Hochschule Zittau/Görlitz
UNIVERSITY OF APPLIED SCIENCES

Faculty of
MECHANICAL ENGINEERING
Department of
TECHNICAL THERMODYNAMICS

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

FluidLAB
with LibHuAir
for MATLAB®

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

FluidLAB

for MATLAB®

Contents

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0 Package Contents

0.1 Zip file for 32-bit MATLAB®

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

"CD_FluidLAB_LibHuAir.zip"

Humid Air Calculated as Ideal Mixture of Real Fluids

Including the following files:

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

0.2 Zip file for 64-bit MATLAB®

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

"CD_FluidLAB_LibHuAir_x64.zip"

Humid Air Calculated as Ideal Mixture of Real Fluids

Including the following files:

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

1. Property Functions

1.1 Calculation Programs

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

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

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

Variable Types for Function Call

All functions not starting with C_ :	REAL*8
All functions starting with C_ :	INTEGER*4
All variables:	REAL*8

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

Component		Mole Fraction
Nitrogen	N_2	0.7812
Oxygen	O_2	0.2096
Argon	Ar	0.0092

Reference States

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

Units

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

Range of Validity

Temperature: t = - 143.15 °C ... 1726.85 °C
Mixture pressure: p = 6.112 mbar ... 1000 bar

Calculation Algorithm

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

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 $0\,°C \le t \le 800\,°C$ from IAPWS-85 [6], [7]
    for t < 0°C and t > 800°C from *Brandt* [12]

Supersaturated humid air (liquid fog or ice fog)

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

  Ideal mixture of saturated humid air and water
  - Saturated humid air (see above)
  - v, h, u, s, c_p of liquid droplets from IAPWS-IF97 [1], [2], [3], [4]
  - λ, η of liquid droplets from IAPWS-85 [6], [7]
- Ice fog $(x_w > x_{ws})$ and $t < 0.01°C$

  Ideal mixture of saturated humid air and ice
  - Saturated humid air (see above)
  - v, h, s of ice crystals from IAPWS-06 [18], [19]
  - λ, c_p of ice crystals as constant value
  - η, κ, w of saturated humid air

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

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

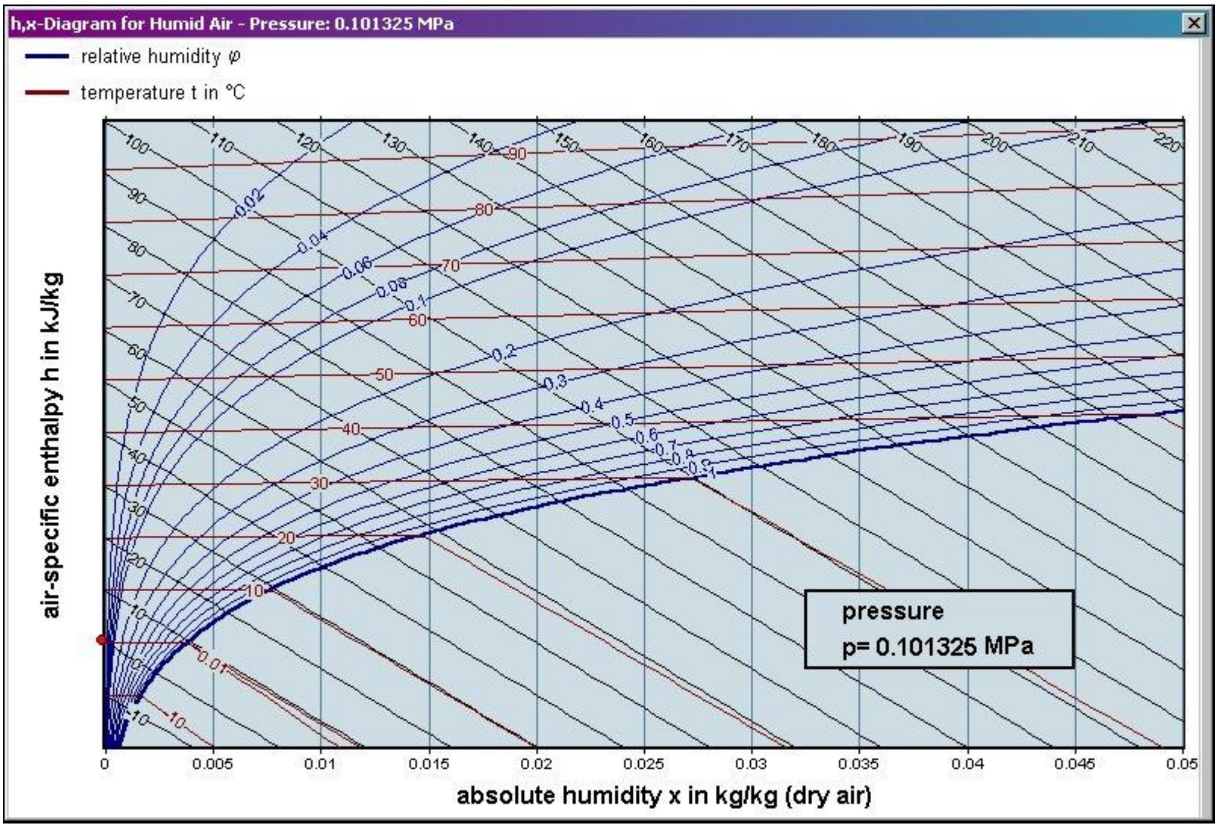
- $f(p,T)$ from Herrmann et al. [25], [26],
- $p_S(t)$ for $t \ge 273.16$ K from IAPWS - IF97 [1], [2], [3], [4],
- $p_S(t)$ for $t < 273.15$ K from IAPWS-08 [16], [17].

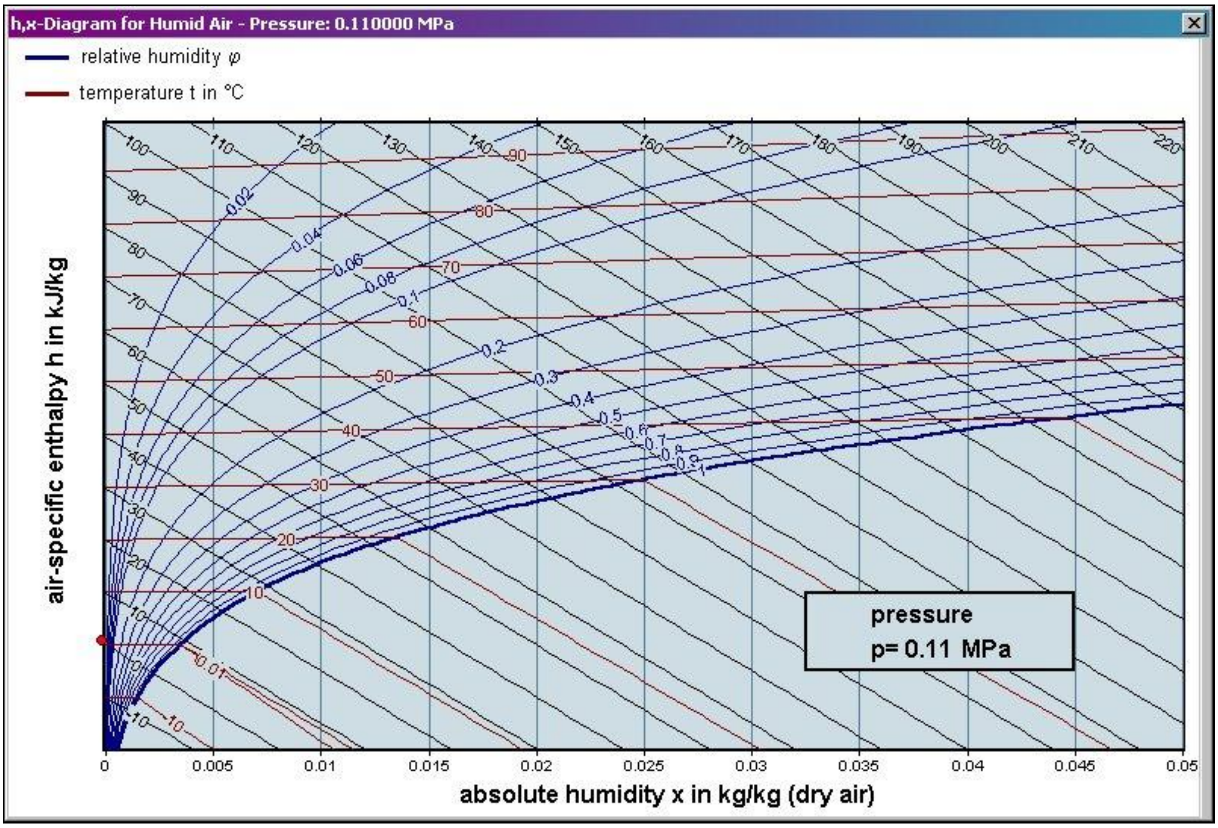
1.2 Thermodynamic Diagrams

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

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

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




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

2 Application of FluidLAB in MATLAB

The FluidLAB Add-In has been developed to calculate thermodynamic properties in MATLAB®. Within FluidLAB, it enables the direct call of functions relating to humid air from the LibHuAir property library.

2.1 Installing FluidLAB LibHuAir

Installing FluidLAB including LibHuAir for 32-bit MATLAB®

This section describes the installation of FluidLAB LibHuAir for a 32-bit version of MATLAB®.
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_FluidLAB_LibHuAir.zip", you will see the folder

CD_FluidLAB_LibHuAir

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

Open this folder by double-clicking on it.

In this folder you will see the following files:

FluidLAB_LibHuAir_Docu_Eng.pdf
FluidLAB_LibHuAir_Setup.exe
LibHuAir.dll.

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

FluidLAB_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 "Next >" button.

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

C:\Program Files\FluidLAB\LibHuAir (for English version of Windows)
C:\Programme\FluidLAB\LibHuAir (for German version of Windows).

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

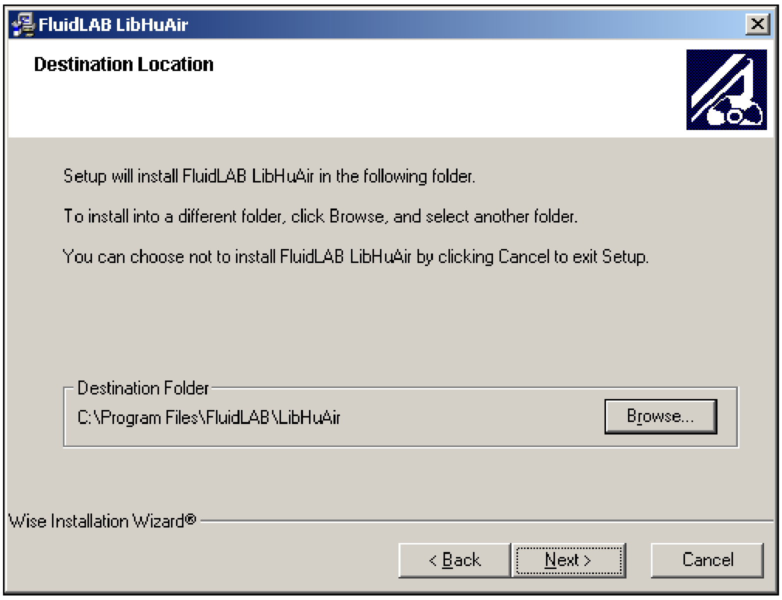


Figure 2.1: Dialog window "Destination Location"

If you wish to change directories, click the "Browse…" button and select your desired directory. The instructions in this documentation refer to the stated default directory. Leave this window by clicking the "Next >" button.

The dialog window "Start Installation" pops up. Click the "Next >" button to continue installation. The FluidLAB files are now being copied into the created directory on your hard drive. Click the "Finish >" button in the following window to complete installation.

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

advapi32.dll	LC.dll
Dformd.dll	msvcp60.dll
Dforrt.dll	msvcrt.dll
INSTALL.LOG	Unwise.exe
LibHuAir.dll	Unwise.ini

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

To do this, open the CD 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 FluidLAB directory (the standard being

C:\Program Files\FluidLAB\LibHuAir (for English version of Windows)

C:\Programme\FluidLAB\LibHuAir (for German version of Windows))

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 and the property functions are available in MATLAB.

Installing FluidLAB including LibHuAir for 64-bit MATLAB®

This section describes the installation of FluidLAB LibHuAir.

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_FluidLAB_LibHuAir_x64.zip", you will see the folder

CD_FluidLAB_LibHuAir

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

Open this folder by double-clicking on it.

In this folder you will see the following two files:

FluidLAB_LibHuAir_Docu_Eng.pdf

FluidLAB_LibHuAir_64_Setup.msi

LibHuAir.dll

Setup.exe.

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

Setup.exe.

Installation of FluidLAB LibHuAir starts with a window noting that the installer will guide you through the installation process. Click the "Next >" button to continue.

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

C:\Program Files\FluidLAB\LibHuAir (for English version of Windows)
C:\Programme\FluidLAB\LibHuAir (for German version of Windows)

By clicking the "Browse…" button, you can change the installation directory before installation (see Figure 2.2).

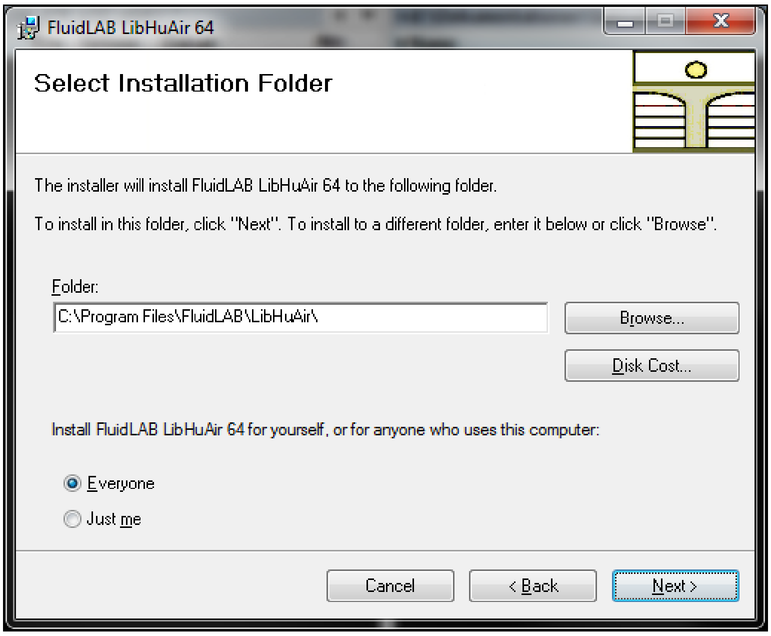


Figure 2.2: "Select Installation Folder"

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

After FluidLAB has been installed, you will see the sentence "FluidLAB LibHuAir 64 has been successfully installed." Confirm this by clicking the "Close" button.

The installation program has copied the following files for LibHuAir into the directory

"C:\Program Files\FluidLAB\LibHuAir" (for English version of Windows)
"C:\Programme\FluidLAB\LibHuAir" (for German version of Windows):

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

Now, you have to overwrite the file "LibHuAir.dll" in your FluidLAB directory with the file of the same name provided on your CD with FluidLAB.
To do this, open the CD 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 FluidLAB directory (the standard being C:\Program Files\FluidLAB\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 and the property functions are available in MATLAB.

The installation programs for both the 32-bit and the 64-bit Windows version have copied the following function files for LibHuAir into the directory

"C:\Program Files\FluidLAB\LibHuAir" (for English version of Windows)
"C:\Programme\FluidLAB\LibHuAir" (for German version of Windows)):

- Dynamic Link Library "LibHuAir.dll" and other necessary system DLL files.
- MATLAB®-Interface-Programme for calculable functions

a_ptxw_HuAir	t_phlxw_HuAir
cp_ptxw_HuAir	t_pslxw_HuAir
Eta_ptxw_HuAir	tf_ptxw_HuAir
hl_ptxw_HuAir	tTau_pxw_HuAir
Lambda_ptxw_HuAir	ul_ptxw_HuAir
Ny_ptxw_HuAir	vl_ptxw_HuAir
pd_ptxw_HuAir	Xil_xw_HuAir
pds_pt_HuAir	Xiw_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.	

Please note that there is a difference in the file extension of the function files.

The 32-bit installation program has copied function files with the file extension

.mexw32

and the 64-bit installation program has copied function files with the file extension

.mexw64

into your LibHuAir directory (the standard being

C:\Program Files\FluidLAB\LibHuAir (for English version of Windows)
C:\Programme\FluidLAB\LibHuAir (for German version of Windows).

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 FluidLAB.
To do this, open the CD folder "CD_FluidLAB_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\FluidLAB\LibHuAir (for English version of Windows)
C:\Programme\FluidLAB\LibHuAir (for German version of Windows))

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.

2.2 Licensing the LibHuAir Property Library

The licensing procedure has to be carried out when a FluidLAB prompt message appears in MATLAB®. In this case, you will see the "License Information" window for LibHuAir (see figure below).

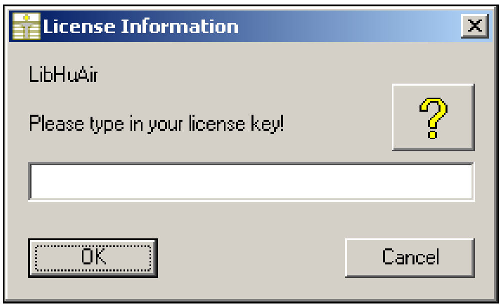


Figure 2.3: "License Information" window

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:

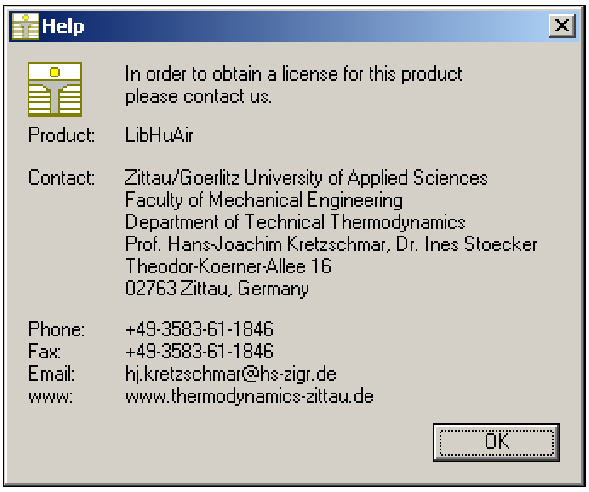


Figure 2.4: "Help" window

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

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

2.3 Example: Calculation of the Air-Specific Enthalpy $h_l = f(p,t,x_w)$ for Humid Air in an M-File

Now we will calculate, step by step, the air-specific enthalpy h_l as a function of mixture pressure p, temperature t and absolute humidity x_W for humid air using FluidLAB.

Please carry out the following instructions:

- Start Windows-Explorer®, Total Commander®, My Computer or another file manager program.
  The following description refers to Windows-Explorer
- Your Windows-Explorer should be set to Details for a better view. Click the "Views" button and select "Details".
- Switch into the program directory of FluidLAB in which you will find the folder "\LibHuAir"; in the standard case:

  "C:\Program Files\FluidLAB" (for English version of Windows)
  "C:\Programme\FluidLAB" (for German version of Windows)
- Create the folder "\LibHuAir_Example". Click "File", then click "New" in the menu that appears and afterwards select "Folder". Name the new folder "\LibHuAir_Example".
- You will see the following window:

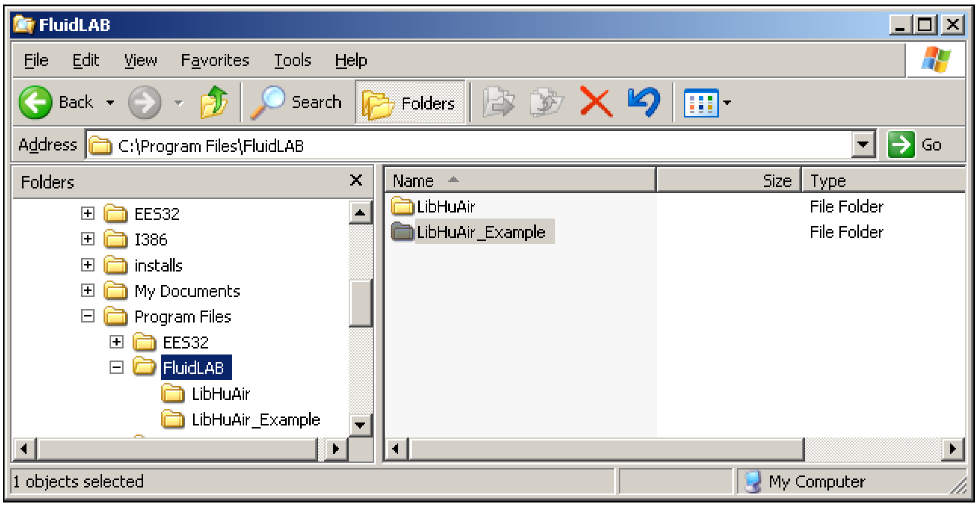


Figure 2.5: "FluidLAB" folder

- Switch into the directory "\LibHuAir" within "\FluidLAB", in the standard case:
  "C:\Program Files\FluidLAB\LibHuAir" (for English version of Windows)
  "C:\Programme\FluidLAB\LibHuAir" (for German version of Windows).

- If you have installed the 32-bit version of FluidLAB LibHuAir you will see the following window:

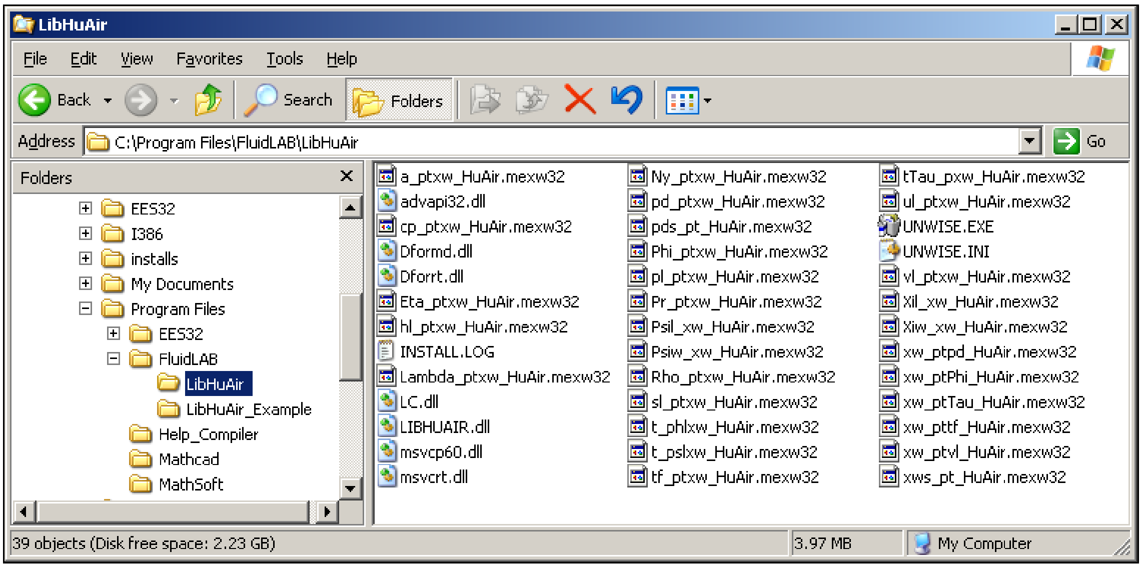


Figure 2.6: Contents of the folder "LibHuAir" (32-bit version)

- If you have installed the 64-bit version of FluidLAB LibHuAir you will see the following window:

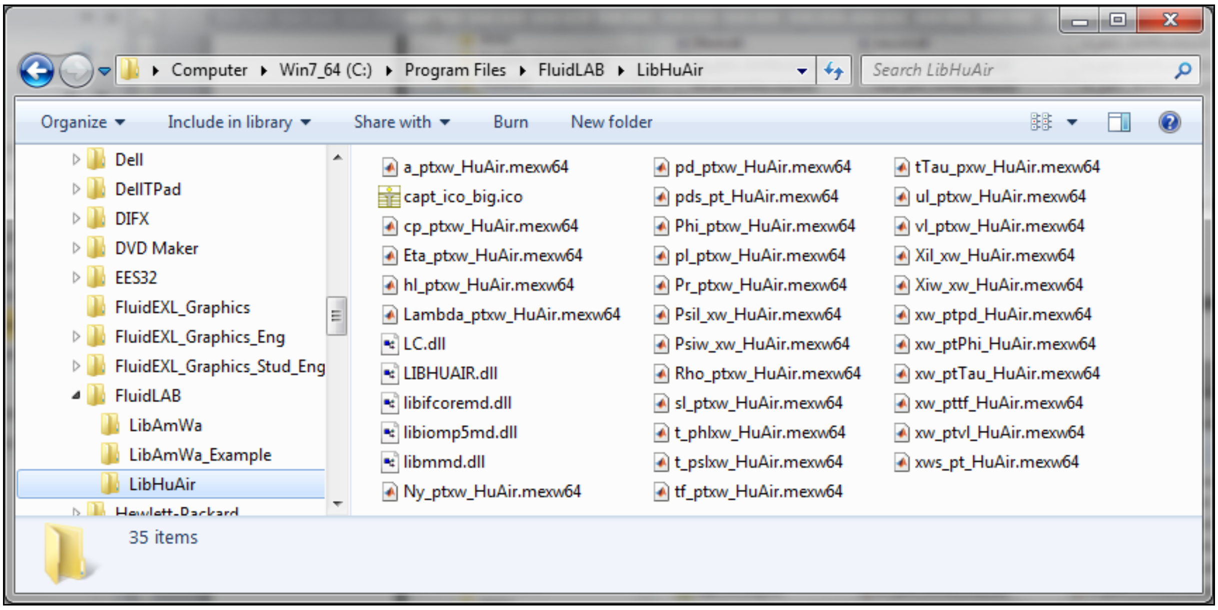


Figure 2.7: Contents of the folder "LibHuAir" (64-bit version)

If you have installed the 32-bit version of LibHuAir you will now have to copy the following files into the directory

"C:\Program Files\FluidLAB\LibHuAir_Example" (for English version of Windows)
"C:\Programme\FluidLAB\LibHuAir_Example" (for German version of Windows)

in order to calculate the function $h_l = f(p,t,x_w)$.

- The following files are needed:

  • "advapi32.dll"

- "Dformd.dll"
- "Dforrt.dll"
- "hl_ptxw_HuAir.mexw32"
- "LC.dll"
- "LibHuAir.dll"
- "msvcp60.dll"
- "msvcrt.dll"

- Click the file "hl_ptxw_HuAir.mexw32", then click "Edit" in the upper menu bar and select "Copy".
- Switch into the directory
  "C:\Program Files\FluidLAB\LibHuAir_Example" (for English version of Windows)
  "C:\Programme\FluidLAB\LibHuAir_Example" (for German version of Windows),
  click "Edit" and select "Paste".
- Repeat these steps in order to copy the other files listed above. You may also select all the above-named files and then copy them as a group (press the Control button to enable multiple markings).
- You will see the following window:

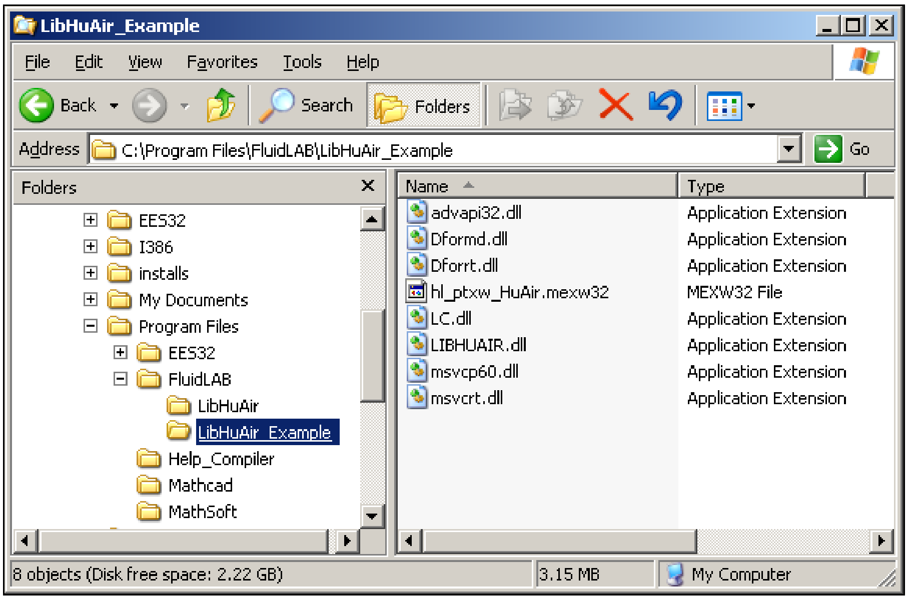


Figure 2.8: Contents of the folder "LibHuAir_Example"

If you have installed the 64-bit version of LibHuAir you will now have to copy the following files into the directory

"C:\Program Files\FluidLAB\LibHuAir_Example" (for English version of Windows)
"C:\Programme\FluidLAB\LibHuAir_Example" (for German version of Windows)

in order to calculate the function $h_l = f(p,t,x_w)$.

- The following files are needed:
  - "hl_ptxw_HuAir.mexw64"
  - "LC.dll"
  - "LibHuAir.dll"
  - "libifcoremd.dll"
  - "libiomp5.dll"
  - "libmmd.dll."
- Click the file "hl_ptxw_HuAir.mexw64", then click "Edit" in the upper menu bar and select "Copy."
- Switch into the directory

  "C:\Program Files\FluidLAB\LibHuAir_Example" (for English version of Windows)
  "C:\Programme\FluidLAB\LibHuAir_Example" (for German version of Windows),

  click "Edit" and then "Paste."
- Repeat these steps in order to copy the other files listed above. You may also select all the above-named files and then copy them as a group (press the Control button to enable multiple markings).
- You will see the following window:

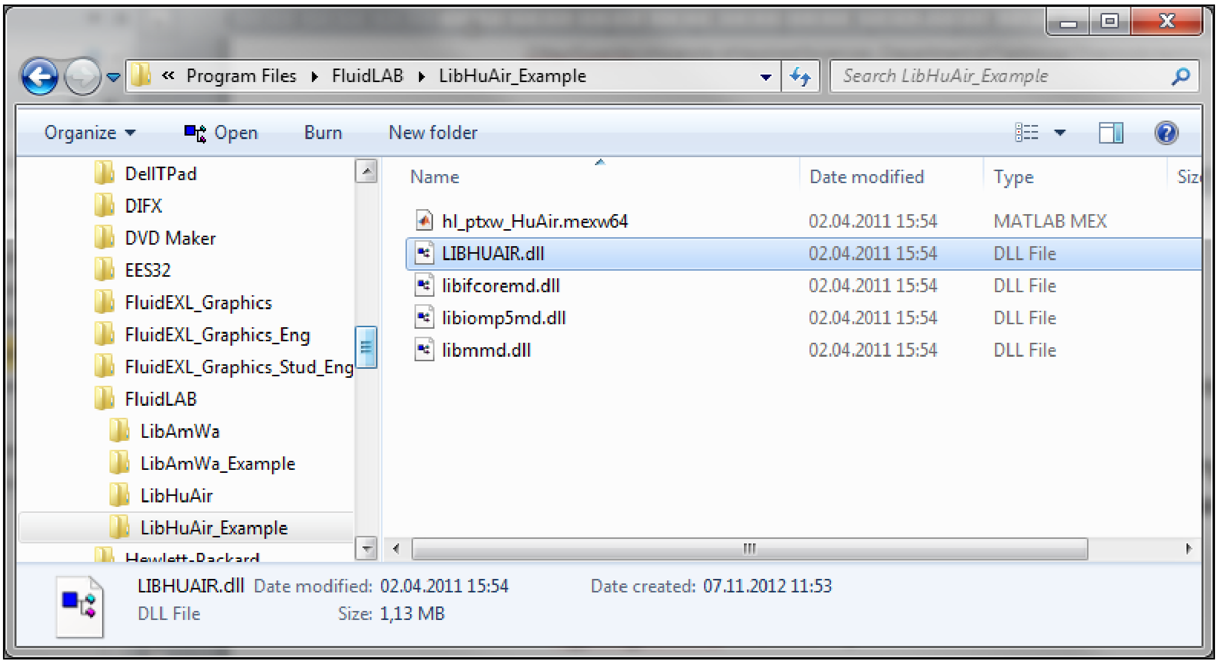


Figure 2.9: Contents of the folder "LibHuAir_Example"

- Start MATLAB® (if you have not started it already).
- Click the button marked in the next figure in order to open the folder "\LibHuAir_Example" in the "Current Directory" window.

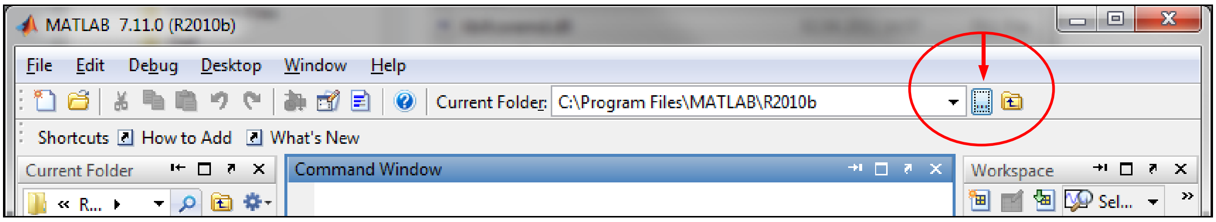


Figure 2.10: Selection of the working directory

- Find and select the directory

  "C:\Program Files\FluidLAB\LibHuAir_Example" (for English version of Windows)

  "C:\Programme\FluidLAB\LibHuAir_Example" (for German version of Windows)

  in the menu which appears (see the following figure).

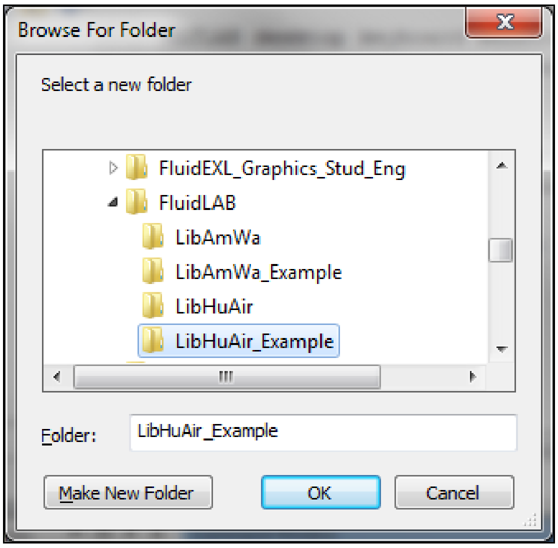


Figure 2.11: Choosing the "LibHuAir_Example" folder

- Confirm your selection by clicking the "OK" button.
- You will see the following window:
- First of all you need to create an M–File in MATLAB®. Within MATLAB® click "File", then select "New" and afterwards click "M-File" in MATLAB 2006 or earlier versions or click "Script" in MATLAB 2010.
- If the "Editor" window appears as a separate window, you can embed it into MATLAB® by clicking the insertion arrow (see next figure) in order to obtain a better view.

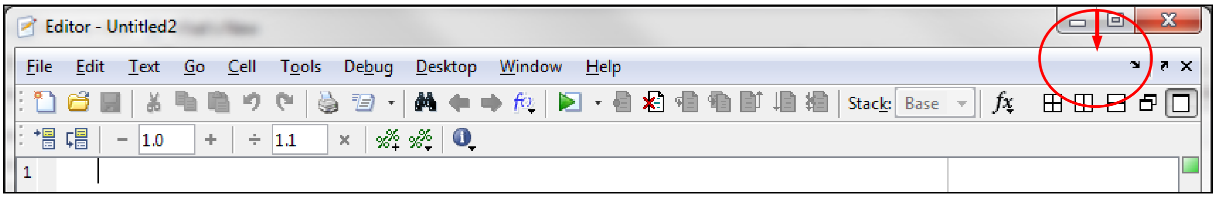


Figure 2.12: Embedding the "Editor" window

- In the figure below you will see the "Editor - Untitled" window.

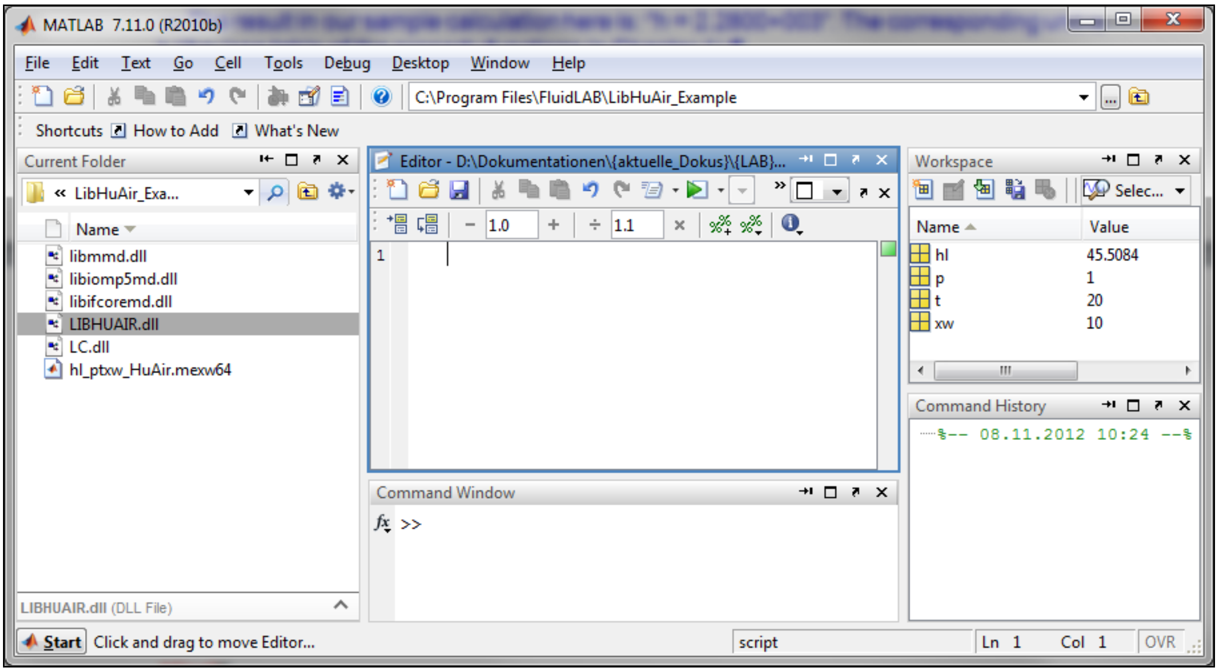


Figure 2.13: Embedded "Editor" window

- Now write the following lines in the "Editor - Untitled" window:

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

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

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

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

- Save the "M-File" by clicking the "File" button and then click "Save As...".
- The menu "Save file as:" appears; In this menu, the folder name "LibHuAir_Example" must be displayed in the "Save in:" field
- Next to "File name" you have to type in "Example_hl_ptxw_HuAir.m" and afterwards click the "Save" button.

Note.
The name of the example file has to be different in comparison to the name of the used function. For example, the file could not be named "hl_ptxw_HuAir.m" in this case. Otherwise an error message will appear during the calculation.

- You will now see the following window:

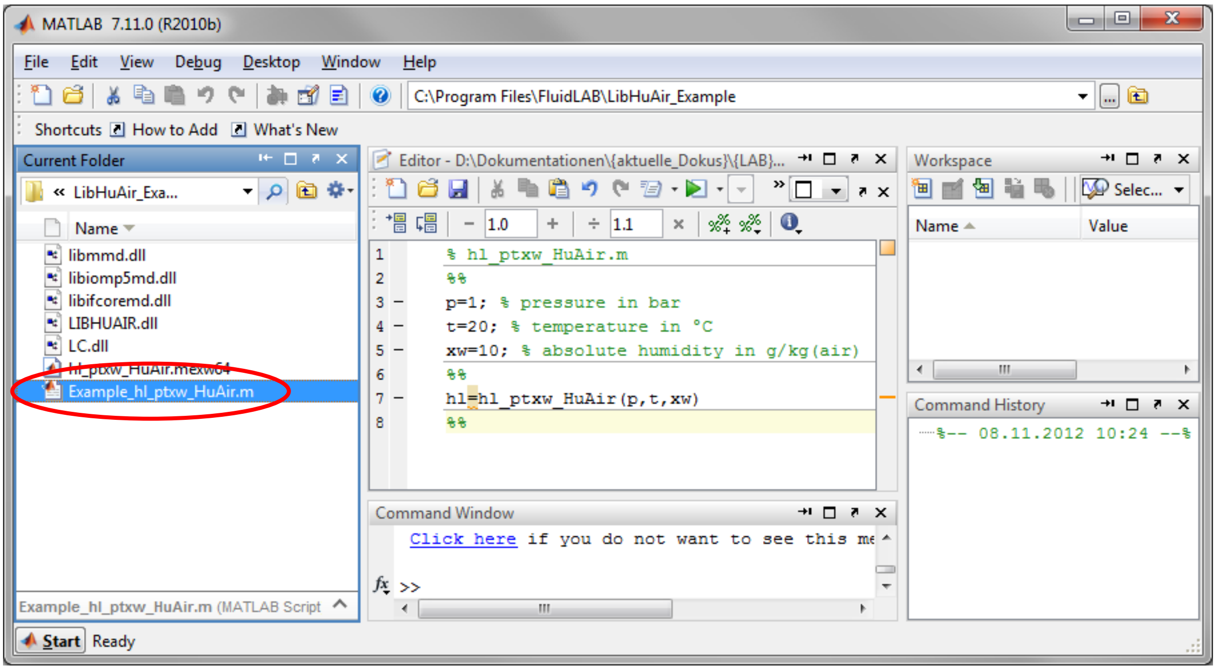


Figure 2.14: "Example_hl_ptxw_HuAir.m" M-file

- Within the "Current Folder" window the file "Example_hl_ptxw_HuAir.m" appears.
- Right-click on this file and select "Run" in the menu which appears (see next figure).

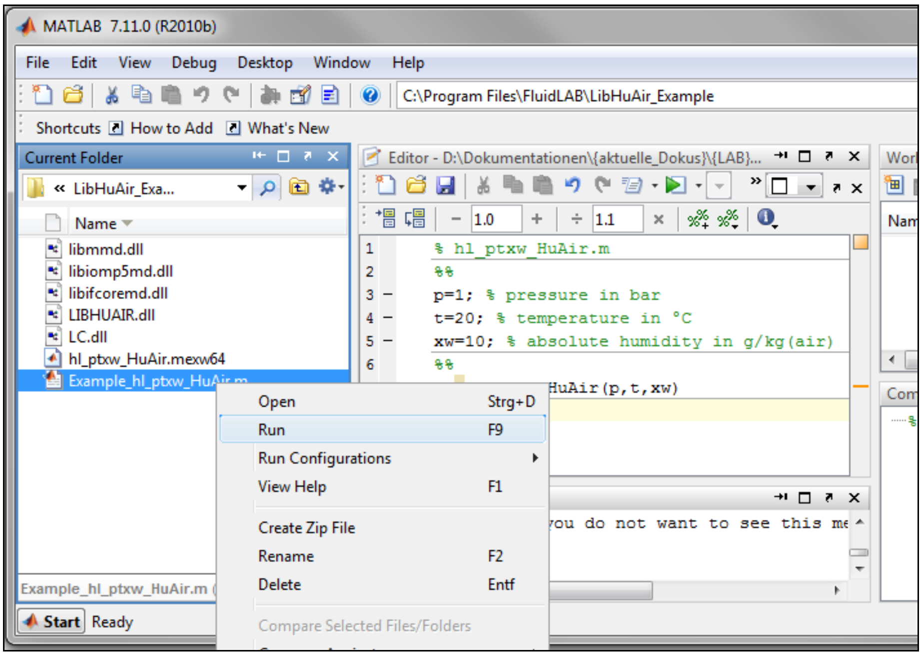


Figure 2.15: Running the "Example_hl_ptxw_HuAir.m" M-file

- You will see the following window:

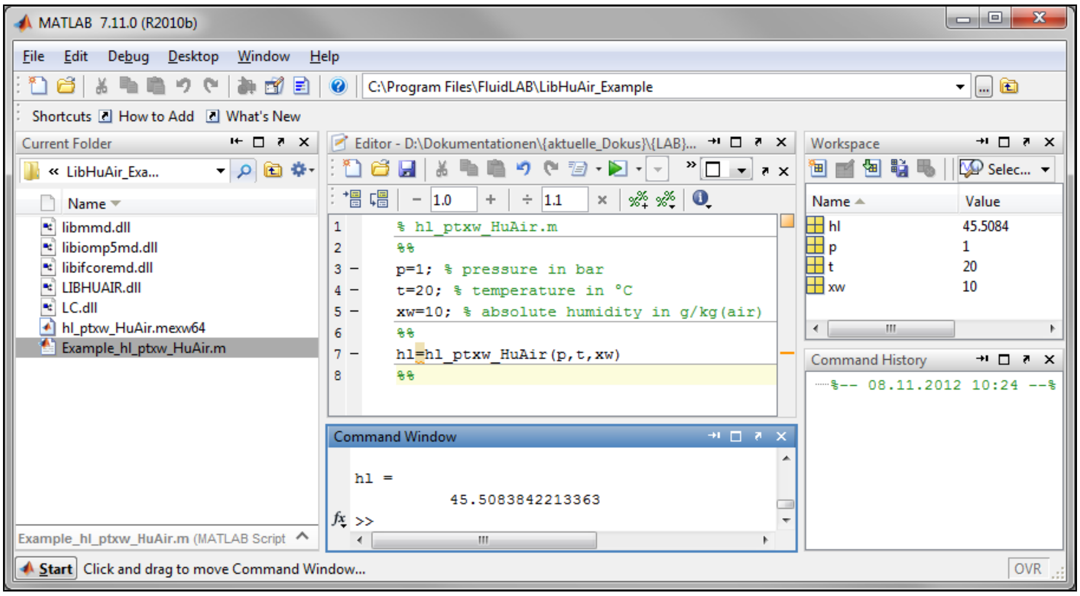


Figure 2.16: MATLAB® with calculated result

⇒ The result in our sample calculation here is: "hl = 45.5083842213363" The corresponding unit is kJ/kg (see table of the property functions in Chapter 1)

To be able to calculate other values, you have to copy the associated mexw32 or mexw64 files as well because MATLAB® can only access functions that are located in the "Current Directory" window. The example calculated can be found in the directory

C:\Program Files\FluidLAB\LibHuAir_Example" (for English version of Windows)

C:\Programme\FluidLAB\LibHuAir_Example" (for German version of Windows),

and you may use it as a basis for further calculations using FluidLAB.

Hint!

If the input values are located outside the range of validity of LibHuAir, the calculation of the chosen function to be calculated function results in -1000. You can find more exact details on every function and its corresponding range of validity in the enclosed program documentation in Chapter 3.

2.4 Example: Calculation of the Air-Specific Enthalpy $h_l = f(p,t,x_w)$ for Humid Air in the Command Window

- Please follow the instructions from page 2/4 to 2/6.
- Start MATLAB (if you did not start it before).
- Click the button marked in the following image in order to open the folder "\LibHuAir_Example" in the window "Current Directory.

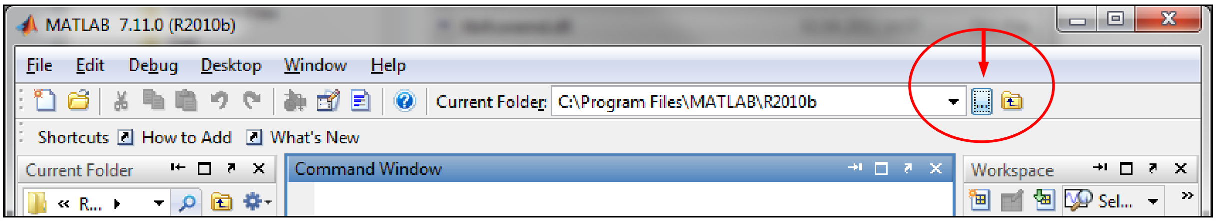


Figure 2.17: Selection of the working directory

- Search and click the directory "C:\Program Files\FluidLAB\LibHuAir_Example" in the pop--
  Find and select the directory

  "C:\Program Files\FluidLAB\LibHuAir_Example" (for English version of Windows)
  "C:\Programme\FluidLAB\LibHuAir_Example" (for German version of Windows)

  in the menu which appears (see the following figure).

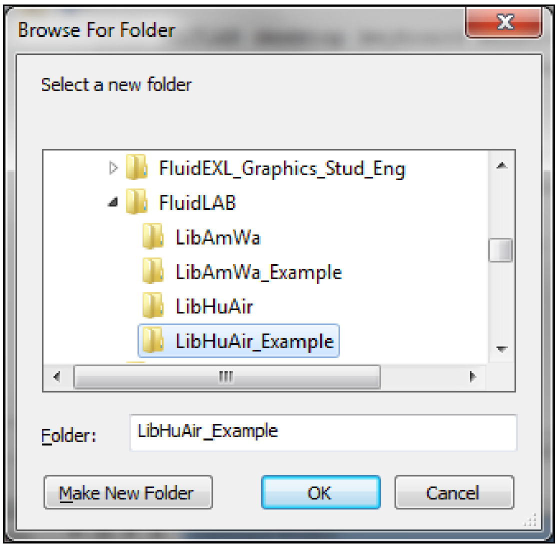


Figure 2.18: Choosing the "LibHuAir_Example" folder

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

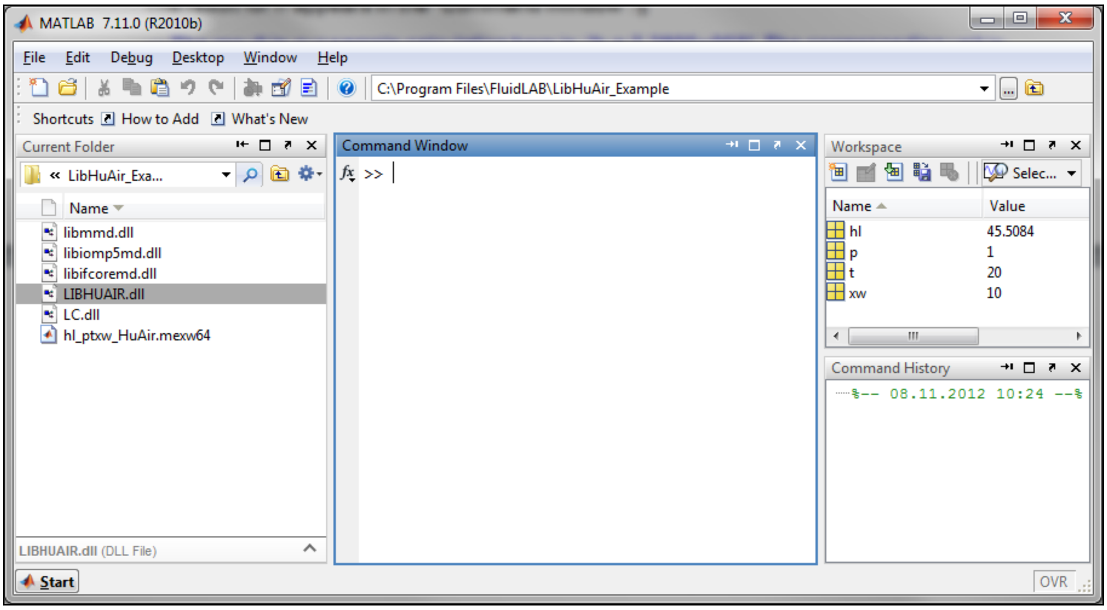


Figure 2.19: MATLAB® with necessary files

Corresponding to the table of property functions in Chapter 1 you have to call up the function "hl_ptxw_HuAir" as follows for calculating h_l=f(p,t,x_w):

- Write "hl=hl_ptxw_HuAir(1,20,10)" within the "Command Window".

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

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

- Confirm your entry by pressing the "ENTER" button.
- You will see the following window:

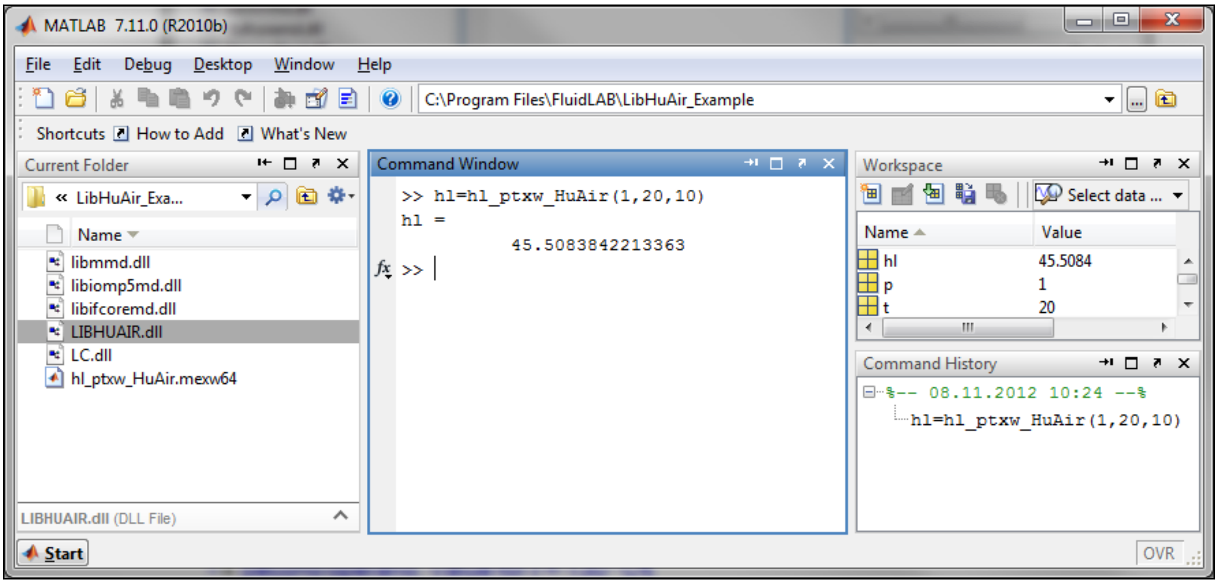


Figure 2.20: MATLAB® with calculated result

⇒ The result in our sample calculation here is: "hl = 45.5083842213363" The corresponding unit is kJ/kg (see table of the property functions in Chapter 1)

To be able to calculate other values, you have to copy the associated mexw32 or mexw64 files as well because MATLAB® can only access functions that are located in the "Current Directory" window. The example calculated can be found in the directory

C:\Program Files\FluidLAB\LibHuAir_Example" (for English version of Windows)

C:\Programme\FluidLAB\LibHuAir_Example" (for German version of Windows),

and you may use it as a basis for further calculations using FluidLAB.

2.5 Removing FluidLAB LibHuAir

To remove the property library LibHuAir from your hard drive in Windows®, click "Start" in the Windows® task bar, select "Settings" and click "Control Panel".

Now double-click on "Add or Remove Programs". In the list box of the "Add or Remove Programs" window that appears select "FluidLAB LibHuAir" by clicking on it and click the "Change/Remove" button.

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

Confirm the following menu "Perform Uninstall" by clicking the "Finish" button.

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

Now, FluidLAB has been removed.

If there is no library other than LibHuAir installed, the directory "FluidLAB" 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 m^2/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 $a = \dfrac{\lambda}{\rho \cdot c_p}$
- 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 $0°C \leq t \leq 800°C$ from IAPWS-85 [6]
for t < 0°C and t > 800°C from *Brandt* [12]

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

ρ from IAPWS-IF97 [1], [2], [3], [4]
for t < 0.01 °C from IAPWS-06 [18], [19]

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

Function Name:

cp_ptxw_HuAir

Fortran Programs:

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

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

Input Values:

p - Mixture pressure p in bar

t - Temperature t in °C

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

Result:

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

Range of Validity:

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

Comments:

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

Results for wrong input values:

cp_ptxw_HuAir, cp = -1

References:

Dry Air:
from *Lemmon* et al. [14]

Steam in humid air and liquid droplets in fog:
from IAPWS-IF97 [1], [2], [3], [4]

Dissociation:
from VDI Guideline 4670 [13]

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

Function Name:

Eta_ptxw_HuAir

Fortran Programs:

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

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

Input values:

p - Mixture pressure p in bar

t - Temperature t in °C

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

Result:

Eta_ptxw_HuAir, Eta - Dynamic viscosity in Pa s

Range of Validity:

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

Comments:

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

Results for wrong input values:

Eta_ptxw_HuAir, Eta = -1

References:

Dry Air:
from *Lemmon* et al. [15]

Steam in humid air and liquid droplets in fog:
for $0°C \leq t \leq 800°C$ from IAPWS-85 [7]
for t < 0°C and t > 800°C from *Brandt* [12]

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

Function Name:

hl_ptxw_HuAir

Fortran Programs:

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

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

Input values:

p - Mixture pressure p in bar

t - Temperature t in °C

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

Result:

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

Range of Validity:

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

Comments:

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

Result for wrong input values:

hl_ptxw_HuAir, hl = -1000

References:

Dry Air:
from *Lemmon* et al. [14]

Steam in humid air and liquid droplets in fog:
from IAPWS-IF97 [1], [2], [3], [4]

Ice crystals in fog:
according to IAPWS-06 [18], [19]

Dissociation:
from VDI Guideline 4670 [13]

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

Function Name:

Lambda_ptxw_HuAir

Fortran Programs:

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

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

Input values:

p - Mixture pressure p in bar

t - Temperature t in °C

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

Result:

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

Range of Validity:

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

Comments:

- Model of ideal mixture of real fluids

Result for wrong input values:

Lambda_ptxw_HuAir, Lambda = -1

References:

Dry Air:
from *Lemmon* et al. [15]

Steam in humid air and humid droplets in fog:
for $0\,°C \leq t \leq 800\,°C$ from IAPWS-85 [6]
for t < 0°C and t > 800°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 m^2/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 $\nu = \frac{\eta}{\rho} = \eta \cdot v$
- Model of ideal mixture of real fluid

Result for wrong input values:

Ny_ptxw_HuAir, Ny = -1

References:

Dry Air:

η from *Lemmon* et al. [15]

ρ from *Lemmon* et al. [14]

Steam in humid air and liquid droplets in fog:

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

ρ from IAPWS-IF97 [1], [2], [3], [4]
for t < 0.01 °C from IAPWS-06 [18], [19]

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

Function Name:

pd_ptxw_HuAir

Fortran Programs:

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

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

Input values:

p - Mixture pressure p in bar

t - Temperature t in °C

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

Result:

pd_ptxw_HuAir, pd - Partial pressure of steam in bar

Range of Validity:

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

Comments:

- Partial pressure of steam $p_d = \dfrac{x_w}{\dfrac{R_l}{R_w} + x_w} \cdot p$ for $x_w \le x_{ws}(p,t)$
- For $x_w > x_{ws}(p,t)$ result $p_d = p_{ds}(p,t)$
- Saturation vapor pressure at saturation $p_{ds} = f \cdot p_s(t)$

  with $p_{ds}(p,t)$ for $t \ge 0.01°C$ - vapor pressure of water

  for $t < 0.01°C$ - sublimation pressure of water
- Result for pure steam, liquid water and water ice: $p_d = 0$

Result for wrong input values:

pd_ptxw_HuAir, pd = -1

References:

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

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

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

Saturation Pressure of Water p_{ds} = f(p,t)

Function Name:

pds_pt_HuAir

Fortran Programs:

REAL*8 FUNCTION pds_pt_HuAir(p,t), REAL*8 p,t

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

Input values:

p - Mixture pressure p in bar

t - Temperature t in °C

Result:

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

Range of Validity:

Temperature t : from -143.15°C to $t_s(p, p_d)$
(boiling temperature of water in gas mixtures)

Mixture pressure p : from 6.112 mbar to 165.29 bar

Comments:

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

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

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

Result for wrong input values:

pds_pt_HuAir, pds = -1

References:

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

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

if $t < 0.01$ °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 $t_{critical}$ = 373,946°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:

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

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

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

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

Result for wrong input values:

Phi_ptxw_HuAir, Phi = - 1

References:

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

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

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

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

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:

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

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

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

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

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

Result for wrong input values:

pl_ptxw_HuAir, pl = -1

References:

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

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

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

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

Function Name:

Pr_ptxw_HuAir

Fortran Programs:

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

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

Input values:

p - Mixture pressure p in bar

t - Temperature t in °C

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

Result:

Pr_ptxw_HuAir, Pr - *Prandtl*-number

Range of Validity:

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

Comments:

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

Result for wrong input values:

Pr_ptxw_HuAir , Pr = - 1

References:

Dry Air:

λ from *Lemmon* et al. [15]

η from *Lemmon* et al. [15]

c_p from *Lemmon* et al. [14]

Steam in humid air and liquid droplets in fog:

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

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

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

Dissociation:

from VDI Guideline 4670 [13]

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

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 $\psi_l = 1 - \dfrac{R_w \cdot x_w}{R(1 + x_w)}$

Result for wrong input values:

Psil_xw_HuAir, Psil = - 1

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

Function Name:

Psiw_xw_HuAir

Fortran Programs:

REAL*8 FUNCTION Psiw_xw_HuAir(xw), REAL*8 xw

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

Input values:

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

Result:

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

Range of Validity:

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

Comments:

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

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/m^3

Range of Validity:

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

Comments:

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

Result for wrong input values:

Rho_ptxw_HuAir, Rho = -1

References:

Dry Air:
from *Lemmon* et al. [14]

Steam in humid air and liquid droplets in fog:
from IAPWS-IF97 [1], [2], [3], [4]

Ice crystals in fog:
from IAPWS-06 [18], [19]

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

Function Name:

sl_ptxw_HuAir

Fortran Programs:

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

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

Input values:

p - Mixture pressure p in bar

t - Temperature t in °C

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

Result:

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

Range of Validity:

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

Comments:

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

Result for wrong input values:

sl_ptxw_HuAir, sl = - 1000

References:

Dry Air:
from *Lemmon* et al. [14]

Steam in humid air and liquid droplets in fog:
from IAPWS-IF97 [1], [2], [3], [4]

Ice crystals in fog:
from to IAPWS-06 [18], [19]

Dissociation:
from VDI Guideline 4670 [13]

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

Function Name:

t_phlxw_HuAir

Fortran Programs:

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

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

Input values:

p - Mixture pressure p in bar

h_l - Air-specific enthalpy in kJ/kg_{Air}

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

Result:

t_phlxw_HuAir, t - Temperature in °C

Range of Validity:

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

Comments:

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

Calculation of $h_l(p,t,x_w)$:

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

Result for wrong input values:

t_phlxw_HuAir , t = - 1000

References:

Dry Air:
from *Lemmon* et al. [14]

Steam in humid air and liquid droplets in fog:
from IAPWS-IF97 [1], [2], [3], [4]

Ice crystals in fog:
from to IAPWS-06 [18], [19]

Dissociation:
from VDI Guideline 4670 [13]

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

Function Name:

t_pslxw_HuAir

Fortran Programs:

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

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

Input values:

p - Mixture pressure p in bar

s_l - Air-specific entropy in $kJ/(kg_{Air}\ K)$

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

Result:

t_pslxw_HuAir, t - Temperature in °C

Range of Validity:

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

Comments:

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

Calculation of $s_l(p,t,x_w)$:

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

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

Result for wrong input values:

t_pslxw_HuAir, t = -1000

References:

Dry Air:
from *Lemmon* et al. [22]

Steam in humid air and liquid droplets in fog:
from IAPWS-IF97 [1], [2], [3], [4]

Ice crystals in fog:
from IAPWS-06 [18], [19]

Dissociation:
from VDI Guideline 4670 [13]

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

Function Name:

tf_ptxw_HuAir

Fortran Programs:

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

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

Input values:

p - Mixture pressure p in bar

t - Temperature t in °C

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

Result:

tf_ptxw_HuAir, tf - Wet bulb temperature in °C

Range of Validity:

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

Comments:

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

Result for wrong input values:

tf_ptxw_HuAir, tf = - 1000

References:

Dry Air:
from *Lemmon* et al. [22]

Steam in humid air and liquid droplets in fog:
from IAPWS-IF97 [1], [2], [3], [4]

Dissociation:
from VDI Guideline 4670 [13]

Dew Point Temperature $t_\tau = f(p,x_W)$

Function Name:

tTau_pxw_HuAir

Fortran Programs:

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

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

Input values:

p - Mixture pressure p in bar

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

Result:

tdew_pxw_HuAir, tdew - Dew point temperature in °C

Range of Validity:

Mixture pressure p : from 6.112 mbar to 165.29 bar

Absolute humidity x_w : $\geq x_{ws}(p, -30°C)$

Comments:

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

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

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

Result for wrong input values:

tdew_pxw_HuAir, tdew = - 1000

References:

$t_{ds}(p,p_d)$ for $t_\tau \geq 0.01°C$ from IAPWS-IF97 [1], [2], [3], [4]

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

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

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

Function Name:

ul_ptxw_HuAir

Fortran Programs:

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

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

Input values:

p - Mixture pressure p in bar

t - Temperature t in °C

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

Result:

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

Range of Validity:

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

Comments:

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

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

Result for wrong input values:

ul_ptxw_HuAir, ul = - 1000

References:

Dry Air:
h, v from *Lemmon* et al. [14]

Steam in humid air and liquid droplets in fog:
h, v from IAPWS-IF97 [1], [2], [3], [4]

Ice crystals in fog:
h, v according to IAPWS-06 [18], [19]

Dissociation:
from VDI Guideline 4670 [13]

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

Function Name:

vl_ptxw_HuAir

Fortran Programs:

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

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

Input values:

p - Mixture pressure p in bar

t - Temperature t in °C

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

Result:

vl_ptxw_HuAir, vl - Air-specific volume in m^3/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 $\xi_l = 1 - \dfrac{x_w}{1 + x_w}$

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 $\xi_w = \dfrac{x_w}{1 + x_w}$

Result for wrong input values:

Xiw_xw_HuAir, Xiw = - 1

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

Function Name:

xw_ptPhi_HuAir

Fortran Programs:

REAL*8 FUNCTION xw_ptPhi_HuAir(p,t,Phi), REAL*8 p,t,Phi

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

Input values:

p - Mixture pressure p in bar

t - Temperature t in °C

Phi - Relative humidity in %

Result:

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

Range of Validity:

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

Mixture pressure p : from 6.112 mbar to 165.29 bar

Relative Humidity φ: from 0 % to 100 %

Comments:

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

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

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

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

Result for wrong input values:

xw_ptPhi_HuAir, xw = - 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 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 $t \le$ 373,946°C, to 165.29 bar for t > 373,946°C

Comments:

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

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

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

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

Result for wrong input values:

xw_ptpd_HuAir, xw = - 1

References:

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

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

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

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

Function Name:

xw_ptTau_HuAir

Fortran Programs:

REAL*8 FUNCTION xw_ptTau_HuAir(p,tTau), REAL*8 p,tTau

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

Input values:

p - Mixture pressure p in bar

t_τ - Dew point temperature in °C

Result:

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

Range of Validity:

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

Mixture pressure p : from 6.112 mbar to 165.29 bar

Comments:

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

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

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

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

Result for wrong input values:

xw_ptTau_HuAir, xw = - 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 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 $h_l^{unsaturated}(p,t,x_w) = h_l^{fog}(p,t_f,x_w)$

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

Result for wrong input values:

xw_pttf_HuAir, xw = - 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 m^3/kg_{Air}

Result:

xw_ptvl_HuAir, x_w - Absolute humidity 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

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 $(x_w \le x_{ws})$, 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, xw = - 1

References:

Dry Air:
from *Lemmon* et al. [14]

Steam in humid air and liquid droplets in fog:
from IAPWS-IF97 [1], [2], [3], [4]

Ice crystals in fog:
according to IAPWS-06 [18], [19]

Dissociation:
from VDI Guideline 4670 [13]

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

Function Name:

xws_pt_HuAir

Fortran Programs:

REAL*8 FUNCTION xws_pt_HuAir(p,t), REAL*8 p,t

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

Input values:

p - Mixture pressure p in bar

t - Temperature t in °C

Result:

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

Range of Validity:

Temperature t : from -143.15°C to $t_s(p,p_d)$ (boiling temp. from water in gas mixtures)

Mixture pressure p : from 6.112 mbar to 165.29 bar

Comments:

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 $t \geq 0.01°C$ - Vapor pressure of water

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

Result for wrong input values:

xws_pt_HuAir, x_{ws} = - 1

References:

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

$p_{ds}(p,t)$ if t ≥ 0.01°C from IAPWS-IF97 [1], [2], [3], [4]

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

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

Steam and Water

Library LibIF97

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

Humid Combustion Gas Mixtures

Library LibHuGas

Model: Ideal mixture of the real fluids:

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

and of the ideal gases:

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

Consideration of:

Dissociation from VDI 4670 and Poynting effect

Humid Air

Library LibHuAir

Model: Ideal mixture of the real fluids:

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

Consideration of:

- Dissociation from the VDI 4670
- Poynting effect from ASHRAE RP-1485

Carbon Dioxide including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1994)

Seawater

Library LibSeaWa

IAPWS Formulation 2008 of Feistel and IAPWS-IF97

Ice

Library LibICE

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

Ideal Gas Mixtures

Library LibIdGasMix

Model: Ideal mixture of the ideal gases:

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

Consideration of:

- Dissociation from the VDI Guideline 4670
- Poynting effect

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Library LibIdAir

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

Dry Air including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Nitrogen

Library LibN2

Formulation of Span et al. (2000)

Hydrogen

Library LibH2

Formulation of Leachman et al. (2007)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth (1995)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButan_Iso

Formulation of Bücker et al. (2003)

n-Butane

Library LibButan_n

Formulation of Bücker et al. (2003)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

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

Helmholtz energy equation for the mixing term

(also useable for calculating Kalina Cycle)

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

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

Formulation of the International Institute of Refrigeration (1997)

Siloxanes as ORC Working Fluids

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

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

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

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

Formulation of Colonna et al. (2006)

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

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

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

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

Formulation of Colonna et al. (2008)

Propane

Library LibPropan

Formulation of Lemmon et al. (2007)

Methanol

Library LibCH3OH

Formulation of de Reuck and Craven (1993)

Ethanol

Library LibC2H5OH

Formulation of Dillon and Penoncello (2004)

Helium

Library LibHe

Formulation of Arp et al. (1998)

Hydrocarbons

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

Isopentane C_5H_{12} **Library LibC5H12_ISO**

Neopentane C_5H_{12} **Library LibC5H12_NEO**

Isohexane C_5H_{14} **Library LibC5H14**

Toluen C_7H_8 **Library LibC7H8**

Formulation of Lemmon and Span (2006)

Further Fluids

Carbon monoxide CO **Library LibCO**

Carbonyl sulfide COS **Library LibCOS**

Hydrogen sulfide H_2S **Library LibH2S**

Dinitrogen monooxide N_2O **Library LibN2O**

Sulfur dioxide SO_2 **Library LibSO2**

Acetone C_3H_6O **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

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Fax.: +49-3583-61-1846

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

Thermodynamic Properties

- Vapor pressure p_s
- Saturation temperature T_s
- Density ρ
- Specific volume v
- Enthalpy h
- Internal energy u
- Entropy s
- Exergy e
- Isobaric heat capacity c_p
- Isochoric heat capacity c_v
- Isentropic exponent k
- 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 listed before.

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

The following thermodynamic and transport properties can be calculated[a] 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 k
- Speed of sound w
- Surface tension σ

Thermodynamic Derivatives

- Partial derivatives can be calculated.

Transport Properties

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

Backward Functions

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

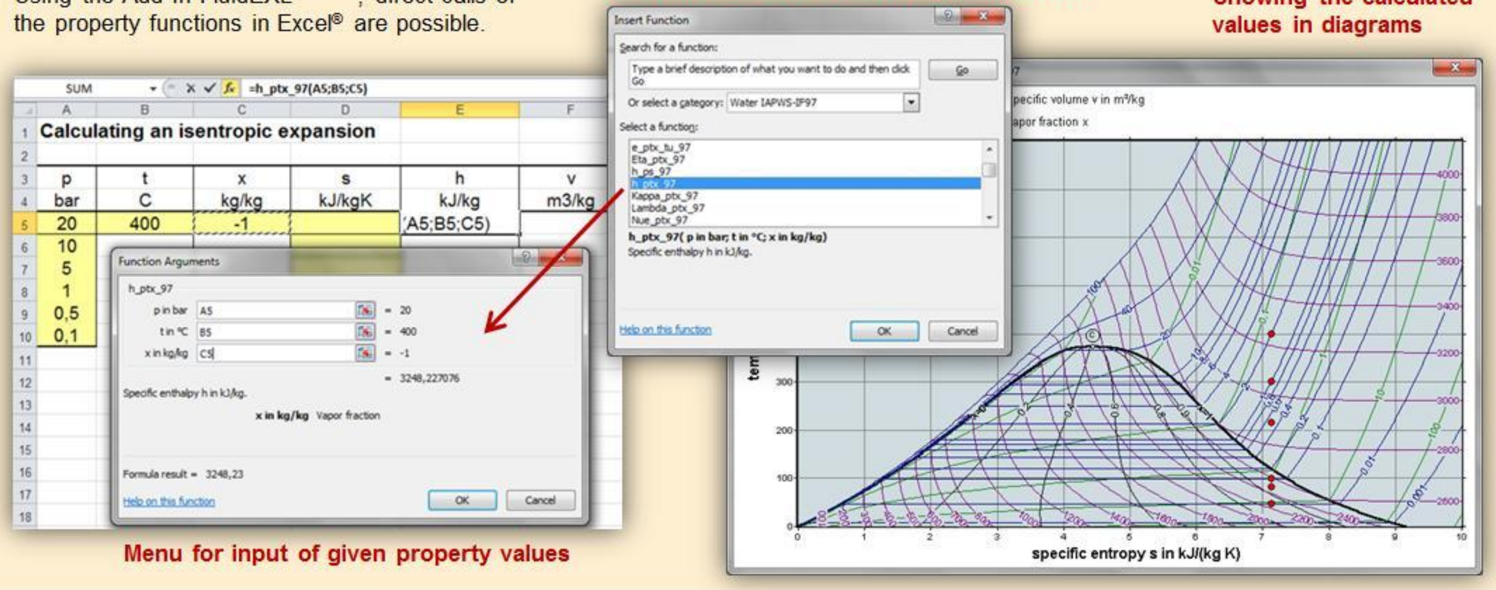
[a] Not all of these property functions are available in all property libraries.

Add-In FluidEXL*Graphics* for Excel®

Using the Add-In FluidEXL*Graphics*, direct calls of the property functions in Excel® are possible.

Choosing a property library and a function

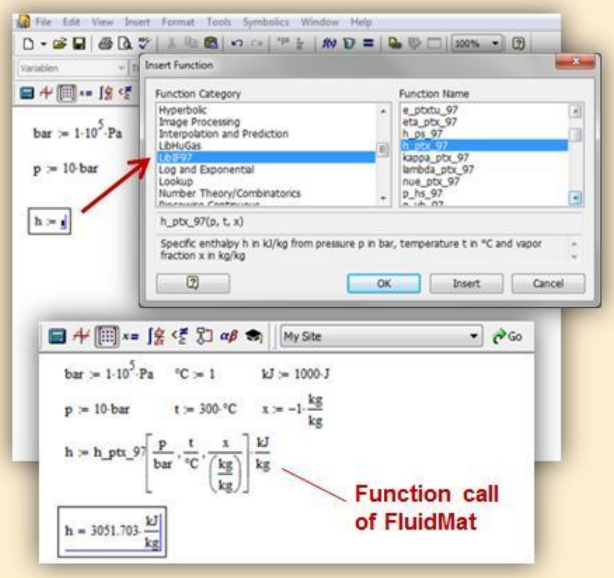
Showing the calculated values in diagrams



Menu for input of given property values

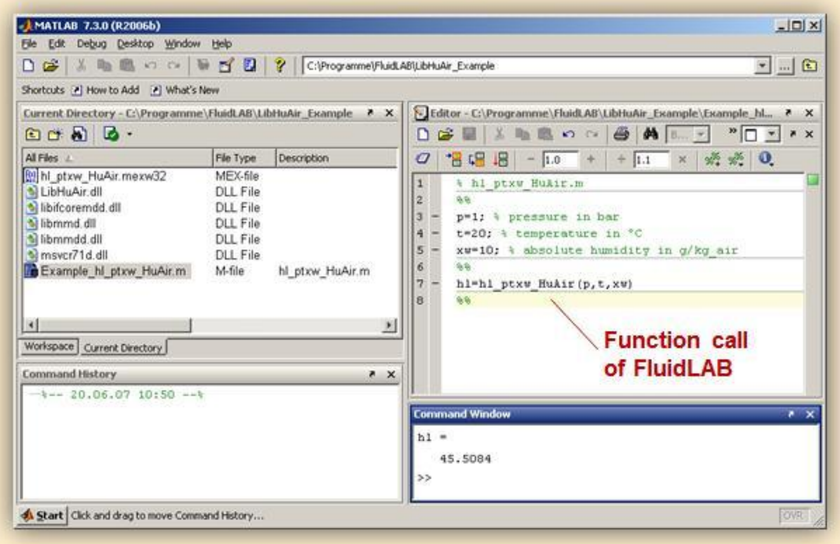
Add-In FluidMAT for Mathcad®

The property libraries can be used in Mathcad®.



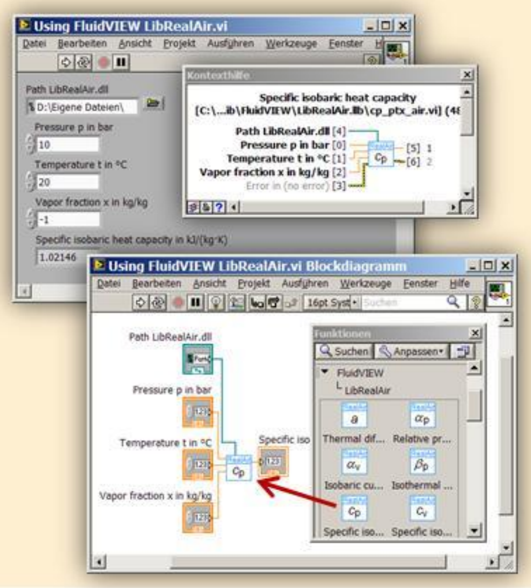
Add-In FluidLAB for MATLAB®

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



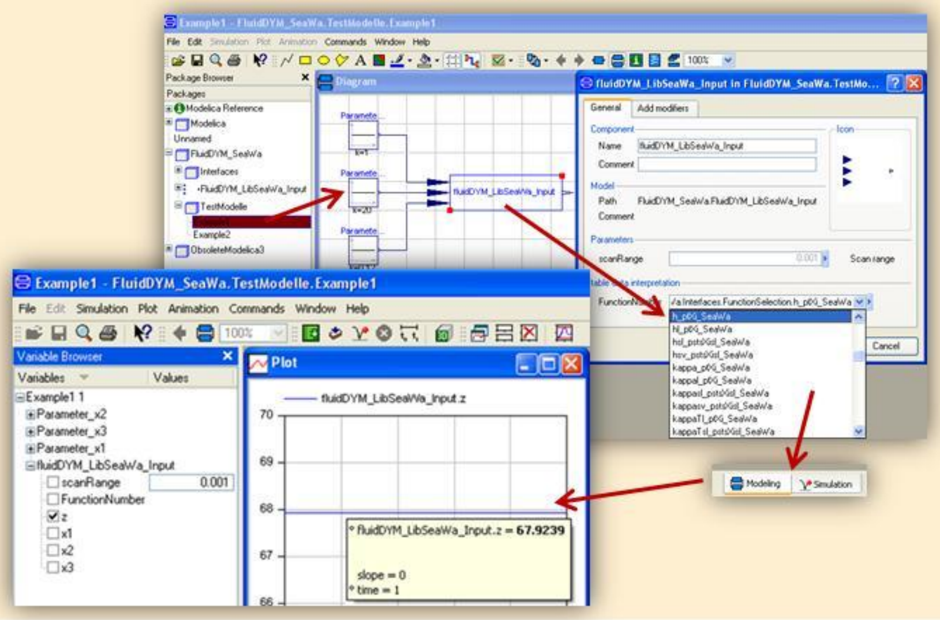
Add-On FluidVIEW for LabVIEW®

Using FluidVIEW, the property functions can be calculated in LabVIEW®.

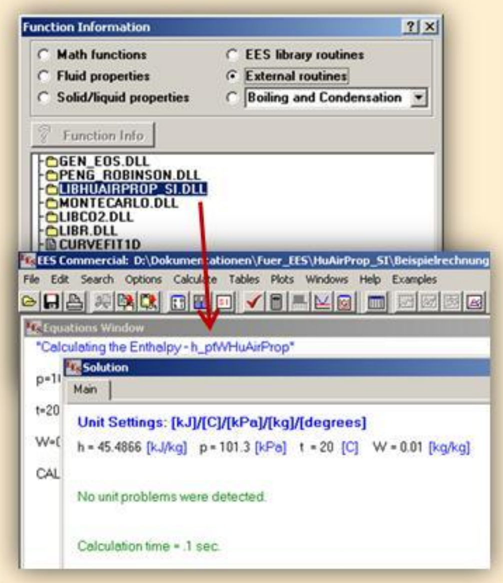


Add-In FluidDYM for DYMOLA® (Modelica) and SimulationX®

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

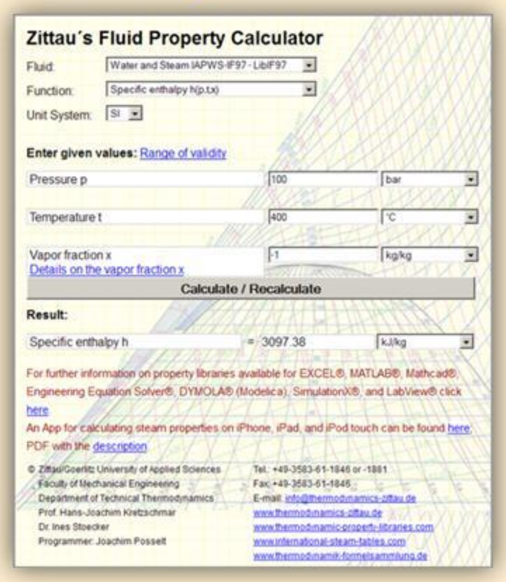


Add-In FluidEES for Engineering Equation Solver®



App International Steam Tables for iPhone, iPad, and iPod touch

Online Property Calculator at www.thermodynamics-zittau.de



Property Software for Pocket Calculators

FluidCasio

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

FluidHP

HP 48 | HP 49

FluidTI

TI 83, TI 84, TI 89 | TI Voyage 200 | TI 92

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Fax.: +49-3583-61-1846

www.thermodynamic-property-libraries.com

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6. Satisfied Customers

Date: 10/2011

The following companies and institutions use the property libraries

- FluidEXL*Graphics* for Excel®
- FluidLAB for MATLAB®
- FluidMAT for Mathcad®
- FluidEES for Engineering Equation Solver® EES
- FluidDYM for Dymola® (Modelica)
- FluidVIEW for LabVIEW®:

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

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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
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Voith, Heidenheim	04/2010
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Universitaet der Bundeswehr, Munich	04/2010
Technical University of Hamburg-Harburg	04/2010
Vattenfall Europe, Berlin	04/2010
HUBER Consulting Engineers, Berching	04/2010
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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
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Technical University of Freiberg	01/2010
ILK, Dresden	01/2010, 12/2010
Fischer-Uhrig Consulting Engineers, Berlin	01/2010

2009

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

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

2008

Pink, Langenwang	01/2008
Fischer-Uhrig, Berlin	01/2008
University of Karlsruhe	01/2008
MAAG, Kuesnacht, Switzerland	02/2008
M&M Turbine Technology, Bielefeld	02/2008
Lentjes, Ratingen	03/2008
Siemens Power Generation, Goerlitz	04/2008
Evonik, Zwingenberg (general EBSILON program license)	04/2008
WEBASTO, Neubrandenburg	04/2008
CFC Solutions, Munich	04/2008
RWE IT, Essen	04/2008
Rerum Cognitio, Zwickau	04/2008, 05/2008
ARUP, Berlin	05/2008
Research Center, Karlsruhe	07/2008
AWECO, Neukirch	07/2008
Technical University of Dresden, Professorship of Building Services	07/2008
Technical University of Cottbus, Chair in Power Plant Engineering	07/2008, 10/2008
Ingersoll-Rand, Unicov, Czech Republic	08/2008
Technip Benelux BV, Zoetermeer, Netherlands	08/2008
Fennovoima Oy, Helsinki, Finland	08/2008

Fichtner Consulting & IT, Stuttgart	09/2008
PEU, Espenhain	09/2008
Poyry, Dresden	09/2008
WINGAS, Kassel	09/2008
TUEV Sued, Dresden	10/2008
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	10/2008, 11/2008
AWTEC, Zurich, Switzerland	11/2008
Siemens Power Generation, Erlangen	12/2008

2007

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

Energieversorgung Halle	10/2007
AL-KO, Jettingen	10/2007
Grenzebach BSH, Bad Hersfeld	10/2007
Wiesbaden University of Applied Sciences, Department of Engineering Sciences	10/2007
Endress+Hauser Messtechnik, Hannover	11/2007
Munich University of Applied Sciences, Department of Mechanical Engineering	11/2007
Rerum Cognitio, Zwickau	12/2007
Siemens Power Generation, Erlangen	11/2007
University of Rostock, Chair in Technical Thermodynamics	11/2007, 12/2007

2006

STORA ENSO Sachsen, Eilenburg	01/2006
Technical University of Munich, Chair in Energy Systems	01/2006
NUTEC Engineering, Bisikon, Switzerland	01/2006, 04/2006
Conwel eco, Bochov, Czech Republic	01/2006
Offenburg University of Applied Sciences	01/2006
KOCH Transporttechnik, Wadgassen	01/2006
BEG Bremerhavener Entsorgungsgesellschaft	02/2006
Deggendorf University of Applied Sciences, Department of Mechanical Engineering and Mechatronics	02/2006
University of Stuttgart, Department of Thermal Fluid Flow Engines	02/2006
Technical University of Munich, Chair in Apparatus and Plant Engineering	02/2006
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, Department of Thermodynamics	04/2006
EnviCon & Plant Engineering, Nuremberg	04/2006
Brassel Engineering, Dresden	05/2006
University of Halle-Merseburg, Department of USET Merseburg incorporated society	05/2006
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	05/2006

Fichtner Consulting & IT Stuttgart (company licenses and distribution)	05/2006
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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 Professorship of Thermic Energy Machines and Plants	04/2005
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
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MAN B&W Diesel A/S, Copenhagen, Denmark	02/2004
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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
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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
Petterssson+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
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Stadtwerke Hannover	09/2002
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Dillinger Huette, Dillingen	11/2002
G.U.N.T. Geraetebau, Barsbuettel (general license and training test benches)	12/2002
VEAG, Berlin (group license)	12/2002

2001

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

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AG KKK - PGW Turbo, Leipzig	01/2000
PREUSSAG NOELL, Wuerzburg	01/2000
M&M Turbine Technology, Bielefeld	01/2000

IBR Engineering Reis, Nittendorf-Undorf	02/2000
GK, Hannover	03/2000
KRUPP-UHDE, Dortmund (company license)	03/2000
UMAG W. UDE, Husum	03/2000
VEAG, Berlin (group license)	03/2000
Thinius Engineering, Erkrath	04/2000
SaarEnergie, Saarbruecken	05/2000, 08/2000
DVO Data Processing Service, Oberhausen	05/2000
RWTH Aachen University	06/2000
VAUP Process Automation, Landau	08/2000
Knuerr-Lommatec, Lommatzsch	09/2000
AVACON, Helmstedt	10/2000
Compania Electrica, Bogota, Colombia	10/2000
G.U.N.T. Geraetebau, Barsbuettel (general license for training test benches)	11/2000
Steinhaus Informationssysteme, Datteln (general license for process data software)	12/2000

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

1998

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

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

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