



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

**FluidLAB
with LibHuAir
for MATLAB[®]
and Simulink[®]**

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

FluidLAB with LibHuAir for MATLAB®

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0 Package Contents

0.1 Zip file for 32-bit MATLAB®

The following zip file is delivered for your computer running a 32-bit version of MATLAB®.

"CD_FluidLAB_LibHuAir.zip"

Humid Air Calculated as Ideal Mixture of Real Fluids

Including the following files:

FluidLAB_LibHuAir_Setup.exe	- Installation program for the FluidLAB Add-On for use in MATLAB®
LibHuAir.dll	- Dynamic Link Library for humid air for use in MATLAB®
FluidLAB_LibHuAir_Docu_Eng.pdf	- User's Guide

0.2 Zip file for 64-bit MATLAB®

The following zip file is delivered for your computer running a 64-bit version of MATLAB®.

"CD_FluidLAB_LibHuAir_x64.zip"

Humid Air Calculated as Ideal Mixture of Real Fluids

Including the following files:

Setup.exe	- Self-extracting and self-installing program for FluidLAB
FluidLAB_LibHuAir_64_Setup.msi	- Installation program for the FluidLAB Add-On for use in MATLAB®
LibHuAir.dll	- Dynamic Link Library for humid air for use in MATLAB®
FluidLAB_LibHuAir_Docu_Eng.pdf	- User's Guide

1. Property Functions

1.1 Calculation Programs

Functional Dependence	Function Name	Call as Fortran Program	Property or Function	Unit of the Result	Source or Algorithm	Site Info
$a = f(p, t, x_w)$	a_ptxw_HuAir	= a_ptxw_HuAir(p,t,xw) or = C_a_ptxw_HuAir(a,p,t,xw)	Thermal diffusivity	m ² /s	[1-4], [6], [12], [14], [15]	3/1
$c_p = f(p, t, x_w)$	cp_ptxw_HuAir	= cp_ptxw_HuAir(p,t,xw), or = C_cp_ptxw_HuAir(cp,p,t,xw)	Specific isobaric heat capacity	kJ/(kg · K)	[1-4], [13], [14]	3/2
$\eta = f(p, t, x_w)$	Eta_ptxw_HuAir	= Eta_ptxw_HuAir(p,t,xw), or = C_Eta_ptxw_HuAir(Eta,p,t,xw)	Dynamic viscosity	Pa · s	[7], [12], [15]	3/3
$h_l = f(p, t, x_w)$	hl_ptxw_HuAir	= hl_ptxw_HuAir(p,t,xw), or = C_hl_ptxw_HuAir(h,p,t,xw)	Air-specific enthalpy	kJ/kg _{Air}	[1-4], [13], [14], [18], [19]	3/4
$\lambda = f(p, t, x_w)$	Lambda_ptxw_HuAir	= Lambda_ptxw_HuAir(p,t,xw), or = C_Lambda_ptxw_HuAir(Lambda,p,t,xw)	Thermal conductivity	W/(m · K)	[6], [12], [15]	3/5
$\nu = f(p, t, x_w)$	Ny_ptxw_HuAir	= Ny_ptxw_HuAir(p,t,xw), or = C_Ny_ptxw_HuAir(Ny,p,t,xw)	Kinematic viscosity	m ² /s	[1-4], [7], [12], [14], [15]	3/6
$p_d = f(p, t, x_w)$	pd_ptxw_HuAir	= pd_ptxw_HuAir(p,t,xw), or = C_pd_ptxw_HuAir(pd,p,t,xw)	Partial pressure of steam	bar	[1-4], [16], [17], [25], [26]	3/7
$p_{ds} = f(p, t)$	pds_pt_HuAir	= pds_pt_HuAir(p,t), or = C_pds_pt_HuAir(pd,p,t)	Saturation pressure of water	bar	[1-4], [16], [17], [25], [26]	3/8
$\varphi = f(p, t, x_w)$	Phi_ptxw_HuAir	= Phi_ptxw_HuAir(p,t,xw), or = C_Phi_ptxw_HuAir(Phi,p,t,xw)	Relative humidity	%	[1-4], [16], [17], [25], [26]	3/9
$p_l = f(p, t, x_w)$	pl_ptxw_HuAir	= pl_ptxw_HuAir(p,t,xw), or = C_pl_ptxw_HuAir(pl,p,t,xw)	Partial pressure of air	bar	[1-4], [16], [17], [25], [26]	3/10
$Pr = f(p, t, x_w)$	Pr_ptxw_HuAir	= Pr_ptxw_HuAir(p,t,xw), or = C_Pr_ptxw_HuAir(Pr,p,t,xw)	PRANDTL-number	-	[1-4], [6], [7], [12-15]	3/11
$\psi_l = f(x_w)$	Psil_xw_HuAir	= Psil_xw_HuAir(xw), or = C_Psil_xw_HuAir(Psil,xw)	Mole fraction of air	kmol/kmol	-	3/12

Functional Dependence	Function Name	Call as Fortran Program	Property or Function	Unit of the Result	Source or Algorithm	Site Info
$\psi_w = f(x_w)$	Psiw_xw_HuAir	= Psiw_xw_HuAir(xw), or = C_Psiw_xw_HuAir(Psiw,xw)	Mole fraction of water	kmol/kmol	-	3/13
$\rho = f(p, t, x_w)$	Rho_ptxw_HuAir	= Rho_ptxw_HuAir(p,t,xw), or = C_Rho_ptxw_HuAir(Rho,p,t,xw)	Density	kg/m ³	[1-4], [14], [18], [19]	3/14
$s_l = f(p, t, x_w)$	sl_ptxw_HuAir	= sl_ptxw_HuAir(p,t,xw), or = C_sl_ptxw_HuAir(Rho,p,t,xw)	Air-specific entropy	kJ/(kg _{Air} K)	[1-4], [13], [14], [18], [19]	3/15
$t = f(p, h_l, x_w)$	t_phlxw_HuAir	= t_phlxw_HuAir(p,hl,xw), or = C_t_phlxw_HuAir(t,p,hl,xw)	Backward function: temperature from air-specific enthalpy and humidity ratio (absolute humidity)	°C	[1-4], [13], [14], [18], [19]	3/16
$t = f(p, s_l, x_w)$	t_pslxw_HuAir	= t_pslxw_HuAir(p,hl,xw), or = C_t_pslxw_HuAir(t,p,sl,xw)	Backward function: temperature from air-specific entropy and humidity ratio (absolute humidity)	°C	[1-4], [13], [14], [18], [19]	3/17
$t_f = f(p, t, x_w)$	tf_ptxw_HuAir	= tf_ptxw_HuAir(p,t,xw), or = C_tf_ptxw_HuAir(tf,p,t,xw)	Wet bulb temperature	°C	[1-4], [13], [14]	3/18
$t_\tau = f(p, x_w)$	tTau_pxw_HuAir	= tTau_pxw_HuAir(p,xw), or = C_tTau_pxw_HuAir(tTau,p,xw)	Dew point temperature	°C	[1-4], [16], [17]	3/19
$u_l = f(p, t, x_w)$	ul_ptxw_HuAir	= ul_ptxw_HuAir(p,t,xw), or = C_ul_ptxw_HuAir(ul,p,t,xw)	Air-specific internal energy	kJ/kg _{Air}	[1-4], [13], [14], [18], [19]	3/20
$v_l = f(p, t, x_w)$	vl_ptxw_HuAir	= vl_ptxw_HuAir(p,t,xw), or = C_vl_ptxw_HuAir(vl,p,t,xw)	Air-specific volume	m ³ /kg _{Air}	[1-4], [14], [18], [19]	3/21
$\xi_1 = f(x_w)$	Xil_xw_HuAir	= Xil_xw_HuAir(xw), or = C_Xil_xw_HuAir(Xil,xw)	Mass fraction of air	kg/kg	-	3/22
$\xi_w = f(x_w)$	Xiw_xw_HuAir	= Xiw_xw_HuAir(xw), or = C_Xiw_xw_HuAir(Xiw,xw)	Mass fraction of water	kg/kg	-	3/23
$x_w = f(p, t, p_d)$	xw_ptpd_HuAir	= xw_ptpd_HuAir(p,t,pd), or = C_xw_ptpd_HuAir(xw,p,t,pd)	Humidity ratio (Absolute humidity) from partial pressure of steam	g _{water} /kg _{Air}	[1-4], [16], [17], [25], [26]	3/25
$x_w = f(p, t, \phi)$	xw_ptPhi_HuAir	= xw_ptPhi_HuAir(p,t,Phi), or = C_xw_ptPhi_HuAir(xw,p,t,Phi)	Humidity ratio (Absolute humidity) from temperature and relative humidity	g _{water} /kg _{Air}	[1-4], [16], [17], [25], [26]	3/24

Functional Dependence	Function Name	Cal as Fortran Program	Property or Function	Unit of the Result	Source or Algorithm	Site Info
$x_w = f(p, t, t_r)$	xw_ptTau_HuAir	= xw_ptTau_HuAir(p,tTau), or = C_xw_ptTau_HuAir(xw,p,tTau)	Humidity ratio (Absolute humidity) from dew point temperature	g _{water} /kg _{Air}	[1-4], [16], [17], [25], [26]	3/26
$x_w = f(p, t, t_f)$	xw_pttf_HuAir	= xw_pttf_HuAir(p,t,tf), or = C_xw_pttf_HuAir(xw,p,t,tf)	Humidity ratio (Absolute humidity) from temperature and wet bulb temperature	g _{water} /kg _{Air}	[1-4], [13], [14]	3/27
$x_w = f(p, t, v_1)$	xw_ptvl_HuAir	= xw_ptvl_HuAir(p,t,vl), or = C_xw_ptvl_HuAir(xw,p,t,vl)	Backward function: Humidity ratio (Absolute humidity) from temperature and air-specific volume	g _{water} /kg _{Air}	[1-4], [16], [17], [25], [26]	3/28
$x_{ws} = f(p, t)$	xws_pt_HuAir	= xws_pt_HuAir(p,t), or = C_xws_pt_HuAir(xws,p,t)	Humidity ratio (Absolute humidity) of saturated humid air	g _{water} /kg _{Air}	[1-4], [16], [17], [25], [26]	3/29

Variable Types for Function Call

All functions <u>not</u> starting with C_ :	REAL*8
All functions starting with C_ :	INTEGER*4
All variables:	REAL*8

Composition of Dry Air (from Lemmon et al. [14], [15]) :

Component		Mole Fraction
Nitrogen	N ₂	0.7812
Oxygen	O ₂	0.2096
Argon	Ar	0.0092

Reference States

Property	Dry air	Water
Pressure	1.01325 bar	6.11657 mbar
Temperature	0 °C	0.01 °C
Enthalpy	0 kJ/ kg _{Air}	0.000611783 kJ/ kg _{Air}
Internal energy	- 78.37885533 kJ/ kg _{Air}	0 kJ/ kg _{Air}
Entropy	0.161802887 kJ/(kg _{Air} K)	0 kJ/ (kg _{Air} K)

Units

- p - Mixture pressure in bar
- t - Temperature in °C
- x_w - Humidity ratio (Absolute humidity) in g steam(water, ice)/kg dry air
- φ - Relative humidity in % (only defined for unsaturated and saturated humid air)

Range of Validity

- Temperature: $t = -143.15 \text{ °C} \dots 1726.85 \text{ °C}$
- Mixture pressure: $p = 6.112 \text{ mbar} \dots 1000 \text{ bar}$

Calculation Algorithm

Saturated and unsaturated air ($0 < x_w \leq x_{ws}$):

Ideal mixture of dry air and steam

- Dry air:

- v_l, h_l, u_l, s_l, c_p from *Lemmon et al.* [14]
- λ, η from *Lemmon et al.* [15]

- Steam:

- v, h, u, s, c_p 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]
- for $t < 0 \text{ °C}$ and $t > 800 \text{ °C}$ from *Brandt* [12]

Supersaturated humid air (liquid fog or ice fog)

- Liquid fog ($x_w > x_{ws}$) and $t \geq 0.01 \text{ °C}$

Ideal mixture of saturated humid air and water

- Saturated humid air (see above)

- v, h, u, s, c_p of liquid droplets from IAPWS-IF97 [1], [2], [3], [4]
- λ, η of liquid droplets from IAPWS-85 [6], [7]

- Ice fog ($x_w > x_{ws}$) and $t < 0.01 \text{ °C}$

Ideal mixture of saturated humid air and ice

- Saturated humid air (see above)

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

$x_{ws}(p, t)$ from saturation pressure $p_{ds}(p, t)$ of water in gas mixtures

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

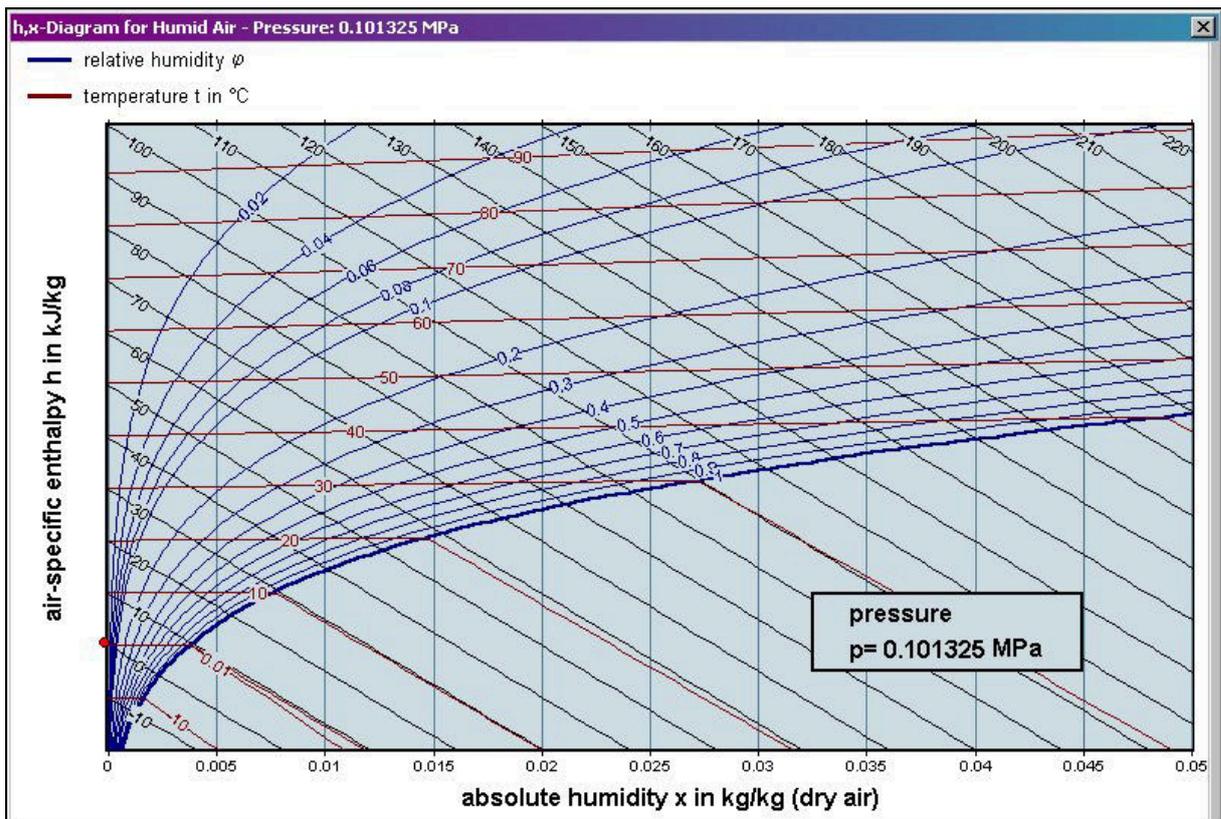
- $f(p, T)$ from Herrmann et al. [25], [26],
- $p_s(t)$ for $t \geq 273.16 \text{ K}$ from IAPWS - IF97 [1], [2], [3], [4],
- $p_s(t)$ for $t < 273.15 \text{ K}$ from IAPWS-08 [16], [17].

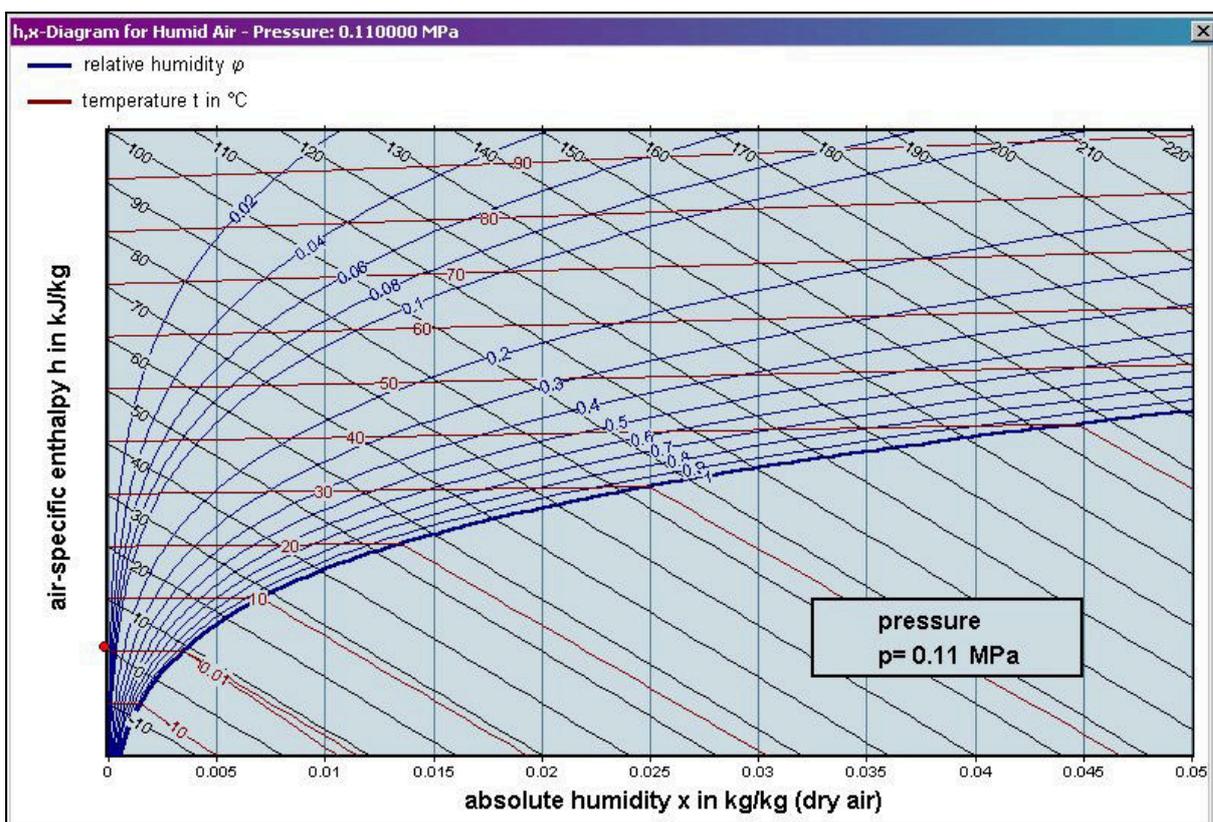
1.2 Thermodynamic Diagrams

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

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

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





2 Application of FluidLAB in MATLAB®

The FluidLAB Add-In has been developed to calculate thermodynamic properties in MATLAB® more conveniently. Within MATLAB® it enables the direct call of functions from the LibHUAIR calculation library.

2.1 Installing FluidLAB including LibHUAIR

This Section describes the installation of FluidLAB including the LibHUAIR property library. After you have downloaded and extracted the zip-file

CD_FluidLAB_LibHUAIR.zip (32 bit version)

or

CD_FluidLAB_LibHUAIR_x64.zip (64 bit version)

you will see the folder

CD_FluidLAB_LibHUAIR\ (32 bit version)

or

CD_FluidLAB_LibHUAIR_x64\ (64 bit version)

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

Open this folder by double-clicking on it.

In this folder you will see the following files:

FluidLAB_LibHUAIR_Setup.msi (for 32-bit installation)

FluidLAB_LibHUAIR_64_Setup.msi (for 64-bit installation)

FluidLAB_LibHUAIR_Docu_Eng.pdf

LibHUAIR.dll.

setup.exe

In order to run the installation of FluidLAB including the LibHUAIR calculation library, double-click on the file

setup.exe.

If an error message from C++ appears, please double click the file

FluidLAB_LibHUAIR_Setup.msi (for 32-bit installation)

or

FluidLAB_LibHUAIR_64_Setup.msi (for 64-bit installation)

for the installation.

In the following dialog box, "Destination Location", the default path offered automatically for the installation of FluidLAB is

C:\Program Files (x86)\FluidLAB\LibHUAIR\ (for 32-bit installation)

or

C:\Program Files\FluidLAB\LibHUAIR\ (for 64-bit installation).

But, this offered path could cause problems with user rights and thus prevent the installation. Therefore, an example path

D:\Example\

is used in the following explanations, which is located on a drive that does not contain the Windows installation.

By clicking the "Browse..." button, you can change the installation directory before installation (see Figure 2.1).

Note:

The product name "Lib_ _ _ _ _" in the following Figures stands for the Library you are installing or have installed. In this case it is the LibHUAIR library.

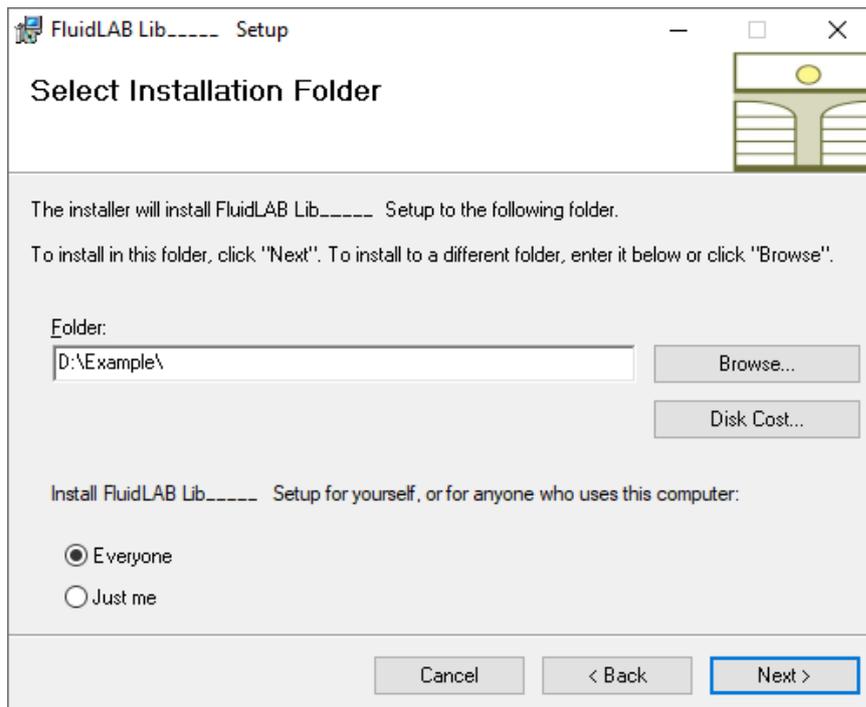


Figure 2.1: "Destination Location"

After you have chosen your desired installation path leave this window by clicking the "Next >" button.

The dialog window "Start Installation" pops up.

Click the "Next >" button to continue installation. The FluidLAB files are now being copied into the created directory on your hard drive.

Click the "Finish >" button in the following window to complete installation.

The installation program has copied the following files into the chosen \LibHUAIR\ directory:

- LibHUAIR.dll,
- LC.dll,
- libifcoremd.dll,
- libiomp5md.dll,
- Libmmd.dll.

In addition, there are specific files for all functions

*.mexw32 (for 32-bit version)

or

*.mexw64 (for 64-bit version).

The names of these functions are listed in Section 1.

Note:

To use the FluidLAB library LibHUAIR you can simply copy all delivered files into your MATLAB project folder or link the installation path to your project. How to add a path to your MATLAB project is described below in Section 2.4.

Now, you have to overwrite the file "LibHUAIR.dll" in your created \LibHUAIR\ directory with the file of the same name provided in the delivered CD. The directory is either

C:\Program Files (x86)\FluidLAB\LibHUAIR (for 32-bit installation)

or

C:\Program Files\FluidLAB\LibHUAIR (for 64-bit installation)

or the directory you have specified, e.g.

D:\Example\.

Now, the LibHUAIR property functions are available in MATLAB®.

2.2 Licensing the LibHUAIR Property Library

The licensing procedure must be carried out when the prompt message appears. In this case, you will see the "License Information" window for LibHUAIR (see Figure below).



Figure 2.2: "License Information" window

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

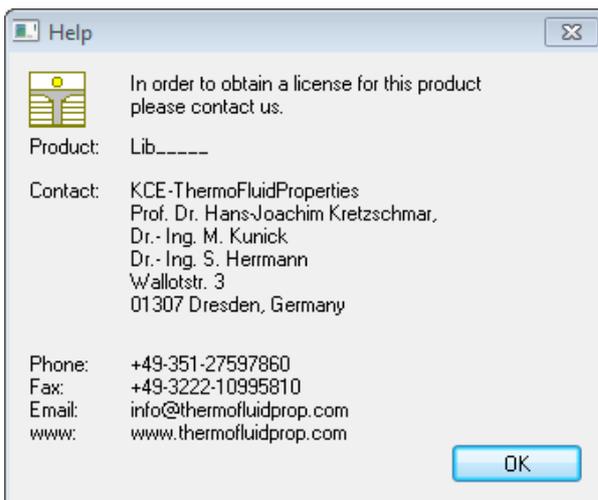


Figure 2.3: "Help" window

If you do not enter a valid license it is still possible to use MATLAB® by clicking "Cancel". In this case, the LibHUAIR property library will display the result "-1111111" for every calculation.

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

2.3 Example Calculation

Now we will calculate, step by step, an example of a function to show how to use FluidLAB mit the LibHUAIR library.

In the following we use the recommended folder D:\Example\.

Note:

Of course, any other folder in which the LibHUAIR files are stored will also work, for example your current MATLAB® project directory.

Please carry out the following instructions:

- Start MATLAB® and choose your FluidLAB folder with the library LibHUAIR files in the upper directory bar of MATLAB® (shown in Figure 2.4, marked with 1).
- Now we create a new MATLAB® file to write our example calculation script. Click on the symbol shown in Figure 2.4, marked with 2.
- We have to save the file and give it a name. In our example we use "example.m" as the file name. To save click on the symbol shown in Figure 2.4, marked with 3.
- Type the following lines into the "example.m" window:
The code is also shown in Figure 2.4, marked with 4.

Text to be written:	Explanation:
<code>% hl_ptxw_HuAir.m</code>	file name as comment
<code>%%</code>	paragraph separation
<code>p=1; % pressure in bar</code>	declaration of the variables pressure, temperature and humidity
<code>t=20; % temperature in °C</code>	
<code>xw=10; % absolute humidity in g/kg(air)</code>	humidity
<code>%%</code>	paragraph separation
<code>hl=hl_ptxw_HuAir(p,t,xw)</code>	function call
<code>%%</code>	paragraph separation

- To calculate the example press F5 on your keyboard or click on the symbol shown in Figure 2.4, marked with 5.
- In the "Command Window" you will see the result "h = 45.5084", marked with 6 in Figure 2.4. The corresponding unit is kJ/kg (see table of the property functions in Chapter 1).

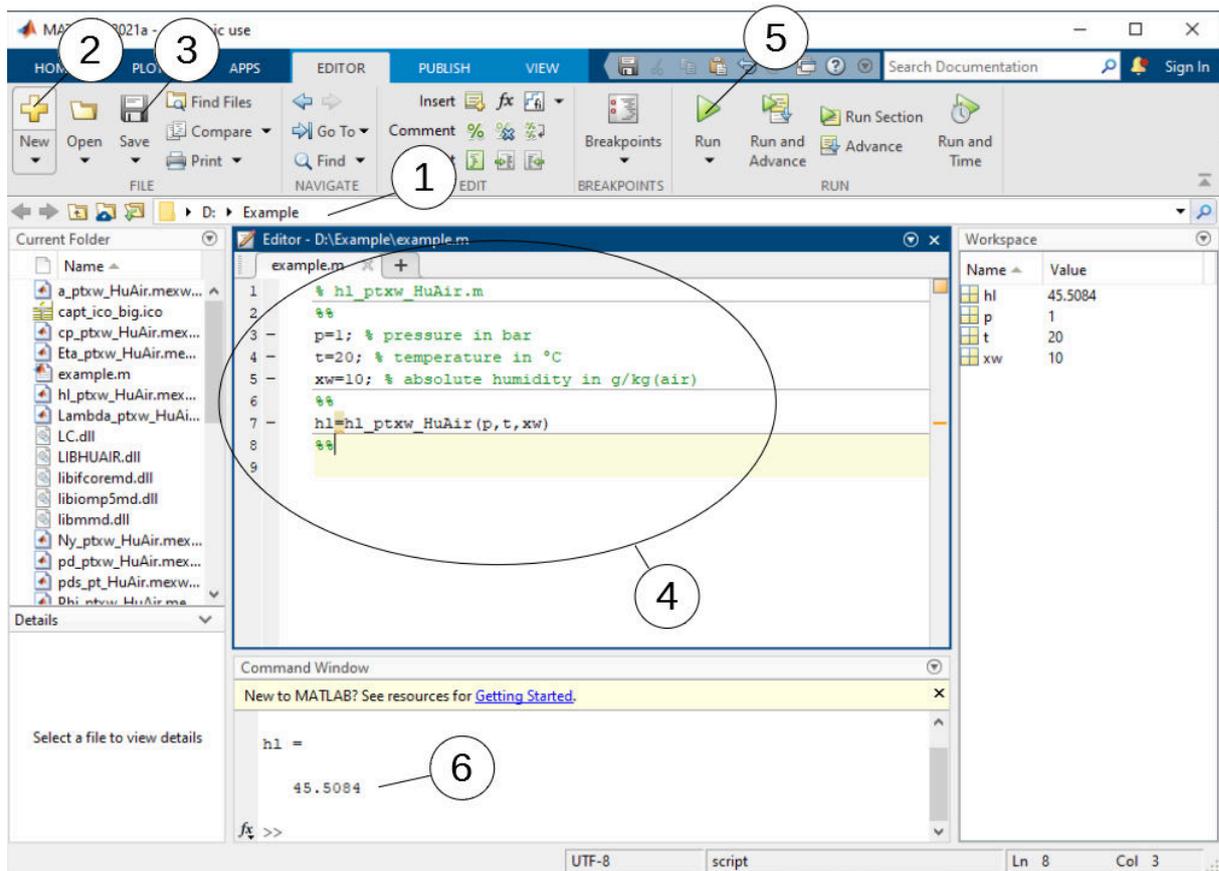


Figure 2.4: Example calculation in MATLAB®

- Remarks:

- The program interprets the first line which starts with " %" to be a data description in "Current Directory"
- Paragraph separations which are mandatory are being realised through " %%". By this, declaration of variables and calculation instructions are also being separated.
- The words which are printed in green, start with " %" and stand behind the variables are comments. In fact they are not necessary but they are reasonable for your overview and comprehensibility.
- You have to leave out the semicolons behind the numerical values if you wish to see the result for h and the input parameters as well.

The values of the function parameters in their corresponding units stand for:

- **First operand:** Value for $p = 1$ bar
(Range of validity: $p = 0.006112$ bar ... 165.29 bar)
- **Second operand:** Value for $t = 20^\circ\text{C}$
(Range of validity: $t = -143.15^\circ\text{C}$... 1726.85°C)
- **Third operand:** Value for $x_w = 10$ g water/kg dry air
(Range of validity: $x_w \geq 0$ g/kg)

2.4 Using FluidLAB with SIMULINK

To use the functions of FluidLAB with the simulation program SIMULINK you have to start SIMULINK in MATLAB® by clicking on Simulink in the upper menu bar shown in Figure 2.5.

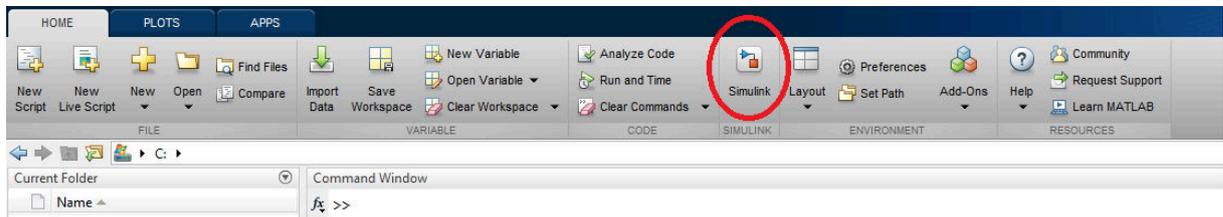


Figure 2.5: Starting Simulink

Then choose a blank model or a simulation in which you would like to use FluidLAB. Now you need to add a MATLAB function block that you can find in the library browser shown in Figure 2.6.

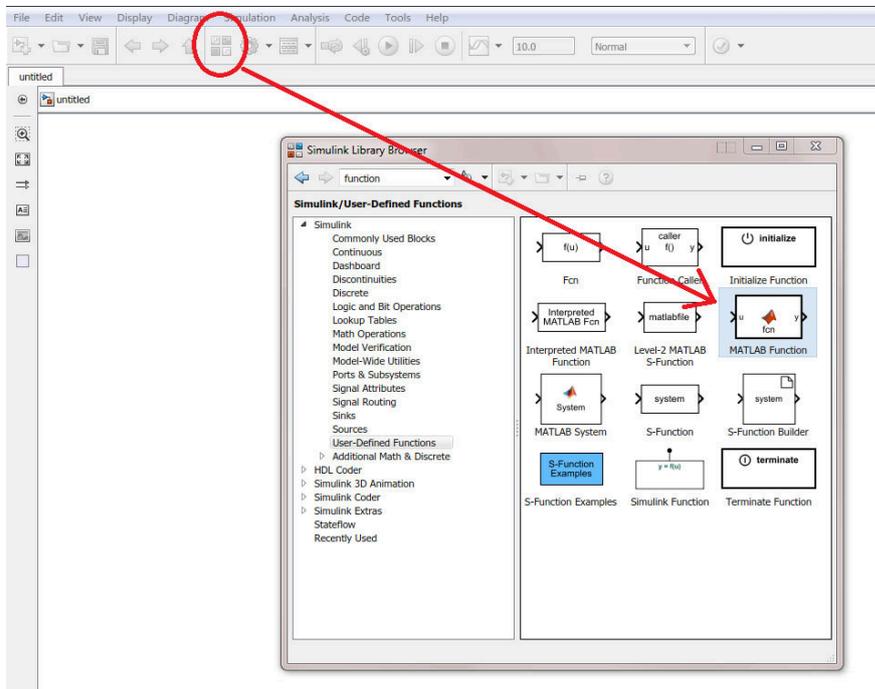


Figure 2.6: Simulink library browser and choosing a MATLAB Function

By dragging and dropping you can drag a Simulink block in your model. The function needs inputs and output that you can find in the Simulink library browser under sources and sinks. For this example constants were taken for the inputs and a display block were taken for outputting.

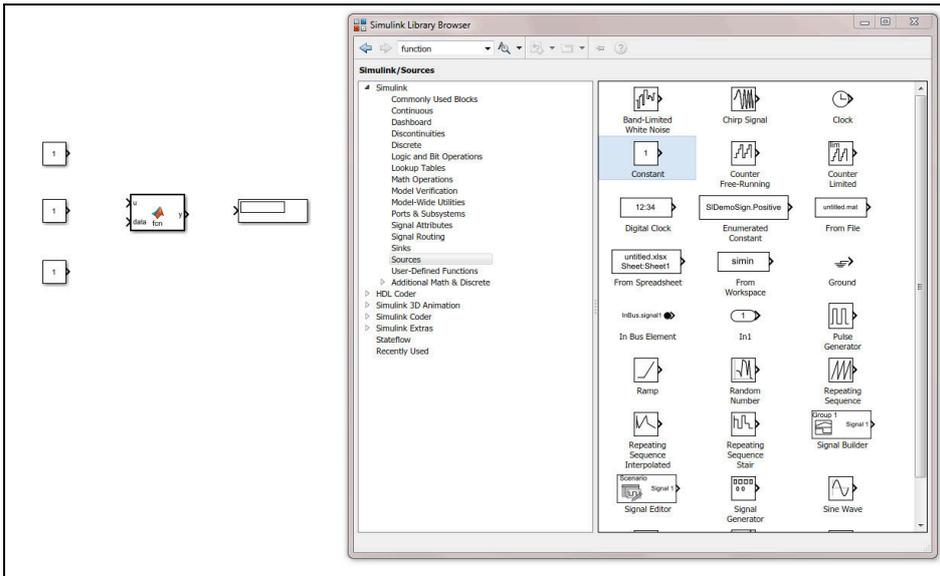


Figure 2.7: Inputs and outputs of the example

Now you have to link inputs and outputs to the MATLAB function block. By pressing and holding the left mouse button on the arrow of a block, you can draw a line and drag it to the MATLAB function block. With this method you can link all blocks together.

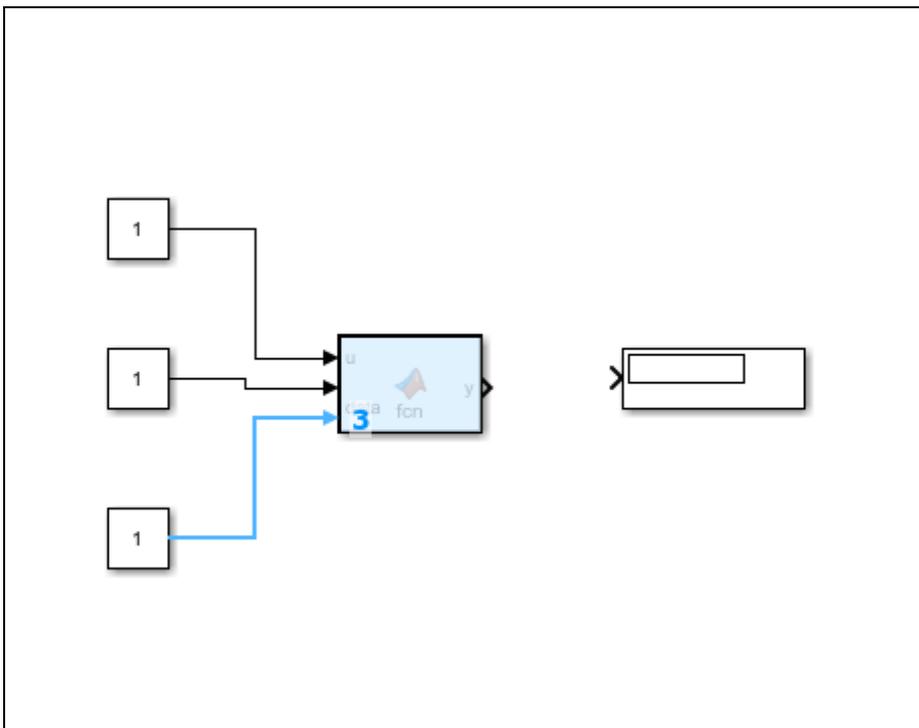


Figure 2.8: Linking blocks in Simulink

You can define the value of a constant block by double-click on them. If you want to calculate the example use the values you can find in Section 2.3. With a double-click on the MATLAB function block you can define the function in MATLAB®. The following source code is for the example calculation and the table below describes the source code closer. You can adapt these few lines to call all other function of FluidLAB:

```
function h = fcn(p, t, x)
coder.extrinsic('addpath');
coder.extrinsic('h_ptx_HuAir');
addpath('D:\Example');
h = = coder.nullcopy(zeros(size(1)));
h = h_ptx_HuAir(p,t,x);
```

Matlab source code	Explanation
function h = fcn(p, t, x)	function header, you can define the function name and the inputs like p, t and x of the example
coder.extrinsic('addpath');	necessary to add a path
coder.extrinsic('h_ptx_HuAir');	Choose the function name of the FluidLAB function
addpath('D:\Example');	Add the installation path of FluidLAB
h = coder.nullcopy(zeros(size(1)));	Declaration of the output value h and filling it with zeros
h = h_ptx_HuAir(p,t,x);	Linking the FluidLAB function to the MATLAB function block

You can copy and paste the sourcecode in MATLAB® or write it into the MATLAB® editor. The simulation will start by clicking the run button in Matlab or Simulink and you can see the example in the display block of the simulation which is shown in Figure 2.23.

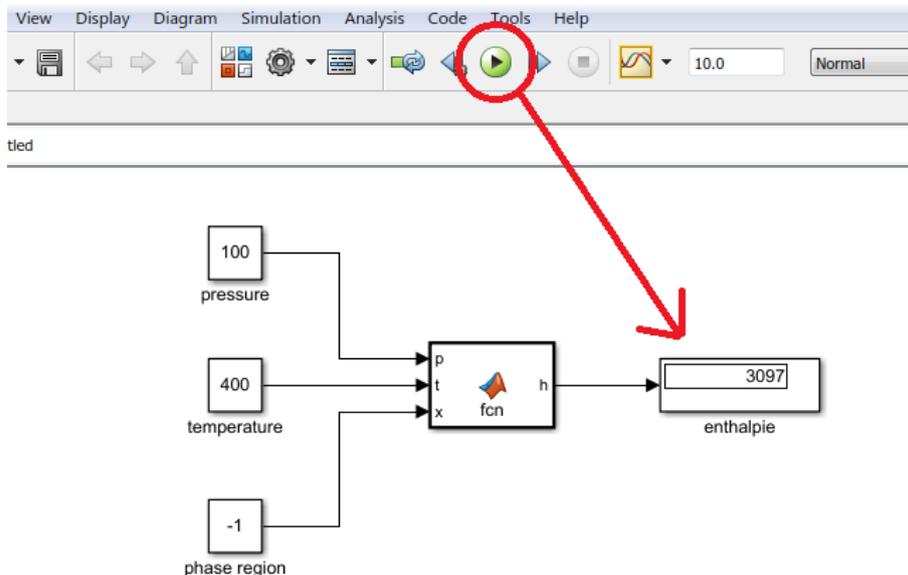


Figure 2.9: Starting the simulation and result of the calculation

Your result is may an other than shown in Figure 2.9. If you want to calculate the example please use the values from section 2.3.

2.5 Removing FluidLAB including LibHUAIR

- To remove the LibHUAIR property library from your hard disk drive in Windows®, click "Start" in the Windows® task bar, select "Settings" and click "Control Panel".
- Now double-click on "Add or Remove Programs".
- In the list box of the "Add or Remove Programs" window that appears select "FluidLAB LibHUAIR" by clicking on it and click the "Change/Remove" button.
- In the following dialog box click "Automatic" and thereafter click the "Next>" button.
- Confirm the following menu "Perform Uninstall" by clicking the "Finish" button.
- Finally, close the windows "Add or Remove Programs" and "Control Panel" windows.
- Now, FluidLAB has been removed.

3. Program Documentation

Thermal Diffusivity $a = f(p,t,x_w)$

Function Name:

a_ptxw_HuAir

Fortran Programs:

REAL*8 FUNCTION a_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw

INTEGER*4 FUNCTION C_a_ptxw_HuAir(a,p,t,xw), REAL*8 a,p,t,xw

Input Values:

p - Mixture pressure p in bar

t - Temperature t in °C

x_w - Absolute humidity x_w in g/kg_{Air}

Result:

a_ptxw_HuAir, a - Thermal diffusivity in m² / s

Range of Validity:

Temperature t : from -73.15°C to 1726.85°C

Mixture pressure p : from 6.112 mbar to 165.29 bar

Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

- Thermal diffusivity $a = \frac{\lambda}{\rho \cdot c_p}$
- Model of ideal mixture of real fluids

Results for wrong input values:

a_ptxw_HuAir, a = - 1

References:

Dry Air:

λ from *Lemmon* et al. [15]

c_p from *Lemmon* et al. [14]

ρ from *Lemmon* et al. [14]

Steam in humid air and liquid droplets in fog:

λ for $0^\circ\text{C} \leq t \leq 800^\circ\text{C}$ from IAPWS-85 [6]
for $t < 0^\circ\text{C}$ and $t > 800^\circ\text{C}$ from *Brandt* [12]

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

ρ from IAPWS-IF97 [1], [2], [3], [4]

for $t < 0.01^\circ\text{C}$ from IAPWS-06 [18], [19]

Specific Isobaric Heat Capacity $c_p = f(p, t, x_w)$

Function Name:

cp_ptxw_HuAir

Fortran Programs:

REAL*8 FUNCTION cp_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw

INTEGER*4 FUNCTION C_cp_ptxw_HuAir(cp,p,t,xw), REAL*8 cp,p,t,xw

Input Values:

p - Mixture pressure p in bar

t - Temperature t in °C

x_w - Absolute humidity x_w in g/kg_{Air}

Result:

cp_ptxw_HuAir, cp - Specific isobaric heat capacity in kJ/(kg K)

Range of Validity:

Temperature t : from -143.15°C to 1726.85°C

Mixture pressure p : from 6.112 mbar to 165.29 bar

Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

- For unsaturated and saturated humid air ($x_w \leq x_{ws}$), calculation as ideal mixture of real gases (dry air and steam)
- For supersaturated humid air ($x_w \geq x_{ws}$), calculation is not possible
- For temperatures greater than 500°C, the dissociation is taken into consideration

Results for wrong input values:

cp_ptxw_HuAir, cp = -1

References:

Dry Air:

from *Lemmon* et al. [14]

Steam in humid air and liquid droplets in fog:

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

Dissociation:

from VDI Guideline 4670 [13]

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

Function Name:

Eta_ptxw_HuAir

Fortran Programs:

REAL*8 FUNCTION Eta_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw

INTEGER*4 FUNCTION C_Eta_ptxw_HuAir(Eta,p,t,xw), REAL*8 Eta,p,t,xw

Input values:

p - Mixture pressure p in bar
 t - Temperature t in °C
 x_w - Absolute humidity x_w in g/kg_{Air}

Result:

Eta_ptxw_HuAir, Eta - Dynamic viscosity in Pa s

Range of Validity:

Temperature t : from -73.15°C to 1726.85°C
 Mixture pressure p : from 6.112 mbar to 165.29 bar
 Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

- Model of ideal mixture of real fluids
- Neglect of ice crystals in ice fog (t < 0.01°C and x_w > x_{ws})

Results for wrong input values:

Eta_ptxw_HuAir, Eta = -1

References:

Dry Air:
 from *Lemmon et al.* [15]
 Steam in humid air and liquid droplets in fog:
 for 0°C ≤ t ≤ 800°C from IAPWS-85 [7]
 for t < 0°C and t > 800°C from *Brandt* [12]

Air-Specific Enthalpy $h_l = f(p, t, x_w)$

Function Name:

hl_ptxw_HuAir

Fortran Programs:

```
REAL*8 FUNCTION hl_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw
INTEGER*4 FUNCTION C_hl_ptxw_HuAir(hl,p,t,xw), REAL*8 hl,p,t,xw
```

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C
 x_w - Absolute humidity x_w in g/kg_{Air}

Result:

hl_ptxw_HuAir, hl - Air-specific enthalpy in kJ/kg_{Air}

Range of Validity:

Temperature t : from -143.15°C to 1726.85°C
Mixture pressure p : from 6.112 mbar to 165.29 bar
Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

- For unsaturated and saturated humid air ($x_w \leq x_{ws}$), calculation as ideal mixture of real gases (dry air and steam)
- For fog ($x_w > x_{ws}$), calculation as ideal mixture of saturated humid air and water, ice
- For temperatures greater than 500°C, the dissociation is taken into consideration

Result for wrong input values:

hl_ptxw_HuAir, hl = -1000

References:

Dry Air:
from *Lemmon* et al. [14]
Steam in humid air and liquid 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]

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

Lambda_ptxw_HuAir

Fortran Programs:

```
REAL*8 FUNCTION Lambda_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw
INTEGER*4 FUNCTION C_Lambda_ptxw_HuAir(Lambda,p,t,xw),
REAL*8 Lambda,p,t,xw
```

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C
 x_w - Absolute humidity x_w in g/kg_{Air}

Result:

Lambda_ptxw_HuAir, Lambda - Heat conductivity in W/(m K)

Range of Validity:

Temperature t : from -73.15°C to 1726.85°C
Mixture pressure p : from 6.112 mbar to 165.29 bar
Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

- Model of ideal mixture of real fluids

Result for wrong input values:

Lambda_ptxw_HuAir, Lambda = -1

References:

Dry Air:
from *Lemmon* et al. [15]
Steam in humid air and humid droplets in fog:
for $0^\circ\text{C} \leq t \leq 800^\circ\text{C}$ from IAPWS-85 [6]
for $t < 0^\circ\text{C}$ and $t > 800^\circ\text{C}$ from *Brandt* [12]

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

Ny_ptxw_HuAir

Fortran Programs:

REAL*8 FUNCTION Ny_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw

INTEGER*4 FUNCTION C_Ny_ptxw_HuAir(Ny,p,t,xw), REAL*8 Ny,p,t,xw

Input values:

p - Mixture pressure p in bar

t - Temperature t in °C

x_w - Absolute humidity x_w in g/kg_{Air}**Result:**Ny_ptxw_HuAir, Ny - Kinematic viscosity in m²/s**Range of Validity:**

Temperature t : from -73.15°C to 1726.85°C

Mixture pressure p : from 6.112 mbar to 165.29 bar

Absolute humidity x_w : ≥ 0 g/kg_{Air}**Comments:**

- Kinematic viscosity $\nu = \frac{\eta}{\rho} = \eta \cdot \nu$
- Model of ideal mixture of real fluid

Result for wrong input values:

Ny_ptxw_HuAir, Ny = -1

References:

Dry Air:

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

Steam in humid air and liquid droplets in fog:

η for 0°C ≤ t ≤ 800°C from IAPWS-85 [7]

for t < 0°C and t > 800°C from *Brandt* [12]

ρ from IAPWS-IF97 [1], [2], [3], [4]

for t < 0.01 °C from IAPWS-06 [18], [19]

Partial Pressure of Steam $p_d = f(p, t, x_w)$

Function Name:

pd_ptxw_HuAir

Fortran Programs:

```
REAL*8 FUNCTION pd_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw
INTEGER*4 FUNCTION C_pd_ptxw_HuAir(pd,p,t,xw), REAL*8 pd,p,t,xw
```

Input values:

p - Mixture pressure p in bar
 t - Temperature t in °C
 x_w - Absolute humidity x_w in g/kg_{Air}

Result:

pd_ptxw_HuAir, pd - Partial pressure of steam in bar

Range of Validity:

Temperature t : from -143.15°C to 1726.85°C
 Mixture pressure p : from 6.112 mbar to 165.29 bar
 Absolute humidity x_w : from 0 g/kg_{Air} to x_{ws}(p, t)

Comments:

- Partial pressure of steam $p_d = \frac{x_w}{\frac{R_l}{R_w} + x_w} \cdot p$ for $x_w \leq x_{ws}(p, t)$
- For $x_w > x_{ws}(p, t)$ result $p_d = p_{ds}(p, t)$
- Saturation vapor pressure at saturation $p_{ds} = f \cdot p_s(t)$
 with $p_{ds}(p, t)$ for $t \geq 0.01^\circ\text{C}$ - vapor pressure of water
 for $t < 0.01^\circ\text{C}$ - sublimation pressure of water
- Result for pure steam, liquid water and water ice: $p_d = 0$

Result for wrong input values:

pd_ptxw_HuAir, pd = -1

References:

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

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

pds_pt_HuAir

Fortran Programs:

```
REAL*8 FUNCTION pds_pt_HuAir(p,t), REAL*8 p,t
INTEGER*4 FUNCTION C_pds_pt_HuAir(pds,p,t), REAL*8 pds,p,t
```

Input values:

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

Result:

pds_pt_HuAir, pds - Saturation vapor pressure of water in humid air in bar

Range of Validity:

Temperature t : from -143.15°C to $t_s(p,p_d)$
(boiling temperature of water in gas mixtures)
Mixture pressure p : from 6.112 mbar to 165.29 bar

Comments:

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

Result for wrong input values:

pds_pt_HuAir, pds = -1

References:

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

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

Function Name:

Phi_ptxw_HuAir

Fortran Programs:

REAL*8 FUNCTION Phi_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw

INTEGER*4 FUNCTION C_Phi_ptxw_HuAir(Phi,p,t,xw), REAL*8 Phi,p,t,xw

Input values:

p - Mixture pressure p in bar

t - Temperature t in °C

x_w - Absolute humidity x_w in g/kg_{Air}

Result:

Phi_ptxw_HuAir, Phi - Relative humidity in %

Range of Validity:

Temperature t : from -143.15°C to $t_{\text{critical}} = 373,946^\circ\text{C}$ (critical temperature of water)

Mixture pressure p : from 6.112 mbar to 165.29 bar

Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

$$\text{Relative humidity } \varphi = \frac{x_w}{\frac{R_l}{R_w} + x_w} \frac{p}{p_{ds}(p, t)} \cdot 100\%$$

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

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

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

Result for wrong input values:

Phi_ptxw_HuAir, Phi = - 1

References:

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

$p_s(t)$ if $t \geq 0.01^\circ\text{C}$ from IAPWS-IF97 [1], [2], [3], [4]

if $t < 0.01^\circ\text{C}$ from IAPWS-08 [16], [17]

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

pl_ptxw_HuAir

Fortran Programs:

```
REAL*8 FUNCTION pl_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw
INTEGER*4 FUNCTION C_pl_ptxw_HuAir(pl,p,t,xw), REAL*8 pl,p,t,xw
```

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C
 x_w - Absolute humidity x_w in g/kg_{Air}

Result:

pl_ptxw_HuAir, pl - Partial pressure of air in bar

Range of Validity:

Temperature t : from -143.15°C to 1726.85°C
Mixture pressure p : from 6.112 mbar to 165.29 bar
Absolute humidity x_w : from 0 g/kg_{Air} to $x_{ws}(p, t)$

Comments:

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

when $x_w > x_{ws}(p, t)$ result $p_l = p - p_{ds}(p, t)$

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

with $p_{ds}(p, t)$ for $t \geq 0.01^\circ\text{C}$ - vapor pressure of water in gas mixtures

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

Result for wrong input values:

pl_ptxw_HuAir, pl = -1

References:

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

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

Pr_ptxw_HuAir

Fortran Programs:

REAL*8 FUNCTION Pr_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw

INTEGER*4 FUNCTION C_Pr_ptxw_HuAir(Pr,p,t,xw), REAL*8 Pr,p,t,xw

Input values:

- p - Mixture pressure p in bar
- t - Temperature t in °C
- x_w - Absolute humidity x_w in g/kg_{Air}

Result:Pr_ptxw_HuAir, Pr - *Prandtl*-number**Range of Validity:**

- Temperature t : from -73.15°C to 1726.85°C
- Mixture pressure p : from 6.112 mbar to 165.29 bar
- Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

- Prandtl-number $Pr = \frac{\nu}{a} = \frac{\eta \cdot c_p}{\lambda}$
- Model of ideal mixture of real fluids

Result for wrong input values:

Pr_ptxw_HuAir , Pr = - 1

References:

Dry Air:

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

Steam in humid air and liquid droplets in fog:

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

Dissociation:

- from VDI Guideline 4670 [13]

Mole Fraction of Air $\psi_I = f(x_w)$
Function Name:

Psil_xw_HuAir

Fortran Programs:

```
REAL*8 FUNCTION Psil_xw_HuAir(xw), REAL*8 xw
INTEGER*4 FUNCTION C_Psil_xw_HuAir(Psil, xw), REAL*8 Psil, xw
```

Input values:

x_w - Absolute humidity x_w in g/kg_{Air}

Result:

Psil_xw_HuAir, Psil - Mole fraction of air in kmol / kmol

Range of Validity:

Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

Mole fraction of dry air $\psi_I = 1 - \frac{R_w \cdot x_w}{R(1 + x_w)}$

Result for wrong input values:

Psil_xw_HuAir, Psil = - 1

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

Psiw_xw_HuAir

Fortran Programs:

```
REAL*8 FUNCTION Psiw_xw_HuAir(xw), REAL*8 xw
INTEGER*4 FUNCTION C_Psiw_xw_HuAir(Psiw,xw), REAL*8 Psiw, xw
```

Input values:

x_w - Absolute humidity x_w in g/kg_{Air}

Result:

Psiw_xw_HuAir, Psiw - Mole fraction of water in kmol / kmol

Range of Validity:

Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

Mole fraction of water $\psi_w = \frac{R_w \cdot x_w}{R(1 + x_w)}$

Result for wrong input values:

Psiw_xw_HuAir , Psiw = - 1

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

Rho_ptxw_HuAir

Fortran Programs:

```
REAL*8 FUNCTION Rho_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw
INTEGER*4 FUNCTION C_Rho_ptxw_HuAir(Rho,p,t,xw), REAL*8 Rho,p,t,xw
```

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C
 x_w - Absolute humidity x_w in g/kg_{Air}

Result:

Rho_ptxw_HuAir, Rho - Density in kg/m³

Range of Validity:

Temperature t : from -143.15°C to 1726.85°C
Mixture pressure p : from 6.112 mbar to 165.29 bar
Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

- For unsaturated and saturated humid air ($x_w \leq x_{ws}$), calculation as ideal mixture of real gases (dry air and steam)
- For fog ($x_w > x_{ws}$), calculation as ideal mixture of saturated humid air and water, ice

Result for wrong input values:

Rho_ptxw_HuAir, Rho = -1

References:

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

Air-Specific Entropy $s_l = f(p, t, x_w)$

Function Name:

sl_ptxw_HuAir

Fortran Programs:

```
REAL*8 FUNCTION sl_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw
INTEGER*4 FUNCTION C_sl_ptxw_HuAir(sl,p,t,xw), REAL*8 sl,p,t,xw
```

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C
 x_w - Absolute humidity x_w in g/kg_{Air}

Result:

sl_ptxw_HuAir, sl - Air-specific entropy in kJ/(kg_{Air} K)

Range of Validity:

Temperature t : from -143.15°C to 1726.85°C
Mixture pressure p : from 6.112 mbar to 165.29 bar
Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

- For unsaturated and saturated humid air ($x_w \leq x_{ws}$), calculation as ideal mixture of real gases (dry air and steam)
- For fog ($x_w > x_{ws}$), calculation as ideal mixture of saturated humid air and water, ice
- For temperatures greater than 500°C, the dissociation is taken into consideration

Result for wrong input values:

sl_ptxw_HuAir, sl = - 1000

References:

Dry Air:
from *Lemmon et al.* [14]
Steam in humid air and liquid 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]

Backward Function: $t = f(p, h_l, x_w)$
Function Name:

t_phlxw_HuAir

Fortran Programs:

REAL*8 FUNCTION t_phlxw_HuAir(p,hl,xw), REAL*8 p,hl,xw

INTEGER*4 FUNCTION C_t_phlxw_HuAir(t,p,hl,xw), REAL*8 t,p,hl,xw

Input values:

p - Mixture pressure p in bar

h_l - Air-specific enthalpy in kJ/kg_{Air}x_w - Absolute humidity x_w in g/kg_{Air}**Result:**

t_phlxw_HuAir, t - Temperature in °C

Range of Validity:

Temperature t : from -143.15°C to 1726.85°C

Mixture pressure p : from 6.112 mbar to 165.29 bar

Absolute humidity x_w : ≥ 0 g/kg_{Air}**Comments:**Iteration from t of h_l(p,t,x_w)Calculation of h_l(p,t,x_w):

- For unsaturated and saturated humid air ($x_w \leq x_{ws}$), calculation as ideal mixture of real gases (dry air and steam)
- For fog ($x_w > x_{ws}$), calculation as ideal mixture of saturated humid air and water, ice
- For temperatures greater than 500°C, the dissociation is taken into consideration

Result for wrong input values:

t_phlxw_HuAir , t = - 1000

References:

Dry Air:

from Lemmon et al. [14]

Steam in humid air and liquid 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]

Backward Function: $t = f(p, s_l, x_w)$
Function Name:

t_pslxw_HuAir

Fortran Programs:

REAL*8 FUNCTION t_pslxw_HuAir(p,sl,xw), REAL*8 p,sl,xw

INTEGER*4 FUNCTION C_t_pslxw_HuAir(t,p,sl,xw), REAL*8 t,p,sl,xw

Input values:

p - Mixture pressure p in bar

s_l - Air-specific entropy in kJ/(kg_{Air} K)x_w - Absolute humidity x_w in g/kg_{Air}**Result:**

t_pslxw_HuAir, t - Temperature in °C

Range of Validity:

Temperature t : from -143.15°C to 1726.85°C

Mixture pressure p : from 6.112 mbar to 165.29 bar

Absolute humidity x_w : ≥ 0 g/kg_{Air}**Comments:**Iteration from t of s_l(p,t,x_w)Calculation of s_l(p,t,x_w):

- For unsaturated and saturated humid air ($x_w \leq x_{ws}$), calculation as ideal mixture of real gases (dry air and steam)
- For fog ($x_w > x_{ws}$), calculation as ideal mixture of saturated humid air and water, ice

From 500°C influence because of dissociation taken into consideration.

Result for wrong input values:

t_pslxw_HuAir, t = -1000

References:

Dry Air:

from Lemmon et al. [22]

Steam in humid air and liquid droplets in fog:

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

Ice crystals in fog:

from IAPWS-06 [18], [19]

Dissociation:

from VDI Guideline 4670 [13]

Wet Bulb Temperature $t_f = f(p, t, x_w)$

Function Name:

tf_ptxw_HuAir

Fortran Programs:

```
REAL*8 FUNCTION tf_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw
INTEGER*4 FUNCTION C_tf_ptxw_HuAir(tf,p,t,xw), REAL*8 tf,p,t,xw
```

Input values:

p - Mixture pressure p in bar
 t - Temperature t in °C
 x_w - Absolute humidity x_w in g/kg_{Air}

Result:

tf_ptxw_HuAir, tf - Wet bulb temperature in °C

Range of Validity:

Temperature t : from 0.01°C to 1726,85 °C
 Mixture pressure p : from 6.112 mbar to 165.29 bar
 Absolute humidity x_w : from 0 g/kg to x_{ws}(p,t)

Comments:

- Iteration from t_f of $h_l^{\text{unsaturated}}(p, t, x_w) = h_l^{\text{fog}}(p, t_f, x_w)$
- For temperatures greater than 500°C, the dissociation is taken into consideration

Result for wrong input values:

tf_ptxw_HuAir, tf = - 1000

References:

Dry Air:
 from *Lemmon et al.* [22]
 Steam in humid air and liquid droplets in fog:
 from IAPWS-IF97 [1], [2], [3], [4]
 Dissociation:
 from VDI Guideline 4670 [13]

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

tTau_pxw_HuAir

Fortran Programs:

REAL*8 FUNCTION tTau_pxw_HuAir(p,xw), REAL*8 p,xw

INTEGER*4 FUNCTION C_tTau_pxw_HuAir(tTau,p,xw), REAL*8 tTau,p,xw

Input values:

p - Mixture pressure p in bar

 x_w - Absolute humidity x_w in g/kg_{Air}**Result:**

tdew_pxw_HuAir, tdew - Dew point temperature in °C

Range of Validity:

Mixture pressure p : from 6.112 mbar to 165.29 bar

Absolute humidity x_w : $\geq x_{ws}(p, -30^\circ\text{C})$ **Comments:**

Dew point temperature $t_\tau = t_s(p, p_d)$ for $t \geq 0.01^\circ\text{C}$
 (boiling temperature of water in gas mixtures)

$t_\tau = t_{sub}(p, p_d)$ for $t < 0.01^\circ\text{C}$
 (sublimation temperature from water in gas mixtures)

$$\text{with } p_d = \frac{x_w}{\frac{R_l}{R_w} + x_w} p$$

Result for wrong input values:

tdew_pxw_HuAir, tdew = - 1000

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

Air-Specific Internal Energy $u_l = f(p, t, x_w)$

Function Name:

ul_ptxw_HuAir

Fortran Programs:

```
REAL*8 FUNCTION ul_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw
INTEGER*4 FUNCTION C_ul_ptxw_HuAir(ul,p,t,xw), REAL*8 ul,p,t,xw
```

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C
 x_w - Absolute humidity x_w in g/kg_{Air}

Result:

ul_ptxw_HuAir, ul - Air-specific internal energy in kJ/kg_{Air}

Range of Validity:

Temperature t : from -143.15°C to 1726.85°C
Mixture pressure p : from 6.112 mbar to 165.29 bar
Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

Calculation: $u_l = h_l - p \cdot v_l$

- For unsaturated and saturated humid air ($x_w \leq x_{ws}$), calculation as ideal mixture of real gases (dry air and steam)
- For fog ($x_w > x_{ws}$), calculation as ideal mixture of saturated humid air and water, ice
- For temperatures greater than 500°C, the dissociation is taken into consideration

Result for wrong input values:

ul_ptxw_HuAir, ul = - 1000

References:

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

Air-specific Volume $v_l = f(p, t, x_w)$

Function Name:

vl_ptxw_HuAir

Fortran Programs:

```
REAL*8 FUNCTION vl_ptxw_HuAir(p,t,xw), REAL*8 p,t,xw
INTEGER*4 FUNCTION C_vl_ptxw_HuAir(vl, p, t ,xw), REAL*8 vl,p,t,xw
```

Input values:

p - Mixture pressure p in bar
 t - Temperature t in °C
 x_w - Absolute humidity x_w in g/kg_{Air}

Result:

vl_ptxw_HuAir, vl - Air-specific volume in m³/kg_{Air}

Range of Validity:

Temperature t : from -143.15°C to 1726.85°C
 Mixture pressure p : from 6.112 mbar to 165.29 bar
 Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

- For unsaturated and saturated humid air ($x_w \leq x_{ws}$), calculation as ideal mixture of real gases (dry air and steam)
- For fog ($x_w > x_{ws}$), calculation as ideal mixture of saturated humid air and water, ice

Result for wrong input values:

vl_ptxw_HuAir, vl = -1

References:

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

Mass Fraction of Air $\xi_l = f(x_w)$
Function Name:

Xil_xw_HuAir

Fortran Programs:

```
REAL*8 FUNCTION Xil_xw_HuAir(xw), REAL*8 xw
INTEGER*4 FUNCTION C_Xil_xw_HuAir(Xil,xw), REAL*8 Xil,xw
```

Input values:

x_w - Absolute humidity x_w in g/kg_{Air}

Result:

Xil_xw_HuAir, Xil - Mass fraction of air

Range of Validity:

Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

Mass fraction of dry air $\xi_l = 1 - \frac{x_w}{1 + x_w}$

Result for wrong input values:

Xil_xw_HuAir , Xil = - 1

Mass Fraction of Water $\xi_w = f(x_w)$
Function Name:

Xiw_xw_HuAir

Fortran Programs:

```
REAL*8 FUNCTION Xiw_xw_HuAir(xw), REAL*8 xw
INTEGER*4 FUNCTION C_Xiw_xw_HuAir(Xiw,xw), REAL*8 Xiw,xw
```

Input values:

x_w - Absolute humidity x_w in g/kg_{Air}

Result:

Xiw_xw_HuAir, Xiw - Mass fraction of water

Range of Validity:

Absolute humidity x_w : ≥ 0 g/kg_{Air}

Comments:

Mass fraction of water $\xi_w = \frac{x_w}{1+x_w}$

Result for wrong input values:

Xiw_xw_HuAir, Xiw = - 1

Absolute Humidity from Relative Humidity $x_w = f(p,t,\varphi)$
Function Name:

xw_ptPhi_HuAir

Fortran Programs:

```
REAL*8 FUNCTION xw_ptPhi_HuAir(p,t,Phi), REAL*8 p,t,Phi
INTEGER*4 FUNCTION C_xw_ptPhi_HuAir(xw,p,t,Phi), REAL*8 xw,p,t,Phi
```

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C
Phi - Relative humidity in %

Result:

xw_ptPhi_HuAir, x_w - Absolute humidity from temperature and relative humidity
in g/kg_{Air}

Range of Validity:

Temperature t : from -143.15°C to $t_{critical} = 373,946^\circ\text{C}$ (critical temperature of water)
Mixture pressure p : from 6.112 mbar to 165.29 bar
Relative Humidity φ : from 0 % to 100 %

Comments:

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

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

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

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

Result for wrong input values:

xw_ptPhi_HuAir, $x_w = -1$

References:

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

Absolute Humidity from Partial Pressure of Steam $x_w = f(p,t,p_d)$
Function Name:

xw_ptpd_HuAir

Fortran Programs:

```
REAL*8 FUNCTION xw_ptpd_HuAir(p,t,pd), REAL*8 p,t,pd
INTEGER*4 FUNCTION C_xw_ptpd_HuAir(xw,p,t,pd), REAL*8 xw,p,t,pd
```

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C
p_d - Partial pressure of steam in bar

Result:

xw_ptpd_HuAir, x_w - Absolute humidity from partial pressure in g/kg_{Air}

Range of Validity:

Temperature t : from -143.15°C to 1726.85°C
Mixture pressure p : from 6.112 mbar to 165.29 bar
Partial pressure of steam p_d : from 6.112 mbar to p_{ds}(p,t) for t ≤ 373,946°C,
to 165.29 bar for t > 373,946°C

Comments:

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

Saturation vapor pressure at saturation p_{ds} = f · p_s(t)

with p_{ds}(p,t) for t ≥ 0.01°C - Vapor pressure of water

for t < 0.01°C - Sublimation pressure of water

Result for wrong input values:

xw_ptpd_HuAir, x_w = - 1

References:

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

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

xw_ptTau_HuAir

Fortran Programs:

```
REAL*8 FUNCTION xw_ptTau_HuAir(p,tTau), REAL*8 p,tTau
INTEGER*4 FUNCTION C_xw_ptTau_HuAir(xw,p,tTau), REAL*8 xw, p,tTau
```

Input values:

p - Mixture pressure p in bar
 t_τ - Dew point temperature in °C

Result:

xw_ptTau_HuAir, x_w - Absolute humidity from temperature and dew point temperature in g/kg_{Air}

Range of Validity:

Dew point temperature t_τ : from -143.15°C to $t_{ds}(p, p_d)$
 (boiling temperature of water in gas mixtures)
 Mixture pressure p : from 6.112 mbar to 165.29 bar

Comments:

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

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

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

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

Result for wrong input values:

xw_ptTau_HuAir, $x_w = -1$

References:

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

$p_{ds}(p, t)$ if $t \geq 0.01^\circ\text{C}$ from IAPWS-IF97 [1], [2], [3], [4]

if $t < 0.01^\circ\text{C}$ from IAPWS-08 [16], [17]

Absolute Humidity from Wet Bulb Temperature $x_w = f(p, t, t_f)$
Function Name:

xw_pttf_HuAir

Fortran Programs:

```
REAL*8 FUNCTION xw_pttf_HuAir(p,t,tf), REAL*8 p,t,tf
INTEGER*4 FUNCTION C_xw_pttf_HuAir(xw,p,t,tf), REAL*8 xw,p,t,tf
```

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C
 t_f - Wet bulb temperature in °C

Result:

xw_pttf_HuAir, x_w - Absolute humidity from temperature and wet bulb temperature in g/kg_{Air}

Range of Validity:

Temperature t : from 0.01°C to 1726.85°C
Wet bulb temperature t_f : from 0.01°C to the given temperature t, to $t_s(p, p_d)$ (boiling temp. of water in gas mixtures)
Mixture pressure p : from 6.112 mbar to 165.29 bar

Comments:

Iteration of x_w from $h_1^{\text{unsaturated}}(p, t, x_w) = h_1^{\text{fog}}(p, t_f, x_w)$

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

Result for wrong input values:

xw_pttf_HuAir, $x_w = -1$

References:

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

Backward Function: $x_w = f(p, t, v_l)$
Function Name:

xw_ptvl_HuAir

Fortran Programs:

```
REAL*8 FUNCTION xw_ptvl_HuAir(p,t,vl), REAL*8 p,t,vl
INTEGER*4 FUNCTION C_xw_ptvl_HuAir(xw, p,t,vl), REAL*8 xw,p,t,vl
```

Input values:

p - Mixture pressure p in bar
t - Temperature t in °C
 v_l - Air-specific volume in $\text{m}^3/\text{kg}_{\text{Air}}$

Result:

xw_ptvl_HuAir, x_w - Absolute humidity in $\text{g}/\text{kg}_{\text{Air}}$

Range of Validity:

Temperature t : from -143.15°C to 1726.85°C
Mixture pressure p : from 6.112 mbar to 165.29 bar

Comments:

Iteration of x_w from $v_l(p, t, x_w)$

Calculation from $v_l(p, t, x_w)$:

- For unsaturated and saturated humid air ($x_w \leq x_{ws}$), calculation as ideal mixture of real gases (dry air and steam)
- For fog ($x_w > x_{ws}$), calculation as ideal mixture of saturated humid air and water, ice

Result for wrong input values:

xw_ptvl_HuAir, $x_w = -1$

References:

Dry Air:
from *Lemmon et al.* [14]
Steam in humid air and liquid 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]

Absolute Humidity of Saturated Humid Air $x_{ws} = f(p,t)$
Function Name:

xws_pt_HuAir

Fortran Programs:

```
REAL*8 FUNCTION xws_pt_HuAir(p,t), REAL*8 p,t
INTEGER*4 FUNCTION C_xws_pt_HuAir(xws,p,t), REAL*8 xws,p,t
```

Input values:

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

Result:

xws_pt_HuAir, x_{ws} - Absolute humidity of saturated air in g/kg_{Air}

Range of Validity:

Temperature t : from -143.15°C to $t_s(p,p_d)$ (boiling temp. from water in gas mixtures)
Mixture pressure p : from 6.112 mbar to 165.29 bar

Comments:

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

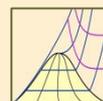
with $p_{ds}(p,t)$ for $t \geq 0.01^\circ\text{C}$ - Vapor pressure of water
for $t < 0.01^\circ\text{C}$ - Sublimation pressure of water

Result for wrong input values:

xws_pt_HuAir, $x_{ws} = -1$

References:

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



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)

Library LibSBTL_IF97 Library LibSBTL_95

- Extremely fast property calculations according to the IAPWS Guideline 2015
- Spline-based Table Look-up Method (SBTL) applied to the Industrial Formulation IAPWS-IF97 and to the Scientific Formulation IAPWS-95 for Computational Fluid Dynamics and simulating non-stationary processes

Humid Combustion Gas Mixtures

Library LibHuGas

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

Humid Air

Library LibHuAir

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

Carbon Dioxide Including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1996)

Seawater

Library LibSeaWa

IAPWS Industrial Formulation 2013

Ice

Library LibICE

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

Ideal Gas Mixtures

Library LibIdGasMix

Model: Ideal mixture of the ideal gases:

Ar	NO	He	Propylene
Ne	H 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

Humid Air

Library ASHRAE LibHuAirProp

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

- Dry air
- Steam

Consideration of:

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

www.ashrae.org/bookstore

Dry Air Including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth et al. (1993)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of Bucker and Wagner (2006)

n-Butane

Library LibButane_n

Formulation of Bucker and Wagner (2006)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

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

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

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

C ₂ H ₆ O ₂	Ethylene glycol
C ₃ H ₈ O ₂	Propylene glycol
C ₂ H ₅ OH	Ethanol
CH ₃ OH	Methanol
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
CHKO ₂	Potassium formate
LiCl	Lithium chloride
NH ₃	Ammonia

Formulation of the International Institute of Refrigeration (IIR 2010)

Ethanol**Library LibC2H5OH**

Formulation of Schroeder (2012)

Methanol**Library LibCH3OH**

Formulation of de Reuck and Craven (1993)

Propane**Library LibPropane**

Formulation of Lemmon et al. (2009)

Siloxanes as ORC Working Fluids

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

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

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

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

Formulation of Colonna et al. (2006)

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

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

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

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

Formulation of Colonna et al. (2008)

Nitrogen and Oxygen**Libraries****LibN2 and LibO2**

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

Hydrogen**Library LibH2**

Formulation of Leachman et al. (2009)

Helium**Library LibHe**

Formulation of Arp et al. (1998)

Hydrocarbons

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

Isopentane C_5H_{12} **Library LibC5H12_ISO**

Neopentane C_5H_{12} **Library LibC5H12_NEO**

Isohexane C_6H_{14} **Library LibC6H14**

Toluene C_7H_8 **Library LibC7H8**

Formulation of Lemmon and Span (2006)

Further Fluids

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

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

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

Nitrous oxide **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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Professor Hans-Joachim Kretzschmar

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01307 Dresden, Germany

Internet: www.thermofluidprop.com

E-mail: info@thermofluidprop.com

Phone: +49-351-27597860

Mobile: +49-172-7914607

Fax: +49-3222-4262250

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

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

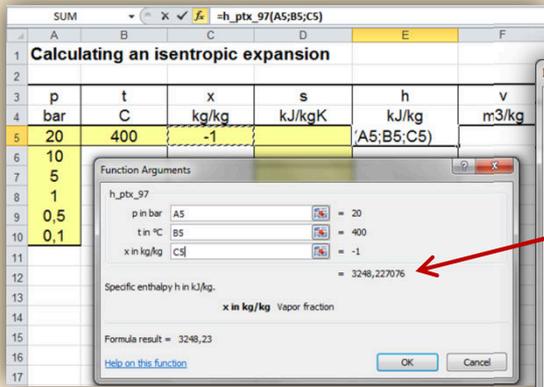
Thermodynamic Derivatives

- Partial derivatives can be calculated.

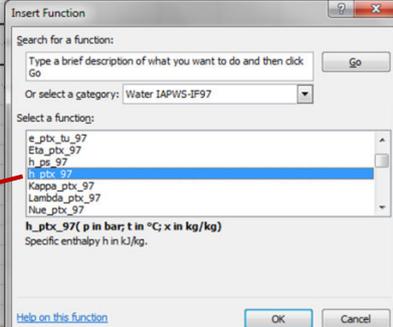
^a Not all of these property functions are available in all property libraries.

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

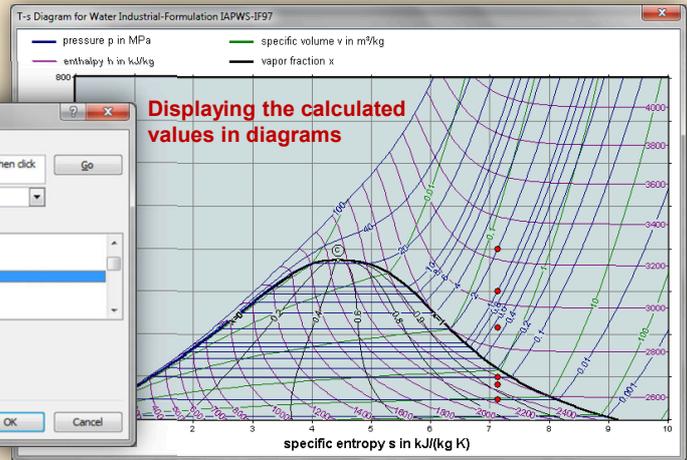
Add-In FluidEXL^{Graphics} for Excel[®]



Choosing a property library and a function



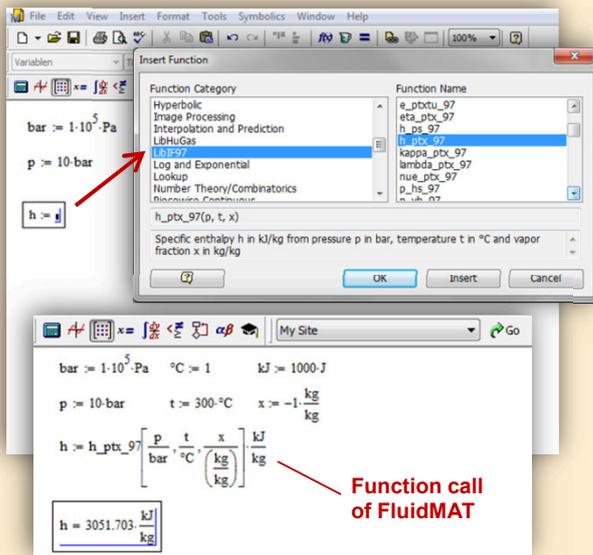
Displaying the calculated values in diagrams



Menu for the input of given property values

Add-In FluidMAT for Mathcad[®]

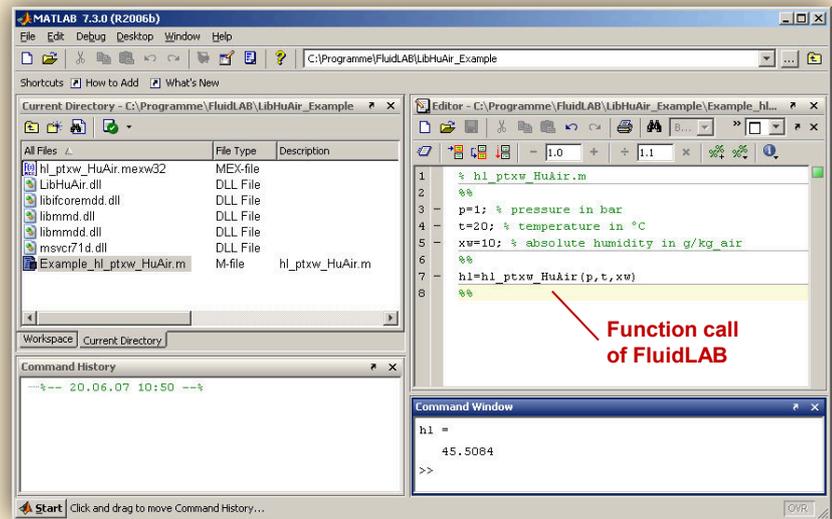
The property libraries can be used in Mathcad[®].



Function call of FluidMAT

Add-In FluidLAB for MATLAB[®]

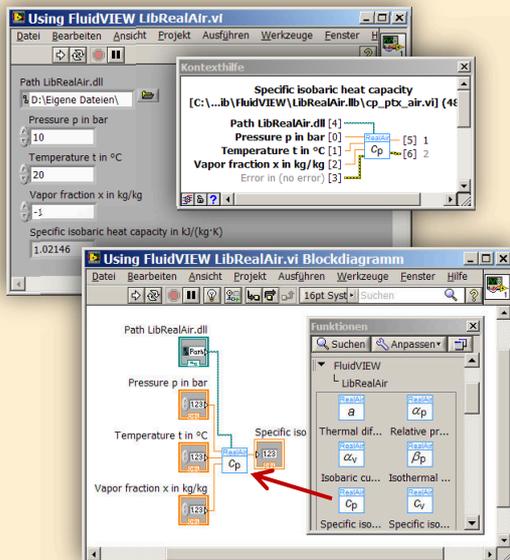
Using the Add-In FluidLAB the property functions can be called in MATLAB[®].



Function call of FluidLAB

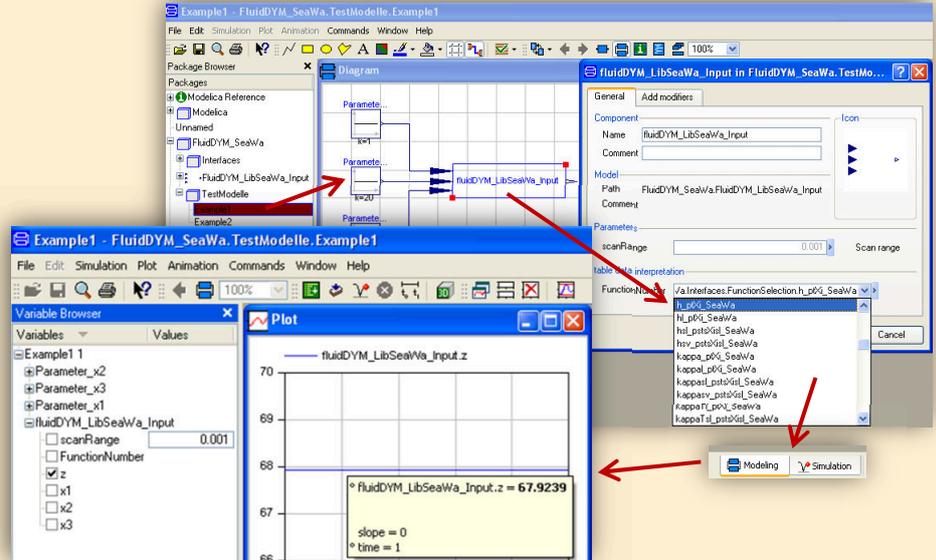
Add-On FluidVIEW for LabVIEW[™]

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

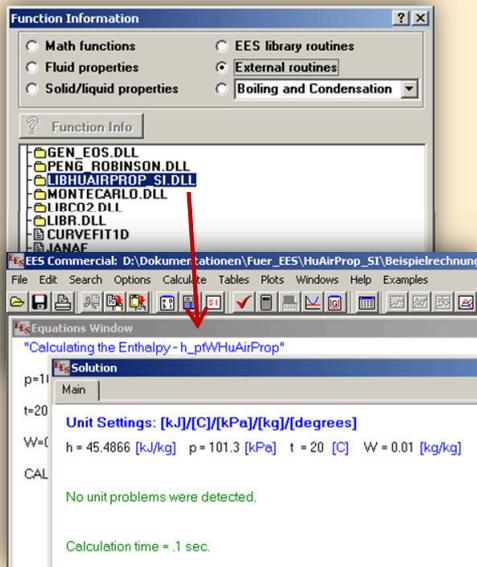


Add-In FluidDYM for DYMOLA[®] (Modelica) and SimulationX[®]

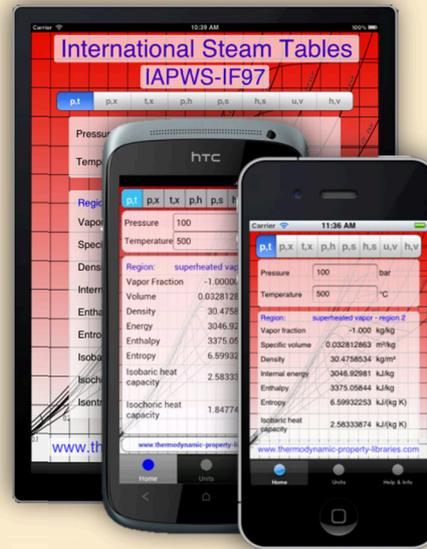
The property functions can be called in DYMOLA[®] and SimulationX[®].



Add-In FluidEES for Engineering Equation Solver®



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



Online Property Calculator at www.thermofluidprop.com

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 = 3097.38 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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www.thermodinamica-zitau.de
www.thermodynamic-property-libraries.com
www.international-steam-tables.com
www.thermodinamik-formelsammlung.de

Property Software for Pocket Calculators

FluidCasio



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

FluidHP



HP 48 HP 49

FluidTI



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

For more information please contact:

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives can be calculated.

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

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6. Satisfied Customers

Date: 05/2018

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) and SimulationX®
- FluidVIEW for LabVIEW™.

2018

Universität Madrid, Madrid, Spanien	05/2018
HS Zittau/ Görlitz, Fakultät Wirtschaft, Zittau	05/2018
HS Niederrhein, Krefeld	05/2018
GRS, Köln	03/2018
RONAL AG, Härklingen, Schweiz	02/2018
Ingenieurbüro Leipert, Riegelsberg	02/2018
AIXPROCESS, Aachen	02/2018
KRONES, Neutraubling	02/2018
Doosan Lentjes, Ratingen	01/2018

2017

Compact Kältetechnik, Dresden	12/2017
Endress + Hauser Messtechnik GmbH +Co. KG, Hannover	12/2017
TH Mittelhessen, Gießen	11/2017
Haarslev Industries, Sønderød, Denmark	11/2017
Hochschule Zittau/Görlitz, Fachgebiet Energiesystemtechnik	11/2017
ATESTEO, Alsdorf	10/2017
Wijbenga, PC Geldermalsen, Netherlands	10/2017
Fels-Werke GmbH, Elbingerode	10/2017
KIT Karlsruhe, Institute für Neutronenphysik und Reaktortechnik	09/2017
Air-Consult, Jena	09/2017
Papierfabrik Koehler, Oberkirch	09/2017
ZWILAG, Würenlingen, Switzerland	09/2017
TLK-Thermo Universität Braunschweig, Braunschweig	08/2017
Fichtner IT Consulting AG, Stuttgart	07/2017
Hochschule Ansbach, Ansbach	06/2017
RONAL, Härkingen, Switzerland	06/2017
BORSIG Service, Berlin	06/2017

BOGE Kompressoren, Bielefeld	06/2017
STEAG Energy Services, Zwingenberg	06/2017
CES clean energy solutions, Wien, Austria	04/2017
Princeton University, Princeton, USA	04/2017
B2P Bio-to-Power, Wadersloh	04/2017
TU Dresden, Institute for Energy Engineering, Dresden	04/2017
SAINT-GOBAIN, Vaujourns, France	03/2017
TU Bergakademie Freiberg, Chair of Thermodynamics, Freiberg	03/2017
SCHMIDT + PARTNER, Therwil, Switzerland	03/2017
KAESER Kompressoren, Gera	03/2017
F&R, Praha, Czech Republic	03/2017
ULT Umwelt-Lufttechnik, Löbau	02/2017
JS Energie & Beratung, Erding	02/2017
Kelvion Brazed PHE, Nobitz-Wilchwitz	02/2017
MTU Aero Engines, München	02/2017
Hochschule Zittau/Görlitz, IPM	01/2017
CombTec ProCE, Zittau	01/2017
SHELL Deutschland Oil, Wesseling	01/2017
MARTEC Education Center, Frederikshaven, Denmark	01/2017
SynErgy Thermal Management, Krefeld	01/2017

2016

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

Webasto Thermo & Comfort SE, Gliching	08/2016
TU Dresden, Dresden	08/2016
Endress+Hauser Messtechnik GmbH+Co. KG, Hannover	08/2016
D + B Kältetechnik, Althausen	07/2016
Fichtner IT Consulting AG, Stuttgart	07/2016
AB Electrolux, Krakow, Poland	07/2016
ENEXIO Germany GmbH, Herne	07/2016
VPC GmbH, Vetschau/Spreewald	07/2016
INWAT, Lodz, Poland	07/2016
E.ON SE, Düsseldorf	07/2016
Planungsbüro Waidhas GmbH, Chemnitz	07/2016
EEB Enerko, Aldershoven	07/2016
IHEBA Naturenergie GmbH & Co. KG, Pfaffenhofen	07/2016
SSP Kälteplaner AG, Wolfertschwenden	07/2016
EEB ENERKO Energiewirtschaftliche Beratung GmbH, Berlin	07/2016
BOGE Kompressoren Otto BOGE GmbH & Co KG, Bielefeld	06/2016
Universidad Carlos III de Madrid, Madrid, Spain	04/2016
INWAT, Lodzi, Poland	04/2016
Planungsbüro Waidhas GmbH, Chemnitz	04/2016
STEAG Energy Services GmbH, Laszlo Küppers, Zwingenberg	03/2016
WULFF & UMAG Energy Solutions GmbH, Husum	03/2016
FH Bielefeld, Bielefeld	03/2016
EWT Eckert Wassertechnik GmbH, Celle	03/2016
ILK Institut für Luft- und Kältetechnik GmbH, Dresden	02/2016, 06/2016 (2x)
IEV KEMA - DNV GV – Energie, Dresden	02/2016
Allborg University, Department of Energie, Aalborg, Denmark	02/2016
G.A.M. Heat GmbH, Gräfenhainichen	02/2016
Institut für Luft- und Kältetechnik, Dresden	02/2016, 05/2016, 06/2016
Bosch, Stuttgart	02/2016
INL Idaho National Laboratory, Idaho, USA	11/2016, 01/2016
Friedl ID, Wien, Austria	01/2016
Technical University of Dresden, Dresden	01/2016

2015

EES Enerko, Aachen	12/2015
Ruldolf IB, Strau, Austria	12/2015
Allborg University, Department of Energie, Aalborg, Denmark	12/2015
University of Lyubljana, Slovenia	12/2015
Steinbrecht IB, Berlin	11/2015
Universidad Carlos III de Madrid, Madrid, Spain	11/2015
STEAK, Essen	11/2015

Bosch, Lohmar	10/2015
Team Turbo Machines, Rouen, France	09/2015
BTC – Business Technology Consulting AG, Oldenburg	07/2015
KIT Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen	07/2015
ILK, Dresden	07/2015
Schniewindt GmbH & Co. KG, Neuenwalde	08/2015

2014

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

2013

TRANTER-GmbH, Artern	12/2013
SATAKE, Shanghai, China	12/2013
VOITH, Kunshan, China	12/2013
ULT, Löbau	12/2013
MAN, Copenhagen, Dänemark	11/2013
DREWAG, Dresden	11/2013
Haarslev Industries, Herlev, Dänemark	11/2013
STEAG, Herne	11/2013, 12/2013
Ingersoll-Rand, Oberhausen	11/2013
Wilhelm-Büchner HS, Darmstadt	10/2013

IAV, Chemnitz	10/2013
Technical University of Regensburg	10/2013
PD-Energy, Bitterfeld	09/2013
Thermofin, Heinsdorfergrund	09/2013
SHI, New Jersey, USA	09/2013
M&M Turbinentechnik, Bielefeld	08/2013
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TIG-Group, Husum	08/2013
COMPAREX, Leipzig	08/2013, 11/2013
for RWE Essen	12/2013
University of Budapest, Hungary	08/2013
Siemens, Frankenthal	08/2013, 10/2013
	11/2013
VGB, Essen	07/2013, 11/2013
Brunner Energieberatung, Zurich, Switzerland	07/2013
Technical University of Deggendorf	07/2013
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University of Princeton, USA	07/2013
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IGUS GmbH, Dresden	06/2013
BHR Bilfinger, Essen	06/2013
SÜDSALZ, Bad Friedrichshall	06/2013, 12/2013
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KIER, Gajeong-ro, Südkorea	05/2013
Schwing/Stetter GmbH, Memmingen	05/2013
Vattenfall, Berlin	05/2013
AUTARK, Kleinmachnow	05/2013
STEAG, Zwingenberg	05/2013
Hochtief, Düsseldorf	05/2013
University of Stuttgart	04/2013
Technical University -Bundeswehr, Munich	04/2013
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Kältetechnik Dresden + Bremen, Alfhausen	04/2013
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ENTEC, Auerbach	02/2013
Caterpillar, Kiel	02/2013
Technical University of Wismar	02/2013
Technical University of Dusseldorf	02/2013

ILK, Dresden	01/2013, 08/2013
Fichtner IT, Stuttgart	01/2013, 11/2013
Schnepf Ingeniuerbüro, Nagold	01/2013
Schütz Engineering, Wadgassen	01/2013
Endress & Hauser, Reinach, Switzerland	01/2013
Oschatz GmbH, Essen	01/2013
frischli Milchwerke, Rehburg-Loccum	01/2013

2012

Voith, Bayreuth	12/2012
Technical University of Munich	12/2012
Dillinger Huette	12/2012
University of Stuttgart	11/2012
Siemens, Muehlheim	11/2012
Sennheiser, Hannover	11/2012
Oschatz GmbH, Essen	10/2012
Fichtner IT, Stuttgart	10/2012, 11/2012
Helbling Technik AG, Zurich, Switzerland	10/2012
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Rerum Cognitio Forschungszentrum, Frankfurt	09/2012
Pöryr Deutschland GmbH, Dresden	08/2012
Extracciones, Guatemala	08/2012
RWE, Essen	08/2012
Weghaus Consulting Engineers, Wuerzburg	08/2012
GKS, Schweinfurt	07/2012
COMPAREX, Leipzig for RWE Essen	07/2012
GEA, Nobitz	07/2012
Meyer Werft, Papenburg	07/2012
STEAG, Herne	07/2012
GRS, Cologne	06/2012
Fichtner IT Consult, Chennai, India	06/2012
Siemens, Freiburg	06/2012
Nikon Research of America, Belmont, USA	06/2012
Niederrhein University of Applied Sciences, Krefeld	06/2012
STEAG, Zwingenberg	06/2012
Mainova, Frankfurt on Main via Fichtner IT Consult	05/2012
Endress & Hauser	05/2012
PEU, Espenheim	05/2012
Luzern University of Applied Sciences, Switzerland	05/2012

BASF, Ludwigshafen (general license) via Fichtner IT Consult	05/2012
SPX Balcke-Dürr, Ratingen	05/2012, 07/2012
Gruber-Schmidt, Wien, Austria	04/2012
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SKW, Piesteritz	04/2012
TERA Ingegneria, Trento, Italy	04/2012
Siemens, Erlangen	04/2012, 05/2012
LAWI Power, Dresden	04/2012
Stadtwerke Leipzig	04/2012
SEITZ, Wetzikon, Switzerland	03/2012, 07/2012
M & M, Bielefeld	03/2012
Sennheiser, Wedemark	03/2012
SPG, Montreuil Cedex, France	02/2012
German Destillation, Sprendlingen	02/2012
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Palo Alto Research Center, USA	02/2012
WIPAK, Walsrode	02/2012
Freudenberg, Weinheim	01/2012
Fichtner, Stuttgart	01/2012
airinotec, Bayreuth	01/2012, 07/2012
University Auckland, New Zealand	01/2012
VPC, Vetschau	01/2012
Franken Guss, Kitzingen	01/2012

2011

XRG-Simulation, Hamburg	12/2011
Smurfit Kappa PPT, AX Roermond, Netherlands	12/2011
AWTEC, Zurich, Switzerland	12/2011
eins-energie, Bad Elster	12/2011
BeNow, Rodenbach	11/2011
Luzern University of Applied Sciences, Switzerland	11/2011
GMVA, Oberhausen	11/2011
CCI, Karlsruhe	10/2011
W.-Büchner University of Applied Sciences, Pfungstadt	10/2011
PLANAIR, La Sagne, Switzerland	10/2011
LAWI, Dresden	10/2011
Lopez, Munguia, Spain	10/2011
University of KwaZulu-Natal, Westville, South Africa	10/2011

Voith, Heidenheim	09/2011
SpgBe Montreal, Canada	09/2011
SPG TECH, Montreuil Cedex, France	09/2011
Voith, Heidenheim-Mergelstetten	09/2011
MTU Aero Engines, Munich	08/2011
MIBRAG, Zeitz	08/2011
RWE, Essen	07/2011
Fels, Elingerode	07/2011
Weihenstephan University of Applied Sciences	07/2011, 09/2011 10/2011
Forschungszentrum Juelich	07/2011
RWTH Aachen University	07/2011, 08/2011
INNEO Solutions, Ellwangen	06/2011
Caliqua, Basel, Switzerland	06/2011
Technical University of Freiberg	06/2011
Fichtner IT Consulting, Stuttgart	05/2011, 06/2011, 08/2011
Salzgitter Flachstahl, Salzgitter	05/2011
Helbling Beratung & Bauplanung, Zurich, Switzerland	05/2011
INEOS, Cologne	04/2011
Enseleit Consulting Engineers, Siebigerode	04/2011
Witt Consulting Engineers, Stade	03/2011
Helbling, Zurich, Switzerland	03/2011
MAN Diesel, Copenhagen, Denmark	03/2011
AGO, Kulmbach	03/2011
University of Duisburg	03/2011, 06/2011
CCP, Marburg	03/2011
BASF, Ludwigshafen	02/2011
ALSTOM Power, Baden, Switzerland	02/2011
Universität der Bundeswehr, Munich	02/2011
Calorifer, Elgg, Switzerland	01/2011
STRABAG, Vienna, Austria	01/2011
TUEV Sued, Munich	01/2011
ILK Dresden	01/2011
Technical University of Dresden	01/2011, 05/2011 06/2011, 08/2011
2010	
Umweltinstitut Neumarkt	12/2010
YIT Austria, Vienna, Austria	12/2010
MCI Innsbruck, Austria	12/2010

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

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

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ALSTOM Power, Baden, Schweiz	01/2009, 03/2009 05/2009
Nordostschweizerische Kraftwerke AG, Doettingen, Switzerland	02/2009
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Brandenburg University of Technology, Cottbus	02/2009
Hamburg University of Applied Sciences	02/2009
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EPP Software, Marburg	03/2009
Bernd Munstermann, Telgte	03/2009
Suedzucker, Zeitz	03/2009
CPP, Marburg	03/2009
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Regensburg University of Applied Sciences	05/2009
Gatley & Associates, Atlanta, USA	05/2009
BOSCH, Stuttgart	06/2009, 07/2009
Dr. Nickolay, Consulting Engineers, Gommersheim	06/2009
Ferrostal Power, Saarlouis	06/2009
BHR Bilfinger, Essen	06/2009
Intraserv, Wiesbaden	06/2009
Lausitz University of Applied Sciences, Senftenberg	06/2009
Nuernberg University of Applied Sciences	06/2009

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Institute of Air Handling and Refrigeration ILK, Dresden	11/2009
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Techgroup, Ratingen	11/2009
Robert Sack, Heidelberg	11/2009
EC, Heidelberg	11/2009
MCI, Innsbruck, Austria	12/2009
Saacke, Bremen	12/2009
ENERKO, Aldenhoven	12/2009

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Pink, Langenwang	01/2008
Fischer-Uhrig, Berlin	01/2008
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MAAG, Kuesnacht, Switzerland	02/2008
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CFC Solutions, Munich	04/2008
RWE IT, Essen	04/2008
Rerum Cognitio, Zwickau	04/2008, 05/2008
ARUP, Berlin	05/2008
Research Center, Karlsruhe	07/2008
AWECO, Neukirch	07/2008
Technical University of Dresden,	07/2008
Professorship of Building Services	
Technical University of Cottbus,	07/2008, 10/2008
Chair in Power Plant Engineering	
Ingersoll-Rand, Unicov, Czech Republic	08/2008

Technip Benelux BV, Zoetermeer, Netherlands	08/2008
Fennovoima Oy, Helsinki, Finland	08/2008
Fichtner Consulting & IT, Stuttgart	09/2008
PEU, Espenhain	09/2008
Poyry, Dresden	09/2008
WINGAS, Kassel	09/2008
TUEV Sued, Dresden	10/2008
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	10/2008, 11/2008
AWTEC, Zurich, Switzerland	11/2008
Siemens Power Generation, Erlangen	12/2008

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

Wiesbaden University of Applied Sciences, Department of Engineering Sciences	10/2007
Endress+Hauser Messtechnik, Hannover	11/2007
Munich University of Applied Sciences, Department of Mechanical Engineering	11/2007
Rerum Cognitio, Zwickau	12/2007
Siemens Power Generation, Erlangen	11/2007
University of Rostock, Chair in Technical Thermodynamics	11/2007, 12/2007

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STORA ENSO Sachsen, Eilenburg	01/2006
Technical University of Munich, Chair in Energy Systems	01/2006
NUTEC Engineering, Bisikon, Switzerland	01/2006, 04/2006
Conwel eco, Bochov, Czech Republic	01/2006
Offenburg University of Applied Sciences	01/2006
KOCH Transporttechnik, Wadgassen	01/2006
BEG Bremerhavener Entsorgungsgesellschaft	02/2006
Deggendorf University of Applied Sciences, Department of Mechanical Engineering and Mechatronics	02/2006
University of Stuttgart, Department of Thermal Fluid Flow Engines	02/2006
Technical University of Munich, Chair in Apparatus and Plant Engineering	02/2006
Energietechnik Leipzig (company license), Siemens Power Generation, Erlangen	02/2006, 03/2006
RWE Power, Essen	03/2006
WAETAS, Pobershau	04/2006
Siemens Power Generation, Goerlitz Technical University of Braunschweig, Department of Thermodynamics	04/2006
EnviCon & Plant Engineering, Nuremberg	04/2006
Brassel Engineering, Dresden	05/2006
University of Halle-Merseburg, Department of USET Merseburg incorporated society	05/2006
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	05/2006
Fichtner Consulting & IT Stuttgart (company licenses and distribution)	05/2006
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ThyssenKrupp Marine Systems, Kiel	07/2006

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Siemens Power Generation, Berlin	11/2006
Zikesch Armaturentechnik, Essen	11/2006
Wismar University of Applied Sciences, Seafaring Department	11/2006
BASF, Schwarzheide	12/2006
Enertech Energie und Technik, Radebeul	12/2006

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J.H.K Plant Engineering and Service, Bremerhaven	01/2005
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FCIT, Stuttgart	01/2005
Energietechnik Leipzig (company license)	02/2005, 04/2005
	07/2005
eta Energieberatung, Pfaffenhofen	02/2005
FZR Forschungszentrum, Rossendorf/Dresden	04/2005
University of Saarbruecken	04/2005
Technical University of Dresden	04/2005
Professorship of Thermic Energy Machines and Plants	
Grenzebach BSH, Bad Hersfeld	04/2005
TUEV Nord, Hamburg	04/2005
Technical University of Dresden, Waste Management	05/2005
Siemens Power Generation, Goerlitz	05/2005
Duesseldorf University of Applied Sciences, Department of Mechanical Engineering and Process Engineering	05/2005
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Dumas Verfahrenstechnik, Hofheim	06/2005
Alensys Engineering, Erkner	07/2005
Stadtwerke Leipzig	07/2005
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Basel University of Applied Sciences, Department of Mechanical Engineering, Switzerland	10/2005

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University of Saarbruecken	04/2004
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HEW-Kraftwerk, Tiefstack	06/2004
h s energieanlagen, Freising	07/2004
FCIT, Stuttgart	08/2004
Physikalisch Technische Bundesanstalt (PTB), Braunschweig	08/2004
Mainova Frankfurt	08/2004
Rietschle Energieplaner, Winterthur, Switzerland	08/2004
MAN Turbo Machines, Oberhausen	09/2004
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STEAG Kraftwerk, Herne	10/2004, 12/2004
University of Weimar	10/2004
energeticals (e-concept), Munich	11/2004
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Enertech EUT, Radebeul (company license)	11/2004
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Paper Factory, Utzenstorf, Switzerland	01/2003
MAB Plant Engineering, Vienna, Austria	01/2003

Wulff Energy Systems, Husum	01/2003
Technip Benelux BV, Zoetermeer, Netherlands	01/2003
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Rietschle Energieplaner, Winterthur, Switzerland	02/2003
DLR, Leupholdhausen	04/2003
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Pettersson+Ahrends, Ober-Moerlen	05/2003
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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
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Eco Design, Saitamaken, Japan	01/2001
M&M Turbine Technology, Bielefeld	01/2001, 09/2001
MVV Energie, Mannheim	02/2001
Technical University of Dresden, Department of Power Machinery and Plants	02/2001
PREUSSAG NOELL, Wuerzburg	03/2001
Fichtner Consulting & IT Stuttgart	04/2001
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SaarEnergie, Saarbruecken	05/2001
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Neusiedler AG, Ulmerfeld, Austria	09/2001

h s energieranlagen, Freising	09/2001
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AG KKK - PGW Turbo, Leipzig	01/2000
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VAUP Process Automation, Landau	08/2000
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Regensburg University of Applied Sciences	04/1999
Fichtner Consulting & IT, Stuttgart (company licenses and distribution)	07/1999
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Technical University of Graz, Department of Thermal Engineering, Austria	11/1999
Ostendorf Engineering, Gummersbach	12/1999

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SCA Hygiene Products, Munich	10/1998
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Gerb, Dresden	06/1997
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