

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

**FluidEXL Graphics**  
with **LibHuAir\_Xiw**  
for Excel®

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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\_Xiw**

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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\_Xiw\_x64.zip

including the following folders and files:

\FLUFT\  
\Formulation97\  
FluidEXL\_Graphics\_LibHuAir\_Xiw\_Docu\_Eng.pdf  
FluidEXL\_Graphics\_Eng.xla  
LC.dll  
LibHuAir\_Xiw.dll  
LibHuAir\_Xiw.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\_Xiw.zip

including the following folders and files:

\FLUFT\  
\Formulation97\  
FluidEXL\_Graphics\_LibHuAir\_Xiw\_Docu\_Eng.pdf  
FluidEXL\_Graphics\_Eng.xla  
LC.dll  
LibHuAir\_Xiw.dll  
LibHuAir\_Xiw.chm.

# 1. Property Functions

## 1.1 Functions

Functional Dependence	Function Name	Call from Fortran Program	Property or Function	Unit	Source or Algorithm	Information on page
$a = f(p, t, \xi_w)$	a_ptXiw_HuAir	= A_PTIXIW_HUAIR(p,t,Xiw,succ)	Thermal diffusivity	$\text{m}^2/\text{s}$	[1-4], [6], [12], [14], [15]	3/2
$c_p = f(h, s, \xi_w)$	cp_hsXiw_HuAir	= CP_HSXIW_HUAIR(h,s,Xiw,succ)	Backward function: Isobaric heat capacity from enthalpy and entropy	$\text{kJ}/(\text{kg}\cdot\text{K})$	[1-4], [13], [14]	3/3
$c_p = f(p, h, \xi_w)$	cp_phXiw_HuAir	= CP_PHXIW_HUAIR(p,h,Xiw,succ)	Backward function: Isobaric heat capacity from pressure and enthalpy	$\text{kJ}/(\text{kg}\cdot\text{K})$	[1-4], [13], [14]	3/4
$c_p = f(p, s, \xi_w)$	cp_psXiw_HuAir	= CP_PSXIW_HUAIR(p,s,Xiw,succ)	Backward function: Isobaric heat capacity from pressure and entropy	$\text{kJ}/(\text{kg}\cdot\text{K})$	[1-4], [13], [14]	3/5
$c_p = f(p, t, \xi_w)$	cp_ptXiw_HuAir	= CP_PTIXIW_HUAIR(p,t,Xiw,succ)	Specific isobaric heat capacity	$\text{kJ}/(\text{kg}\cdot\text{K})$	[1-4], [13], [14]	3/6
$c_p = f(t, s, \xi_w)$	cp_tsXiw_HuAir	= CP_TSXIW_HUAIR(t,s,Xiw,succ)	Backward function: Specific isobaric heat capacity from temperature and entropy	$\text{kJ}/(\text{kg}\cdot\text{K})$	[1-4], [13], [14]	3/7
$c_v = f(p, t, \xi_w)$	cv_ptXiw_HuAir	= CV_PTIXIW_HUAIR(p,t,Xiw,succ)	Specific isochoric heat capacity	$\text{kJ}/(\text{kg}\cdot\text{K})$	[1-4], [13], [14]	3/8
$\eta = f(p, t, \xi_w)$	Eta_ptXiw_HuAir	= ETA_PTIXIW_HUAIR(p,t,Xiw,succ)	Dynamic viscosity	$\text{Pa}\cdot\text{s}$	[7], [12], [15]	3/9
$h = f(p, s, \xi_w)$	h_psXiw_HuAir	= H_PSXIW_HUAIR(p,s,Xiw,succ)	Backward function: Specific enthalpy from pressure and entropy	$\text{kJ/kg}$	[1-4], [13], [14], [18], [19]	3/10
$h = f(p, t, \xi_w)$	h_ptXiw_HuAir	= H_PTIXIW_HUAIR(p,t,Xiw,succ)	Specific enthalpy	$\text{kJ/kg}$	[1-4], [13], [14], [18], [19]	3/11
$h = f(t, s, \xi_w)$	h_tsXiw_HuAir	= H_TSXIW_HUAIR(t,s,Xiw,succ)	Backward function: Specific enthalpy from temperature and entropy	$\text{kJ/kg}$	[1-4], [13], [14], [18], [19]	3/12

Functional Dependence	Function Name	Call from Fortran Program	Property or Function	Unit	Source or Algorithm	Information on page
$\kappa = f(p, s, \xi_w)$	Kappa_psXiw_HuAir	= KAPPA_PSXIW_HUAIR(p,s,Xiw,succ)	Backward function: Isentropic exponent from pressure and entropy	-	[1-4], [13], [14]	3/13
$\kappa = f(p, t, \xi_w)$	Kappa_ptXiw_HuAir	= KAPPA_PTIXIW_HUAIR(p,t,Xiw,succ)	Isentropic exponent	-	[1-4], [13], [14]	3/14
$\lambda = f(p, t, \xi_w)$	Lambda_ptXiw_HuAir	= LAMBDA_PTIXIW_HUAIR(p,t,Xiw,succ)	Thermal conductivity	W/(m · K)	[6], [12], [15]	3/15
$\nu = f(p, t, \xi_w)$	Ny_ptXiw_HuAir	= NY_PTIXIW_HUAIR(p,t,Xiw,succ)	Kinematic viscosity	m <sup>2</sup> /s	[1-4], [7], [12], [14], [15]	3/16
$p = f(h, s, \xi_w)$	p_hsXiw_HuAir	= P_HSXIW_HUAIR(h,s,Xiw,succ)	Backward function: Pressure from enthalpy and entropy	bar	[1-4], [13], [14], [18], [19]	3/17
$p = f(t, s, \xi_w)$	p_tsXiw_HuAir	= P_TSXIW_HUAIR(t,s,Xiw,succ)	Backward function: Pressure from temperature and entropy	bar	[1-4], [13], [14], [18], [19]	3/18
$p_d = f(p, t, \xi_w)$	pd_ptXiw_HuAir	= PD_PTIXIW_HUAIR(p,t,Xiw,succ)	Partial pressure of steam	bar	[1-4], [16], [17], [25], [26]	3/19
$p_{dsatt} = f(p, t)$	pdsatt_pt_HuAir	= PDSATT_PT_HUAIR(p,t,succ)	Saturation vapor pressure of water	bar	[1-4], [16], [17], [25], [26]	3/20
$\varphi = f(p, t, \xi_w)$	Phi_ptXiw_HuAir	= PHI_PTIXIW_HUAIR(p,t,Xiw,succ)	Relative humidity	-	[1-4], [16], [17], [25], [26]	3/21
$p_l = f(p, t, \xi_w)$	pl_ptXiw_HuAir	= PL_PTIXIW_HUAIR(p,t,Xiw,succ)	Partial pressure of air	bar	[1-4], [16], [17], [25], [26]	3/22
$Pr = f(p, t, \xi_w)$	Pr_ptXiw_HuAir	= PR_PTIXIW_HUAIR(p,t,Xiw,succ)	PRANDTL-Number	-	[1-4], [6], [7], [12-15]	3/23
$\psi_l = f(\xi_w)$	Psil_Xiw_HuAir	= PSIL_XIW_HUAIR(Xiw,succ)	Mole fraction of air	kmol/kmol		3/24
$\psi_w = f(\xi_w)$	Psiw_Xiw_HuAir	= PSIW_XIW_HUAIR(Xiw,succ)	Mole fraction of water	kmol/kmol		3/25
$Region = f(h, s, \xi_w)$	Region_hsXiw_HuAir	= REGION_HSXIW_HUAIR(p,h,Xiw)	Region of state from enthalpy and entropy	-	[1-4], [14], [18], [19]	3/26
$Region = f(p, h, \xi_w)$	Region_phXiw_HuAir	= REGION_PHXIW_HUAIR(p,h,Xiw)	Region of state from pressure and enthalpy	-	[1-4], [14], [18], [19]	3/27

Functional Dependence	Function Name	Call from Fortran Program	Property or Function	Unit	Source or Algorithm	Information on page
$Region = f(p, s, \xi_w)$	Region_psXiw_HuAir	= REGION_PSXIW_HUAIR(p,s,Xiw)	Region of state from pressure and entropy	-	[1-4], [14], [18], [19]	3/28
$Region = f(p, T, \xi_w)$	Region_ptXiw_HuAir	= REGION_PTIXIW_HUAIR(p,t,Xiw)	Region of state from pressure and temperature	-	[1-4], [14], [18], [19]	3/29
$Region = f(t, s, \xi_w)$	Region_tsXiw_HuAir	= REGION_TSXIW_HUAIR(t,s,Xiw)	Region of state from temperature and entropy	-	[1-4], [14], [18], [19]	3/30
$\rho = f(p, t, \xi_w)$	Rho_ptXiw_HuAir	= RHO_PTIXIW_HUAIR(p,t,Xiw,succ)	Density	kg/m <sup>3</sup>	[1-4], [14], [18], [19]	3/31
$s = f(p, h, \xi_w)$	s_phXiw_HuAir	= S_PHXIW_HUAIR(p,h,Xiw,succ)	Backward function: Entropy from pressure and enthalpy	kJ/(kg·K)	[1-4], [13], [14], [18], [19]	3/32
$s = f(p, t, \xi_w)$	s_ptXiw_HuAir	= S_PTIXIW_HUAIR(p,t,Xiw,succ)	Specific entropy	kJ/(kg·K)	[1-4], [13], [14], [18], [19]	3/33
$\sigma = f(t)$	Sigma_t_HuAir	= SIGMA_T_HUAIR (t,succ)	Surface tension of water	N/m	[8]	3/34
$t = f(h, s, \xi_w)$	t_hsXiw_HuAir	= T_HSXIW_HUAIR(h,s,Xiw,succ)	Backward function: Temperature from enthalpy and entropy	°C	[1-4], [13], [14], [18], [19]	3/35
$t = f(p, h, \xi_w)$	t_phXiw_HuAir	= T_PHXIW_HUAIR(p,h,Xiw,succ)	Backward function: Temperature from pressure and enthalpy	°C	[1-4], [13], [14], [18], [19]	3/36
$t = f(p, s, \xi_w)$	t_psXiw_HuAir	= T_PSXIW_HUAIR(p,s,Xiw,succ)	Backward function: Temperature from pressure and entropy	°C	[1-4], [13], [14], [18], [19]	3/37
$t = f(p, t_f, \xi_w)$	t_ptfXiw_HuAir	= T_PTFXIW_HUAIR(p,tf,Xiw,succ)	Temperature	°C	[1-4], [13], [22]	3/38
$t_f = f(p, t, \xi_w)$	tf_ptXiw_HuAir	= TF_PTIXIW_HUAIR(p,t,Xiw,succ)	Wet bulb temperature	°C	[1-4], [13], [22]	3/39
$t_\tau = f(p, \xi_w)$	tTau_pXiw_HuAir	= TTAU_PXIW_HUAIR(p,Xiw,succ)	Dew point temperature	°C	[1-4], [16], [17]	3/40
$u = f(p, t, \xi_w)$	u_ptXiw_HuAir	= U_PTIXIW_HUAIR(p,t,Xiw,succ)	Internal energy	kJ/kg	[1-4], [13], [14], [18], [19]	3/41
$v = f(h, s, \xi_w)$	v_hsXiw_HuAir	= V_HSXIW_HUAIR(h,s,Xiw,succ)	Backward function: Specific volume from enthalpy and entropy	m <sup>3</sup> /kg	[1-4], [13], [14], [18], [19]	3/42

Functional Dependence	Function Name	Call from Fortran Program	Property or Function	Unit	Source or Algorithm	Information on page
$v = f(p, h, \xi_w)$	v_phXiw_HuAir	= V_PHXIW_HUAIR(p,h,Xiw,succ)	Backward function: Specific volume from pressure and enthalpy	m <sup>3</sup> /kg	[1-4], [13], [14], [18], [19]	3/43
$v = f(p, s, \xi_w)$	v_psXiw_HuAir	= V_PSXIW_HUAIR(p,s,Xiw,succ)	Backward function: Specific volume from pressure and entropy	m <sup>3</sup> /kg	[1-4], [13], [14], [18], [19]	3/44
$v = f(p, t, \xi_w)$	v_ptXiw_HuAir	= V_PTXIW_HUAIR(p,t,Xiw,succ)	Specific volume	m <sup>3</sup> /kg	[1-4], [14], [18], [19]	3/45
$v = f(t, s, \xi_w)$	v_tsXiw_HuAir	= V_TSXIW_HUAIR(t,s,Xiw,succ)	Backward function: Specific volume from temperature and entropy	m <sup>3</sup> /kg	[1-4], [13], [14], [18], [19]	3/46
$w = f(p, t, \xi_w)$	w_ptXiw_HuAir	= W_PTXIW_HUAIR(p,t,Xiw,succ)	ISENTROPIC speed of sound	m/s	[1-4], [13], [14]	3/47
$\xi_w = f(p, t, p_d)$	Xiw_ptpd_HuAir	= XIW_PTPD_HUAIR(p,t,pd,succ)	Mass fraction of water from partial pressure of steam	kg/kg	[1-4], [16], [17], [25], [26]	3/48
$\xi_w = f(p, t, \varphi)$	Xiw_ptPhi_HuAir	= XIW_PTPHI_HUAIR(p,t,Phi,succ)	Mass fraction of water from temperature and relative humidity	kg/kg	[1-4], [16], [17], [25], [26]	3/49
$\xi_w = f(p, t_{\tau})$	Xiw_ptTau_HuAir	= XIW_PTTAU_HUAIR(p,tTau,succ)	Mass fraction of water from dew point temperature	kg/kg	[1-4], [16], [17], [25], [26]	3/50
$\xi_w = f(p, t, t_f)$	Xiw_pttf_HuAir	= XIW_PTTF_HUAIR(p,t,tf,succ)	Mass fraction of steam from temperature and wet bulb temperature	kg/kg	[1-4], [13], [14]	3/51
$\xi_{wf} = f(p, t, \xi_w)$	Xiwf_ptXiw_HuAir	= XIWF_PTXIW_HUAIR (p,t,Xiw,succ)	Mass fraction of liquid water	kg/kg	[1-4], [16], [17], [25], [26]	3/52
$\xi_{wsatt} = f(p, t)$	Xiwsatt_pt_HuAir	= XIWSATT_PT_HUAIR(p,t,succ)	Mass fraction steam of saturated air	kg/kg	[1-4], [16], [17], [25], [26]	3/53
$x_w = f(\xi_w)$	xw_Xiw_HuAir	= XW_XIW_HUAIR(Xiw,succ)	Humidity ratio (absolute humidity) from mass fraction of water	kg/kg <sub>Air</sub>		3/54

### Types of variables for function calls

All functions, except Region_...	REAL*8
All variables, except succ	REAL*8
Region_..., succ	INTEGER*4

### Definition of the output value "succ":

succ	Meaning
0	Calculation not successful
1	Calculation successful

### Definition of the region of state "Region":

Region	Meaning
0	Outside range of validity
1	Dry air
2	Unsaturated humid air
3	Liquid fog
4	Ice fog
5	Mixture of liquid fog and ice fog at 0 °C exactly
6	Pure water

### Reference states:

Factor	Dry air	Water
Pressure	1.01325 bar	611.657 Pa
Temperature	0 °C	273.16 K
Enthalpy	0 kJ/kg	0.611783 J/kg
Internal energy	-78.37885533 kJ/kg	0 J/kg
Entropy	0.161802887 kJ/(kg K)	0 J/(kg K)

### Composition of dry air (from Lemmon et al. [22], [23]):

Component	Mole fraction	
Nitrogen	N <sub>2</sub>	0.7812
Oxygen	O <sub>2</sub>	0.2096
Argon	Ar	0.0092

## Parameters

- p - Total pressure in bar
- t - Temperature in °C
- $X_{iw}$  - Mass fraction of water in kg water(steam)/kg humid air
- succ - Output parameter: succ = 1 if calculation successful, or else succ = 0

## Range of validity

- Temperature  $t = -143.15 \text{ } ^\circ\text{C} \dots 1726.85 \text{ } ^\circ\text{C}$
- Pressure  $p = 6.112 \text{ mbar} \dots 1000 \text{ bar}$

## Calculation algorithms

Unsaturated and saturated humid air ( $0 \leq X_{iw} \leq X_{ws}$ ):

Ideal mixture of dry air and steam

Dry air:

- v, h, u, s,  $c_p$ ,  $c_v$ ,  $\kappa$ , w from Lemmon et al. [14]
- $\lambda$ ,  $\eta$  from Lemmon et al. [15]

Steam:

- v, h, u, s,  $c_p$ ,  $c_v$ ,  $\kappa$ , w of steam from IAPWS-IF97 [1], [2], [3], [4]
- $\lambda$ ,  $\eta$  for  $0^\circ\text{C} \leq t \leq 800^\circ\text{C}$  from IAPWS-85 [6], [7] (Mixture of volume fractions)  
for  $t < 0^\circ\text{C}$  and  $t > 800^\circ\text{C}$  from Brandt [12] (Mixture of volume fractions)

Supersaturated humid air (liquid fog or ice fog)

Liquid fog ( $X_{iw} > X_{wsatt}$ ) and  $t \geq 0^\circ\text{C}$

Ideal mixture of saturated humid air and water liquid

- saturated humid air as specified above
- v, h, u, s,  $\kappa$ , w of liquid drops from IAPWS-IF97 [1], [2], [3], [4]
- $\lambda$ ,  $\eta$  of liquid drops from IAPWS-85, IAPWS-08 [6], [7] (Mixture of volume fractions)

Ice fog ( $X_{iw} > X_{wsatt}$ ) and  $t < 0^\circ\text{C}$

Ideal mixture of saturated humid air and water ice

- saturated humid air as specified above
- v, h, s of ice crystals from IAPWS-06 [18], [19]
- $\lambda$  of ice crystals as non varying value
- $\eta$ ,  $\kappa$ , w of saturated humid air

$X_{wsatt}(p,t)$  from saturation pressure  $p_{dsatt}(p,t)$  of water in mixtures of gases

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

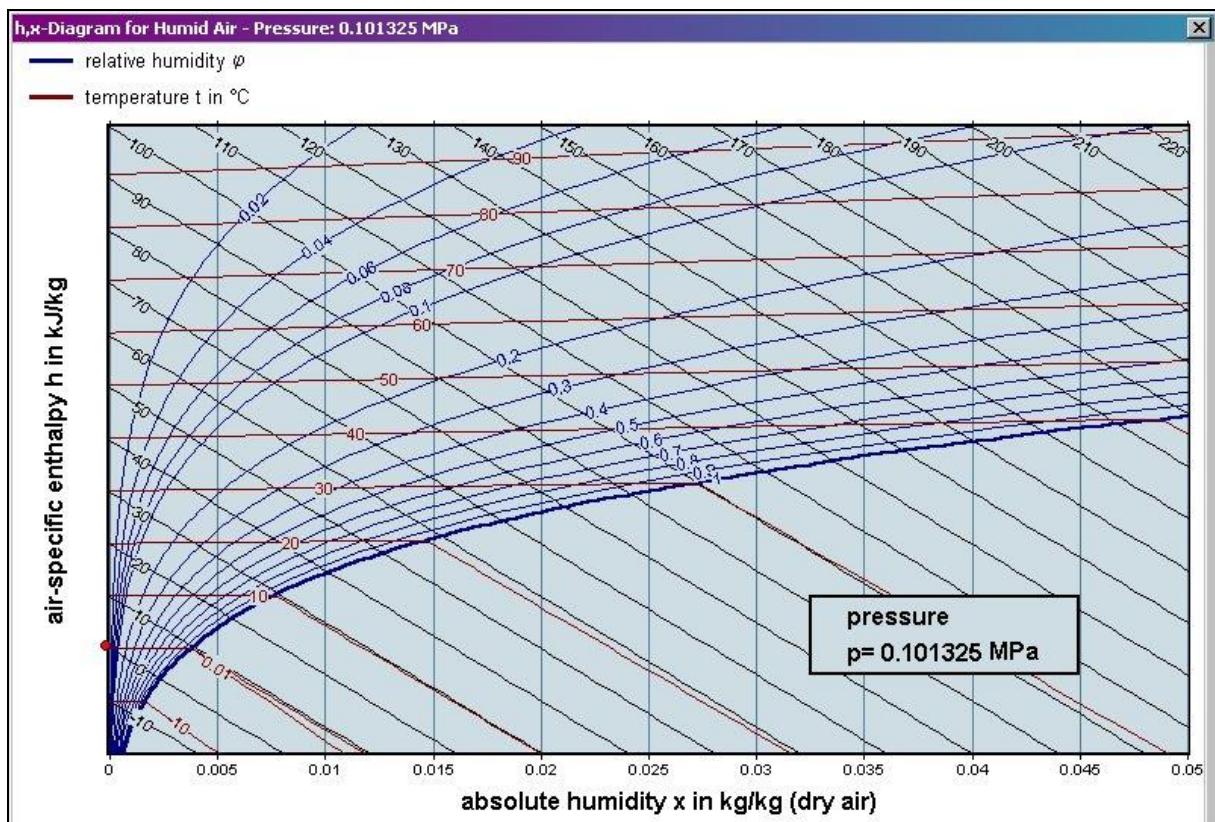
- $f(p,t)$  from Herrmann et al. [25], [26],
- $p_s(t)$  for  $T \geq 0.01 \text{ } ^\circ\text{C}$  from IAPWS - IF97 [1], [2], [3], [4],
- $p_s(t)$  for  $T < 0 \text{ } ^\circ\text{C}$  from IAPWS-08 [16], [17].

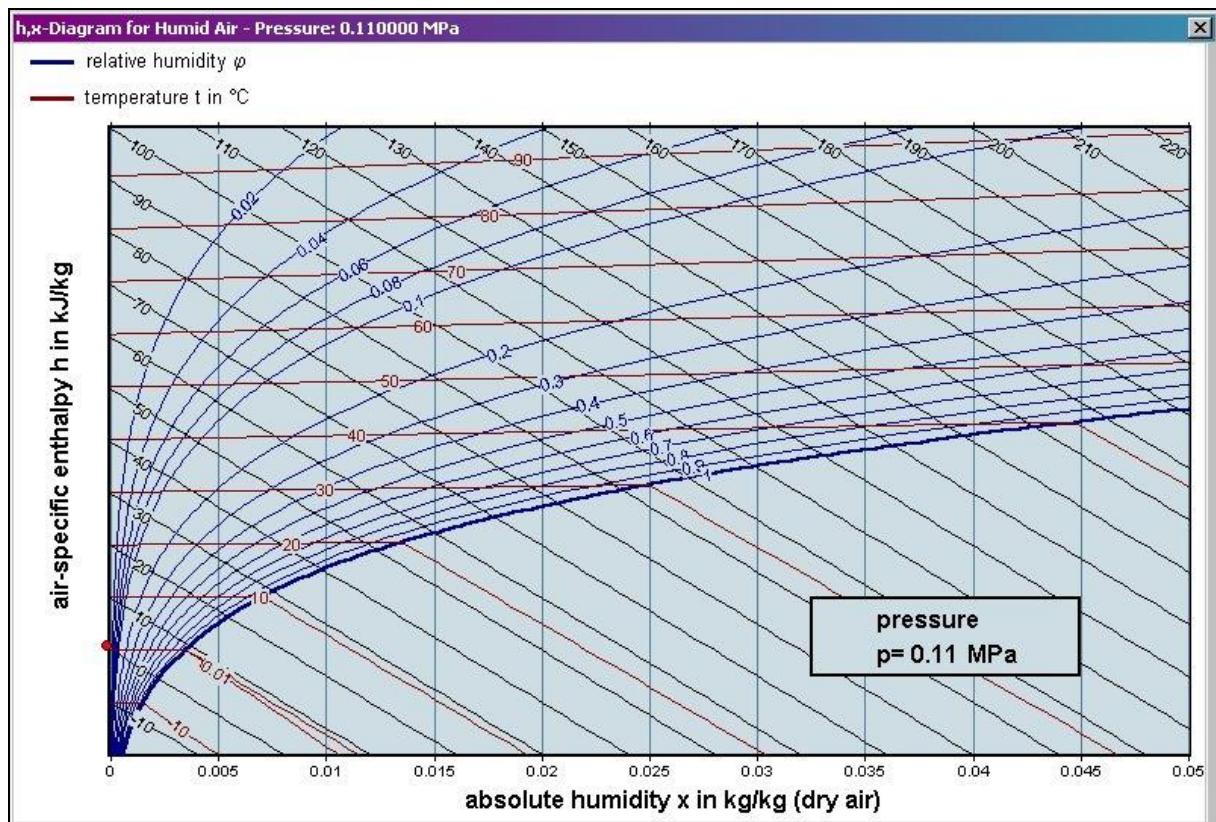
## 1.2 Thermodynamic Diagrams

FluidEXL Graphics enables the user to represent the calculated properties 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 point will be displayed, 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\_Xiw 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\_Xiw\_x64\_Eng.zip (for 64 bit version)

or

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

you will see the folder

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

or

\CD\_FluidEXL\_Graphics\_LibHuAir\_Xiw\_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\_Xiw\_Docu\_Eng

LC.dll

LibHuAir\_Xiw.dll

LibHuAir\_Xiw.chm

Reg\_.reg

Now, please copy the following folders and files

\FLUFT\

\Formulation97\

FluidEXL\_Graphics\_Eng.xla

LibHuAir\_Xiw.dll

LibHuAir\_Xiw.chm

LC.dll

into the folder

C:\Users\[your name]\AppData\Roaming\Microsoft\AddIns\,

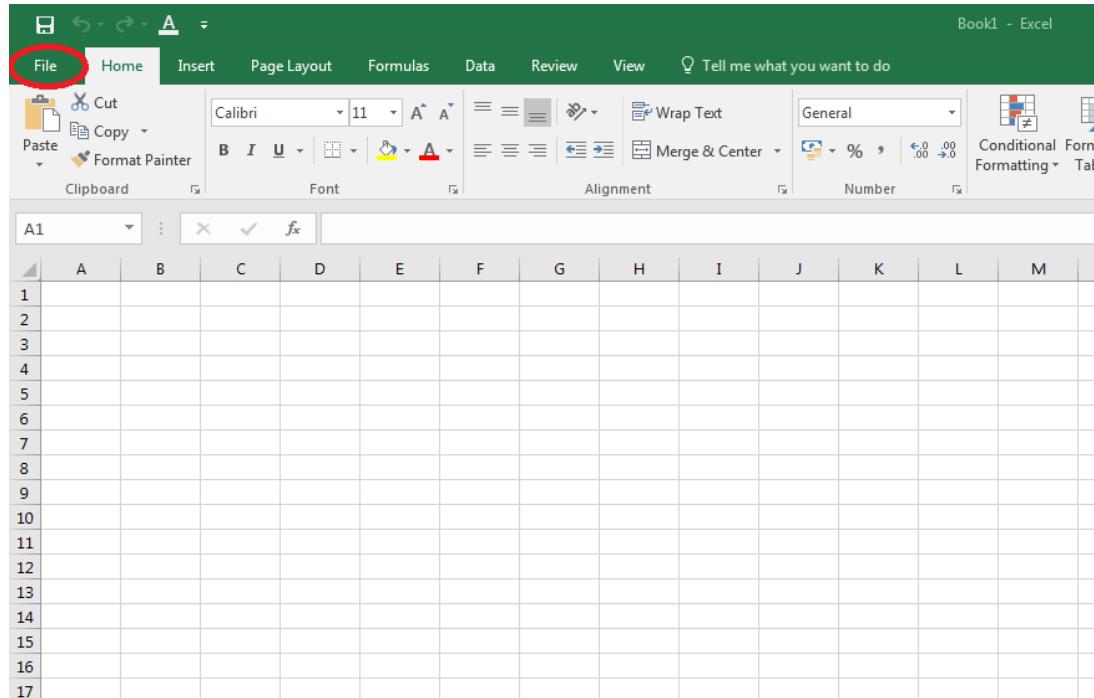
where [your name] is your name in the Windows system.

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

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

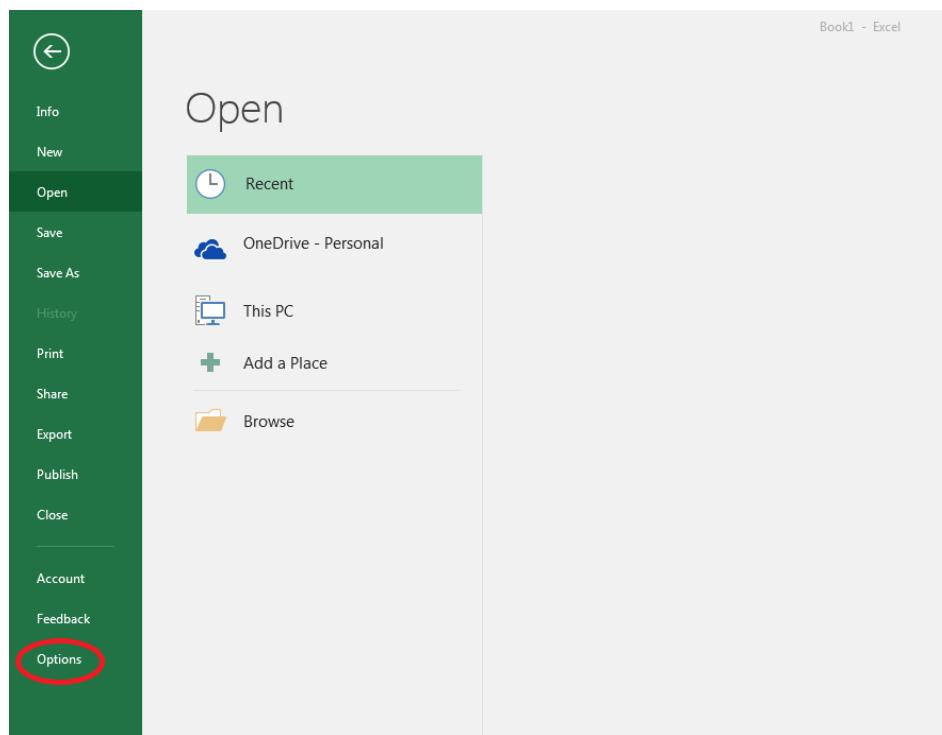
After installation in Windows®, FluidEXL *Graphics* must be registered in Excel® as an Add-In. To do this, start Excel® and carry out the following steps:

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



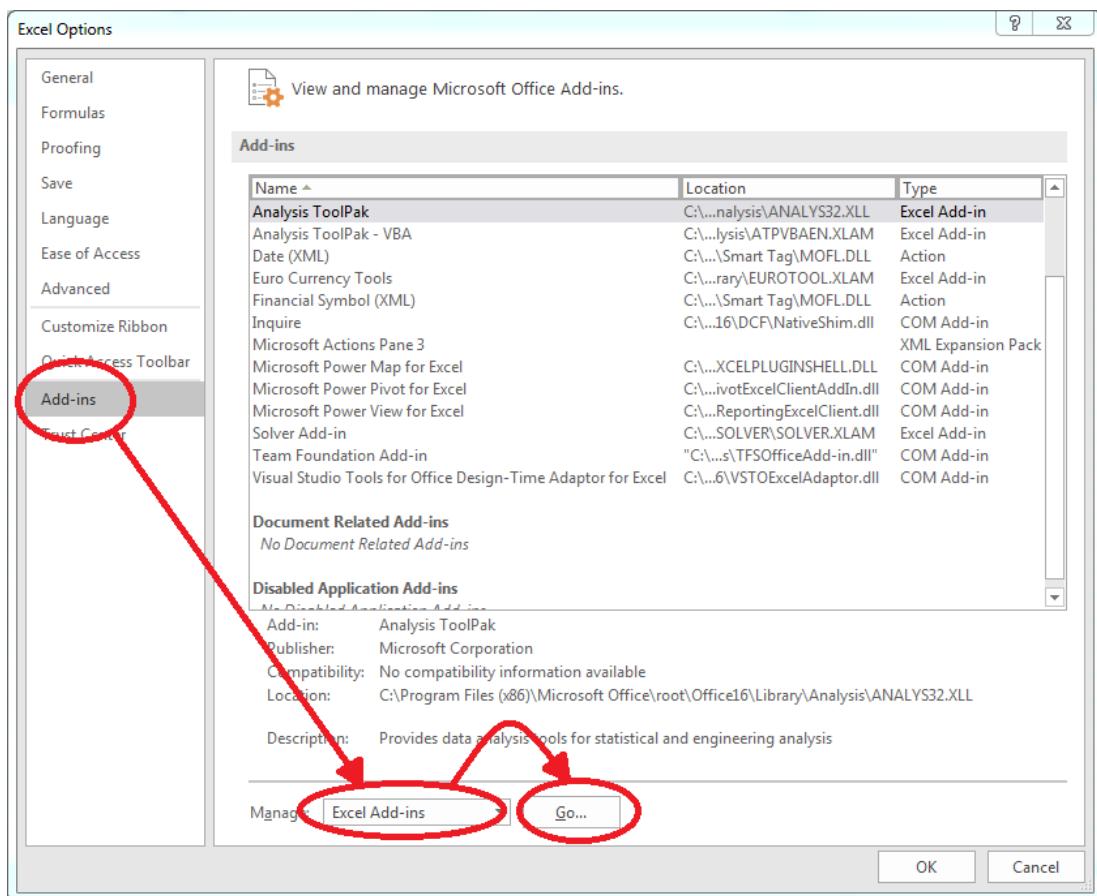
**Figure 2.1:** Registering FluidEXL *Graphics* as Add-In in Excel® 2016

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



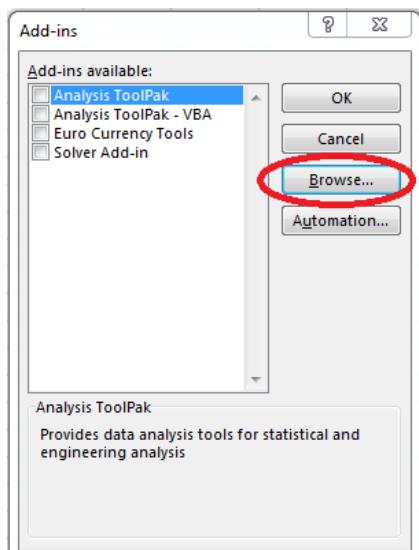
**Figure 2.2:** Registering FluidEXL *Graphics* as Add-In in Excel® 2016

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



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

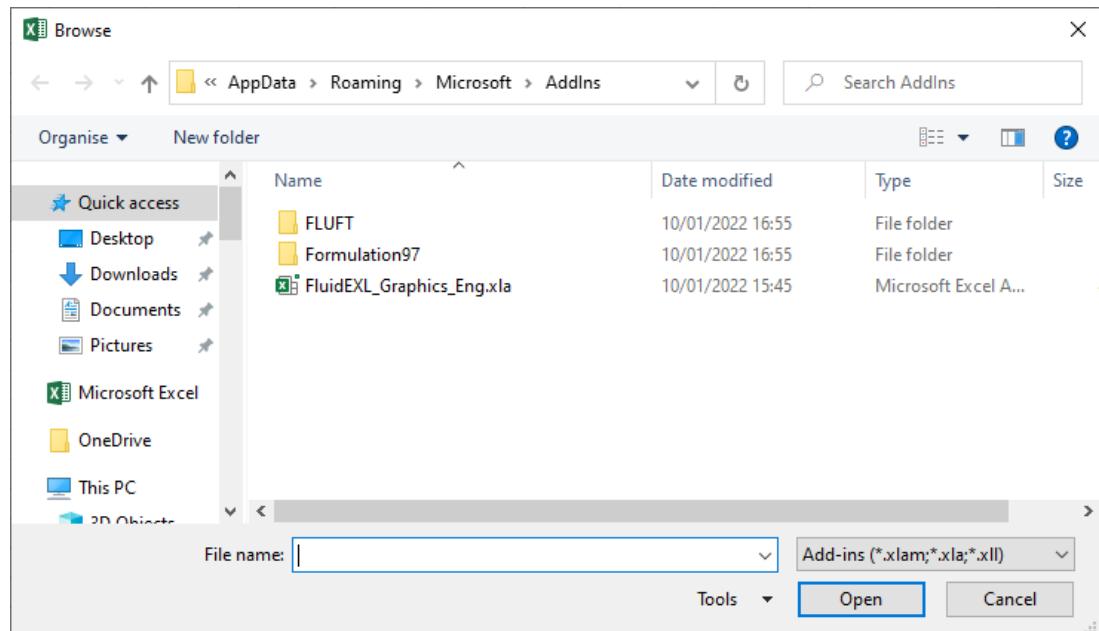
- Select "Excel Add-ins" next to "Manage:" in the lower area of the menu
- Then click the "Go..." button
- Click "Browse" in the following window (Fig. 2.4)



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

- Excel opens the AddIns folder. This is usually [C:\Users\\[your name\]\AppData\Roaming\Microsoft>AddIns](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

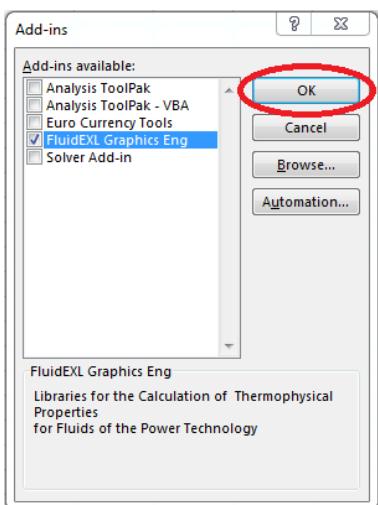
Please copy this path and paste it into your file manager.

Now, please copy the following directories and files:

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

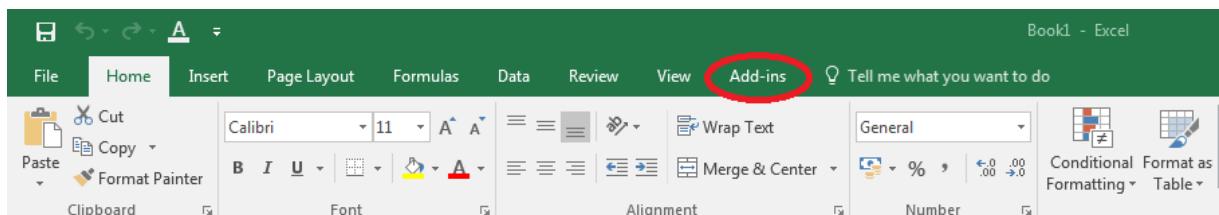
from the delivered CD-folder into this folder.

- 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.



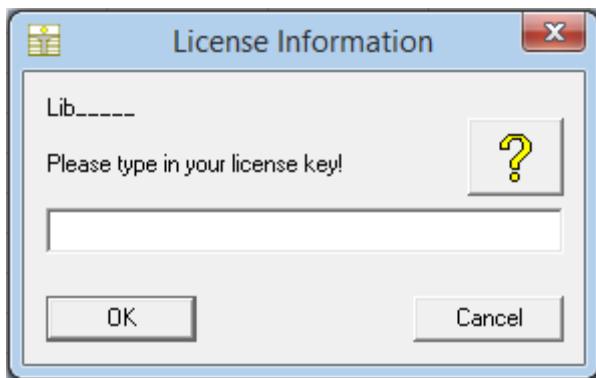
**Figure 2.8:** FluidEXL *Graphics* menu bar

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

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

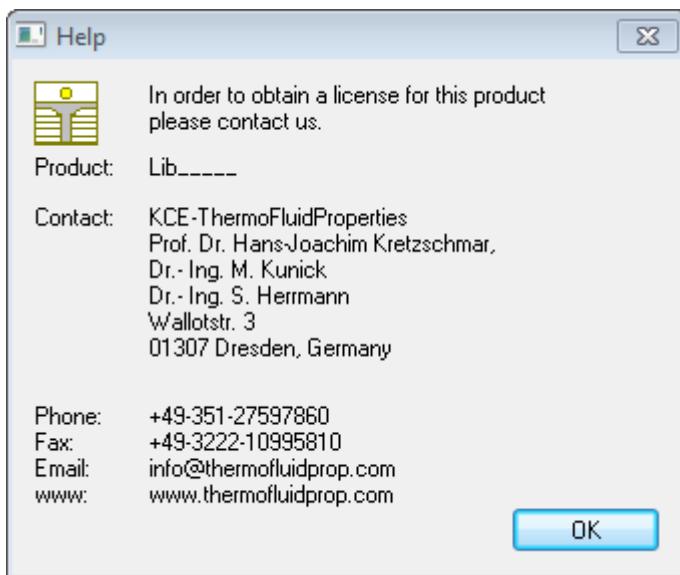
### 2.3 Licensing the LibHuAir\_Xiw Property Library

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\_Xiw 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\_Graphics according to the description in section 2.6 of this User's Guide.

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

LibHuAir\_Xiw.dll

LibHuAir\_Xiw.chm

in the installation folder of FluidEXL\_Graphics (the standard being)

C:\Program Files\FluidEXL\_Graphics\_Eng

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

#### **Note:**

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

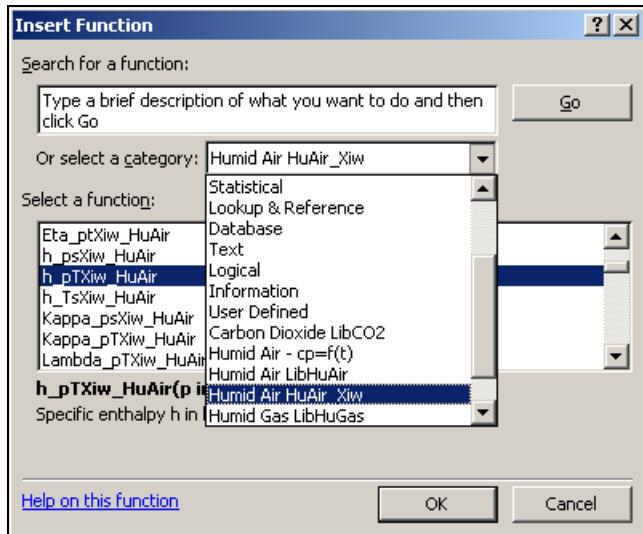
## 2.4 Example calculation

We will now calculate, step by step, the specific enthalpy  $h$  for humid air as a function of given mixture pressure  $p$ , given temperature  $t$ , and given mass fraction of water  $X_{iw}$  using FluidEXL\_Graphics. The following description relates to Excel 2003. The procedure is analogous for Excel 2000, 2002 (XP), and 2007.

The following steps have to be carried out:

- Start Excel®
- Enter the value for  $p$  in bar in a cell  
(Range of validity:  $0.01 \leq p \leq 1000$  bar)  
⇒ e.g.: Enter the value 1.01325 into cell A4
- Enter the value for  $t$  in °C in a cell  
(Range of validity:  $t = -143.15 \dots 1726.85$  °C)  
⇒ e.g.: Enter the value 20 into cell B4
- Enter the value for  $x_w$  in kg water(steam)/kg humid air in a cell  
(Range of validity:  $0 \leq X_{iw} \leq 1$  kg/kg)  
⇒ e.g.: Enter the value 0.01 into cell C4
- Click on the cell in which the calculated air-specific enthalpy  $h$  in kJ/kg is to be displayed  
⇒ e.g.: Click on the cell D4
- Click "Calculate" in the FluidEXL\_Graphics menu bar

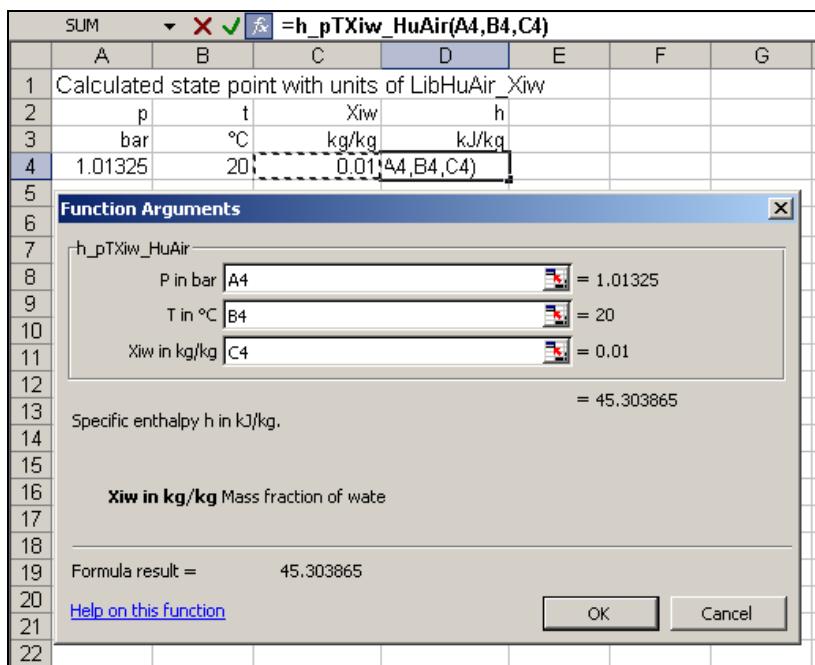
The "Insert Function" window appears as shown in Figure 2.14.



**Figure 2.14:** Choice of library and function

- Click "Humid Air HuAir Xiw" next to "Or select a category:"
- Click "h\_ptXiw\_HuAir" under "Select a function:"
- Click the "OK" button

The menu for the function  $h_{ptXiw\_HuAir}$ , as shown in Figure 2.15, appears.



**Figure 2.15:** Input menu for the function

- The cursor is now situated on the line next to "P in bar". The value for the mixture pressure  $p$  can be entered either by clicking the cell which contains the value for  $p$  or by typing the number of the cell or by typing the value for  $p$  directly into the window.  
⇒ e. g.: Click on the cell A4
- Situate the cursor on the line next to "T in °C". Now the value for the temperature can be entered either by clicking the cell which contains the value for  $t$  or by typing the number of the cell or by typing the value for  $t$  directly into the window.  
⇒ e. g.: Type B4 into the window next to "t in °C"
- Situate the cursor on the line next to "Xiw in kg/kg". Now the value for the mass fraction of water  $Xiw$  can be entered either by clicking the cell which contains the value for  $Xiw$  or by typing the number of the cell or by typing the value for  $Xiw$  directly into the window.  
⇒ e. g.: Click on the cell C4
- Click the "OK" button

The result for  $h$  in kJ/kg appears in the cell selected above.

⇒ The result in our sample calculation here is:  $h = 45.303865$  kJ/kg.

The calculation of  $h = f(p, T, Xiw)$  has thus been completed.

You can now arbitrarily change the values for  $p$ ,  $t$  or  $Xiw$  in the appropriate cells. The enthalpy  $h$  is recalculated and updated every time you change the data. This shows that the Excel® 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 function to be calculated will result in -1 or -1000.

For further property functions calculable in FluidEXL<sup>Graphics</sup> 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 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  $p = 0.101325 \text{ MPa}$
- *h-x* Diagram  $p = 0.11 \text{ MPa}$

In order to represent the calculated state point in the *h-x* diagram it is necessary to convert the units as follows:

- Convert the given value of  $p$  in bar into  $p$  in MPa:

$$p = \frac{p}{\text{bar}} \cdot 10^{-1} \text{ MPa}$$

⇒ e.g.: Click the cell A9, then type "=A4/10" and press Enter.

The result 0.102325 for  $p$  in MPa appears in cell A9.

- The temperature  $t$  in  $^{\circ}\text{C}$  needs not to be converted.
- Convert the given value of  $\xi_w$  ( $X_{iw}$ ) in (kg / kg) into the absolute humidity  $x_w$  in (g / kg dry air):

$$x_w = \frac{\xi_w}{1 - \xi_w} \cdot 1000 \frac{\text{g}}{\text{kg}_{\text{dry air}}}$$

⇒ e.g.: Click the cell C9, then type "=C4/(1-C4)\*1000" and press Enter.

The result 10.1010101 for  $x_w$  in (g / kg dry air) appears in cell C9.

- Convert the calculated value of  $h$  in (kJ / kg) into  $h_l$  in (kJ / kg dry air):

$$h_l = \frac{h}{\text{kJ/kg}} \cdot \left( \frac{1}{1 - \xi_w} \right) \text{ kJ/kg}_{\text{dry air}}$$

⇒ e.g.: Click the cell D9, then type "=D4/(1-C4)" and press Enter.

The result 45.76147878 in (kJ / kg dry air) appears in cell D9.

Now, the data can be represented in a *h-x* diagram for  $p = 0.101325 \text{ MPa}$ :

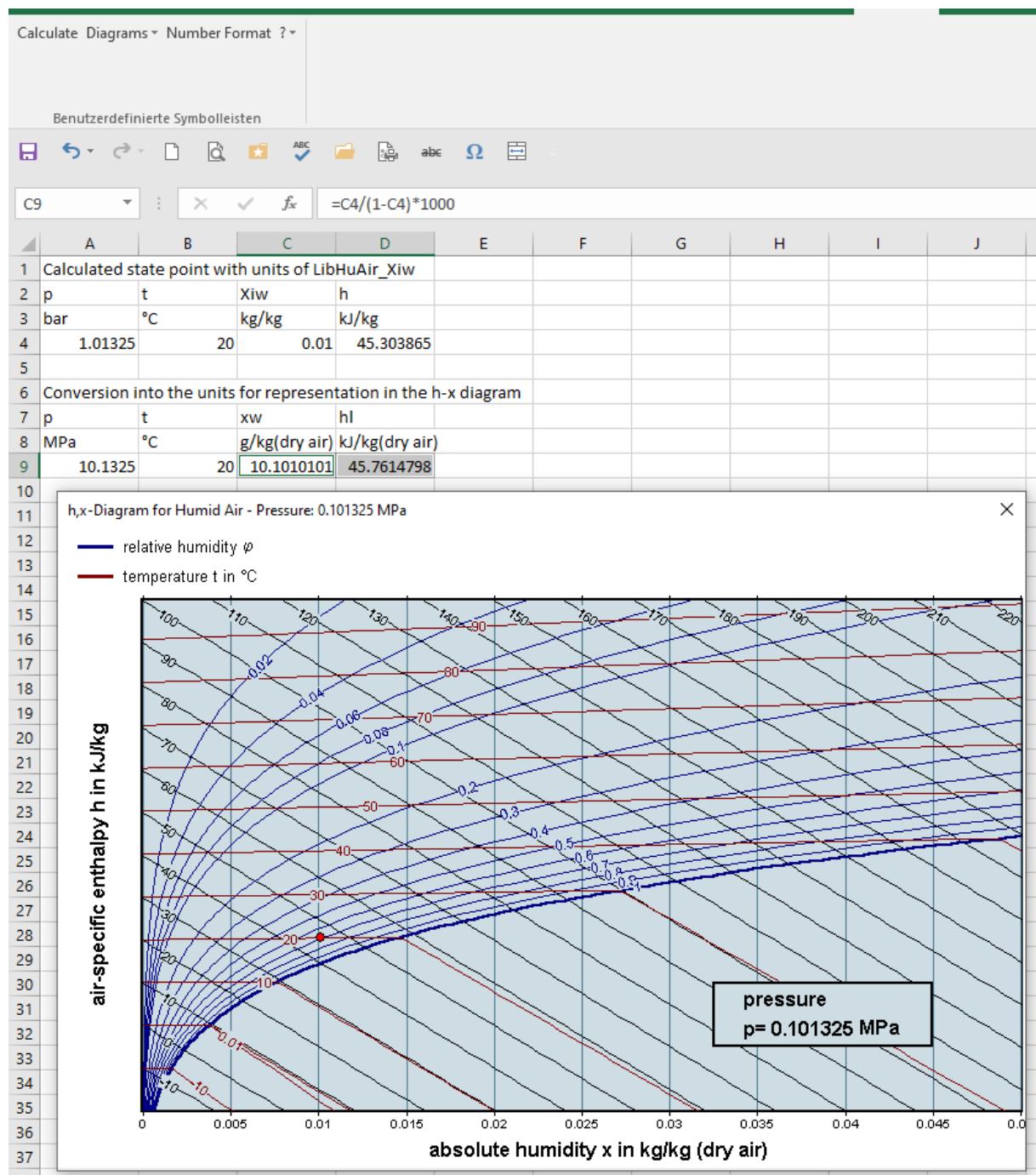
- Click on the cell with the value for  $h$  (as  $h$  is the Y-axis in the diagram)  
⇒ e. g.: Click on the cell D1
- Hold down the "Ctrl" key and simultaneously click the cell containing the value for  $x_w$  (as  $x_w$  is the X-axis in the diagram)  
⇒ e. g.: Hold down the "Ctrl" key and click on 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
- 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 2.16:** *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® which also belongs to the Office suite®.

- 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® 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, click "Microsoft Excel - ..." in the Windows task bar.

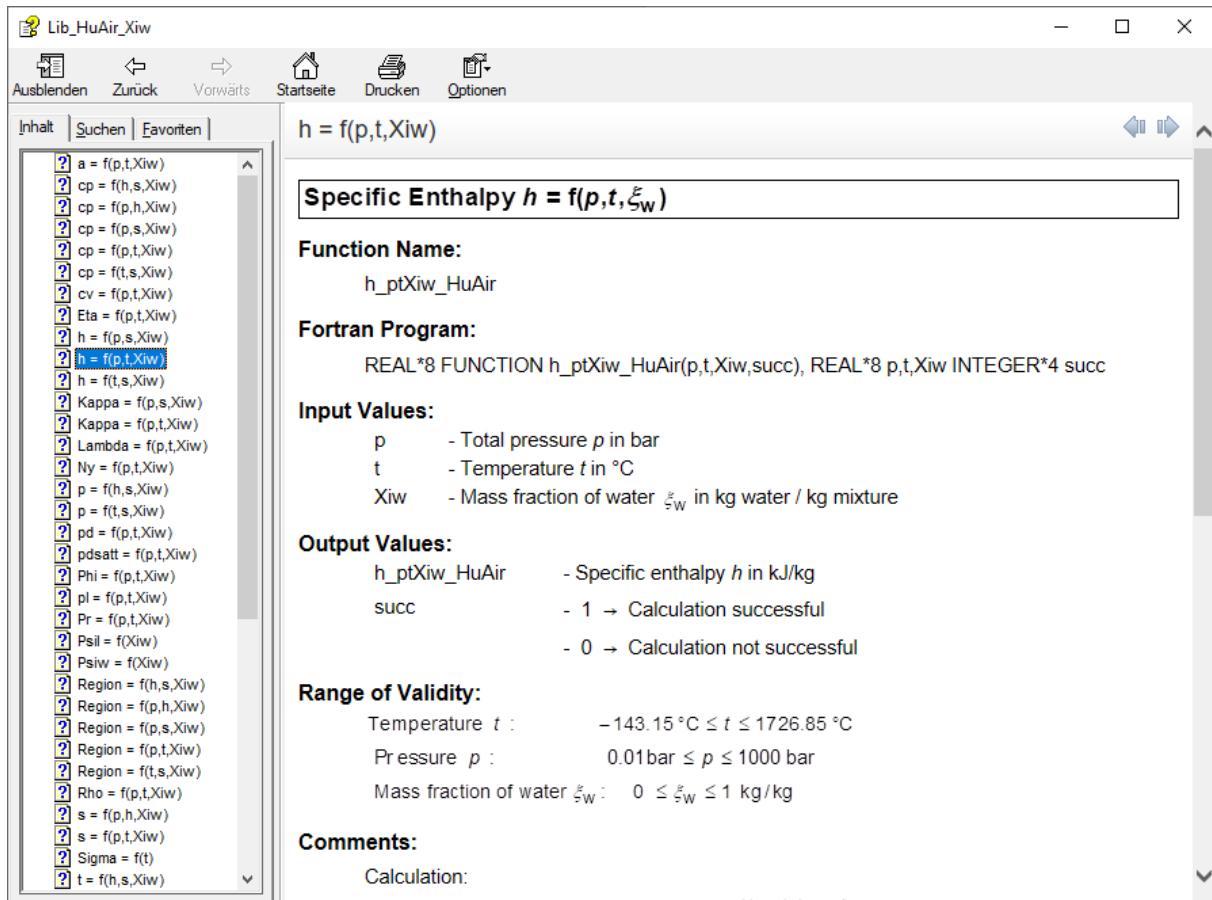
Proceed in the same way to print further diagrams.

## 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\_Xiw" 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 2.17:** Help Window

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

C:\Program Files\FluidEXL\_Graphics\_Eng  
to use the help system.

## 2.7 Removing FluidEXLGraphics

### 2.7.1 Removing LibHuAir\_Xiw Library

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

LibHuAir\_Xiw.dll

LibHuAir\_Xiw.chm

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

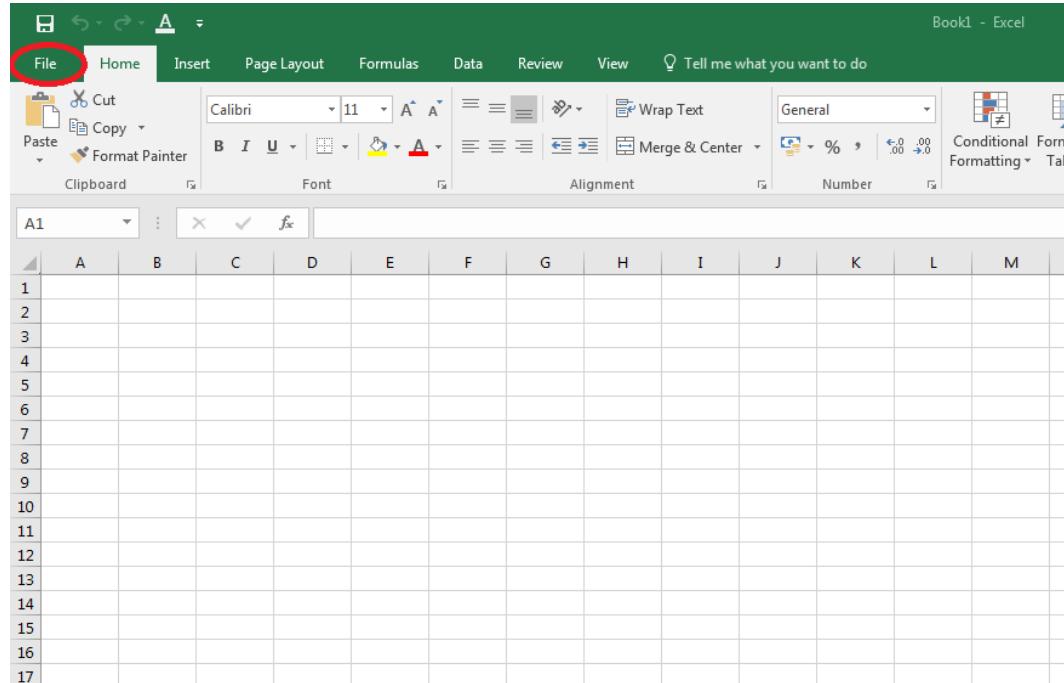
C:\Program Files\FluidEXL\_Graphics\_Eng

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

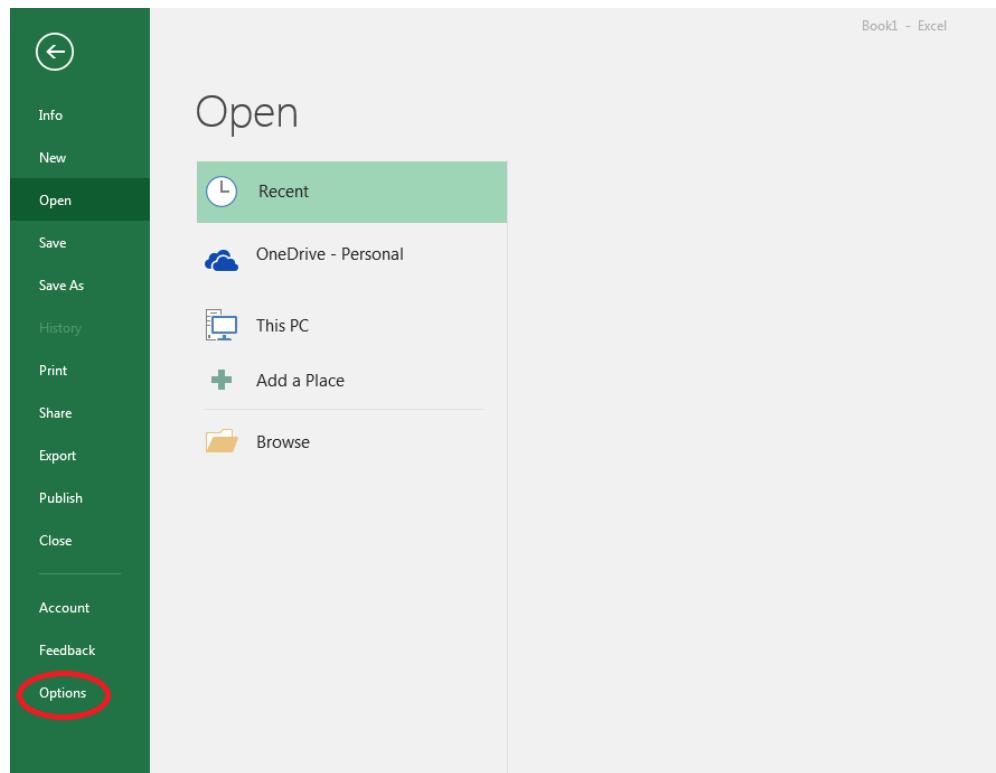
### 2.7.2 Unregistering and uninstalling FluidEXL *Graphics* as Add-In in versions of Excel® from 2007 onwards (for earlier versions see 2.6.3)

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

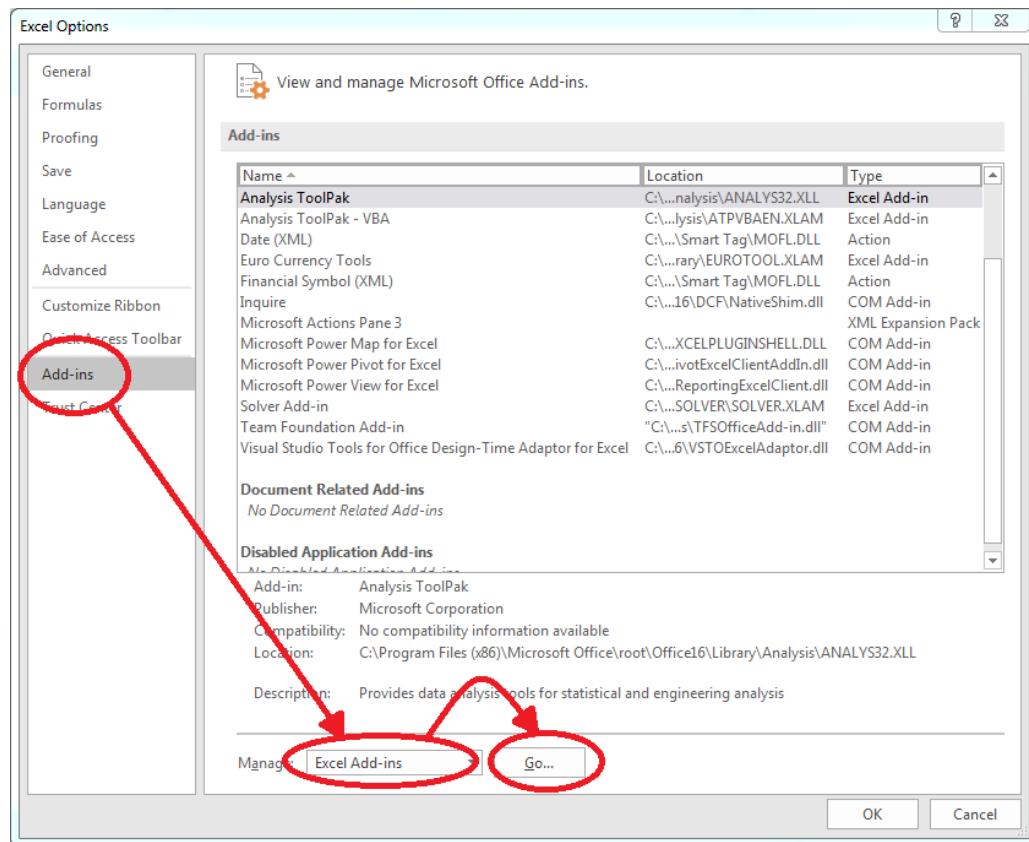


**Figure 2.18:** Unregistering FluidEXL *Graphics* as Add-In in Excel® 2016



**Figure 2.19** Unregistering FluidEXL Graphics as Add-In in Excel® 2016

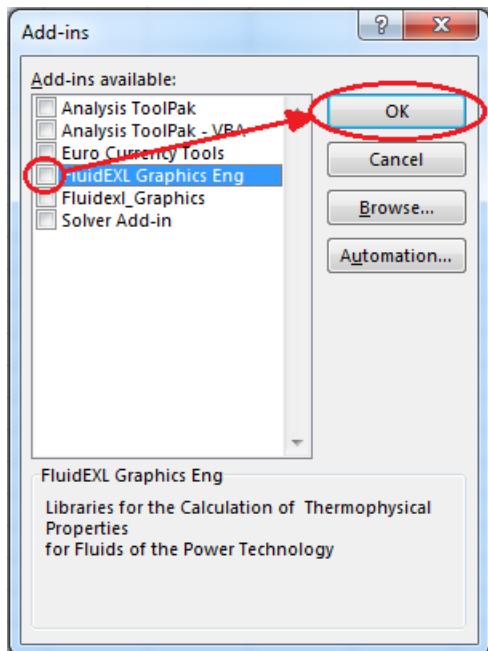
- Click on "Add-Ins" in the next menu (Figure 2.20)



**Figure 2.20:** 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 2.21:** 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.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\_Xiw.dll

LibHuAir\_Xiw.chm

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

C:\Program Files\FluidEXL\_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 $a = f(p, t, \xi_w)$

##### Function Name:

a\_ptXiw\_HuAir

##### Fortran Program:

```
REAL*8 FUNCTION a_ptXiw_HuAir(p,t,Xiw,succ), REAL*8 p,t,Xiw, INTEGER*4 succ
```

##### Input Values:

- p - Total pressure  $p$  in bar
- t - Temperature  $t$  in °C
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

##### Output Values:

- |               |  |
|---------------|--|
| a_ptXiw_HuAir | - Thermal diffusivity $a$ in m <sup>2</sup> /s   |
| succ          | <ul style="list-style-type: none"> <li>- 1 → Calculation successful</li> <li>- 0 → Calculation not successful</li> </ul> |

##### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

##### Comments:

- Thermal diffusivity  $a = \frac{\lambda}{\rho \cdot c_p}$
- Model of ideal mixture of real properties about volume fractions
- Calculation of fog ( $\xi_w > \xi_{wsatt}$ ) is not possible

##### Results for Wrong Input Values:

a\_ptXiw\_HuAir = -1, succ = 0

##### References:

Dry air:

- $\lambda$  from Lemmon et al. [15]
- $c_p$  from Lemmon et al. [14]
- $\rho$  from Lemmon et al. [14]

Steam in humid air and water droplets in fog:

- $\lambda$  for  $0 \text{ }^{\circ}\text{C} \leq t \leq 800 \text{ }^{\circ}\text{C}$  from IAPWS – 85 [6]
- for  $t < 0 \text{ }^{\circ}\text{C}$  and  $t > 800 \text{ }^{\circ}\text{C}$  from Brandt [12]
- $c_p$  from IAPWS-IF97 [1], [2], [3], [4]
- $\rho$  from IAPWS-IF97 [1], [2], [3], [4]
- for  $t < 0.01 \text{ }^{\circ}\text{C}$  from IAPWS-06 [18], [19]

## Specific Isobaric Heat Capacity $c_p = f(h, s, \xi_w)$

### Function Name:

cp\_hsXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION cp_hsXiw_HuAir(h,s,Xiw,succ) , REAL*8 h,s,Xiw INTEGER*4 succ
```

### Input Values:

- $h$  - Specific enthalpy  $h$  in kJ/kg
- $s$  - Specific Entropy  $s$  in kJ/(kg K)
- $Xiw$  - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |                |  |
|----------------|--|
| cp_hsXiw_HuAir | - Specific isobaric heat capacity $c_p$ in kJ/(kg·K)   |
| succ           | <ul style="list-style-type: none"> <li>- 1 → Calculation successful</li> <li>- 0 → Calculation not successful</li> </ul> |

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^\circ\text{C} \leq t \leq 1726.85 \text{ }^\circ\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Iteration of  $p$  and  $t$  from  $h(p, t, \xi_w)$  and  $s(p, t, \xi_w)$  and calculation of  $c_p$  from  $c_p(p, t, \xi_w)$

Calculation:

- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ ) as ideal mixture of real gases (dry air and steam)
- not possible for fog ( $\xi_w > \xi_{wsatt}$ )
- Effects of dissociation are taken into consideration from 500 °C upwards

### Results for Wrong Input Values:

cp\_hsXiw\_HuAir = -1, succ = 0

### References:

Dry air:

from Lemmon et al. [14]

Steam in humid air:

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

Dissociation:

from VDI Guideline 4670 [13]

## Specific Isobaric Heat Capacity $c_p = f(p, h, \xi_w)$

### Function Name:

cp\_phXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION cp_phXiw_HuAir(p,h,Xiw,succ), REAL*8 p,h,Xiw, INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- h - Specific enthalpy  $h$  in kJ/kg
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |                |  |
|----------------|--|
| cp_phXiw_HuAir | - Specific isobaric heat capacity $c_p$ in kJ/(kg·K)   |
| succ           | <ul style="list-style-type: none"> <li>- 1 → Calculation successful</li> <li>- 0 → Calculation not successful</li> </ul> |

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^\circ\text{C} \leq t \leq 1726.85 \text{ }^\circ\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Iteration of  $T$  from  $h(p, t, \xi_w)$  and calculation of  $c_p$  from  $c_p(p, t, \xi_w)$

Calculation:

- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ ) as ideal mixture of real gases (dry air and steam)
- not possible for fog ( $\xi_w > \xi_{wsatt}$ )
- Effects of dissociation are taken into consideration from 500 °C upwards

### Results for Wrong Input Values:

cp\_phXiw\_HuAir = -1, succ = 0

### References:

Dry air:

from Lemmon et al. [14]

Steam in humid air:

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

Dissociation:

from VDI Guideline 4670 [13]

## Specific Isobaric Heat Capacity $c_p = f(p, s, \xi_w)$

### Function Name:

cp\_psXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION cp_psXiw_HuAir(p,s,Xiw,succ), REAL*8 p,s,Xiw, INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- s - Specific Entropy  $s$  in kJ/(kg K)
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |                |  |
|----------------|--|
| cp_psXiw_HuAir | - Specific isobaric heat capacity $c_p$ in kJ/(kg·K)   |
| succ           | <ul style="list-style-type: none"> <li>- 1 → Calculation successful</li> <li>- 0 → Calculation not successful</li> </ul> |

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^\circ\text{C} \leq t \leq 1726.85 \text{ }^\circ\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Iteration of  $T$  from  $s(p, t, \xi_w)$  and calculation of  $c_p$  from  $c_p(p, t, \xi_w)$

Calculation:

- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ ) as ideal mixture of real gases (dry air and steam)
- not possible for fog ( $\xi_w > \xi_{wsatt}$ )
- Effects of dissociation are taken into consideration from 500 °C upwards

### Results for Wrong Input Values:

cp\_psXiw\_HuAir = - 1, succ = 0

### References:

Dry air:

from Lemmon et al. [14]

Steam in humid air:

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

Dissociation:

from VDI Guideline 4670 [13]

## Specific Isobaric Heat Capacity $c_p = f(p, t, \xi_w)$

### Function Name:

cp\_ptXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION cp_ptXiw_HuAir(p,t,Xiw,succ), REAL*8 p,t,Xiw, INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- t - Temperature  $t$  in °C
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |                |  |
|----------------|--|
| cp_ptXiw_HuAir | - Specific isobaric heat capacity $c_p$ in kJ/(kg·K) |
| succ           | - 1 → Calculation successful                         |
|                | - 0 → Calculation not successful                     |

### Range of Validity:

- Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$
- Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$
- Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Calculation:

- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ ) as ideal mixture of real gases (dry air and steam)
- not possible for fog ( $\xi_w > \xi_{wsatt}$ )
- Effects of dissociation are taken into consideration from 500 °C upwards

### Results for Wrong Input Values:

cp\_ptXiw\_HuAir = -1, succ = 0

### References:

Dry air:

from Lemmon et al. [14]

Steam in humid air:

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

Dissociation:

from VDI Guideline 4670 [13]

## Specific Isobaric Heat Capacity $c_p = f(t, s, \xi_w)$

### Function Name:

cp\_tsXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION cp_tsXiw_HuAir(t,s,Xiw,succ), REAL*8 p,t,Xiw, INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- t - Temperature  $t$  in °C
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |                |  |
|----------------|--|
| cp_TsXiw_HuAir | - Specific isobaric heat capacity $c_p$ in kJ/(kg·K)   |
| succ           | <ul style="list-style-type: none"> <li>- 1 → Calculation successful</li> <li>- 0 → Calculation not successful</li> </ul> |

### Range of Validity:

- Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$
- Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$
- Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Iteration of  $p$  from  $s(p, t, \xi_w)$  and calculation of  $c_p$  from  $c_p(p, t, \xi_w)$

#### Calculation:

- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ ) as ideal mixture of real gases (dry air and steam)
- not possible for fog ( $\xi_w > \xi_{wsatt}$ )
- Effects of dissociation are taken into consideration from 500 °C upwards

### Results for Wrong Input Values:

cp\_TsXiw\_HuAir = -1, succ = 0

### References:

#### Dry air:

from Lemmon et al. [14]

#### Steam in humid air:

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

#### Dissociation:

from VDI Guideline 4670 [13]

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

### Function Name:

cv\_ptXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION cv_ptXiw_HuAir(p,t,Xiw,succ), REAL*8 p,t,Xiw, INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- t - Temperature  $t$  in °C
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |                |  |
|----------------|--|
| cv_ptXiw_HuAir | - Specific isochoric heat capacity $c_v$ in kJ/(kg·K)            |
| succ           | - 1 → Calculation successful<br>- 0 → Calculation not successful |

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^\circ\text{C} \leq t \leq 1726.85 \text{ }^\circ\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

#### Calculation:

- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ ) as ideal mixture of real gases (dry air and steam)
- not possible for fog ( $\xi_w > \xi_{wsatt}$ )
- Effects of dissociation are taken into consideration from 500 °C upwards

### Results for Wrong Input Values:

cv\_ptXiw\_HuAir = -1, succ = 0

### References:

#### Dry air:

from Lemmon et al. [14]

#### Steam in humid air:

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

#### Dissociation:

from VDI Guideline 4670 [13]

## Dynamic Viscosity $\eta = f(p, t, \xi_w)$

### Function Name:

Eta\_ptXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION Eta_ptXiw_HuAir(p,t,Xiw,succ), REAL*8 p, t, Xiw INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- t - Temperature  $t$  in °C
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- Eta\_ptXiw\_HuAir - Dynamic viscosity  $\eta$  in Pa·s
- succ
  - 1 → Calculation successful
  - 0 → Calculation not successful

### Range of Validity:

- Temperature  $t$  :  $-143.15 \text{ } ^\circ\text{C} \leq t \leq 1726.85 \text{ } ^\circ\text{C}$
- Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$
- Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

- Model of ideal mixture of real fluids about volume fractions
- Negligence of ice crystals at ice fog ( $t < 0.01 \text{ } ^\circ\text{C}$  and  $\xi_w > \xi_{wsatt}$ )

### Results for Wrong Input Values:

Eta\_ptXiw\_HuAir = -1, succ = 0

### References:

- Dry air:
  - from Lemmon et al. [17]
- Steam in humid air and water droplets in fog:
  - for  $0 \text{ } ^\circ\text{C} \leq t \leq 800 \text{ } ^\circ\text{C}$  from IAPWS – 85 [7]
  - for  $t < 0 \text{ } ^\circ\text{C}$  and  $t > 800 \text{ } ^\circ\text{C}$  from Brandt [12]

## Specific Enthalpy $h = f(p, s, \xi_w)$

### Function Name:

`h_psXiw_HuAir`

### Fortran Program:

```
REAL*8 FUNCTION h_psXiw_HuAir(p,s,Xiw,succ), REAL*8 p,s,Xiw INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- s - Specific Entropy  $s$  in kJ/(kg K)
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |                            |  |
|----------------------------|--|
| <code>h_psXiw_HuAir</code> | - Specific enthalpy $h$ in kJ/kg   |
| <code>succ</code>          | <ul style="list-style-type: none"> <li>- 1 → Calculation successful</li> <li>- 0 → Calculation not successful</li> </ul> |

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^\circ\text{C} \leq t \leq 1726.85 \text{ }^\circ\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Iteration of  $t$  from  $s(p, t, \xi_w)$  and calculation of  $h$  from  $h(p, t, \xi_w)$

Calculation:

- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ ) as ideal mixture of real gases (dry air and steam)
- for fog ( $\xi_w > \xi_{wsatt}$ ) as ideal mixture of saturated humid air and water liquid or water ice
- Effects of dissociation are taken into consideration from 500 °C upwards

### Results for Wrong Input Values:

`h_psXiw_HuAir = - 1 · 10100, succ = 0`

### References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water 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]

## Specific Enthalpy $h = f(p, t, \xi_w)$

### Function Name:

`h_ptXiw_HuAir`

### Fortran Program:

```
REAL*8 FUNCTION h_ptXiw_HuAir(p,t,Xiw,succ), REAL*8 p,t,Xiw INTEGER*4 succ
```

### Input Values:

- $p$  - Total pressure  $p$  in bar
- $t$  - Temperature  $t$  in °C
- $Xiw$  - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |                            |  |
|----------------------------|--|
| <code>h_ptXiw_HuAir</code> | - Specific enthalpy $h$ in kJ/kg   |
| <code>succ</code>          | <ul style="list-style-type: none"> <li>- 1 → Calculation successful</li> <li>- 0 → Calculation not successful</li> </ul> |

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Calculation:

- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ ) as ideal mixture of real gases (dry air and steam)
- for fog ( $\xi_w > \xi_{wsatt}$ ) as ideal mixture of saturated humid air and water liquid or water ice
- Effects of dissociation are taken into consideration from 500 °C upwards

### Results for Wrong Input Values:

`h_ptXiw_HuAir` = - 1 · 10<sup>100</sup>, `succ` = 0

### References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water 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]

## Specific Enthalpy $h = f(t, s, \xi_w)$

### Function Name:

`h_tsXiw_HuAir`

### Fortran Program:

```
REAL*8 FUNCTION h_tsXiw_HuAir(t,s,Xiw,succ), REAL*8 t,s,Xiw INTEGER*4 succ
```

### Input Values:

- $t$  - Temperature  $t$  in °C
- $s$  - Specific Entropy  $s$  in kJ/(kg K)
- $X_{iw}$  - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |                            |  |
|----------------------------|--|
| <code>h_TsXiw_HuAir</code> | - Specific enthalpy $h$ in kJ/kg   |
| <code>succ</code>          | <ul style="list-style-type: none"> <li>- 1 → Calculation successful</li> <li>- 0 → Calculation not successful</li> </ul> |

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Iteration of  $p$  from  $s(p, t, \xi_w)$  and calculation of  $h$  from  $h(p, t, \xi_w)$

Calculation:

- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ ) as ideal mixture of real gases (dry air and steam)
- for fog ( $\xi_w > \xi_{wsatt}$ ) as ideal mixture of saturated humid air and water liquid or water ice
- Effects of dissociation are taken into consideration from 500 °C upwards
- Calculation of the mixture of liquid fog and ice at  $t = 0.01 \text{ }^{\circ}\text{C}$  is not possible

### Results for Wrong Input Values:

`h_TsXiw_HuAir = - 1 · 10100, succ = 0`

### References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water 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]

## Isentropic Exponent $\kappa = f(p, s, \xi_w)$

### Function Name:

Kappa\_psXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION Kappa_psXiw_HuAir(p,s,Xiw,succ), REAL*8 p,s,Xiw
INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- s - Specific Entropy  $s$  in kJ/(kg K)
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- Kappa\_psXiw\_HuAir - Isentropic exponent  $\kappa$
- succ
  - 1 → Calculation successful
  - 0 → Calculation not successful

### Range of Validity:

- Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$
- Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$
- Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

- Iteration of  $t$  from  $s(p,t,\xi_w)$  and calculation of  $\kappa$  from  $\kappa(p,s,\xi_w)$
- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ )

$$\kappa = -\frac{v}{p} \cdot \left( \frac{\partial p}{\partial v} \right)_t \cdot \frac{c_p}{c_v}$$

- for liquid fog ( $\xi_w > \xi_{wsatt}$ ): Model of ideal mixture of real fluids about volume fractions
- for ice fog ( $\xi_w > \xi_{wsatt}$ ): Calculation of saturated humid air

### Results for Wrong Input Values:

Kappa\_psXiw\_HuAir = -1, succ = 0

### References:

Dry air:  
from Lemmon et al. [14]

Steam in humid air and water droplets in fog:  
from IAPWS-IF97 [1], [2], [3], [4]

Dissociation:  
from VDI Guideline 4670 [13]

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

### Function Name:

Kappa\_ptXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION Kappa_ptXiw_HuAir(p,t,Xiw,succ), REAL*8 p,t,Xiw
INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- t - Temperature  $t$  in °C
- $\xi_{\text{W}}$  - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- Kappa\_ptXiw\_HuAir - Isentropic exponent  $\kappa$
- succ
  - 1 → Calculation successful
  - 0 → Calculation not successful

### Range of Validity:

- Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$
- Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$
- Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ )
- $$\kappa = -\frac{v}{p} \cdot \left( \frac{\partial p}{\partial v} \right)_t \cdot \frac{c_p}{c_v}$$
- for liquid fog ( $\xi_w > \xi_{wsatt}$ ): Model of ideal mixture of real fluids about volume fractions
- for ice fog ( $\xi_w > \xi_{wsatt}$ ): Calculation of saturated humid air

### Results for Wrong Input Values:

Kappa\_ptXiw\_HuAir = -1, succ = 0

### References:

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

## Thermal Conductivity $\lambda = f(p, t, \xi_w)$

### Function Name:

Lambda\_ptXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION Lambda_ptXiw_HuAir(p,t,Xiw,succ), REAL*8 p, t, Xiw
                                         INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- t - Temperature  $t$  in °C
- $\xi_w$  - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |                    |  |
|--------------------|--|
| Lambda_ptXiw_HuAir | - Thermal conductivity in W/(m·K)  |
| succ               | <ul style="list-style-type: none"> <li>- 1 → Calculation successful</li> <li>- 0 → Calculation not successful</li> </ul> |

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

- Model of ideal mixture of real fluids about volume fractions

### Results for Wrong Input Values:

Lambda\_ptXiw\_HuAir = -1, succ=0

### References:

Dry air:

from Lemmon et al. [15]

Steam in humid air and water droplets in fog:

for  $273.15 \text{ K} \leq T \leq 1073.15 \text{ K}$  from IAPWS-85 [6]

for  $T < 273.15 \text{ K}$  and  $T > 1073.15 \text{ K}$  from Brandt [12]

## Kinematic Viscosity $\nu = f(p, t, \xi_w)$

### Function Name:

Ny\_ptXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION Ny_ptXiw_HuAir(p,t,Xiw,succ), REAL*8 p,t,Xiw INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- t - Temperature  $t$  in °C
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |                |  |
|----------------|--|
| Ny_ptXiw_HuAir | - Kinematic viscosity $\nu$ in m <sup>2</sup> /s |
| succ           | - 1 → Calculation successful                     |
|                | - 0 → Calculation not successful                 |

### Range of Validity:

- Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$
- Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$
- Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

- Kinematic viscosity  $\nu = \frac{\eta}{\rho} = \eta \cdot \nu$
- Model of ideal mixture of real fluids about volume fractions

### Results for Wrong Input Values:

Ny\_ptXiw\_HuAir = -1, succ = 0

### References:

Dry air:

- $\eta$  from Lemmon et al. [15]
- $\rho$  from Lemmon et al. [14]

Steam in humid air and water droplets in fog:

- $\eta$  for  $273.15 \text{ K} \leq T \leq 1073.15 \text{ K}$  from IAPWS-08 [7]
- for  $T < 273.15 \text{ K}$  and  $T > 1073.15 \text{ K}$  from Brandt [12]
- $\rho$  from IAPWS-IF97 [1], [2], [3], [4]
- for  $T < 273.16 \text{ K}$  from IAPWS-06 [18], [19]

## Pressure $p = f(h, s, \xi_w)$

### Function Name:

p\_hsXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION p_hsXiw_HuAir(h,s,Xiw,succ), REAL*8 h,s,Xiw INTEGER*4 succ
```

### Input Values:

- $h$  - Specific enthalpy  $h$  in kJ/kg
- $s$  - Specific entropy  $s$  in kJ/(kg K)
- $Xiw$  - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |               |                                  |
|---------------|----------------------------------|
| p_hsXiw_HuAir | - Total pressure $p$ in bar      |
| succ          | - 1 → Calculation successful     |
|               | - 0 → Calculation not successful |

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^\circ\text{C} \leq t \leq 1726.85 \text{ }^\circ\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Iteration of  $p$  and  $t$  from  $h(p, t, \xi_w)$  and  $s(p, t, \xi_w, \text{succ})$

Calculation:

- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ ) as ideal mixture of real gases (dry air and steam)
- for fog ( $\xi_w > \xi_{wsatt}$ ) as ideal mixture of saturated humid air and water liquid or water ice
- Effects of dissociation are taken into consideration from 500 °C upwards
- Calculation of the mixture of liquid fog and ice at  $t = 0.01 \text{ }^\circ\text{C}$  is not possible

### Results for Wrong Input Values:

p\_hsXiw\_HuAir = -1, succ = 0

### References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water 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]

## Pressure $p = f(t, s, \xi_w)$

### Function Name:

`p_tsXiw_HuAir`

### Fortran Program:

```
REAL*8 FUNCTION p_tsXiw_HuAir(t,s,Xiw,succ), REAL*8 t,s,Xiw INTEGER*4 succ
```

### Input Values:

- $t$  - Temperature  $t$  in °C
- $s$  - Specific entropy  $s$  in kJ/(kg K)
- $Xiw$  - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |                            |  |
|----------------------------|--|
| <code>p_tsXiw_HuAir</code> | - Total pressure $p$ in bar  |
| <code>succ</code>          | <ul style="list-style-type: none"> <li>- 1 → Calculation successful</li> <li>- 0 → Calculation not successful</li> </ul> |

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Iteration of  $p$  from  $s(p, t, \xi_w)$

Calculation:

- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ ) as ideal mixture of real gases (dry air and steam)
- for fog ( $\xi_w > \xi_{wsatt}$ ) as ideal mixture of saturated humid air and water liquid or water ice
- Effects of dissociation are taken into consideration from 500 °C upwards
- Calculation of the mixture of liquid fog and ice at  $t = 0.01 \text{ }^{\circ}\text{C}$  is not possible

### Results for Wrong Input Values:

`p_tsXiw_HuAir` = -1, `succ` = 0

### References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water 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]

## Partial Pressure of Water $p_d = f(p, t, \xi_w)$

### Function Name:

pd\_ptXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION pd_ptXiw_HuAir(p,t,Xiw,succ), REAL*8 p,t,Xiw INTEGER*4 succ
```

### Input Values:

- $p$  - Total pressure  $p$  in bar
- $t$  - Temperature  $t$  in °C
- $Xiw$  - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- pd\_ptXiw\_HuAir - Partial pressure of water  $p_d$  in bar
- succ - 1 → Calculation successful
- 0 → Calculation not successful

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

- Partial pressure of water  $p_d = \frac{1}{\frac{1-\xi_w}{\xi_w} \cdot \frac{R_l}{R_w} + 1}$  for  $\xi_w \leq \xi_{wsatt}(p, t)$

- for  $\xi_w > \xi_{wsatt}(p, t)$  result  $p_d = p_{dsatt}(p, t)$

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

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

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

Result for pure steam, liquid water and water ice:  $p_d = 0$

### Results for Wrong Input Values:

pd\_ptXiw\_HuAir = -1; succ=0

### References:

- $f(p, t)$  Herrmann et al. [20], [21]
- $p_s(t)$  if  $t \geq 0.01 \text{ }^{\circ}\text{C}$  from IAPWS-IF97 [1], [2], [3], [4]  
if  $t < 0.01 \text{ }^{\circ}\text{C}$  from IAPWS-08 [16], [17]

## Saturation Vapor Pressure of Water $p_{\text{dsatt}} = f(p, t)$

### Function Name:

`pdsatt_pt_HuAir`

### Fortran Program:

```
REAL*8 FUNCTION pdsatt_pt_HuAir(p,t,succ), REAL*8 p,t INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- t - Temperature  $t$  in °C

### Output Values:

- |                              |  |
|------------------------------|--|
| <code>pdsatt_pT_HuAir</code> | - Saturation vapor pressure $p_{\text{dsatt}}$ of water in humid air in bar  |
| <code>succ</code>            | <ul style="list-style-type: none"> <li>- 1 → Calculation successful</li> <li>- 0 → Calculation not successful</li> </ul> |

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

### Comments:

Saturation vapor pressure at saturation  $p_{\text{dsatt}} = f \cdot p_s(t)$   
 with  $p_s(t)$       for  $t \geq 0.01 \text{ }^{\circ}\text{C}$  - vapor pressure of water  
                       for  $t < 0.01 \text{ }^{\circ}\text{C}$  - sublimation pressure of water

### Results for Wrong Input Values:

`pdsatt_pt_HuAir` = - 1, `succ`=0

### References:

- |           |  |
|-----------|--|
| $f(p, t)$ | Herrmann et al. [20], [21]   |
| $p_s(t)$  | <ul style="list-style-type: none"> <li>if <math>t \geq 0.01 \text{ }^{\circ}\text{C}</math> from IAPWS-IF97 [1], [2], [3], [4]</li> <li>if <math>t &lt; 0.01 \text{ }^{\circ}\text{C}</math> from IAPWS-08 [16], [17]</li> </ul> |

## Relative Humidity $\varphi = f(p, t, \xi_w)$

### Function Name:

Phi\_ptXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION Phi_ptXiw_HuAir(p,t,Xiw,succ), REAL*8 p, t, Xiw
                                         INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- T - Temperature  $T$  in °C
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- Phi\_ptXiw\_HuAir - Relative humidity  $\varphi$
- succ - 1 → Calculation successful  
- 0 → Calculation not successful

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq t_{\text{krit}} = 373.946 \text{ }^{\circ}\text{C}$   
( $t_{\text{krit}}$  - critical Temperature of water)

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 - 1 \cdot 10^{-8} \text{ kg/kg}$

### Comments:

$$\text{Relative humidity } \varphi = \frac{1}{\frac{1 - \xi_w}{\xi_w} \cdot \frac{R_l}{R_w} + 1} \cdot \frac{p}{p_{\text{dsatt}}(p, T)}$$

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

with  $p_s(t)$       for  $t \geq 0.01 \text{ }^{\circ}\text{C}$  - vapor pressure of water  
                      for  $t < 0.01 \text{ }^{\circ}\text{C}$  - sublimation pressure of water

### Results for Wrong Input Values:

Phi\_ptXiw\_HuAir = -1, succ=0

### References:

- $f(p, t)$       Herrmann et al. [20], [21]
- $p_s(t)$       if  $t \geq 0.01 \text{ }^{\circ}\text{C}$  from IAPWS-IF97 [1], [2], [3], [4]  
                      if  $t < 0.01 \text{ }^{\circ}\text{C}$  from IAPWS-08 [16], [17]

## Partial Pressure of Air $p_l = f(p, t, \xi_w)$

### Function Name:

pl\_ptXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION pl_ptXiw_HuAir(p,t,Xiw,succ), REAL*8 p,t,Xiw INTEGER*4 succ
```

### Input Values:

- $p$  - Total pressure  $p$  in bar
- $t$  - Temperature  $t$  in °C
- $Xiw$  - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- pl\_ptXiw\_HuAir - Partial pressure of air  $p_l$  in bar
- succ - 1 → Calculation successful  
- 0 → Calculation not successful

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

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

at  $\xi_w > \xi_{wsatt}(p, t)$ : result  $p_l = p - p_{dsatt}(p, t)$

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

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

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

Result for pure steam, liquid water and water ice:  $p_l = 0$

### Results for Wrong Input Values:

pl\_ptXiw\_HuAir = -1, succ = 0

### References:

- $f(p, t)$  Herrmann et al. [20], [21]
- $p_s(t)$  if  $t \geq 0.01 \text{ }^{\circ}\text{C}$  from IAPWS-IF97 [1], [2], [3], [4]  
if  $t < 0.01 \text{ }^{\circ}\text{C}$  from IAPWS-08 [16], [17]

## Prandtl-Number $Pr = f(p, t, \xi_w)$

### Function Name:

Pr\_ptXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION Pr_ptxw_HuAir(p,t,Xiw,succ), REAL*8 p,t,Xiw INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- t - Temperature  $t$  in °C
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |               |  |
|---------------|--|
| Pr_ptxw_HuAir | - Prandtl-Number $Pr$  |
| succ          | <ul style="list-style-type: none"> <li>- 1 → Calculation successful</li> <li>- 0 → Calculation not successful</li> </ul> |

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

- Prandtl-Number  $Pr = \frac{\nu}{a} = \frac{\eta \cdot c_p}{\lambda}$
- Model of ideal mixture of real fluids about volume fractions
- Calculation of fog ( $\xi_w > \xi_{wsatt}$ ) is not possible

### Results for Wrong Input Values:

Pr\_ptXiw\_HuAir = -1, succ = 0

### References:

Dry air:

- $\lambda$  from Lemmon et al. [15]
- $c_p$  from Lemmon et al. [14]
- $\eta$  from Lemmon et al. [15]

Steam in humid air and water droplets in fog:

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

Dissociation:

from VDI Guideline 4670 [13]

## Mole Fraction of Air $\psi_1 = f(\xi_w)$

### Function Name:

`Psil_Xiw_HuAir`

### Fortran Program:

```
REAL*8 FUNCTION Psil_Xiw_HuAir(Xiw,succ), REAL*8 Xiw INTEGER*4 succ
```

### Input Values:

$Xiw$  - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

<code>Psil_Xiw_HuAir</code>	- Mole fraction of air in $\psi_1$ kmol / kmol
<code>succ</code>	<ul style="list-style-type: none"> <li>- 1 → Calculation successful</li> <li>- 0 → Calculation not successful</li> </ul>

### Range of Validity:

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1$  kg/kg

### Comments:

$$\text{Mole fraction of dry air } \psi_1 = 1 - \frac{R_w}{R \cdot \left( \frac{1 - \xi_w}{\xi_w} + 1 \right)}$$

### Results for Wrong Input Values:

`Psil_Xiw_HuAir = - 1, succ = 0`

## Mole Fraction of Water $\psi_w = f(\xi_w)$

### Function Name:

Psiw\_Xiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION Psiw_Xiw_HuAir(Xiw,succ), REAL*8 Xiw INTEGER*4 succ
```

### Input Values:

$X_iw$  - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

Psiw\_Xiw\_HuAir - Mole fraction of water  $\psi_w$  kmol / kmol

succ - 1 → Calculation successful

- 0 → Calculation not successful

### Range of Validity:

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1$  kg/kg

### Comments:

$$\text{Mole fraction of water: } \psi_w = \frac{R_w}{R \cdot \left( \frac{1 - \xi_w}{\xi_w} + 1 \right)} \text{ with } R = \xi_l R_l + \xi_w R_w$$

### Results for Wrong Input Values:

Psiw\_Xiw\_HuAir = -1, succ=0

## Region = $f(h, s, \xi_w)$

### Function Name:

Region\_hsXiw\_HuAir

### Fortran Program:

```
INTEGER*4 FUNCTION Region_hsXiw_HuAir(h,s,Xiw), REAL*8 h,s,Xiw
```

### Input Values:

- $h$  - Specific enthalpy  $h$  in kJ/kg
- $s$  - Specific entropy  $s$  in kJ/(kg K)
- $Xiw$  - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

Region_hsXiw_HuAir	Region of state of humid air:
	0 → Outside region of state
	1 → Dry air
	2 → Unsaturated humid air
	3 → Liquid mist
	4 → Ice fog
	5 → Mixture of liquid fog and ice fog at 0.01 °C exactly
	6 → Pure water

### Range of Validity:

- Temperature  $t$  :  $-143.15 \text{ } ^\circ\text{C} \leq t \leq 1726.85 \text{ } ^\circ\text{C}$
- Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$
- Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Iteration of  $p$  and  $t$  from  $h(p,t,\xi_w)$  and  $s(p,t,\xi_w, \text{succ})$ . With this result it is possible to calculate *Region*.

### Results for Wrong Input Values:

Region\_hsXiw\_HuAir = 0

### References:

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

## Region = $f(p, h, \xi_w)$

### Function Name:

Region\_phXiw\_HuAir

### Fortran Program:

```
INTEGER*4 FUNCTION Region_phXiw_HuAir(p, h, Xiw,), REAL*8 p, h, Xiw
```

### Input Values:

- p - Total pressure  $p$  in bar
- h - Specific enthalpy  $h$  in kJ/kg
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

Region_phXiw_HuAir	Region of state of humid air:
	0 → Outside region of state
	1 → Dry air
	2 → Unsaturated humid air
	3 → Liquid mist
	4 → Ice fog
	5 → Mixture of liquid fog and ice fog at 0.01 °C exactly
	6 → Pure water

### Range of Validity:

- Temperature  $t$  :  $-143.15 \text{ } ^\circ\text{C} \leq t \leq 1726.85 \text{ } ^\circ\text{C}$
- Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$
- Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Iteration of  $t$  from  $h(p, t, \xi_w)$ . With this result it is possible to calculate *Region*.

### Results for Wrong Input Values:

Region\_phXiw\_HuAir = 0

### References:

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

## Region = $f(p, s, \xi_w)$

### Function Name:

Region\_psXiw\_HuAir

### Fortran Program:

```
INTEGER*4 FUNCTION Region_psXiw_HuAir(p, s, Xiw), REAL*8 p, s, Xiw
```

### Input Values:

- p - Total pressure  $p$  in bar
- s - Specific entropy  $s$  in  $\text{kJ}/(\text{kg K})$
- $\xi_w$  - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

Region_psXiw_HuAir	Region of state of humid air:
	0 → Outside region of state
	1 → Dry air
	2 → Unsaturated humid air
	3 → Liquid mist
	4 → Ice fog
	5 → Mixture of liquid fog and ice fog at 0.01 °C exactly
	6 → Pure water

### Range of Validity:

- Temperature  $t$  :  $-143.15 \text{ }^\circ\text{C} \leq t \leq 1726.85 \text{ }^\circ\text{C}$
- Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$
- Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Iteration of  $t$  from  $s(p, t, \xi_w)$ . With this result it is possible to calculate *Region*.

### Results for Wrong Input Values:

Region\_psXiw\_HuAir = 0

### References:

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

## Region = $f(p, t, \xi_w)$

### Function Name:

Region\_ptXiw\_HuAir

### Fortran Program:

```
INTEGER*4 FUNCTION Region_ptXiw_HuAir(p, t, Xiw), REAL*8 p, t, Xiw
```

### Input Values:

- p - Total pressure  $p$  in bar
- t - Temperature  $t$  in °C
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- Region\_ptXiw\_HuAir - Region of state of humid air:
  - 0 → Outside region of state
  - 1 → Dry air
  - 2 → Unsaturated humid air
  - 3 → Liquid mist
  - 4 → Ice fog
  - 5 → Mixture of liquid fog and ice fog at 0.01 °C exactly
  - 6 → Pure water

### Range of Validity:

- Temperature  $t$  :  $-143.15 \text{ } ^\circ\text{C} \leq t \leq 1726.85 \text{ } ^\circ\text{C}$
- Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$
- Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

### Results for Wrong Input Values:

Region\_ptXiw\_HuAir = 0

### References:

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

## Region = $f(t, s, \xi_w)$

### Function Name:

Region\_tsXiw\_HuAir

### Fortran Program:

```
INTEGER*4 FUNCTION Region_tsXiw_HuAir(t, s, Xiw), REAL*8 t, s, Xiw
```

### Input Values:

- t - Temperature  $t$  in °C
- s - Specific entropy  $s$  in kJ/(kg K)
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

Region_tsXiw_HuAir	Region of state of humid air:
	0 → Outside region of state
	1 → Dry air
	2 → Unsaturated humid air
	3 → Liquid mist
	4 → Ice fog
	5 → Mixture of liquid fog and ice fog at 0.01 °C exactly
	6 → Pure water

### Range of Validity:

- Temperature  $t$  :  $-143.15 \text{ } ^\circ\text{C} \leq t \leq 1726.85 \text{ } ^\circ\text{C}$
- Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$
- Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Iteration of  $p$  from  $s(p, t, \xi_w)$ . With this result it is possible to calculate *Region*.

### Results for Wrong Input Values:

Region\_tsXiw\_HuAir = 0

### References:

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

## Density $\rho = f(p, t, \xi_w)$

### Function Name:

Rho\_ptXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION Rho_ptXiw_HuAir(p,t,Xiw,succ), REAL*8 p, t, Xiw
                           INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- t - Temperature  $t$  in °C
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- Rho\_ptXiw\_HuAir - Density  $\rho$  in kg/m<sup>3</sup>
- succ
  - 1 → Calculation successful
  - 0 → Calculation not successful

### Range of Validity:

- Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$
- Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$
- Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Calculation:

- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ ) as ideal mixture of real gases (dry air and steam)
- for fog ( $\xi_w > \xi_{wsatt}$ ) as ideal mixture of saturated humid air and water liquid or water ice

### Results for Wrong Input Values:

Rho\_ptXiw\_HuAir = - 1, succ = 0

### References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water droplets in fog:

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

Ice crystals in fog:

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

## Specific Entropy $s = f(p, h, \xi_w)$

### Function Name:

s\_phXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION s_phXiw_HuAir(p,h,Xiw,succ), REAL*8 p,h,Xiw
                           INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- h - Specific entropy  $h$  in kJ/kg
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |               |  |
|---------------|--|
| s_ptXiw_HuAir | - Specific Entropy $s$ in kJ/(kg K)  |
| succ          | <ul style="list-style-type: none"> <li>- 1 → Calculation successful</li> <li>- 0 → Calculation not successful</li> </ul> |

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^\circ\text{C} \leq t \leq 1726.85 \text{ }^\circ\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Iteration of  $t$  from  $h(p, t, \xi_w)$  and calculation of  $s$  from  $s(p, t, \xi_w)$

Calculation:

- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ ) as ideal mixture of real gases (dry air and steam)
- for fog ( $\xi_w > \xi_{wsatt}$ ) as ideal mixture of saturated humid air and water liquid or water ice
- Effects of dissociation are taken into consideration from 500 °C upwards

### Results for Wrong Input Values:

$s_{phXiw\_HuAir} = -1 \cdot 10^{100}$ , succ=0

### References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water 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]

## Specific Entropy $s = f(p, t, \xi_w)$

### Function Name:

s\_ptXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION s_ptXiw_HuAir(p,t,Xiw,succ), REAL*8 p, t, Xiw INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- t - Temperature  $t$  in °C
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |               |                                     |
|---------------|-------------------------------------|
| s_ptXiw_HuAir | - Specific Entropy $s$ in kJ/(kg K) |
| succ          | - 1 → Calculation successful        |
|               | - 0 → Calculation not successful    |

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

#### Calculation:

- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ ) as ideal mixture of real gases (dry air and steam)
- for fog ( $\xi_w > \xi_{wsatt}$ ) as ideal mixture of saturated humid air and water liquid or water ice
- Effects of dissociation are taken into consideration from 500 °C upwards

### Results for Wrong Input Values:

s\_ptXiw\_HuAir = - 1 · 10<sup>100</sup>, succ=0

### References:

#### Dry air:

from Lemmon et al. [14]

#### Steam in humid air and water 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]

## Surface Tension $\sigma = f(t)$

### Function Name:

Sigma\_t\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION Sigma_t_HuAir(t, succ), REAL*8 t INTEGER*4 succ
```

### Input Values:

t - Temperature  $t$  in °C

### Output Values:

Sigma_t_HuAir	- Surface tension $\sigma$ in N/m
succ	- 1 → Calculation successful
	- 0 → Calculation not successful

### Range of Validity:

Temperature  $t$  :  $0 \text{ }^{\circ}\text{C} \leq t \leq t_{\text{krit}} = 373.946 \text{ }^{\circ}\text{C}$

### Comments:

Calculation: for pure water from IAPWS-IF97

### Results for Wrong Input Values:

Sigma\_t\_HuAir = - 1

### References: [8]

## Temperature $t = f(h, s, \xi_w)$

### Function Name:

`t_hsXiw_HuAir`

### Fortran Program:

```
REAL*8 FUNCTION T_hsXiw_HuAir(h, s, Xiw, succ), REAL*8 h, s, Xiw
                           INTEGER*4 succ
```

### Input Values:

- $h$  - Specific enthalpy  $h$  in kJ/kg
- $s$  - Specific entropy  $s$  in kJ/(kg K)
- $\xi_w$  - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |                            |  |
|----------------------------|--|
| <code>t_hsXiw_HuAir</code> | - Temperature $t$ in °C  |
| <code>succ</code>          | <ul style="list-style-type: none"> <li>- 1 → Calculation successful</li> <li>- 0 → Calculation not successful</li> </ul> |

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Iteration of  $t$  and  $p$  from  $h(p, t, \xi_w)$  and  $s(p, t, \xi_w)$

Calculation:

- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ ) as ideal mixture of real gases (dry air and steam)
- for fog ( $\xi_w > \xi_{wsatt}$ ) as ideal mixture of saturated humid air and water liquid or water ice
- Effects of dissociation are taken into consideration from 500 °C upwards

### Results for Wrong Input Values:

`t_hsXiw_HuAir` = -1, `succ` = 0

### References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water 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]

## Temperature $t = f(p, h, \xi_w)$

### Function Name:

`t_phXiw_HuAir`

### Fortran Program:

```
REAL*8 FUNCTION t_phXiw_HuAir(p, h, Xiw, succ), REAL*8 p, h, Xiw
                           INTEGER*4 succ
```

### Input Values:

- $p$  - Total pressure  $p$  in bar
- $h$  - Specific enthalpy  $h$  in kJ/kg
- $\xi_w$  - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |                            |  |
|----------------------------|--|
| <code>t_phXiw_HuAir</code> | - Temperature $t$ in °C  |
| <code>succ</code>          | <ul style="list-style-type: none"> <li>- 1 → Calculation successful</li> <li>- 0 → Calculation not successful</li> </ul> |

### Range of Validity:

- Temperature  $t$  :  $-143.15 \text{ }^\circ\text{C} \leq t \leq 1726.85 \text{ }^\circ\text{C}$
- Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$
- Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Iteration of  $t$  from  $h(p, t, \xi_w)$

Calculation:

- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ ) as ideal mixture of real gases (dry air and steam)
- for fog ( $\xi_w > \xi_{wsatt}$ ) as ideal mixture of saturated humid air and water liquid or water ice
- Effects of dissociation are taken into consideration from 500 °C upwards

### Results for Wrong Input Values:

`t_phXiw_HuAir` = - 1, `succ` = 0

### References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water 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]

## Temperature $t = f(p, s, \xi_w)$

### Function Name:

`t_psXiw_HuAir`

### Fortran Program:

```
REAL*8 FUNCTION t_psXiw_HuAir(p, s, Xiw, succ), REAL*8 p, s, Xiw
                           INTEGER*4 succ
```

### Input Values:

- $p$  - Total pressure  $p$  in bar
- $s$  - Specific entropy  $s$  in kJ/(kg K)
- $\xi_w$  - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |                            |  |
|----------------------------|--|
| <code>t_psXiw_HuAir</code> | - Temperature $t$ in °C  |
| <code>succ</code>          | <ul style="list-style-type: none"> <li>- 1 → Calculation successful</li> <li>- 0 → Calculation not successful</li> </ul> |

### Range of Validity:

- Temperature  $t$  :  $-143.15 \text{ }^\circ\text{C} \leq t \leq 1726.85 \text{ }^\circ\text{C}$
- Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$
- Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Iteration of  $t$  from  $s(p, t, \xi_w)$

Calculation:

- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ ) as ideal mixture of real gases (dry air and steam)
- for fog ( $\xi_w > \xi_{wsatt}$ ) as ideal mixture of saturated humid air and water liquid or water ice
- Effects of dissociation are taken into consideration from 500 °C upwards

### Results for Wrong Input Values:

`t_psXiw_HuAir` = -1, `succ` = 0

### References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water 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]

## Temperature $t = f(p, t_f, \xi_w)$ —○

### Function Name:

`t_ptfXiw_HuAir`

### Fortran Program:

```
REAL*8 FUNCTION t_ptfXiw_HuAir(p, tf, Xiw, succ), REAL*8 p, tf, Xiw
                           INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- tf - Wet Bulb Temperature  $t_f$  in °C
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |                             |                                  |
|-----------------------------|----------------------------------|
| <code>t_ptfXiw_HuAir</code> | - Temperature $t$ in °C          |
| <code>succ</code>           | - 1 → Calculation successful     |
|                             | - 0 → Calculation not successful |

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Effects of dissociation are taken into consideration from 500 °C upwards

### Results for Wrong Input Values:

`t_ptfXiw_HuAir` = - 1, `succ` = 0

### References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water droplets in fog:

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

Dissociation:

from VDI Guideline 4670 [13]

## Wet Bulb Temperature $t_f = f(p, t, \xi_w)$

### Function Name:

tf\_ptXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION tf_ptXiw_HuAir(p, t, Xiw, succ), REAL*8 p, t, Xiw
                           INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- t - Temperature  $t$  in °C
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- tf\_ptXiw\_HuAir - Wet bulb Temperature (cooling limit Temperature)  $t_f$  in °C
- succ
  - 1 → Calculation successful
  - 0 → Calculation not successful

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Iteration of  $t_f$  from  $h_{\text{unsaturated}}(p, t, X_i_w) = h(p, t_f, X_i_w)$

Effects of dissociation are taken into consideration from 500 °C upwards

### Results for Wrong Input Values:

tf\_ptXiw\_HuAir = -1, succ = 0

### References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water droplets in fog:

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

Dissociation:

from VDI Guideline 4670 [13]

## Dew Point Temperature $t_\tau = f(p, \xi_w)$

### Function Name:

tTau\_pXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION tTau_pXiw_HuAir(p, Xiw, succ), REAL*8 p, Xiw
                           INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- tTau\_pXiw\_HuAir - Dew point Temperature  $t_\tau$  in °C
- succ
  - 1 → Calculation successful
  - 0 → Calculation not successful

### Range of Validity:

- Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$
- Mass fraction of water  $\xi_w$  :  $\xi_{wsatt}(p, -30^\circ\text{C}) \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Dew point Temperature of water in mixtures of gases:

$$t_\tau = t_s(p, p_d) \text{ for } t \geq 0.01^\circ\text{C}$$

(  $t_s$  – Boiling Temperature of water in mixtures of gases )

$$t_\tau = t_{\text{sub}}(p, p_d) \text{ for } t < 0.01^\circ\text{C}$$

(  $t_{\text{sub}}$  – Sublimation Temperature of water in mixtures of gases )

with  $p_d = \frac{1}{\frac{1 - \xi_w}{\xi_w} \cdot \frac{R_l}{R_w} + 1}$

Dew point Temperature of pure water:

$$t_\tau = t_s(p)$$

(  $t_s$  – Boiling Temperature of pure water )

### Results for Wrong Input Values:

tTau\_pXiw\_HuAir = -1, succ = 0

### References:

- $t_s(p, p_d)$  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]

## Specific Internal Energy $u = f(p, t, \xi_w)$

### Function Name:

u\_ptXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION u_ptXiw_HuAir(p, t, Xiw, succ), REAL*8 p, t, Xiw
INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- t - Temperature  $t$  in °C
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- u\_ptXiw\_HuAir - Specific internal energy  $u$  in kJ/kg
- succ
  - 1 → Calculation successful
  - 0 → Calculation not successful

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

- Calculation:  $u = h - p \cdot v$
- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ ) as ideal mixture of real gases (dry air and steam)
- for fog ( $\xi_w > \xi_{wsatt}$ ) as ideal mixture of saturated humid air and water liquid or water ice
- Effects of dissociation are taken into consideration from 500 °C upwards

### Results for Wrong Input Values:

u\_ptXiw\_HuAir = - 1·10<sup>100</sup>, succ = 0

### References:

Dry air:

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

Steam in humid air and water 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]

## Specific Volume $v = f(h, s, \xi_w)$

### Function Name:

`v_hsXiw_HuAir`

### Fortran Program:

```
REAL*8 FUNCTION v_hsXiw_HuAir(h, s, Xiw, succ), REAL*8 h, s, Xiw
                           INTEGER*4 succ
```

### Input Values:

- $h$  - Specific enthalpy  $h$  in kJ/kg
- $s$  - Specific Entropy  $s$  in kJ/(kg K)
- $\xi_{\text{W}}$  - Mass fraction of water  $\xi_{\text{W}}$  in kg water / kg mixture

### Output Values:

- |                            |  |
|----------------------------|--|
| <code>v_hsXiw_HuAir</code> | - Specific volume $v$ in m <sup>3</sup> /kg  |
| <code>succ</code>          | <ul style="list-style-type: none"> <li>- 1 → Calculation successful</li> <li>- 0 → Calculation not successful</li> </ul> |

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_{\text{W}}$  :  $0 \leq \xi_{\text{W}} \leq 1 \text{ kg/kg}$

### Comments:

Iteration of  $p$  and  $t$  from  $h(p, t, \xi_{\text{W}})$  and  $s(p, t, \xi_{\text{W}})$  and calculation of  $v(p, t, \xi_{\text{W}})$

Calculation:

- for unsaturated and saturated humid air ( $\xi_{\text{W}} \leq \xi_{\text{wsatt}}$ ) as ideal mixture of real gases (dry air and steam)
- for fog ( $\xi_{\text{W}} > \xi_{\text{wsatt}}$ ) as ideal mixture of saturated humid air and water liquid or water ice
- Calculation of the mixture of liquid fog and ice at  $t = 0.01 \text{ }^{\circ}\text{C}$  is not possible

### Results for Wrong Input Values:

`v_hsXiw_HuAir` = -1, `succ` = 0

### References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water 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]

## Specific Volume $v = f(p, h, \xi_w)$

### Function Name:

v\_phXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION v_phXiw_HuAir(p, h, Xiw, succ), REAL*8 p, h, Xiw
                           INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- h - Specific enthalpy  $h$  in kJ/(kg K)
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |               |   |
|---------------|---|
| v_phXiw_HuAir | - Specific volume $v$ in m <sup>3</sup> /kg |
| succ          | - 1 → Calculation successful                |
|               | - 0 → Calculation not successful            |

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Iteration of  $t$  from  $h(p, t, \xi_w)$  and calculation of  $v(p, t, \xi_w)$

Calculation:

- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ ) as ideal mixture of real gases (dry air and steam)
- for fog ( $\xi_w > \xi_{wsatt}$ ) as ideal mixture of saturated humid air and water liquid or water ice

### Results for Wrong Input Values:

v\_phXiw\_HuAir = -1, succ = 0

### References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water 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]

## Specific Volume $v = f(p, s, \xi_w)$

### Function Name:

v\_psXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION v_psXiw_HuAir(p, s, Xiw, succ), REAL*8 p, s, Xiw
                           INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- s - Specific Entropy  $s$  in kJ/(kg K)
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |               |   |
|---------------|---|
| v_psXiw_HuAir | - Specific volume $v$ in m <sup>3</sup> /kg |
| succ          | - 1 → Calculation successful                |
|               | - 0 → Calculation not successful            |

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Iteration of  $t$  from  $s(p, t, \xi_w)$  and calculation of  $v(p, t, \xi_w)$

Calculation:

- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ ) as ideal mixture of real gases (dry air and steam)
- for fog ( $\xi_w > \xi_{wsatt}$ ) as ideal mixture of saturated humid air and water liquid or water ice

### Results for Wrong Input Values:

v\_psXiw\_HuAir = - 1, succ = 0

### References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water 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]

## Specific Volume $v = f(p, t, \xi_w)$

### Function Name:

`v_ptXiw_HuAir`

### Fortran Program:

```
REAL*8 FUNCTION v_ptXiw_HuAir(p, t, Xiw, succ), REAL*8 p, t, Xiw
                           INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- t - Temperature  $t$  in °C
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |                            |   |
|----------------------------|---|
| <code>v_ptXiw_HuAir</code> | - Specific volume $v$ in m <sup>3</sup> /kg |
| <code>succ</code>          | - 1 → Calculation successful                |
|                            | - 0 → Calculation not successful            |

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

#### Calculation:

- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ ) as ideal mixture of real gases (dry air and steam)
- for fog ( $\xi_w > \xi_{wsatt}$ ) as ideal mixture of saturated humid air and water liquid or water ice

### Results for Wrong Input Values:

`v_ptXiw_HuAir` = - 1, `succ` = 0

### References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water droplets in fog:

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

Ice crystals in fog:

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

## Specific Volume $v = f(t, s, \xi_w)$

### Function Name:

`v_tsXiw_HuAir`

### Fortran Program:

```
REAL*8 FUNCTION v_tsXiw_HuAir(t, s, Xiw, succ), REAL*8 t, s, Xiw
                           INTEGER*4 succ
```

### Input Values:

- t - Temperature  $t$  in °C
- s - Specific entropy  $s$  in kJ/(kg K)
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |                            |   |
|----------------------------|---|
| <code>v_tsXiw_HuAir</code> | - Specific volume $v$ in m <sup>3</sup> /kg |
| <code>succ</code>          | - 1 → Calculation successful                |
|                            | - 0 → Calculation not successful            |

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Iteration of  $p$  from  $s(p, t, \xi_w)$  and calculation of  $v(p, t, \xi_w)$

Calculation:

- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ ) as ideal mixture of real gases (dry air and steam)
- for fog ( $\xi_w > \xi_{wsatt}$ ) as ideal mixture of saturated humid air and water liquid or water ice
- Calculation of the mixture of liquid fog and ice at  $t = 0.01 \text{ }^{\circ}\text{C}$  is not possible

### Results for Wrong Input Values:

`v_tsXiw_HuAir` = -1, `succ` = 0

### References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water 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]

## Isentropic Speed of Sound $w = f(p, t, \xi_w)$

### Function Name:

w\_ptXiw\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION w_ptXiw_HuAir(p, t, Xiw, succ), REAL*8 p, t, Xiw
INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- t - Temperature  $t$  in °C
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- w\_ptXiw\_HuAir - Isentropic speed of sound  $w$  in m/s
- succ
  - 1 → Calculation successful
  - 0 → Calculation not successful

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

- for unsaturated and saturated humid air ( $\xi_w \leq \xi_{wsatt}$ )

$$w = \sqrt{p \cdot v \cdot \kappa} \text{ with } \kappa = -\frac{v}{p} \cdot \left( \frac{\partial p}{\partial v} \right)_t \cdot \frac{c_p}{c_v}$$

- for liquid fog ( $\xi_w > \xi_{wsatt}$ ): Model of ideal mixture of real fluids about volume fractions

- for ice fog ( $\xi_w \leq \xi_{wsatt}$ ): Calculation of saturated humid air

### Results for Wrong Input Values:

w\_ptXiw\_HuAir = -1, succ = 0

### References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water droplets in fog:

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

Dissociation:

from VDI Guideline 4670 [13]

## Humidity Ratio (Absolute Humidity) $x_w = f(\xi_w)$

**Function Name:**

`xw_Xiw_HuAir`

**Fortran Program:**

```
REAL*8 FUNCTION xw_Xiw_HuAir(Xiw, succ), REAL*8 Xiw INTEGER*4 succ
```

**Input Values:**

$\text{Xiw}$  - Mass fraction of water  $\xi_w$  in kg water / kg mixture

**Output Values:**

<code>xw_Xiw_HuAir</code>	- Humidity Ratio (Absolute humidity) $x_w$ in kg water / kg air
<code>succ</code>	<ul style="list-style-type: none"> <li>- 1 → Calculation successful</li> <li>- 0 → Calculation not successful</li> </ul>

**Range of Validity:**

Mass fraction of water  $\xi_w$ :  $0 \leq \xi_w \leq 1$  kg/kg

**Comments:**

Humidity Ratio (Absolute humidity) in mixture of gas:

$$x_w = \frac{\xi_w}{1 - \xi_w}$$

Result for pure water  $x_w = 1 \cdot 10^{100}$

**Results for Wrong Input Values:**

`xw_Xiw_HuAir = -1, succ = 0`

## Mass Fraction of Water $\xi_w = f(p, t, \varphi)$

### Function Name:

Xiw\_ptPhi\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION Xiw_ptPhi_HuAir(p,t,Phi,succ), REAL*8 p,t,Phi INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- t - Temperature  $t$  in °C
- Phi - relative humidity

### Output Values:

- Xiw\_ptPhi\_HuAir - Mass fraction of water  $\xi_w$  in kg / kg
- succ
  - 1 → Calculation successful
  - 0 → Calculation not successful

### Range of Validity:

- Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq t_{\text{krit}} = 373.946 \text{ }^{\circ}\text{C}$   
( $t_{\text{krit}}$  - critical Temperature of water)
- Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$
- Relative humidity  $\varphi$  :  $0 \leq \varphi \leq 1$

### Comments:

$$\text{Mass fraction of water } \xi_w = \frac{x_w}{1+x_w} \text{ with } x_w = \frac{R_l}{R_w} \frac{\varphi \cdot p_{\text{dsatt}}(p, t)}{p - \varphi \cdot p_{\text{dsatt}}(p, t)}$$

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

with  $p_s(t)$       for  $t \geq 0.01 \text{ }^{\circ}\text{C}$  - vapor pressure of water  
                         for  $t < 0.01 \text{ }^{\circ}\text{C}$  - sublimation pressure of water

### Results for Wrong Input Values:

Xiw\_ptPhi\_HuAir = -1, succ = 0

### References:

- $f(p, t)$       Herrmann et al. [20], [21]
- $p_s(t)$       if  $t \geq 0.01 \text{ }^{\circ}\text{C}$  from IAPWS-IF97 [1], [2], [3], [4]  
                         if  $t < 0.01 \text{ }^{\circ}\text{C}$  from IAPWS-08 [16], [17]

## Mass Fraction of Water $\xi_w = f(p, t, p_d)$

### Function Name:

Xiw\_ptpd\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION Xiw_ptpd_HuAir(p, t, pd, succ), REAL*8 p, t, pd
                           INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- t - Temperature  $t$  in °C
- pd - Partial pressure of water  $p_d$  in bar

### Output Values:

- Xiw\_ptpd\_HuAir - Mass fraction of water  $\xi_w$  in kg / kg
- succ - 1 → Calculation successful  
- 0 → Calculation not successful

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Mass fraction of water  $\xi_w$  :  $0 \leq \xi_w \leq 1 \text{ kg/kg}$

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^{\circ}\text{C} \leq t \leq 1726.85 \text{ }^{\circ}\text{C}$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Partial pressure of water  $p_d$  :  $0.01 \text{ bar} \leq p \leq p_{\text{dsatt}}(p, t) \text{ for } t \leq 373.946 \text{ }^{\circ}\text{C},$   
 $\leq 1000 \text{ bar for } t > 373.946 \text{ }^{\circ}\text{C}$

### Comments:

$$\text{Mass fraction of water } \xi_w = \frac{x_w}{1+x_w} \text{ with } x_w = \frac{R_l}{R_w} \frac{p_d}{p - p_d}$$

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

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

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

### Results for Wrong Input Values:

Xiw\_ptpd\_HuAir = -1, succ = 0

### References:

- $f(p, t)$  Herrmann et al. [20], [21]
- $p_s(t)$  if  $t \geq 0.01 \text{ }^{\circ}\text{C}$  from IAPWS-IF97 [1], [2], [3], [4]  
if  $t < 0.01 \text{ }^{\circ}\text{C}$  from IAPWS-08 [16], [17]

## Mass Fraction of Water $\xi_w = f(p, t_\tau)$

### Function Name:

Xiw\_ptTau\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION Xiw_ptTau_HuAir(p, tTau, succ), REAL*8 p, tTau
                           INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- $t_\tau$  - Dew point Temperature  $t_\tau$  in °C

### Output Values:

- Xiw\_ptTau\_HuAir - Mass fraction of water  $\xi_w$  in kg / kg
- succ
  - 1 → Calculation successful
  - 0 → Calculation not successful

### Range of Validity:

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Dew point temperature  $t_\tau$  :  $-143.15 \text{ }^\circ\text{C} \leq t_\tau \leq t_s(p, p_d)$   
 $(t_s - \text{Boiling Temperature of water in mixtures of gases})$

### Comments:

$$\text{Mass fraction of water } \xi_w = \frac{x_w}{1+x_w} \text{ with } x_w = \frac{R_l}{R_w} \frac{p_{dsatt}(p, t_\tau)}{p - p_{dsatt}(p, t_\tau)}$$

Saturation vapor pressure at saturation  $p_{dsatt} = f \cdot p_s(t_\tau)$

with  $p_s(t_\tau)$  for  $t_\tau \geq 0.01 \text{ }^\circ\text{C}$  - vapor pressure of water

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

### Results for Wrong Input Values:

Xiw\_ptTau\_HuAir = -1, succ = 0

### References:

- $f(p, t_\tau)$  Herrmann et al. [20], [21]
- $p_s(t_\tau)$  if  $t_\tau \geq 0.01 \text{ }^\circ\text{C}$  from IAPWS-IF97 [1], [2], [3], [4]  
 if  $t_\tau < 0.01 \text{ }^\circ\text{C}$  from IAPWS-08 [16], [17]

## Mass Fraction of Steam $\xi_w = f(p, t, t_f)$

### Function Name:

Xiw\_pttf\_HuAir

### Fortran Program:

```
REAL*8 FUNCTION Xiw_pttf_HuAir(p, t, tf, succ), REAL*8 p, t, tf
                           INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- t - Temperature  $t$  in °C
- tf - Wet bulb Temperature  $t_f$  in °C

### Output Values:

- |                |   |
|----------------|---|
| Xiw_pttf_HuAir | - Mass fraction of steam $\xi_w$ in kg / kg |
| succ           | - 1 → Calculation successful                |
|                | - 0 → Calculation not successful            |

### Range of Validity:

Temperature  $t$  :  $-143.15 \text{ }^\circ\text{C} \leq t \leq 1726.85 \text{ }^\circ\text{C}$

Wet bulb temperature  $t_f$  :  $-143.15 \text{ }^\circ\text{C} \leq t_f \leq t$  or  $t_s(p, p_d)$   
 $(t_s - \text{Boiling Temperature of water in mixtures of gases})$

Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

### Comments:

Iteration of  $\xi_w$  from  $h_{\text{unsaturated}}(p, t, X_{i_w}) = h(p, t_f, X_{i_w})$

Effects of dissociation are taken into consideration from 500 °C upwards

### Results for Wrong Input Values:

Xiw\_pttf\_HuAir = -1, succ = 0

### References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water droplets in fog:

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

Dissociation:

from VDI Guideline 4670 [13]

## Mass Fraction of Liquid Water $\xi_{wf} = f(p, t, \xi_w)$

### Function Name:

`Xiwf_ptXiw_HuAir`

### Fortran Program:

```
REAL*8 FUNCTION Xiwf_ptXiw_HuAir(p, t, Xiw, succ), REAL*8 p, t, Xiw
                           INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- t - Temperature  $t$  in °C
- Xiw - Mass fraction of water  $\xi_w$  in kg water / kg mixture

### Output Values:

- |                               |  |
|-------------------------------|--|
| <code>Xiwf_ptXiw_HuAir</code> | - Mass fraction of water $\xi_{wf}$ in kg / kg   |
| <code>succ</code>             | <ul style="list-style-type: none"> <li>- 1 → Calculation successful</li> <li>- 0 → Calculation not successful</li> </ul> |

### Range of Validity:

- Temperature  $t$  :  $t_\tau(p, \xi_w) \leq t \leq t_s(p, p_d)$   
( $t_s$  – Boiling Temperature of water in mixtures of gases)
- Pressure  $p$  :  $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$
- Mass fraction of water  $\xi_w$  :  $\xi_{wsatt}(p, t) \leq \xi_w \leq 1 \text{ kg/kg}$

### Comments:

Mass fraction of liquid water:  $\xi_{wf} = \frac{x_w - x_{ws}}{1 + x_w}$

with:  $x_w = \frac{R_l}{R_w} \frac{\varphi \cdot p_{dsatt}(p, t)}{p - \varphi \cdot p_{dsatt}(p, t)}$  and  $x_{ws} = \frac{R_l}{R_w} \frac{p_{dsatt}(p, t)}{p - p_{dsatt}(p, t)}$

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

with  $p_s(t)$  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 liquid water  $\xi_{wf} = 1$

Result for pure steam:  $\xi_{wf} = 0$

Result for pure water ice:  $\xi_{wf} = 0$

### Results for Wrong Input Values:

`Xiwf_ptXiw_HuAir = -1, succ = 0`

### References:

- $f(p, t)$  Herrmann et al. [20], [21]
- $p_s(t)$  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]

## Saturation Mass Fraction of Water $\xi_{wsatt} = f(p, t)$

### Function Name:

`Xiwsatt_pt_HuAir`

### Fortran Program:

```
REAL*8 FUNCTION Xiwsatt_pt_HuAir(p, t, succ), REAL*8 p, t
                           INTEGER*4 succ
```

### Input Values:

- p - Total pressure  $p$  in bar
- t - Temperature  $t$  in °C

### Output Values:

- `Xiwsatt_pt_HuAir` - Saturation mass fraction of water  $\xi_{wsatt}$  in kg / kg
- `succ`
  - 1 → Calculation successful
  - 0 → Calculation not successful

### Range of Validity:

- Temperature  $t$  :  $0^\circ\text{C} \leq t \leq t_s(p, p_d)^\circ\text{C}$   
( $t_s$  – Boiling Temperature of water in mixtures of gases)
- Pressure  $p$  :  $0.01\text{ bar} \leq p \leq 1000\text{ bar}$

### Comments:

Specific humidity of water for saturated humid air:

$$\xi_{wsatt} = \frac{x_{ws}}{1 + x_{ws}} \quad \text{with} \quad x_{ws} = \frac{R_l}{R_w} \cdot \frac{p_{dsatt}(p, t)}{p - p_{dsatt}(p, t)}$$

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

- with  $p_s(t)$  for  $t \geq 0.01^\circ\text{C}$  - vapor pressure of water
- for  $t < 0.01^\circ\text{C}$  - sublimation pressure of water

### Results for Wrong Input Values:

`Xiwsatt_pt_HuAir` = -1, `succ` = 0

### References:

- $f(p, t)$  Herrmann et al. [20], [21]
- $p_s(t)$  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]

## 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 Thermo-dynamic 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:  
 $\text{CO}_2$  - Span, Wagner     $\text{H}_2\text{O}$  - IAPWS-95  
 $\text{O}_2$  - Schmidt, Wagner     $\text{N}_2$  - Span et al.  
 $\text{Ar}$  - Tegeler et al.

and of the ideal gases:

$\text{SO}_2$ ,  $\text{CO}$ ,  $\text{Ne}$   
(Scientific Formulation of Bücker 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	$\text{H}_2\text{O}$	$\text{F}_2$	Propane
$\text{N}_2$	$\text{SO}_2$	$\text{NH}_3$	Iso-Butane
$\text{O}_2$	$\text{H}_2$	Methane	n-Butane
CO	$\text{H}_2\text{S}$	Ethane	Benzene
$\text{CO}_2$	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](http://www.ashrae.org/bookstore)

### 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 Bücker and Wagner (2006)

#### n-Butane

#### Library LibButane\_n

Formulation of Bücker 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

$\text{C}_2\text{H}_6\text{O}_2$	Ethylene glycol
$\text{C}_3\text{H}_8\text{O}_2$	Propylene glycol
$\text{C}_2\text{H}_5\text{OH}$	Ethanol
$\text{CH}_3\text{OH}$	Methanol
$\text{C}_3\text{H}_8\text{O}_3$	Glycerol
$\text{K}_2\text{CO}_3$	Potassium carbonate
$\text{CaCl}_2$	Calcium chloride
$\text{MgCl}_2$	Magnesium chloride
$\text{NaCl}$	Sodium chloride
$\text{C}_2\text{H}_3\text{KO}_2$	Potassium acetate
$\text{CHKO}_2$	Potassium formate
$\text{LiCl}$	Lithium chloride
$\text{NH}_3$	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  $C_{14}H_{42}O_5Si_6$  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  $H_2S$  Library LibH2S

Nitrous oxide  $N_2O$  Library LibN2O

Sulfur dioxide  $SO_2$  Library LibSO2

Acetone  $C_3H_6O$  Library LibC3H6O

Formulation of Lemmon and Span (2006)



## For more information please contact:

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Email: [info@thermofluidprop.com](mailto:info@thermofluidprop.com)

Phone: +49-351-27597860

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

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

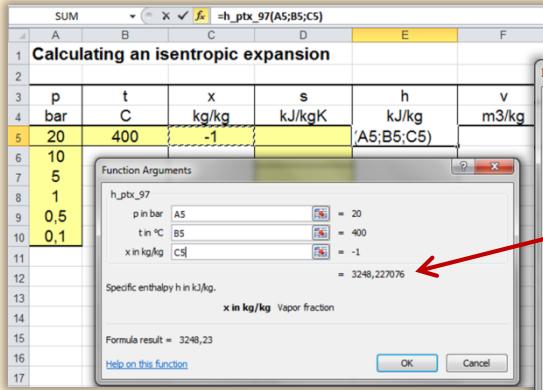
### Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

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

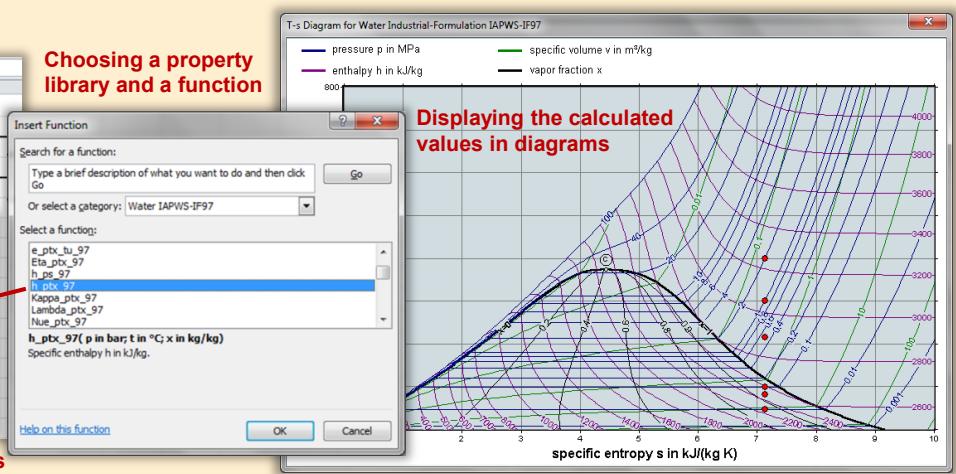
## Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

### Add-In FluidEXL Graphics for Excel®



Menu for the input of given property values

Choosing a property library and a function

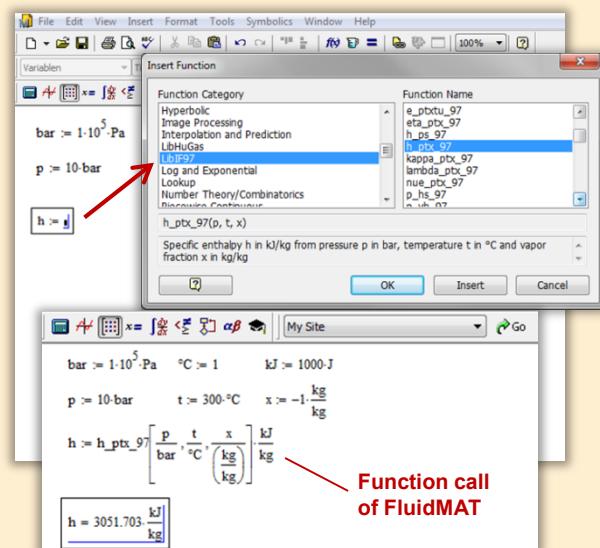


Displaying the calculated values in diagrams

### Add-On FluidMAT for Mathcad®

### Add-On FluidPRIME for Mathcad Prime®

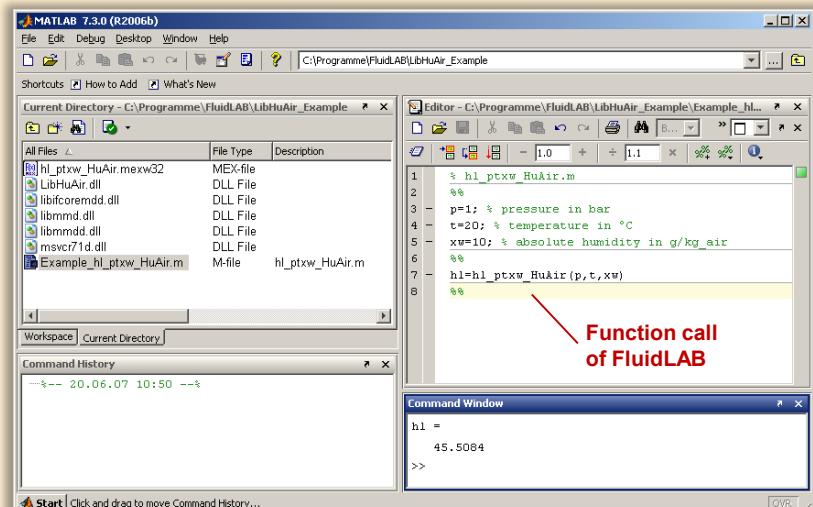
The property libraries can be used in Mathcad® and Mathcad Prime®.



Function call of FluidMAT

### Add-On FluidLAB for MATLAB® and SIMULINK®

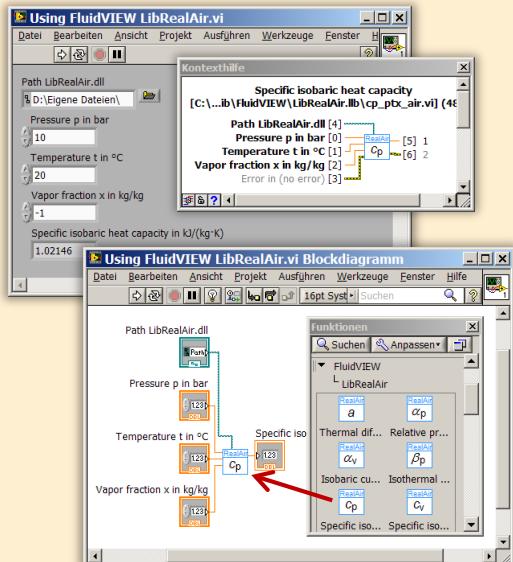
Using the Add-In FluidLAB the property functions can be called in MATLAB® and SIMULINK®.



Function call of FluidLAB

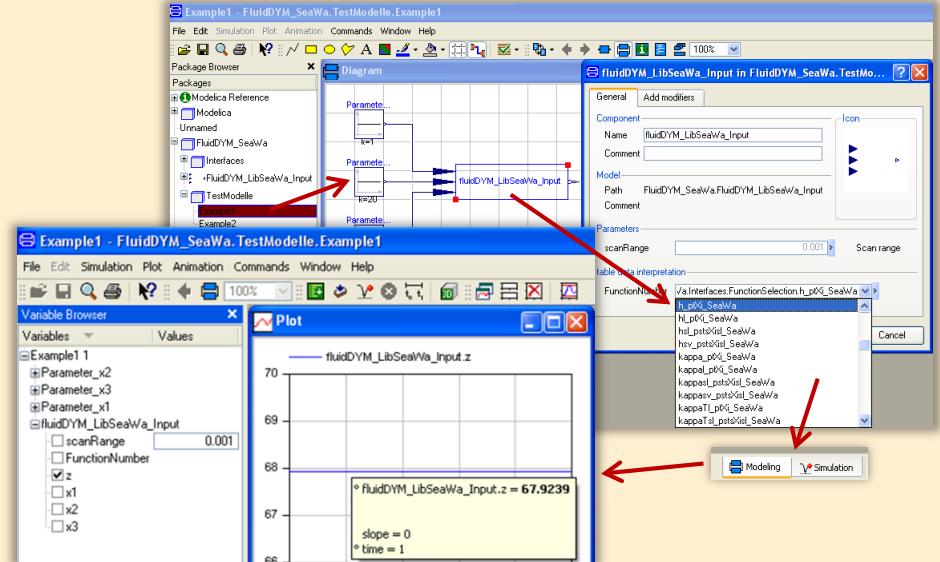
### Add-On FluidVIEW for LabVIEW™

The property functions can be calculated in LabVIEW™.

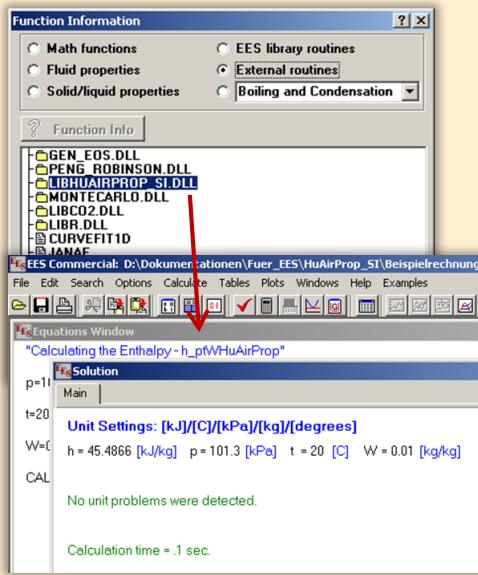


### Add-On FluidDYM for DYMOLA® (Modelica) and SimulationX®

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



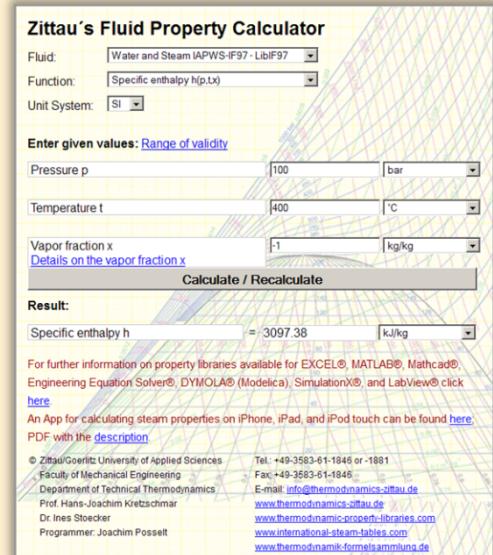
## Add-On FluidEES for Engineering Equation Solver®



## 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



### FluidHP



### FluidTI



## For more information please contact:



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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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## 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, Sprenge	03/2022
HS Hannover, Maschinenbau & BioVT	
M+M Turbinentechnik, Bad Salzuflen	
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, Lauta	
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	

## 2020

Drill Cool, Bakersfield CA, USA	12/2020
Manders, The Netherlands	
RWE Supply & Tranding, 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 Ingenierbüro	
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	
Ruchi 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 Enginering 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	
Ruchi 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
Pöry, Zürich, Switzerland	
RWTH Aachen, Institut für Strahltriebe 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	

## 2018

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