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Property Library for Humid Air

**FluidVIEW
with LibHuAir_Xiw
for LabVIEW™**

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Property Library for Humid Air
Calculated as an Ideal Mixture of Real Fluids
Including DLL and Add-on for LabVIEW™

FluidVIEW
LibHuAir_Xiw

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0. Package Contents

0.1 Zip files for 32-bit LabVIEW™

In order to install FluidVIEW on a computer running a 32-bit version of Windows® the zip file **CD_FluidVIEW_LibHuAir_Xiw.zip** is delivered. The directory structure of the archive is corresponding to the default directory of LabVIEW™. All contained files, their paths and the structure of the archive are shown in the screenshot of the WinRAR file archiver and compression tool illustrated in Figure 0.1.

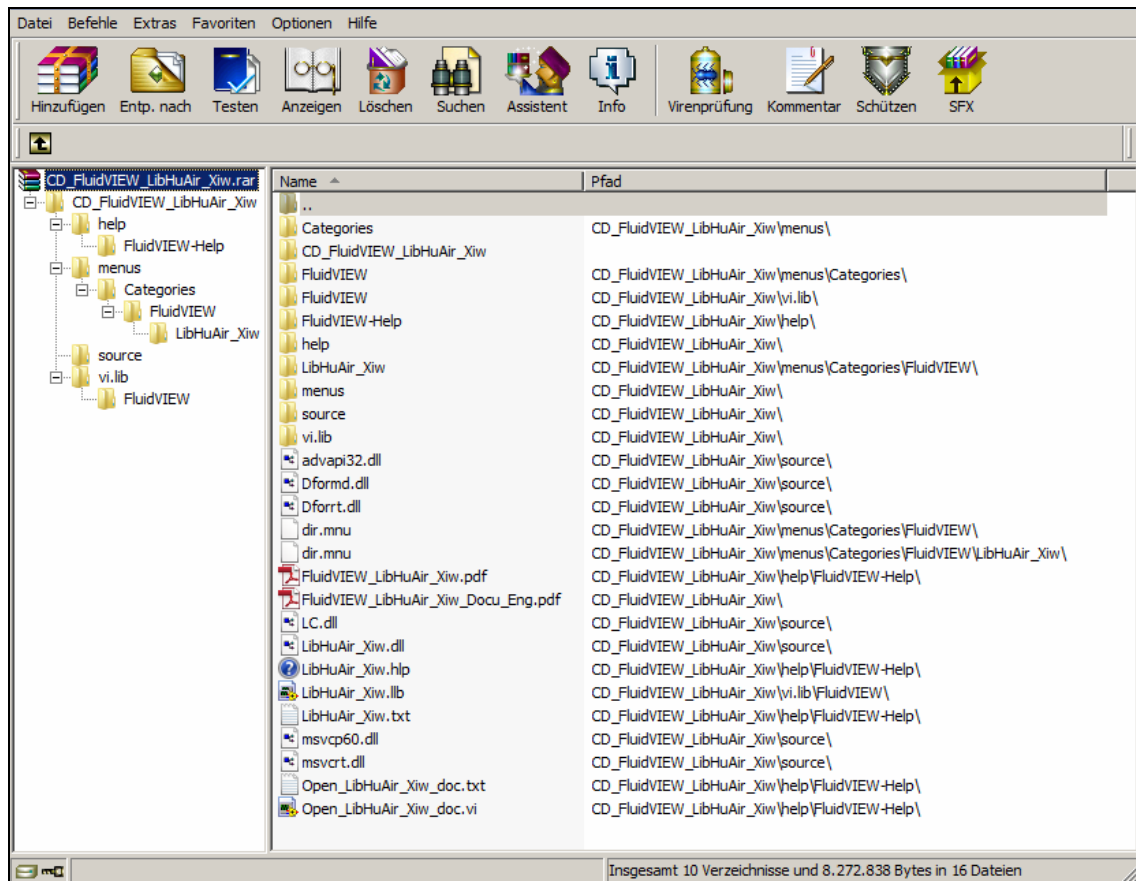


Figure 0.1 Screenshot of WinRAR showing the **CD_FluidVIEW_LibHuAir_Xiw.zip** archive.

The effects of the sixteen files, which are stored in the different directories of the zip archive, are shown in the Tables 0.1, 0.2, 0.3 and 0.4.

Table 0.1 Effects of the files located in the archive directory **CD_FluidVIEW_LibHuAir_Xiw.zip\vi.lib\FluidVIEW\LibHuAir_Xiw**

Filename	Effects
LibHuAir_Xiw.llb	LabVIEW™ library file, containing every function of the LibHuAir_Xiw property library in the form of subprograms (SubVIs)

Table 0.2 Effects of the files located in the archive directory **CD_FluidVIEW_LibHuAir_Xiw.zip\menus\Categories\FluidVIEW**

Filename	Effects
dir.mnu	The palette view of LabVIEW™ is based on the palette files (*.mnu). They include the palette data (e. g. the display name, the palette icon, the palette description, the help information, the synchronize information and the items)

Table 0.3 Effects of the files located in the archive directory **CD_FluidVIEW_LibHuAir_Xiw.zip\source**

Filename	Effects
LibHuAir_Xiw.dll	Dynamic-link library containing the algorithms for the calculation of humid air at low and high pressures, calculated as an ideal mixture of the real fluids dry air and steam, water and/or ice; also for calculating compressed air storage processes with total-mass specific quantities, calculated as an ideal mixture of real fluids.
advapi32.dll	Runtime library
Dformd.dll	Runtime library for the Fortran DLL
Dfortrt.dll	Runtime library for the Fortran DLL
LC.dll	Auxiliary library
msvcp60.dll	Runtime library
msvcrt.dll	Runtime library

Table 0.4 Effects of the files located in the archive directory **CD_FluidVIEW_LibHuAir_Xiw\help\FluidVIEW-help**

Filename	Effects
FluidVIEW_LibHuAir_Xiw.pdf	User's guide of the property library LibHuAir_Xiw for the LabVIEW™ Add-On FluidVIEW
LibHuAir_Xiw.hlp	Help file with descriptions for each function
OpenLibHuAir_Xiw_doc.vi	LabVIEW™ instrument to open the user's guide via the help menu
LibHuAir_Xiw.txt	Text file to change the name of the menu item of the help file
OpenLibHuAir_Xiw_doc.txt	Text file to change the name of the menu item of the file OpenLibHuAir_Xiw_doc.vi

0.2 Zip files for 64-bit LabVIEW™

In order to install FluidVIEW on a computer running a 64-bit version of Windows® the zip file **CD_FluidVIEW_LibHuAir_Xiw_x64.zip** is delivered. The directory structure of the archive is corresponding to the default directory of LabVIEW™. All contained files, their paths and the structure of the archive are shown in the screenshot of the WinRAR file archiver and compression tool illustrated in Figure 0.2.

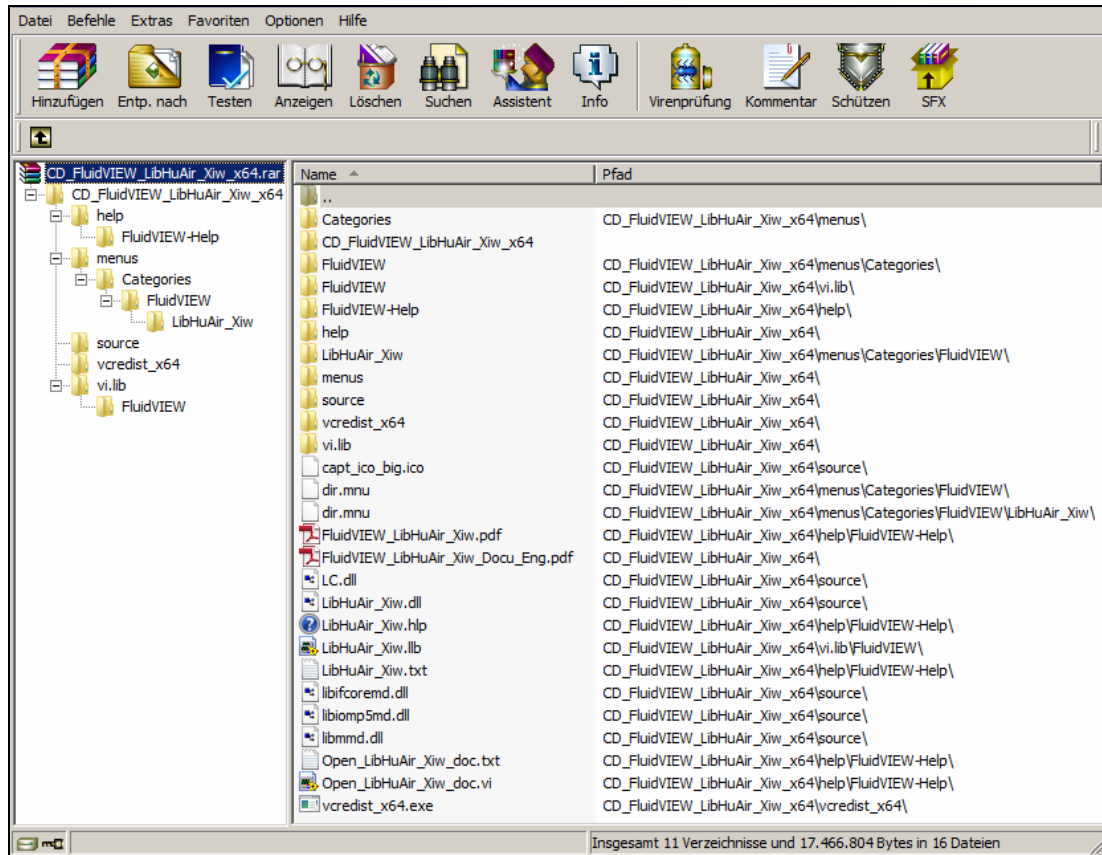


Figure 0.2 Screenshot of WinRAR showing the **CD_FluidVIEW_LibHuAir_Xiw_x64.zip** archive.

The effects of the sixteen files, which are stored in the different directories of the zip archive, are shown in the Tables 0.5, 0.6, 0.7 and 0.8.

Table 0.5 Effects of the files located in the archive directory **CD_FluidVIEW_LibHuAir_Xiw_x64\vi.lib \FluidVIEW\LibHuAir_Xiw**

Filename	Effects
LibHuAir_Xiw.llb	LabVIEW™ library file, containing every function of the LibHuAir_Xiw property library in the form of subprograms (SubVIs)

Table 0.6 Effects of the files located in the archive directory **CD_FluidVIEW_LibHuAir_Xiw_x64\menus \Categories\FluidVIEW**

Filename	Effects
dir.mnu	The palette view of LabVIEW™ is based on the palette files (*.mnu). They include the palette data (e. g. the display name, the palette icon, the palette description, the help information, the synchronize information and the items)

Table 0.7 Effects of the files located in the archive directory **CD_FluidVIEW_LibHuAir_Xiw_x64\source**

Filename	Effects
LibHuAir_Xiw.dll	Dynamic-link library containing the algorithms for the calculation of humid air at low and high pressures, calculated as an ideal mixture of the real fluids dry air and steam, water and/or ice; also for calculating compressed air storage processes with total-mass specific quantities, calculated as an ideal mixture of real fluids.
Capt_ico_big.ico	Icon file
Libmmd.dll	Runtime library
Libifcoremd.dll	Runtime library
LC.dll	Auxiliary library
Libiomp5md.dll	Runtime library

Table 0.8 Effects of the files located in the archive directory **CD_FluidVIEW_LibHuAir_Xiw_x64\help\FluidVIEW-help**

Filename	Effects
FluidVIEW_LibHuAir_Xiw.pdf	User's guide of the LibHuAir_Xiw property library for the LabVIEW™ Add-On FluidVIEW
LibHuAir_Xiw.hlp	Help file with descriptions for each function
OpenLibHuAir_Xiw_doc.vi	LabVIEW™ instrument to open the user's guide via the help menu
LibHuAir_Xiw.txt	Text file to change the name of the menu item of the help file
OpenLibHuAir_Xiw_doc.txt	Text file to change the name of the menu item of the file OpenLibHuAir_Xiw_doc.vi

Table 0.9 Effects of the files located in the archive directory **CD_FluidVIEW_LibHuAir_Xiw_x64\vc redistrib_x64**

Filename	Effects
vc redistrib_x64.exe	Executable file to install the Microsoft Visual C++ 2008 Redistributable Package (x64). Within runtime components of Visual C++ Libraries required to run 64-bit applications developed with Visual C++ on a computer that does not have Visual C++ 2010 installed.

1. Property Functions

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

Functional Dependence	Function Name	Call from Fortran Program	Property or Function	Unit	Source or Algorithm	Information on page
$\lambda = f(p, t, \xi_w)$	Lambda_ptXiw_HuAir	= Lambda_ptXiw_HuAir(p,t,Xiw,succ)	Thermal conductivity	W/(m · K)	[6], [12], [15]	3/14
$\nu = f(p, t, \xi_w)$	Ny_ptXiw_HuAir	= Ny_ptXiw_HuAir(p,t,Xiw,succ)	Kinematic viscosity	m ² /s	[1-4], [7], [12], [14], [15]	3/15
$p = f(h, s, \xi_w)$	p_hsXiw_HuAir	= p_hsXiw_HuAir(h,s,Xiw,succ)	Backward function: Pressure from enthalpy and entropy	bar	[1-4], [13], [14], [18], [19]	3/16
$p = f(t, s, \xi_w)$	p_tsXiw_HuAir	= p_tsXiw_HuAir(t,s,Xiw,succ)	Backward function: Pressure from temperature and entropy	bar	[1-4], [13], [14], [18], [19]	3/17
$p_d = f(p, t, \xi_w)$	pd_ptXiw_HuAir	= pd_ptXiw_HuAir(p,t,Xiw,succ)	Partial pressure of steam	bar	[1-4], [16], [17], [25], [26]	3/18
$p_{dsatt} = f(p, t)$	pdsatt_pt_HuAir	= pdsatt_pt_HuAir(p,t,succ)	Saturation vapor pressure of water	bar	[1-4], [16], [17], [25], [26]	3/19
$\varphi = f(p, t, \xi_w)$	Phi_ptXiw_HuAir	= Phi_ptXiw_HuAir(p,t,Xiw,succ)	Relative humidity	-	[1-4], [16], [17], [25], [26]	3/20
$p_l = f(p, t, \xi_w)$	pl_ptXiw_HuAir	= pl_ptXiw_HuAir(p,t,Xiw,succ)	Partial pressure of air	bar	[1-4], [16], [17], [25], [26]	3/21
$Pr = f(p, t, \xi_w)$	Pr_ptXiw_HuAir	= Pr_ptXiw_HuAir(p,t,Xiw,succ)	PRANDTL-Number	-	[1-4], [6], [7], [12-15]	3/22
$\psi_l = f(\xi_w)$	Psil_Xiw_HuAir	= Psil_Xiw_HuAir(Xiw,succ)	Mole fraction of air	kmol/kmol		3/23
$\psi_w = f(\xi_w)$	Psiw_Xiw_HuAir	= Psiw_Xiw_HuAir(Xiw,succ)	Mole fraction of water	kmol/kmol		3/24
$Region = f(h, s, \xi_w)$	Region_hsXiw_HuAir	= Region_hsXiw_HuAir(p,h,Xiw)	Region of state from enthalpy and entropy	-	[1-4], [14], [18], [19]	3/25
$Region = f(p, h, \xi_w)$	Region_phXiw_HuAir	= Region_phXiw_HuAir(p,h,Xiw)	Region of state from pressure and enthalpy	-	[1-4], [14], [18], [19]	3/26
$Region = f(p, s, \xi_w)$	Region_psXiw_HuAir	= Region_psXiw_HuAir(p,s,Xiw)	Region of state from pressure and entropy	-	[1-4], [14], [18], [19]	3/27
$Region = f(p, T, \xi_w)$	Region_ptXiw_HuAir	= Region_ptXiw_HuAir(p,t,Xiw)	Region of state from pressure and temperature	-	[1-4], [14], [18], [19]	3/28

Functional Dependence	Function Name	Call from Fortran Program	Property or Function	Unit	Source or Algorithm	Information on page
$Region = f(t, s, \xi_w)$	Region_tsXiw_HuAir	= Region_tsXiw_HuAir(t,s,Xiw)	Region of state from temperature and entropy	-	[1-4], [14], [18], [19]	3/29
$\rho = f(p, t, \xi_w)$	Rho_ptXiw_HuAir	= Rho_ptXiw_HuAir(p,t,Xiw,succ)	Density	kg/m ³	[1-4], [14], [18], [19]	3/30
$s = f(p, h, \xi_w)$	s_phXiw_HuAir	= s_phXiw_HuAir(p,h,Xiw,succ)	Backward function: Entropy from pressure and enthalpy	kJ/(kg·K)	[1-4], [13], [14], [18], [19]	3/31
$s = f(p, t, \xi_w)$	s_ptXiw_HuAir	= s_ptXiw_HuAir(p,t,Xiw,succ)	Specific entropy	kJ/(kg·K)	[1-4], [13], [14], [18], [19]	3/32
$\sigma = f(t)$	Sigma_t_HuAir	= Sigma_t_HuAir (t,succ)	Surface tension of water	N/m	[8]	3/33
$t = f(h, s, \xi_w)$	t_hsXiw_HuAir	= t_hsXiw_HuAir(h,s,Xiw,succ)	Backward function: Temperature from enthalpy and entropy	°C	[1-4], [13], [14], [18], [19]	3/34
$t = f(p, h, \xi_w)$	t_phXiw_HuAir	= t_phXiw_HuAir(p,h,Xiw,succ)	Backward function: Temperature from pressure and enthalpy	°C	[1-4], [13], [14], [18], [19]	3/35
$t = f(p, s, \xi_w)$	t_psXiw_HuAir	= t_psXiw_HuAir(p,s,Xiw,succ)	Backward function: Temperature from pressure and entropy	°C	[1-4], [13], [14], [18], [19]	3/36
$t_f = f(p, t, \xi_w)$	tf_ptXiw_HuAir	= tf_ptXiw_HuAir(p,t,Xiw,succ)	Wet bulb temperature	°C	[1-4], [13], [22]	3/37
$t_\tau = f(p, \xi_w)$	tTau_pXiw_HuAir	= tTau_pXiw_HuAir(p,Xiw,succ)	Dew point temperature	°C	[1-4], [16], [17]	3/38
$u = f(p, t, \xi_w)$	u_ptXiw_HuAir	= u_ptXiw_HuAir(p,t,Xiw,succ)	Internal energy	kJ/kg	[1-4], [13], [14], [18], [19]	3/39
$v = f(h, s, \xi_w)$	v_hsXiw_HuAir	= v_hsXiw_HuAir(h,s,Xiw,succ)	Backward function: Specific volume from enthalpy and entropy	m ³ /kg	[1-4], [13], [14], [18], [19]	3/40
$v = f(p, h, \xi_w)$	v_phXiw_HuAir	= v_phXiw_HuAir(p,h,Xiw,succ)	Backward function: Specific volume from pressure and enthalpy	m 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
$v = f(p, s, \xi_w)$	v_psXiw_HuAir	= v_psXiw_HuAir(p,s,Xiw,succ)	Backward function: Specific volume from pressure and entropy	m ³ /kg	[1-4], [13], [14], [18], [19]	3/42
$v = f(p, t, \xi_w)$	v_ptXiw_HuAir	= v_ptXiw_HuAir(p,t,Xiw,succ)	Specific volume	m ³ /kg	[1-4], [14], [18], [19]	3/43
$v = f(t, s, \xi_w)$	v_tsXiw_HuAir	= v_tsXiw_HuAir(t,s,Xiw,succ)	Backward function: Specific volume from temperature and entropy	m ³ /kg	[1-4], [13], [14], [18], [19]	3/44
$w = f(p, t, \xi_w)$	w_ptXiw_HuAir	= w_ptXiw_HuAir(p,t,Xiw,succ)	Isentropic speed of sound	m/s	[1-4], [13], [14]	3/45
$x_w = f(\xi_w)$	xw_Xiw_HuAir	= xw_Xiw_HuAir(Xiw,succ)	Humidity ratio (absolute humidity) from mass fraction of water	kg/kg _{Air}		3/46
$\xi_w = f(p, t, \phi)$	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]	3/47
$\xi_w = f(p, t, p_d)$	Xiw_ptpd_HuAir	= Xiw_ptpd_HuAir(p,t,pd,succ)	Mass fraction of water from partial pressure of steam	kg/kg	[1-4], [16], [17], [25], [26]	3/48
$\xi_w = f(p, t_\tau)$	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]	3/49
$\xi_w = f(p, t, t_f)$	Xiw_pttf_HuAir	= Xiw_pttf_HuAir(p,t,tf,succ)	Mass fraction of steam from temperature and wet bulb temperature	kg/kg	[1-4], [13], [14]	3/50
$\xi_{wf} = f(p, t, \xi_w)$	Xiwf_ptXiw_HuAir	= Xiwf_ptXiw_HuAir (p,t,Xiw,succ)	Mass fraction of liquid water	kg/kg	[1-4], [16], [17], [25], [26]	3/51
$\xi_{wsatt} = f(p, t)$	Xiwsatt_pt_HuAir	= Xiwsatt_pt_HuAir(p,t,succ)	Mass fraction steam of saturated air	kg/kg	[1-4], [16], [17], [25], [26]	3/52

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

Range of validity

- Temperature $t = -30\text{ °C} \dots 1726.85\text{ °C}$
- Pressure $p = 0.01\text{ bar} \dots 1000\text{ bar}$

Calculation algorithms

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

Ideal mixture of dry air and steam

Dry air:

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

Steam:

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

Supersaturated humid air (liquid fog or ice fog)

Liquid fog ($X_{iw} > X_{iwsatt}$) and $t \geq 0\text{ °C}$

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 ($X_{iw} > X_{iwsatt}$) and $t < 0\text{ °C}$

Ideal mixture of saturated humid air and water ice

- saturated humid air as specified above
- v, h, s of ice crystals from IAPWS-06 [18], [19]
- λ of ice crystals as non varying value
- η, κ, w of saturated humid air

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

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

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

2 Application of FluidVIEW in LabVIEW™

The FluidVIEW Add-on has been developed to calculate thermodynamic properties in LabVIEW™ (version 10.0 or higher) more conveniently. Within LabVIEW™, it enables the direct call of functions relating to humid air as an ideal mixture of the real fluids dry air and steam, water and/or ice from the LibHuAir_Xiw property library.

2.1 Installing FluidVIEW

If a FluidVIEW property library has not yet been installed, please complete the initial installation procedure described below.

If a FluidVIEW property library has already been installed, you only need to copy several files which belong to the LibHuAir_Xiw library. In this case, follow the subsection "Adding the LibHuAir_Xiw Library" on page 2/3.

In both cases folders and files from the zip archive

CD_FluidVIEW_LibHuAir_Xiw.zip	(for 32-bit version of LabVIEW™)
CD_FluidVIEW_LibHuAir_Xiw_x64.zip	(for 64-bit version of LabVIEW™)

have to be copied into the default directory of the LabVIEW™ development environment. In the following text these zipped directories for the 32-bit or 64-bit operating system will be symbolised with the term **<CD>**.

You can see the current default directory of LabVIEW™ in the paths page (options dialog box). To display this page please select *Tools* and click on *Options* to open the options dialog box and then select *Paths* from the category list.

By choosing *Default Directory* from the drop-down list the absolute pathname to the default directory, where LabVIEW™ automatically stores information, is displayed. In the following sections the pathname of the default directory will be symbolised by the term **<LV>**.

Additional Requirement When Using the 64-bit Operating System

If you want to use FluidVIEW on a 64-bit computer that does not have Visual C++ installed, please make sure the Microsoft Visual C++ 2010 x64 Redistributable Package is installed.

If it is not the case, please install it by double clicking the file

vcredist_x64.exe

which you find in the folder **lvcredist_x64** in the **64-bit** CD folder

"CD_FluidVIEW_LibHuAir_Xiw_x64."

In the following window you are required to accept the Microsoft® license terms to install the Microsoft Visual C++ 2010 runtime libraries by ticking the box next to "I have read and accept the license terms" (see Figure 2.1).

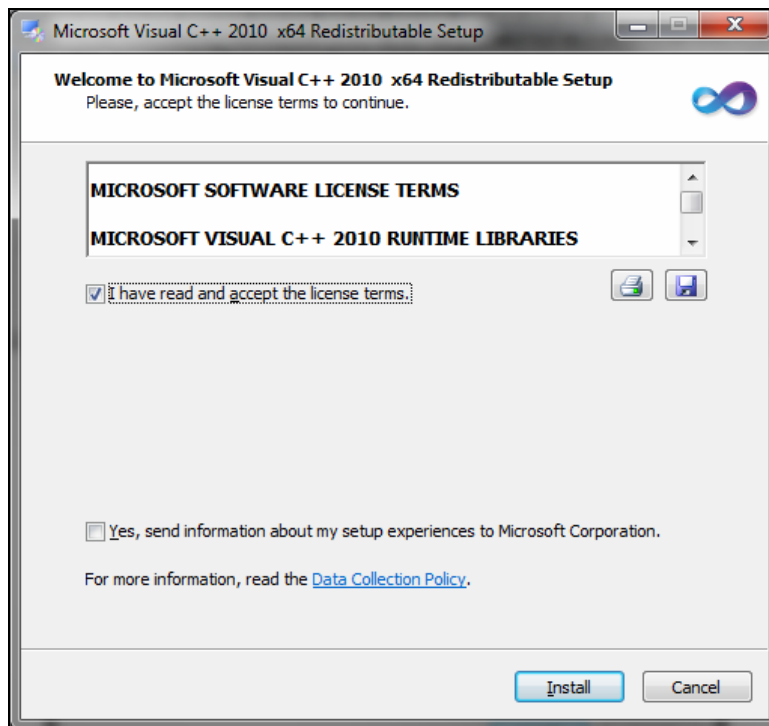


Figure 2.1 Accepting the license terms to install the Microsoft Visual C++ 2010 x64 Redistributable Package

Now click on "Install" to continue installation.

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

Now you can use the FluidVIEW Add-On on your 64-bit operating system. Please follow the instructions below to install FluidVIEW.

Initial Installation of FluidVIEW

The initial installation of FluidVIEW is carried out by copying three directories with its contents from the zip archive to the standard directory of LabVIEW™. The directories that have to be copied, their paths in the zip archive and their target paths are listed in Table 2.1. The installation is complete after copying the files and restarting LabVIEW™.

Due to the fact, that the functions of the DLL are called with a variable pathname, the source files you will find in the directory **<CD>\source** can be stored in a random directory on the hard disk. The pathname of LibHuAir_Xiw.dll, which is located in this directory, has to be indicated in order to calculate the property functions (see example calculation in section 2.4 on page 2/10).

All source files have to be stored in the same directory to make the property functions of the LibHuAir_Xiw library work. These files are for the

- **32-bit system:**

LibHuAir_Xiw.dll, advapi32.dll, Dformd.dll, Dforrt.dll, LC.dll, msvcp60.dll, and msvcrt.dll

and for the

- **64-bit system:**

LibHuAir_Xiw.dll, capt_ico_big.ico, LC.dll, libifcoremd.dll, libiomp5md.dll, and libmmd.dll.

Table 2.1 Directories which have to be copied from the zip archive in the default directory of LabVIEW™ (<LV>) for the initial installation of FluidVIEW

Name of the directory	Parent directory in the zip archive	Target path in the default directory of LabVIEW (<LV>)
FluidVIEW	<CD>\vi.lib	<LV>\vi.lib
FluidVIEW	<CD>\menus\Categories	<LV>\menus\Categories
FluidVIEW-Help	<CD>\help	<LV>\help

Adding the LibHuAir_Xiw Library

In order to add the LibHuAir_Xiw property library to an existing FluidVIEW installation, one folder with its contents and five files have to be copied from the zip archive to the standard directory of LabVIEW™. This directory, the files plus their pathnames in the zip archive and their target paths are listed in Table 2.2. The installation is complete after copying the files and restarting LabVIEW™.

Due to the fact, that the functions of the DLL are called with a variable pathname, the source files you will find in the directory **<CD>\source** can be stored in a random directory on the hard disk. The pathname of LibHuAir_Xiw.dll, which is located in this directory, has to be indicated in order to calculate the property functions (see example calculation in section 2.4 on page 2/10).

All source files have to be stored in the same directory to make the property functions of the LibHuAir_Xiw library work. These files are for the

- **32-bit system:**

LibHuAir_Xiw.dll, advapi32.dll, Dformd.dll, Dforrt.dll, LC.dll, msvc60.dll, and msvcrt.dll

and for the

- **64-bit system:**

LibHuAir_Xiw.dll, capt_ico_big.ico, LC.dll, libifcoremd.dll, libiomp5md.dll, and libmmd.dll

Table 2.2 Data which have to be copied from the zip archive in the default directory of LabVIEW™ (<LV>) for adding the LibHuAir_Xiw property library to an existing installation of FluidVIEW

File name with file extension or name of the directory	Parent directory in the zip archive	Target path in the default directory of LabVIEW (<LV>)
LibHuAir_Xiw.llb	<CD>\vi.lib\FluidVIEW	<LV>\vi.lib\FluidVIEW
LibHuAir_Xiw	<CD>\menus\Categories \FluidVIEW	<LV>\menus\Categories \FluidVIEW
LibHuAir_Xiw.hlp	<CD>\help\FluidVIEW-Help	<LV>\help\FluidVIEW-Help
LibHuAir_Xiw.txt	<CD>\help\FluidVIEW-Help	<LV>\help\FluidVIEW-Help
FluidVIEW_LibHuAir_Xiw.pdf	<CD>\help\FluidVIEW-Help	<LV>\help\FluidVIEW-Help
Open_LibHuAir_Xiw_doc.vi	<CD>\help\FluidVIEW-Help	<LV>\help\FluidVIEW-Help
Open_LibHuAir_Xiw_doc.txt	<CD>\help\FluidVIEW-Help	<LV>\help\FluidVIEW-Help

After you have restarted LabVIEW™ you will find the functions of the LibHuAir_Xiw property library in the functions palette under the sub palette FluidVIEW. An example calculation of the air specific enthalpy h_l is shown in section 2.4.

2.2 The FluidVIEW Help System

FluidVIEW provides detailed online help functions. If you are running Windows Vista or Windows 7, please note the paragraph "Using the FluidVIEW Online-Help in Windows Vista or Windows 7."

General Information

The FluidVIEW Help System consists of the Microsoft WinHelp file **LibHuAir_Xiw.hlp** and this user's guide as PDF document **FluidView_LibHuAir_Xiw.pdf**. Both files can be opened via the help menu. To do this please click *Help* in the menu bar. In the submenu *FluidVIEW-Help* you will find the commands *LibHuAir_Xiw Help File* and *LibHuAir_Xiw User's Guide* to open an appropriate file.

Context-Sensitive Help

If you have activated the context help function in LabVIEW™ (Ctrl-H) and move the cursor over a FluidVIEW object basic information is displayed in the context help window. The in- and output parameters plus a short information text are displayed for a property function. By clicking the **Detailed help** button in the **Context help** window the online help will be opened. The context help window of the function `v_phXiw_HuAir.vi` is shown in Figure 2.2.

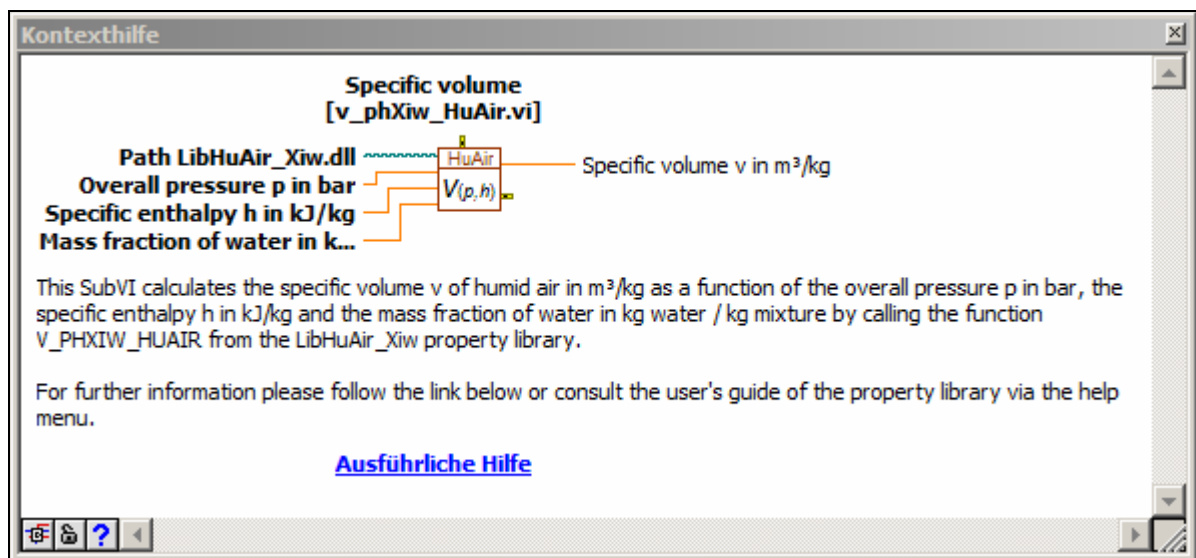


Figure 2.2 Context help window of the function `vl_phXiw_HuAir.vi`

Using the FluidVIEW Online-Help in Windows Vista or Windows 7

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

The procedure is analogous for Windows® Vista.

Open Microsoft Internet Explorer® and go to <http://support.microsoft.com/kb/917607>. Scroll down until you see the headline "Resolution". Under the first point you will find the links to

download the Windows Help program. Click on the link "Windows Help program (WinHlp32.exe) for Windows 7" (see Figure 2.3)

 RESOLUTION

To resolve this issue, obtain the Windows Help program (WinHlp32.exe) for the versions of Windows that support it. To obtain the correct version for your operating system, you must know whether you have a Windows 32-bit or Windows 64-bit system. If you are not sure which version of Windows you are running, follow the steps under "If you are not sure which Windows version is installed."

Note To determine which version of Windows you are running, you must be logged on as an administrator. To verify that you are logged on as an administrator, follow the steps under "To verify that you are logged on as an administrator."

[↑ Back to the top](#)

If you are not sure which Windows version is installed

If you are not sure which version of Windows is installed on your computer, follow the steps in the following wizard.

[Click here to view or hide step-by-step instructions with pictures](#)

[↑ Back to the top](#)

To verify that you are logged on as an administrator

To verify that you are logged on as an administrator, follow the steps in the following wizard.

[Click here to view or hide step-by-step instructions with pictures](#) **How to obtain the correct version of the Windows Help program (WinHlp32.exe)**

- Click one of the following "Windows Help program" links, depending on the operating system that you are running:
 -  [Windows Help program \(WinHlp32.exe\) for Windows Vista](#)
 -  [Windows Help program \(WinHlp32.exe\) for Windows 7](#)
 -  [Windows Help program \(WinHlp32.exe\) for Windows Server 2008](#)
 -  [Windows Help program \(WinHlp32.exe\) for Windows Server 2008 R2](#)

Note The Windows Help program is not supported for Windows 8 Server Beta, and no download will be provided for this Windows version. The Windows Help program is supported for the x64 and x86 editions of the Windows 8 client, and a download package for these editions will be made available in this article at a later date.

- Click **Continue** to run Genuine Windows Validation. For more information about how to install Genuine Windows Validation Component, visit the following Microsoft website:
<http://www.microsoft.com/download/en/genuine-validation.aspx?id=5143>
- Download and install **Windows6.*-KB917607-x64.msu** or **Windows6.*-KB917607-x86.msu**, depending on the edition of the operating system that you are running.

Figure 2.3 Selecting your Windows® Version

You will be forwarded to the Microsoft Download Center where you can download the Microsoft Windows Help program. First, a validation of your Windows License is required. To do this click on the "Continue" button (see Figure 2.4).

Validation Required

For more information about the validation process, [click here](#).

Quick details

Version:	1.0	Date published:	10/14/2009
Change language:	English		

KB articles:	KB917607
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Files in this download

The links in this section correspond to files available for this download. Download the files appropriate for you.

File name	Size
Windows6.1-KB917607-x64.msu	702 KB
Windows6.1-KB917607-x86.msu	688 KB

CONTINUE

Figure 2.4 Microsoft® Download Center

Afterwards a web page with instructions on how to install the Genuine Windows Validation Component opens. At the top of your Windows Internet Explorer you will see a yellow information bar. It reads

"This website wants to install the following add-on: 'Windows Genuine Advantage' from 'Microsoft Corporation'. If you trust this website and the add-on and want to install it, click here."

Right-click this bar and select "Install ActiveX Control" in the context menu. A dialog window appears in which you are asked if you want to install the software. Click the "Install" button to continue. After the validation has been carried out you will be able to download the appropriate version of Windows Help program (see Figure 2.5).

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

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

Windows6.1-KB917607-x64.msu.

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

Windows6.1-KB917607-x86.msu.

Genuine Microsoft Software

Please click **Download** to download the software.

Quick details

Version: 1.0

Date published: 10/14/2009

Change language:

English

KB articles: [KB917607](#)

Files in this download

The links in this section correspond to files available for this download. Download the files appropriate for you.

File name	Size	
Windows6.1-KB917607-x64.msu	702 KB	DOWNLOAD
Windows6.1-KB917607-x86.msu	688 KB	DOWNLOAD

Figure 2.5 Downloading the Windows Help Program

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

Installation starts with a window searching for updates on your computer.

After the program has finished searching you may be asked, if you want to install the "Update for Windows (KB917607)."

(If you have already installed this update, you will see the message "Update for Windows (KB917607) is already installed on this computer.")

The installation can be continued by clicking the "Yes" button.

In the next window you have to accept the Microsoft license terms before installing the update by clicking on "I Accept".

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

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

2.3 Licensing the LibHuAir_Xiw Property Library

The licensing procedure has to be carried out when calculating a LibHuAir_Xiw function and a FluidVIEW prompt message appears. In this case, you will see the "License Information" window (see figure below).

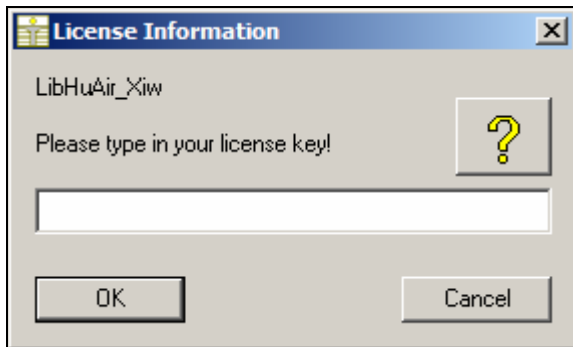


Figure 2.6 "License Information" window

Here you will have to type in the license key which you have obtained from the Zittau/Goerlitz University of Applied Sciences. You can find contact information on the "Content" page of this User's Guide or by clicking the yellow question mark in the "License Information" window. Then the following window will appear:

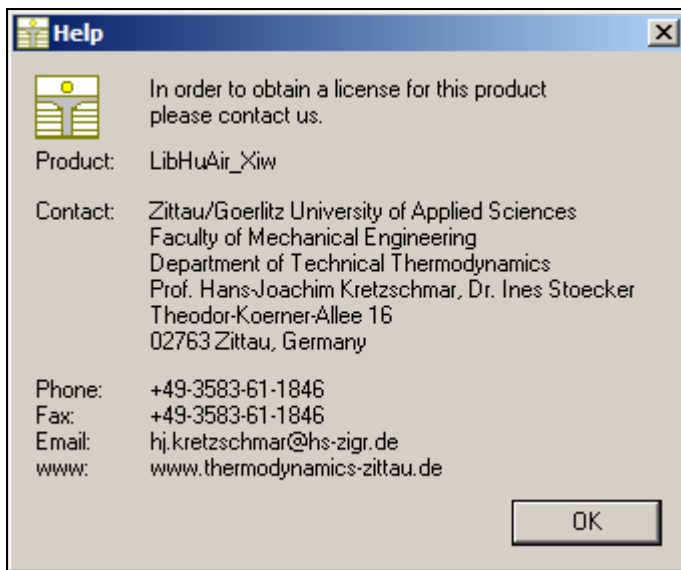


Figure 2.7 "Help" window

If you do not enter a valid license it is still possible to run your VI by clicking "Cancel". In this case, the LibHuAir_Xiw property library will display the result "-1.11111E+7" for every calculation.

The "License Information" window will appear every time you reopen your Virtual Instrument (VI) or reload the path of the LibHuAir_Xiw.dll. Should you not wish to license the LibHuAir_Xiw property library, you have to uninstall FluidVIEW according to the description in section 2.5 of this User's Guide.

2.4 Example: Calculation of $h = f(p, t, \xi_w)$

After the delivered files have been copied in the appropriate folders of the default directory LabVIEW™ (described in section 2.1), the LibHuAir_Xiw property library is ready to use. The function nodes of the LibHuAir_Xiw property library can be used by dragging them from the functions palette into the block diagram and connecting them with the wires representing the required input parameters.

Now we will calculate, step by step, the specific enthalpy h as a function of overall pressure p , temperature t , and mass fraction of water ξ_w , using FluidVIEW.

- Start LabVIEW™ and wait for the *Getting Started* window to be displayed. Then select *Blank VI*. The *Blank VI* will be displayed in two windows, the front panel and the block diagram.
- Open the functions palette in the block diagram **via view / Functions Palette** (or by clicking the right mouse button anywhere in the free area of the block diagram) if not yet displayed.
- In addition to the default LabVIEW™ palettes the functions palette contains the sub palette *FluidVIEW* (see Figure 2.8) with the sub palette *LibHuAir_Xiw* (see Figure 2.9).

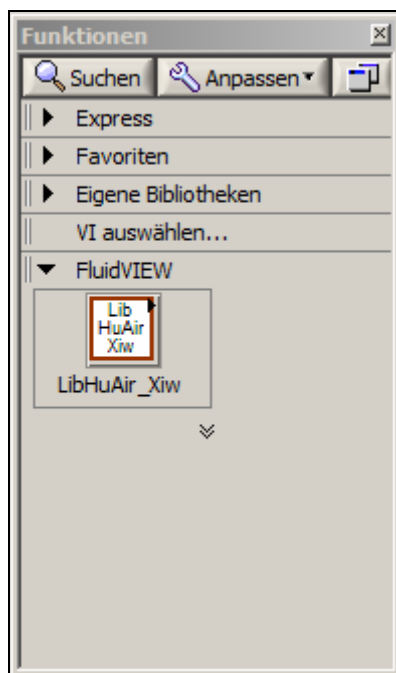


Figure 2.8

Functions palette with the sub palettes FluidVIEW and LibHuAir_Xiw

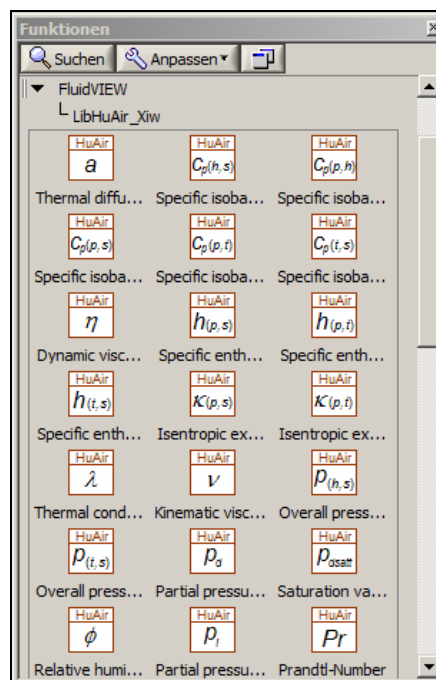


Figure 2.9

Functions palette with the property functions of the LibHuAir_Xiw library

In order to calculate the specific enthalpy h , drag the function (SubVI) whose symbol shows the $h(p, t)$ from the functions palette into the block diagram.

While the short names of the SubVIs behind the symbols will be shown in the control tip, the full names and brief descriptions of the property functions are displayed in the *Context Help* window (see Figure 2.2). To use the context help press <Ctrl>+<H> on your keyboard.

- After placing the node of the SubVI **h_ptXiw_HuAir.vi** on your block diagram the required input parameters have to be defined.

The input parameters which are set as required appear in bold type in the Context Help window. In this case these input parameters are **Path LibHuAir_Xiw.dll** (LabVIEW™ data type: Path), **Overall pressure p in bar** (LabVIEW™ data type: Double precision, floating-point), **Temperature t in °C** (LabVIEW™ data type: Double precision, floating-point) and **Mass fraction of water ξ_w in kg water / kg mixture** (LabVIEW™ data type: Double precision, floating-point).

- To define these variables wire their input terminals with input elements on the front panel. You can accomplish this in one step by choosing **Create / Control** in the context menu of all required input terminals. In order to wire the output terminal of the function node with an output element on the front panel, choose **Create / Indicator** in the context menu of the output terminal **Specific enthalpy h in kJ/kg** (LabVIEW™ data type: Double precision, floating-point). After cleaning up the block diagram by pressing <Ctrl>+<U> it has the appearance illustrated in Figure 2.10. The same input and output elements are available on the appropriate front panel (see Figure 2.11).

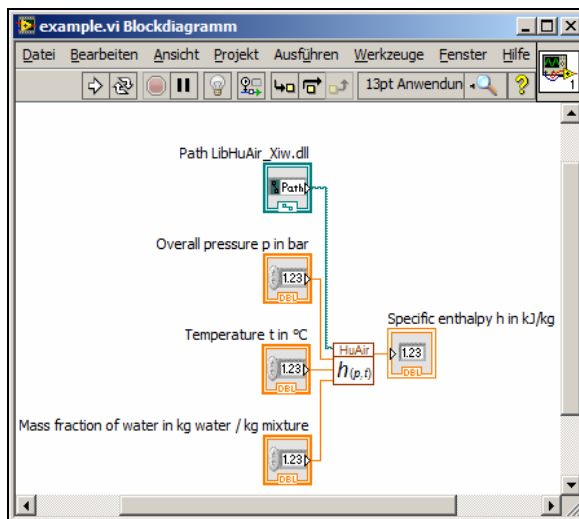


Figure 2.10
Block diagram of the example calculation

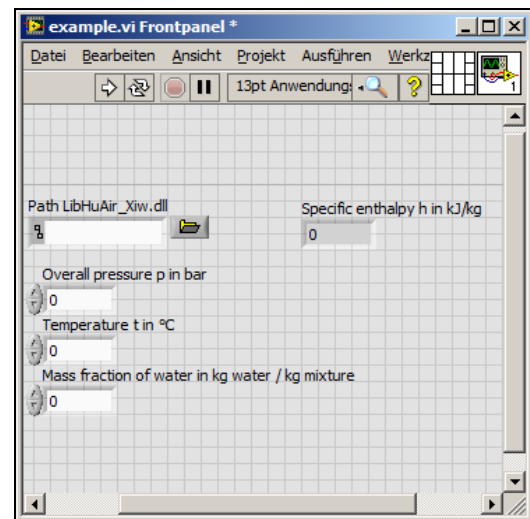


Figure 2.11
Front panel of the example calculation

- Enter a value in the input element *Overall pressure p in bar* on the front panel (Range of validity: $p = 0,01 \text{ bar} \dots 1000 \text{ bar}$)
⇒ e. g.: Enter the value 1.01325.
- Enter a value in the input element *Temperature t in °C* on the front panel (Range of validity: $t = -30 \dots 1726.85^\circ\text{C}$)
⇒ e. g.: Enter the value 20.

Enter a value in the input element *Mass fraction of water ξ_w in kg water / kg mixture* on the front panel.

(Range of validity $0 \leq \xi_w \leq 1 \text{ kg/kg}$)

⇒ e. g.: Enter the value 0,01.

- Enter the path of the LibHuAir_Xiw.dll in the input element *Path LibHuAir_Xiw.dll* on the front panel (as explained in section 2.1 the LibHuAir_Xiw.dll and the other library files from the directory <CD>\source have to be stored in the same directory on the hard disc

which is arbitrary). To do this you can use the *File Open Dialog* which appears by clicking the yellow folder symbol on the right of the input element.

- To run the calculation of the specific enthalpy click on the *Run* button or press <Ctrl>+<R>. The result for h in kJ/kg appears in the output element (see Figure 2.12).

⇒ The result for h_i in our sample calculation is $h = 45.303865$ kJ/kg

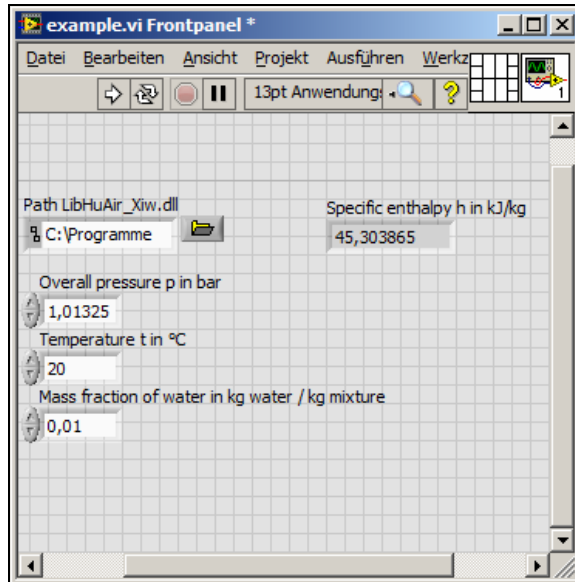


Figure 2.12 Result of the example calculation of h

The calculation of $h = f(p, t, \xi_w)$ has thus been completed. Correspondingly, the specific entropy $s = f(p, t, \xi_w)$ can be calculated with the same values for p , t , and ξ_w . The following changes need to be implemented.

- Open the context menu of the function node *specific enthalpy* on the block diagram. Under **Replace / Palette LibHuAir_Xiw** you will find the function **specific entropy** symbolized with $s(p, t)$. The node on the block diagram changes to **specific entropy** by clicking on this symbol. Since the input parameters are the same as before their labels need not be changed. Only the label of the output parameter can be changed from *specific enthalpy h in kJ/kg* to *specific entropy s in kJ/(kg·K)* by double clicking on it and typing the new name.
- On the front panel you can see that the new label for the output element *Specific entropy s in kJ/(kg·K)* was taken automatically. Since the values in the input elements are still present the calculation can be started now by pressing <Ctrl>+<R> or clicking the *Run* button. The result for s in kJ/(kg·K) appears in the output element.

⇒ The result for s in our sample calculation is 0.3235 in kJ/(kg·K).

The calculation of $s = f(p, t, \xi_w)$ has been carried out. You can now arbitrarily change the values for p , t , or ξ_w in the appropriate input elements.

Note:

If the calculation results in -1000 , this indicates that the values entered are located outside the range of validity. More detailed information on each function and its range of validity is available in chapter 3. For further property functions calculable with FluidVIEW, see the function table in chapter 1.

2.5 Removing FluidVIEW

Should you wish to remove the LibHuAir_Xiw library or the complete FluidVIEW Add-on you have to delete the files that have been copied in the default directory of the LabVIEW™ development environment <LV>.

Removing the FluidVIEW Add-on

To remove the FluidVIEW Add-on please delete the folders listed in Table 2.3 from the default directory of LabVIEW™.

Table 2.3 Directories that have to be deleted from the default directory of LabVIEW™ to remove the FluidVIEW Add-on

Name of the directory	Parent directory in the default directory of LabVIEW™ (<LV>)
FluidVIEW	<LV>\vi.lib
FluidVIEW	<LV>\menus\Categories
FluidVIEW-Help	<LV>\help

Removing only the LibHuAir_Xiw library

To remove only the LibHuAir_Xiw library please delete the folders or files listed in Table 2.4 from the default directory of LabVIEW™.

Table 2.4 Data that have to be deleted from the default directory of LabVIEW™ (<LV>) to remove only the LibHuAir_Xiw library.

File name with file extension or name of the directory	Parent directory in the default directory of LabVIEW (<LV>)
LibHuAir_Xiw.llb	<LV>\vi.lib\FluidVIEW
LibHuAir_Xiw	<LV>\menus\Categories\FluidVIEW
LibHuAir_Xiw.hlp	<LV>\help\FluidVIEW-Help
LibHuAir_Xiw.txt	<LV>\help\FluidVIEW-Help
FluidVIEW_LibHuAir_Xiw.pdf	<LV>\help\FluidVIEW-Help
Open_LibHuAir_Xiw_doc.vi	<LV>\help\FluidVIEW-Help
Open_LibHuAir_Xiw_doc.txt	<LV>\help\FluidVIEW-Help

The changes will take effect after restarting LabVIEW™.

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 m²/s
 succ - 1 → Calculation successful
 - 0 → Calculation not successful

Range of Validity:

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

Comments:

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

Results for Wrong Input Values:

a_ptXiw_HuAir = - 1, succ = 0

References:

Dry air:

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

Specific Isobaric Heat Capacity $c_p = f(h, s, \xi_w)$
Function Name:

cp_hsXiw_HuAir

Fortran Program:

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

Input Values:

- h - Specific enthalpy h in kJ/kg
- s - Specific Entropy s in kJ/(kg K)
- X_{iw} - Mass fraction of water ξ_w in kg water / kg mixture

Output Values:

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

Range of Validity:

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

Comments:

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

Calculation:

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

Results for Wrong Input Values:

cp_hsXiw_HuAir = - 1, succ = 0

References:

Dry air:

from Lemmon et al. [14]

Steam in humid air:

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

Dissociation:

from VDI Guideline 4670 [13]

Specific Isobaric Heat Capacity $c_p = f(p, h, \xi_w)$
Function Name:

cp_phXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

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

Range of Validity:

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

Comments:

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

Calculation:

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

Results for Wrong Input Values:

cp_phXiw_HuAir = - 1, succ = 0

References:

Dry air:

from Lemmon et al. [14]

Steam in humid air:

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

Dissociation:

from VDI Guideline 4670 [13]

Specific Isobaric Heat Capacity $c_p = f(p, s, \xi_w)$
Function Name:

cp_psXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

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

Range of Validity:

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

Comments:

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

Calculation:

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

Results for Wrong Input Values:

cp_psXiw_HuAir = - 1, succ = 0

References:

Dry air:

from Lemmon et al. [14]

Steam in humid air:

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

Dissociation:

from VDI Guideline 4670 [13]

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

cp_ptXiw_HuAir

Fortran Program:

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

Input Values:

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

Comments:

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

Results for Wrong Input Values:

cp_ptXiw_HuAir = - 1, succ = 0

References:

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

Specific Isobaric Heat Capacity $c_p = f(t, s, \xi_w)$
Function Name:

cp_tsXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

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

Range of Validity:

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

Comments:

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

Calculation:

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

Results for Wrong Input Values:

cp_TsXiw_HuAir = - 1, succ = 0

References:

Dry air:

from *Lemmon* et al. [14]

Steam in humid air:

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

Dissociation:

from VDI Guideline 4670 [13]

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

Eta_ptXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

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

Range of Validity:

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

Comments:

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

Results for Wrong Input Values:

Eta_ptXiw_HuAir = - 1, succ = 0

References:

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

Specific Enthalpy $h = f(p, s, \xi_w)$
Function Name:

h_psXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

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

Range of Validity:

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

Comments:

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

Calculation:

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

Results for Wrong Input Values:

h_psXiw_HuAir = - 1·10¹⁰⁰, succ = 0

References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water droplets in fog:

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

Ice crystals in fog:

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

Dissociation:

from VDI Guideline 4670 [13]

Specific Enthalpy $h = f(p, t, \xi_w)$
Function Name:

h_ptXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

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

Range of Validity:

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

Comments:

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

Results for Wrong Input Values:

h_ptXiw_HuAir = - 1·10¹⁰⁰, succ = 0

References:

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

Specific Enthalpy $h = f(t, s, \xi_w)$
Function Name:

h_tsXiw_HuAir

Fortran Program:

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

Input Values:

- t - Temperature t in °C
- s - Specific Entropy s in kJ/(kg K)
- Xiw - Mass fraction of water ξ_w in kg water / kg mixture

Output Values:

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

Range of Validity:

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

Comments:

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

Calculation:

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

Results for Wrong Input Values:

h_TsXiw_HuAir = - 1·10¹⁰⁰, succ = 0

References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water droplets in fog:

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

Ice crystals in fog:

from IAPWS-06 [18], [19]

Dissociation:

from VDI Guideline 4670 [13]

Isentropic Exponent $\kappa = f(p, s, \xi_w)$
Function Name:

Kappa_psXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

Kappa_psXiw_HuAir - Isentropic exponent κ
succ - 1 → Calculation successful
 - 0 → Calculation not successful

Range of Validity:

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

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 ($\xi_w \leq \xi_{wsatt}$)

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

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

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

Results for Wrong Input Values:

Kappa_psXiw_HuAir = - 1, succ = 0

References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water droplets in fog:

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

Dissociation:

from VDI Guideline 4670 [13]

Isentropic Exponent $\kappa = f(p, t, \xi_w)$
Function Name:

Kappa_ptXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

Kappa_ptXiw_HuAir - Isentropic exponent κ
succ - 1 → Calculation successful
 - 0 → Calculation not successful

Range of Validity:

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

Comments:

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

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

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

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

Results for Wrong Input Values:

Kappa_ptXiw_HuAir = - 1, succ = 0

References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water droplets in fog:

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

Dissociation:

from VDI Guideline 4670 [13]

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

Lambda_ptXiw_HuAir

Fortran Program:

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

Input Values:

p - Total pressure p in bar
t - Temperature t in °C
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 → Calculation successful
 - 0 → Calculation not successful

Range of Validity:

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

Comments:

- Model of ideal mixture of real fluids about volume fractions

Results for Wrong Input Values:

Lambda_ptXiw_HuAir = - 1, succ=0

References:

Dry air:

from *Lemmon* et al. [15]

Steam in humid air and water droplets in fog:

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

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

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

Ny_ptXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

Ny_ptXiw_HuAir - Kinematic viscosity ν in m²/s
succ - 1 → Calculation successful
 - 0 → Calculation not successful

Range of Validity:

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

Comments:

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

Results for Wrong Input Values:

Ny_ptXiw_HuAir = - 1, succ = 0

References:

Dry air:

η from *Lemmon* et al. [15]

ρ from *Lemmon* et al. [14]

Steam in humid air and water droplets in fog:

η for $273.15\text{ K} \leq T \leq 1073.15\text{ K}$ from IAPWS-08 [7]
 for $T < 273.15\text{ K}$ and $T > 1073.15\text{ K}$ from *Brandt* [12]

ρ from IAPWS-IF97 [1], [2], [3], [4]
 for $T < 273.16\text{ K}$ from IAPWS-06 [18], [19]

Pressure $p = f(h, s, \xi_w)$
Function Name:

p_hsXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

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

Range of Validity:

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

Comments:

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

Calculation:

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

Range of Validity:

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

Comments:

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

Calculation:

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

Range of Validity:

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

Comments:

- Partial pressure of water $p_d = \frac{1}{\frac{1-\xi_w}{\xi_w} \cdot \frac{R_l}{R_w} + 1}$ for $\xi_w \leq \xi_{wsatt}(p, t)$
- for $\xi_w > \xi_{wsatt}(p, t)$ result $p_d = p_{dsatt}(p, t)$
Saturation vapor pressure at saturation $p_{dsatt} = f \cdot p_s(t)$
with $p_s(t)$ for $t \geq 0.01\text{ °C}$ - vapor pressure of water
 for $t < 0.01\text{ °C}$ - sublimation pressure of water

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

Results for Wrong Input Values:

pd_ptXiw_HuAir = - 1; succ=0

References:

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

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

pdsatt_pt_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

pdsatt_pT_HuAir - Saturation vapor pressure p_{dsatt} of water in humid air in bar
succ - 1 → Calculation successful
 - 0 → Calculation not successful

Range of Validity:

Temperature t : $-30\text{ °C} \leq t \leq 1726.85\text{ °C}$
Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$

Comments:

Saturation vapor pressure at saturation $p_{\text{dsatt}} = f \cdot p_s(t)$
with $p_s(t)$ for $t \geq 0.01\text{ °C}$ - vapor pressure of water
 for $t < 0.01\text{ °C}$ - 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 $t \geq 0.01\text{ °C}$ from IAPWS-IF97 [1], [2], [3], [4]
 if $t < 0.01\text{ °C}$ from IAPWS-08 [16], [17]

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

Phi_ptXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

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

Range of Validity:

Temperature t : $-30\text{ °C} \leq t \leq t_{\text{krit}} = 373.946\text{ °C}$
 (t_{krit} - critical Temperature of water)
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Mass fraction of water ξ_w : $0 \leq \xi_w \leq 1 - 1 \cdot 10^{-8}\text{ kg/kg}$

Comments:

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

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

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

 for $t < 0.01\text{ °C}$ - 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 $t \geq 0.01\text{ °C}$ from IAPWS-IF97 [1], [2], [3], [4]
 if $t < 0.01\text{ °C}$ from IAPWS-08 [16], [17]

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

pl_ptXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

pl_ptXiw_HuAir - Partial pressure of air p_l in bar
succ - 1 → Calculation successful
 - 0 → Calculation not successful

Range of Validity:

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

Comments:

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

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

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

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

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

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

Results for Wrong Input Values:

pl_ptXiw_HuAir = - 1, succ = 0

References:

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

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

Pr_ptXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

Pr_ptxw_HuAir - *Prandtl-Number* Pr
succ - 1 → Calculation successful
 - 0 → Calculation not successful

Range of Validity:

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

Comments:

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

Results for Wrong Input Values:

Pr_ptXiw_HuAir = - 1, succ = 0

References:

Dry air:

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

Dissociation:

from VDI Guideline 4670 [13]

Mole Fraction of Air $\psi_1 = f(\xi_w)$
Function Name:

Psil_Xiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

Psil_Xiw_HuAir - Mole fraction of air in ψ_1 kmol / kmol

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

Range of Validity:

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

Comments:

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

Results for Wrong Input Values:

Psil_Xiw_HuAir = - 1, succ = 0

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

Psiw_Xiw_HuAir

Fortran Program:

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

Input Values:

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 → Calculation successful
- 0 → Calculation not successful

Range of Validity:

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

Comments:

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

Results for Wrong Input Values:

Psiw_Xiw_HuAir = - 1, succ=0

$$\text{Region} = f(h, s, \xi_w)$$

Function Name:

Region_hsXiw_HuAir

Fortran Program:

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

Input Values:

- h - Specific enthalpy h in kJ/kg
- s - Specific entropy s in kJ/(kg K)
- Xiw - Mass fraction of water 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 : $-30\text{ °C} \leq t \leq 1726.85\text{ °C}$
- Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
- Mass fraction of water ξ_w : $0 \leq \xi_w \leq 1\text{ kg/kg}$

Comments:

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

Results for Wrong Input Values:

Region_hsXiw_HuAir = 0

References:

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

$$\text{Region} = f(p, h, \xi_w)$$

Function Name:

Region_phXiw_HuAir

Fortran Program:

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

Input Values:

p - Total pressure p in bar
 h - Specific enthalpy h in kJ/kg
 Xiw - Mass fraction of water 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 : $-30\text{ °C} \leq t \leq 1726.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Mass fraction of water ξ_w : $0 \leq \xi_w \leq 1\text{ kg/kg}$

Comments:

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

Results for Wrong Input Values:

Region_phXiw_HuAir = 0

References:

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

$$\text{Region} = f(p, s, \xi_w)$$

Function Name:

Region_psXiw_HuAir

Fortran Program:

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

Input Values:

p - Total pressure p in bar
 s - Specific entropy s in 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 : $-30\text{ °C} \leq t \leq 1726.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Mass fraction of water ξ_w : $0 \leq \xi_w \leq 1\text{ kg/kg}$

Comments:

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

Results for Wrong Input Values:

Region_psXiw_HuAir = 0

References:

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

$\text{Region} = f(p, t, \xi_w)$

Function Name:

Region_ptXiw_HuAir

Fortran Program:

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

Input Values:

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

Comments:**Results for Wrong Input Values:**

Region_ptXiw_HuAir = 0

References:

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

$$\text{Region} = f(t, s, \xi_w)$$

Function Name:

Region_tsXiw_HuAir

Fortran Program:

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

Input Values:

t - Temperature t in °C
s - Specific entropy s in kJ/(kg K)
Xiw - Mass fraction of water 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 : $-30\text{ °C} \leq t \leq 1726.85\text{ °C}$
Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
Mass fraction of water ξ_w : $0 \leq \xi_w \leq 1\text{ kg/kg}$

Comments:

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

Results for Wrong Input Values:

Region_tsXiw_HuAir = 0

References:

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

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

Rho_ptXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

Rho_ptXiw_HuAir - Density ρ in kg/m³
succ - 1 → Calculation successful
 - 0 → Calculation not successful

Range of Validity:

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

Comments:

Calculation:

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

Results for Wrong Input Values:

Rho_ptXiw_HuAir = - 1, succ = 0

References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water droplets in fog:

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

Ice crystals in fog:

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

Specific Entropy $s = f(p, h, \xi_w)$
Function Name:

s_phXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

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

Range of Validity:

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

Comments:

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

Calculation:

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

Results for Wrong Input Values:

s_phXiw_HuAir = - 1·10¹⁰⁰, succ=0

References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water droplets in fog:

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

Ice crystals in fog:

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 → Calculation successful
 - 0 → Calculation not successful

Range of Validity:

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

Comments:

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

Results for Wrong Input Values:

s_ptXiw_HuAir = - 1·10¹⁰⁰, succ=0

References:

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

Surface Tension $\sigma = f(t)$
Function Name:

Sigma_t_HuAir

Fortran Program:

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

Input Values:

t - Temperature t in °C

Output Values:

Sigma_t_HuAir - Surface tension σ in N/m
succ - 1 → Calculation successful
- 0 → Calculation not successful

Range of Validity:

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

Comments:

Calculation: for pure water from IAPWS-IF97

Results for Wrong Input Values:

Sigma_t_HuAir = - 1

References: [8]

Temperature $t = f(h, s, \xi_w)$
Function Name:

t_hsXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

- t_hsXiw_HuAir - Temperature t in °C
- succ - 1 → Calculation successful
- 0 → Calculation not successful

Range of Validity:

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

Comments:

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

Calculation:

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

Results for Wrong Input Values:

t_hsXiw_HuAir = - 1, succ = 0

References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water droplets in fog:

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

Ice crystals in fog:

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

Dissociation:

from VDI Guideline 4670 [13]

Temperature $t = f(p, h, \xi_w)$
Function Name:

t_phXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

t_phXiw_HuAir - Temperature t in °C
succ - 1 → Calculation successful
 - 0 → Calculation not successful

Range of Validity:

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

Comments:

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

Calculation:

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

Results for Wrong Input Values:

t_phXiw_HuAir = - 1, succ = 0

References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water droplets in fog:

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

Ice crystals in fog:

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

Dissociation:

from VDI Guideline 4670 [13]

Temperature $t = f(p, s, \xi_w)$
Function Name:

t_psXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

- t_psXiw_HuAir - Temperature t in °C
- succ - 1 → Calculation successful
- 0 → Calculation not successful

Range of Validity:

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

Comments:

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

Calculation:

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

Results for Wrong Input Values:

t_psXiw_HuAir = - 1, succ = 0

References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water droplets in fog:

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

Ice crystals in fog:

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

Dissociation:

from VDI Guideline 4670 [13]

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

tf_ptXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

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

Range of Validity:

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

Comments:

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

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

Results for Wrong Input Values:

tf_ptXiw_HuAir = - 1, succ = 0

References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water droplets in fog:

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

Dissociation:

from VDI Guideline 4670 [13]

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

tTau_pXiw_HuAir

Fortran Program:

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

Input Values:

p - Total pressure p in bar
 Xiw - Mass fraction of water ξ_w in kg water / kg mixture

Output Values:

tTau_pXiw_HuAir - Dew point Temperature t_τ in °C
 succ - 1 → Calculation successful
 - 0 → Calculation not successful

Range of Validity:

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

Comments:

Dew point Temperature of water in mixtures of gases:

$t_\tau = t_s(p, p_d)$ for $t \geq 0.01^\circ\text{C}$
 (t_s – Boiling Temperature of water in mixtures of gases)
 $t_\tau = t_{sub}(p, p_d)$ for $t < 0.01^\circ\text{C}$
 (t_{sub} – Sublimation Temperature of water in mixtures of gases)

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

Dew point Temperature of pure water:

$t_\tau = t_s(p)$
 (t_s – Boiling Temperature of pure water)

Results for Wrong Input Values:

tTau_pXiw_HuAir = - 1, succ = 0

References:

$t_s(p, p_d)$ for $t_\tau \geq 0.01^\circ\text{C}$ from IAPWS-IF97 [1], [2], [3], [4]
 $t_{sub}(p, p_d)$ for $T_\tau < 0.01^\circ\text{C}$ from IAPWS - 08 [16], [17]
 $t_s(p)$ from IAPWS-IF97 [1], [2], [3], [4]

Specific Internal Energy $u = f(p, t, \xi_w)$
Function Name:

u_ptXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

u_ptXiw_HuAir - Specific internal energy u in kJ/kg
succ - 1 → Calculation successful
 - 0 → Calculation not successful

Range of Validity:

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

Comments:

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

Results for Wrong Input Values:

u_ptXiw_HuAir = - 1·10¹⁰⁰, 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 m³/kg
succ - 1 → Calculation successful
 - 0 → Calculation not successful

Range of Validity:

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

Comments:

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

Calculation:

- for unsaturated and saturated humid air ($\xi_w \leq \xi_{wsatt}$) as ideal mixture of real gases (dry air and steam)
- for fog ($\xi_w > \xi_{wsatt}$) as ideal mixture of saturated humid air and water liquid or water ice
- Calculation of the mixture of liquid fog and ice at $t = 0.01\text{ °C}$ 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 m³/kg
succ - 1 → Calculation successful
 - 0 → Calculation not successful

Range of Validity:

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

Comments:

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

Calculation:

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

Results for Wrong Input Values:

v_phXiw_HuAir = -1, succ = 0

References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water droplets in fog:

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

Ice crystals in fog:

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

Dissociation:

from VDI Guideline 4670 [13]

Specific Volume $v = f(p, s, \xi_w)$
Function Name:

v_psXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

v_psXiw_HuAir - Specific volume v in m³/kg
succ - 1 → Calculation successful
 - 0 → Calculation not successful

Range of Validity:

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

Comments:

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

Calculation:

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

Results for Wrong Input Values:

v_psXiw_HuAir = - 1, succ = 0

References:

Dry air:

from *Lemmon* et al. [14]

Steam in humid air and water droplets in fog:

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

Ice crystals in fog:

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

Dissociation:

from VDI Guideline 4670 [13]

Specific Volume $v = f(p, t, \xi_w)$
Function Name:

v_ptXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

v_ptXiw_HuAir - Specific volume v in m³/kg
succ - 1 → Calculation successful
 - 0 → Calculation not successful

Range of Validity:

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

Comments:

Calculation:

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

Results for Wrong Input Values:

v_ptXiw_HuAir = - 1, succ = 0

References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water droplets in fog:

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

Ice crystals in fog:

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

Specific Volume $v = f(t, s, \xi_w)$
Function Name:

v_tsXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

v_tsXiw_HuAir - Specific volume v in m³/kg
succ - 1 → Calculation successful
 - 0 → Calculation not successful

Range of Validity:

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

Comments:

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

Calculation:

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

Results for Wrong Input Values:

v_tsXiw_HuAir = - 1, succ = 0

References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water droplets in fog:

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

Ice crystals in fog:

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

Dissociation:

from VDI Guideline 4670 [13]

Isentropic Speed of Sound $w = f(p, t, \xi_w)$
Function Name:

w_ptXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

w_ptXiw_HuAir - Isentropic speed of sound w in m/s
succ - 1 → Calculation successful
 - 0 → Calculation not successful

Range of Validity:

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

Comments:

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

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

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

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

Results for Wrong Input Values:

w_ptXiw_HuAir = - 1, succ = 0

References:

Dry air:

from Lemmon et al. [14]

Steam in humid air and water droplets in fog:

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

Dissociation:

from VDI Guideline 4670 [13]

Humidity Ratio (Absolute Humidity) $x_w = f(\xi_w)$
Function Name:

xw_Xiw_HuAir

Fortran Program:

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

Input Values:

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 → Calculation successful
- 0 → Calculation not successful

Range of Validity:

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

Comments:

Humidity Ratio (Absolute humidity) in mixture of gas:

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

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

Results for Wrong Input Values:

xw_Xiw_HuAir = - 1, succ = 0

Mass Fraction of Water $\xi_w = f(p, t, \varphi)$
Function Name:

Xiw_ptPhi_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

Xiw_ptPhi_HuAir - Mass fraction of water ξ_w in kg / kg
succ - 1 → Calculation successful
 - 0 → Calculation not successful

Range of Validity:

Temperature t : $-30\text{ °C} \leq t \leq t_{\text{krit}} = 373.946\text{ °C}$
 (T_{krit} - critical Temperature of water)
Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
Relative humidity φ : $0 \leq \varphi \leq 1$

Comments:

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

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

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

 for $t < 0.01\text{ °C}$ - 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 $t \geq 0.01\text{ °C}$ from IAPWS-IF97 [1], [2], [3], [4]
 if $t < 0.01\text{ °C}$ from IAPWS-08 [16], [17]

Mass Fraction of Water $\xi_w = f(p, t, p_d)$
Function Name:

Xiw_ptpd_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

Xiw_ptpd_HuAir - Mass fraction of water ξ_w in kg / kg
succ - 1 → Calculation successful
 - 0 → Calculation not successful

Range of Validity:

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

Range of Validity:

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

Comments:

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

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

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

 for $t < 0.01\text{ °C}$ - 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 $t \geq 0.01\text{ °C}$ from IAPWS-IF97 [1], [2], [3], [4]
 if $t < 0.01\text{ °C}$ from IAPWS-08 [16], [17]

Mass Fraction of Water $\xi_w = f(p, t_\tau)$
Function Name:

Xiw_ptTau_HuAir

Fortran Program:

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

Input Values:

p - Total pressure p in bar
 t_τ - Dew point Temperature t_τ in °C

Output Values:

Xiw_ptTau_HuAir - Mass fraction of water ξ_w in kg / kg
succ - 1 → Calculation successful
 - 0 → Calculation not successful

Range of Validity:

Pressure p : $0.01\text{bar} \leq p \leq 1000\text{ bar}$
Dew point temperature t_τ : $-30\text{ °C} \leq t_\tau \leq t_s(p, p_d)$
 (t_s – Boiling Temperature of water in mixtures of gases)

Comments:

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

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

with $p_s(t_\tau)$ for $t_\tau \geq 0.01\text{°C}$ - 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 $t_\tau \geq 0.01\text{°C}$ from IAPWS-IF97 [1], [2], [3], [4]
 if $t_\tau < 0.01\text{°C}$ from IAPWS-08 [16], [17]

Mass Fraction of Steam $\xi_w = f(p, t, t_f)$
Function Name:

Xiw_pttf_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

Xiw_pttf_HuAir - Mass fraction of steam ξ_w in kg / kg
succ - 1 → Calculation successful
 - 0 → Calculation not successful

Range of Validity:

Temperature t : $-30\text{ °C} \leq t \leq 1726.85\text{ °C}$
Wet bulb temperature t_f : $-30\text{ °C} \leq t_f \leq t$ or $t_s(p, p_d)$
 (t_s – Boiling Temperature of water in mixtures of gases)
Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$

Comments:

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

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

Results for Wrong Input Values:

Xiw_pttf_HuAir = - 1, succ = 0

References:

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

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

Xiwf_ptXiw_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

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

Range of Validity:

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

Comments:

Mass fraction of liquid water: $\xi_{wf} = \frac{x_w - x_{ws}}{1 + x_w}$
with: $x_w = \frac{R_l}{R_w} \frac{\varphi \cdot p_{dsatt}(p, t)}{p - \varphi \cdot p_{dsatt}(p, t)}$ and $x_{ws} = \frac{R_l}{R_w} \frac{p_{dsatt}(p, t)}{p - p_{dsatt}(p, t)}$
Saturation vapor pressure at saturation $p_{dsatt} = f \cdot p_s(t)$
with $p_s(t)$ for $t \geq 0.01^\circ\text{C}$ - vapor pressure of water
 for $t < 0.01^\circ\text{C}$ - sublimation pressure of water

Result for pure liquid water $\xi_{wf} = 1$
Result for pure steam: $\xi_{wf} = 0$
Result for pure water ice: $\xi_{wf} = 0$

Results for Wrong Input Values:

Xiwf_ptXiw_HuAir = - 1, succ = 0

References:

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

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

Xiwsatt_pt_HuAir

Fortran Program:

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

Input Values:

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

Output Values:

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

Range of Validity:

Temperature t : $0\text{ °C} \leq t \leq t_s(p, p_d)\text{ °C}$
 (t_s – Boiling Temperature of water in mixtures of gases)

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

Comments:

Specific humidity of water for saturated humid air:

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

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

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

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

Results for Wrong Input Values:

Xiwsatt_pt_HuAir = - 1, succ = 0

References:

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



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

Water and Steam

Library LibIF97

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

Humid Combustion Gas Mixtures

Library LibHuGas

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

Humid Air

Library LibHuAir

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

Carbon Dioxide including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1994)

Seawater

Library LibSeaWa

IAPWS Formulation 2008 of Feistel and IAPWS-IF97

Ice

Library LibICE

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

Ideal Gas Mixtures

Library LibIdGasMix

- Model: Ideal mixture of the ideal gases:
- | | | | |
|-----------------|------------------|-----------------|------------|
| Ar | NO | He | Propylene |
| Ne | H ₂ O | F ₂ | Propane |
| N ₂ | SO ₂ | NH ₃ | Iso-Butane |
| O ₂ | H ₂ | Methane | n-Butane |
| CO | H ₂ S | Ethane | Benzene |
| CO ₂ | OH | Ethylene | Methanol |
| Air | | | |

- Consideration of:
- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

- Consideration of:
- Dissociation from the VDI Guideline 4670

Dry Air including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Nitrogen

Library LibN2

Formulation of Span et al. (2000)

Hydrogen

Library LibH2

Formulation of Leachman et al. (2007)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth (1995)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of Bückner et al. (2003)

n-Butane

Library LibButane_n

Formulation of Bückner et al. (2003)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

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

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

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

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

Formulation of the International Institute of Refrigeration (1997)

Siloxanes as ORC Working Fluids

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

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

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

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

Formulation of Colonna et al. (2006)

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

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

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

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

Formulation of Colonna et al. (2008)

Propane

Library LibPropane

Formulation of Lemmon et al. (2007)

Methanol

Library LibCH3OH

Formulation of de Reuck and Craven (1993)

Ethanol

Library LibC2H5OH

Formulation of Schroeder et al. (2012)

Helium

Library LibHe

Formulation of Arp et al. (1998)

Hydrocarbons

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

Isopentane C_5H_{12} **Library LibC5H12_ISO**

Neopentane C_5H_{12} **Library LibC5H12_NEO**

Isohexane C_6H_{14} **Library LibC5H14**

Toluene C_7H_8 **Library LibC7H8**

Formulation of Lemmon and Span (2006)

Further Fluids

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

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

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

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

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

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

Formulation of Lemmon and Span (2006)

For more information please contact:

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives can be calculated.

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



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

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

SUM	A	B	C	D	E	F
1	Calculating an isentropic expansion					
2						
3	p	t	x	s	h	v
4	bar	°C	kg/kg	kJ/kgK	kJ/kg	m³/kg
5	20	400	-1		A5:B5:C5	
6	10					
7	5					
8	1					
9	0,5					
10	0,1					
11						
12						
13						
14						
15						
16						
17						

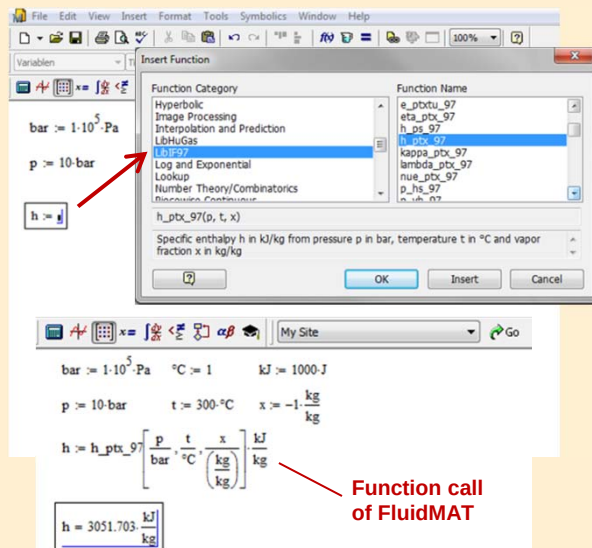
Choosing a property library and a function

Displaying the calculated values in diagrams

Menu for the input of given property values

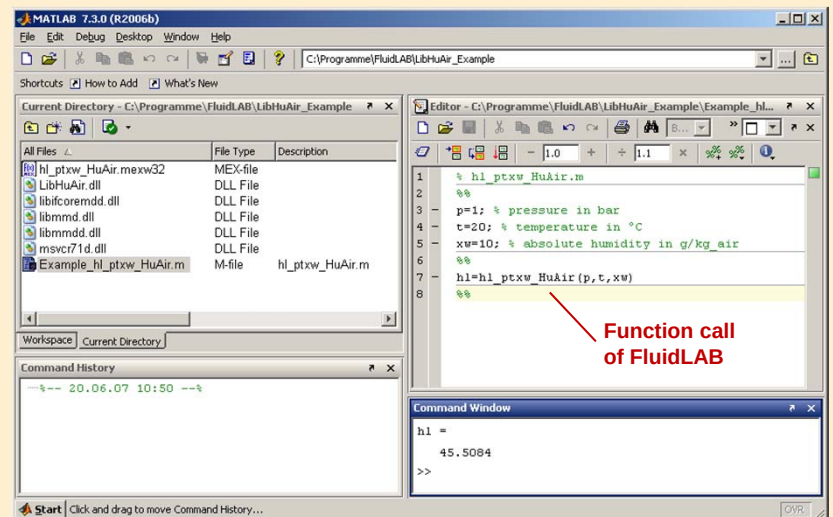
Add-In FluidMAT for Mathcad[®]

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



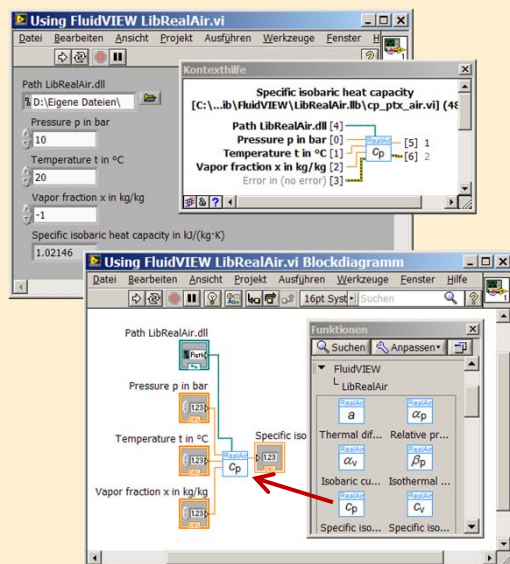
Add-In FluidLAB for MATLAB[®]

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



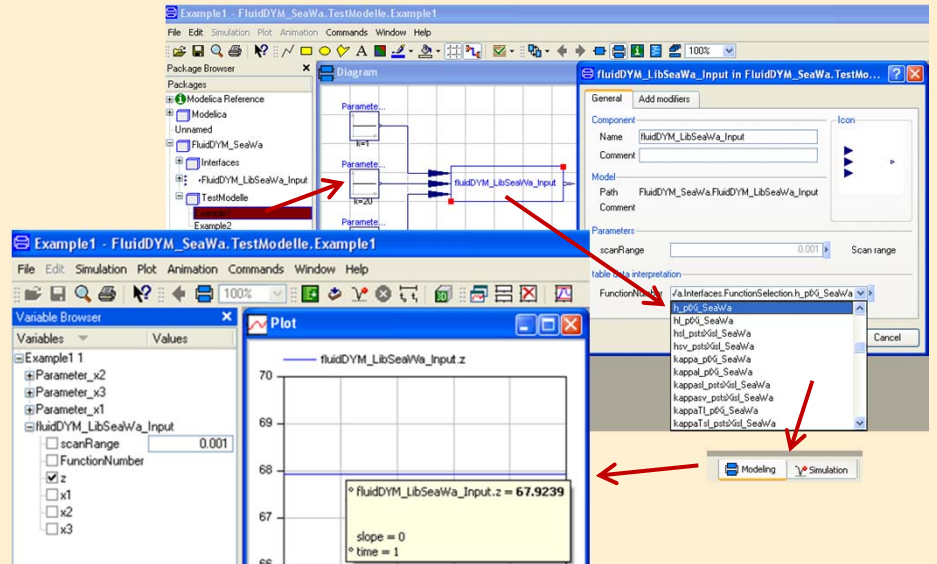
Add-On FluidVIEW for LabVIEW[®]

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

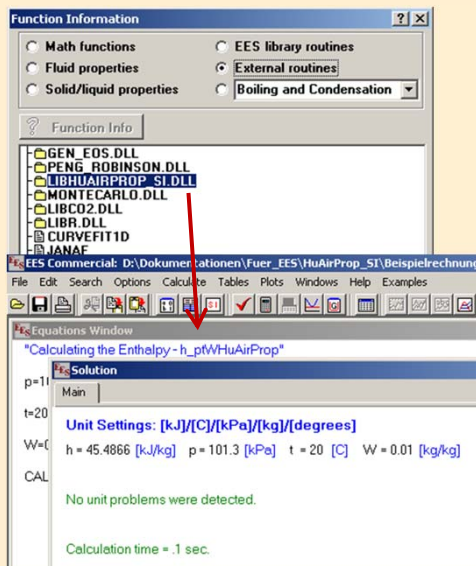


Add-In FluidDYM for DYMOLA[®] (Modelica) and SimulationX[®]

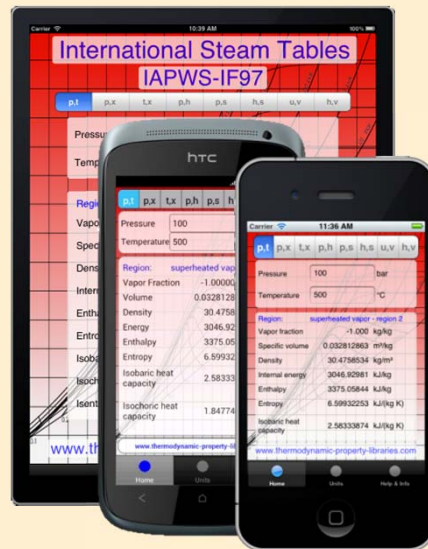
The property functions can be called in DYMOLA[®] and SimulationX[®].



Add-In FluidEES for Engineering Equation Solver®



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



Online Property Calculator at www.thermodynamics-zittau.de

Zittau's Fluid Property Calculator

Fluid:

Function:

Unit System:

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

Pressure p: bar

Temperature t: °C

Vapor fraction x: kg/kg

Calculate / Recalculate

Result:

Specific enthalpy h = kJ/kg

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

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

PDF with the description

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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 83 TI Voyage 200 TI 92

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

Thermodynamic Properties

- Vapor pressure p_s
- Saturation temperature T_s
- Density ρ
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- $p, T(v, h)$
- $p, T(v, u)$

Thermodynamic Derivatives

- Partial derivatives can be calculated.

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

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6. Satisfied Customers

Date: 10/2011

The following companies and institutions use the property libraries

- FluidEXL^{Graphics} for Excel[®]
- FluidLAB for MATLAB[®]
- FluidMAT for Mathcad[®]
- FluidEES for Engineering Equation Solver[®] EES
- FluidDYM for Dymola[®] (Modelica)
- FluidVIEW for LabVIEW[®]:

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University of Stuttgart, Institute of Thermodynamics and Heat Engineering	02/2004
MAN B&W Diesel A/S, Copenhagen, Denmark	02/2004
Siemens AG Power Generation, Erlangen	02/2004
Ulm University of Applied Sciences	03/2004
Visteon, Kerpen	03/2004, 10/2004
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	04/2004
Rerum Cognitio, Zwickau	04/2004
University of Saarbruecken	04/2004
Grenzebach BSH, Bad Hersfeld	04/2004
SOFBID Zwingenberg (general EBSILON program license)	04/2004
EnBW Energy Solutions, Stuttgart	05/2004
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
Munich University of Applied Sciences	12/2004
STORA ENSO Sachsen, Eilenburg	12/2004
Technical University of Cottbus, Chair in Power Plant Engineering	12/2004
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
ALSTOM Power, Baden, Switzerland	01/2003, 07/2003
VER, Dresden	02/2003
Rietschle Energieplaner, Winterthur, Switzerland	02/2003
DLR, Leupholdhausen	04/2003
Emden University of Applied Sciences, Department of Technology	05/2003
Pettersson+Ahrends, Ober-Moerlen	05/2003
SOFBID ,Zwingenberg (general EBSILON program license)	05/2003
Ingenieurbuero Ostendorf, Gummersbach	05/2003
TUEV Nord, Hamburg	06/2003
Muenstermann GmbH, Telgte-Westbevern	06/2003
University of Cali, Colombia	07/2003
Atlas-Stord, Rodovre, Denmark	08/2003
ENERKO, Aldenhoven	08/2003
STEAG RKB, Leuna	08/2003
eta Energieberatung, Pfaffenhofen	08/2003
exergie, Dresden	09/2003
AWTEC, Zurich, Switzerland	09/2003
Energie, Timelkam, Austria	09/2003

Electrowatt-EKONO, Zurich, Switzerland	09/2003
LG, Annaberg-Buchholz	10/2003
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
SorTech, Freiburg	12/2003
Mainova, Frankfurt	12/2003
Energieversorgung Halle	12/2003

2002

Hamilton Medical AG, Rhaezuens, Switzerland	01/2002
Bochum University of Applied Sciences, Department of Thermo- and Fluid Dynamics	01/2002
SAAS, Possendorf/Dresden	02/2002
Siemens, Karlsruhe (general license for the WinIS information system)	02/2002
FZR Forschungszentrum, Rossendorf/Dresden	03/2002
CompAir, Simmern	03/2002
GKS Gemeinschaftskraftwerk, Schweinfurt	04/2002
ALSTOM Power Baden, Switzerland (group licenses)	05/2002
InfraServ, Gendorf	05/2002
SoftSolutions, Muehlhausen (company license)	05/2002
DREWAG, Dresden (company license)	05/2002
SOFBID, Zwingenberg (general EBSILON program license)	06/2002
Kleemann Engineering, Dresden	06/2002
Caliqua, Basel, Switzerland (company license)	07/2002
PCK Raffinerie, Schwedt (group license)	07/2002
Fischer-Uhrig Engineering, Berlin	08/2002
Fichtner Consulting & IT, Stuttgart (company licenses and distribution)	08/2002
Stadtwerke Duisburg	08/2002

Stadtwerke Hannover	09/2002
Siemens Power Generation, Goerlitz	10/2002
Energieversorgung Halle (company license)	10/2002
Bayer, Leverkusen	11/2002
Dillinger Huette, Dillingen	11/2002
G.U.N.T. Geraetebau, Barsbuettel (general license and training test benches)	12/2002
VEAG, Berlin (group license)	12/2002

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ALSTOM Power, Baden, Switzerland	01/2001, 06/2001, 12/2001
KW2 B. V., Amersfoot, Netherlands	01/2001, 11/2001
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 Power Machinery and Plants	02/2001
PREUSSAG NOELL, Wuerzburg	03/2001
Fichtner Consulting & IT Stuttgart (company licenses and distribution)	04/2001
Muenstermann GmbH, Telgte-Westbevern	05/2001
SaarEnergie, Saarbruecken	05/2001
Siemens, Karlsruhe (general license for the WinIS information system)	08/2001
Neusiedler AG, Ulmerfeld, Austria	09/2001
h s energieranlagen, Freising	09/2001
Electrowatt-EKONO, Zurich, Switzerland	09/2001
IPM Zittau/Goerlitz University of Applied Sciences (general license)	10/2001
eta Energieberatung, Pfaffenhofen	11/2001
ALSTOM Power Baden, Switzerland	12/2001
VEAG, Berlin (group license)	12/2001

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SOFBID, Zwingenberg (general EBSILON program license)	01/2000
AG KKK - PGW Turbo, Leipzig	01/2000
PREUSSAG NOELL, Wuerzburg	01/2000
M&M Turbine Technology, Bielefeld	01/2000

IBR Engineering Reis, Nittendorf-Undorf	02/2000
GK, Hannover	03/2000
KRUPP-UHDE, Dortmund (company license)	03/2000
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
RWTH Aachen University	06/2000
VAUP Process Automation, Landau	08/2000
Knuerr-Lommatec, Lommatzsch	09/2000
AVACON, Helmstedt	10/2000
Compania Electrica, Bogota, Colombia	10/2000
G.U.N.T. Geraetebau, Barsbuettel (general license for training test benches)	11/2000
Steinhaus Informationssysteme, Datteln (general license for process data software)	12/2000

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Bayernwerk, Munich	01/1999
DREWAG, Dresden (company license)	02/1999
KEMA IEV, Dresden	03/1999
Regensburg University of Applied Sciences	04/1999
Fichtner Consulting & IT, Stuttgart (company licenses and distribution)	07/1999
Technical University of Cottbus, Chair in Power Plant Engineering	07/1999
Technical University of Graz, Department of Thermal Engineering, Austria	11/1999
Ostendorf Engineering, Gummersbach	12/1999

1998

Technical University of Cottbus, Chair in Power Plant Engineering	05/1998
Fichtner Consulting & IT (CADIS information systems) Stuttgart (general KPRO program license)	05/1998
M&M Turbine Technology Bielefeld	06/1998
B+H Software Engineering Stuttgart	08/1998
Alfa Engineering, Switzerland	09/1998
VEAG Berlin (group license)	09/1998
NUTEC Engineering, Bisikon, Switzerland	10/1998

SCA Hygiene Products, Munich	10/1998
RWE Energie, Neurath	10/1998
Wilhelmshaven University of Applied Sciences	10/1998
BASF, Ludwigshafen (group license)	11/1998
Energieversorgung, Offenbach	11/1998

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Gerb, Dresden	06/1997
Siemens Power Generation, Goerlitz	07/1997