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TECHNICAL THERMODYNAMICS

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

FluidEXL*Graphics* with LibHuAir_Xiw for Excel®

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

LibHuAir_Xiw

FluidEXL*Graphics*

Contents

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0. Package Contents

0.1 Zip files for 32-bit Windows®

The following zip files are delivered for your computer running a 32-bit version of Windows®.

English zip file "CD_FluidEXL_Graphics_LibHuAir_Xiw_Eng.zip" including the following files:

FluidEXL_Graphics_Eng_Setup.exe	- Self-extracting and self-installing program for FluidEXL*Graphics*
FluidEXL_Graphics_Eng.xla	- FluidEXL*Graphics* Add-In
FluidEXL_Graphics_LibHuAir_Xiw_Docu_Eng.pdf	- User's Guide
LibHuAir_Xiw.hlp	- Help file for the LibHuAir_Xiw property library
LibHuAir_Xiw.dll	- Dynamic link library with functions for humid air

German zip file "CD_FluidEXL_Graphics_LibHuAir_Xiw.zip" including the following files:

FluidEXL_Graphics_Setup.exe	- Self-extracting and self-installing program for FluidEXL*Graphics*
FluidEXL_Graphics.xla	- German Add-In for FluidEXL*Graphics*
FluidEXL_Graphics_LibHuAir_Xiw_Docu_Eng.pdf	- User's Guide
LibHuAir_Xiw.hlp	- Help file for the LibHuAir_Xiw property library
LibHuAir_Xiw.dll	- Dynamic link library with functions for humid air

0.2 Zip files for 64-bit Windows®

The following zip files are delivered for your computer running a 64-bit version of Windows®.

English zip file "CD_FluidEXL_Graphics_LibHuAir_Xiw_x64_Eng.zip" including the following files and folders:

Files:

Setup.exe	- Self-extracting and self-installing program for FluidEXL*Graphics*
FluidEXL_Graphics_Eng_64_Setup.msi	- Self-extracting and self-installing program
FluidEXL_Graphics_Eng.xla	- FluidEXL*Graphics* Add-In
FluidEXL_Graphics_LibHuAir_Xiw_Docu_Eng.pdf	- User's Guide
LibHuAir_Xiw.dll	- Dynamic link library with functions for humid air
LibHuAir_Xiw.hlp	- Help file for the LibHuAir_Xiw property library

Folders:

/vcredist_x64	- Folder containing the "Microsoft Visual C++ 2010 x64 Redistributable Pack"
/WindowsInstaller3_1	- Folder containing the "Microsoft Windows Installer"

German zip file "CD_FluidEXL_Graphics_LibHuAir_Xiw_x64.zip" including the following files and folders:

Files:

Setup.exe	- Self-extracting and self-installing program for FluidEXL*Graphics*
FluidEXL_Graphics_64_Setup.msi	- Self-extracting and self-installing program
FluidEXL_Graphics.xla	- FluidEXL*Graphics* Add-In
FluidEXL_Graphics_LibHuAir_Xiw_Docu_Eng.pdf	- User's Guide
LibHuAir_Xiw.dll	- Dynamic link library with functions for humid air
LibHuAir_Xiw.hlp	- Help file for the LibHuAir_Xiw property library

Folders:

/vcredist_x64	- Folder containing the "Microsoft Visual C++ 2010 x64 Redistributable Pack"
/WindowsInstaller3_1	- Folder containing the "Microsoft Windows Installer"

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_ptXiw_HuAir(p,t,Xiw,succ)	Thermal diffusivity	m^2/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	kJ/(kg·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	kJ/(kg·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	kJ/(kg·K)	[1-4], [13], [14]	3/5
$c_p = f(p,t,\xi_w)$	cp_ptXiw_HuAir	= cp_ptXiw_HuAir(p,t,Xiw,succ)	Specific isobaric heat capacity	kJ/(kg·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	kJ/(kg·K)	[1-4], [13], [14]	3/7
$c_v = f(p,t,\xi_w)$	cv_ptXiw_HuAir	= cv_ptXiw_HuAir(p,t,Xiw,succ)	Specific isochoric heat capacity	kJ/(kg·K)	[1-4], [13], [14]	3/8
$\eta = f(p,t,\xi_w)$	Eta_ptXiw_HuAir	= Eta_ptXiw_HuAir(p,t,Xiw,succ)	Dynamic viscosity	Pa·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	kJ/kg	[1-4], [13], [14], [18], [19]	3/10
$h = f(p,t,\xi_w)$	h_ptXiw_HuAir	= h_ptXiw_HuAir(p,t,Xiw,succ)	Specific enthalpy	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	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
$\kappa = \mathrm{f}(p,s,\xi_\mathrm{w})$	Kappa_psXiw_HuAir	= Kappa_psXiw_HuAir(p,s,Xiw,succ)	Backward function: Isentropic exponent from pressure and entropy	-	[1-4], [13], [14]	3/13
$\kappa = \mathrm{f}(p,t,\xi_\mathrm{w})$	Kappa_ptXiw_HuAir	= Kappa_ptXiw_HuAir(p,t,Xiw,succ)	Isentropic exponent	-	[1-4], [13], [14]	3/14
$\lambda = \mathrm{f}(p,t,\xi_\mathrm{w})$	Lambda_ptXiw_HuAir	= Lambda_ptXiw_HuAir(p,t,Xiw,succ)	Thermal conductivity	$\mathrm{W/(m \cdot K)}$	[6], [12], [15]	3/15
$\nu = \mathrm{f}(p,t,\xi_\mathrm{w})$	Ny_ptXiw_HuAir	= Ny_ptXiw_HuAir(p,t,Xiw,succ)	Kinematic viscosity	$\mathrm{m^2/s}$	[1-4], [7], [12], [14], [15]	3/16
$p = \mathrm{f}(h,s,\xi_\mathrm{w})$	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
$p = \mathrm{f}(t,s,\xi_\mathrm{w})$	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
$p_\mathrm{d} = \mathrm{f}(p,t,\xi_\mathrm{w})$	pd_ptXiw_HuAir	= pd_ptXiw_HuAir(p,t,Xiw,succ)	Partial pressure of steam	bar	[1-4], [16], [17], [25], [26]	3/19
$p_\mathrm{dsatt} = \mathrm{f}(p,t)$	pdsatt_pt_HuAir	= pdsatt_pt_HuAir(p,t,succ)	Saturation vapor pressure of water	bar	[1-4], [16], [17], [25], [26]	3/20
$\varphi = \mathrm{f}(p,t,\xi_\mathrm{w})$	Phi_ptXiw_HuAir	= Phi_ptXiw_HuAir(p,t,Xiw,succ)	Relative humidity	-	[1-4], [16], [17], [25], [26]	3/21
$p_\mathrm{l} = \mathrm{f}(p,t,\xi_\mathrm{w})$	pl_ptXiw_HuAir	= pl_ptXiw_HuAir(p,t,Xiw,succ)	Partial pressure of air	bar	[1-4], [16], [17], [25], [26]	3/22
$Pr = \mathrm{f}(p,t,\xi_\mathrm{w})$	Pr_ptXiw_HuAir	= Pr_ptXiw_HuAir(p,t,Xiw,succ)	PRANDTL-Number	-	[1-4], [6], [7], [12-15]	3/23
$\psi_\mathrm{l} = \mathrm{f}(\xi_\mathrm{w})$	Psil_Xiw_HuAir	= Psil_Xiw_HuAir(Xiw,succ)	Mole fraction of air	kmol/kmol		3/24
$\psi_\mathrm{w} = \mathrm{f}(\xi_\mathrm{w})$	Psiw_Xiw_HuAir	= Psiw_Xiw_HuAir(Xiw,succ)	Mole fraction of water	kmol/kmol		3/25
$Region = \mathrm{f}(h,s,\xi_\mathrm{w})$	Region_hsXiw_HuAir	= Region_hsXiw_HuAir(p,h,Xiw)	Region of state from enthalpy and entropy	-	[1-4], [14], [18], [19]	3/26
$Region = \mathrm{f}(p,h,\xi_\mathrm{w})$	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
$Region = \mathrm{f}(p,s,\xi_\mathrm{w})$	Region_psXiw_HuAir	= Region_psXiw_HuAir(p,s,Xiw)	Region of state from pressure and entropy	-	[1-4], [14], [18], [19]	3/28
$Region = \mathrm{f}(p,T,\xi_\mathrm{w})$	Region_ptXiw_HuAir	= Region_ptXiw_HuAir(p,t,Xiw)	Region of state from pressure and temperature	-	[1-4], [14], [18], [19]	3/29
$Region = \mathrm{f}(t,s,\xi_\mathrm{w})$	Region_tsXiw_HuAir	= Region_tsXiw_HuAir(t,s,Xiw)	Region of state from temperature and entropy	-	[1-4], [14], [18], [19]	3/30
$\rho = \mathrm{f}(p,t,\xi_\mathrm{w})$	Rho_ptXiw_HuAir	= Rho_ptXiw_HuAir(p,t,Xiw,succ)	Density	$\mathrm{kg/m^3}$	[1-4], [14], [18], [19]	3/31
$s = \mathrm{f}(p,h,\xi_\mathrm{w})$	s_phXiw_HuAir	= s_phXiw_HuAir(p,h,Xiw,succ)	Backward function: Entropy from pressure and enthalpy	$\mathrm{kJ/(kg \cdot K)}$	[1-4], [13], [14], [18], [19]	3/32
$s = \mathrm{f}(p,t,\xi_\mathrm{w})$	s_ptXiw_HuAir	= s_ptXiw_HuAir(p,t,Xiw,succ)	Specific entropy	$\mathrm{kJ/(kg \cdot K)}$	[1-4], [13], [14], [18], [19]	3/33
$\sigma = \mathrm{f}(t)$	Sigma_t_HuAir	= Sigma_t_HuAir (t,succ)	Surface tension of water	N/m	[8]	3/34
$t = \mathrm{f}(h,s,\xi_\mathrm{w})$	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
$t = \mathrm{f}(p,h,\xi_\mathrm{w})$	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
$t = \mathrm{f}(p,s,\xi_\mathrm{w})$	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
$t_\mathrm{f} = \mathrm{f}(p,t,\xi_\mathrm{w})$	tf_ptXiw_HuAir	= tf_ptXiw_HuAir(p,t,Xiw,succ)	Wet bulb temperature	°C	[1-4], [13], [22]	3/38
$t_\tau = \mathrm{f}(p,\xi_\mathrm{w})$	tTau_pXiw_HuAir	= tTau_pXiw_HuAir(p,Xiw,succ)	Dew point temperature	°C	[1-4], [16], [17]	3/39
$u = \mathrm{f}(p,t,\xi_\mathrm{w})$	u_ptXiw_HuAir	= u_ptXiw_HuAir(p,t,Xiw,succ)	Internal energy	kJ/kg	[1-4], [13], [14], [18], [19]	3/40
$v = \mathrm{f}(h,s,\xi_\mathrm{w})$	v_hsXiw_HuAir	= v_hsXiw_HuAir(h,s,Xiw,succ)	Backward function: Specific volume from enthalpy and entropy	$\mathrm{m^3/kg}$	[1-4], [13], [14], [18], [19]	3/41

Functional Dependence	Function Name	Call from Fortran Program	Property or Function	Unit	Source or Algorithm	Information on page
$v = \mathrm{f}(p,h,\xi_w)$	v_phXiw_HuAir	= v_phXiw_HuAir(p,h,Xiw,succ)	Backward function: Specific volume from pressure and enthalpy	m^3/kg	[1-4], [13], [14], [18], [19]	3/42
$v = \mathrm{f}(p,s,\xi_w)$	v_psXiw_HuAir	= v_psXiw_HuAir(p,s,Xiw,succ)	Backward function: Specific volume from pressure and entropy	m^3/kg	[1-4], [13], [14], [18], [19]	3/43
$v = \mathrm{f}(p,t,\xi_w)$	v_ptXiw_HuAir	= v_ptXiw_HuAir(p,t,Xiw,succ)	Specific volume	m^3/kg	[1-4], [14], [18], [19]	3/44
$v = \mathrm{f}(t,s,\xi_w)$	v_tsXiw_HuAir	= v_tsXiw_HuAir(t,s,Xiw,succ)	Backward function: Specific volume from temperature and entropy	m^3/kg	[1-4], [13], [14], [18], [19]	3/45
$w = \mathrm{f}(p,t,\xi_w)$	w_ptXiw_HuAir	= w_ptXiw_HuAir(p,t,Xiw,succ)	Isentropic speed of sound	m/s	[1-4], [13], [14]	3/46
$x_w = \mathrm{f}(\xi_w)$	xw_Xiw_HuAir	= xw_Xiw_HuAir(Xiw,succ)	Humidity ratio (absolute humidity) from mass fraction of water	kg/kg_{Air}		3/47
$\xi_w = \mathrm{f}(p,t,\varphi)$	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]	3/48
$\xi_w = \mathrm{f}(p,t,p_d)$	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]	3/49
$\xi_w = \mathrm{f}(p,t_\tau)$	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
$\xi_w = \mathrm{f}(p,t,t_f)$	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
$\xi_{wf} = \mathrm{f}(p,t,\xi_w)$	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
$\xi_{wsatt} = \mathrm{f}(p,t)$	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

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_2	0.7812
Oxygen	O_2	0.2096
Argon	Ar	0.0092

Parameters

p - Total pressure in bar
t - Temperature in °C
Xiw - 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 = - 30 °C ... 1726.85 °C
Pressure p = 0.01 bar ... 1000 bar

Calculation algorithms

Unsaturated and saturated humid air $(0 \le Xi_w \le Xi_{ws})$:

Ideal mixture of dry air and steam

Dry air:

- v, h, u, s, c_p, c_v, κ, w from *Lemmon* et al. [14]
- λ, η from *Lemmon* et al. [15]

Steam:

- v, h, u, s, c_p, c_v, κ, w of steam from IAPWS-IF97 [1], [2], [3], [4]
- λ, η for $0°C \le t \le 800°C$ from IAPWS-85 [6], [7] (Mixture of volume fractions)
  for t < 0 °C and t > 800 °C from *Brandt* [12] (Mixture of volume fractions)

Supersaturated humid air (liquid fog or ice fog)

Liquid fog $(Xi_w > Xi_{wsatt})$ and $t \ge 0°C$

Ideal mixture of saturated humid air and water liquid
- saturated humid air as specified above
- v, h, u, s, κ, w of liquid drops from IAPWS-IF97 [1], [2], [3], [4]
- λ, η of liquid drops from IAPWS-85, IAPWS-08 [6], [7] (Mixture of volume fractions)

Ice fog $(Xi_w > Xi_{wsatt})$ and $t < 0°C$

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]
- λ of ice crystals as non varying value
- η, κ, w of saturated humid air

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

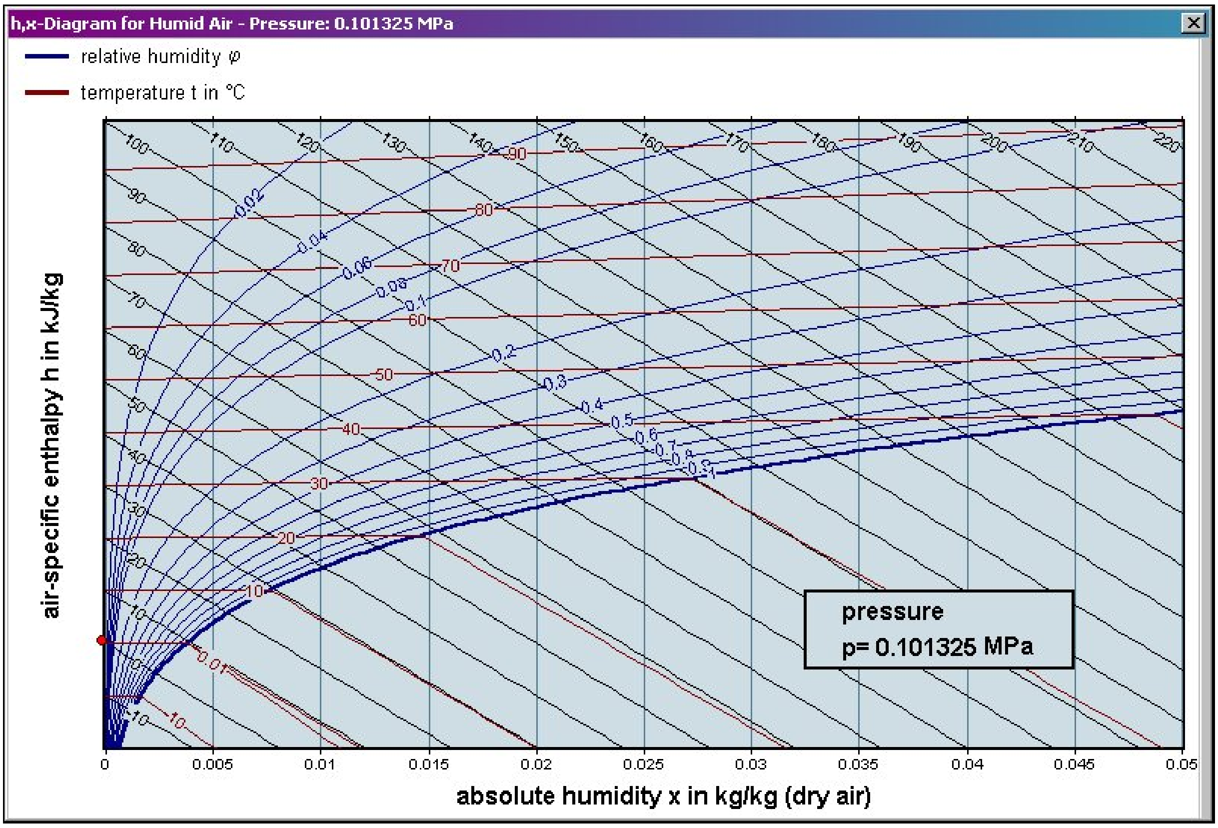
$p_{dsatt}(p,t)$ is the saturation vapor pressure from $p_{dsatt}(p,t) = f(p,t) \cdot p_s(t)$
- $f(p,t)$ from Herrmann et al. [25], [26],
- $p_s(t)$ for T ≥ 0.01 °C from IAPWS - IF97 [1], [2], [3], [4],
- $p_s(t)$ for T < 0 °C from IAPWS-08 [16], [17].

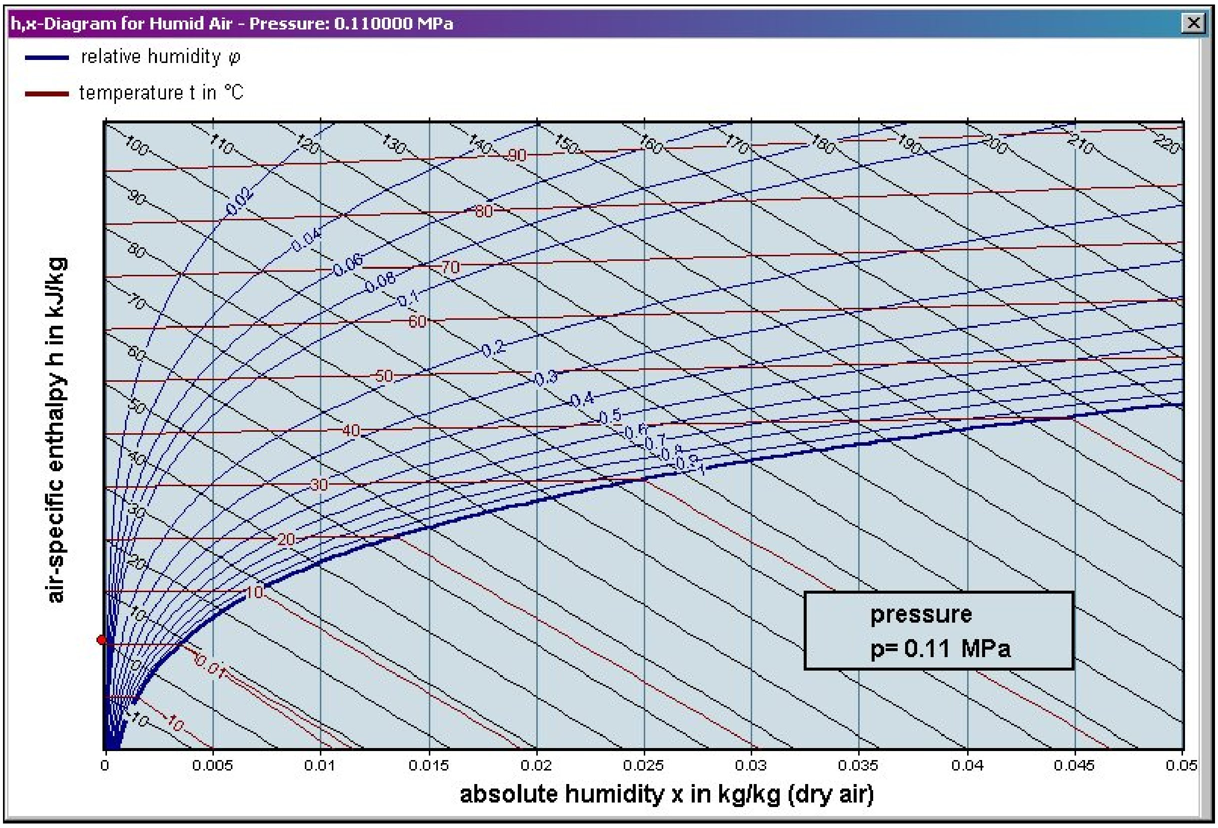
1.2 Thermodynamic Diagrams

FluidEXL*Graphics* enables the user to represent the calculated properties in the following thermodynamic diagrams:

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

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




h,x-Diagram for Humid Air - Pressure: 0.110000 MPa
relative humidity φ
temperature t in °C
air-specific enthalpy h in kJ/kg
absolute humidity x in kg/kg (dry air)
pressure
p= 0.11 MPa

2. Application of FluidEXL*Graphics* in Excel®

The Add-In FluidEXL*Graphics* has been developed to calculate thermodynamic properties in Excel® more conveniently. Within Excel, it enables the direct call of functions relating to humid air from the LibHuAir_Xiw property library. Furthermore, the program enables representation of calculated values in various thermodynamic diagrams.

2.1 Installing FluidEXL*Graphics*

If FluidEXL*Graphics* has not yet been installed or if there is a version installed which has been delivered before June 2010, please complete the initial installation procedure described below.

If FluidEXL*Graphics* has already been installed in a version which has been delivered after June 2010, you simply need to copy the files which belong to the LibHuAir_Xiw library. In this case, follow the subsection "Adding the LibHuAir_Xiw Library" on page 2/11.

Installing FluidEXL*Graphics* for 32-bit Excel®

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

Before you begin, it is best to uninstall any trial version or full version of FluidEXL*Graphics* delivered before June 2010.

After you have downloaded and extracted the zip-file

"CD_FluidEXL_Graphics_LibHuAir_Xiw_Eng.zip" (for English version of Windows®)
"CD_FluidEXL_Graphics_LibHuAir_Xiw.zip" (for German version of Windows)

you will see the folder

CD_FluidEXL_Graphics_LibHuAir_Xiw_Eng (for English version of Windows)
CD_FluidEXL_Graphics_LibHuAir_Xiw (for German version of Windows)

in your Windows Explorer, Norton Commander, etc.

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

Within this folder you will see the following files:

FluidEXL_Graphics_Eng_Setup.exe (for English version of Windows)
FluidEXL_Graphics_Setup.exe (for German version of Windows)
FluidEXL_Graphics_Eng.xla (for English version of Windows)
FluidEXL_Graphics.xla (for German version of Windows)
LibHuAir_Xiw.dll
LibHuAir_Xiw.hlp.

In order to run the installation of FluidEXL*Graphics*, double-click the file

FluidEXL_Graphics_Eng_Setup.exe (for English version of Windows)
FluidEXL_Graphics_Setup.exe (for German version of Windows).

Installation may start with a window noting that all Windows programs should be closed. When this is the case, the installation can be continued. Click the "Continue" button.

In the following dialog box, "Choose Destination Location", the default path offered automatically for the installation of FluidEXL*Graphics* is

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
C:\Programme\FluidEXL_Graphics (for German version of Windows).

By clicking the "Browse…" button, you can change the installation directory before installation (see figure below).

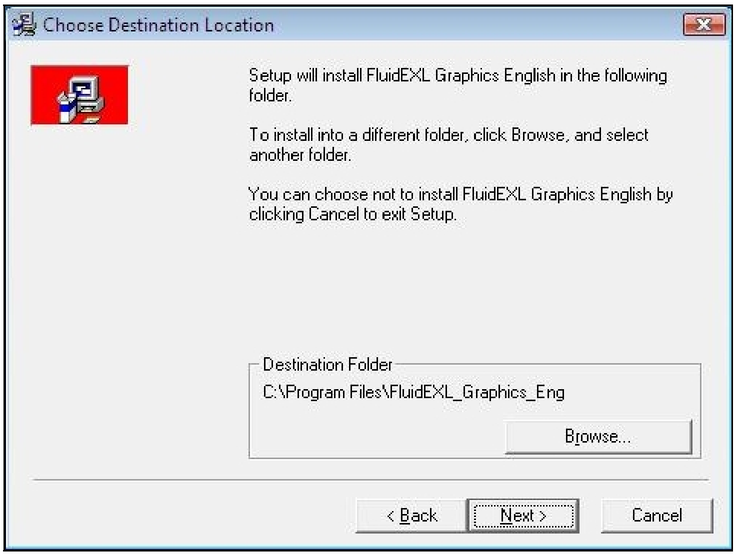


Image 2.1: Choose Destination Location

Finally, click on "Next" to continue installation; click "Next" again in the "Start Installation" window which follows in order to start the installation of FluidEXL*Graphics*.

After FluidEXL*Graphics* has been installed, the sentence "FluidEXL Graphics English has been successfully installed." will be shown. Confirm this by clicking the "Finish" button.

The installation of FluidEXL*Graphics* has been completed.

During the installation process the following files

Advapi32.dll	LC.dll
DFORMD.dll	Msvcp60.dll
Dforrt.dll	Msvcrt.dll
UNWISE.EXE	UNWISE.INI
INSTALL_EXL.LOG	
FluidEXL_Graphics_Eng.xla	(for English version of Windows)
FluidEXL_Graphics.xla	(for German version of Windows)

have been copied into the chosen destination folder, in the standard case

C:\Program Files\FluidEXL_Graphics_Eng	(for English version of Windows)
C:\Programme\FluidEXL_Graphics	(for German version of Windows).

In the next step, the files

FluidEXL_Graphics_Eng.xla	(for English version of Windows)
FluidEXL_Graphics.xla	(for German version of Windows)
LibHuAir_Xiw.dll	
LibHuAir_Xiw.hlp	

in the extracted zip-folder

CD_FluidEXL_Graphics_LibHuAir_Xiw_Eng	(for English version of Windows)
CD_FluidEXL_Graphics_LibHuAir_Xiw	(for German version of Windows)

must be copied into the chosen destination folder (the standard being

C:\Program Files\FluidEXL_Graphics_Eng	(for English version of Windows)
C:\Programme\FluidEXL_Graphics	(for German version of Windows))

using an appropriate program such as Explorer or Norton Commander.

Installing FluidEXL*Graphics* for 64-bit Excel®

In this section, the installation of FluidEXL*Graphics* for a 64-bit Excel® version is described. Before you begin, it is best to uninstall any trial version or full version of FluidEXL*Graphics* delivered before June 2010.

After you have downloaded and extracted the zip-file

"CD_FluidEXL_Graphics_LibHuAir_Xiw_Eng.zip" (for English version of Windows)
"CD_FluidEXL_Graphics_LibHuAir_Xiw.zip" (for German version of Windows)

you will see the folder

CD_FluidEXL_Graphics_LibHuAir_Xiw_Eng (for English version of Windows)
CD_FluidEXL_Graphics_LibHuAir_Xiw (for German version of Windows)

in your Windows Explorer, Norton Commander etc.

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

Within this folder you will see the following files

FluidEXL_Graphics_LibHuAir_Xiw_Docu_Eng.pdf
FluidEXL_Graphics_Eng.xla (for English version of Windows)
FluidEXL_Graphics.xla (for German version of Windows)
FluidEXL_Graphics_Eng_Setup_64.msi (for English version of Windows)
FluidEXL_Graphics_Setup_64.msi (for German version of Windows)
LibHuAir_Xiw.dll
LibHuAir_Xiw.hlp
Setup.exe

and the folders

vcredist_x64
WindowsInstaller3_1.

In order to run the installation of FluidEXL*Graphics*, double-click the file

Setup.exe.

If the "Microsoft Visual C++ 2010 x64 Redistributable Pack" is not running on your computer yet, installation will start with a window noting that the "Visual C++ 2010 runtime library (x64)" will be installed on your machine (see Figure 2.2).

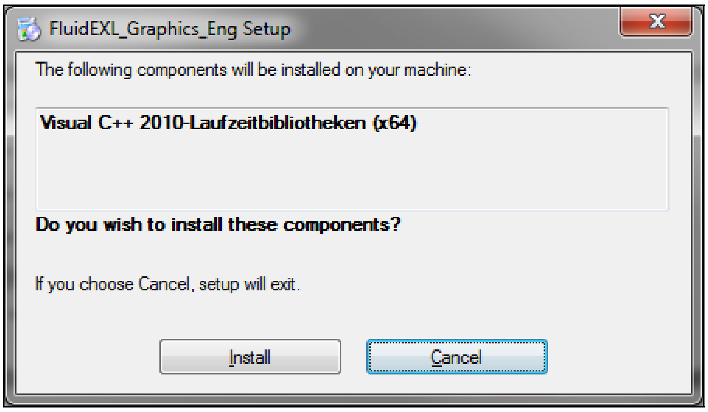


Figure 2.2: Installing the "Visual C++ 2010 runtime library (x64)"

Click on "Install" to continue.

In the following window you are required to accept the Microsoft® license terms to install the "Microsoft Visual C++ 2010 x64 Redistributable Pack" by ticking the box next to "I have read and accept the license terms" (see Figure 2.3).

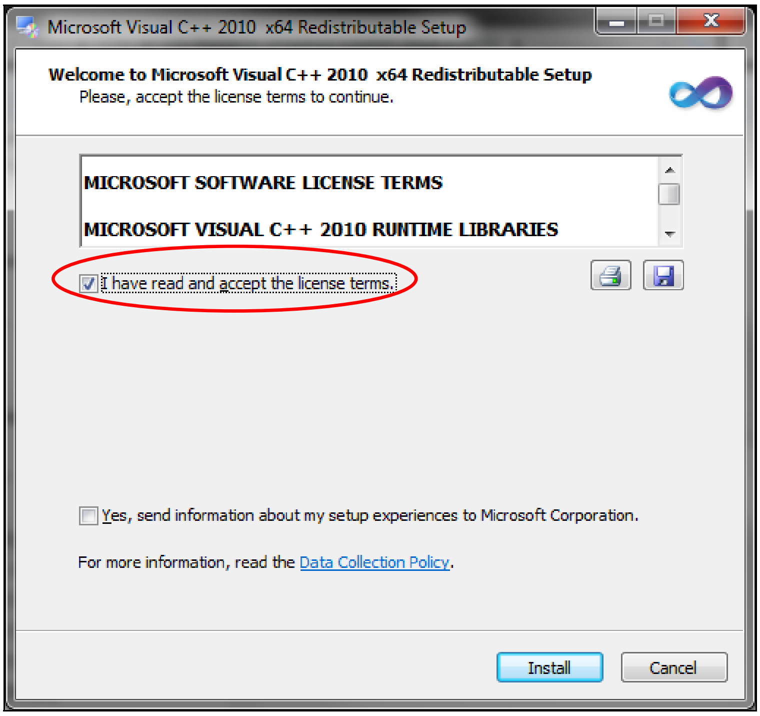


Figure 2.3: Accepting the license terms

Now click on "Install" to continue installation.

After the "Microsoft Visual C++ 2010 x64 Redistributable Pack" has been installed, you will see the sentence "Microsoft Visual C++ 2010 x64 Redistributable has been installed." Confirm this by clicking "Finish."

Now the installation of FluidEXL*Graphics* starts with a window noting that the installer will guide you through the installation. Click the "Next >" button to continue.

In the following dialog box (see Figure 2.4), "Select Installation Folder," the default path offered automatically for the installation of FluidEXL*Graphics* is

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
C:\Programme\FluidEXL_Graphics (for German version of Windows).

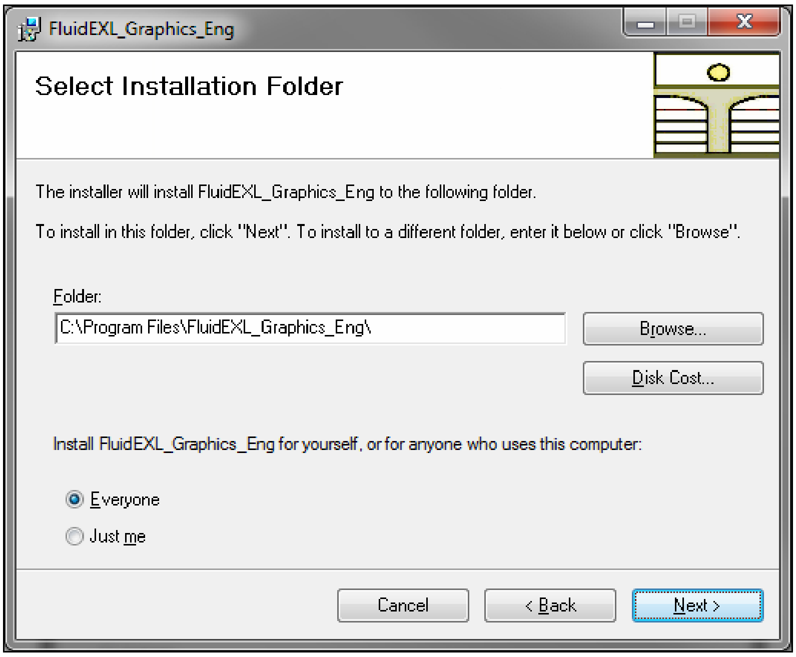


Figure 2.4: Choosing the Installation Folder of FluidEXL^{Graphics}

Finally, click on "Next >" to continue installation; click "Next >" again in the "Confirm Installation" window which follows in order to start the installation of FluidEXL^{Graphics}.

After FluidEXL^{Graphics} has been installed, you will see the sentence

"FluidEXL Graphics English has been successfully installed."

"FluidEXL Graphics wurde erfolgreich installiert."

Confirm this by clicking the "Close" button.

During the installation process the following files

capt_ico_big.ico	libmmd.dll
libifcoremd.dll	LC.dll
libiomp5md.dll	

will have been copied into the destination folder chosen, the standard being

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
C:\Programme\FluidEXL_Graphics (for German version of Windows).

In the next step, the following files

FluidEXL_Graphics_Eng.xla (for English version of Windows)
FluidEXL_Graphics.xla (for German version of Windows)
LibHuAir_Xiw.dll
LibHuAir_Xiw.hlp

which can be found in your extracted folder must be copied into the chosen destination folder (the standard being

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
C:\Programme\FluidEXL_Graphics (for German version of Windows))

using an appropriate program such as Explorer or Norton Commander.

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

Registering FluidEXL*Graphics* as Add-In in Excel®, versions 2003 or earlier

After the installation of FluidEXL*Graphics*, the program must be registered as an Add-In in Excel®. In order to do so, start Excel and carry out the following steps:

- Click "Tools" in the upper Menu bar in Excel
- Here, click on "Add-Ins..." in the menu

After a short delay, the dialog box "Add-Ins" will appear

- Click "Browse..."
- In the following dialog box, chose your destination folder (the standard being
  C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
  C:\Programme\FluidEXL_Graphics (for German version of Windows))
- Here select the file
  "FluidEXL_Graphics_Eng.xla" (for English version of Windows) or
  "FluidEXL_Graphics.xla" (for German version of Windows)

  and afterwards click "OK".

Now, the entry

"FluidEXL Graphics Eng" (for English version of Windows)
"FluidEXL Graphics" (for German version of Windows)

will appear in your list of Add-Ins.

Note:

As long as the check box next to the file name

"FluidEXL Graphics Eng" (for English version of Windows) or
"FluidEXL Graphics" (for German version of Windows),

is checked, this Add-In will be loaded automatically every time you start Excel until you unmark the box by clicking on it again.

- In order to register FluidEXL*Graphics* as an Add-In click "OK" in the "Add-Ins" dialog box.

Now, the new FluidEXL*Graphics* menu bar will appear in the upper menu area of your Excel screen, marked with a red circle in the next figure.

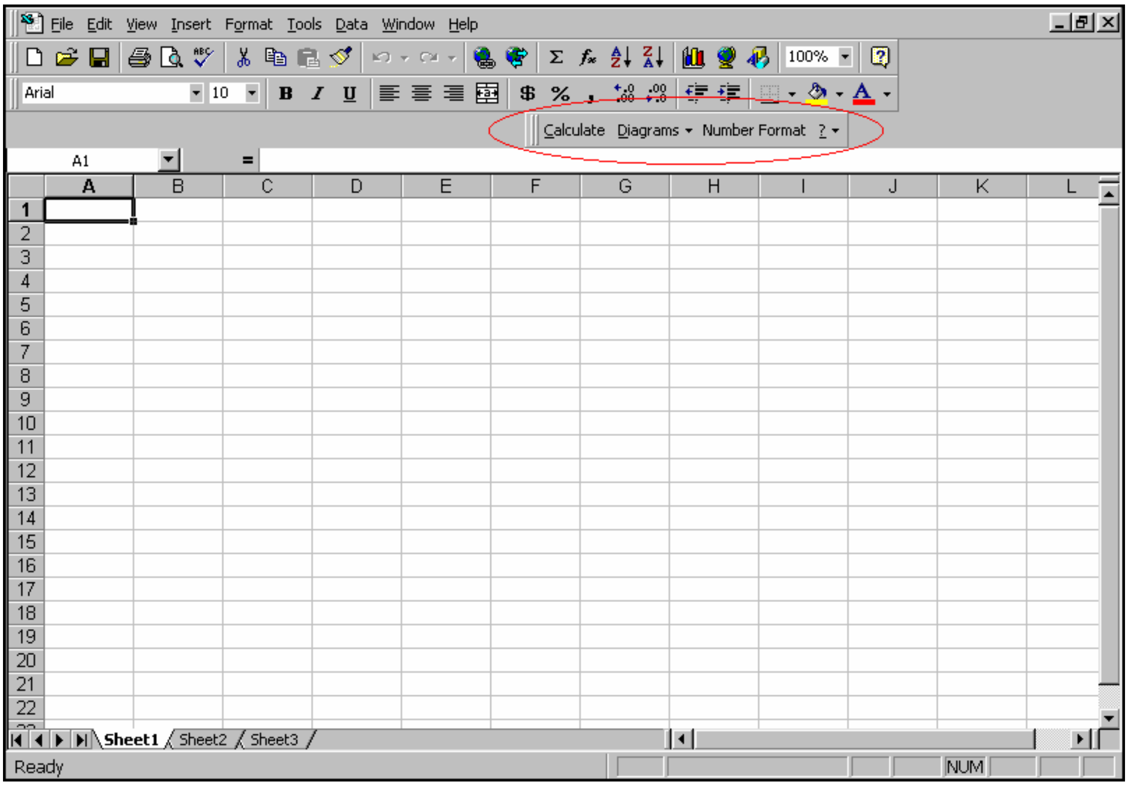


Figure 2.5: Menu bar of FluidEXL*Graphics*

You can now select the "Ideal Gas Mixtures LibHuAir_Xiw" DLL library out of Excel via this menu bar.

Registering FluidEXL*Graphics* as Add-In in Excel® 2007 (or later versions)

After installation in Windows®, FluidEXL*Graphics* must be registered in Excel® as from version 2007 as an Add-In. For this, start Excel and carry out the following steps:

- Click the Windows Office button in the upper left hand corner of Excel
- Click on the "Excel Options" button in the menu which then appears (see Figure 2.6)

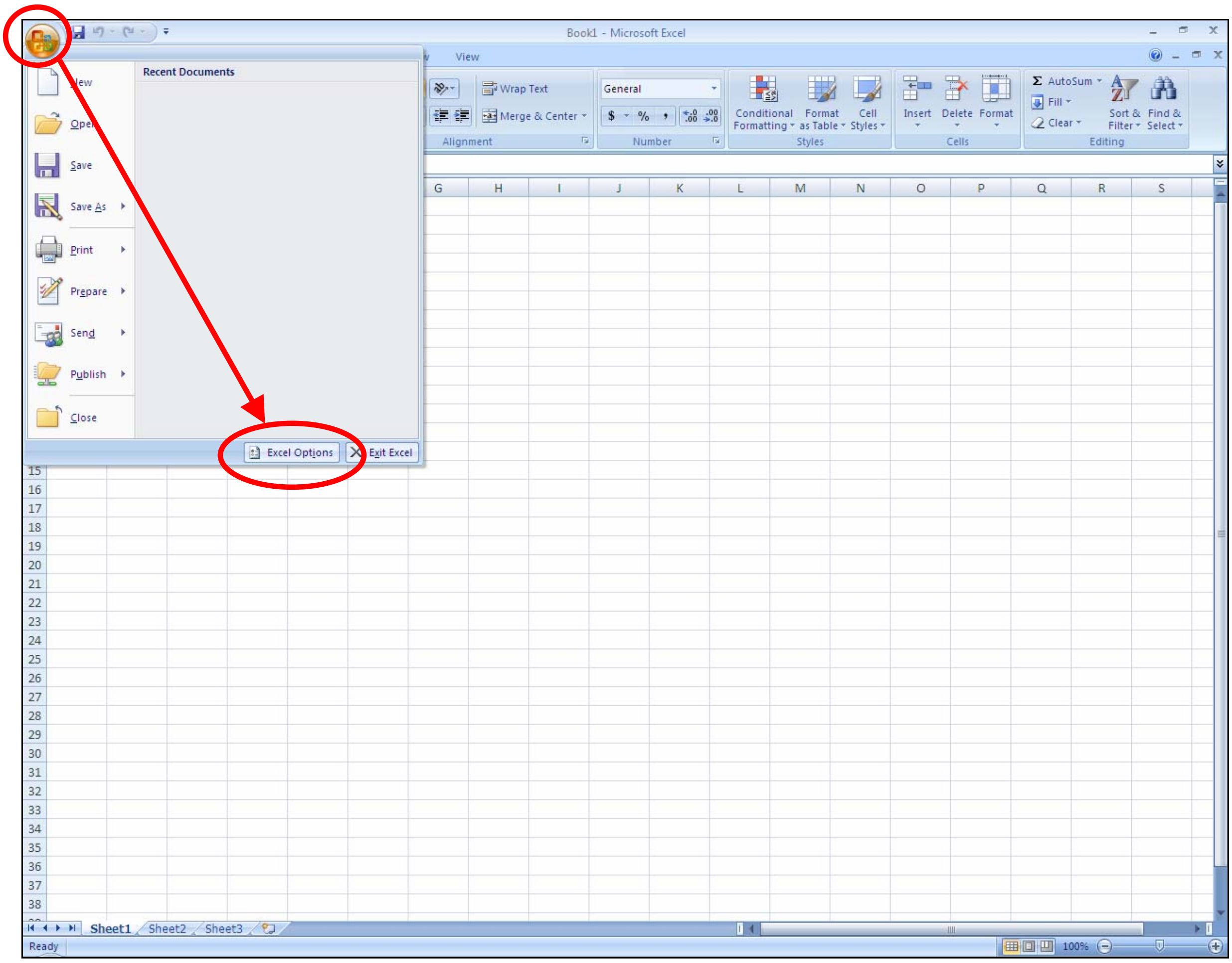


Figure 2.6: Registering FluidEXL*Graphics* as Add-In in Excel 2007

- Click on "Add-Ins" in the next menu

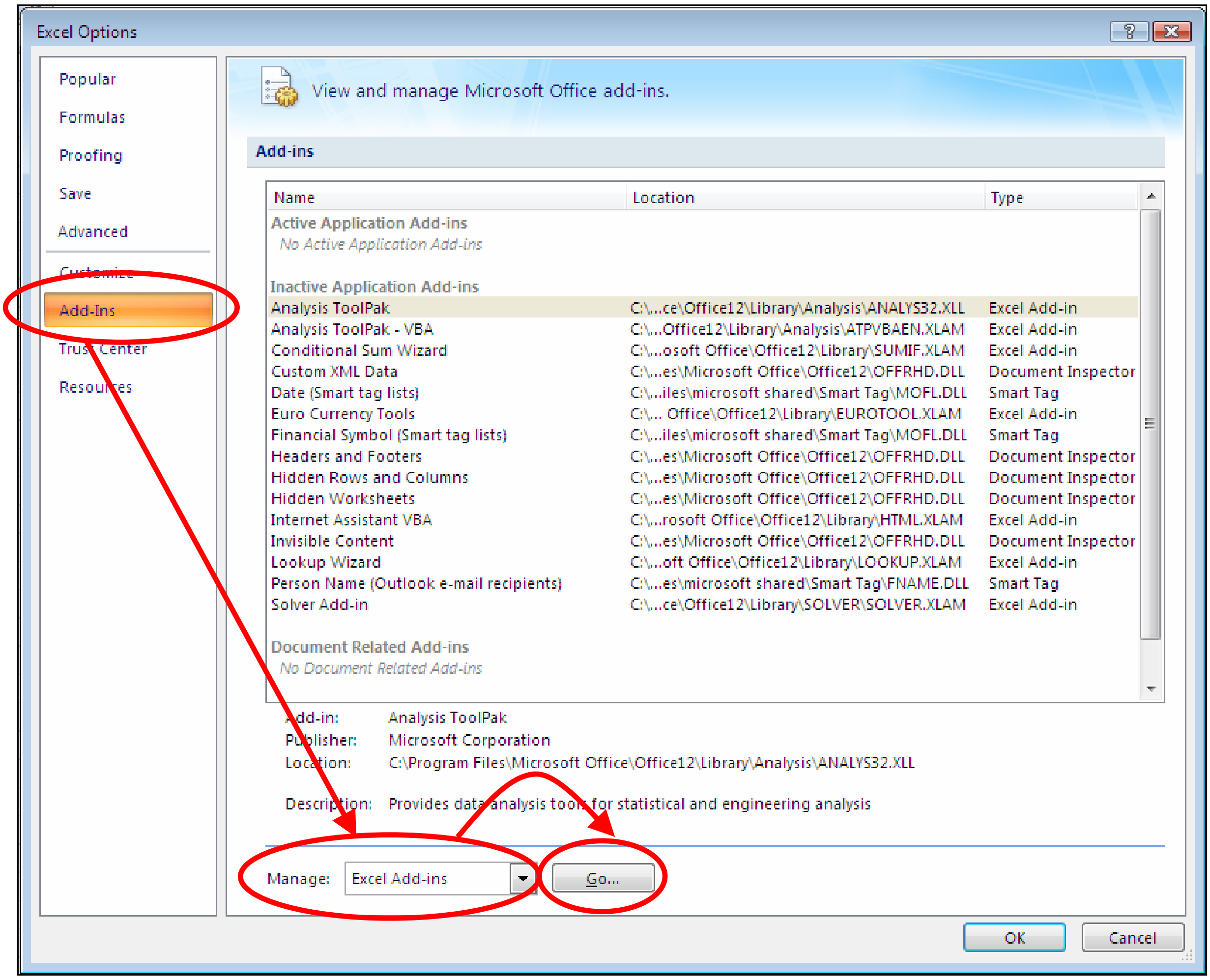


Figure 2.7: Dialog window "Add-Ins"

- Should it not be shown in the list automatically, select "Excel Add-ins" (found next to "Manage:" in the lower area of the menu)
- Then click the "Go…" button
- Click "Browse" in the following window and locate the destination folder, generally

  C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
  C:\Programme\FluidEXL_Graphics (for German version of Windows);

  within that folder click on the file named

  "FluidEXL_Graphics_Eng.xla" (for English version of Windows)
  "FluidEXL_Graphics.xla" (for German version of Windows)

  and then hit "OK".

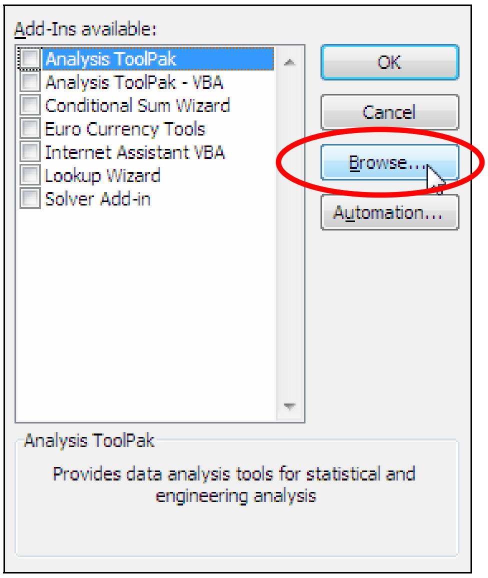


Figure 2.8: Dialog window "Add-Ins available"

- Now, "FluidEXL Graphics Eng" will be shown in your list of Add-Ins.
  (If a check-mark is situated in the box next to the name "FluidEXL Graphics", this Add-In will automatically be loaded whenever Excel starts. This will continue to occur unless the check-mark is removed from the box by clicking on it.)

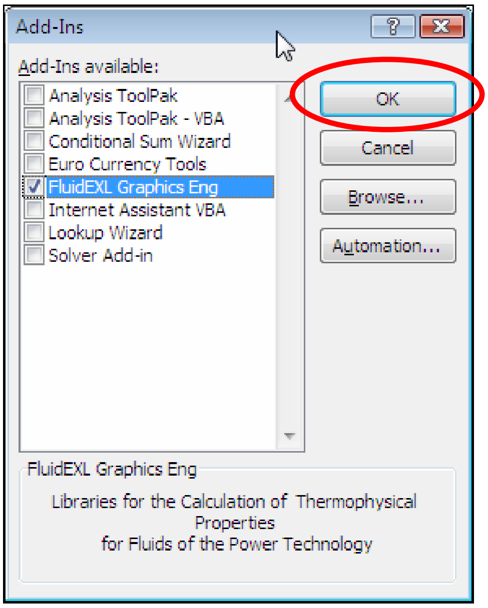


Figure 2.9: Dialog window "Add-Ins"

- In order to register the Add-In click the "OK" button in the "Add-Ins" window.

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

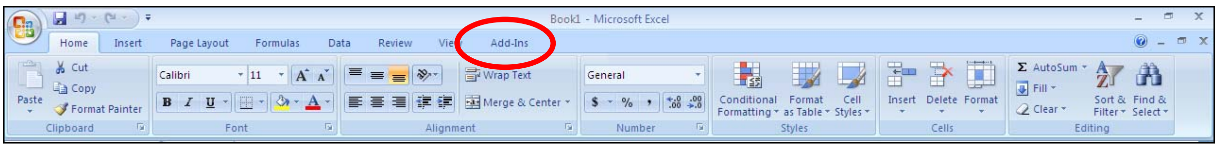


Figure 2.10: Menu item "Add-Ins"

In the upper menu region of Excel, the FluidEXL*Graphics* menu bar will appear as indicated by the red circle in the next image.

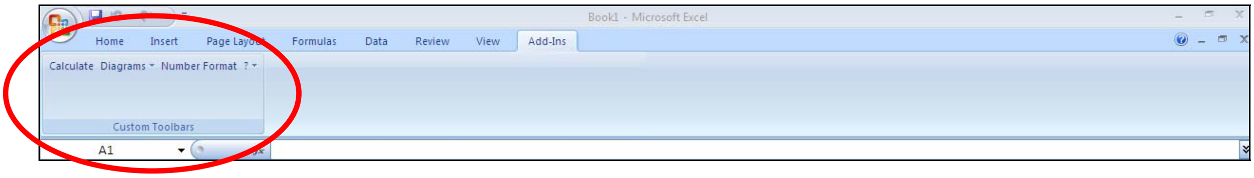


Figure 2.11: FluidEXL*Graphics* menu bar

Installation of FluidEXL*Graphics* in Excel (versions 2007 and later) is now finished. FluidEXL*Graphics* can be used analogous to the description for using with earlier Excel versions.

Adding the LibHuAir_Xiw Library (FluidEXL*Graphics* is already installed)

If FluidEXL*Graphics* has already been installed in the June 2010 version, you only have to copy the following files

FluidEXL_Graphics.xla

LibHuAir_Xiw.dll

LibHuAir_Xiw.hlp

provided in the extracted folder

CD_FluidEXL_Graphics_LibHuAir_Xiw_Eng	(for English version of Windows)
CD_FluidEXL_Graphics_LibHuAir_Xiw	(for German version of Windows)

into the folder you have chosen for the installation of FluidEXL*Graphics* (the standard being

C:\Program Files\FluidEXL_Graphics_Eng	(for English version of Windows®) or
C:\Programme\FluidEXL_Graphics	(for German version of Windows)),

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

From within Excel you can now select the "Humid Air HuAir Xiw" DLL library property functions via the FluidEXL*Graphics* menu bar (the example calculation can be found in chapter 2.5 on page 2/19).

2.3 The FluidEXL*Graphics* Help System

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

If you are running Windows Vista or Windows 7, please note the paragraph

"Using the FluidEXL*Graphics* Online-Help in Windows Vista or Windows 7."

For general information in Excel®

- Click "Help" in the FluidEXL*Graphics* menu bar.

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

- Click "Calculate" in the FluidEXL*Graphics* menu bar.
- Select the "Humid Air HuAir 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.
- If the "Office Assistant" is active, first double-click "Help on this feature" and in the next menu click "Help on selected function".

If the LibHuAir_Xiw.hlp function help cannot be found, you will be asked whether you want to look for it yourself – answer with "Yes." Click on the LibHuAir_Xiw.hlp file in the installation folder of FluidEXL*Graphics* in the window which is opened, the standard being

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows) or
C:\Programme\FluidEXL_Graphics (for German version of Windows),

and click "Yes" in order to complete the search.

Using the FluidEXL*Graphics* Online Help in Windows Vista or Windows 7

If you are running Windows Vista or Windows 7 on your computer, you might not be able to open Help files. To view these files you have to install the Microsoft® Windows Help program which is provided by Microsoft®. Please carry out the following steps in order to download and install the Windows Help program.

Open Microsoft Internet Explorer® and go to the following address:

http://support.microsoft.com/kb/917607/

You will see the following web page:

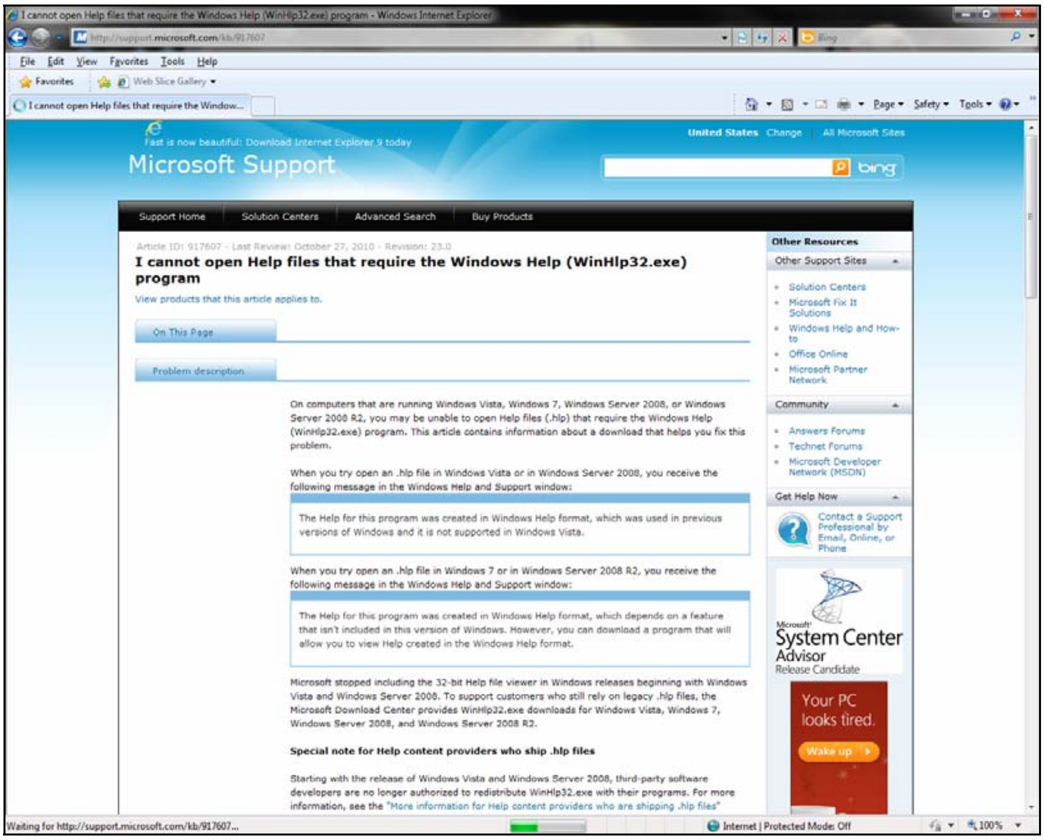


Figure 2.12: Microsoft® Support web page

Scroll down until you see the headline "Resolution." Here you can see the bold hint:

"Download the appropriate version of Windows Help program (WinHlp32.exe), depending on the operating system that you are using:"

The following description relates to Windows® 7. The procedure is analogous for Windows® Vista.

Click on the link "Windows Help program (WinHlp32.exe) for Windows 7" (see Figure 2.13).

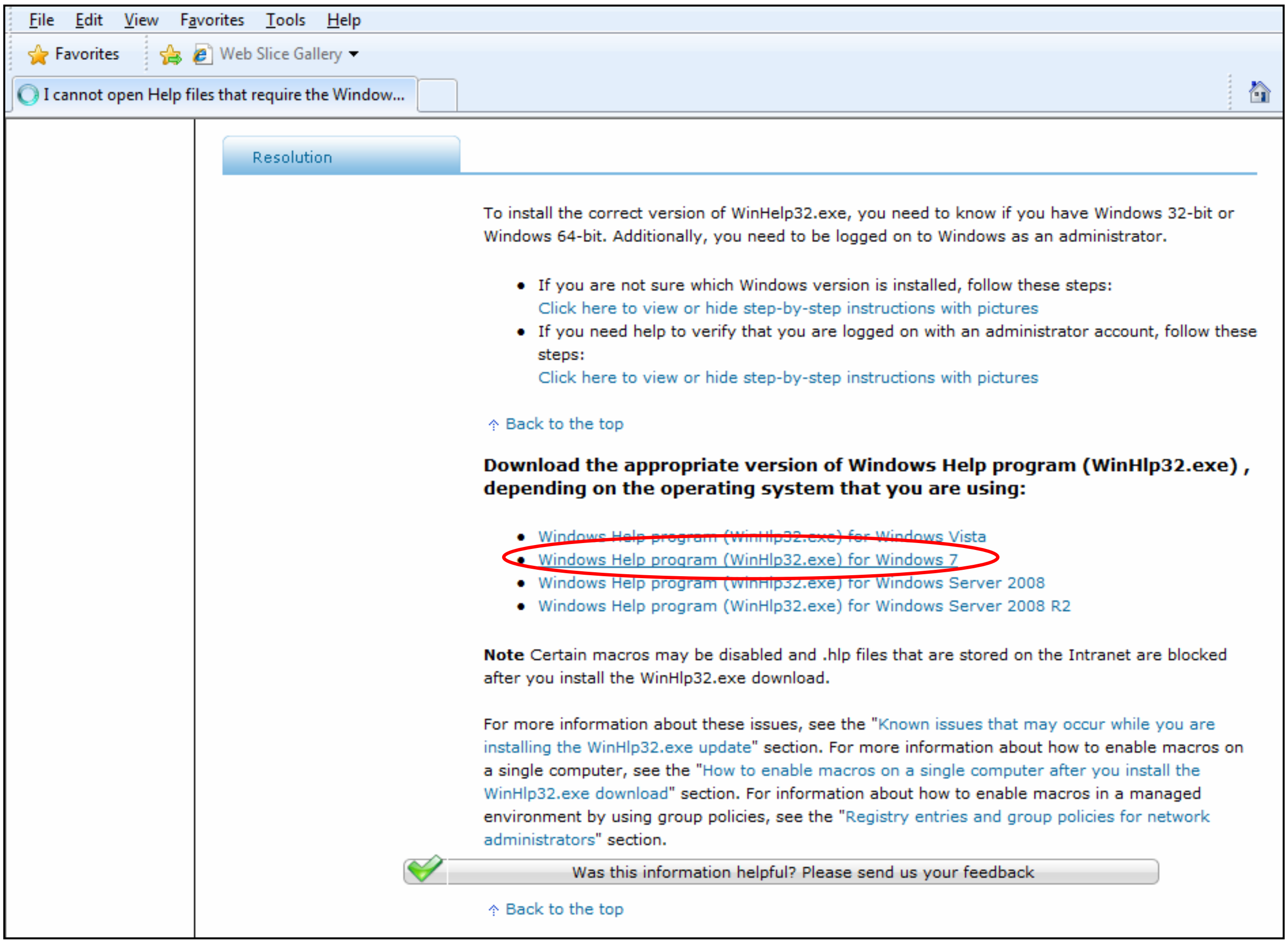


Figure 2.13: Selecting your Windows version

You will be forwarded to the Microsoft Download Center where you can download the Microsoft Windows Help program.

First, a validation of your Windows License is required.

To do this click on the "Continue" button (see Figure 2.14).

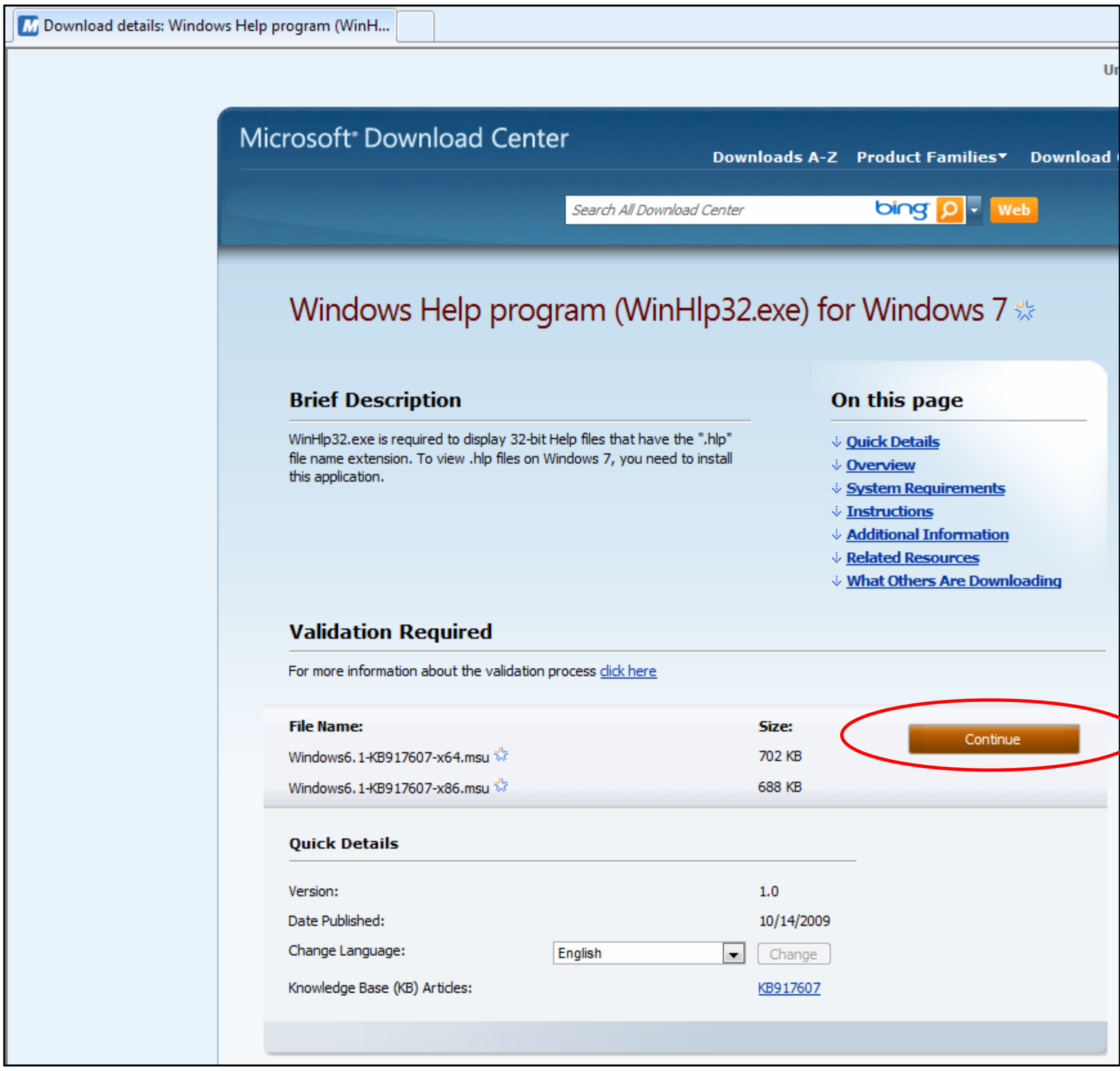


Figure 2.14: Microsoft® Download Center

You will be forwarded to a web page with instructions on how to install the Genuine Windows Validation Component.
At the top of your Windows Internet Explorer you will see a yellow information bar.
Right-click this bar and select "Install ActiveX Control" in the context menu (see Figure 2.15).

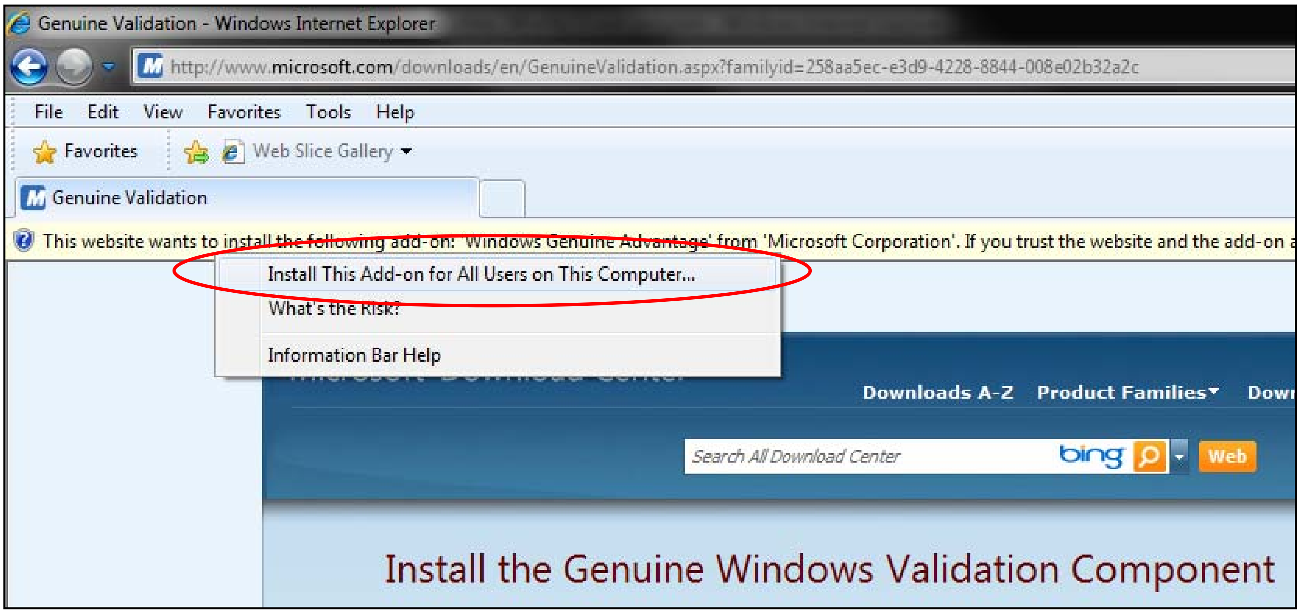


Figure 2.15: Installing the Genuine Windows Validation Component

A dialog window appears in which you will be asked if you want to install the software. Click the "Install" button to continue (see Figure 2.16).

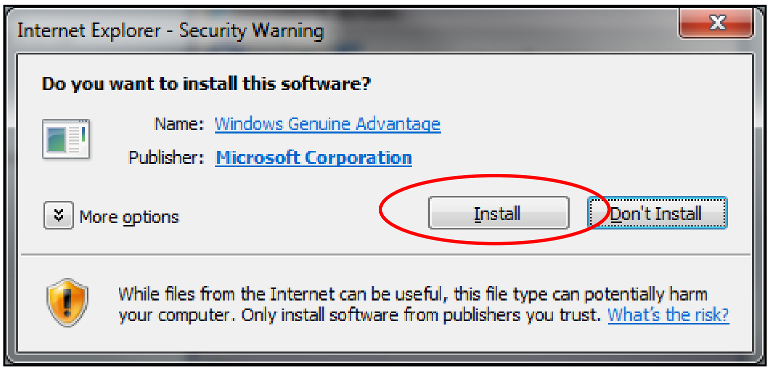


Figure 2.16: Internet Explorer – Security Warning

After the validation has been carried out you will be able to download the appropriate version of Windows Help program (see Figure 2.17).

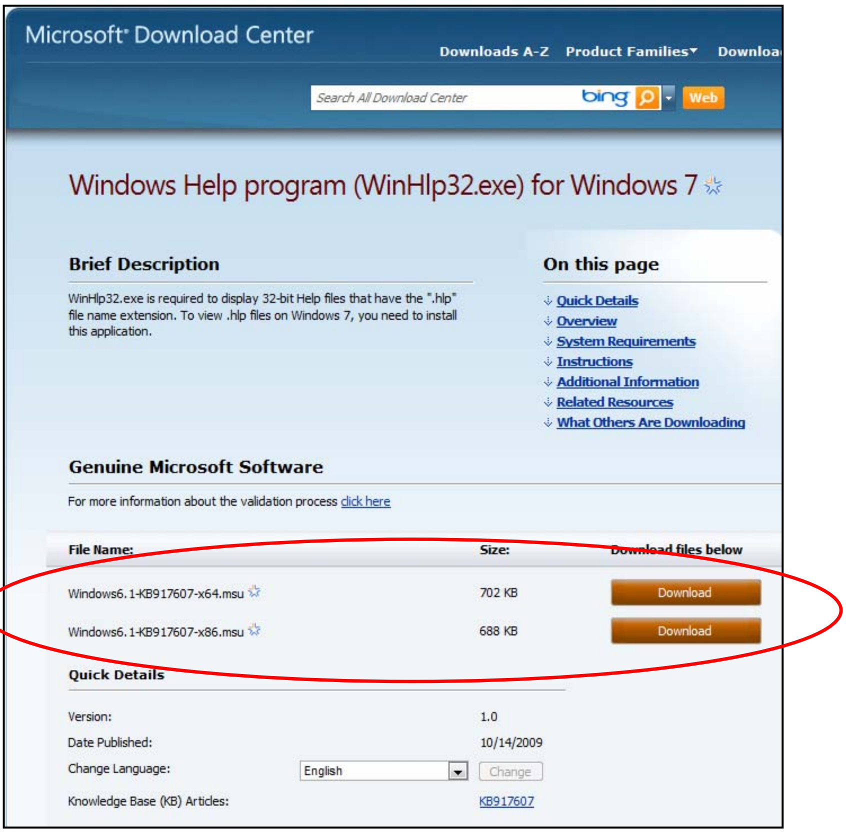


Figure 2.17: Downloading the Windows Help program

To download and install the correct file you need to know which Windows version (32 bit or 64 bit) you are running on your computer.

If you are running a 64 bit operating system, please download the file

Windows6.1-KB917607-x64.msu.

If you are running a 32 bit operating system, please download the file

Windows6.1-KB917607-x86.msu.

In order to run the installation of the Windows Help program double-click the file you have just downloaded on your computer:

Windows6.1-KB917607-x64.msu (for 64 bit operating system)

Windows6.1-KB917607-x86.msu. (for 32 bit operating system).

Installation starts with a window searching for updates on your computer. After the program has finished searching you may see the following window.

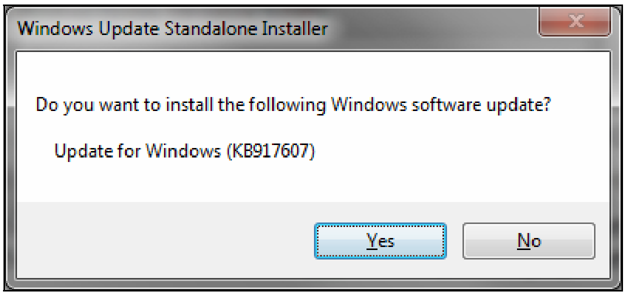


Figure 2.18: Windows Update Standalone Installer

In this case, the installation can be continued by clicking the "Yes" button.
(If you have already installed this update, you will see the message "Update for Windows (KB917607) is already installed on this computer.")

In the next window you have to accept the Microsoft license terms before installing the update by clicking on "I Accept" (see Figure 2.19)

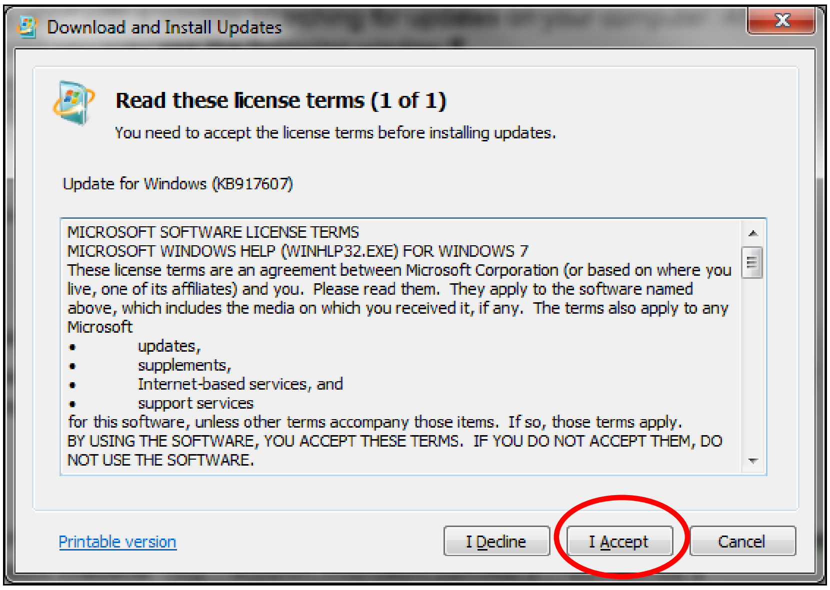


Figure 2.19: Windows License Terms

Installation starts once you have clicked the "I Accept" button (see Figure 2.20).

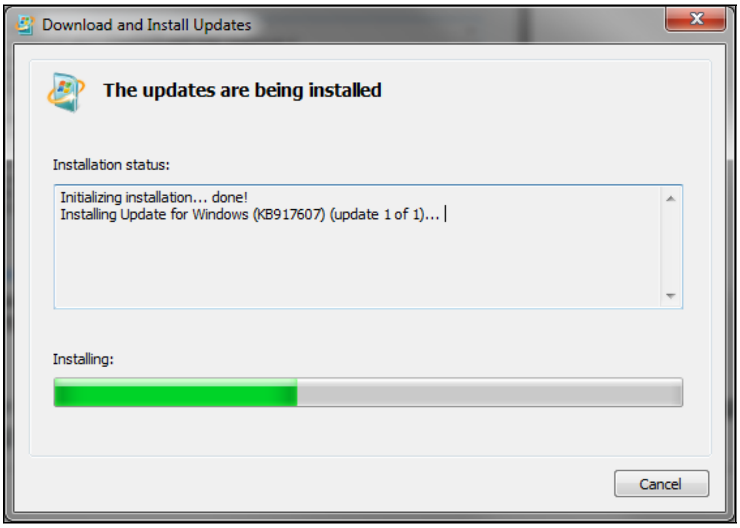


Figure 2.20: Installation process

After the Windows Help program has been installed, the notification "Installation complete" will appear. Confirm this by clicking the "Close" button.

The installation of the Windows Help program has been completed and you will now be able to open the Help files.

2.4 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).

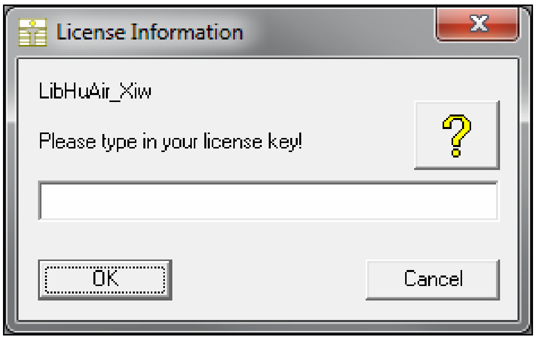


Figure 2.21: "License Information" window

Here you will have to type in the license key which you have obtained from the Zittau/Goerlitz University of Applied Sciences. 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:

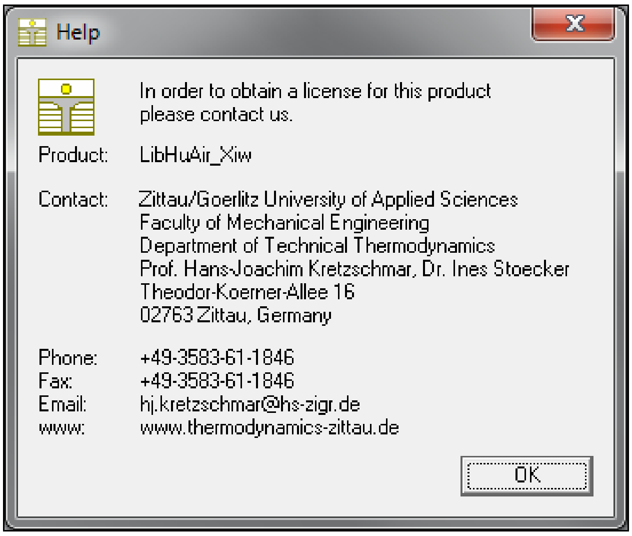


Figure 2.22: "Help" window

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 2.7 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.hlp

in the installation folder of FluidEXL*Graphics* (the standard being

C:\Program Files\FluidEXL_Graphics_Eng	(for English version of Windows)
C:\Programme\FluidEXL_Graphics	(for German version of Windows))

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

2.5 Example: Calculation of *h* = f(*p*,*t*,*Xiw*)

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 *Xiw* 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 ≤ p ≤ 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 = - 30 ... 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 ≤ Xiw ≤ 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 2.23.

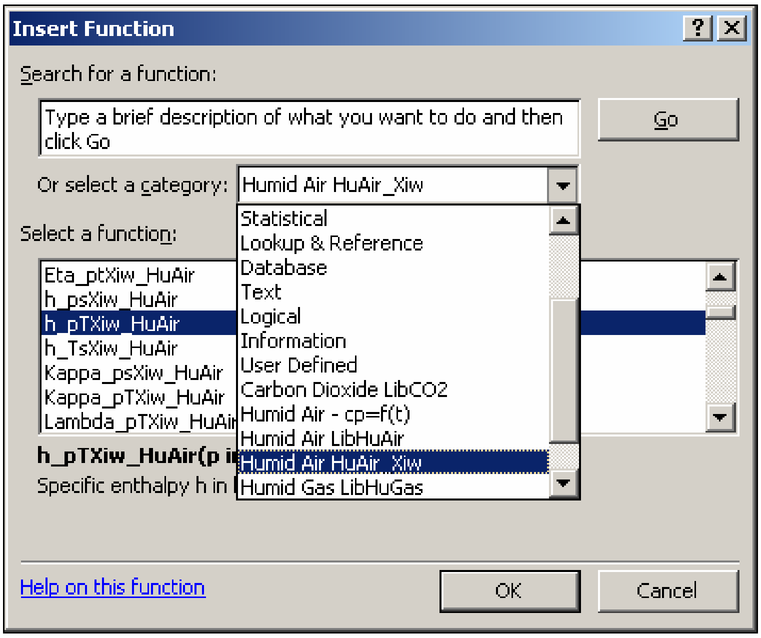


Figure 2.23: Choice of library and function name

- 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 2.24, appears.

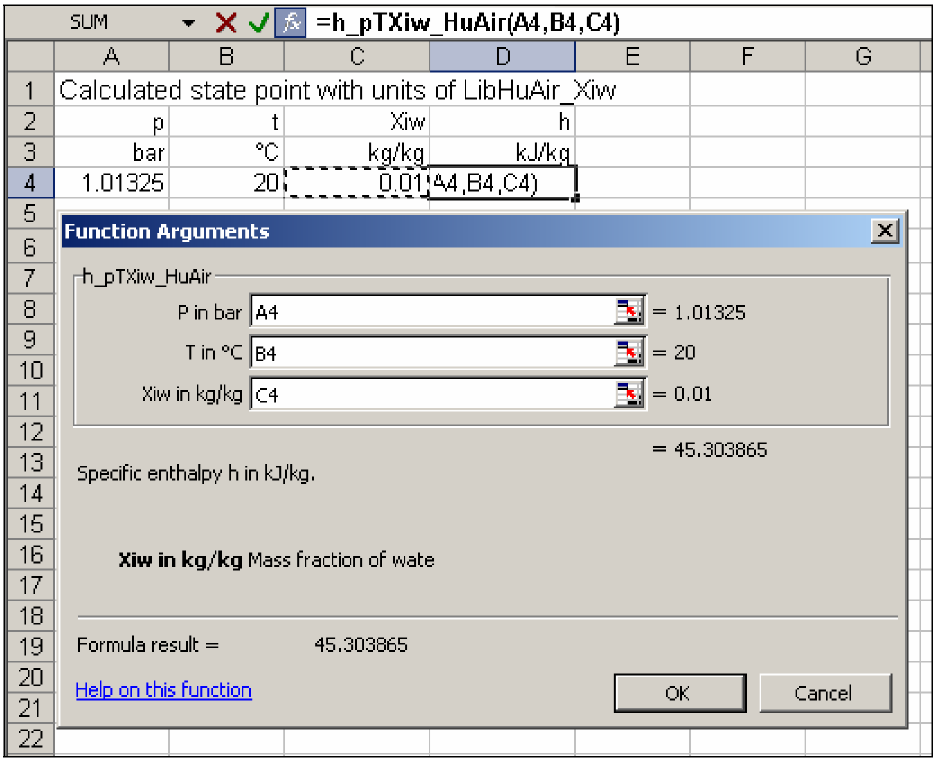


Figure 2.24: Input menu for the function

- 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*Graphics* see the function table in Chapter 1.

Number Formats

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

- Click the cell or select and click on the cells you wish to format
- 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 - Fix 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.

2.6 Representation of Calculated Properties in Thermodynamic Charts

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

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

In order to represent the calculated state point in the *h*-*x* diagram it is necessary to convert the units as follows (see Figure 2.5):

- 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 °C needs not to be converted.
- Convert the given value of ξ_w (*Xiw*) 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.

D9 | f_x =D4/(1-C4)

	A	B	C	D	E	F
1	Calculated state point with units of LibHuAir_Xiw					
2	p	t	Xiw	h		
3	bar	°C	kg/kg	kJ/kg		
4	1.01325	20	0.01	45.303865		
5						
6	Conversion into the units for representation in the h-x diagram					
7	p	t	xw	hl		
8	MPa	°C	g/kg(dry air)	kJ/kg(dry air)		
9	0.101325	20	10.1010101	45.7614798		
10						

Figure 2.25: Example conversion of the units

Now, the data can be represented in a *h*-*x* diagram for p = 0.101325 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 *xw* (as *xw* 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

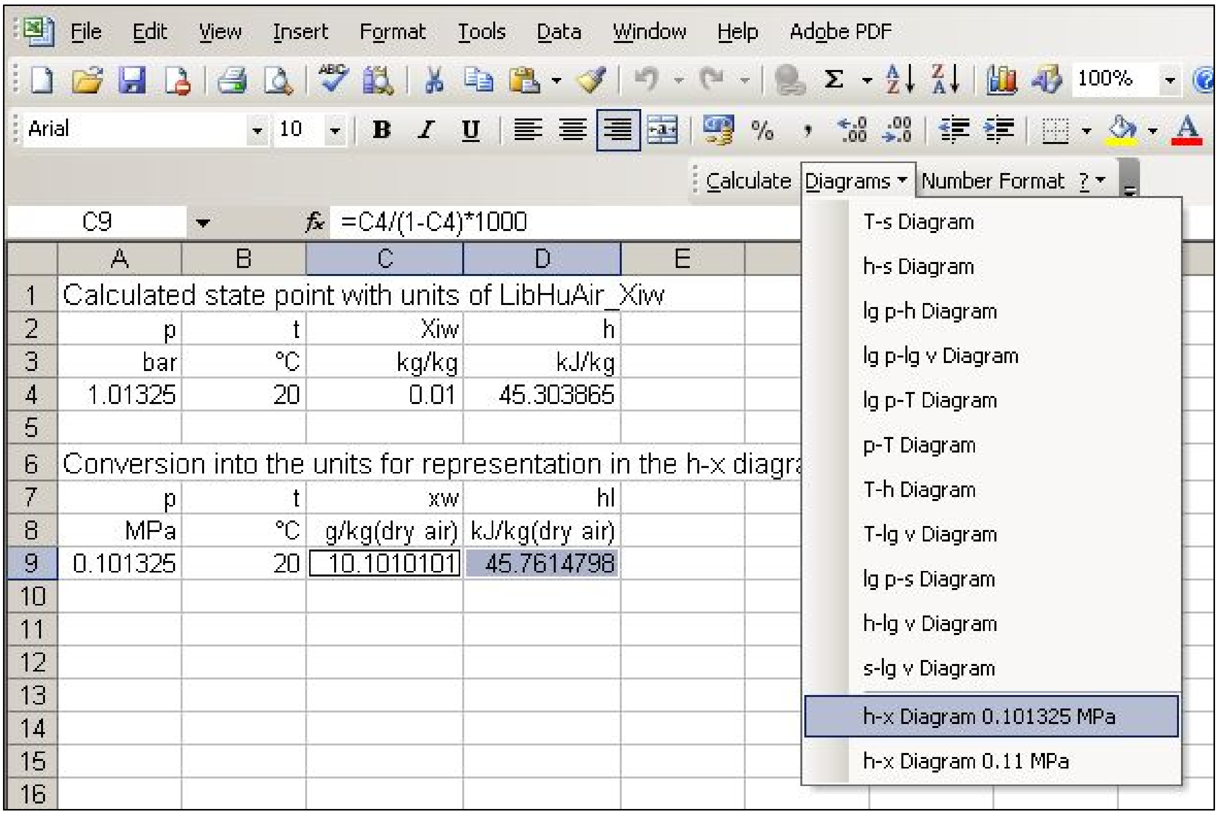


Figure 2.26: Marking the values and choosing the diagram

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

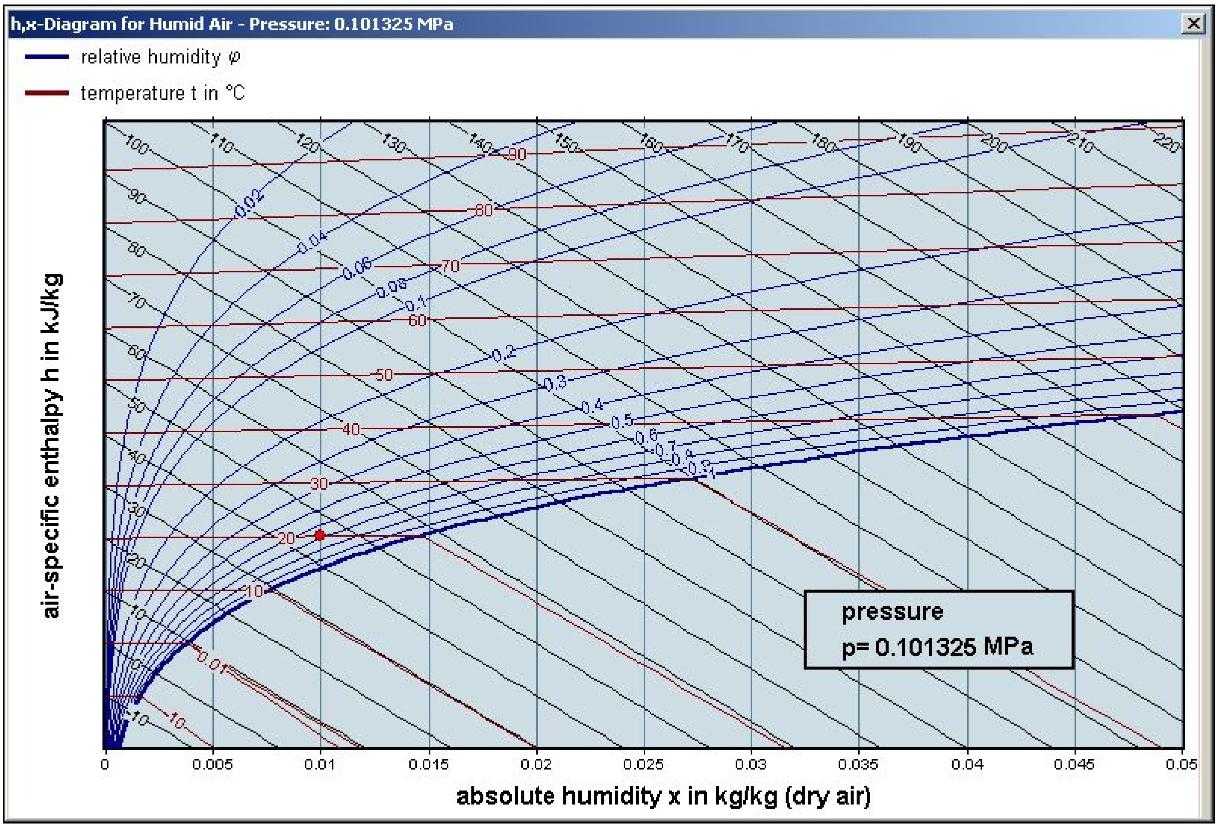


Figure 2.27: *h-x* Diagram including the state point

Note:

If the coloring is distorted you need to increase the amount of colors displayed on the screen by Windows® to more than 256 colors. The preference can be set within Windows by going to "Control Panel" and then under "Screen".

To close the *h-x* diagram, click on the "x" in the upper-right hand corner of the *h-x* Diagram window.

Note - Diagrams with various state points:

If you calculate various state points, they can be represented in <u>one</u> 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.

2.7 Removing FluidEXL*Graphics*

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

LibHuAir_Xiw.dll
LibHuAir_Xiw.hlp

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

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows®)
C:\Programme\FluidEXL_Graphics (for German version of Windows),

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

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

To remove FluidEXL*Graphics* completely, proceed as follows: First cancel the registration of

FluidEXL_Graphics_Eng.xla (for English version of Windows®) or
FluidEXL_Graphics.xla (for German version of Windows)

in Excel®.

In order to do that, click "Tools" in the upper menu bar of Excel and here "Add-Ins…" Unmark the box on the left-hand side of

"FluidEXL Graphics Eng" (for English version of Windows) or
"FluidEXL Graphics" (for German version of Windows)

in the window that appears and click the "OK" button. The additional menu bar of FluidEXL*Graphics* will disappear 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" (for English version of Windows) or
"FluidEXL Graphics" (for German version of Windows),

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

As the next step delete the files

LibHuAir_Xiw.dll
LibHuAir_Xiw.hlp

in the directory selected for the installation of FluidEXL*Graphics* (the standard being

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
C:\Programme\FluidEXL_Graphics (for German version of Windows),

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

In order to remove FluidEXL*Graphics* from Windows and the hard disk, 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" (for English version of Windows) or
"FluidEXL Graphics" (for German version of Windows)

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.

Unregistering FluidEXL*Graphics* as Add-In in Excel® 2007 (or later versions)

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

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

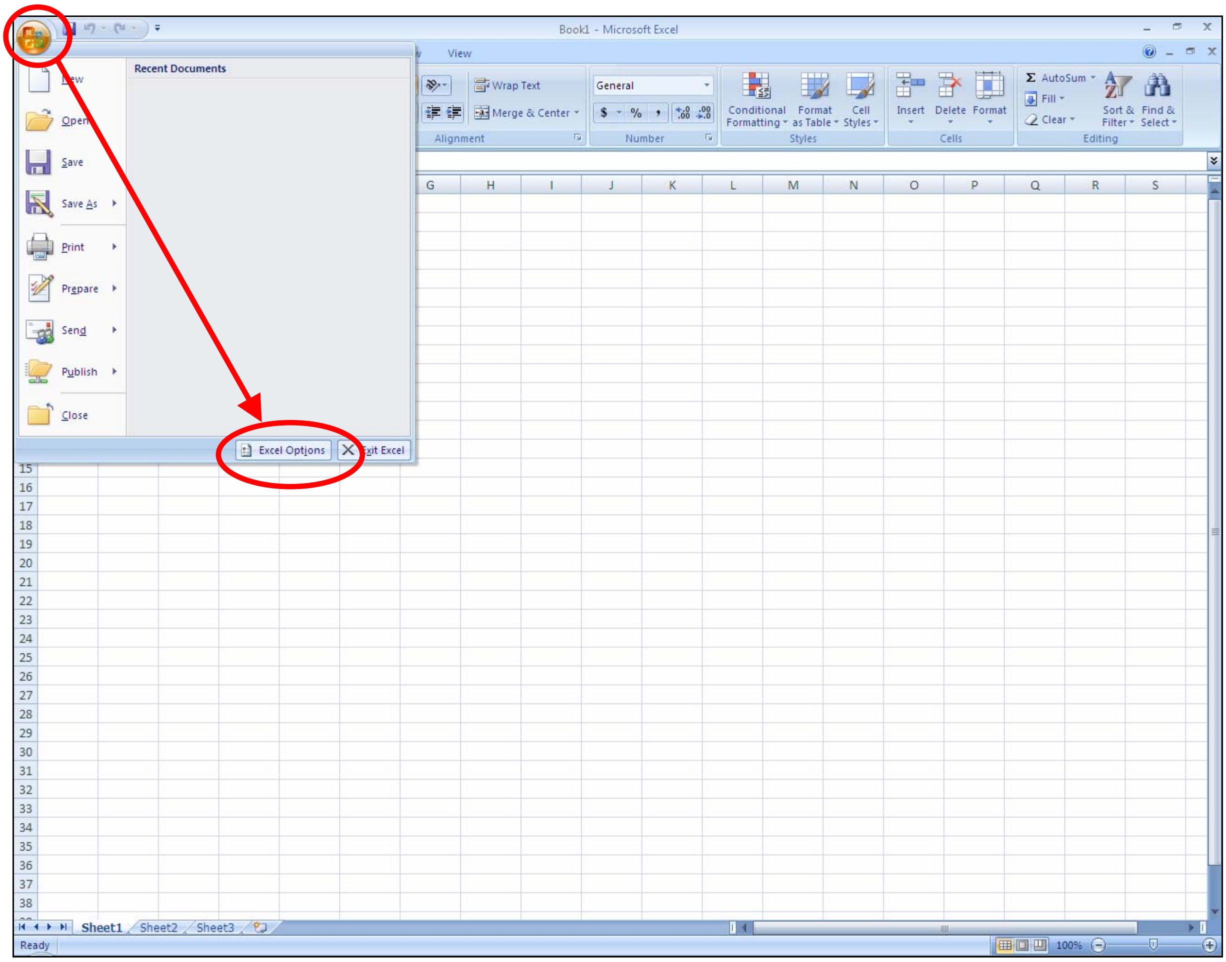


Figure 2.28: Unregistering FluidEXL*Graphics* as Add-In in Excel 2007

- Click on "Add-Ins" in the next menu

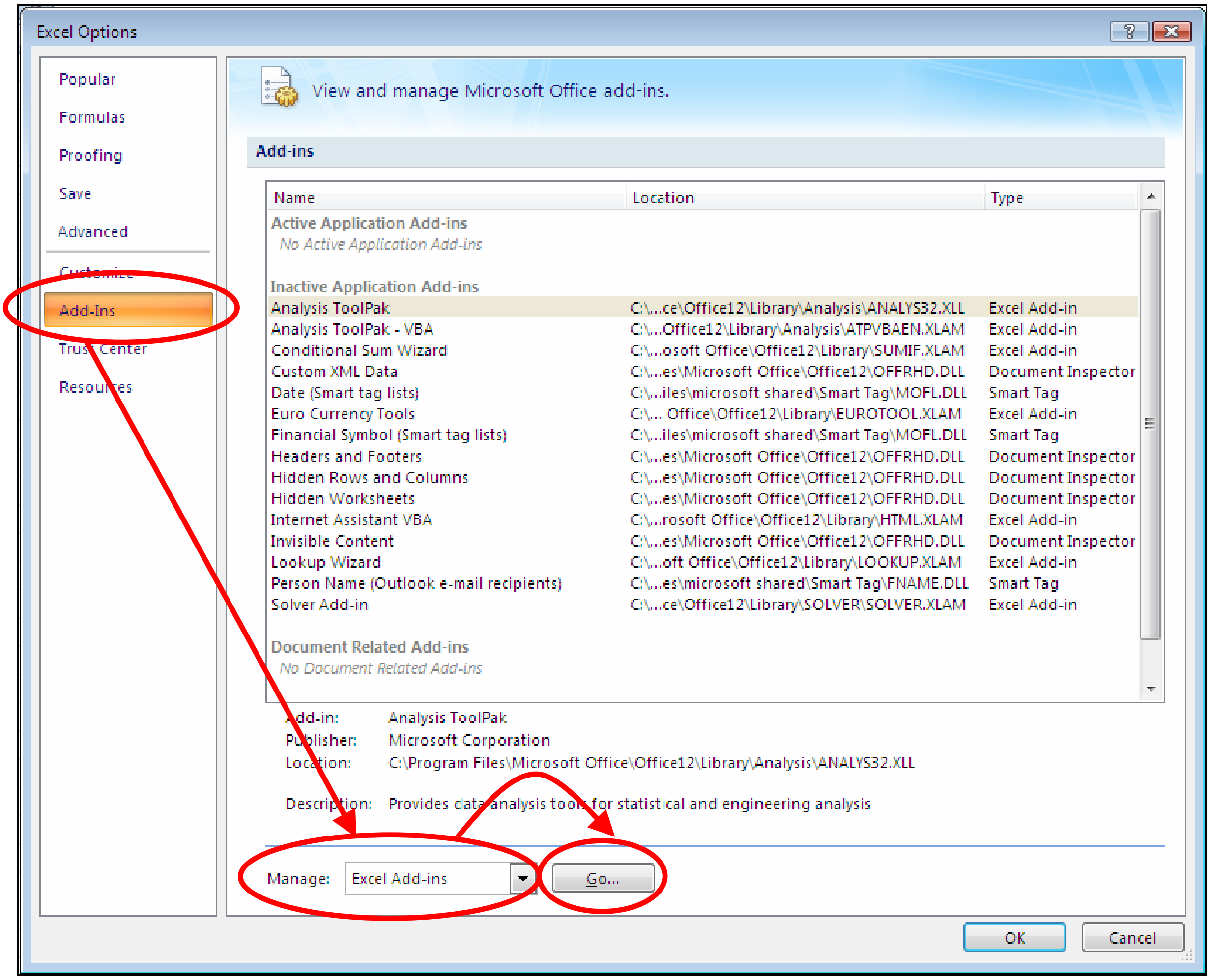


Figure 2.29: Dialog window "Excel Options"

- If it is not shown in the list automatically, select "Excel Add-ins" next to "Manage:" in the lower area of the menu
- Then click the "Go…" button
- Remove the checkmark in front of

  "FluidEXL Graphics Eng" (for English version of Windows)

  "FluidEXL Graphics" (for German version of Windows)

in the window which now appears. Click the "OK" button to confirm your entry.

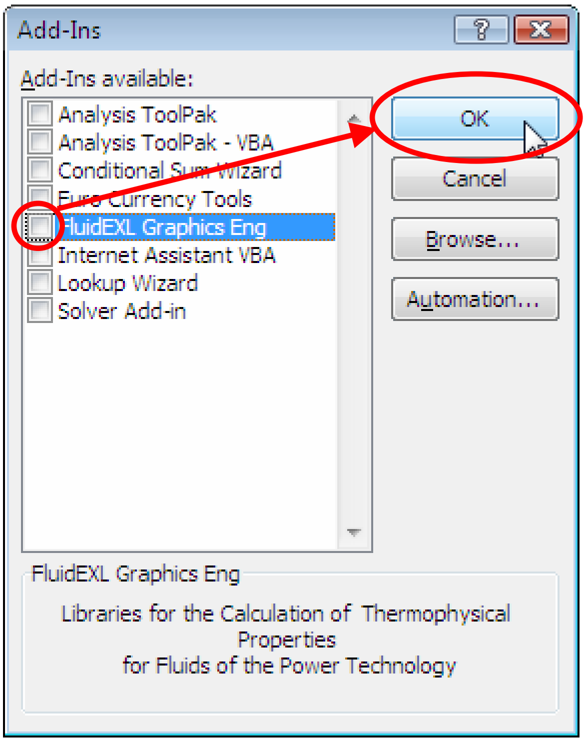


Figure 2.30: Dialog window "Add-Ins"

In order to remove FluidEXL*Graphics* from Windows® and from your hard drive, click "Start" in the lower task bar; then click "Settings" and "Control Panel." Now, double click "Add or Remove Programs," click on

"FluidEXL Graphics Eng"	(for English version of Windows)
"FluidEXL Graphics"	(for German version of Windows)

in the list box and then click the "Add/Remove..." button. Mark "Automatic" and click the "Next >" button. Now click the "Finish" button in the "Perform Uninstall" window. Click "Yes to All" in the "Remove Shared Component" window. Finally, the windows "Add or Remove Programs" and "Control Panel" should be closed.

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 ξ_w in kg water / kg mixture

Output Values:

a_ptXiw_HuAir	- Thermal diffusivity a in m^2/s
succ	- 1 $\rightarrow$ Calculation successful
	- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Temperature t :	$-30\ °C \le t \le 1726.85\ °C$
Pressure p :	$0.01\ \text{bar} \le p \le 1000\ \text{bar}$
Mass fraction of water ξ_w :	$0 \le \xi_w \le 1\ \text{kg/kg}$

Comments:

- Thermal diffusivity $a = \dfrac{\lambda}{\rho \cdot c_p}$
- 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:

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

Steam in humid air and water droplets in fog:

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

Specific Isobaric Heat Capacity c_p = f(h,s,ξ_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 ξ_w in kg water / kg mixture

Output Values:

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

Range of Validity:

Temperature t : $-30\,°C \le t \le 1726.85\,°C$

Pressure p : $0.01\,bar \le p \le 1000\,bar$

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

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 $(\xi_w \le \xi_{wsatt})$ 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 ξ_w in kg water / kg mixture

Output Values:

cp_phXiw_HuAir - Specific isobaric heat capacity c_p in kJ/(kg·K)

succ - 1 → Calculation successful

- 0 → Calculation not successful

Range of Validity:

Temperature t : $-30\,°C \le t \le 1726.85\,°C$

Pressure p : $0.01\,bar \le p \le 1000\,bar$

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

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 $(\xi_w \le \xi_{wsatt})$ 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 ξ_w in kg water / kg mixture

Output Values:

cp_psXiw_HuAir - Specific isobaric heat capacity c_p in kJ/(kg·K)

succ - 1 $\rightarrow$ Calculation successful

- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Temperature t : $-30\,°C \le t \le 1726.85\,°C$

Pressure p : $0.01\,\text{bar} \le p \le 1000\,\text{bar}$

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

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 ($\xi_w \le \xi_{wsatt}$) 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 ξ_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 : $-30\,°C \le t \le 1726.85\,°C$

Pressure p : $0.01\,\text{bar} \le p \le 1000\,\text{bar}$

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

Comments:

Calculation:

- for unsaturated and saturated humid air $(\xi_w \le \xi_{wsatt})$ 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 ξ_w in kg water / kg mixture

Output Values:

cp_TsXiw_HuAir - Specific isobaric heat capacity c_p in kJ/(kg·K)

succ - 1 → Calculation successful

- 0 → Calculation not successful

Range of Validity:

Temperature t : $-30\ °C \le t \le 1726.85\ °C$

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

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

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 $(\xi_w \le \xi_{wsatt})$ 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,ξ_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 ξ_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

- 0 → Calculation not successful

Range of Validity:

Temperature t : $-30\,°C \le t \le 1726.85\,°C$

Pressure p : $0.01\,bar \le p \le 1000\,bar$

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

Comments:

Calculation:

- for unsaturated and saturated humid air $(\xi_w \le \xi_{wsatt})$ 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 ξ_W in kg water / kg mixture

Output Values:

Eta_ptXiw_HuAir	- Dynamic viscosity η in Pa·s
succ	- 1 → Calculation successful
	- 0 → Calculation not successful

Range of Validity:

Temperature t :	$-30\,°C \le t \le 1726.85\,°C$
Pressure p :	$0.01\,bar \le p \le 1000\,bar$
Mass fraction of water ξ_W :	$0 \le \xi_W \le 1$ kg/kg

Comments:

- Model of ideal mixture of real fluids about volume fractions
- Negligence of ice crystals at ice fog (t < 0.01 °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 $0\,°C \le t \le 800\,°C$ from IAPWS – 85 [7]

for t < 0 °C and t > 800 °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 ξ_w in kg water / kg mixture

Output Values:

h_psXiw_HuAir	- Specific enthalpy *h* in kJ/kg
succ	- 1 $\rightarrow$ Calculation successful
	- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Temperature t :	$-30\,°C \le t \le 1726.85\,°C$
Pressure p :	$0.01\,bar \le p \le 1000\,bar$
Mass fraction of water ξ_w :	$0 \le \xi_w \le 1\ kg/kg$

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 $(\xi_w \le \xi_{wsatt})$ 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 = $-1 \cdot 10^{100}$, 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:

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 ξ_w in kg water / kg mixture

Output Values:

h_ptXiw_HuAir	- Specific enthalpy *h* in kJ/kg
succ	- 1 → Calculation successful
	- 0 → Calculation not successful

Range of Validity:

Temperature t :	$-30\,°C \le t \le 1726.85\,°C$
Pressure p :	$0.01\,\text{bar} \le p \le 1000\,\text{bar}$
Mass fraction of water ξ_w :	$0 \le \xi_w \le 1\ \text{kg/kg}$

Comments:

Calculation:

- for unsaturated and saturated humid air $(\xi_w \le \xi_{wsatt})$ 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 = - $1 \cdot 10^{100}$, 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:

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)
Xiw	- Mass fraction of water ξ_w in kg water / kg mixture

Output Values:

h_TsXiw_HuAir	- Specific enthalpy h in kJ/kg
succ	- 1 → Calculation successful
	- 0 → Calculation not successful

Range of Validity:

Temperature t : $-30\,°C \le t \le 1726.85\,°C$

Pressure p : $0.01\,\text{bar} \le p \le 1000\,\text{bar}$

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

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 $(\xi_w \le \xi_{wsatt})$ 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 °C is not possible

Results for Wrong Input Values:

h_TsXiw_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:

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 ξ_w in kg water / kg mixture

Output Values:

Kappa_psXiw_HuAir	- Isentropic exponent κ
succ	- 1 $\rightarrow$ Calculation successful
	- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Temperature t :	$-30\ °C \le t \le 1726.85\ °C$
Pressure p :	$0.01\,\text{bar} \le p \le 1000\,\text{bar}$
Mass fraction of water ξ_w :	$0 \le \xi_w \le 1\ \text{kg/kg}$

Comments:

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

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

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

- 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

Xiw - Mass fraction of water ξ_w in kg water / kg mixture

Output Values:

Kappa_ptXiw_HuAir - Isentropic exponent κ

succ - 1 $\rightarrow$ Calculation successful

- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Temperature t : $-30\,°C \le t \le 1726.85\,°C$

Pressure p : $0.01\,\text{bar} \le p \le 1000\,\text{bar}$

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

Comments:

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

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

- 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
Xiw - Mass fraction of water ξ_w in kg water / kg mixture

Output Values:

Lambda_ptXiw_HuAir - Thermal conductivity in W/(m·K)
succ - 1 $\rightarrow$ Calculation successful
- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Temperature t : $-30\,°C \le t \le 1726.85\,°C$
Pressure p : $0.01\,\text{bar} \le p \le 1000\,\text{bar}$
Mass fraction of water ξ_w : $0 \le \xi_w \le 1\ \text{kg/kg}$

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 K $\le$ T $\le$ 1073.15 K from IAPWS-85 [6]
for T < 273.15 K and T > 1073.15 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 ξ_w in kg water / kg mixture

Output Values:

Ny_ptXiw_HuAir	- Kinematic viscosity ν in m^2/s
succ	- 1 $\rightarrow$ Calculation successful
	- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Temperature t :	$-30\,°C \le t \le 1726.85\,°C$
Pressure p :	$0.01\,bar \le p \le 1000\,bar$
Mass fraction of water ξ_w :	$0 \le \xi_w \le 1\ kg/kg$

Comments:

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

Results for Wrong Input Values:

Ny_ptXiw_HuAir = - 1, succ = 0

References:

Dry air:

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

Steam in humid air and water droplets in fog:

η	for 273.15 K ≤ T ≤ 1073.15 K from IAPWS-08 [7]
	for T < 273.15 K and T > 1073.15 K from *Brandt* [12]
ρ	from IAPWS-IF97 [1], [2], [3], [4]
	for T < 273.16 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 ξ_W in kg water / kg mixture

Output Values:

p_hsXiw_HuAir	- Total pressure p in bar
succ	- 1 $\rightarrow$ Calculation successful
	- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Temperature t :	$-30\ °C \le t \le 1726.85\ °C$
Pressure p :	$0.01\,\text{bar} \le p \le 1000\,\text{bar}$
Mass fraction of water ξ_W :	$0 \le \xi_W \le 1\ \text{kg/kg}$

Comments:

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

Calculation:

- for unsaturated and saturated humid air $(\xi_W \le \xi_{Wsatt})$ 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 °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 ξ_w in kg water / kg mixture

Output Values:

p_tsXiw_HuAir	- Total pressure p in bar
succ	- 1 $\rightarrow$ Calculation successful
	- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Temperature t :	$-30\,°C \le t \le 1726.85\,°C$
Pressure p :	$0.01\,bar \le p \le 1000\,bar$
Mass fraction of water ξ_w :	$0 \le \xi_w \le 1\;kg/kg$

Comments:

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

Calculation:

- for unsaturated and saturated humid air $(\xi_w \le \xi_{wsatt})$ 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 °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,ξ_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 ξ_w in kg water / kg mixture

Output Values:

pd_ptXiw_HuAir - Partial pressure of water p_d in bar

succ - 1 $\rightarrow$ Calculation successful

- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Temperature t : $-30\,°C \le t \le 1726.85\,°C$

Pressure p : $0.01\,\text{bar} \le p \le 1000\,\text{bar}$

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

Comments:

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

- 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 $t \ge 0.01°C$ - vapor pressure of water

for $t < 0.01°C$ - 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. [25], [26]

$p_s(t)$ if $t \ge 0.01°C$ from IAPWS-IF97 [1], [2], [3], [4]

if $t < 0.01°C$ from IAPWS-08 [16], [17]

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

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:

pdsatt_pT_HuAir - Saturation vapor pressure p_{dsatt} of water in humid air in bar

succ - 1 → Calculation successful

- 0 → Calculation not successful

Range of Validity:

Temperature t : $-30\,°C \le t \le 1726.85\,°C$

Pressure p : $0.01\,bar \le p \le 1000\,bar$

Comments:

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

with $p_s(t)$ for $t \ge 0.01°C$ - vapor pressure of water

for $t < 0.01°C$ - sublimation pressure of water

Results for Wrong Input Values:

pdsatt_pt_HuAir = - 1, succ=0

References:

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

$p_s(t)$ if $t \ge 0.01°C$ from IAPWS-IF97 [1], [2], [3], [4]

if $t < 0.01°C$ from IAPWS-08 [16], [17]

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

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 ξ_w in kg water / kg mixture

Output Values:

Phi_ptXiw_HuAir - Relative humidity φ
succ - 1 → Calculation successful
- 0 → Calculation not successful

Range of Validity:

Temperature t : $-30\,°C \le t \le t_{krit} = 373.946\,°C$
(t_{krit} - critical Temperature of water)

Pressure p : $0.01\,\text{bar} \le p \le 1000\,\text{bar}$

Mass fraction of water ξ_w : $0 \le \xi_w \le 1 - 1 * 10^{-8}$ kg/kg

Comments:

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

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

with $p_s(t)$ for $t \ge 0.01°C$ - vapor pressure of water
for $t < 0.01°C$ - sublimation pressure of water

Results for Wrong Input Values:

Phi_ptXiw_HuAir = - 1, succ=0

References:

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

$p_s(t)$ if $t \ge 0.01°C$ from IAPWS-IF97 [1], [2], [3], [4]
if $t < 0.01°C$ 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 ξ_w in kg water / kg mixture

Output Values:

pl_ptXiw_HuAir	- Partial pressure of air p_l in bar
succ	- 1 $\rightarrow$ Calculation successful
	- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Temperature t : $-30\,°C \le t \le 1726.85\,°C$

Pressure p : $0.01\,\text{bar} \le p \le 1000\,\text{bar}$

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

Comments:

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 $t \ge 0.01°C$ - vapor pressure of water

for $t < 0.01°C$ - 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. [25], [26]
$p_s(t)$	if $t \ge 0.01°C$ from IAPWS-IF97 [1], [2], [3], [4]
	if $t < 0.01°C$ 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 ξ_w in kg water / kg mixture

Output Values:

Pr_ptxw_HuAir - *Prandtl*-Number *Pr*

succ - 1 → Calculation successful

- 0 → Calculation not successful

Range of Validity:

Temperature t : $-30\,°C \le t \le 1726.85\,°C$

Pressure p : $0.01\,bar \le p \le 1000\,bar$

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

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:

λ from *Lemmon* et al. [15]

c_p from *Lemmon* et al. [14]

η from *Lemmon* et al. [15]

Steam in humid air and water droplets in fog:

λ for $0\,°C \le t \le 800\,°C$ from IAPWS – 85 [6]
for $t < 0$ °C and $t > 800$ °C from *Brandt* [12]

η for $0\,°C \le t \le 800\,°C$ from IAPWS – 85 [7]
for $t < 0$ °C and $t > 800$ °C from *Brandt* [12]

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

Dissociation:

from VDI Guideline 4670 [13]

Mole Fraction of Air $\psi_l = f(\xi_w)$

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 ξ_w in kg water / kg mixture

Output Values:

Psil_Xiw_HuAir - Mole fraction of air in ψ_l kmol / kmol

succ - 1 $\rightarrow$ Calculation successful

- 0 $\rightarrow$ Calculation not successful

Range of Validity:

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

Comments:

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

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:

Xiw - Mass fraction of water ξ_w in kg water / kg mixture

Output Values:

Psiw_Xiw_HuAir - Mole fraction of water ψ_W kmol / kmol

succ - 1 $\rightarrow$ Calculation successful

- 0 $\rightarrow$ Calculation not successful

Range of Validity:

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

Comments:

Mole fraction of water: $\psi_w = \dfrac{R_w}{R \cdot \left(\dfrac{1-\xi_w}{\xi_w} + 1 \right)}$ 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,ξ_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 ξ_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 : $-30\,°C \le t \le 1726.85\,°C$

Pressure p : $0.01\,\text{bar} \le p \le 1000\,\text{bar}$

Mass fraction of water ξ_W : $0 \le \xi_W \le 1\ \text{kg/kg}$

Comments:

Iteration of p and t from $h(p,t,\xi_W)$ and $s(p,t,\xi_W$, 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,ξ_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 ξ_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 : $-30\,°C \le t \le 1726.85\,°C$

Pressure p : $0.01\,\text{bar} \le p \le 1000\,\text{bar}$

Mass fraction of water ξ_W : $0 \le \xi_W \le 1\ \text{kg/kg}$

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,ξ_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 kJ/(kg K)
Xiw	- Mass fraction of water ξ_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 :	$-30\,°C \le t \le 1726.85\,°C$
Pressure p :	$0.01\,bar \le p \le 1000\,bar$
Mass fraction of water ξ_W :	$0 \le \xi_W \le 1\ kg/kg$

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,ξ_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 ξ_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 : $-30\,°C \le t \le 1726.85\,°C$

Pressure p : $0.01\,\text{bar} \le p \le 1000\,\text{bar}$

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

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,ξ_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 ξ_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 :	$-30\,°C \le t \le 1726.85\,°C$
Pressure p :	$0.01\,bar \le p \le 1000\,bar$
Mass fraction of water ξ_w :	$0 \le \xi_w \le 1$ 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 ξ_w in kg water / kg mixture

Output Values:

Rho_ptXiw_HuAir	- Density ρ in kg/m^3
succ	- 1 $\rightarrow$ Calculation successful
	- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Temperature t : $-30\,°C \le t \le 1726.85\,°C$

Pressure p : $0.01\,\text{bar} \le p \le 1000\,\text{bar}$

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

Comments:

Calculation:

- for unsaturated and saturated humid air $(\xi_w \le \xi_{wsatt})$ 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 ξ_w in kg water / kg mixture

Output Values:

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

Range of Validity:

Temperature t : $-30\,°C \le t \le 1726.85\,°C$
Pressure p : $0.01\,bar \le p \le 1000\,bar$
Mass fraction of water ξ_w : $0 \le \xi_w \le 1\ kg/kg$

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 $(\xi_w \le \xi_{wsatt})$ 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 ξ_w in kg water / kg mixture

Output Values:

s_ptXiw_HuAir	- Specific Entropy *s* in kJ/(kg K)
succ	- 1 $\rightarrow$ Calculation successful
	- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Temperature t :	$-30\,°C \le t \le 1726.85\,°C$
Pressure p :	$0.01\,bar \le p \le 1000\,bar$
Mass fraction of water ξ_w :	$0 \le \xi_w \le 1\ kg/kg$

Comments:

Calculation:

- for unsaturated and saturated humid air $(\xi_w \le \xi_{wsatt})$ 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 = $-1 \cdot 10^{100}$, 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]

Surface Tension σ = 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 σ in N/m
succ	- 1 $\rightarrow$ Calculation successful
	- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Temperature t : $0\ °C \le t \le t_{krit} = 373.946\ °C$

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)
Xiw	- Mass fraction of water ξ_w in kg water / kg mixture

Output Values:

t_hsXiw_HuAir	- Temperature *t* in °C
succ	- 1 $\rightarrow$ Calculation successful
	- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Temperature t :	$-30\,°C \le t \le 1726.85\,°C$
Pressure p :	$0.01\,bar \le p \le 1000\,bar$
Mass fraction of water ξ_w :	$0 \le \xi_w \le 1\ kg/kg$

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 $(\xi_w \le \xi_{wsatt})$ 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
Xiw	- Mass fraction of water ξ_w in kg water / kg mixture

Output Values:

t_phXiw_HuAir	- Temperature t in °C
succ	- 1 $\rightarrow$ Calculation successful
	- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Temperature t :	$-30\,°C \le t \le 1726.85\,°C$
Pressure p :	$0.01\,\text{bar} \le p \le 1000\,\text{bar}$
Mass fraction of water ξ_w :	$0 \le \xi_w \le 1\ \text{kg/kg}$

Comments:

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

Calculation:

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

Xiw - Mass fraction of water ξ_w in kg water / kg mixture

Output Values:

t_psXiw_HuAir - Temperature *t* in °C

succ - 1 → Calculation successful

- 0 → Calculation not successful

Range of Validity:

Temperature t : $-30\,°C \le t \le 1726.85\,°C$

Pressure p : $0.01\,\text{bar} \le p \le 1000\,\text{bar}$

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

Comments:

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

Calculation:

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

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 ξ_W in kg water / kg mixture

Output Values:

tf_ptXiw_HuAir	- Wet bulb Temperature (cooling limit Temperature) t_f in °C
succ	- 1 $\rightarrow$ Calculation successful
	- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Temperature t :	$-30\,°C \le t \le 1726.85\,°C$
Pressure p :	$0.01\,\text{bar} \le p \le 1000\,\text{bar}$
Mass fraction of water ξ_W :	$0 \le \xi_W \le 1\ \text{kg/kg}$

Comments:

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

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_τ = f(p,ξ_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 ξ_w in kg water / kg mixture

Output Values:

tTau_pXiw_HuAir - Dew point Temperature t_τ in °C

succ - 1 $\rightarrow$ Calculation successful

- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Pressure p : $0.01\,\text{bar} \le p \le 1000\,\text{bar}$

Mass fraction of water ξ_w : $\xi_{wsatt}(p,-30°C) \le \xi_w \le 1\ \text{kg/kg}$

Comments:

Dew point Temperature of water in mixtures of gases:

$t_\tau = t_s(p, p_d)$ for $t \ge 0.01°C$

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

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

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

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

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 $t_\tau \ge 0.01°C$ from IAPWS-IF97 [1], [2], [3], [4]

$t_{sub}(p, p_d)$ for $T_\tau < 0.01°C$ 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 ξ_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 : $-30\,°C \le t \le 1726.85\,°C$
Pressure p : $0.01\,\text{bar} \le p \le 1000\,\text{bar}$
Mass fraction of water ξ_w : $0 \le \xi_w \le 1\ \text{kg/kg}$

Comments:

Calculation: u = h - p · v

- for unsaturated and saturated humid air $(\xi_w \le \xi_{wsatt})$ 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 = $-1 \cdot 10^{100}$, 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)
Xiw	- Mass fraction of water ξ_w in kg water / kg mixture

Output Values:

v_hsXiw_HuAir	- Specific volume *v* in m^3/kg
succ	- 1 $\rightarrow$ Calculation successful
	- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Temperature t :	$-30\,°C \le t \le 1726.85\,°C$
Pressure p :	$0.01\,bar \le p \le 1000\,bar$
Mass fraction of water ξ_w :	$0 \le \xi_w \le 1\ kg/kg$

Comments:

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

Calculation:

- for unsaturated and saturated humid air $(\xi_w \le \xi_{wsatt})$ 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 °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 ξ_w in kg water / kg mixture

Output Values:

v_phXiw_HuAir	- Specific volume *v* in m^3/kg
succ	- 1 $\rightarrow$ Calculation successful
	- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Temperature t : $-30\,°C \le t \le 1726.85\,°C$

Pressure p : $0.01\,bar \le p \le 1000\,bar$

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

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 $(\xi_w \le \xi_{wsatt})$ 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 ξ_W in kg water / kg mixture

Output Values:

v_psXiw_HuAir	- Specific volume v in m^3/kg
succ	- 1 → Calculation successful
	- 0 → Calculation not successful

Range of Validity:

Temperature t :	$-30\,°C \le t \le 1726.85\,°C$
Pressure p :	$0.01\,\text{bar} \le p \le 1000\,\text{bar}$
Mass fraction of water ξ_W :	$0 \le \xi_W \le 1\ \text{kg/kg}$

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 $(\xi_W \le \xi_{Wsatt})$ 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 ξ_w in kg water / kg mixture

Output Values:

v_ptXiw_HuAir - Specific volume *v* in m^3/kg
succ - 1 → Calculation successful
- 0 → Calculation not successful

Range of Validity:

Temperature t : $-30\,°C \le t \le 1726.85\,°C$
Pressure p : $0.01\,\text{bar} \le p \le 1000\,\text{bar}$
Mass fraction of water ξ_w : $0 \le \xi_w \le 1\ \text{kg/kg}$

Comments:

Calculation:

- for unsaturated and saturated humid air $(\xi_w \le \xi_{wsatt})$ 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 ξ_W in kg water / kg mixture

Output Values:

v_tsXiw_HuAir	- Specific volume v in m^3/kg
succ	- 1 $\rightarrow$ Calculation successful
	- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Temperature t :	$-30\,°C \le t \le 1726.85\,°C$
Pressure p :	$0.01\,bar \le p \le 1000\,bar$
Mass fraction of water ξ_W :	$0 \le \xi_W \le 1\ kg/kg$

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 $(\xi_W \le \xi_{Wsatt})$ 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 °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 ξ_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 : $-30\,°C \le t \le 1726.85\,°C$
Pressure p : $0.01\,\text{bar} \le p \le 1000\,\text{bar}$
Mass fraction of water ξ_w : $0 \le \xi_w \le 1\ \text{kg/kg}$

Comments:

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

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

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

Function Name:

xw_Xiw_HuAir

Fortran Program:

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

Input Values:

Xiw - Mass fraction of water ξ_w in kg water / kg mixture

Output Values:

xw_Xiw_HuAir - Humidity Ratio (Absolute humidity) x_w in kg water / kg air

succ - 1 $\rightarrow$ Calculation successful

- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Mass fraction of water ξ_w : $0 \le \xi_w \le 1$ 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 ξ_w in kg / kg
succ	- 1 $\rightarrow$ Calculation successful
	- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Temperature t : $-30\,°C \le t \le t_{krit} = 373.946\,°C$
(T_{krit} - critical Temperature of water)

Pressure p : $0.01\,\text{bar} \le p \le 1000\,\text{bar}$

Relative humidity φ : $0 \le \varphi \le 1$

Comments:

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

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

with $p_s(t)$ for $t \ge 0.01$°C - vapor pressure of water

for $t < 0.01$°C - sublimation pressure of water

Results for Wrong Input Values:

Xiw_ptPhi_HuAir = - 1, succ = 0

References:

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

$p_s(t)$ if $t \ge 0.01$°C from IAPWS-IF97 [1], [2], [3], [4]

if $t < 0.01$°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 ξ_w in kg / kg
succ	- 1 $\rightarrow$ Calculation successful
	- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Temperature t :	$-30\,°C \le t \le 1726.85\,°C$
Pressure p :	$0.01\,\text{bar} \le p \le 1000\,\text{bar}$
Mass fraction of water ξ_w :	$0 \le \xi_w \le 1\ \text{kg/kg}$

Range of Validity:

Temperature t:	- 30 °C $\le$ t $\le$ 1726.85 °C
Pressure p:	0.01 bar $\le$ p $\le$ 1000 bar
Partial pressure of water p_d :	0.01 bar $\le$ p $\le$ $p_{dsatt}(p,t)$ for t $\le$ 373.946 °C,
	$\le$ 1000 bar for t > 373.946 °C

Comments:

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

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

with $p_s(t)$ for $t \ge 0.01$°C - vapor pressure of water

for $t < 0.01$°C - sublimation pressure of water

Results for Wrong Input Values:

Xiw_ptpd_HuAir = - 1, succ = 0

References:

$f(p,t)$	Herrmann et al. [25], [26]
$p_s(t)$	if $t \ge 0.01$°C from IAPWS-IF97 [1], [2], [3], [4]
	if $t < 0.01$°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_τ - Dew point Temperature t_τ in °C

Output Values:

Xiw_ptTau_HuAir - Mass fraction of water ξ_w in kg / kg

succ - 1 → Calculation successful

- 0 → Calculation not successful

Range of Validity:

Pressure p : $0.01\,\text{bar} \le p \le 1000\,\text{bar}$

Dew point temperature t_τ : $-30\,°\text{C} \le t_\tau \le t_s(p, p_d)$

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

Comments:

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

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

with $p_s(t_\tau)$ for $t_\tau \ge 0.01$°C - vapor pressure of water

for $t_\tau < 0.01$°C - sublimation pressure of water

Results for Wrong Input Values:

Xiw_ptTau_HuAir = - 1, succ = 0

References:

$f(p, t_\tau)$ Herrmann et al. [25], [26]

$p_s(t_\tau)$ if $t_\tau \ge 0.01$°C from IAPWS-IF97 [1], [2], [3], [4]

if $t_\tau < 0.01$°C from IAPWS-08 [16], [17]

Mass Fraction of Steam ξ_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 ξ_w in kg / kg

succ - 1 → Calculation successful
- 0 → Calculation not successful

Range of Validity:

Temperature t : $-30\,°C \le t \le 1726.85\,°C$

Wet bulb temperature t_f : $-30\,°C \le t_f \le t$ or $t_s(p, p_d)$
(t_s – Boiling Temperature of water in mixtures of gases)

Pressure p : $0.01\,\text{bar} \le p \le 1000\,\text{bar}$

Comments:

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

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 ξ_w in kg water / kg mixture

Output Values:

Xiwf_ptXiw_HuAir - Mass fraction of water ξ_{wf} in kg / kg
succ - 1 $\rightarrow$ Calculation successful
- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Temperature t : $t_\tau(p,\xi_w) \le t \le t_s(p,p_d)$
(t_s – Boiling Temperature of water in mixtures of gases)

Pressure p : $0.01\,\text{bar} \le p \le 1000\,\text{bar}$

Mass fraction of water ξ_w : $\xi_{wsatt}(p,t) \le \xi_w \le 1\ \text{kg/kg}$

Comments:

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

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

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

with $p_s(t)$ for $t \ge 0.01$°C - vapor pressure of water
for $t < 0.01$°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. [25], [26]
$p_s(t)$ if $t \ge 0.01$°C from IAPWS-IF97 [1], [2], [3], [4]
if $t < 0.01$°C from IAPWS-08 [16], [17]

Saturation Mass Fraction of Water ξ_{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 ξ_{wsatt} in kg / kg

succ - 1 $\rightarrow$ Calculation successful
- 0 $\rightarrow$ Calculation not successful

Range of Validity:

Temperature t : $0\,°C \le t \le t_s(p, p_d)\,°C$

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

Pressure p : $0.01\,\text{bar} \le p \le 1000\,\text{bar}$

Comments:

Specific humidity of water for saturated humid air:

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

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

with $p_s(t)$ for $t \ge 0.01°C$ - vapor pressure of water
for $t < 0.01°C$ - sublimation pressure of water

Results for Wrong Input Values:

Xiwsatt_pt_HuAir = - 1, succ = 0

References:

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

$p_s(t)$ if $t \ge 0.01°C$ from IAPWS-IF97 [1], [2], [3], [4]
if $t < 0.01°C$ from IAPWS-08 [16], [17]

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

Water and Steam

Library LibIF97

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

Humid Combustion Gas Mixtures

Library LibHuGas

Model: Ideal mixture of the real fluids:

CO_2 - Span and Wagner
H_2O - IAPWS-95
N_2 - Span et al.
O_2 - Schmidt and Wagner
Ar - Tegeler et al.

and of the ideal gases:

SO_2, CO, Ne (Scientific Formulation of Bücker et al.)

Consideration of:

Dissociation from VDI 4670 and Poynting effect

Humid Air

Library LibHuAir

Model: Ideal mixture of the real fluids:

- Dry Air from Lemmon et al.
- Steam, water and ice from IAPWS-IF97 and IAPWS-06

Consideration of:

- Condensation and freezing of steam
- Dissociation from the VDI 4670
- Poynting effect from ASHRAE RP-1485

Carbon Dioxide including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1994)

Seawater

Library LibSeaWa

IAPWS Formulation 2008 of Feistel and IAPWS-IF97

Ice

Library LibICE

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

Ideal Gas Mixtures

Library LibIdGasMix

Model: Ideal mixture of the ideal gases:

Ar	NO	He	Propylene
Ne	H_2O	F_2	Propane
N_2	SO_2	NH_3	Iso-Butane
O_2	H_2	Methane	n-Butane
CO	H_2S	Ethane	Benzene
CO_2	OH	Ethylene	Methanol
Air			

Consideration of:

- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

Dry Air including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Nitrogen

Library LibN2

Formulation of Span et al. (2000)

Hydrogen

Library LibH2

Formulation of Leachman et al. (2007)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth (1995)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of Bücker et al. (2003)

n-Butane

Library LibButane_n

Formulation of Bücker et al. (2003)

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 Kalina Cycle)

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

$C_2H_6O_2$	Ethylene glycol
$C_3H_8O_2$	Propylene glycol
C_2H_5OH	Ethyl alcohol
CH_3OH	Methyl alcohol
$C_3H_8O_3$	Glycerol
K_2CO_3	Potassium carbonate
$CaCl_2$	Calcium chloride
$MgCl_2$	Magnesium chloride
NaCl	Sodium chloride
$C_2H_3KO_2$	Potassium acetate

Formulation of the International Institute of Refrigeration (1997)

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)

Propane

Library LibPropane

Formulation of Lemmon et al. (2007)

Methanol

Library LibCH3OH

Formulation of de Reuck and Craven (1993)

Ethanol

Library LibC2H5OH

Formulation of Schroeder et al. (2012)

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_5H_{14} **Library LibC5H14**

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**

Dinitrogen monooxide 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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Fax.: +49-3583-61-1846

The following thermodynamic and transport properties can be calculated[a]:

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives can be calculated.

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

www.thermodynamic-property-libraries.com

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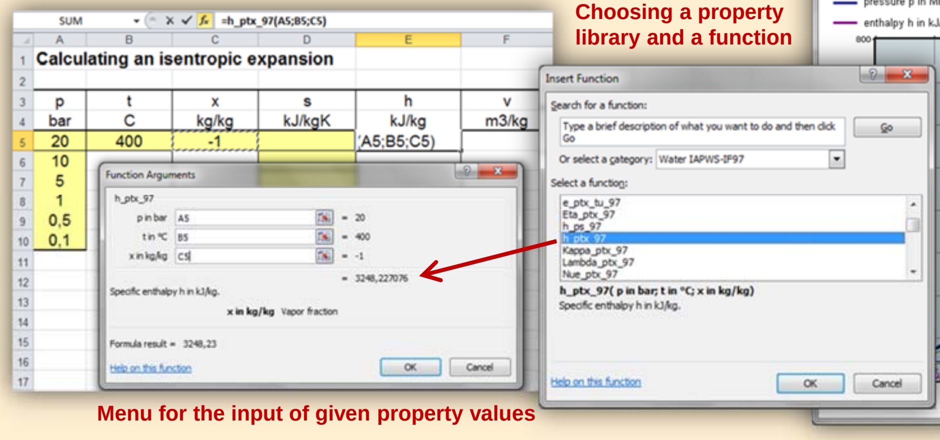
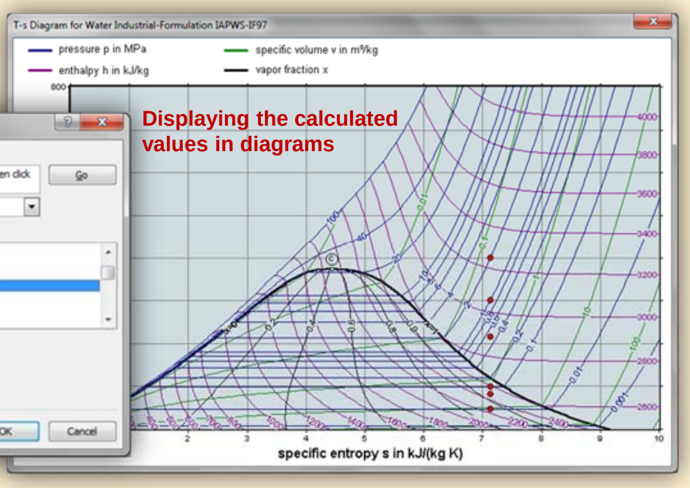
Property Software for Calculating Heat Cycles, Boilers, Turbines, and Refrigerators

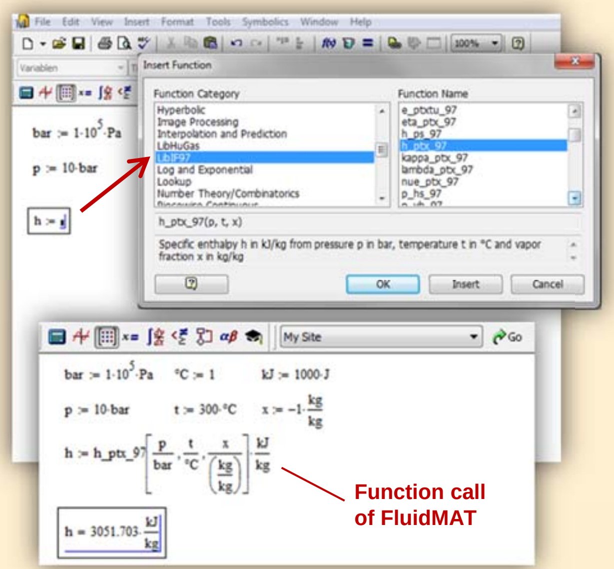
Add-In FluidEXL *Graphics* for Excel®





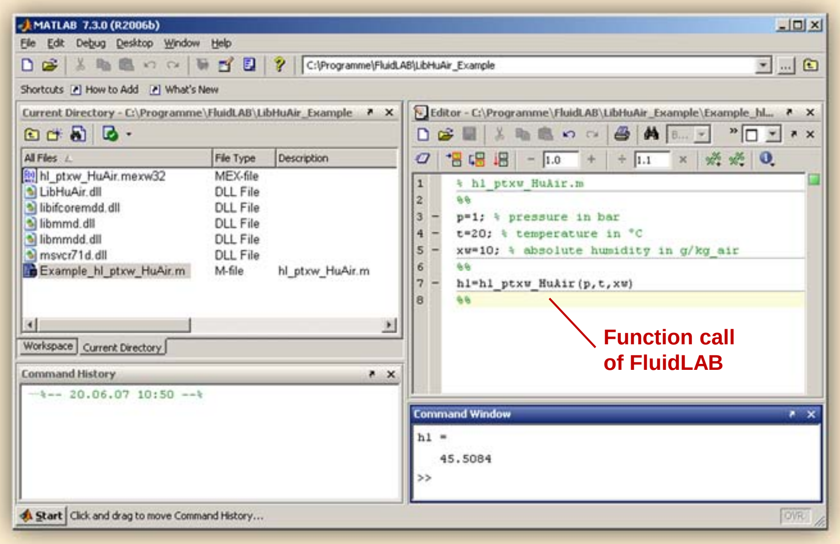
Add-In FluidMAT for Mathcad®

The property libraries can be used in Mathcad®.



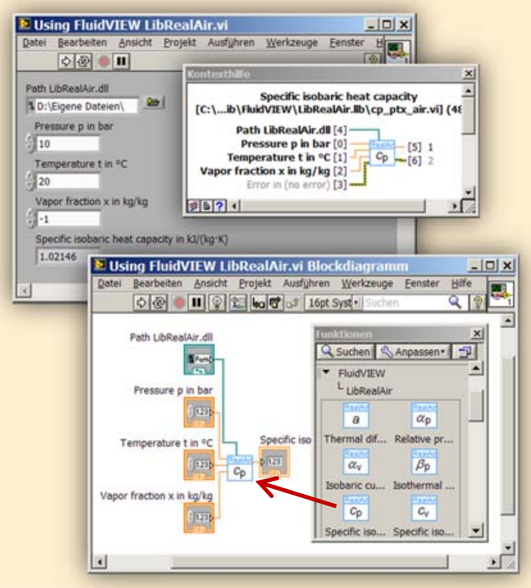
Add-In FluidLAB for MATLAB®

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



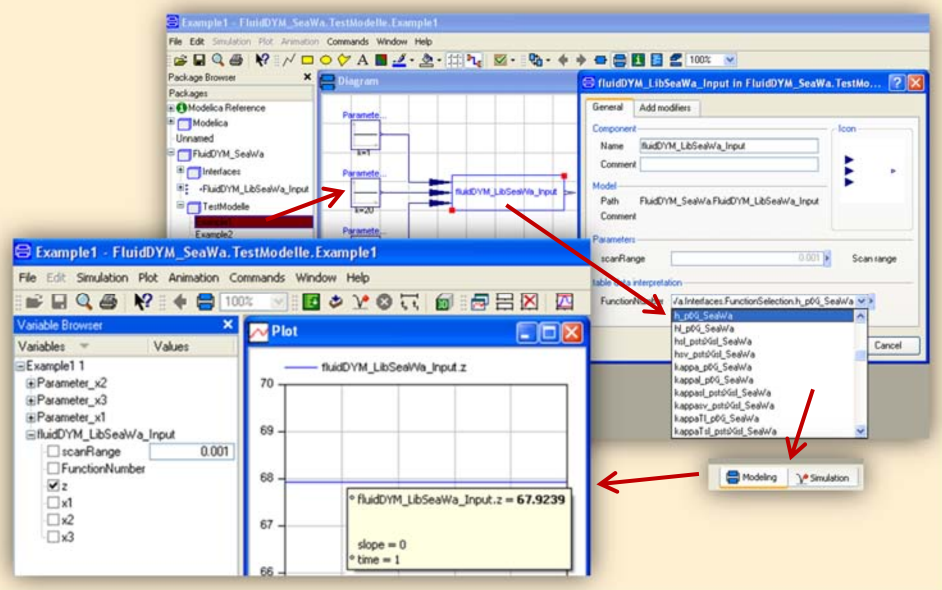
Add-On FluidVIEW for LabVIEW®

The property functions can be calculated in LabVIEW®.

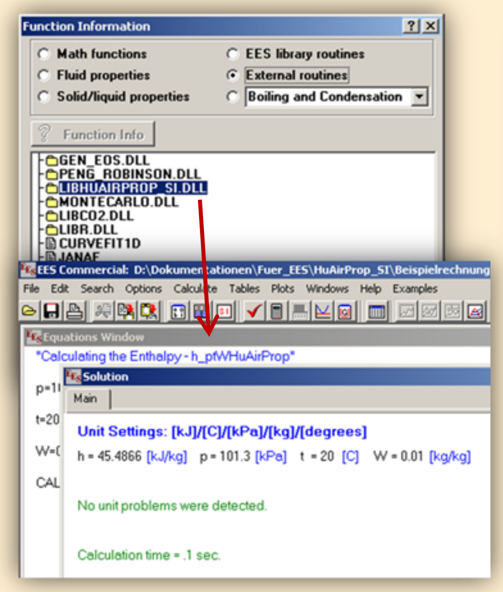


Add-In FluidDYM for DYMOLA® (Modelica) and SimulationX®

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

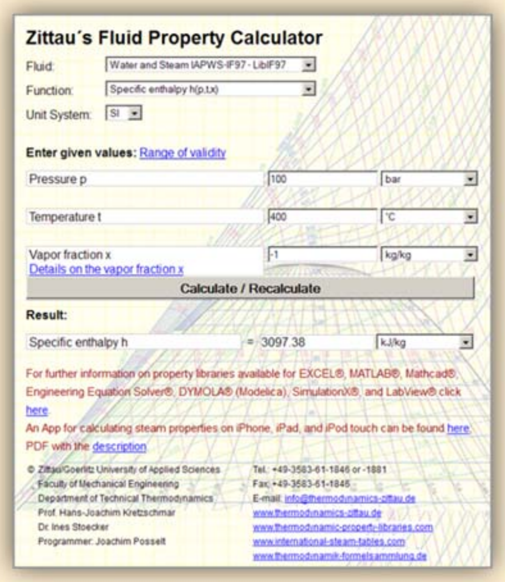


Add-In FluidEES for Engineering Equation Solver®



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

Online Property Calculator at www.thermodynamics-zittau.de



Property Software for Pocket Calculators

FluidCasio


fx 9750 G II


CFX 9850
fx-GG20


CFX 9860 G
Graph 85


ALGEBRA
FX 2.0

FluidHP


HP 48


HP 49

FluidTI


TI Nspire CX CAS
TI Nspire CAS


TI 83
TI 84
TI 89


TI Voyage 200


TI 92

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives can be calculated.

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

www.thermodynamic-property-libraries.com

5. References

[1] Revised Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam IAPWS-IF97.
IAPWS Executive Secretariat (2007), available at www.iapws.org

[2] Wagner, W.; Kretzschmar, H.-J.:
International Steam Tables.
Springer-Verlag, Berlin (2008), www.international-steam-tables.com

[3] Wagner, W.; Cooper, J. R.; Dittmann, A.; Kijima, J.; Kretzschmar, H.-J.; Kruse, A.; Mares, R.; Oguchi, K.; Sato, H.; Stöcker, I.; Sifner, O.; Takaishi, Y.; Tanishita, I.; Trübenbach, J.; Willkommen, Th.:
The IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam.
J. Eng. Gas Turbines Power 122 (2000), S. 150-182.

[4] Wagner, W.; Rukes, B.:
IAPWS-IF97: Die neue Industrie-Formulation.
BWK 50 (1998) Nr. 3, S. 42-97.

[5] Kretzschmar, H.-J.:
Mollier *h*,*s*-Diagramm.
Springer-Verlag, Berlin (2008).

[6] Revised Release on the IAPS Formulation 1985 for the Thermal Conductivity of Ordinary Water Substance.
IAPWS Executive Secretariat (2008), available at www.iapws.org

[7] Release on the IAPWS Formulation 2008 for the Viscosity of Ordinary Water Substance.
IAPWS Executive Secretariat (2008), available at www.iapws.org

[8] IAPWS Release on Surface Tension of Ordinary Water Substance 1994.
IAPWS Executive Secretariat (1994), available at www.iapws.org

[9] Release on the IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use.
IAPWS Executive Secretariat (1995), available at www.iapws.org

[10] Wagner, W.; Pruß, A.:
The IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use.
J. Phys. Chem. Ref. Data 31 (2002), S. 387-535.

[11] Kretzschmar, H.-J.:
Zur Aufbereitung und Darbietung thermophysikalischer Stoffdaten für die Energietechnik.
Habilitation, TU Dresden, Fakultät Maschinenwesen (1990).

[12] Brandt, F.:
Wärmeübertragung in Dampferzeugern und Wärmetauschern.
FDBR-Fachbuchreihe, Bd. 2, Vulkan Verlag Essen (1985).

[13] VDI Richtlinie 4670
Thermodynamische Stoffwerte von feuchter Luft und Verbrennungsgasen. (2003).

[14] Lemmon, E. W.; Jacobsen, R. T.; Penoncello, S. G.; Friend, D. G.:
Thermodynamic Properties of Air and Mixtures of Nitrogen, Argon, and Oxygen from 60 to 2000 K at Pressures to 2000 MPa.
J. Phys. Chem. Ref. Data 29 (2000), S. 331-385.

[15] Lemmon, E. W.; Jacobsen, R. T.:
Viscosity and Thermal Conductivity Equations for Nitrogen, Oxygen, Argon, and Air.
Int. J. Thermophys. 25 (2004), S. 21-69.

[16] Revised Release on the Pressure along the Melting and Sublimation Curves of Ordinary Water Substance.
IAPWS Executive Secretariat (2008), available at www.iapws.org

[17] Wagner, W.; Feistel, R.; Riethmann, T.:
New Equations for the Melting Pressure and Sublimation Pressure of H2O Ice Ih.
To be submitted to J. Phys. Chem. Ref. Data.

[18] Revised Release on the Equation of State 2006 for H_2O Ice Ih.
IAPWS Executive Secretariat (2009), available at www.iapws.org

[19] Feistel, R.; Wagner, W.:
A New Equation of State for H2O Ice Ih.
J. Phys. Chem. Ref. Data 35 (2006), S. 1021-1047.

[20] Nelson, H. F.; Sauer, H. J.:
Formulation of High-Temperature Properties for Moist Air.
HVAC&R Research 8 (2002), S. 311-334.

[21] Gatley, D. P.:
Understanding Psychrometrics, 2nd ed.
ASHRAE, Atlanta (2005).

[22] Gatley, D.; Herrmann, S.; Kretzschmar, H.-J.:
A Twenty-First Century Molar Mass for Dry Air.
HVAC&R Research 14 (2008), S. 655-662.

[23] Herrmann, S.; Kretzschmar, H.-J.; Teske, V.; Vogel, E.; Ulbig, P.; Span, R.; Gatley, D. P.:
Determination of Thermodynamic and Transport Properties for Humid Air for Power-Cycle Calculations.
Bericht PTB-CP-3, Physikalisch-Technische Bundesanstalt Braunschweig und Berlin (Hrsg.), Wirtschaftsverlag NW, Verlag für neue Wissenschaft GmbH, Bremerhaven (2009). ISBN: 978-3-86509-917-4.

[24] Herrmann, S.; Kretzschmar, H.-J.; Teske, V.; Vogel, E.; Ulbig, P.; Span, R.; Gatley, D. P.:
Properties of Humid Air for Calculating Power Cycles.
J. Eng. Gas Turbines Power 132 (2010), S. 093001-1 – 093001-8 (published online).

[25] Herrmann, S.; Kretzschmar, H.-J.; Gatley, D. P.:
Thermodynamic Properties of Real Moist Air, Dry Air, Steam, Water, and Ice (RP-1485).
HVAC&R Research 15 (2009), S. 961-986.

[26] Herrmann, S.; Kretzschmar, H.-J.; Gatley, D. P.:
Thermodynamic Properties of Real Moist Air, Dry Air, Steam, Water, and Ice.
Final Report ASHRAE RP-1485, American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc., Atlanta, GA (2009).

6. Satisfied Customers

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Helbling Beratung & Bauplanung, Zurich, Switzerland	05/2011
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