ThermoFluidProperties

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

FluidEES
with LibHuAir_Xiw
for Engineering Equation Solver®

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Software for the Calculation of the Properties of Humid Air Calculated as Ideal Mixture of Real Fluids

FluidEES
LibHuAir_Xiw

Contents

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0 Package Contents

Zip-file "CD_FluidEES_LibHuAir_Xiw.zip" includes the following files:

FluidEES_LibHuAir_Xiw_Setup.exe	- Self-extracting and self-installing program
LibHuAir_Xiw.dll	- DLL with functions of the LibHuAir_Xiw library
FluidEES_LibHuAir_Xiw_Docu.pdf	- User's Guide
LibHuAir_Xiw.chm	- Help file for the LibHuAir_Xiwproperty library

1. Property Functions

1.1 Functions

Functional Dependence	Function Name	Call from Fortran Program	Property or Function	Unit	Source or Algorithm	Information on page
$a = \mathrm{f}(p,t,\xi_\mathrm{w})$	a_ptXiw_HuAir	= a_ptXiw_HuAir(p,t,Xiw,succ)	Thermal diffusivity	m^2/s	[1-4], [6], [12], [14], [15]	3/2
$c_p = \mathrm{f}(h,s,\xi_\mathrm{w})$	cp_hsXiw_HuAir	= cp_hsXiw_HuAir(h,s,Xiw,succ)	Backward function: Isobaric heat capacity from enthalpy and entropy	$\mathrm{kJ/(kg \cdot K)}$	[1-4], [13], [14]	3/3
$c_p = \mathrm{f}(p,h,\xi_\mathrm{w})$	cp_phXiw_HuAir	= cp_phXiw_HuAir(p,h,Xiw,succ)	Backward function: Isobaric heat capacity from pressure and enthalpy	$\mathrm{kJ/(kg \cdot K)}$	[1-4], [13], [14]	3/4
$c_p = \mathrm{f}(p,s,\xi_\mathrm{w})$	cp_psXiw_HuAir	= cp_psXiw_HuAir(p,s,Xiw,succ)	Backward function: Isobaric heat capacity from pressure and entropy	$\mathrm{kJ/(kg \cdot K)}$	[1-4], [13], [14]	3/5
$c_p = \mathrm{f}(p,t,\xi_\mathrm{w})$	cp_ptXiw_HuAir	= cp_ptXiw_HuAir(p,t,Xiw,succ)	Specific isobaric heat capacity	$\mathrm{kJ/(kg \cdot K)}$	[1-4], [13], [14]	3/6
$c_p = \mathrm{f}(t,s,\xi_\mathrm{w})$	cp_tsXiw_HuAir	= cp_tsXiw_HuAir(t,s,Xiw,succ)	Backward function: Specific isobaric heat capacity from temperature and entropy	$\mathrm{kJ/(kg \cdot K)}$	[1-4], [13], [14]	3/7
$c_v = \mathrm{f}(p,t,\xi_\mathrm{w})$	cv_ptXiw_HuAir	= cv_ptXiw_HuAir(p,t,Xiw,succ)	Specific isochoric heat capacity	$\mathrm{kJ/(kg \cdot K)}$	[1-4], [13], [14]	3/8
$\eta = \mathrm{f}(p,t,\xi_\mathrm{w})$	Eta_ptXiw_HuAir	= Eta_ptXiw_HuAir(p,t,Xiw,succ)	Dynamic viscosity	$\mathrm{Pa \cdot s}$	[7], [12], [15]	3/9
$h = \mathrm{f}(p,s,\xi_\mathrm{w})$	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
$h = \mathrm{f}(p,t,\xi_\mathrm{w})$	h_ptXiw_HuAir	= h_ptXiw_HuAir(p,t,Xiw,succ)	Specific enthalpy	kJ/kg	[1-4], [13], [14], [18], [19]	3/11
$h = \mathrm{f}(t,s,\xi_\mathrm{w})$	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
$v = \mathrm{f}(p,h,\xi_\mathrm{w})$	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
$v = \mathrm{f}(p,s,\xi_\mathrm{w})$	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
$v = \mathrm{f}(p,t,\xi_\mathrm{w})$	v_ptXiw_HuAir	= v_ptXiw_HuAir(p,t,Xiw,succ)	Specific volume	m^3/kg	[1-4], [14], [18], [19]	3/44
$v = \mathrm{f}(t,s,\xi_\mathrm{w})$	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
$w = \mathrm{f}(p,t,\xi_\mathrm{w})$	w_ptXiw_HuAir	= w_ptXiw_HuAir(p,t,Xiw,succ)	Isentropic speed of sound	m/s	[1-4], [13], [14]	3/46
$\xi_\mathrm{w} = \mathrm{f}(p,t,p_\mathrm{d})$	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
$\xi_\mathrm{w} = \mathrm{f}(p,t,\varphi)$	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
$\xi_\mathrm{w} = \mathrm{f}(p,t_\tau)$	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
$\xi_\mathrm{w} = \mathrm{f}(p,t,t_\mathrm{f})$	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
$\xi_\mathrm{wf} = \mathrm{f}(p,t,\xi_\mathrm{w})$	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
$\xi_\mathrm{wsatt} = \mathrm{f}(p,t)$	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
$x_\mathrm{w} = \mathrm{f}(\xi_\mathrm{w})$	xw_Xiw_HuAir	= xw_Xiw_HuAir(Xiw,succ)	Humidity ratio (absolute humidity) from mass fraction of water	kg/kg_{Air}		3/47

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 $p_{dsatt}(p,t) = f(p,t) \cdot p_s(t)$

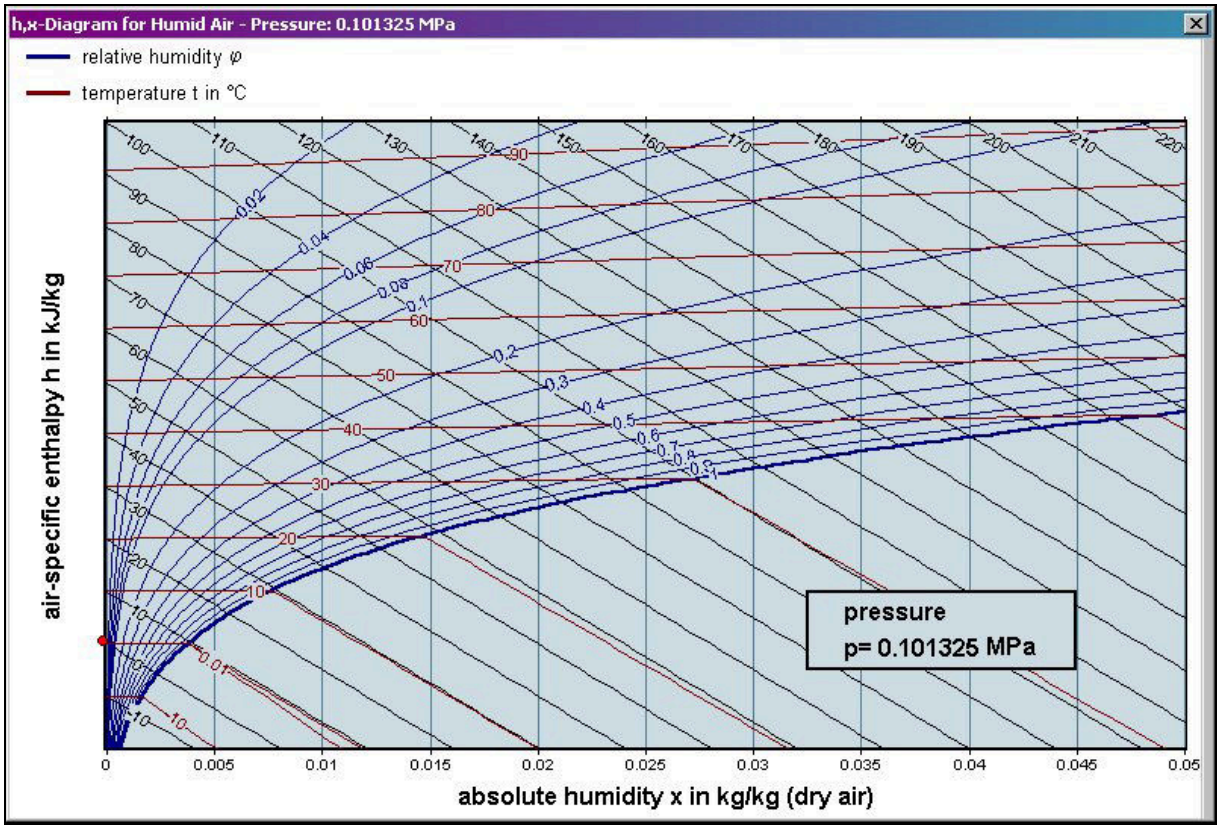
- $f(p,t)$ from Herrmann et al. [25], [26],
- $p_s(t)$ for T ≥ 0.01 °C from IAPWS - IF97 [1], [2], [3], [4],
- $p_s(t)$ for T < 0 °C from IAPWS-08 [16], [17].

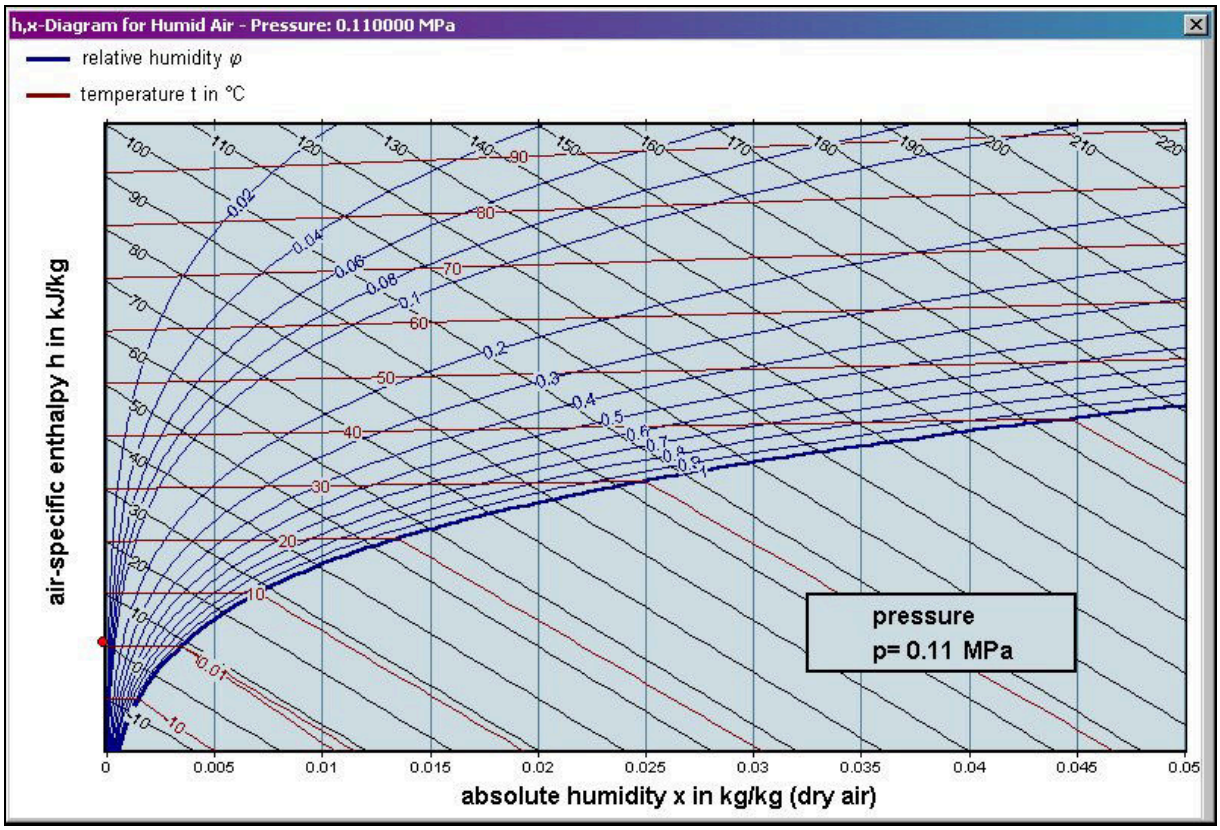
1.2 Thermodynamic Diagrams

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 Add-In FluidEES for Engineering Equation Solver®

The FluidEES Add-In has been developed to conveniently calculate thermodynamic properties in the Engineering Equation Solver® (EES). It enables, within EES®, the direct call of functions relating to ethanol from the LibHuAir_Xiw property library.

2.1 Installing FluidEES including LibHuAir_Xiw

In this section, the installation of FluidEES LibHuAir_Xiw is described.

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

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

CD_FluidEES_LibHuAir_Xiw

in your Windows Explorer®, Norton Commander® or other similar program you are using.

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

Within this folder you will see the following two files:

FluidEES_LibHuAir_Xiw_Docu_Eng.pdf
FluidEES_LibHuAir_Xiw_Setup.exe.

In order to run the installation of FluidEES including the LibHuAir_Xiw property library, first double-click the file

FluidEES_LibHuAir_Xiw_Setup.exe.

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

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

In the following dialog box, "Destination Location" (see figure below), the default path where Engineering Equation Solver has been installed will be shown (the standard location is:

C:\Program Files\EES32\Userlib\LibHuAir_Xiw (for English version of Windows)
C:\Programme\EES32\Userlib\LibHuAir_Xiw (for German version of Windows)).

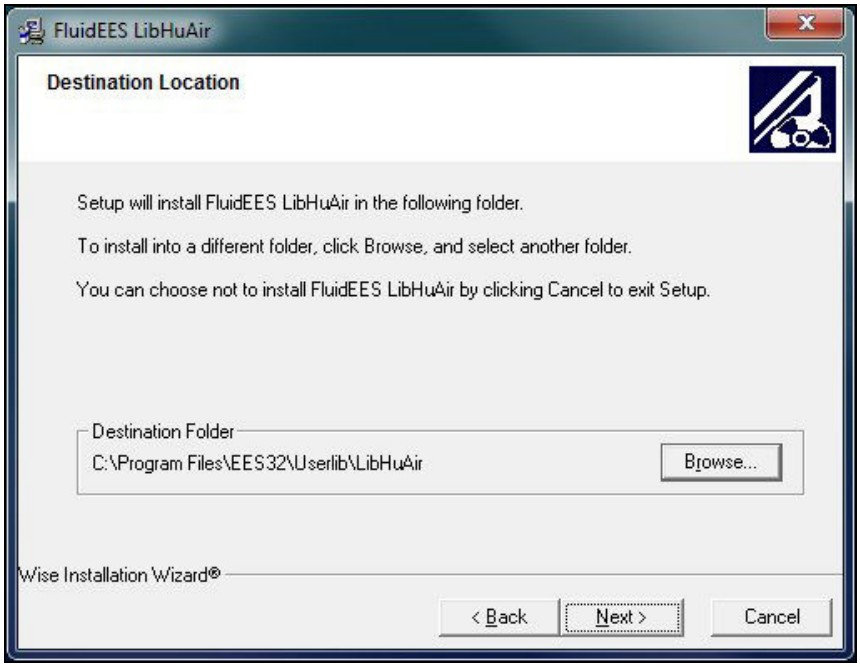


Figure 2.1: "Destination Location"

Click on "Next >" in the window "Destination Location."
Click on the "Next >" button in the "Start Installation" window.
The FluidEES files are now being copied into the "\LibHuAir_Xiw" folder on your hard drive.
Click the "Finish >" button in the next window to complete installation.
The installation program has copied the following files into the directory

C:\Program Files\EES32\Userlib\LibHuAir_Xiw (for English version of Windows)
C:\Programme\EES32\Userlib\LibHuAir_Xiw (for German version of Windows)):

advapi32.dll	- Dynamic link library for use in Windows® programs
Dformd.dll	- Dynamic link library for use in Windows® programs
Dforrt.dll	- Dynamic link library for use in Windows® programs
DFORRTD.dll	- Dynamic link library for use in Windows® programs
INSTALL.LOG	- Log file
LC.dll	- Dynamic link library for use in Windows® programs
LibHuAir_Xiw.ctx	- Interface including property functions of LibHuAir_Xiw for EES®
LibHuAir_Xiw.dll	- Dynamic link library with property functions of LibHuAir_Xiw
LibHuAir_Xiw.chm	- Help file of the LibHuAir_Xiw property library
msvcp60.dll	- Dynamic link library for use in Windows® programs
msvcrt.dll	- Dynamic link library for use in Windows® programs
MSVCRTD.dll	- Dynamic link library for use in Windows® programs
UNWISE.EXE	- File to remove the LibHuAir_Xiw library
UNWISE.INI	- File belonging to the UNWISE.EXE

Now, you have to overwrite the following files

"LibHuAir_Xiw.dll"
"LibHuAir_Xiw.chm"
"LibHuAir_Xiw.ctx"

in your Engineering Equation Solver directory with the files of the same names provided in your extracted CD_FluidEES_LibHuAir_Xiw folder.

To do this, open the "CD_FluidEES_LibHuAir_Xiw" folder in "My Computer" and click on the file "LibHuAir_Xiw.dll" in order to highlight it. Then click on the "Edit" menu in your Explorer and select "Copy".

Now, open your EES directory (the standard being:

C:\Program Files\EES32\Userlib\LibHuAir_Xiw (for English version of Windows)
C:\Programme\EES32\Userlib\LibHuAir_Xiw (for German version of Windows))

and insert the file "LibHuAir_Xiw.dll" by clicking the "Edit" menu in your Explorer and then select "Paste". Answer the question whether you want to replace the file by clicking the "Yes" button. Now, you have overwritten the file "LibHuAir_Xiw.dll" successfully.

Repeat these steps in order to copy the other files listed above.

2.2 The FluidEES Help System

As mentioned earlier, FluidEES also provides detailed online help functions.

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

- Click "Options" in the EES menu bar and select "Function Info".
- The "Function Information" window will appear. Select "External routines" and double-click on the entry "LibHuAir_Xiw.DLL".
- A list with calculable functions of the "LibHuAir_Xiw" library appears.
- Find and select the desired function, e.g. "hl_ptxw_HuAir" and click the 

button above.

If the "LibHuAir_Xiw.chm" function help cannot be found, confirm the question whether you want to look for it yourself with "Yes." Select the "LibHuAir_Xiw.chm" file in the installation menu of FluidEES in the window which is opened, the standard being

C:\Program Files\EES32\Userlib\LibHuAir_Xiw (for English version of Windows)
C:\Programme\EES32\Userlib\LibHuAir_Xiw (for German version of Windows))

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

Licensing the LibHuAir_Xiw Property Library

The licensing procedure must be carried out when Engineering Equation Solver® starts up and a FluidEES prompt message appears. In this case, you will see the "License Information" window for LibHuAir_Xiw (see figure below).

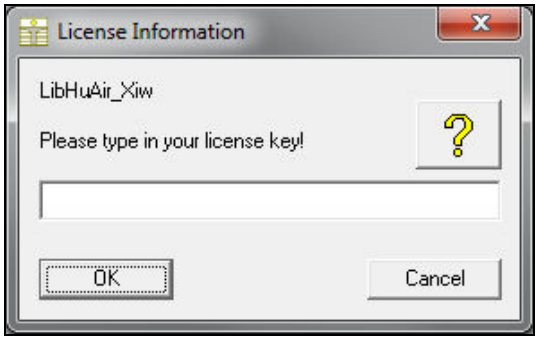


Figure 2.11: "License Information" window

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

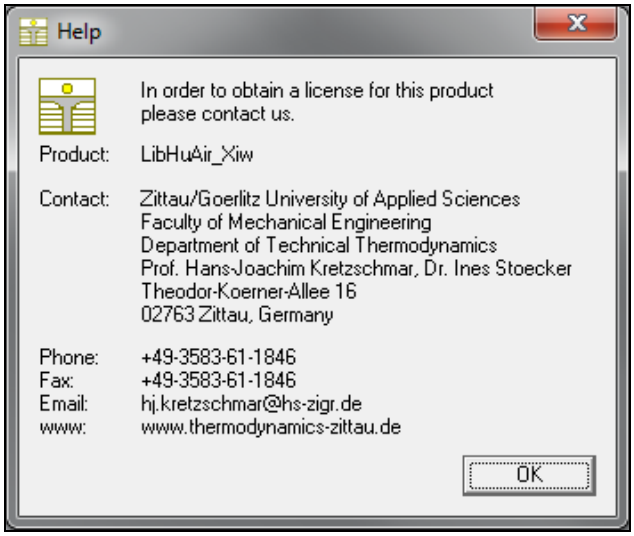


Figure 2.12: "Help" window

If you do not enter a valid license it is still possible to start EES® by clicking "Cancel". In this case, the LibHuAir_Xiw property library will display the result "–11111111" for every calculation you ask it to make.

The "License Information" window will appear every time you use FluidEES LibHuAir_Xiw until you enter a license code to complete registration. If you decide not to use FluidEES LibHuAir_Xiw, you can uninstall the program following the instructions given in section 2.5 of this User's Guide.

With this procedure the LibHuAir_Xiw property library has been licensed.

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

Now we will calculate, step by step, the air-specific enthalpy h_l of humid air as a function of mixture pressure p, temperature t and absolute humidity xi_w using FluidEES with LibHuAir_Xiw in the Engineering Equation Solver®.

How to perform a calculation with FluidEES:

- Start Engineering Equation Solver® (EES).
- The LibHuAir_Xiw library, if installed, is loaded by the program automatically.
- We recommend preparing an EES® sheet, as shown in Figure 2.13.
  Note: the units of p, t, Xiw must correspond to those in Chapter 1.

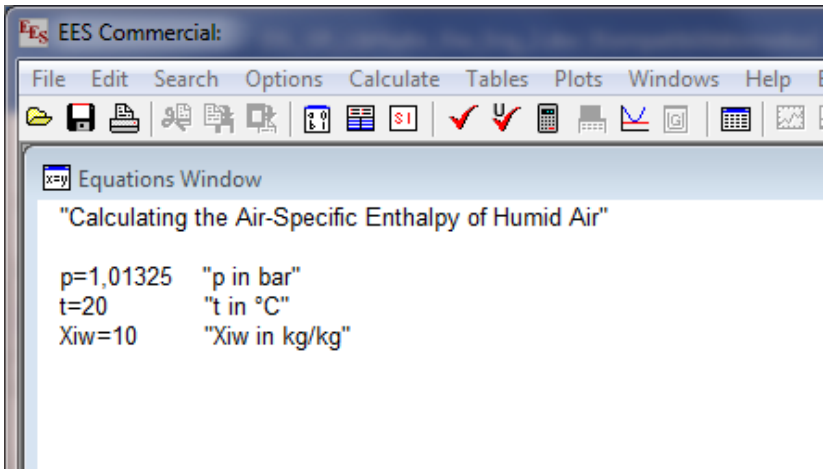


Figure 2.13: Preparing an EES® sheet for the calculation

- The function parameters values stand for:
  - First operand: Total pressure p = 1.01325 bar
    (Range of validity of LibHuAir_Xiw: p = 6.112 mbar ... 1000 bar)
  - Second operand: Temperature t = 20°C
    (Range of validity of LibHuAir_Xiw: t = -143.15°C ... 1726.85°C)
  - Third operand: xi_W = 10 kg_{Water}/kg_{Air} (dry Air)
    (Range of validity of LibHuAir_Xiw: $x_W \geq 0$ g/kg_{Air})
- Confirm your entry by pressing the "ENTER" key.

Note:
EES® adapts to the language that is set in the "Regional and Language Options," which can be found in the "Control Panel." If you run Engineering Equation Solver® on an English version of Windows®, the standard decimal separator will be a dot. If your computer is set to German, for example, the expected decimal separator will be a comma (as shown in Fig. 2.13 and in the following sample calculation). In this case enter a comma in the values above instead of a dot. You can find additional information on this issue by clicking on "Help" in the EES® menu bar and then select "Help Index". Click on "Search" in the window which appears, type "decimal separator" and press the "ENTER" key.

- For calculating hl = f(p,t,xw), call up the function "hl_ptxw_HuAir" of the property library LibHuAir_Xiw as follows:
- Click on "Options" in the EES® menu bar and select "Function Info".
- The "Function Information" window will appear. Select "External routines" and you will see the screen shown here in Figure 2.14.

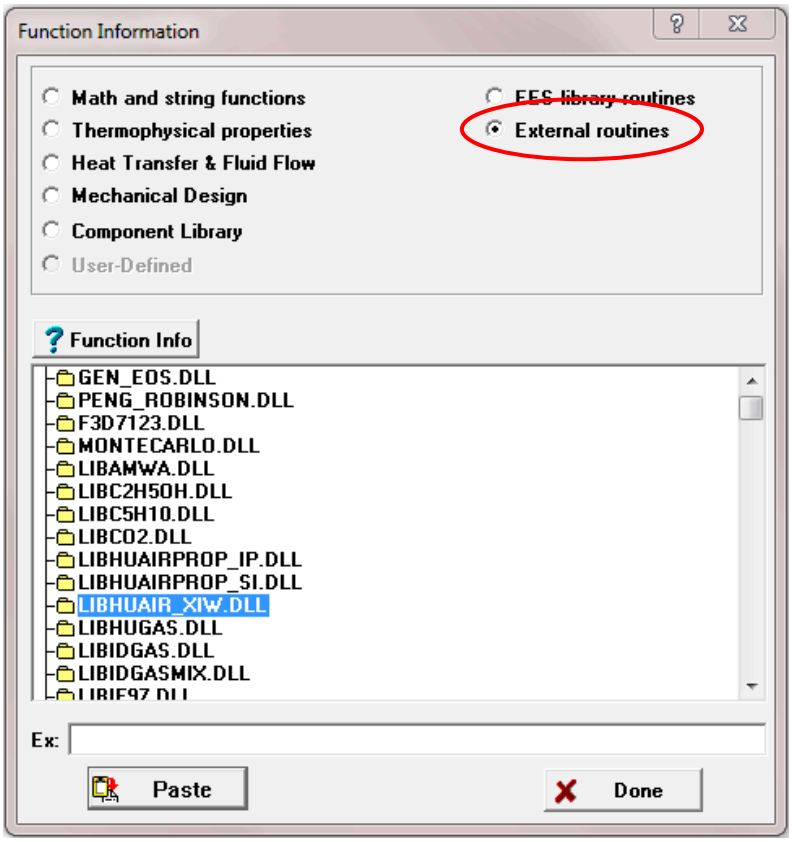


Figure 2.14: "Function Information" window offering different libraries (routines)

- Double-click on the entry "LIBHUAIR_XIW.DLL".
- A list with calculable functions of the "LibHuAir_Xiw" library appears.
- Find and select the desired function, here "hl_ptxw_HuAir_EES" (see Figure 2.15), and click the "Paste" button below.

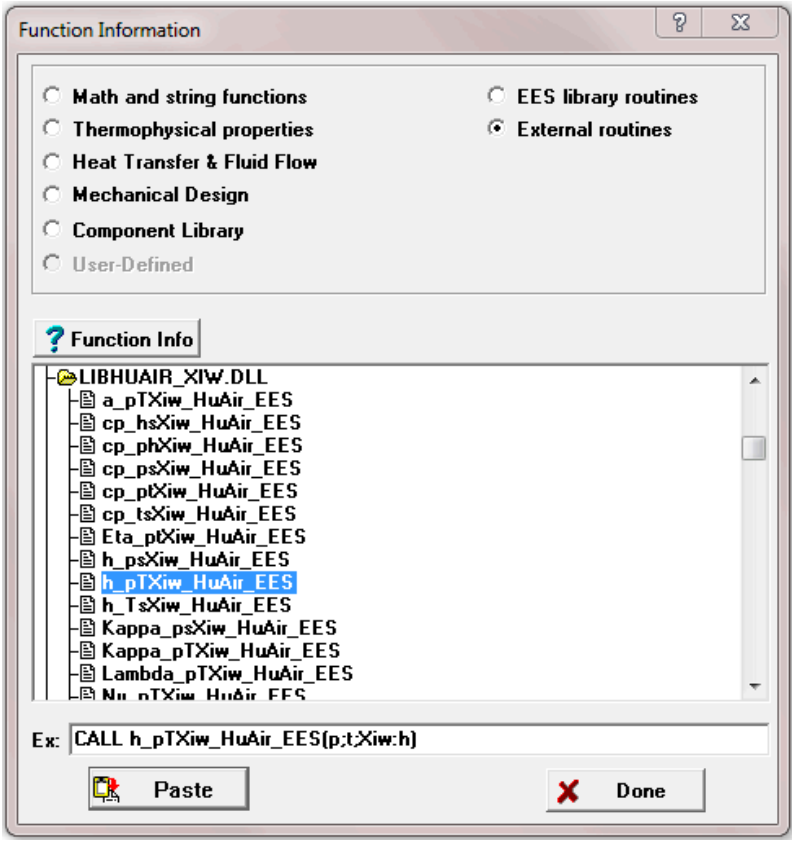


Figure 2.15: Selecting the "hl_ptxw_HuAir_EES" function

- The selected function will be copied and now appears in the "Equations Window" (see Figure 2.16).

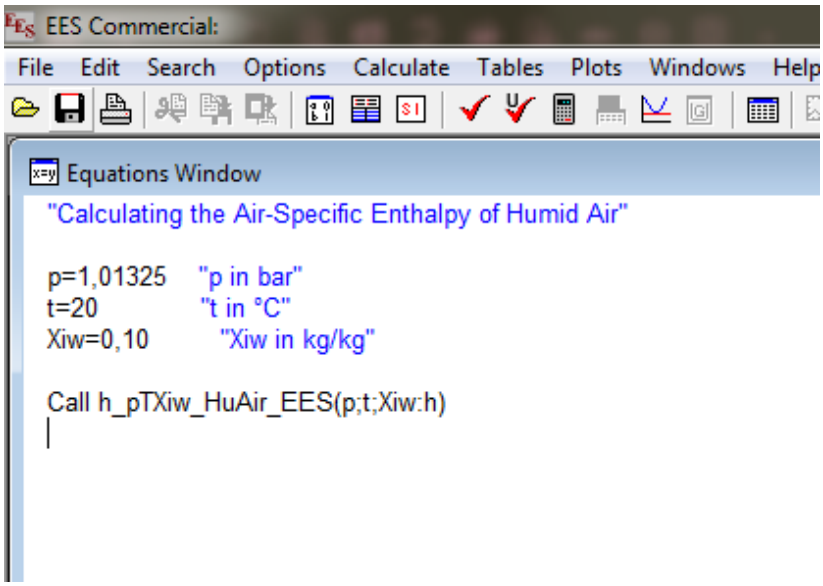


Figure 2.16: "Equations Window" with the call of the property function

- Now, you can check the syntax of the instructions in the "Equations Window" by clicking the  symbol in the upper menu bar of EES®. The program tests whether or not the syntax is correct (e.g. dots as decimal separators versus commas). Confirm the "Information" window which appears by clicking the "OK" button.

- Then click the  symbol in the upper menu bar of EES® to start the calculation.

- Soon you will see the "Calculations Completed" window. Leave this window by clicking the "Continue" button.
- The result for the specific enthalpy *h* appears in the "Solution" window (see Figure 2.17).

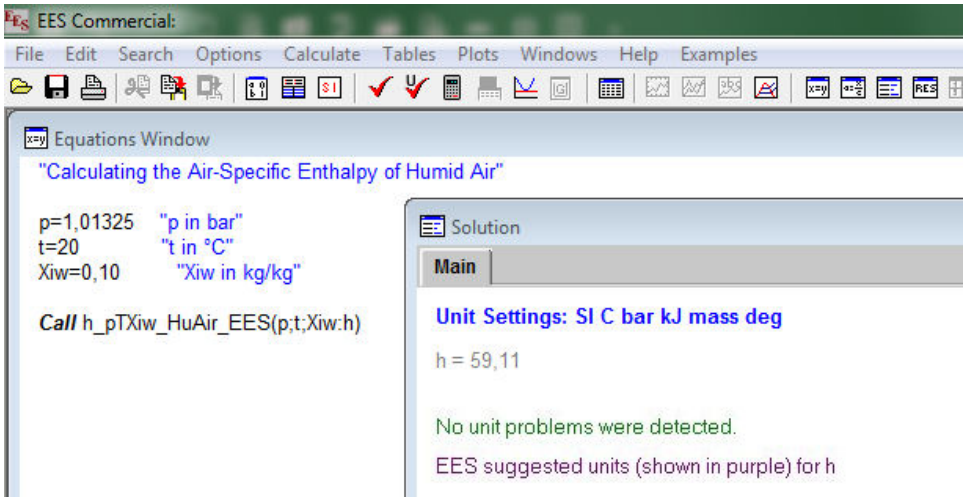


Figure 2.17: "Solution" window showing the result

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

⇒ The result in our sample calculation here is: "h = 59.11".

The corresponding unit is kJ/kg_{Air} (see table of the property functions in Chapter 1).

For further property functions calculable in FluidEES see the function table in Chapter 1.

2.4 Removing FluidEES LibHuAir_Xiw

In order to remove the property library LibHuAir_Xiw from your hard drive in Windows®, click "Start" in the lower task bar, then "Settings" and "Control Panel."

Afterwards double-click on "Add or Remove Programs."

In the list box of the "Add or Remove Programs" menu which appears, select "FluidEES LibHuAir_Xiw" by clicking on it and click the "Change/Remove" button.

In the following dialog box select "Automatic" and then click the "Next >" button.

Then confirm the menu "Perform Uninstall" by clicking the "Finish" button.

Finally, close the "Add or Remove Programs" and "Control Panel" windows.

"FluidEES LibHuAir_Xiw" has now 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 : $0.01\,bar \le p \le 1000\,bar$
Mass fraction of water ξ_w : $0 \le \xi_w \le 1$ 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 $\rightarrow$ 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 $s(p,t,\xi_w)$ 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,ξ_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 $\rightarrow$ 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:

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,ξ_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 : $0 \le \xi_w \le 1$ 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,ξ_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 : $0.01\,bar \le p \le 1000\,bar$
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:

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 $\rightarrow$ 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:

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

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 η = f(p,t,ξ_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 $\rightarrow$ 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:

- 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 : $0.01\,\text{bar} \le p \le 1000\,\text{bar}$
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 *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 $\rightarrow$ 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:

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 $\rightarrow$ 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 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 κ = f(p,s,ξ_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 κ = f(p,t,ξ_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 λ = f(p,t,ξ_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 : $0.01\,bar \le p \le 1000\,bar$
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

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 ν = f(p,t,ξ_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 $\nu = \frac{\eta}{\rho} = \eta \cdot v$
- 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 $\le$ T $\le$ 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 $p_d = f(p,t,\xi_w)$

Function Name:

pd_ptXiw_HuAir

Fortran Program:

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

Input Values:

p - Total pressure p in bar
t - Temperature t in °C
Xiw - Mass fraction of water 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 : $0.01\,bar \le p \le 1000\,bar$
Mass fraction of water ξ_w : $0 \le \xi_w \le 1$ 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 $\rightarrow$ Calculation successful
- 0 $\rightarrow$ Calculation not successful

Range of Validity:

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

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

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 φ = f(p,t,ξ_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 $\rightarrow$ 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 : $0.01\,\text{bar} \le p \le 1000\,\text{bar}$

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 : $0.01\,bar \le p \le 1000\,bar$
Mass fraction of water ξ_w : $0 \le \xi_w \le 1$ kg/kg

Comments:

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

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,ξ_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 $\rightarrow$ 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:

- *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 : $0.01\,bar \le p \le 1000\,bar$

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 $s(p,t,\xi_w$, 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 : $0.01\,bar \le p \le 1000\,bar$

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

Comments:

Iteration of t from $h(p,t,\xi_w)$. 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 : $0.01\,bar \le p \le 1000\,bar$

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

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 ρ = f(p,t,ξ_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 : $0 \le \xi_w \le 1\ \text{kg/kg}$

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:

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 : $0\,°C \leq t \leq t_{krit} = 373.946\,°C$

Comments:

Calculation: for pure water from IAPWS-IF97

Results for Wrong Input Values:

Sigma_t_HuAir = - 1

References: [8]

Temperature t = f(h,s,ξ_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,ξ_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 : $0.01\,bar \le p \le 1000\,bar$
Mass fraction of water ξ_w : $0 \le \xi_w \le 1\ kg/kg$

Comments:

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

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,ξ_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 $\rightarrow$ 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 $s(p,t,\xi_w)$

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,ξ_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 : $0.01\,bar \le p \le 1000\,bar$
Mass fraction of water ξ_w : $0 \le \xi_w \le 1$ kg/kg

Comments:

Iteration of t_f 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:

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)

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

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 $\rightarrow$ 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:

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 $\rightarrow$ 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 $v(p,t,\xi_w)$

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,ξ_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 $\rightarrow$ 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

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 $\rightarrow$ 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 $(\xi_w \le \xi_{wsatt})$

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

- 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) $x_w = f(\xi_w)$

Function Name:

xw_Xiw_HuAir

Fortran Program:

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

Input Values:

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: $x_w = \dfrac{\xi_w}{1-\xi_w}$

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 ξ_w = f(p,t,φ)

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 ξ_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 → 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 : $0 \le \xi_w \le 1\ kg/kg$

Range of Validity:

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

Comments:

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

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 ξ_w = f(p,t_τ)

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 $\rightarrow$ Calculation successful

- 0 $\rightarrow$ 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 $t_\tau \ge 0.01°\text{C}$ - vapor pressure of water

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

Results for Wrong Input Values:

Xiw_ptTau_HuAir = - 1, succ = 0

References:

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

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

if $t_\tau < 0.01°\text{C}$ 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 $\rightarrow$ Calculation successful
- 0 $\rightarrow$ 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 : $0\,°\mathrm{C} \le t \le t_{\mathrm{s}}(p, p_{\mathrm{d}})\,°\mathrm{C}$

(t_{s} – Boiling Temperature of water in mixtures of gases)

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

Comments:

Specific humidity of water for saturated humid air:

$$\xi_{\mathrm{wsatt}} = \frac{x_{\mathrm{ws}}}{1 + x_{\mathrm{ws}}} \quad \text{with} \quad x_{\mathrm{ws}} = \frac{R_{\mathrm{l}}}{R_{\mathrm{w}}} \; \frac{p_{\mathrm{dsatt}}(p,t)}{p - p_{\mathrm{dsatt}}(p,t)}$$

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

with $p_{\mathrm{s}}(t)$ for $t \ge 0.01°\mathrm{C}$ - vapor pressure of water

for $t < 0.01°\mathrm{C}$ - sublimation pressure of water

Results for Wrong Input Values:

Xiwsatt_pt_HuAir = - 1, succ = 0

References:

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

$p_{\mathrm{s}}(t)$ if $t \ge 0.01°\mathrm{C}$ from IAPWS-IF97 [1], [2], [3], [4]

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

KCE ThermoFluidProperties

KCE-ThermoFluidProperties
www.thermofluidprop.com

Hochschule Zittau/Görlitz
UNIVERSITY OF APPLIED SCIENCES

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

Water and Steam

Library LibIF97

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

Library LibIF97_META

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

Humid Combustion Gas Mixtures

Library LibHuGas

Model: Ideal mixture of the real fluids:

CO_2 - Span, Wagner H_2O - IAPWS-95
O_2 - Schmidt, Wagner N_2 - Span et al.
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
- Poynting effect

Humid Air

Library LibHuAir

Model: Ideal mixture of the real fluids:

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

Consideration of:

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

Extremely Fast Property Calculations

Spline-Based Table Look-up Method (SBTL)

Library LibSBTL_IF97
Library LibSBTL_95
Library LibSBTL_HuAir

For steam, water, humid air, carbon dioxide and other fluids and mixtures according IAPWS Guideline 2015 for Computational Fluid Dynamics (CFD), real-time and non-stationary simulations

Carbon Dioxide Including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1996)

Seawater

Library LibSeaWa

IAPWS Industrial Formulation 2013

Ice

Library LibICE

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

Ideal Gas Mixtures

Library LibIdGasMix

Model: Ideal mixture of the ideal gases:

Ar	NO	He	Propylene
Ne	H_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

Humid Air

Library ASHRAE LibHuAirProp

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

Consideration of:

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

www.ashrae.org/bookstore

Dry Air Including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth et al. (1993)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of Bücker and Wagner (2006)

n-Butane

Library LibButane_n

Formulation of Bücker and Wagner (2006)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

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

Helmholtz energy equation for the mixing term

(also useable for calculating the Kalina Cycle)

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

$C_2H_6O_2$	Ethylene glycol
$C_3H_8O_2$	Propylene glycol
C_2H_5OH	Ethanol
CH_3OH	Methanol
$C_3H_8O_3$	Glycerol
K_2CO_3	Potassium carbonate
$CaCl_2$	Calcium chloride
$MgCl_2$	Magnesium chloride
NaCl	Sodium chloride
$C_2H_3KO_2$	Potassium acetate
$CHKO_2$	Potassium formate
LiCl	Lithium chloride
NH_3	Ammonia

Formulation of the International Institute of Refrigeration (IIR 2010)

Ethanol

Library LibC2H5OH

Formulation of
Schroeder et al. (2014)

Methanol

Library LibCH3OH

Formulation of
de Reuck and Craven (1993)

Propane

Library LibPropane

Formulation of
Lemmon et al. (2009)

Siloxanes as ORC Working Fluids

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

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

Tetradecamethylhexasiloxane $C_{14}H_{42}O_5Si_6$ **Library LibMD4M**

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

Formulation of Colonna et al. (2006)

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

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

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

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

Formulation of Colonna et al. (2008)

Nitrogen and Oxygen

Libraries LibN2 and LibO2

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

Hydrogen

Library LibH2

Formulation of
Leachman et al. (2009)

Helium

Library LibHe

Formulation of
Arp et al. (1998)

Hydrocarbons

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

Isopentane C_5H_{12} **Library LibC5H12_Iso**

Neopentane C_5H_{12} **Library LibC5H12_Neo**

Isohexane C_6H_{14} **Library LibC6H14**

Toluene C_7H_8 **Library LibC7H8**

Formulation of Lemmon and Span (2006)

Further Fluids

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

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

Hydrogen sulfide H_2S **Library LibH2S**

Nitrous oxide N_2O **Library LibN2O**

Sulfur dioxide SO_2 **Library LibSO2**

Acetone C_3H_6O **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

KCE ThermoFluidProperties

For more information please contact:

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Email: info@thermofluidprop.com
Phone: +49-351-27597860
Mobile: +49-172-7914607
Fax: +49-3222-1095810

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
- Thermal diffusivity a

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

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

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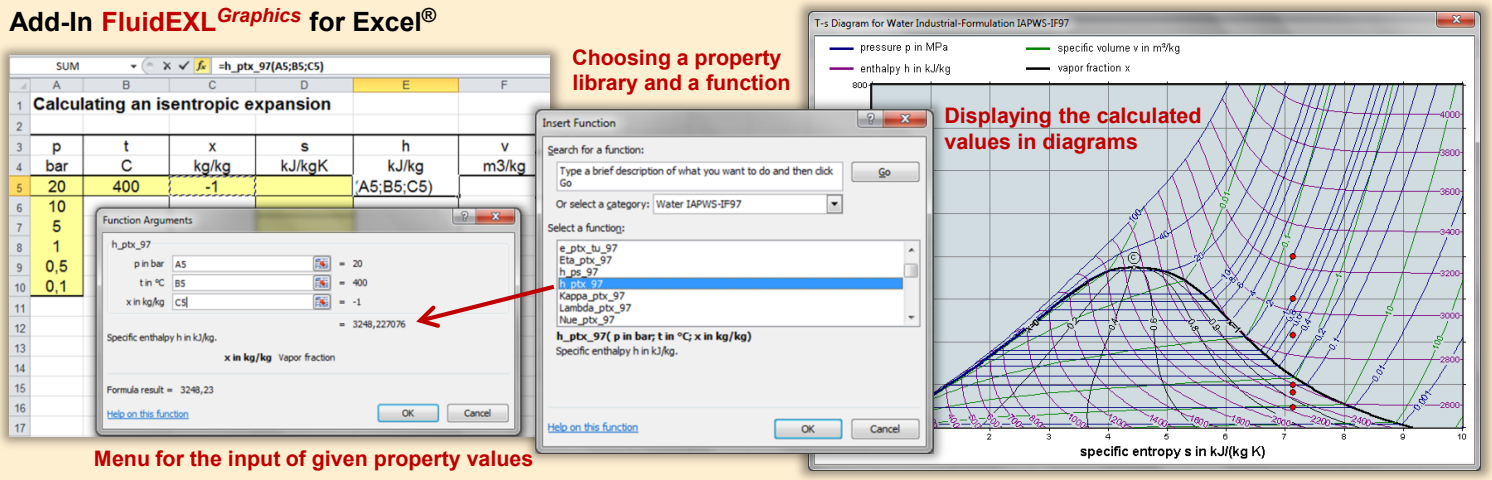
www.thermofluidprop.com

KCE ThermoFluidProperties

Hochschule Zittau/Görlitz
UNIVERSITY OF APPLIED SCIENCES

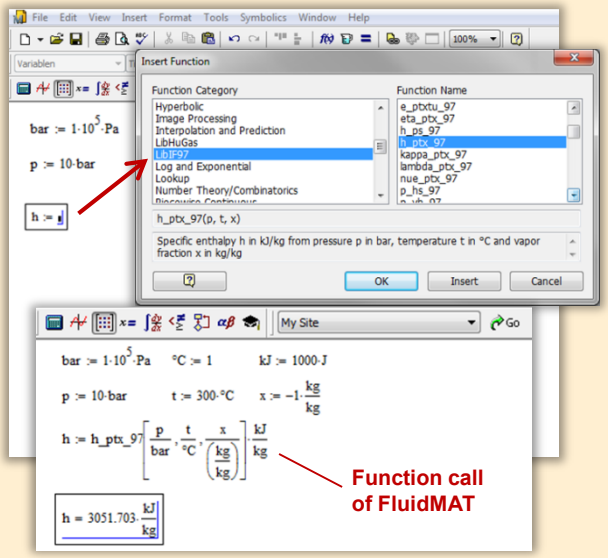
Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

Add-In FluidEXL*Graphics* for Excel®



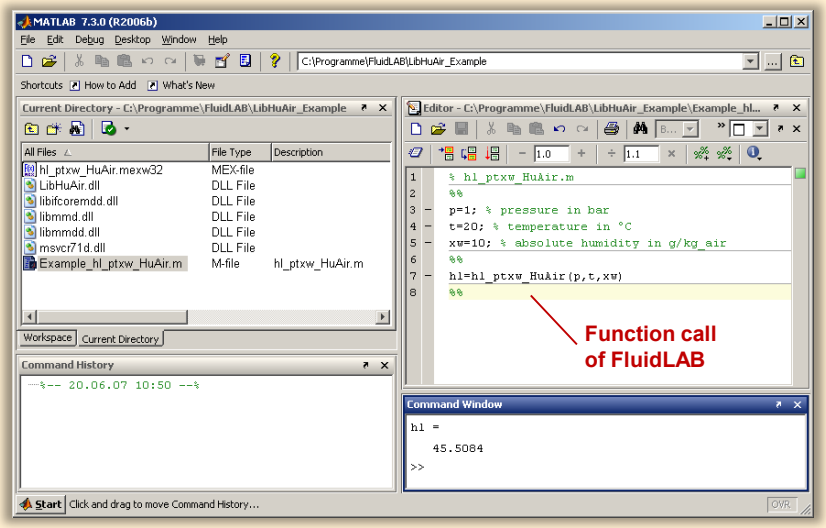
Add-On FluidMAT for Mathcad®
Add-On FluidPRIME for Mathcad Prime®

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



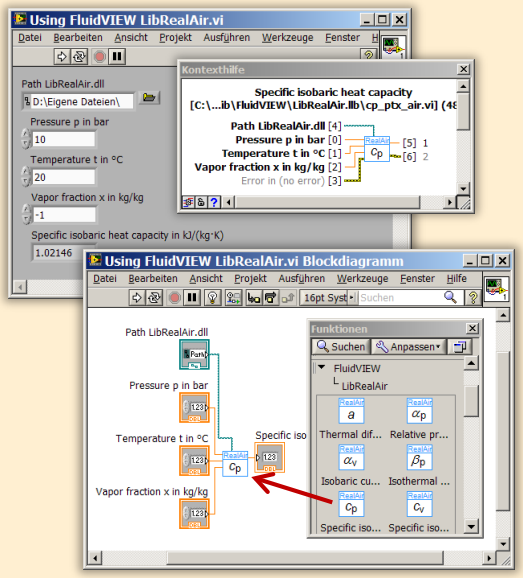
Add-On FluidLAB for MATLAB® and SIMULINK®

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



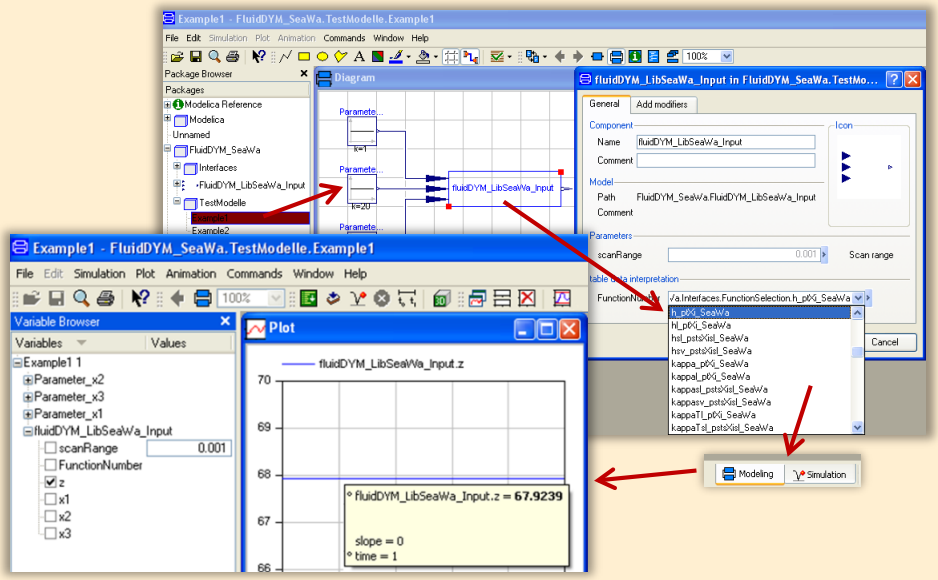
Add-On FluidVIEW for LabVIEW™

The property functions can be calculated in LabVIEW™.

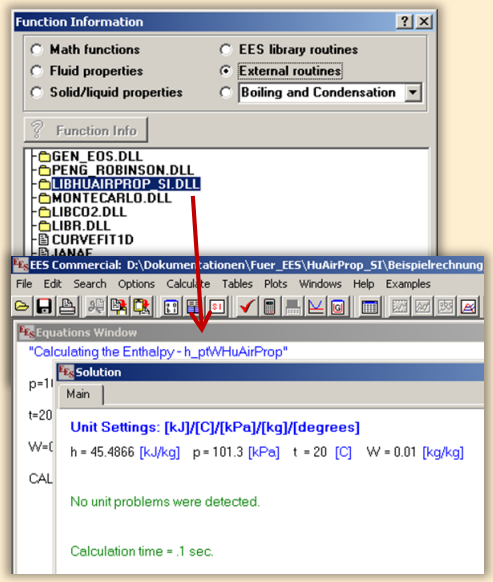


Add-On FluidDYM for DYMOLA® (Modelica) and SimulationX®

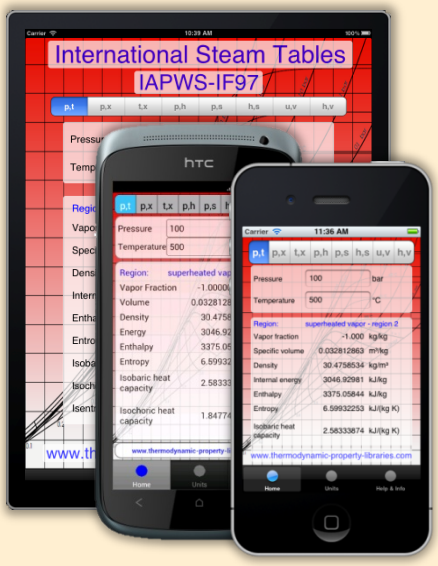
The property functions can be called in DYMOLA® and SimulationX®.



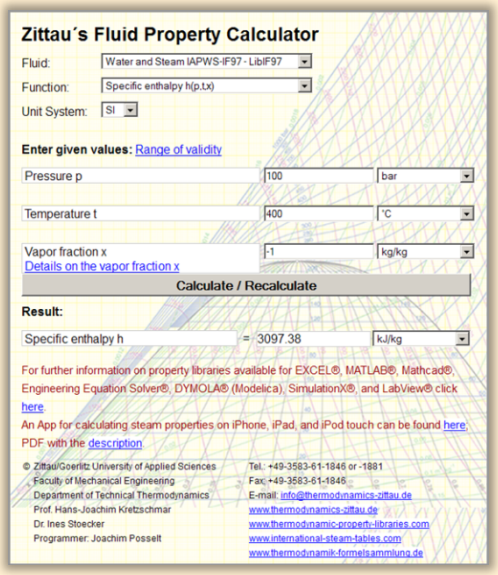
Add-On FluidEES for Engineering Equation Solver®



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



Online Property Calculator at www.thermofluidprop.com



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

For more information please contact:

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

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
- Thermal diffusivity a

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

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

www.thermofluidprop.com

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6. Satisfied Customers

Date: 07/2019

The following companies and institutions use the property libraries:

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

2019

WARNICA, Waterloo, Canada	07/2019
MIBRAG, Zeitz	06/2019
Pöyry, Zürich, Switzerland	06/2019
RWTH Aachen, Inst. Strahlantriebe und Turbomaschinen	06/2019
Midiplan, Bietigheim-Bissingen	06/2019
GKS Schweinfurt	06/2019
HS Zittau/Görlitz, Wirtschaftswissenschaften und Wirtschaftsingenieurwesen	06/2019
ILK Dresden	06/2019
HZDR Helmholtz Zentrum Dresden-Rossendorf	06/2019
TH Köln, TGA	05/2019
IB Knittel, Braunschweig	05/2019
Norsk Energi, Oslo, Norway	05/2019
STEAG Essen	05/2019
Stora Enso, Eilenburg	05/2019
IB Lücke, Paderborn	05/2019
Haarslev, Sonderso, Denmark	05/2019
MAN Augsburg	05/2019
Wieland Werke, Ulm	04/2019
Fels-Werke, Elbingerode	04/2019
Univ. Luxembourg Luxembourg	04/2019
BTU Cottbus, Power Engineering	03/2009
Eins-Energie Sachsen, Schwarzenberg	03/2019
TU Dresden, Kälte- und Kryotechnik	03/2019
ITER, St. Paul Lez Durance Cedex, France	03/2019
Fraunhofer UMSICHT, Oberhausen	03/2019
Comparex Leipzig for Spedition Thiele HEMMERSBACH	03/2019
Rückert NaturGas, Lauf/Pegnitz	03/2019
BASF, Basel, Switzerland	02/2019
Stadtwerke Leipzig	02/2019

Maerz Ofenbau Zürich, Switzerland	02/2019
Hanon Systems Germany, Kerpen	02/2019
Thermofin, Heinsdorfergrund	01/2019
BSH Berlin	01/2019

2018

Jaguar Energy, Guatemala	12/2018
WEBASTO, Gilching	12/2018
Smurfit Kappa, Oosterhout, Netherlands	12/2018
Univ. BW München	12/2018
RAIV, Liberec for VALEO, Prague, Czech Republic	11/2018
VPC Group Vetschau	11/2018
SEITZ, Wetzikon, Switzerland	11/2018
MVV, Mannheim	10/2018
IB Troche	10/2018
KANIS Turbinen, Nürnberg	10/2018
TH Ingolstadt, Institut für neue Energiesysteme	10/2018
IB Kristl & Seibt, Graz, Austria	09/2018
INEOS, Köln	09/2018
IB Lücke, Paderborn	09/2018
Südzucker, Ochsenfurt	08/2018
K&K Turbinenservice, Bielefeld	07/2018
OTH Regensburg, Elektrotechnik	07/2018
Comparex Leipzig for LEAG, Berlin	06/2018
Münstermann, Telgte	05/2018
TH Nürnberg, Verfahrenstechnik	05/2018
Universität Madrid, Madrid, Spanien	05/2018
HS Zittau/Görlitz, Wirtschaftswissenschaften und Wirtschaftsingenieurwesen	05/2018
HS Niederrhein, Krefeld	05/2018
Wilhelm-Büchner HS, Pfungstadt	03/2018
GRS, Köln	03/2018
WIB, Dennheritz	03/2018
RONAL AG, Härklingen, Schweiz	02/2018
Ingenieurbüro Leipert, Riegelsberg	02/2018
AIXPROCESS, Aachen	02/2018
KRONES, Neutraubling	02/2018
Doosan Lentjes, Ratingen	01/2018

2017

Compact Kältetechnik, Dresden	12/2017
Endress + Hauser Messtechnik GmbH +Co. KG, Hannover	12/2017
TH Mittelhessen, Gießen	11/2017
Haarslev Industries, Søndersø, Denmark	11/2017
Hochschule Zittau/Görlitz, Fachgebiet Energiesystemtechnik	11/2017
ATESTEO, Alsdorf	10/2017
Wijbenga, PC Geldermalsen, Netherlands	10/2017
Fels-Werke GmbH, Elbingerode	10/2017

KIT Karlsruhe, Institute für Neutronenphysik und Reaktortechnik	09/2017
Air-Consult, Jena	09/2017
Papierfabrik Koehler, Oberkirch	09/2017
ZWILAG, Würenlingen, Switzerland	09/2017
TLK-Thermo Universität Braunschweig, Braunschweig	08/2017
Fichtner IT Consulting AG, Stuttgart	07/2017
Hochschule Ansbach, Ansbach	06/2017
RONAL, Härkingen, Switzerland	06/2017
BORSIG Service, Berlin	06/2017
BOGE Kompressoren, Bielefeld	06/2017
STEAG Energy Services, Zwingenberg	06/2017
CES clean energy solutions, Wien, Austria	04/2017
Princeton University, Princeton, USA	04/2017
B2P Bio-to-Power, Wadersloh	04/2017
TU Dresden, Institute for Energy Engineering, Dresden	04/2017
SAINT-GOBAIN, Vaujours, France	03/2017
TU Bergakademie Freiberg, Chair of Thermodynamics, Freiberg	03/2017
SCHMIDT + PARTNER, Therwil, Switzerland	03/2017
KAESER Kompressoren, Gera	03/2017
F&R, Praha, Czech Republic	03/2017
ULT Umwelt-Lufttechnik, Löbau	02/2017
JS Energie & Beratung, Erding	02/2017
Kelvion Brazed PHE, Nobitz-Wilchwitz	02/2017
MTU Aero Engines, München	02/2017
Hochschule Zittau/Görlitz, IPM	01/2017
CombTec ProCE, Zittau	01/2017
SHELL Deutschland Oil, Wesseling	01/2017
MARTEC Education Center, Frederikshaven, Denmark	01/2017
SynErgy Thermal Management, Krefeld	01/2017

2016

BOGE Druckluftsysteme, Bielefeld	12/2016
BFT Planung, Aachen	11/2016
Midiplan, Bietigheim-Bissingen	11/2016
BBE Barnich IB	11/2016
Wenisch IB,	11/2016
INL, Idaho Falls	11/2016
TU Kältetechnik, Dresden	11/2016
Kopf SynGas, Sulz	11/2016
INTVEN, Bellevne (USA)	11/2016
DREWAG Dresden, Dresden	10/2016
AGO AG Energie+Anlagen, Kulmbach	10/2016
Universität Stuttgart, ITW, Stuttgart	09/2016
Pöyry Deutschland GmbH, Dresden	09/2016
Siemens AG, Erlangen	09/2016
BASF über Fichtner IT Consulting AG	09/2016
B+B Engineering GmbH, Magdeburg	09/2016
Wilhelm Büchner Hochschule, Pfungstadt	08/2016

Webasto Thermo & Comfort SE, Gliching	08/2016
TU Dresden, Dresden	08/2016
Endress+Hauser Messtechnik GmbH+Co. KG, Hannover	08/2016
D + B Kältetechnik, Althausen	07/2016
Fichtner IT Consulting AG, Stuttgart	07/2016
AB Electrolux, Krakow, Poland	07/2016
ENEXIO Germany GmbH, Herne	07/2016
VPC GmbH, Vetschau/Spreewald	07/2016
INWAT, Lodz, Poland	07/2016
E.ON SE, Düsseldorf	07/2016
Planungsbüro Waidhas GmbH, Chemnitz	07/2016
EEB Enerko, Aldershoven	07/2016
IHEBA Naturenergie GmbH & Co. KG, Pfaffenhofen	07/2016
SSP Kälteplaner AG, Wolfertschwenden	07/2016
EEB ENERKO Energiewirtschaftliche Beratung GmbH, Berlin	07/2016
BOGE Kompressoren Otto BOGE GmbH & Co KG, Bielefeld	06/2016
Universidad Carlos III de Madrid, Madrid, Spain	04/2016
INWAT, Lodzi, Poland	04/2016
Planungsbüro WAIDHAS GmbH, Chemnitz	04/2016
STEAG Energy Services GmbH, Laszlo Küppers, Zwingenberg	03/2016
WULFF & UMAG Energy Solutions GmbH, Husum	03/2016
FH Bielefeld, Bielefeld	03/2016
EWT Eckert Wassertechnik GmbH, Celle	03/2016
ILK Institut für Luft- und Kältetechnik GmbH, Dresden	02/2016, 06/2016
IEV KEMA - DNV GV – Energie, Dresden	02/2016
Allborg University, Department of Energie, Aalborg, Denmark	02/2016
G.A.M. Heat GmbH, Gräfenhainichen	02/2016
Institut für Luft- und Kältetechnik, Dresden	02/2016, 05/2016, 06/2016
Bosch, Stuttgart	02/2016
INL Idaho National Laboratory, Idaho, USA	11/2016, 01/2016
Friedl ID, Wien, Austria	01/2016
Technical University of Dresden, Dresden	01/2016

2015

EES Enerko, Aachen	12/2015
Ruldolf IB, Strau, Austria	12/2015
Allborg University, Department of Energie, Aalborg, Denmark	12/2015
University of Lyubljana, Slovenia	12/2015
Steinbrecht IB, Berlin	11/2015
Universidad Carlos III de Madrid, Madrid, Spain	11/2015
STEAK, Essen	11/2015
Bosch, Lohmar	10/2015
Team Turbo Machines, Rouen, France	09/2015
BTC – Business Technology Consulting AG, Oldenburg	07/2015
KIT Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen	07/2015
ILK, Dresden	07/2015
Schniewindt GmbH & Co. KG, Neuenwalde	08/2015

2014

PROJEKTPLAN, Dohna	04/2014
Technical University of Vienna, Austria	04/2014
MTU Aero Engines AG, Munich	04/2014
GKS, Schweinfurt	03/2014
Technical University of Nuremberg	03/2014
EP-E, Niederstetten	03/2014
Rückert NatUrgas GmbH, Lauf	03/2014
YESS-World, South Korea	03/2014
ZAB, Dessau	02/2014
KIT-TVT, Karlsruhe	02/2014
Stadtwerke Neuburg	02/2014
COMPAREX, Leipzig for RWE Essen	02/2014
Technical University of Prague, Czech Republic	02/2014
HS Augsburg	02/2014
Envi-con, Nuremberg	01/2014
DLR, Stuttgart	01/2014
Doosan Lentjes, Ratingen	01/2014
Technical University of Berlin	01/2014
Technical University of Munich	01/2014
Technical University of Braunschweig	01/2014
M&M Turbinentechnik, Bielefeld	01/2014

2013

TRANTER-GmbH, Artern	12/2013
SATAKE, Shanghai, China	12/2013
VOITH, Kunshan, China	12/2013
ULT, Löbau	12/2013
MAN, Copenhagen, Dänemark	11/2013
DREWAG, Dresden	11/2013
Haarslev Industries, Herlev, Dänemark	11/2013
STEAG, Herne	11/2013, 12/2013
Ingersoll-Rand, Oberhausen	11/2013
Wilhelm-Büchner HS, Darmstadt	10/2013
IAV, Chemnitz	10/2013
Technical University of Regensburg	10/2013
PD-Energy, Bitterfeld	09/2013
Thermofin, Heinsdorfergrund	09/2013
SHI, New Jersey, USA	09/2013
M&M Turbinentechnik, Bielefeld	08/2013
BEG-BHV, Bremerhaven	08/2013
TIG-Group, Husum	08/2013
COMPAREX, Leipzig for RWE Essen	08/2013, 11/2013 12/2013
University of Budapest, Hungary	08/2013
Siemens, Frankenthal	08/2013, 10/2013

	11/2013
VGB, Essen	07/2013, 11/2013
Brunner Energieberatung, Zurich, Switzerland	07/2013
Technical University of Deggendorf	07/2013
University of Maryland, USA	07/2013, 08/2013
University of Princeton, USA	07/2013
NIST, Boulder, USA	06/2013
IGUS GmbH, Dresden	06/2013
BHR Bilfinger, Essen	06/2013
SÜDSALZ, Bad Friedrichshall	06/2013, 12/2013
Technician School of Berlin	05/2013
KIER, Gajeong-ro, Südkorea	05/2013
Schwing/Stetter GmbH, Memmingen	05/2013
Vattenfall, Berlin	05/2013
AUTARK, Kleinmachnow	05/2013
STEAG, Zwingenberg	05/2013
Hochtief, Düsseldorf	05/2013
University of Stuttgart	04/2013
Technical University -Bundeswehr, Munich	04/2013
Rerum Cognitio Forschungszentrum, Frankfurt	04/2013
Kältetechnik Dresen + Bremen, Alfhausen	04/2013
University Auckland, New Zealand	04/2013
MASDAR Institut, Abu Dhabi, United Arab Emirates	03/2013
Simpelkamp, Dresden	02/2013
VEO, Eisenhüttenstadt	02/2013
ENTEC, Auerbach	02/2013
Caterpillar, Kiel	02/2013
Technical University of Wismar	02/2013
Technical University of Dusseldorf	02/2013
ILK, Dresden	01/2013, 08/2013
Fichtner IT, Stuttgart	01/2013, 11/2013
Schnepf Ingeniuerbüro, Nagold	01/2013
Schütz Engineering, Wadgassen	01/2013
Endress & Hauser, Reinach, Switzerland	01/2013
Oschatz GmbH, Essen	01/2013
frischli Milchwerke, Rehburg-Loccum	01/2013

2012

Voith, Bayreuth	12/2012
Technical University of Munich	12/2012
Dillinger Huette	12/2012
University of Stuttgart	11/2012
Siemens, Muehlheim	11/2012
Sennheiser, Hannover	11/2012
Oschatz GmbH, Essen	10/2012
Fichtner IT, Stuttgart	10/2012, 11/2012
Helbling Technik AG, Zurich, Switzerland	10/2012
University of Duisburg	10/2012

Rerum Cognitio Forschungszentrum, Frankfurt	09/2012
Pöyry Deutschland GmbH, Dresden	08/2012
Extracciones, Guatemala	08/2012
RWE, Essen	08/2012
Weghaus Consulting Engineers, Wuerzburg	08/2012
GKS, Schweinfurt	07/2012
COMPAREX, Leipzig for RWE Essen	07/2012
GEA, Nobitz	07/2012
Meyer Werft, Papenburg	07/2012
STEAG, Herne	07/2012
GRS, Cologne	06/2012
Fichtner IT Consult, Chennai, India	06/2012
Siemens, Freiburg	06/2012
Nikon Research of America, Belmont, USA	06/2012
Niederrhein University of Applied Sciences, Krefeld	06/2012
STEAG, Zwingenberg	06/2012
Mainova, Frankfurt on Main via Fichtner IT Consult	05/2012
Endress & Hauser	05/2012
PEU, Espenheim	05/2012
Luzern University of Applied Sciences, Switzerland	05/2012
BASF, Ludwigshafen (general license) via Fichtner IT Consult	05/2012
SPX Balcke-Dürr, Ratingen	05/2012, 07/2012
Gruber-Schmidt, Wien, Austria	04/2012
Vattenfall, Berlin	04/2012
ALSTOM, Baden	04/2012
SKW, Piesteritz	04/2012
TERA Ingegneria, Trento, Italy	04/2012
Siemens, Erlangen	04/2012, 05/2012
LAWI Power, Dresden	04/2012
Stadtwerke Leipzig	04/2012
SEITZ, Wetzikon, Switzerland	03/2012, 07/2012
M & M, Bielefeld	03/2012
Sennheiser, Wedemark	03/2012
SPG, Montreuil Cedex, France	02/2012
German Destilation, Sprendlingen	02/2012
Lopez, Munguia, Spain	02/2012
Endress & Hauser, Hannover	02/2012
Palo Alto Research Center, USA	02/2012
WIPAK, Walsrode	02/2012
Freudenberg, Weinheim	01/2012
Fichtner, Stuttgart	01/2012
airinotec, Bayreuth	01/2012, 07/2012
University Auckland, New Zealand	01/2012
VPC, Vetschau	01/2012
Franken Guss, Kitzingen	01/2012

2011

XRG-Simulation, Hamburg	12/2011
Smurfit Kappa PPT, AX Roermond, Netherlands	12/2011
AWTEC, Zurich, Switzerland	12/2011
eins-energie, Bad Elster	12/2011
BeNow, Rodenbach	11/2011
Luzern University of Applied Sciences, Switzerland	11/2011
GMVA, Oberhausen	11/2011
CCI, Karlsruhe	10/2011
W.-Büchner University of Applied Sciences, Pfungstadt	10/2011
PLANAIR, La Sagne, Switzerland	10/2011
LAWI, Dresden	10/2011
Lopez, Munguia, Spain	10/2011
University of KwaZulu-Natal, Westville, South Africa	10/2011
Voith, Heidenheim	09/2011
SpgBe Montreal, Canada	09/2011
SPG TECH, Montreuil Cedex, France	09/2011
Voith, Heidenheim-Mergelstetten	09/2011
MTU Aero Engines, Munich	08/2011
MIBRAG, Zeitz	08/2011
RWE, Essen	07/2011
Fels, Elingerode	07/2011
Weihenstephan University of Applied Sciences	07/2011, 09/2011 10/2011
Forschungszentrum Juelich	07/2011
RWTH Aachen University	07/2011, 08/2011
INNEO Solutions, Ellwangen	06/2011
Caliqua, Basel, Switzerland	06/2011
Technical University of Freiberg	06/2011
Fichtner IT Consulting, Stuttgart	05/2011, 06/2011, 08/2011
Salzgitter Flachstahl, Salzgitter	05/2011
Helbling Beratung & Bauplanung, Zurich, Switzerland	05/2011
INEOS, Cologne	04/2011
Enseleit Consulting Engineers, Siebigerode	04/2011
Witt Consulting Engineers, Stade	03/2011
Helbling, Zurich, Switzerland	03/2011
MAN Diesel, Copenhagen, Denmark	03/2011
AGO, Kulmbach	03/2011
University of Duisburg	03/2011, 06/2011
CCP, Marburg	03/2011
BASF, Ludwigshafen	02/2011
ALSTOM Power, Baden, Switzerland	02/2011
Universität der Bundeswehr, Munich	02/2011
Calorifer, Elgg, Switzerland	01/2011
STRABAG, Vienna, Austria	01/2011
TUEV Sued, Munich	01/2011

ILK Dresden	01/2011
Technical University of Dresden	01/2011, 05/2011 06/2011, 08/2011

2010

Umweltinstitut Neumarkt	12/2010
YIT Austria, Vienna, Austria	12/2010
MCI Innsbruck, Austria	12/2010
University of Stuttgart	12/2010
HS Cooler, Wittenburg	12/2010
Visteon, Novi Jicin, Czech Republic	12/2010
CompuWave, Brunntal	12/2010
Stadtwerke Leipzig	12/2010
MCI Innsbruck, Austria	12/2010
EVONIK Energy Services, Zwingenberg	12/2010
Caliqua, Basel, Switzerland	11/2010
Shanghai New Energy Resources Science & Technology, China	11/2010
Energieversorgung Halle	11/2010
Hochschule für Technik Stuttgart, University of Applied Sciences	11/2010
Steinmueller, Berlin	11/2010
Amberg-Weiden University of Applied Sciences	11/2010
AREVA NP, Erlangen	10/2010
MAN Diesel, Augsburg	10/2010
KRONES, Neutraubling	10/2010
Vaillant, Remscheid	10/2010
PC Ware, Leipzig	10/2010
Schubert Consulting Engineers, Weißenberg	10/2010
Fraunhofer Institut UMSICHT, Oberhausen	10/2010
Behringer Consulting Engineers, Tagmersheim	09/2010
Saacke, Bremen	09/2010
WEBASTO, Neubrandenburg	09/2010
Concordia University, Montreal, Canada	09/2010
Compañía Eléctrica de Sochagota, Bogota, Colombia	08/2010
Hannover University of Applied Sciences	08/2010
ERGION, Mannheim	07/2010
Fichtner IT Consulting, Stuttgart	07/2010
TF Design, Matieland, South Africa	07/2010
MCE, Berlin	07/2010, 12/2010
IPM, Zittau/Goerlitz University of Applied Sciences	06/2010
TUEV Sued, Dresden	06/2010
RWE IT, Essen	06/2010
Glen Dimplex, Kulmbach	05/2010, 07/2010 10/2010
Hot Rock, Karlsruhe	05/2010
Darmstadt University of Applied Sciences	05/2010
Voith, Heidenheim	04/2010
CombTec, Zittau	04/2010
University of Glasgow, Great Britain	04/2010

Universitaet der Bundeswehr, Munich	04/2010
Technical University of Hamburg-Harburg	04/2010
Vattenfall Europe, Berlin	04/2010
HUBER Consulting Engineers, Berching	04/2010
VER, Dresden	04/2010
CCP, Marburg	03/2010
Offenburg University of Applied Sciences	03/2010
Technical University of Berlin	03/2010
NIST Boulder CO, USA	03/2010
Technical University of Dresden	02/2010
Siemens Energy, Nuremberg	02/2010
Augsburg University of Applied Sciences	02/2010
ALSTOM Power, Baden, Switzerland	02/2010, 05/2010
MIT Massachusetts Institute of Technology Cambridge MA, USA	02/2010
Wieland Werke, Ulm	01/2010
Siemens Energy, Goerlitz	01/2010, 12/2010
Technical University of Freiberg	01/2010
ILK, Dresden	01/2010, 12/2010
Fischer-Uhrig Consulting Engineers, Berlin	01/2010

2009

ALSTOM Power, Baden, Schweiz	01/2009, 03/2009 05/2009
Nordostschweizerische Kraftwerke AG, Doettingen, Switzerland	02/2009
RWE, Neurath	02/2009
Brandenburg University of Technology, Cottbus	02/2009
Hamburg University of Applied Sciences	02/2009
Kehrein, Moers	03/2009
EPP Software, Marburg	03/2009
Bernd Münstermann, Telgte	03/2009
Suedzucker, Zeitz	03/2009
CPP, Marburg	03/2009
Gelsenkirchen University of Applied Sciences	04/2009
Regensburg University of Applied Sciences	05/2009
Gatley & Associates, Atlanta, USA	05/2009
BOSCH, Stuttgart	06/2009, 07/2009
Dr. Nickolay, Consulting Engineers, Gommersheim	06/2009
Ferrostal Power, Saarlouis	06/2009
BHR Bilfinger, Essen	06/2009
Intraserv, Wiesbaden	06/2009
Lausitz University of Applied Sciences, Senftenberg	06/2009
Nuernberg University of Applied Sciences	06/2009
Technical University of Berlin	06/2009
Fraunhofer Institut UMSICHT, Oberhausen	07/2009
Bischoff, Aurich	07/2009
Fichtner IT Consulting, Stuttgart	07/2009
Techsoft, Linz, Austria	08/2009
DLR, Stuttgart	08/2009

Wienstrom, Vienna, Austria	08/2009
RWTH Aachen University	09/2009
Vattenfall, Hamburg	10/2009
AIC, Chemnitz	10/2009
Midiplan, Bietigheim-Bissingen	11/2009
Institute of Air Handling and Refrigeration ILK, Dresden	11/2009
FZD, Rossendorf	11/2009
Techgroup, Ratingen	11/2009
Robert Sack, Heidelberg	11/2009
EC, Heidelberg	11/2009
MCI, Innsbruck, Austria	12/2009
Saacke, Bremen	12/2009
ENERKO, Aldenhoven	12/2009

2008

Pink, Langenwang	01/2008
Fischer-Uhrig, Berlin	01/2008
University of Karlsruhe	01/2008
MAAG, Kuesnacht, Switzerland	02/2008
M&M Turbine Technology, Bielefeld	02/2008
Lentjes, Ratingen	03/2008
Siemens Power Generation, Goerlitz	04/2008
Evonik, Zwingenberg (general EBSILON program license)	04/2008
WEBASTO, Neubrandenburg	04/2008
CFC Solutions, Munich	04/2008
RWE IT, Essen	04/2008
Rerum Cognitio, Zwickau	04/2008, 05/2008
ARUP, Berlin	05/2008
Research Center, Karlsruhe	07/2008
AWECO, Neukirch	07/2008
Technical University of Dresden, Professorship of Building Services	07/2008
Technical University of Cottbus, Chair in Power Plant Engineering	07/2008, 10/2008
Ingersoll-Rand, Unicov, Czech Republic	08/2008
Technip Benelux BV, Zoetermeer, Netherlands	08/2008
Fennovoima Oy, Helsinki, Finland	08/2008
Fichtner Consulting & IT, Stuttgart	09/2008
PEU, Espenhain	09/2008
Poyry, Dresden	09/2008
WINGAS, Kassel	09/2008
TUEV Sued, Dresden	10/2008
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	10/2008, 11/2008
AWTEC, Zurich, Switzerland	11/2008
Siemens Power Generation, Erlangen	12/2008

2007

Audi, Ingolstadt	02/2007
ANO Abfallbehandlung Nord, Bremen	02/2007
TUEV NORD SysTec, Hamburg	02/2007
VER, Dresden	02/2007
Technical University of Dresden, Chair in Jet Propulsion Systems	02/2007
Redacom, Nidau, Switzerland	02/2007
Universität der Bundeswehr, Munich	02/2007
Maxxtec, Sinsheim	03/2007
University of Rostock, Chair in Technical Thermodynamics	03/2007
AGO, Kulmbach	03/2007
University of Stuttgart, Chair in Aviation Propulsions	03/2007
Siemens Power Generation, Duisburg	03/2007
ENTHAL Haustechnik, Rees	05/2007
AWECO, Neukirch	05/2007
ALSTOM, Rugby, Great Britain	06/2007
SAAS, Possendorf	06/2007
Grenzebach BSH, Bad Hersfeld	06/2007
Reichel Engineering, Haan	06/2007
Technical University of Cottbus, Chair in Power Plant Engineering	06/2007
Voith Paper Air Systems, Bayreuth	06/2007
Egger Holzwerkstoffe, Wismar	06/2007
Tissue Europe Technologie, Mannheim	06/2007
Dometic, Siegen	07/2007
RWTH Aachen University, Institute for Electrophysics	09/2007
National Energy Technology Laboratory, Pittsburg, USA	10/2007
Energieversorgung Halle	10/2007
AL-KO, Jettingen	10/2007
Grenzebach BSH, Bad Hersfeld	10/2007
Wiesbaden University of Applied Sciences, Department of Engineering Sciences	10/2007
Endress+Hauser Messtechnik, Hannover	11/2007
Munich University of Applied Sciences, Department of Mechanical Engineering	11/2007
Rerum Cognitio, Zwickau	12/2007
Siemens Power Generation, Erlangen	11/2007
University of Rostock, Chair in Technical Thermodynamics	11/2007, 12/2007

2006

STORA ENSO Sachsen, Eilenburg	01/2006
Technical University of Munich, Chair in Energy Systems	01/2006
NUTEC Engineering, Bisikon, Switzerland	01/2006, 04/2006
Conwel eco, Bochov, Czech Republic	01/2006
Offenburg University of Applied Sciences	01/2006
KOCH Transporttechnik, Wadgassen	01/2006
BEG Bremerhavener Entsorgungsgesellschaft	02/2006
Deggendorf University of Applied Sciences, Department of Mechanical Engineering and Mechatronics	02/2006
University of Stuttgart,	02/2006

Department of Thermal Fluid Flow Engines	
Technical University of Munich,	02/2006
Chair in Apparatus and Plant Engineering	
Energietechnik Leipzig (company license),	02/2006
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RWE Power, Essen	03/2006
WAETAS, Pobershau	04/2006
Siemens Power Generation, Goerlitz	04/2006
Technical University of Braunschweig,	04/2006
Department of Thermodynamics	
EnviCon & Plant Engineering, Nuremberg	04/2006
Brassel Engineering, Dresden	05/2006
University of Halle-Merseburg,	05/2006
Department of USET Merseburg incorporated society	
Technical University of Dresden,	05/2006
Professorship of Thermic Energy Machines and Plants	
Fichtner Consulting & IT Stuttgart	05/2006
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ThyssenKrupp Marine Systems, Kiel	07/2006
Caliqua, Basel, Switzerland (company license)	09/2006
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Konstanz University of Applied Sciences,	10/2006
Course of Studies Construction and Development	
Siemens Power Generation, Duisburg	10/2006
Hannover University of Applied Sciences,	10/2006
Department of Mechanical Engineering	
Siemens Power Generation, Berlin	11/2006
Zikesch Armaturentechnik, Essen	11/2006
Wismar University of Applied Sciences, Seafaring Department	11/2006
BASF, Schwarzheide	12/2006
Enertech Energie und Technik, Radebeul	12/2006

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J.H.K Plant Engineering and Service, Bremerhaven	01/2005
Electrowatt-EKONO, Zurich, Switzerland	01/2005
FCIT, Stuttgart	01/2005
Energietechnik Leipzig (company license)	02/2005, 04/2005
	07/2005
eta Energieberatung, Pfaffenhofen	02/2005
FZR Forschungszentrum, Rossendorf/Dresden	04/2005
University of Saarbruecken	04/2005
Technical University of Dresden	04/2005
Professorship of Thermic Energy Machines and Plants	
Grenzebach BSH, Bad Hersfeld	04/2005
TUEV Nord, Hamburg	04/2005

Technical University of Dresden, Waste Management	05/2005
Siemens Power Generation, Goerlitz	05/2005
Duesseldorf University of Applied Sciences,	05/2005
Department of Mechanical Engineering and Process Engineering	
Redacom, Nidau, Switzerland	06/2005
Dumas Verfahrenstechnik, Hofheim	06/2005
Alensys Engineering, Erkner	07/2005
Stadtwerke Leipzig	07/2005
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Technical University of Cottbus, Chair in Power Plant Engineering	08/2005
Vattenfall Europe, Berlin (group license)	08/2005
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Basel University of Applied Sciences,	10/2005
Department of Mechanical Engineering, Switzerland	
Midiplan, Bietigheim-Bissingen	11/2005
Technical University of Freiberg, Chair in Hydrogeology	11/2005
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Visteon, Kerpen	03/2004, 10/2004
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Professorship of Thermic Energy Machines and Plants	04/2004
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Grenzebach BSH, Bad Hersfeld	04/2004
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HEW-Kraftwerk, Tiefstack	06/2004
h s energieanlagen, Freising	07/2004
FCIT, Stuttgart	08/2004
Physikalisch Technische Bundesanstalt (PTB), Braunschweig	08/2004
Mainova Frankfurt	08/2004
Rietschle Energieplaner, Winterthur, Switzerland	08/2004
MAN Turbo Machines, Oberhausen	09/2004
TUEV Sued, Dresden	10/2004
STEAG Kraftwerk, Herne	10/2004, 12/2004
University of Weimar	10/2004
energeticals (e-concept), Munich	11/2004
SorTech, Halle	11/2004

Enertech EUT, Radebeul (company license)	11/2004
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Freudenberg Service, Weinheim	12/2004

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Paper Factory, Utzenstorf, Switzerland	01/2003
MAB Plant Engineering, Vienna, Austria	01/2003
Wulff Energy Systems, Husum	01/2003
Technip Benelux BV, Zoetermeer, Netherlands	01/2003
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Rietschle Energieplaner, Winterthur, Switzerland	02/2003
DLR, Leupholdhausen	04/2003
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SOFBID ,Zwingenberg (general EBSILON program license)	05/2003
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ENERKO, Aldenhoven	08/2003
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FZR Forschungszentrum, Rossendorf/Dresden	10/2003
EnviCon & Plant Engineering, Nuremberg	11/2003
Visteon, Kerpen	11/2003
VEO Vulkan Energiewirtschaft Oderbruecke, Eisenhuettenstadt	11/2003
Stadtwerke Hannover	11/2003
SaarEnergie, Saarbruecken	11/2003
Fraunhofer-Gesellschaft, Munich	12/2003
Erfurt University of Applied Sciences, Department of Supply Engineering	12/2003
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Energieversorgung Halle	12/2003

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VEAG, Berlin (group license)	12/2002

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Eco Design, Saitamaken, Japan	01/2001
M&M Turbine Technology, Bielefeld	01/2001, 09/2001
MVV Energie, Mannheim	02/2001
Technical University of Dresden, Department of	02/2001
Power Machinery and Plants	
PREUSSAG NOELL, Wuerzburg	03/2001
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Neusiedler AG, Ulmerfeld, Austria	09/2001
h s energieanlagen, Freising	09/2001
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PREUSSAG NOELL, Wuerzburg	01/2000
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IBR Engineering Reis, Nittendorf-Undorf	02/2000
GK, Hannover	03/2000
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UMAG W. UDE, Husum	03/2000
VEAG, Berlin (group license)	03/2000
Thinius Engineering, Erkrath	04/2000
SaarEnergie, Saarbruecken	05/2000, 08/2000
DVO Data Processing Service, Oberhausen	05/2000
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VAUP Process Automation, Landau	08/2000
Knuerr-Lommatec, Lommatzsch	09/2000
AVACON, Helmstedt	10/2000
Compania Electrica, Bogota, Colombia	10/2000
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Technical University of Graz, Department of Thermal Engineering, Austria	11/1999
Ostendorf Engineering, Gummersbach	12/1999

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Technical University of Cottbus, Chair in Power Plant Engineering	05/1998
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SCA Hygiene Products, Munich	10/1998
RWE Energie, Neurath	10/1998
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