prime<sup>®</sup>.



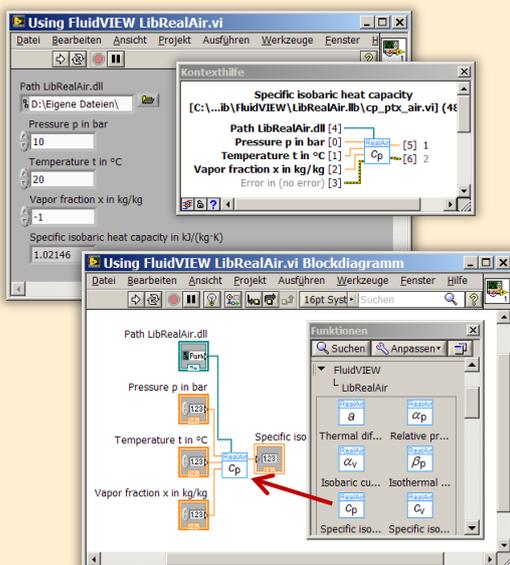
**Add-On FluidLAB for MATLAB<sup>®</sup> and SIMULINK<sup>®</sup>**

Using the Add-In FluidLAB the property functions can be called in MATLAB<sup>®</sup> and SIMULINK<sup>®</sup>.



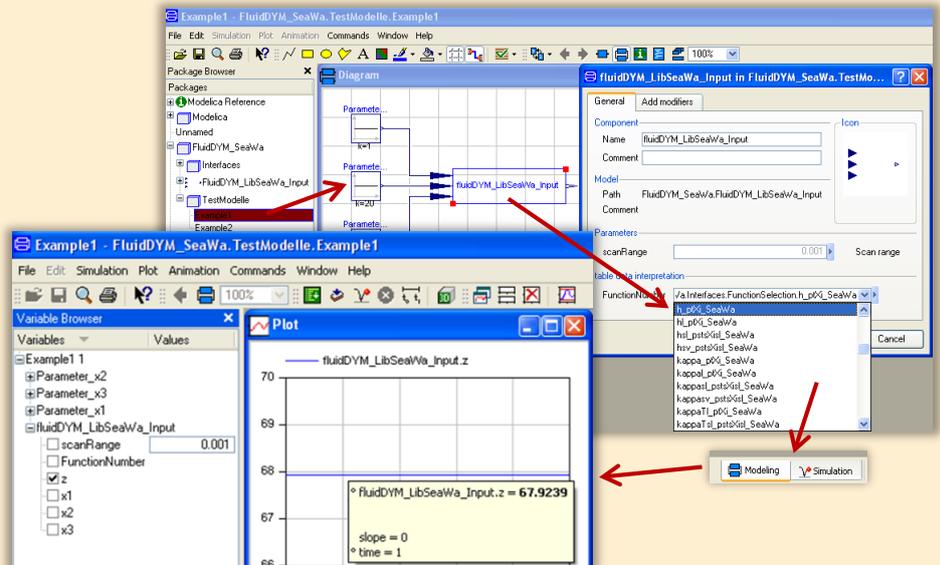
**Add-On FluidVIEW for LabVIEW<sup>™</sup>**

The property functions can be calculated in LabVIEW<sup>™</sup>.

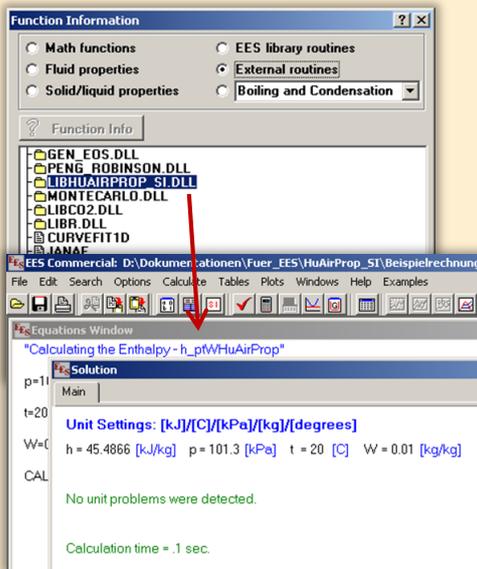


**Add-On FluidDYM for DYMOLA<sup>®</sup> (Modelica) and SimulationX<sup>®</sup>**

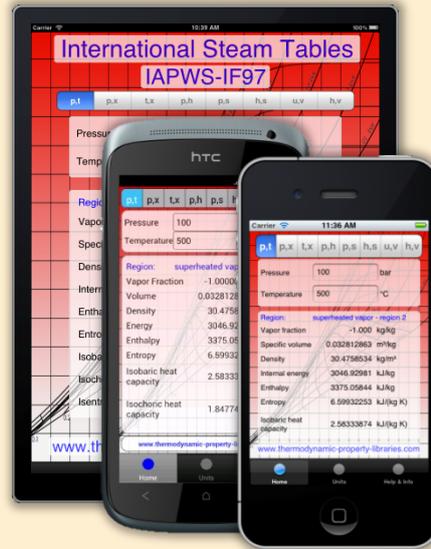
The property functions can be called in DYMOLA<sup>®</sup> and SimulationX<sup>®</sup>.



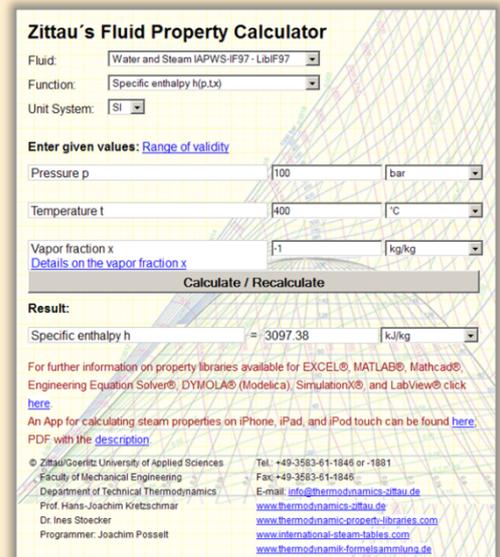
## Add-On FluidEES for Engineering Equation Solver®



## App International Steam Tables for iPhone, iPad, iPod touch, Android Smartphones and Tablets



## Online Property Calculator at [www.thermofluidprop.com](http://www.thermofluidprop.com)



## Property Software for Pocket Calculators

### FluidCasio



fx 9750 G II    CFX 9850 fx-GG20    CFX 9860 G Graph 85    ALGEBRA FX 2.0

### FluidHP



HP 48    HP 49

### FluidTI



TI Nspire CX CAS    TI 83    TI Voyage 200  
TI Nspire CAS    TI 84    TI 92  
TI 89

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The following thermodynamic and transport properties<sup>a</sup> 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  $\rho$
- Specific volume  $v$
- Enthalpy  $h$
- Internal energy  $u$
- Entropy  $s$
- Exergy  $e$
- Isobaric heat capacity  $c_p$
- Isochoric heat capacity  $c_v$
- Isentropic exponent  $\kappa$
- Speed of sound  $w$
- Surface tension  $\sigma$

### Transport Properties

- Dynamic viscosity  $\eta$
- Kinematic viscosity  $\nu$
- Thermal conductivity  $\lambda$
- Prandtl number  $Pr$
- Thermal diffusivity  $a$

### 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 used in process modeling can be calculated.

<sup>a</sup> Not all of these property functions are available in all property libraries.

## 5. References

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(RP-1485).  
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Final Report ASHRAE RP-1485, American Society of Heating, Refrigeration, and Air-  
Conditioning Engineers, Inc., Atlanta, GA, USA (2009, last update 2017).

## 6. Satisfied Customers

Period from 2018 to 2022

The following companies and institutions use the property libraries:

- FluidEXL *Graphics* for Excel® incl. VBA
- FluidLAB for MATLAB® and Simulink
- FluidMAT for Mathcad®
- FluidPRIME for Mathcad Prime®
- FluidEES for Engineering Equation Solver® EES
- FluidDYM for Dymola® (Modelica) and SimulationX®
- FluidVIEW for LabVIEW™
- FluidPYT for Python
- FluidJAVA for Java
- DLLs for Windows Applications
- Shared Objects for Linux
- Shared Objects for macOS.

### 2022

ASTG, Graz, Austria	12/2022
Wandschneider + Gutjahr, Hamburg	
RWE Supply & Trading, Essen	11/2022
Stadtwerke Rosenheim	
CEA, Saclay, France	10/2022
RWE Supply & Trading, Essen	
SEEC Saudi Energy Efficiency Center, Riyadh, Saudi Arabia	
MAN, Copenhagen, Denmark	
Hermeler & Partner Consulting Engineers, Sassenberg	09/2022
Envi Con, Nürnberg	
Drill Cool Systems, Bakersfield CA, USA	
RWE Supply & Trading, Essen	
Maerz Ofenbau, Zürich, Switzerland	
Saale Energie, Schkopau	
ERGO, Dresden	
Mainova, Frankfurt/Main	
Bundeswehr, Koblenz	08/2022
RWE Supply & Trading, Essen	
Grenzebach Corporation, Newnan GE, USA	
AGRANA, Gmuend, Austria	07/2022
MIBRAG, Zeitz	
Hochschule Niederrhein, Krefeld	
ULT, Löbau	06/2022
LEAG, Cottbus	
VPC Group, Vetschau	

Wärme, Hamburg	
ILK, Dresden	
Stricker IB, Küssnacht a. Rigi, Switzerland	
LEAG, Cottbus	05/2022
RWE Supply & Trading, Essen	
IGT Tomalla, Kreuztal	
B+T Engineering, Dübendorf, Switzerland	
Stricker IB, Küssnacht a. Rigi, Switzerland	
Vogelsang & Benning, Bochum	04/2022
Frischli, Rehburg-Loccum	
BPS Consulting, Sprengel	03/2022
HS Hannover, Maschinenbau & BioVT	
M+M Turbinentechnik, Bad Salzungen	
Uni. Strathclyde, Glasgow, UK	02/2022
Delta Energy Group, Jiaozhou City, Qingdao, China	
Wetzel IB, Guben	
Wijbenga, PC Geldermalsen, The Netherlands	
Voith Paper, Heidenheim	
HS Zittau/Görlitz, Maschinenwesen	01/2022
Thermische Abfallbehandlung, Lauterbach	
Webb Institute, Glen Cove NY, USA	
TU Berlin, Umweltverfahrenstechnik	
SachsenEnergie, Dresden	
Doosan, Chang-won-si, Gyeongsangnam-do, South Korea	
KW3, LH Veenendaal, The Netherlands	
Université du Luxembourg, Esch-sur-Alzette	
Enseleit IB, Mansfeld	
Caliqua/Equans, Zürich, Switzerland	
Rudnick & Enners, Alpenrod	

## 2021

Wenisch IB, Vetschau	12/2021
PPCHEM, Hinwil, Switzerland	
KW3, The Netherlands	
BASF Ludwigshafen	
Air-Consult, Jena	
Sjerp & Jongeneel, RB Zoetermeer, The Netherlands	11/2021
Maerz Ofenbau, Zürich, Switzerland	
RWE Supply & Trading, Essen	
Hahn IB, Dresden	10/2021
Therm, South Africa	
RWE Supply & Trading, Essen	
TH Nürnberg, Verfahrenstechnik	09/2021
RWE Supply & Trading, Essen	
Enseleit IB, Mansfeld	
SachsenEnergie, Dresden	
BSH Hausgeräte, Berlin	

Norsk Energi, Oslo, Norway	08/2021
AKM Industrieanlagen, Haltern	
Drill Cool Systems, Bakersfield CA, USA	
Siemens Energy Global, Erlangen	07/2021
Wulff & Umag, Husum	
Planungsbüro Waidhas, Chemnitz	
Burkhardt Energie Technik, Mühlhausen	
Lücke IB, Paderborn	06/2021
TU Dresden, Energieverfahrenstechnik	
Wärme, Hamburg	
AL-KO Therm, Kötz	
PCK Raffinerie, Schwedt	
Vogelsang & Benning, Bochum	05/2021
MTU, München	
VPC Group, Vetschau	
AVG, Köln	04/2021
TH Ulm, Institut für Fahrzeugtechnik	
Marty IB, Oberwil, Switzerland	
HypTec, Lebring, Austria	
Lopez IB, Getxo, Bizkaia, Spain	03/2021
GM Remediation Systems, Leoben, Austria	
Jager Kältetechnik, Osnabrück	
T&M Automation, GR Leidschendam, The Netherlands	
RWE Supply & Trading, Essen	
Stadtwerke Leipzig	
Beuth Hochschule für Technik, Berlin	
Beleth IB, Woeth	02/2021
ZTL, Thal, Austria	
ETABO Bochum	
RWE Supply & Trading, Essen	
Onyx Germany, Berlin	
TU Dresden, Kältetechnik	
GOHL-KTK, Durmersheim	
Therm Development, South Africa	
thermofin, Heinsdorfergrund	
RWE Supply & Trading, Essen	01/2021
STEAG, Essen	
ETA Energieberatung, Pfaffenhofen	
Enex Power, Kirchseeon	
<b>2020</b>	
Drill Cool, Bakersfield CA, USA	12/2020
Manders, The Netherlands	
RWE Supply & Trading, Essen	
NEOWAT Lodz, Poland	
University of Duisburg-Essen, Duisburg	11/2020
Stellenbosch University, South Africa	

University De France-COMTe, France	
RWE, Essen	
STEAG, Herne	
Isenmann Ingenieurbüro	
University of Stuttgart, ITLR, Stuttgart	
Norsk Energi, Oslo, Norway	
TGM Kanis, Nürnberg	
Stadtwerke Neuburg	10/2020
Smurfit Kappa, Roermond, The Netherlands	
RWE, Essen	
Hochschule Zittau/Görlitz, Wirtschaftsingenieurwesen	
Stadtwerke, Neuburg	
ILK, Dresden	
ATESTEO, Alsdorf	
Hochschule Zittau/Görlitz, Maschinenwesen	
TH Nürnberg, Verfahrenstechnik	
Drill Cool, Bakersfield CA,USA	09/2020
RWE, Essen	
2Meyers Ingenieurbüro, Nürnberg	
FELUWA, Mürlenbach	
Stadtwerke Neuburg	
Caverion, Wien, Austria	
GMVA Niederrhein, Oberhausen	
INWAT Lodz, Poland	
Troche Ingenieurbüro, Hayingen	08/2020
CEA Saclay, France	
VPC, Vetschau	07/2020
FSK System-Kälte-Klima, Dortmund	
Exergie Etudes, Sarl, Switzerland	
AWG Wuppertal	
STEAG Energy Services, Zwingenberg	
Hochschule Braunschweig	06/2020
DBI, Leipzig	
GOHL-KTK, Dumersheim	
TU Dresden, Energieverfahrenstechnik	
BASF SE, ESI/EE, Ludwigshafen	
Wärme Hamburg	
Ruchti Ingenieurbüro, Uster, Switzerland	
IWB, Basel, Switzerland	
Midiplan, Bietingen-Bissingen	05/2020
Knieschke, Ingenieurbüro	
RWE, Essen	
Leser, Hamburg	
AGRANA, Gmünd, Austria	
EWT Wassertechnik, Celle	
Hochschule Darmstadt	04/2020
MTU München CCP	
HAW Hamburg	03/2020

Hanon, Novi Jicin, Czech Republic  
 TU Dresden, Kältetechnik  
 MAN, Copenhagen, Denmark  
 EnerTech, Radebeul 02/2020  
 LEAG, Cottbus  
 B+B Engineering Magdeburg  
 Hochschule Offenburg  
 WIB, Dennheritz 01/2020  
 Universität Duisburg-Essen, Strömungsmaschinen  
 Kältetechnik Dresen-Bremen  
 TH Ingolstadt  
 Vattenfall AB, Jokkmokk, Sweden  
 Fraunhofer UMSICHT

## 2019

PEU Leipzig, Rötha 12/2019  
 MB-Holding, Vestenbergsgreuth  
 RWE, Essen  
 Georg-Büchner-Hochschule, Darmstadt 11/2019  
 EEB ENERKO, Aldenhoven  
 Robert Benoufa Energietechnik, Wiesloch  
 Kehrein & Kubanek Klimatechnik, Moers 10/2019  
 Hanon Systems Autopal Services, Hluk, Czech Republic  
 CEA Saclay, Gif Sur Yvette cedex, France  
 Saudi Energy Efficiency Center SEEC, Riyadh, Saudi Arabia  
 VPC, Vetschau 09/2019  
 jGanser PM + Engineering, Forchheim  
 Endress+Hauser Flowtec AG, Reinach, Switzerland  
 Ruchti IB, Uster, Switzerland  
 ZWILAG Zwischenlager Würenlingen, Switzerland 08/2019  
 Hochschule Zittau/Görlitz, Faculty Maschinenwesen  
 Stadtwerke Neubrandenburg  
 Physikalisch Technische Bundesanstalt PTB, Braunschweig  
 GMVA Oberhausen 07/2019  
 Endress+Hauser Flowtec AG, Reinach, Switzerland  
 WARNICA, Waterloo, Canada  
 MIBRAG, Zeitz 06/2019  
 Pöyry, Zürich, Switzerland  
 RWTH Aachen, Institut für Strahlantriebe und Turbomaschinen  
 Midiplan, Bietigheim-Bissingen  
 GKS Schweinfurt  
 HS Zittau/Görlitz, Wirtschaftswissenschaften und Wirtschaftsingenieurwesen  
 ILK Dresden  
 HZDR Helmholtz Zentrum Dresden-Rossendorf  
 TH Köln, Technische Gebäudeausrüstung 05/2019  
 IB Knittel, Braunschweig  
 Norsk Energi, Oslo, Norway

STEAG, Essen	
Stora Enso, Eilenburg	
IB Lücke, Paderborn	
Haarslev, Sonderso, Denmark	
MAN Augsburg	
Wieland Werke, Ulm	04/2019
Fels-Werke, Elbingerode	
Univ. Luxembourg, Luxembourg	
BTU Cottbus, Power Engineering	03/2009
Eins-Energie Sachsen, Schwarzenberg	
TU Dresden, Kälte- und Kryotechnik	
ITER, St. Paul Lez Durance Cedex, France	
Fraunhofer UMSICHT, Oberhausen	
Comparex Leipzig for Spedition Thiele HEMMERSBACH	
Rückert NaturGas, Lauf/Pegnitz	
BASF, Basel, Switzerland	02/2019
Stadtwerke Leipzig	
Maerz Ofenbau Zürich, Switzerland	
Hanon Systems Germany, Kerpen	
Thermofin, Heinsdorfergrund	01/2019
BSH Berlin	
<b>2018</b>	
Jaguar Energy, Guatemala	12/2018
WEBASTO, Gilching	
Smurfit Kappa, Oosterhout, Netherlands	
Univ. BW München	
RAIV, Liberec for VALEO, Prague, Czech Republic	11/2018
VPC Group Vetschau	
SEITZ, Wetzikon, Switzerland	
MVV, Mannheim	10/2018
IB Troche	
KANIS Turbinen, Nürnberg	
TH Ingolstadt, Institut für neue Energiesysteme	
IB Kristl & Seibt, Graz, Austria	09/2018
INEOS, Köln	
IB Lücke, Paderborn	
Südzucker, Ochsenfurt	08/2018
K&K Turbinenservice, Bielefeld	07/2018
OTH Regensburg, Elektrotechnik	
Comparex Leipzig for LEAG, Berlin	06/2018
Münstermann, Telgte	05/2018
TH Nürnberg, Verfahrenstechnik	
Universität Madrid, Madrid, Spanien	
HS Zittau/Görlitz, Wirtschaftsingenieurwesen	
HS Niederrhein, Krefeld	
Wilhelm-Büchner HS, Pfungstadt	03/2018

GRS, Köln	
WIB, Dennheritz	
RONAL AG, Härklingen, Schweiz	02/2018
Ingenieurbüro Leipert, Riegelsberg	
AIXPROCESS, Aachen	
KRONES, Neutraubling	
Doosan Lentjes, Ratingen	01/2018