



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

**FluidDYM
with LibHuAir
for DYMOLA®**

Prof. Hans-Joachim Kretzschmar

Dr. Sebastian Herrmann

Dr. Matthias Kunick

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

FluidDYM for Dymola®

Contents

- 0. Package Contents
- 1. Property Functions
- 2. Application of FluidDYM in Dymola®
 - 2.1 Installing FluidDYM
 - 2.2 Example: Calculation of the Air-Specific Enthalpy $h_l = f(p, t, x_W)$ of Humid Air
 - 2.3 Removing FluidDYM
- 3. Program Documentation
- 4. Property Libraries for Calculating Heat Cycles, Boilers, Turbines, and Refrigerators
- 5. References
- 6. Satisfied Customers

© KCE-ThermoFluidProperties UG (with limited liability) & Co. KG
Professor Hans-Joachim Kretzschmar
Wallotstr. 3, 01307 Dresden, Germany
Phone: +49-351-27597860
Mobile: +49-172-7914607
Fax: +49-3222-4262250
Email: info@thermofluidprop.com
Internet: www.thermofluidprop.com

0 Package Contents

0.1 Zip file for 32-bit DYMOLA®

"CD_FluidDYM_LibCO2.zip"

Including the following files:

FluidDYM_LibCO2_Setup.exe	Installation Program for the FluidDYM Add-In for use in DYMOLA®
LibCO2.dll	Dynamic Link Library f
FluidDYM_LibCO2_Docu.pdf	User's Guide
Folder "Users_Guide"	Includes the complete User's Guide

0.2 Zip file for 64-bit MATLAB®

"CD_FluidDYM_LibCO2_64.zip"

Including the following files and folders:

Files:

Setup.exe	- Self-extracting and self-installing program for FluidLAB
FluidDYM_LibCO2_64.msi	- Installation program for the FluidLAB Add-On for use in MATLAB®
LibCO2.dll	- Dynamic Link Library for carbon dioxide for use in MATLAB®
FluidLAB_LibCO2_Docu.pdf	- User's Guide

Folders:

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

1. Property Functions

Functional Dependence	Function Name	Property or Function	Unit of the Result	Source or Algorithm	Site Info
$a = f(p, t, x_w)$	a_ptxw_HuAir	Thermal diffusivity	m^2/s	[1-4], [6], [12], [14], [15]	3/1
$c_p = f(p, t, x_w)$	cp_ptxw_HuAir	Specific isobaric heat capacity	$\text{kJ}/(\text{kg} \cdot \text{K})$	[1-4], [13], [14]	3/2
$\eta = f(p, t, x_w)$	Eta_ptxw_HuAir	Dynamic viscosity	$\text{Pa} \cdot \text{s}$	[7], [12], [15]	3/3
$h = f(p, t, x_w)$	hl_ptxw_HuAir	Air-specific enthalpy	$\text{kJ}/\text{kg}_{\text{Air}}$	[1-4], [13], [14], [18], [19]	3/4
$\lambda = f(p, t, x_w)$	Lambda_ptxw_HuAir	Thermal conductivity	$\text{W}/(\text{m} \cdot \text{K})$	[6], [12], [15]	3/5
$\nu = f(p, t, x_w)$	Ny_ptxw_HuAir	Kinematic viscosity	m^2/s	[1-4], [7], [12], [14], [15]	3/6
$p_d = f(p, t, x_w)$	pd_ptxw_HuAir	Partial pressure of steam	bar	[1-4], [16], [17], [25], [26]	3/7
$p_{ds} = f(p, t)$	pds_pt_HuAir	Saturation pressure of water	bar	[1-4], [16], [17], [25], [26]	3/8
$\varphi = f(p, t, x_w)$	Phi_ptxw_HuAir	Relative humidity	%	[1-4], [16], [17], [25], [26]	3/9
$p_a = f(p, t, x_w)$	pl_ptxw_HuAir	Partial pressure of air	bar	[1-4], [16], [17], [25], [26]	3/10
$Pr = f(p, t, x_w)$	Pr_ptxw_HuAir	PRANDTL-number	-	[1-4], [6], [7], [12-15]	3/11
$y_1 = f(x_w)$	Psil_xw_HuAir	Mole fraction of air	kmol/kmol	-	3/12

Functional Dependence	Function Name	Property or Function	Unit of the Result	Source or Algorithm	Site Info
$y_w = f(x_w)$	Psiw_xw_HuAir	Mole fraction of water	kmol/kmol	-	3/13
$\rho = f(p, t, x_w)$	Rho_ptxw_HuAir	Density	kg/m ³	[1-4], [14], [18], [19]	3/14
$s_l = f(p, t, x_w)$	sl_ptxw_HuAir	Air-specific entropy	kJ/(kg _{Air} K)	[1-4], [13], [14], [18], [19]	3/15
$t = f(p, h, x_w)$	t_phlxw_HuAir	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	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	Wet bulb temperature	°C	[1-4], [13], [14]	3/18
$t_\tau = f(p, x_w)$	tTau_pxw_HuAir	Dew point temperature	°C	[1-4], [16], [17]	3/19
$u_l = f(p, t, x_w)$	ul_ptxw_HuAir	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	Air-specific volume	m ³ /kg _{Air}	[1-4], [14], [18], [19]	3/21
$\xi_l = f(x_w)$	Xil_xw_HuAir	Mass fraction of air	kg/kg	-	3/22
$\xi_w = f(x_w)$	Xiw_xw_HuAir	Mass fraction of water	kg/kg	-	3/23
$x_w = f(p, t, p_d)$	xw_ptpd_HuAir	Humidity ratio (Absolute humidity) from partial pressure of steam	g _{water} /kg _{Air}	[1-4], [16], [17], [25], [26]	3/25
$x_w = f(p, t, \varphi)$	xw_ptPhi_HuAir	Humidity ratio (Absolute humidity) from temperature and relative humidity	g _{water} /kg _{Air}	[1-4], [16], [17], [25], [26]	3/24

Funktionale Abhängigkeit	Function Name	Property or Function	Unit of the Result	Source or Algorithm	Site Info
$x_w = f(p, t_t)$	xw_ptTau_HuAir	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	Humidity ratio (Absolute humidity) from temperature and wet bulb temperature	g _{water} /kg _{Air}	[1-4], [13], [14]	3/27
$x_w = f(p, t, v_l)$	xw_ptvl_HuAir	Backward function: Humidity ratio (Absolute humidity) from temperature and air-specific volume	g _{water} /kg _{Air}	[1-4], [14], [18], [19]	3/28
$x_{ws} = f(p, t)$	xws_pt_HuAir	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 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, IAPWS-08 [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, IAPWS-08 [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 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 $t \geq 0.01 \text{ °C}$ from IAPWS - IF97 [1], [2], [3], [4],
 - $p_s(t)$ for $t < 0 \text{ °C}$ from IAPWS-08 [16], [17].

2. Application of FluidDYM in Dymola®

The FluidDYM Add-In has been developed to calculate thermodynamic properties in Dymola® more conveniently. Within Dymola® it enables the direct call of functions relating to Humid Air from the LibHuAir property library. The 32-bit version of FluidDYM LibHuAir runs on both the 32-bit and 64-bit version of DYMOLA®.

2.1 Installing FluidDYM

In this section, the installation of FluidDYM and LibHuAir is described.

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

After you have downloaded and extracted the zip-file

"CD_FluidDYM_LibHuAir.zip," (32-bit version)

"CD_FluidDYM_LibHuAir_64.zip," (64-bit version)

you will see the folder

CD_FluidDYM_LibHuAir (32-bit version)

CD_FluidDYM_LibHuAir_64 (64-bit version)

in your Windows Explorer®, Norton Commander® etc.

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

Within the folder for the **32-bit version** you will see the following files

FluidDYM_LibHuAir_Users_Guide.pdf

FluidDYM_LibHuAir_Setup.exe (32-bit version)

and the folder

"Users_Guide."

Within the folder for the **64-bit version** you will see the following files

FluidDYM_LibHuAir_Users_Guide.pdf

FluidDYM_LibHuAir_64_Setup.msi

Setup.exe

and the folder

"Users_Guide."

In order to run the installation of **32-bit** FluidDYM including the LibHuAir property library double-click the file

FluidDYM_LibHuAir_Setup.exe.

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

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

C:\Program Files\FluidDYM\LibHuAir.

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

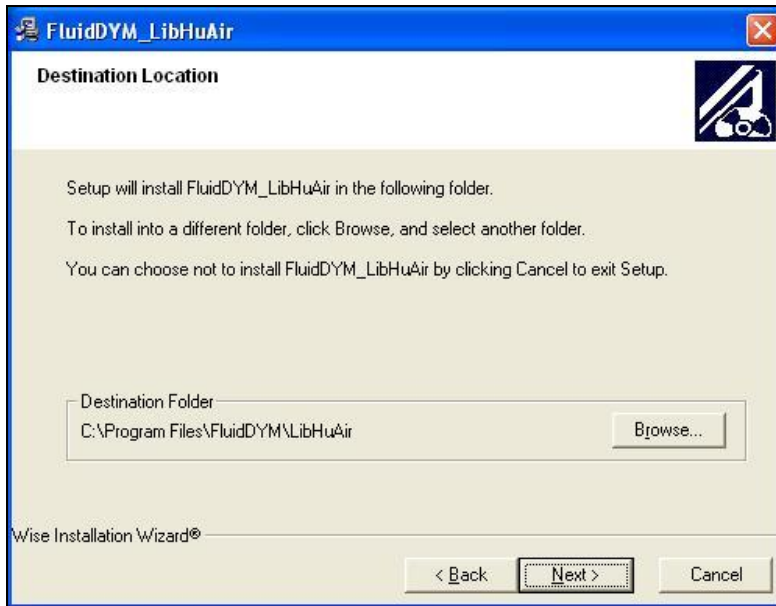


Figure 2.1: Dialog window "Destination Location"

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

After FluidDYM has been installed, you will see the sentence "FluidDYM LibHuAir has been successfully installed." Confirm this by clicking the "Finish" button.

The installation of FluidDYM 32-bit has been completed.

In order to run the installation of **64-bit** FluidDYM including the LibHuAir property library double-click the file

Setup.exe.

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

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

C:\Users\...\Documents\FuildDYM_64\LibHuAir.

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

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

After FluidDYM has been installed, you will see the sentence "FluidDYM LibHuAir has been successfully installed." Confirm this by clicking the "Finish" button.

The installation of FluidDYM 64-bit has been completed.

The installation program has copied the following files into the directory "C:\Program Files\FluidDYM\LibHuAir":

- Dynamic link library "LibHuAir.dll".
- Link up Dynamic link library "LibHuAir_Dym.dll" and other necessary system DLL files.
- Library File "LibHuAir_DYM.lib"
- Header File "LibHuAir_DYM.h" and other necessary system DLL files.
- Modelica File "FluidDYM_LibHuAir.mo", includes the following property functions:

a_ptxw_HuAir	t_phlxw_HuAir
cp_ptxw_HuAir	t_pslxw_HuAir
Eta_ptxw_HuAir	tf_ptxw_HuAir
hl_ptxw_HuAir	tTau_pwx_HuAir
Lambda_ptxw_HuAir	ul_ptxw_HuAir
Ny_ptxw_HuAir	vl_ptxw_HuAir
pd_ptxw_HuAir	Xil_xw_HuAir
pds_pt_HuAir	Xil_xw_HuAir
Phi_ptxw_HuAir	xw_ptpd_HuAir
pl_ptxw_HuAir	xw_ptPhi_HuAir
Pr_ptxw_HuAir	xw_ptTau_HuAir
Psil_xw_HuAir	xw_pttf_HuAir
Psiw_xw_HuAir	xw_ptvl_HuAir
Rho_ptxw_HuAir	xws_pt_HuAir
sl_ptxw_HuAir	

Now, you have to overwrite the file "LIBHUAIR.dll" in your LibHuAir directory with the file of the same name provided in your CD folder with FluidDYM.

To do this, open the CD folder "CD_FluidDYM_LibHuAir_Eng" in "My Computer" and click on the file "LIBHUAIR.dll" in order to highlight it.

Then click on the "Edit" menu in your Explorer and select "Copy".

Now, open your LibHuAir directory (the standard being

C:\Program Files\FluidDYM\LibHuAir)

and insert the file "LIBHUAIR.dll" by clicking the "Edit" menu in your Explorer and then select "Paste".

Answer the question whether you want to replace the file by clicking the "Yes" button. Now, you have overwritten the file "LIBHUAIR.dll" successfully.

In the next step, copy the folder "Users_Guide" into your Dymola LibHuAir directory with the file of the same name provided in your CD folder of FluidDYM.

To do this, open the CD folder "CD_FluidDYM_LibHuAir_Eng" in "My Computer" and click on the folder "Users_Guide" to highlight it. Then click on the "Edit" menu in your Explorer and select "Copy".

Now, open your Dymola LibHuAir directory (the standard being:

C:\Program Files\FluidDYM\LibHuAir)

and insert the folder "Users_Guide" by clicking the "Edit" menu in your Explorer and then selecting "Paste". Now, the folder "Users_Guide" has been successfully placed in your installation directory.

Licensing the LibHuAir Property Library

The licensing procedure has to be carried out when Dymola® is running and a model simulation starts. In this case, you will see the "License Information" window (see figure below).

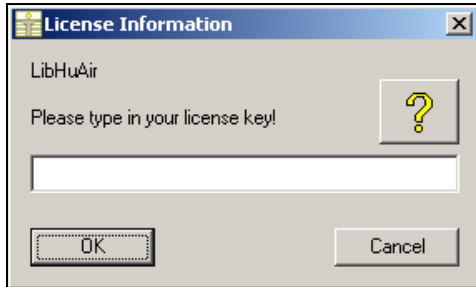


Figure 2.2: "License Information" window

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:

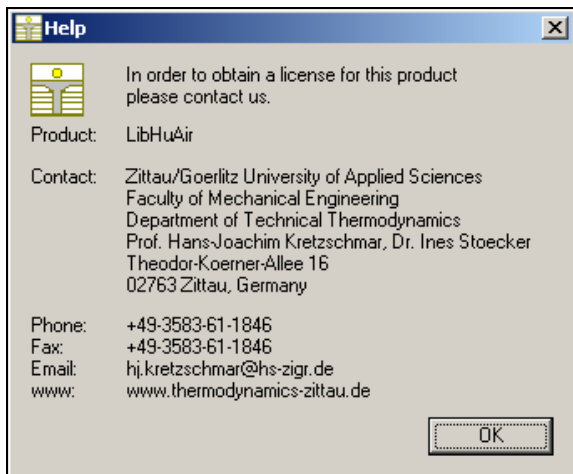


Figure 2.3: "Help" window

If you do not enter a valid license it is still possible to use Dymola® by clicking "Cancel" twice. In this case, the LibHuAir property library will display the result "-11111111" for every calculation.

The "License Information" window will appear every time you start Dymola unless you uninstall FluidDYM_LibHuAir according to the description in section 2.3 of this User's Guide. Should you not wish to license the LibHuAir property library, you have to delete the files

LibHuAir.dll
 LibHuAir_DYM.dll
 LibHuAir_DYM.lib
 LibHuAir_DYM.h
 LibHuAir_DYM.mo

in the installation folder of Dymola® (the standard being

C:\Program Files\FluidDYM)

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

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

Now we will calculate, step by step, the specific enthalpy h of humid air as a function of pressure p , temperature t and humidity ratio x_w , using Dymola®.

Please carry out the following instructions:

- Start Windows Explorer®, Total Commander®, My Computer or another file manager program.
The description here refers to Windows Explorer.
- Your Windows Explorer should be set to Details for a better view. Click the "View" (Ansicht) button and select "Details".
- Switch into the program directory of FluidDYM in which you will find the folder "\LibHuAir"; the standard location is: "C:\Program Files\FluidDYM\LibHuAir"
- Create the folder "\LibHuAir_Example" by clicking on "File" in the Explorer menu, then "New" in the menu which appears, and then selecting "Folder". Name the new folder "\LibHuAir_Example".
- You will see the following window:

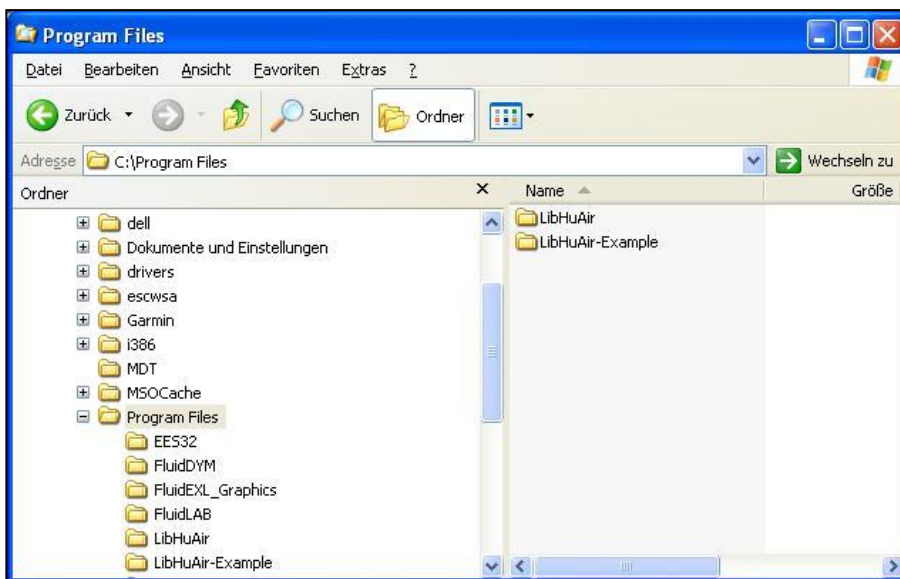


Figure 2.4: Highlighted *LibHuAir_Example* directory in Program Files

- Switch into the directory "\LibHuAir" within "\FluidDYM", the standard being: "C:\Program Files\FluidDYM\LibHuAir".

- You will see the following window:

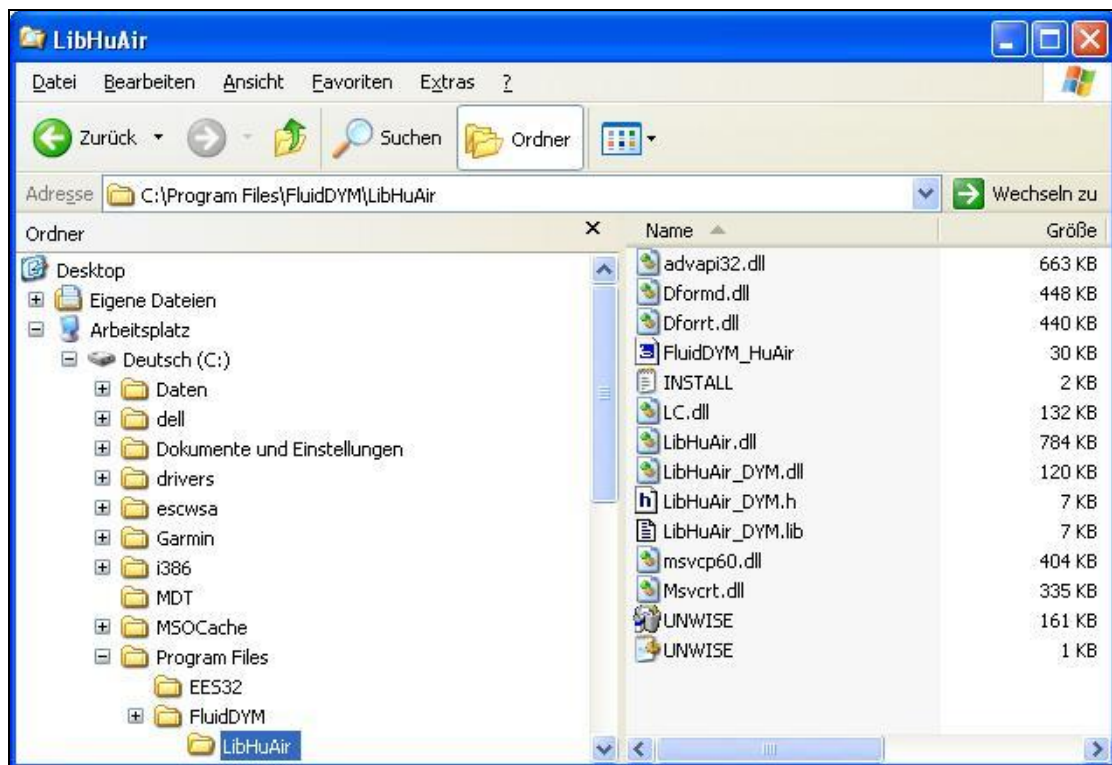


Figure 2.5: *LibHuAir* directory including installed files

In order to calculate the function $h = f(p, t, x_w)$, the following files are necessary. Copy them into the directory "C:\Program Files\FluidDYM\LibHuAir_Example":

- "LibHuAir.dll"
 - "LibHuAir_DYM.dll"
 - "LibHuAir_DYM.lib"
 - "LibHuAir_DYM.h"
 - "FluidDYM_HuAir.mo"
 - "DFORRT.dll"
 - "msvcp60.dll"
 - "LC.dll"
 - "advapi32.dll"
 - "Dformd.dll"
 - "Msvcr7.dll"
 - the folder "Users_Guide"
- Mark up these files, then click "Edit" in the upper menu bar and select "Copy".
 - Switch into the directory "C:\Program Files\FluidDYM\LibHuAir_Example", click "Edit" and then "Paste".

- You will see the following window:

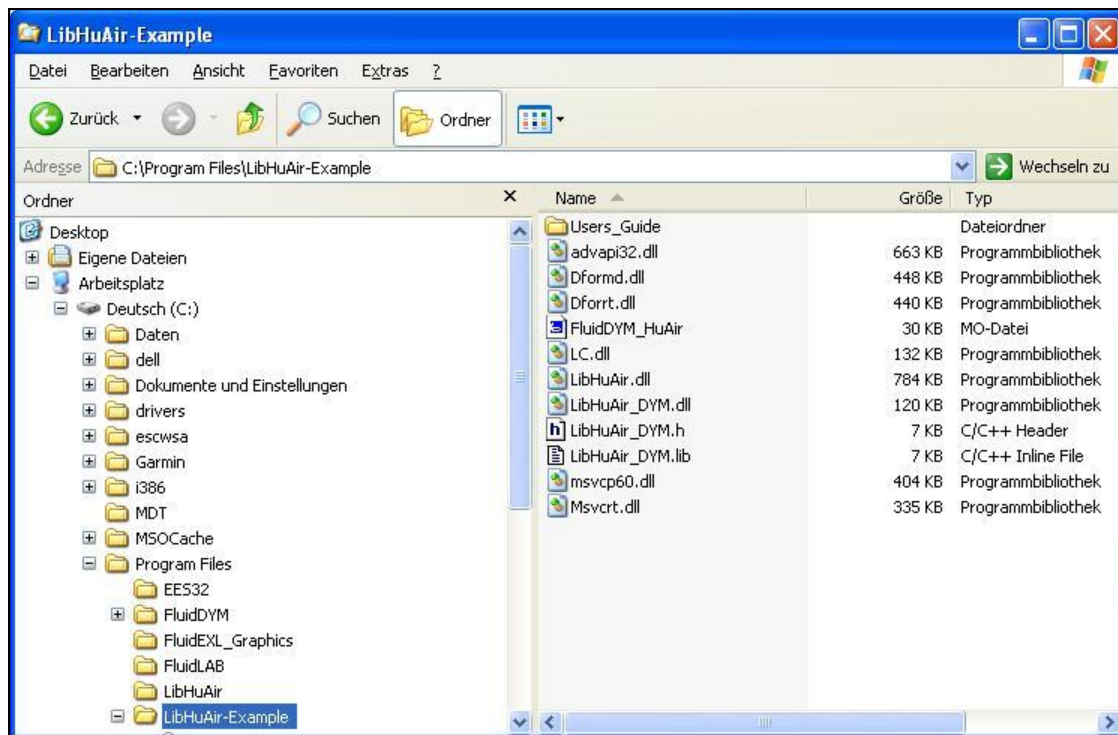


Figure 2.6: *LibHuAir_Example* directory including the newly-copied files

- Start Dymola®.
- Now click on "File" in the Dymola® menu bar and select "Open" (see Figure 2.7).

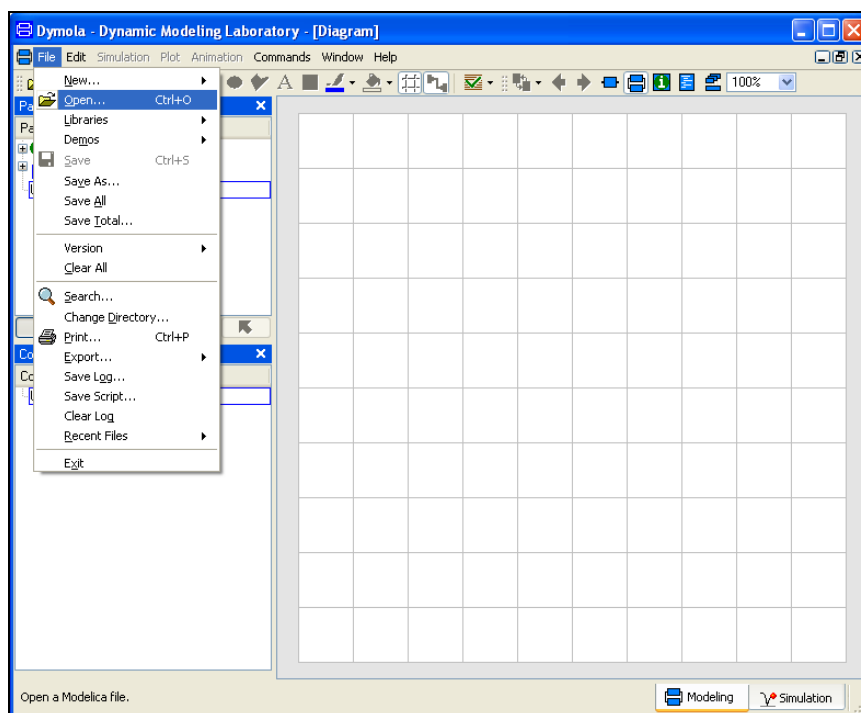


Figure 2.7: Selecting the menu entry "Open"

- Search and click on the directory "C:\Program Files\FluidDYM\LibHuAir_Example" in the pop-up menu.

- Select the "FluidDYM_HuAir.mo" file and click on the "Open" button (see Figure 2.8).

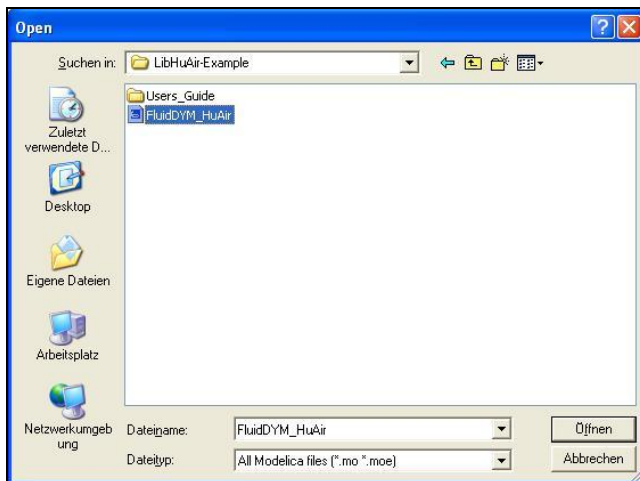


Figure 2.8: Selecting the *FluidDYM_HuAir.mo* file

- The library will be loaded by Dymola which may take a few seconds.
- After Dymola has finished loading the LibHuAir library, you will see the window shown in Figure 2.9.

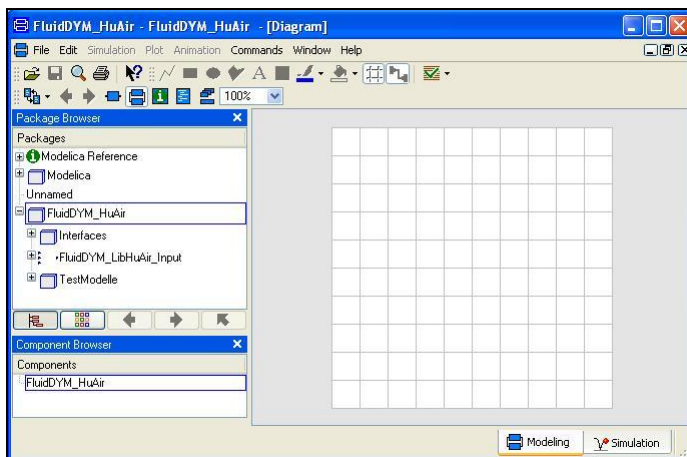


Figure 2.9: Dymola window after loading the *LibHuAir* library

- Now, click on "File" in the Dymola menu bar and select "Change Directory..." in order to open the folder "LibHuAir_Example" (see Figure 2.10).

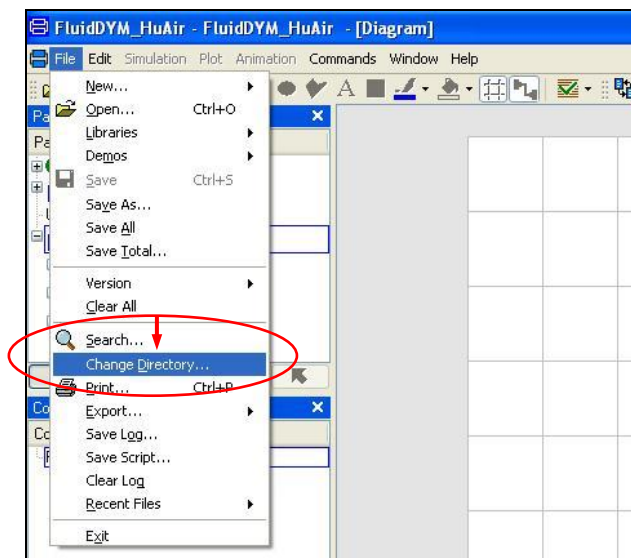


Figure 2.10: Selecting the menu entry "Change Directory..."


- Search and click on the directory "C:\Program Files\FluidDYM\LibHuAir_Example" in the pop-up menu (see Figure 2.11).



Figure 2.11: Selecting the *LibHuAir_Example* directory

- Confirm your selection by clicking the "OK" button.

As indicated in the table of property functions in Chapter 1, you have to call up the function "hl_ptxw_HuAir" as follows for calculating $hl = f(p, t, xw)$.

- Click on the Dymola-Block "Testmodelle," which can be found in the FluidDYM_HuAir package in the "Package Browser" on the left hand side of the Dymola window. Here choose Example1 by double-clicking on it.
- Now click on the  button in the Dymola menu bar in order to switch to the Diagram Mode. You will see the following window:

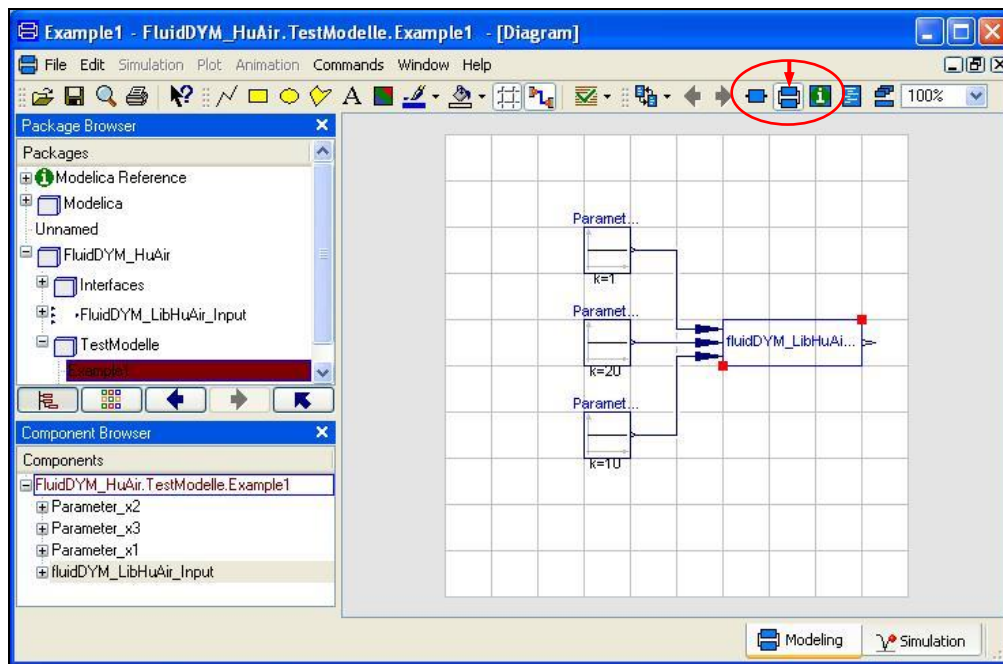


Figure 2.12: Dymola in Diagram Mode

- Now double-click on the "fluidDYM_LibHuAir_Input" block on the right hand side of the Dymola window.
- Search and click the "hl_ptwx_HuAir" function next to "Function Number" in the pop-up menu (see Figure 2.13).

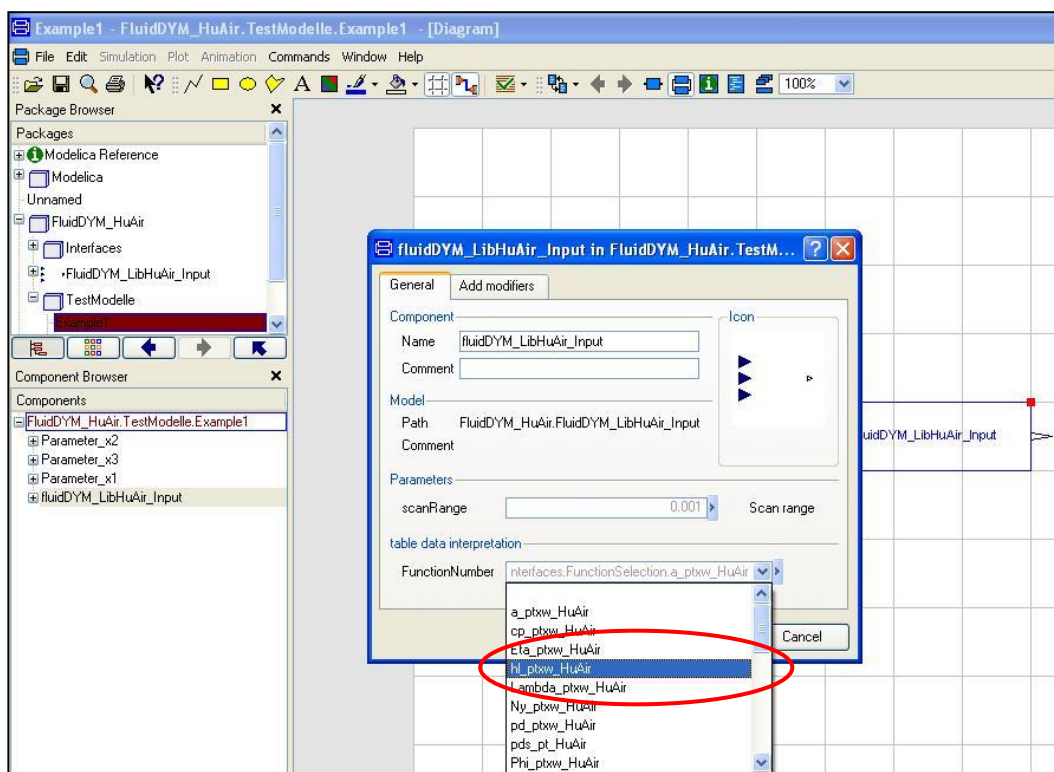


Figure 2.13: Choosing the function *hl_ptwx_HuAir*

- You can set the scan range (how many times the property will be calculated per second) next to "scanRange". The preset value 0.001 means that the property will be calculated 1000 times per second. E.g. if you enter the value 1, the property will be calculated once

per second. Do not change the preset value of 0.001 for our example calculation.

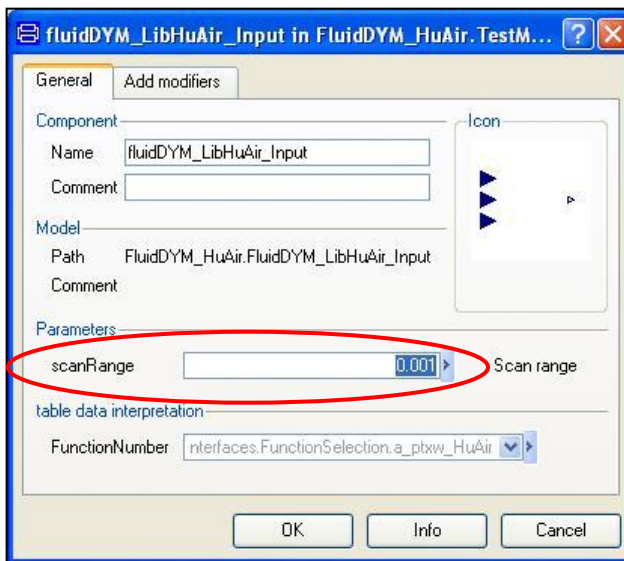


Figure 2.14: Setting the scan range

- Now we will configure the input parameters x_1 to x_3 , where x_1 represents the pressure p , x_2 represents the temperature t , and x_3 represents the humidity ratio x_w . When calculating a function with only two input parameters, the third input parameter x_3 will not be defined.
- First, double click on the "Parameter_x1" block which represents the first input parameter, here the pressure p in bar.

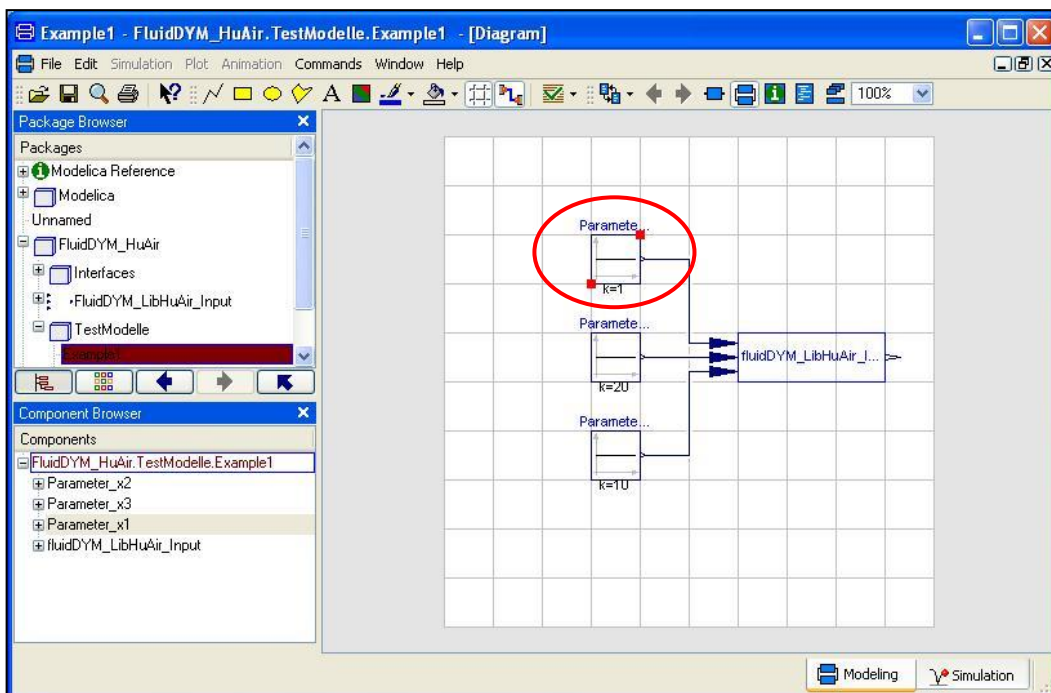


Figure 2.15: "Parameter_x1" block in Dymola

- Enter the value 1 on the line next to "k" in the dialog window which appears and then click the "OK" button (see Figure 2.16).

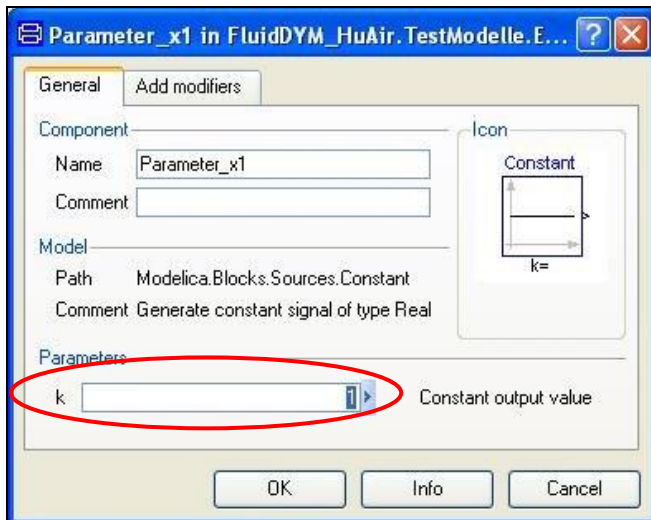


Figure 2.16: Entering the value for the pressure p

- Now, double click on the "Parameter_x2" block which represents the second input parameter, here the temperature t in °C.
- Enter the value 20 on the line next to "k" in the dialog window which appears and then click the "OK" button (see Figure 2.17).

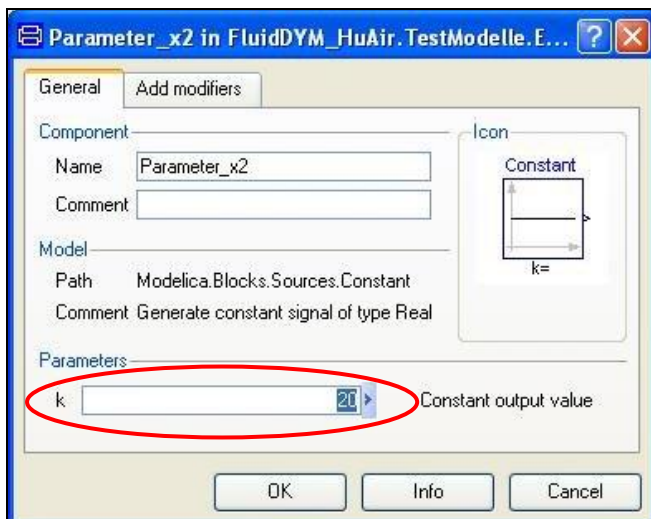


Figure 2.17: Entering the value for the temperature t

- Now, double click on the "Parameter_x3" block which represents the third input parameter, here the humidity ratio x_w in $\text{g}_{\text{Water}}/\text{kg}_{\text{Air}}$.
- Enter the value 0.1 on the line next to "k" in the dialog window which appears and then click the "OK" button (see Figure 2.18).

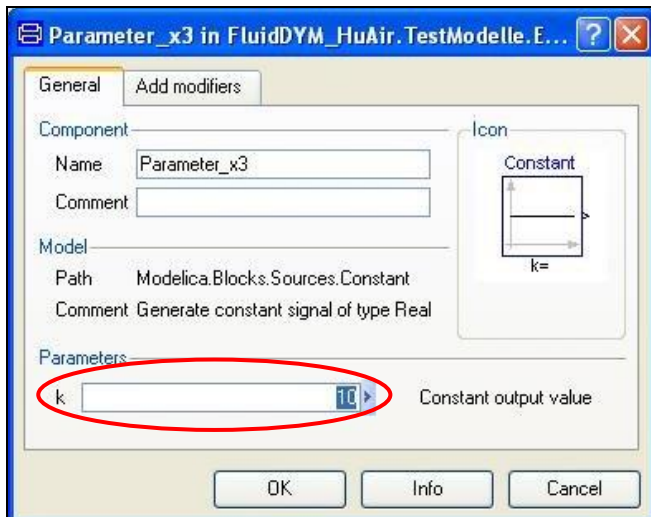
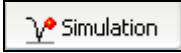


Figure 2.18: Entering the value for the humidity ratio x_w

All parameters have now been defined.

- Click on the  button in the lower right area of Dymola in order to switch into the "Simulation Mode".

In Figure 2.19 you can see how the Dymola "Simulation Mode" looks like.

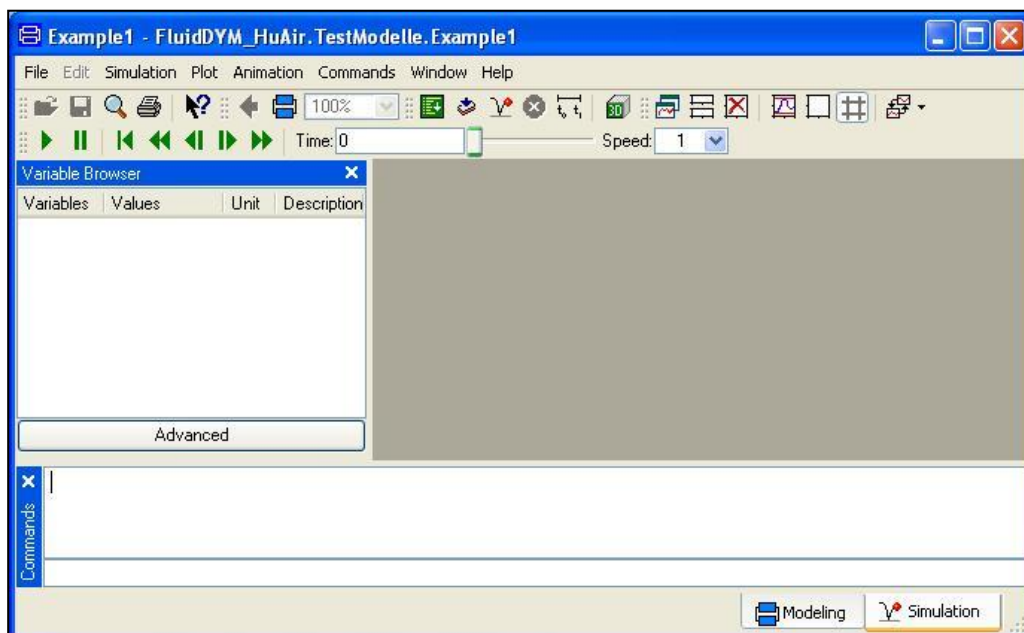


Figure 2.19: "Simulation Mode" window

IMPORTANT NOTICE:

Per default the 64-bit version of Dymola creates a 32-bit simulation process. If you want to create a 64-bit simulation process you must have installed the 64-bit version of FluidDYM and you now need to enter the following command into the command line of Dymola and confirm your entry by pressing the Enter key:

"Advanced.CompileWith64=2"

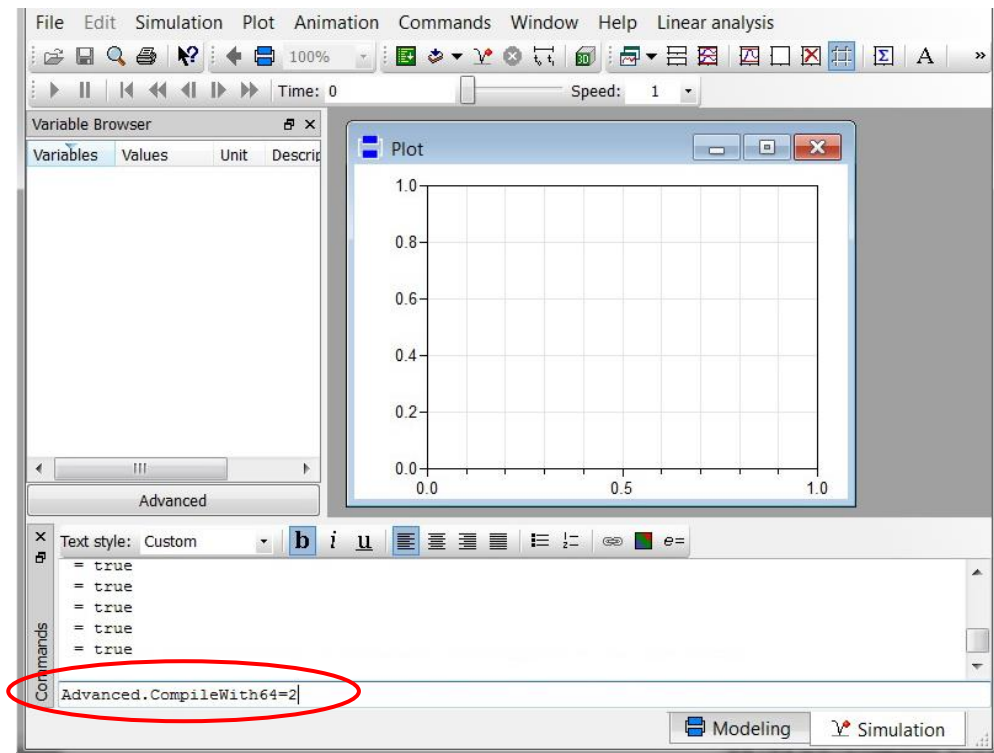



Figure 2.20: "Simulation Mode" window with 64-bit command

Now, your 64-bit Dymola creates 64-bit simulation processes with FluidDYM.

Please note that if you restart Dymola and want to create 64-bit simulation processes again, you will always have to enter this command anew.

For further information concerning this matter, please see the Dymola user's guide.

- Click on the "Simulate" Button  in the Dymola menu bar to start the calculation. Now the model will be compiled and the simulation started.
- Afterwards you will see the following entries within the "Variable Browser" window in Dymola (see Figure 2.21):

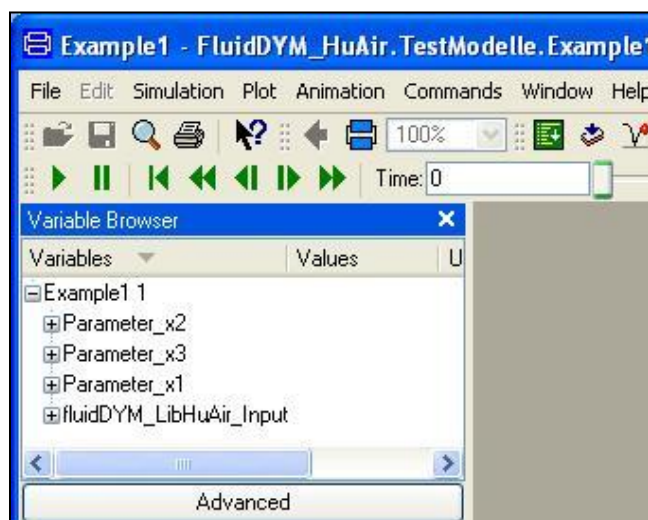



Figure 2.21: "Variable Browser" with new entries

- By clicking on the "NewPlotWindow" button , a new diagram window will be opened.
- Click on "fluidDym_LibHuAir_Input" within the "Variable Browser"; then you will see the input and output parameters "scanRange", "FunctionNumber", "z", "x1", "x2" and "x3" (see Figure 2.22).

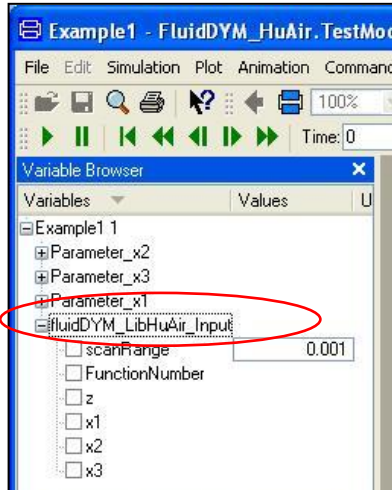


Figure 2.22: Parameters of *fluidDYM_LibHuAir_Input*

- After clicking on the output parameter "z", of the calculated property will be represented graphically in the "PlotWindow".
- Move the mouse over the curve to see the result of the simulation at a specific point in time (see Figure 2.23).

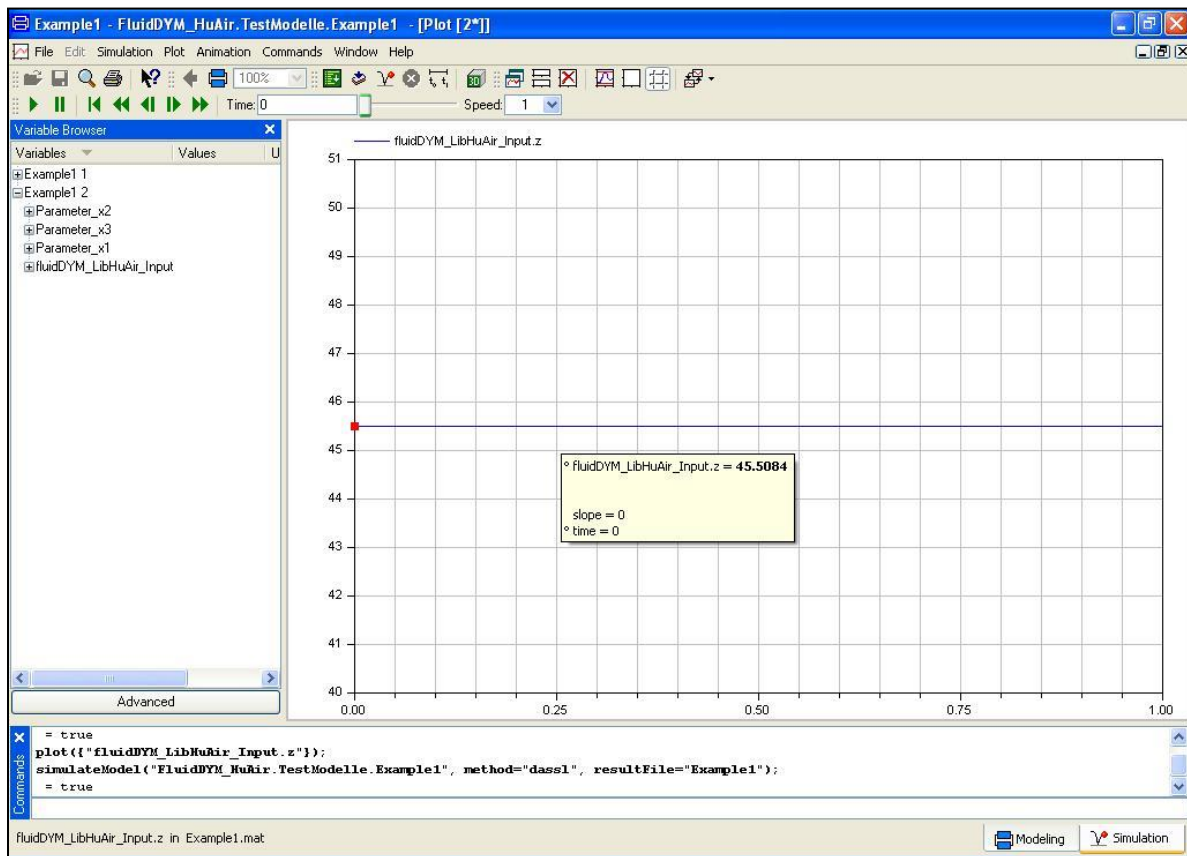



Figure 2.23: "DiagramWindow" showing the result

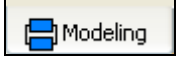
The result for h appears in the "DiagramWindow"

⇒ The result in our sample calculation here is: " $h_l = 45.5084$ ". The corresponding unit is $\text{kJ/kg}_{\text{Air}}$ (see table of the property functions in Chapter 1).


- Now click on the Modeling button  in the lower right area of Dymola in order to switch into the "Modeling Mode". Here you can arbitrarily change the values for p , t , or x_w in the appropriate blocks.

Help Systems in Dymola®

Dymola® provides detailed help functions. You can choose to read the program documentation or the help page of a specific property function, as desired.

Within the "Modeling-Mode"  the help may be accessed via two different steps.

First we will show you how to access the program documentation of the property library.

- Make sure Dymola is set to the "Modeling-Mode".
- Now click the  button in the Dymola menu bar to choose the "Documentation Mode".
- Double-click on the "FluidDYM_HuAir" Block at the left and then click on "Users_Guide" (see Figure 2.24).

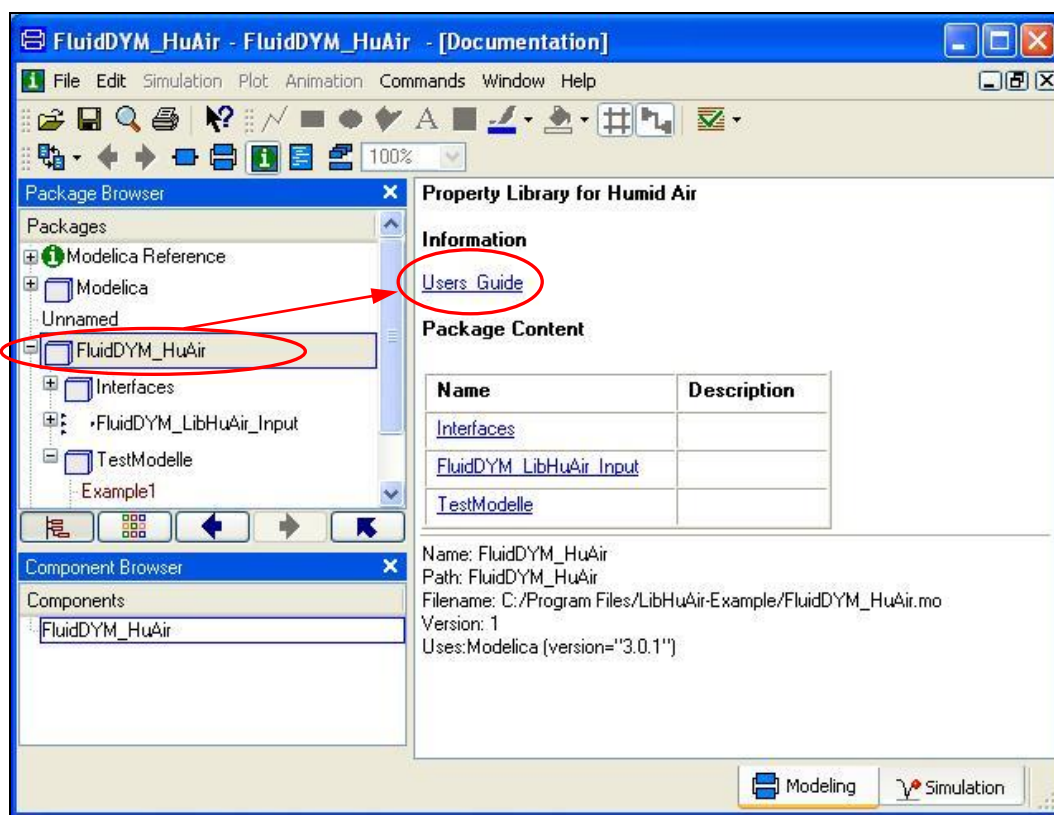



Figure 2.24: Selecting the "Users_Guide"

- The program documentation will be displayed within your default web browser.

Now, we will show you how to access the help page of a specific property function.

- Make sure Dymola is set to the "Modeling-Mode".
- Now click the  button in the Dymola menu bar to choose the "Documentation Mode".
- Double-click on the "FluidDYM_HuAir_Input" block on the left (see Figure 2.25).

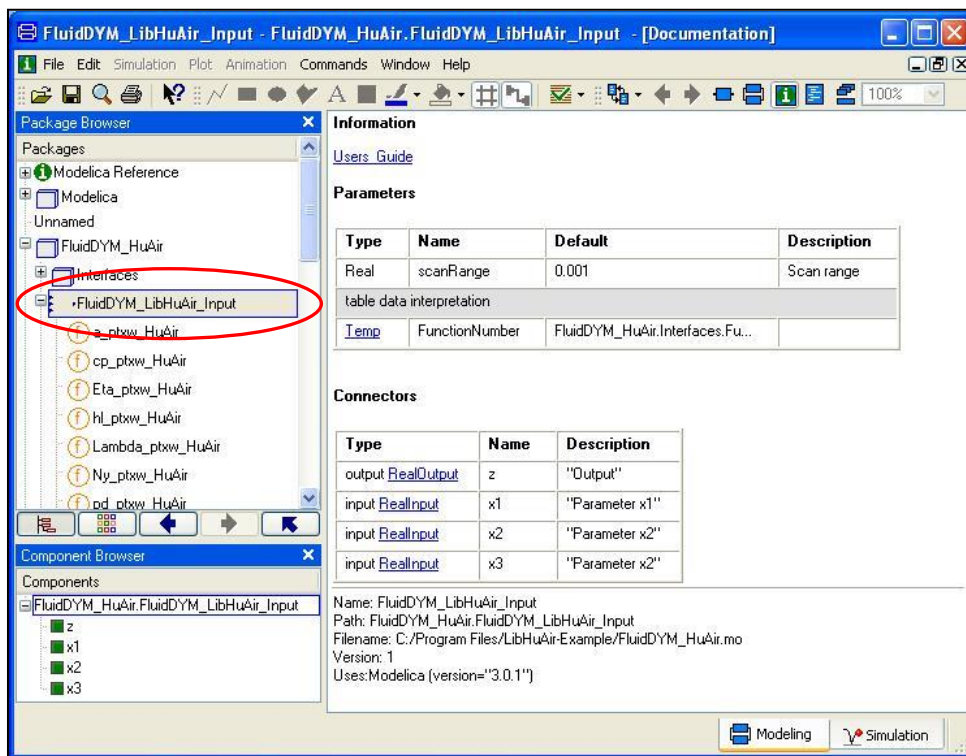


Figure 2.25: Selected "FluidDYM_HuAir_Input" Block

- Below "FluidDYM_HuAir_Input" you will see all functions of the LibHuAir property function (see Figure 2.24).
- Now select a function, e.g. "hl_ptwx_HuAir", and then click on "Users_Guide" (see Figure 2.26).

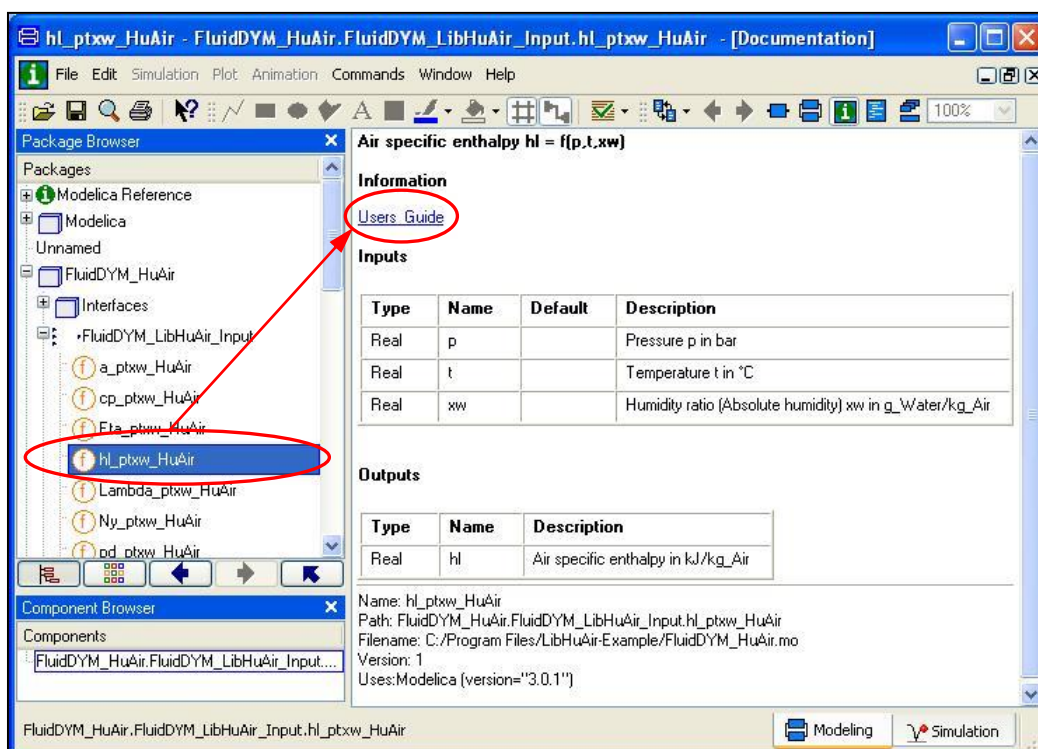


Figure 2.26: Marking the "hl_ptwx_HuAir" function and selecting the "Users_Guide"

- You will now see the help page of the selected function, here "hl_ptxw_HuAir", in your default web browser (see Figure 2.27).

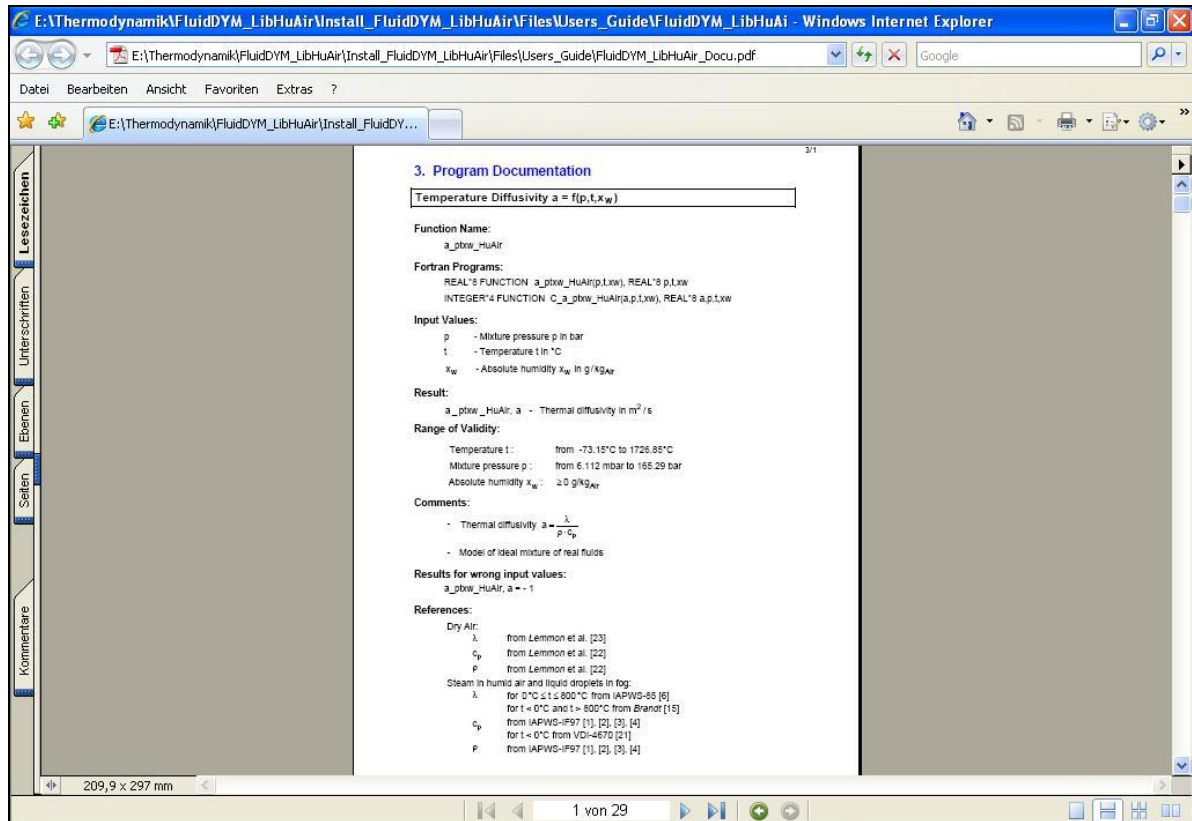


Figure 2.27: Help page of the function "hl_ptXi_HuAir" in the web browser

2.3 Removing LibHuAir in Dymola

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

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

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

In the following dialogue box click "Automatic" and then "Next>". Confirm the "Perform Uninstall" menu which appears by clicking the "Finish" button.

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

"FluidDYM LibHuAir" has now been removed.

If LibHuAir is the only library installed, the directory "FluidDYM" will be removed as well.

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

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 ($t < 0.01^\circ\text{C}$ 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 $0^\circ\text{C} \leq t \leq 800^\circ\text{C}$ from IAPWS-85 [7]
for $t < 0^\circ\text{C}$ and $t > 800^\circ\text{C}$ from *Brandt* [12]

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

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:
from 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 $0^\circ\text{C} \leq t \leq 800^\circ\text{C}$ from IAPWS-85 [7]
 for $t < 0^\circ\text{C}$ and $t > 800^\circ\text{C}$ from *Brandt* [12]
 ρ from IAPWS-IF97 [1], [2], [3], [4]
 for $t < 0.01^\circ\text{C}$ 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 $p_d = p_{ds}(p, t)$
 - with $p_{ds}(p, t)$ for $t \geq 0.01^\circ\text{C}$ - Steam pressure from water in gas mixtures
 - for $t < 0.01^\circ\text{C}$ - Sublimation pressure from water in gas mixtures

Result for wrong input values:

pd_ptxw_HuAir, pd = -1

References:

f(p, t) Herrmann et al. [25], [26]
 $p_{ds}(t)$ 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 pressure of water 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:

$p_{ds}(p,t)$ for $t \geq 0.01^\circ\text{C}$ - Steam 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:

pds_pt_HuAir, pds = -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]

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:

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

with $p_{\text{ds}}(p, t)$ for $t \geq 0.01^\circ\text{C}$ - steam 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:

Phi_ptxw_HuAir, Phi = - 1

References:

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

$p_{\text{ds}}(p, t)$ 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]

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 $p_l = p - p_{ds}(p, t)$

with $p_{ds}(p, t)$ for $t \geq 0.01^\circ\text{C}$ - steam 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]
 $p_{ds}(p, t)$ 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]

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

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]
when $t < 0^\circ\text{C}$ from VDI-4670 [21]

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:**

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

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

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 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,h_l,x_w), REAL*8 p,h_l,x_w
INTEGER*4 FUNCTION C_t_phlxw_HuAir(t,p,h_l,x_w), REAL*8 t,p,h_l,x_w
```

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

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 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 ≤ 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. [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]

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 $h_l^{\text{unsaturated}}(p, t, x_w) = h_l^{\text{fog}}(p, t_f, x_w)$
- Effects of dissociation are taken into consideration from 500 °C upwards

Result for wrong input values:

tf_ptxw_HuAir, tf = - 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]
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)

$t_\tau = t_{\text{sub}}(p, p_d)$ 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]

$t_{\text{sub}}(p, p_d)$ for $t_\tau < 0.01^\circ\text{C}$ from IAPWS-08 [16], [17]

$t_s(p)$ from IAPWS-IF97 [1], [2], [3], [4]

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

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 from 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 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:

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

with p_{ds}(p,t) for t ≥ 0.01°C - Steam pressure of water in gas mixtures
 for t < 0.01°C - Sublimation pressure of water in gas mixtures

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 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:

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

with $p_{ds}(p, t)$ for $t \geq 0.01^\circ\text{C}$ - Steam 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:

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 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:

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

with $p_{ds}(p, t)$ for $t \geq 0.01^\circ\text{C}$ - Steam 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:

xw_ptTau_HuAir, $x_w = -1$

References:

$f(p, t)$ Herrmann et al. [25], [26]
 $p_s(t_\tau)$ if $t_\tau \geq 0.01^\circ\text{C}$ from IAPWS-IF97 [1], [2], [3], [4]
 if $t_\tau < 0.01^\circ\text{C}$ 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 $h_l^{\text{unsaturated}}(p, t, x_w) = h_l^{\text{fog}}(p, t_f, x_w)$
- Effects of dissociation are taken into consideration from 500 °C upwards

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

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:

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 $t \geq 0.01^\circ\text{C}$ - Steam 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:

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:
 CO_2 - Span, Wagner H_2O - IAPWS-95
 O_2 - Schmidt, Wagner N_2 - Span et al.
 Ar - Tegeler et al.
 and of the ideal gases:
 SO_2 , CO, Ne
 (Scientific Formulation of 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_2O	F_2	Propane
N_2	SO_2	NH_3	Iso-Butane
O_2	H_2	Methane	n-Butane
CO	H_2S	Ethane	Benzene
CO_2	OH	Ethylene	Methanol
Air			

Consideration of:

- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

Humid Air

Library ASHRAE LibHuAirProp

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

Consideration of:

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

www.ashrae.org/bookstore

Dry Air Including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth et al. (1993)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of 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

$\text{C}_2\text{H}_6\text{O}_2$	Ethylene glycol
$\text{C}_3\text{H}_8\text{O}_2$	Propylene glycol
$\text{C}_2\text{H}_5\text{OH}$	Ethanol
CH_3OH	Methanol
$\text{C}_3\text{H}_8\text{O}_3$	Glycerol
K_2CO_3	Potassium carbonate
CaCl_2	Calcium chloride
MgCl_2	Magnesium chloride
NaCl	Sodium chloride
$\text{C}_2\text{H}_3\text{KO}_2$	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 C_3H_6O **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

For more information please contact:

KCE-ThermoFluidProperties UG (limited liability) & Co. KG
Professor Hans-Joachim Kretschmar

Wallotstr. 3
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

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

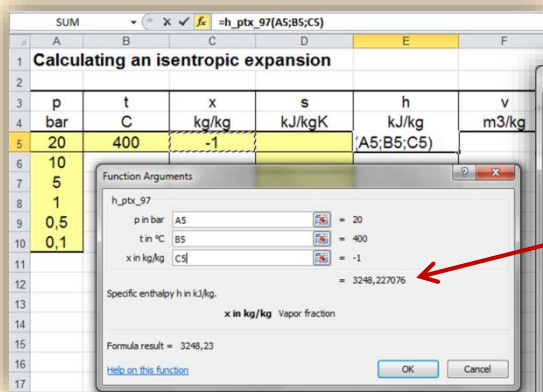
Thermodynamic Derivatives

- Partial derivatives can be calculated.

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

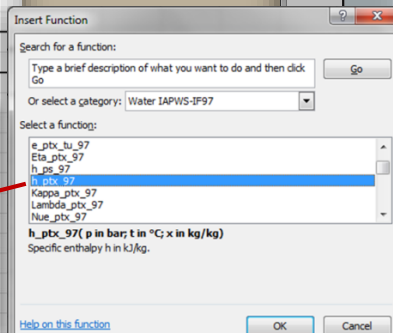
Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

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

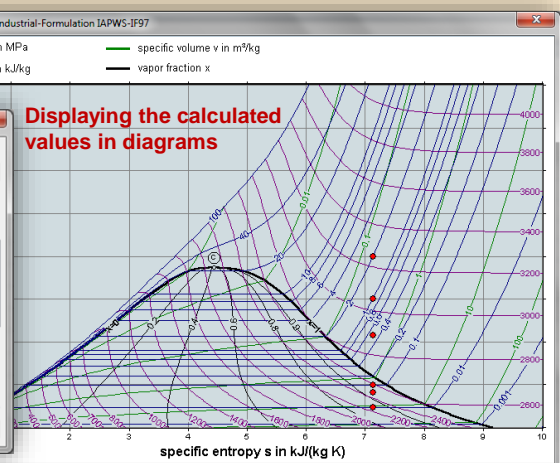


Menu for the input of given property values

Choosing a property library and a function

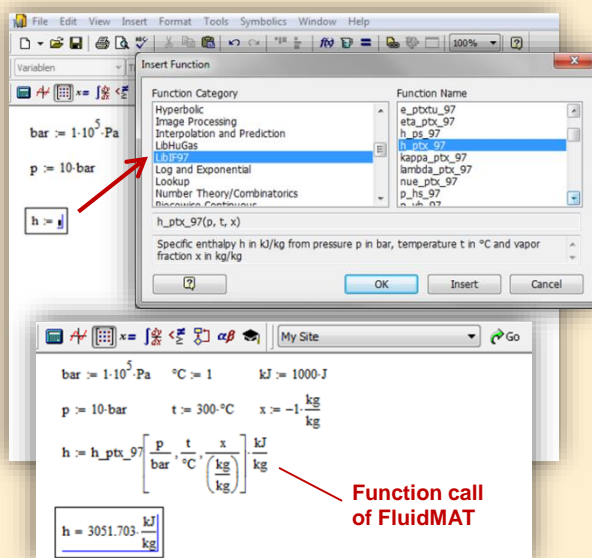


Displaying the calculated values in diagrams



Add-In FluidMAT for Mathcad[®]

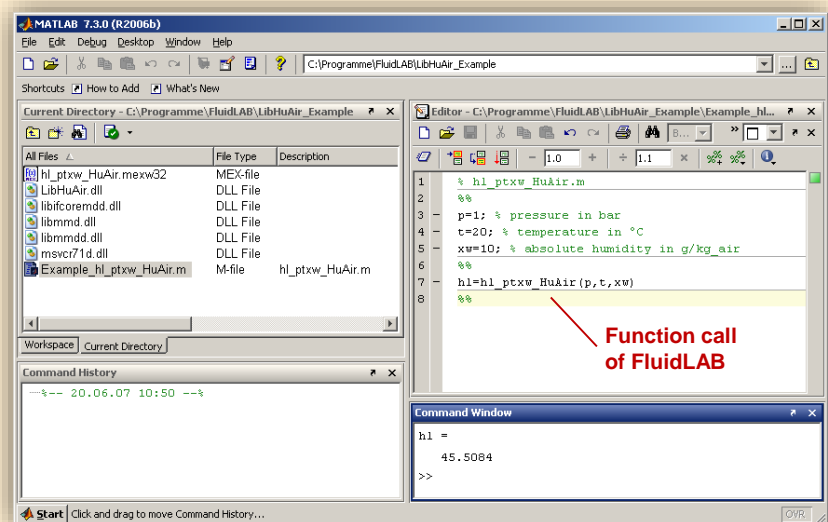
The property libraries can be used in Mathcad[®].



Function call of FluidMAT

Add-In FluidLAB for MATLAB[®]

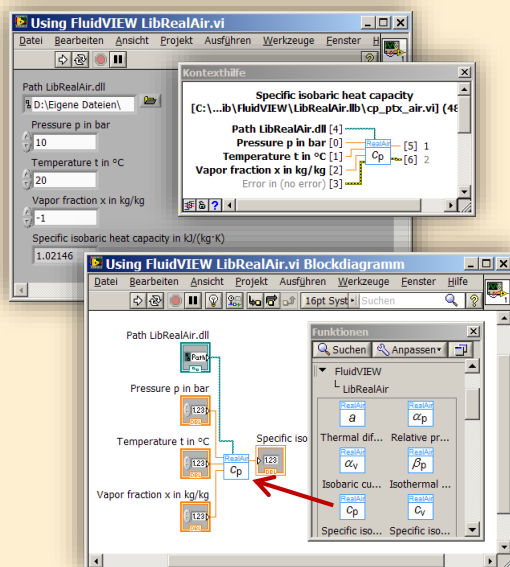
Using the Add-In FluidLAB the property functions can be called in MATLAB[®].



Function call of FluidLAB

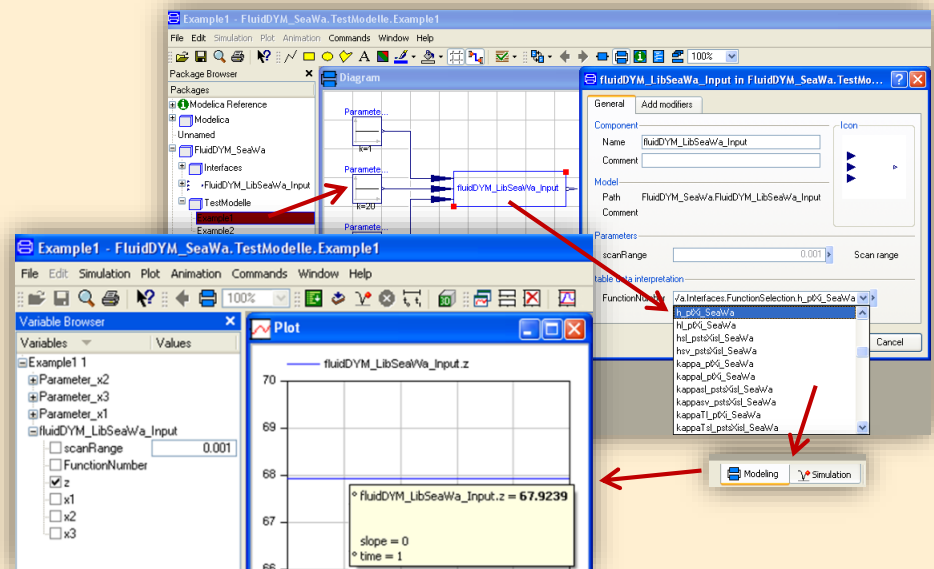
Add-On FluidVIEW for LabVIEW[™]

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

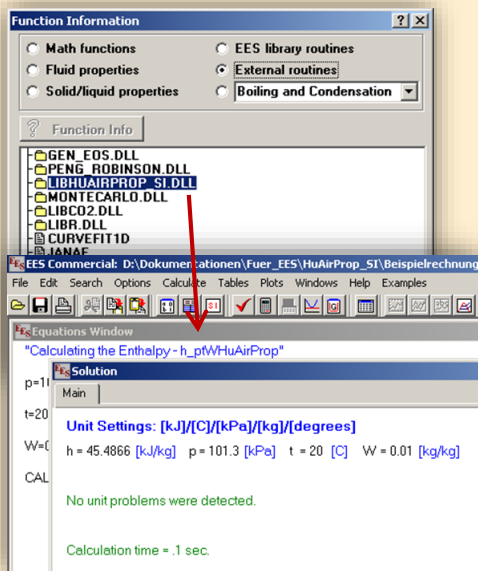


Add-In FluidDYM for DYMOLA[®] (Modelica) and SimulationX[®]

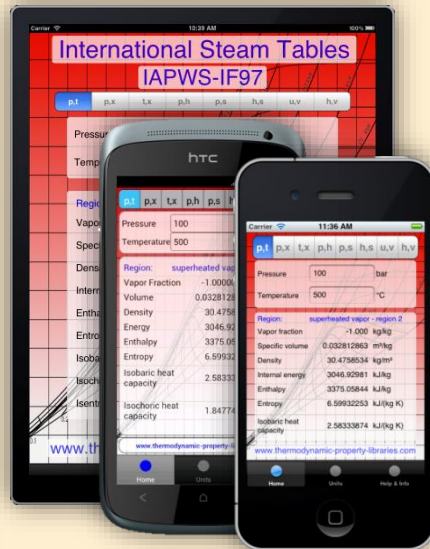
The property functions can be called in DYMOLA[®] and SimulationX[®].



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](#).

© Zittau/Göeritz University of Applied Sciences
Faculty of Mechanical Engineering
Department of Technical Thermodynamics
Prof. Hans-Joachim Kretzschmar
Dr. Ines Stöcker
Programmer: Joachim Posselt

Tel.: +49-3583-61-1946 or -1981
Fax: +49-3583-61-1946
E-mail: info@thermofluidprop.com
www.thermofluidprop.com
www.thermofluidprop.com
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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 Nspire CX CAS TI 83 TI 84 TI 89 TI 92

For more information please contact:

KCE-ThermoFluidProperties UG (limited liability) & Co. KG
Professor Hans-Joachim Kretzschmar

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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
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- 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.

5 References

- [1] Revised Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam IAPWS-IF97.
IAPWS Executive Secretariat (2007), available at www.iapws.org
- [2] Wagner, W.; Kretzschmar, H.-J.:
International Steam Tables.
Springer-Verlag, Berlin (2008), www.international-steam-tables.com
- [3] Wagner, W.; Cooper, J. R.; Dittmann, A.; Kijima, J.; Kretzschmar, H.-J.; Kruse, A.; Mares, R.; Oguchi, K.; Sato, H.; Stöcker, I.; Sifner, O.; Takaishi, Y.; Tanishita, I.; Trübenbach, J.; Willkommen, Th.:
The IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam.
J. Eng. Gas Turbines Power 122 (2000), S. 150-182.
- [4] Wagner, W.; Rukes, B.:
IAPWS-IF97: Die neue Industrie-Formulation.
BWK 50 (1998) Nr. 3, S. 42-97.
- [5] Kretzschmar, H.-J.:
Mollier h,s -Diagramm.
Springer-Verlag, Berlin (2008).
- [6] Revised Release on the IAPS Formulation 1985 for the Thermal Conductivity of Ordinary Water Substance.
IAPWS Executive Secretariat (2008), available at www.iapws.org
- [7] Release on the IAPWS Formulation 2008 for the Viscosity of Ordinary Water Substance.
IAPWS Executive Secretariat (2008), available at www.iapws.org
- [8] IAPWS Release on Surface Tension of Ordinary Water Substance 1994.
IAPWS Executive Secretariat (1994), available at www.iapws.org
- [9] Release on the IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use.
IAPWS Executive Secretariat (1995), available at www.iapws.org
- [10] Wagner, W.; Pruß, A.:
The IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use.
J. Phys. Chem. Ref. Data 31 (2002), S. 387-535-
- [11] Kretzschmar, H.-J.:
Zur Aufbereitung und Darbietung thermophysikalischer Stoffdaten für die Energietechnik.
Habilitation, TU Dresden, Fakultät Maschinenwesen (1990).

- [12] Brandt, F.:
Wärmeübertragung in Dampferzeugern und Wärmetauschern.
FDBR-Fachbuchreihe, Bd. 2, Vulkan Verlag Essen (1985).
- [13] VDI Richtlinie 4670
Thermodynamische Stoffwerte von feuchter Luft und Verbrennungsgasen. (2003).
- [14] Lemmon, E. W.; Jacobsen, R. T.; Penoncello, S. G.; Friend, D. G.:
Thermodynamic Properties of Air and Mixtures of Nitrogen, Argon, and Oxygen from
60 to 2000 K at Pressures to 2000 MPa.
J. Phys. Chem. Ref. Data 29 (2000), S. 331-385.
- [15] Lemmon, E. W.; Jacobsen, R. T.:
Viscosity and Thermal Conductivity Equations for Nitrogen, Oxygen, Argon, and Air.
Int. J. Thermophys. 25 (2004), S. 21-69.
- [16] Revised Release on the Pressure along the Melting and Sublimation Curves of
Ordinary Water Substance.
IAPWS Executive Secretariat (2008), available at www.iapws.org
- [17] Wagner, W.; Feistel, R.; Riethmann, T.:
New Equations for the Melting Pressure and Sublimation Pressure of H₂O Ice Ih.
To be submitted to J. Phys. Chem. Ref. Data.
- [18] Revised Release on the Equation of State 2006 for H₂O Ice Ih.
IAPWS Executive Secretariat (2009), available at www.iapws.org
- [19] Feistel, R.; Wagner, W.:
A New Equation of State for H₂O Ice Ih.
J. Phys. Chem. Ref. Data 35 (2006), S. 1021-1047.
- [20] Nelson, H. F.; Sauer, H. J.:
Formulation of High-Temperature Properties for Moist Air.
HVAC&R Research 8 (2002), S. 311-334.
- [21] Gatley, D. P.:
Understanding Psychrometrics, 2nd ed.
ASHRAE, Atlanta (2005).
- [22] Gatley, D.; Herrmann, S.; Kretschmar, H.-J.:
A Twenty-First Century Molar Mass for Dry Air.
HVAC&R Research 14 (2008), S. 655-662.
- [23] Herrmann, S.; Kretschmar, H.-J.; Teske, V.; Vogel, E.; Ulbig, P.; Span, R.; Gatley,
D. P.:
Determination of Thermodynamic and Transport Properties for Humid Air for Power-
Cycle Calculations.
Bericht PTB-CP-3, Physikalisch-Technische Bundesanstalt Braunschweig und Berlin
(Hrsg.), Wirtschaftsverlag NW, Verlag für neue Wissenschaft GmbH, Bremerhaven
(2009). ISBN: 978-3-86509-917-4.
- [24] Herrmann, S.; Kretschmar, H.-J.; Teske, V.; Vogel, E.; Ulbig, P.; Span, R.; Gatley,
D. P.:
Properties of Humid Air for Calculating Power Cycles.
J. Eng. Gas Turbines Power 132 (2010), S. 093001-1 – 093001-8 (published online).

- [25] Herrmann, S.; Kretzschmar, H.-J.; Gatley, D. P.:
Thermodynamic Properties of Real Moist Air, Dry Air, Steam, Water, and Ice
(RP-1485).
HVAC&R Research 15 (2009), S. 961-986.
- [26] Herrmann, S.; Kretzschmar, H.-J.; Gatley, D. P.:
Thermodynamic Properties of Real Moist Air, Dry Air, Steam, Water, and Ice.
Final Report ASHRAE RP-1485, American Society of Heating, Refrigeration, and Air-
Conditioning Engineers, Inc., Atlanta, GA (2009).

6. Satisfied Customers

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, Vaujours, France	03/2017
TU Bergakademie Freiberg, Chair of Thermodynamics, Freiberg	03/2017
SCHMIDT + PARTNER, Therwil, Switzerland	03/2017
KAESER Kompressoren, Gera	03/2017
F&R, Praha, Czech Republic	03/2017
ULT Umwelt-Lufttechnik, Löbau	02/2017
JS Energie & Beratung, Erding	02/2017
Kelvion Brazed PHE, Nobitz-Wilchwitz	02/2017
MTU Aero Engines, München	02/2017
Hochschule Zittau/Görlitz, IPM	01/2017
CombTec ProCE, Zittau	01/2017
SHELL Deutschland Oil, Wesseling	01/2017
MARTEC Education Center, Frederikshaven, Denmark	01/2017
SynErgy Thermal Management, Krefeld	01/2017

2016

BOGE Druckluftsysteme, Bielefeld	12/2016
BFT Planung, Aachen	11/2016
Midiplan, Bietigheim-Bissingen	11/2016
BBE Barnich IB	11/2016
Wenisch IB,	11/2016
INL, Idaho Falls	11/2016
TU Kältetechnik, Dresden	11/2016
Kopf SynGas, Sulz	11/2016
INTVEN, 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

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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
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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
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Schniewindt GmbH & Co. KG, Neuenwalde	08/2015

2014

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GKS, Schweinfurt	03/2014
Technical University of Nuremberg	03/2014
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Rückert NatUrgas GmbH, Lauf	03/2014
YESS-World, South Korea	03/2014
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KIT-TVT, Karlsruhe	02/2014
Stadtwerke Neuburg	02/2014
COMPAREX, Leipzig for RWE Essen	02/2014
Technical University of Prague, Czech Republic	02/2014
HS Augsburg	02/2014
Envi-con, Nuremberg	01/2014
DLR, Stuttgart	01/2014
Doosan Lentjes, Ratingen	01/2014
Technical University of Berlin	01/2014
Technical University of Munich	01/2014
Technical University of Braunschweig	01/2014
M&M Turbinentechnik, Bielefeld	01/2014

2013

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

IAV, Chemnitz	10/2013
Technical University of Regensburg	10/2013
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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
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University of Princeton, USA	07/2013
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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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VEO, Eisenhüttenstadt	02/2013
ENTEC, Auerbach	02/2013
Caterpillar, Kiel	02/2013
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Schütz Engineering, Wadgassen	01/2013
Endress & Hauser, Reinach, Switzerland	01/2013
Oschatz GmbH, Essen	01/2013
frischli Milchwerke, Rehburg-Loccum	01/2013

2012

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

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

2011

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

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

2010

Umweltinstitut Neumarkt	12/2010
YIT Austria, Vienna, Austria	12/2010
MCI Innsbruck, Austria	12/2010

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

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

2009

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

Technical University of Berlin	06/2009
Fraunhofer Institut UMSICHT, Oberhausen	07/2009
Bischoff, Aurich	07/2009
Fichtner IT Consulting, Stuttgart	07/2009
Techsoft, Linz, Austria	08/2009
DLR, Stuttgart	08/2009
Wienstrom, Vienna, Austria	08/2009
RWTH Aachen University	09/2009
Vattenfall, Hamburg	10/2009
AIC, Chemnitz	10/2009
Midiplan, Bietigheim-Bissingen	11/2009
Institute of Air Handling and Refrigeration ILK, Dresden	11/2009
FZD, Rossendorf	11/2009
Techgroup, Ratingen	11/2009
Robert Sack, Heidelberg	11/2009
EC, Heidelberg	11/2009
MCI, Innsbruck, Austria	12/2009
Saacke, Bremen	12/2009
ENERKO, Aldenhoven	12/2009

2008

Pink, Langenwang	01/2008
Fischer-Uhrig, Berlin	01/2008
University of Karlsruhe	01/2008
MAAG, Kuesnacht, Switzerland	02/2008
M&M Turbine Technology, Bielefeld	02/2008
Lentjes, Ratingen	03/2008
Siemens Power Generation, Goerlitz	04/2008
Evonik, Zwingenberg (general EBSILON program license)	04/2008
WEBASTO, Neubrandenburg	04/2008
CFC Solutions, Munich	04/2008
RWE IT, Essen	04/2008
Rerum Cognitio, Zwickau	04/2008, 05/2008
ARUP, Berlin	05/2008
Research Center, Karlsruhe	07/2008
AWECO, Neukirch	07/2008
Technical University of Dresden,	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

2007

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

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

2006

STORA ENSO Sachsen, Eilenburg	01/2006
Technical University of Munich, Chair in Energy Systems	01/2006
NUTEC Engineering, Bisikon, Switzerland	01/2006, 04/2006
Conwel eco, Bochov, Czech Republic	01/2006
Offenburg University of Applied Sciences	01/2006
KOCH Transporttechnik, Wadgassen	01/2006
BEG Bremerhavener Entsorgungsgesellschaft	02/2006
Deggendorf University of Applied Sciences, Department of Mechanical Engineering and Mechatronics	02/2006
University of Stuttgart,	02/2006
Department of Thermal Fluid Flow Engines	
Technical University of Munich,	02/2006
Chair in Apparatus and Plant Engineering	
Energietechnik Leipzig (company license),	02/2006
Siemens Power Generation, Erlangen	02/2006, 03/2006
RWE Power, Essen	03/2006
WAETAS, Pobershau	04/2006
Siemens Power Generation, Goerlitz	04/2006
Technical University of Braunschweig,	04/2006
Department of Thermodynamics	
EnviCon & Plant Engineering, Nuremberg	04/2006
Brassel Engineering, Dresden	05/2006
University of Halle-Merseburg,	05/2006
Department of USET Merseburg incorporated society	
Technical University of Dresden,	05/2006
Professorship of Thermic Energy Machines and Plants	
Fichtner Consulting & IT Stuttgart (company licenses and distribution)	05/2006
Suedzucker, Ochsenfurt	06/2006
M&M Turbine Technology, Bielefeld	06/2006
Feistel Engineering, Volkach	07/2006
ThyssenKrupp Marine Systems, Kiel	07/2006

Caliqua, Basel, Switzerland (company license)	09/2006
Atlas-Stord, Rodovre, Denmark	09/2006
Konstanz University of Applied Sciences, Course of Studies Construction and Development	10/2006
Siemens Power Generation, Duisburg	10/2006
Hannover University of Applied Sciences, Department of Mechanical Engineering	10/2006
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

2005

TUEV Nord, Hannover	01/2005
J.H.K Plant Engineering and Service, Bremerhaven	01/2005
Electrowatt-EKONO, Zurich, Switzerland	01/2005
FCIT, Stuttgart	01/2005
Energietechnik Leipzig (company license)	02/2005, 04/2005
	07/2005
eta Energieberatung, Pfaffenhofen	02/2005
FZR Forschungszentrum, Rossendorf/Dresden	04/2005
University of Saarbruecken	04/2005
Technical University of Dresden	04/2005
Professorship of Thermic Energy Machines and Plants	
Grenzebach BSH, Bad Hersfeld	04/2005
TUEV Nord, Hamburg	04/2005
Technical University of Dresden, Waste Management	05/2005
Siemens Power Generation, Goerlitz	05/2005
Duesseldorf University of Applied Sciences, Department of Mechanical Engineering and Process Engineering	05/2005
Redacom, Nidau, Switzerland	06/2005
Dumas Verfahrenstechnik, Hofheim	06/2005
Alensys Engineering, Erkner	07/2005
Stadtwerke Leipzig	07/2005
SaarEnergie, Saarbruecken	07/2005
ALSTOM ITC, Rugby, Great Britain	08/2005
Technical University of Cottbus, Chair in Power Plant Engineering	08/2005
Vattenfall Europe, Berlin (group license)	08/2005
Technical University of Berlin	10/2005
Basel University of Applied Sciences, Department of Mechanical Engineering, Switzerland	10/2005

Midiplan, Bietigheim-Bissingen	11/2005
Technical University of Freiberg, Chair in Hydrogeology	11/2005
STORA ENSO Sachsen, Eilenburg	12/2005
Energieversorgung Halle (company license)	12/2005
KEMA IEV, Dresden	12/2005

2004

Vattenfall Europe (group license)	01/2004
TUEV Nord, Hamburg	01/2004
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

2003

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
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SoftSolutions, Muehlhausen (company license)	05/2002
DREWAG, Dresden (company license)	05/2002
SOFBID, Zwingenberg	06/2002
(general EBSILON program license)	
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	08/2002
(company licenses and distribution)	
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	12/2002
(general license and training test benches)	
VEAG, Berlin (group license)	12/2002

2001

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	04/2001
(company licenses and distribution)	
Muenstermann GmbH, Telgte-Westbevern	05/2001
SaarEnergie, Saarbruecken	05/2001
Siemens, Karlsruhe	08/2001
(general license for the WinIS information system)	
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

2000

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

1999

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	05/1998
(general KPRO program license)	
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

1997

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