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MECHANICAL ENGINEERING

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

**FluidEES
with LibHuAir
for Engineering Equation Solver®**

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Property Library for Humid Air

Calculated as Ideal Mixture of Real Fluids

FluidEES

LibHuAir

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0 Package Contents

Zip-file "CD_FluidEES_LibHuAir_Eng.zip" for Engineering Equation Solver®

Property library LibHuAir for humid air

Including the following files:

FluidEES_LibHuAir_Docu_Eng.pdf

User's Guide

FluidEES_LibHuAir_Setup.exe

Installation program for the FluidEES
Add-In for use in Engineering Equation
Solver®

LibHuAir.ctx

Function registration in EES® of the
LibHuAir property library

LibHuAir.dll

Dynamic link library including property
algorithms for humid air

LibHuAir.hlp

Help file for the LibHuAir property library

1. Property Functions

1.1 Calculation Programs

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

Functional Dependence	Function Name	Call as Fortran Program	Property or Function	Unit of the Result	Source or Algorithm	Site Info
$\psi_w = f(x_w)$	Psiw_xw_HuAir	= Psiw_xw_HuAir(xw), or = C_Psiw_xw_HuAir(Psiw,xw)	Mole fraction of water	kmol/kmol	-	3/13
$\rho = f(p, t, x_w)$	Rho_ptxw_HuAir	= Rho_ptxw_HuAir(p,t,xw), or = C_Rho_ptxw_HuAir(Rho,p,t,xw)	Density	kg/m ³	[1-4], [14], [18], [19]	3/14
$s_l = f(p, t, x_w)$	sl_ptxw_HuAir	= sl_ptxw_HuAir(p,t,xw), or = C_sl_ptxw_HuAir(Rho,p,t,xw)	Air-specific entropy	kJ/(kg _{Air} K)	[1-4], [13], [14], [18], [19]	3/15
$t = f(p, h_l, x_w)$	t_phlxw_HuAir	= t_phlxw_HuAir(p,hl,xw), or = C_t_phlxw_HuAir(t,p,hl,xw)	Backward function: temperature from air-specific enthalpy and humidity ratio (absolute humidity)	°C	[1-4], [13], [14], [18], [19]	3/16
$t = f(p, s_l, x_w)$	t_pslxw_HuAir	= t_pslxw_HuAir(p,hl,xw), or = C_t_pslxw_HuAir(t,p,sl,xw)	Backward function: temperature from air-specific entropy and humidity ratio (absolute humidity)	°C	[1-4], [13], [14], [18], [19]	3/17
$t_f = f(p, t, x_w)$	tf_ptxw_HuAir	= tf_ptxw_HuAir(p,t,xw), or = C_tf_ptxw_HuAir(tf,p,t,xw)	Wet bulb temperature	°C	[1-4], [13], [14]	3/18
$t_\tau = f(p, x_w)$	tTau_pxw_HuAir	= tTau_pxw_HuAir(p,xw), or = C_tTau_pxw_HuAir(tTau,p,xw)	Dew point temperature	°C	[1-4], [16], [17]	3/19
$u_l = f(p, t, x_w)$	ul_ptxw_HuAir	= ul_ptxw_HuAir(p,t,xw), or = C_ul_ptxw_HuAir(ul,p,t,xw)	Air-specific internal energy	kJ/kg _{Air}	[1-4], [13], [14], [18], [19]	3/20
$v_l = f(p, t, x_w)$	vl_ptxw_HuAir	= vl_ptxw_HuAir(p,t,xw), or = C_vl_ptxw_HuAir(vl,p,t,xw)	Air-specific volume	m ³ /kg _{Air}	[1-4], [14], [18], [19]	3/21
$\xi_l = f(x_w)$	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
$x_w = f(p, t_r)$	xw_ptTau_HuAir	= xw_ptTau_HuAir(p,tTau), or = C_xw_ptTau_HuAir(xw,p,tTau)	Humidity ratio (Absolute humidity) from dew point temperature	g _{water} /kg _{Air}	[1-4], [16], [17], [25], [26]	3/26
$x_w = f(p, t, t_f)$	xw_pttf_HuAir	= xw_pttf_HuAir(p,t,tf), or = C_xw_pttf_HuAir(xw,p,t,tf)	Humidity ratio (Absolute humidity) from temperature and wet bulb temperature	g _{water} /kg _{Air}	[1-4], [13], [14]	3/27
$x_w = f(p, t, v_l)$	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 <u>not</u> starting with C_ :	REAL*8
All functions starting with C_ :	INTEGER*4
All variables:	REAL*8

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

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

Reference States

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

Units

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

Range of Validity

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

Calculation Algorithm

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

Ideal mixture of dry air and steam

- Dry air:
 - v_l, h_l, u_l, s_l, c_p from Lemmon et al. [14]
 - λ, η from Lemmon et al. [15]
- Steam:
 - v, h, u, s, c_p of steam from IAPWS-IF97 [1], [2], [3], [4]
 - λ, η for $0 \text{ °C} \leq t \leq 800 \text{ °C}$ from IAPWS-85 [6], [7]
 - for $t < 0 \text{ °C}$ and $t > 800 \text{ °C}$ from Brandt [12]

Supersaturated humid air (liquid fog or ice fog)

- Liquid fog ($x_w > x_{ws}$) and $t \geq 0.01 \text{ °C}$
 - Ideal mixture of saturated humid air and water
 - Saturated humid air (see above)
 - v, h, u, s, c_p of liquid droplets from IAPWS-IF97 [1], [2], [3], [4]
 - λ, η of liquid droplets from IAPWS-85 [6], [7]
- Ice fog ($x_w > x_{ws}$) and $t < 0.01 \text{ °C}$
 - Ideal mixture of saturated humid air and ice
 - Saturated humid air (see above)
 - v, h, s of ice crystals from IAPWS-06 [18], [19]
 - λ, c_p of ice crystals as constant value
 - η, κ, w of saturated humid air

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

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

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

2 Add-In FluidEES for Engineering Equation Solver®

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

2.1 Installing FluidEES including LibHuAir

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

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

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

CD_FluidEES_LibHuAir

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

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

Within this folder you will see the following two files:

FluidEES_LibHuAir_Docu_Eng.pdf

FluidEES_LibHuAir_Setup.exe.

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

FluidEES_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" (see figure below), the default path where Engineering Equation Solver has been installed will be shown (the standard location is:

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

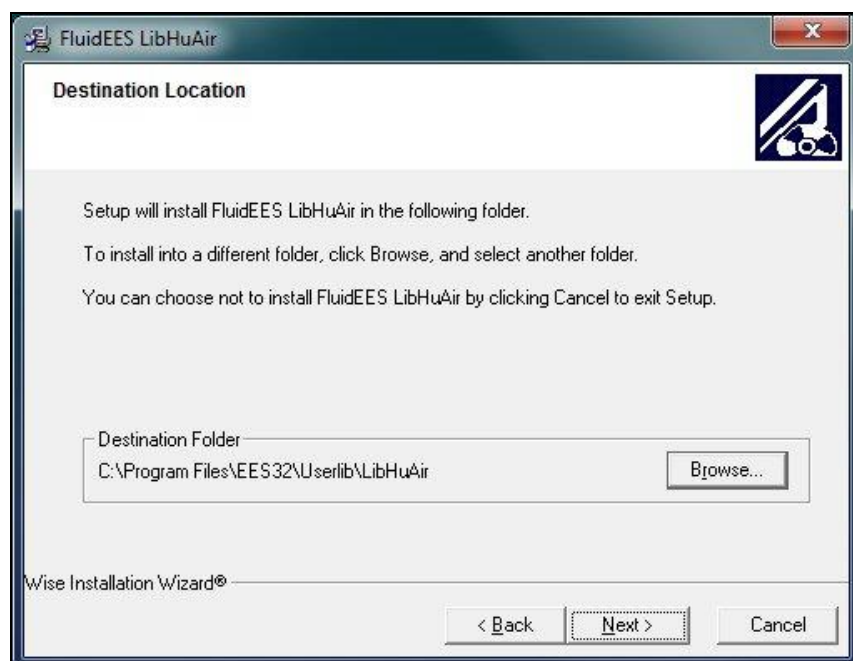


Figure 2.1: "Destination Location"

Click on "Next >" in the window "Destination Location."

Click on the "Next >" button in the "Start Installation" window.

The FluidEES files are now being copied into the "LibHuAir" folder on your hard drive.

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

The installation program has copied the following files into the directory

C:\Program Files\EES32\Userlib\LibHuAir (for English version of Windows)

C:\Programme\EES32\Userlib\LibHuAir (for German version of Windows)):

advapi32.dll	- Dynamic link library for use in Windows® programs
Dformd.dll	- Dynamic link library for use in Windows® programs
Dforrt.dll	- Dynamic link library for use in Windows® programs
DFORRTD.dll	- Dynamic link library for use in Windows® programs
INSTALL.LOG	- Log file
LC.dll	- Dynamic link library for use in Windows® programs
LibHuAir.ctx	- Interface including property functions of LibHuAir for EES®
LibHuAir.dll	- Dynamic link library with property functions of LibHuAir
LibHuAir.hlp	- Help file of the LibHuAir property library
msvc60.dll	- Dynamic link library for use in Windows® programs
msvcrt.dll	- Dynamic link library for use in Windows® programs
MSVCRTD.dll	- Dynamic link library for use in Windows® programs
UNWISE.EXE	- File to remove the LibHuAir library
UNWISE.INI	- File belonging to the UNWISE.EXE

Now, you have to overwrite the following files

"LibHuAir.dll"

"LibHuAir.hlp"

"LibHuAir.ctx"

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

To do this, open the "CD_FluidEES_LibHuAir" folder 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 EES directory (the standard being:

C:\Program Files\EES32\Userlib\LibHuAir (for English version of Windows)

C:\Programme\EES32\Userlib\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.

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

2.2 The FluidEES Help System

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

If you are running Windows Vista or Windows 7, please note the paragraph

"Using the FluidEES Online-Help in Windows Vista or Windows 7."

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

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

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

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

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

Using the FluidEES Online Help in Windows Vista or Windows 7

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

Open Microsoft Internet Explorer® and go to the following address:

<http://support.microsoft.com/kb/917607>

You will see the following web page:



Figure 2.2: Microsoft® Support web page

Scroll down until you see the headline "Resolution." Here you can see the bold hint:

"Download the appropriate version of Windows Help program (WinHlp32.exe), depending on the operating system that you are using."

The following description relates to Windows® 7. The procedure is the same for Windows® Vista.

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

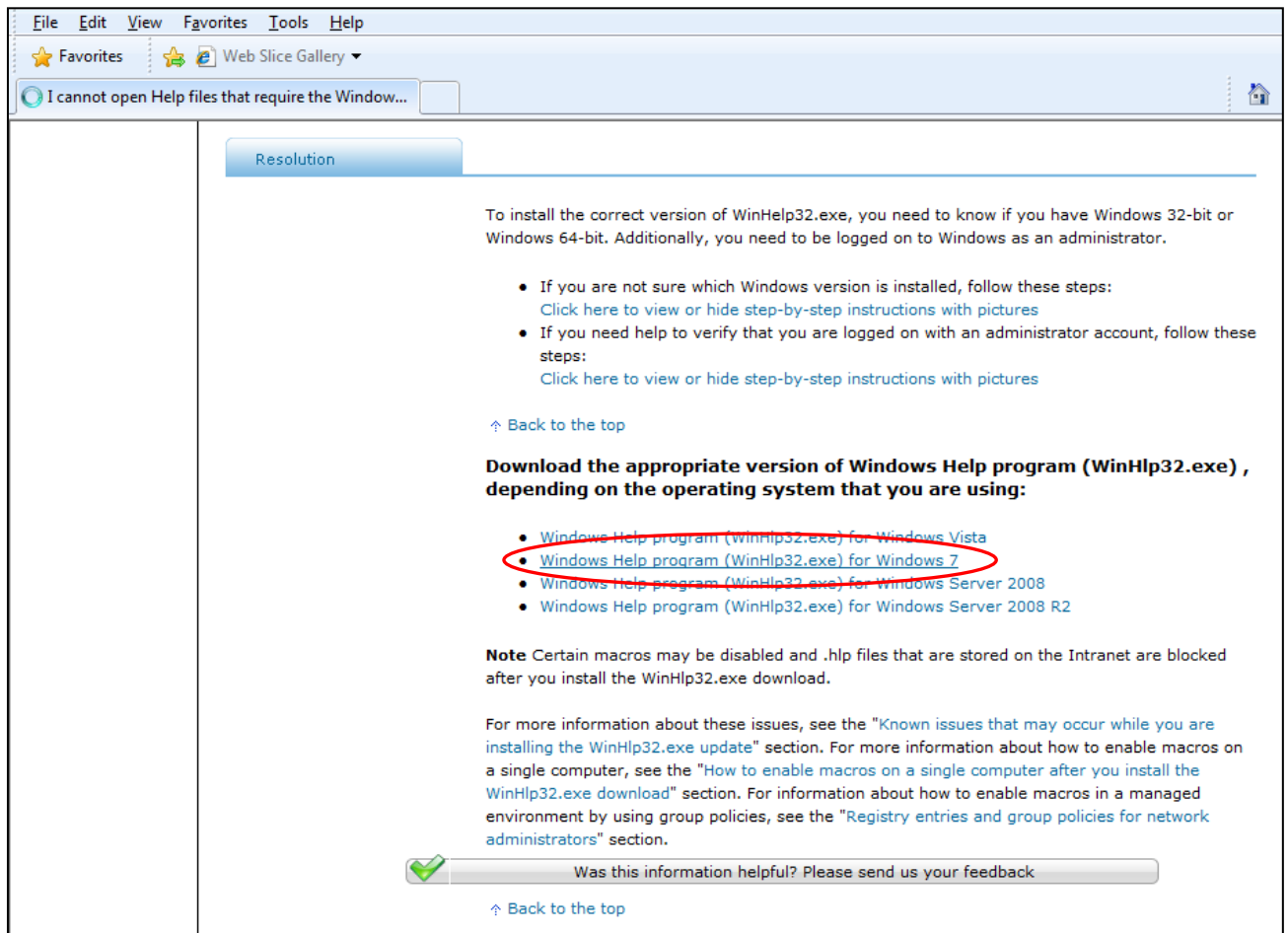


Figure 2.3: Selecting your Windows version

You will be forwarded to the Microsoft Download Center where you can download the Microsoft Windows Help program.

First, a validation of your Windows License is required.

To do this click on the "Continue" button (see Figure 2.4).

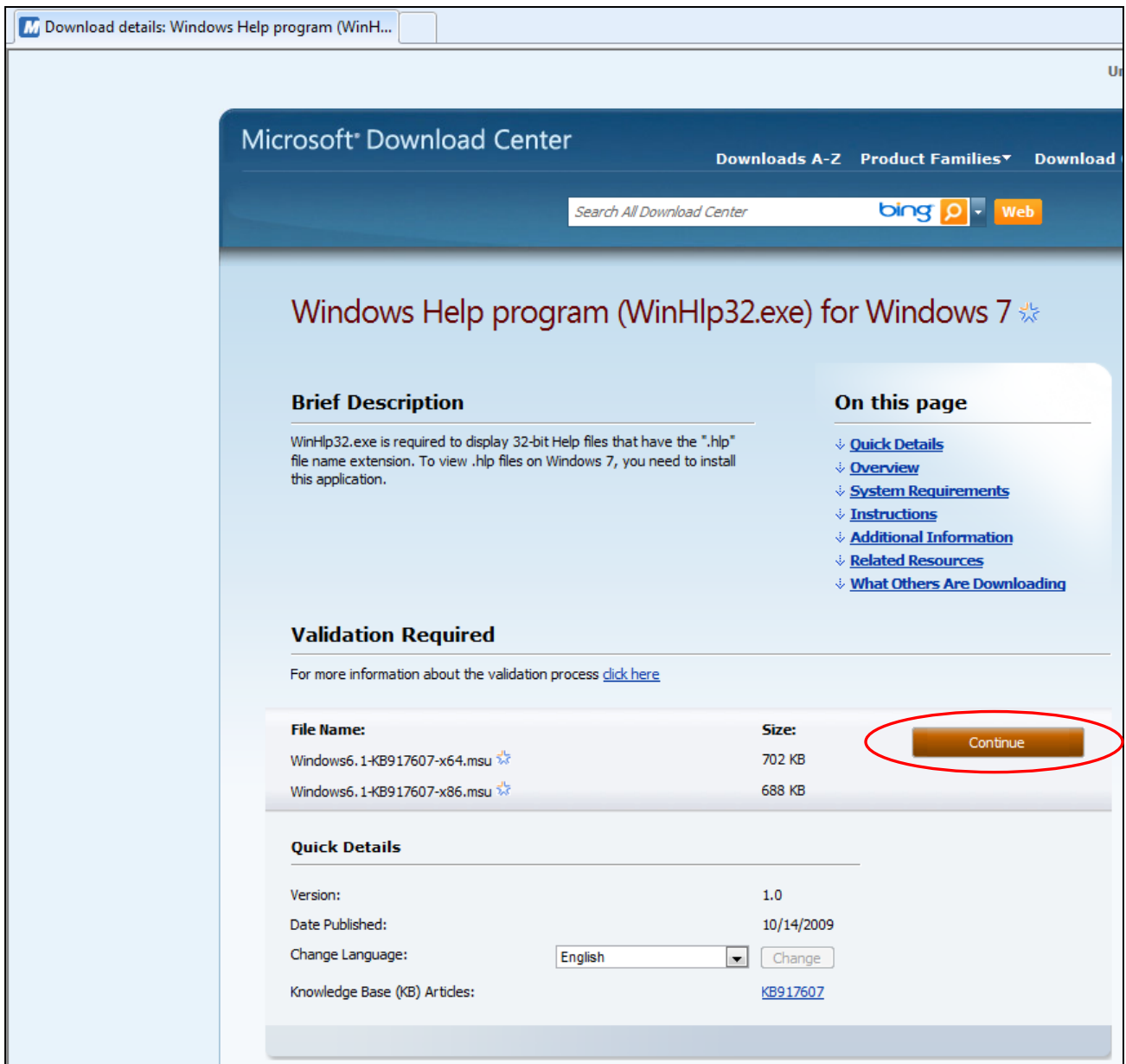


Figure 2.4: Microsoft® Download Center

You will be forwarded to a web page with instructions on how to install the Genuine Windows Validation Component.

At the top of your Windows Internet Explorer you will see a yellow information bar. Right-click this bar and select "Install ActiveX Control" in the context menu (see Figure 2.5).

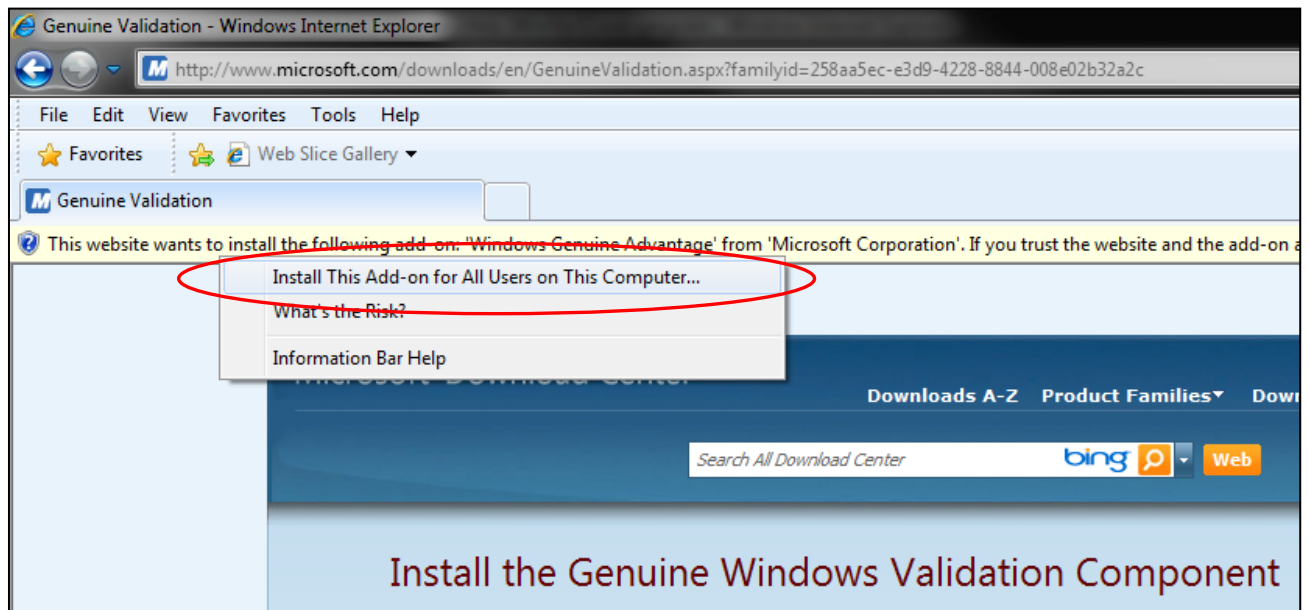


Figure 2.5: Installing the Genuine Windows Validation Component

A dialog window appears in which you will be asked if you want to install the software. Click the "Install" button to continue (see Figure 2.6)

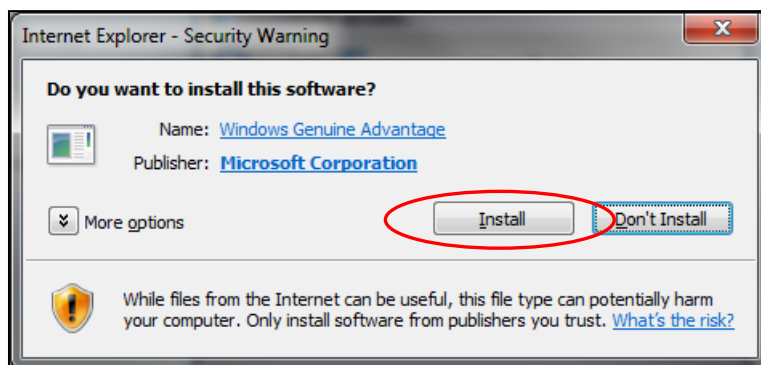


Figure 2.6: Internet Explorer – Security Warning

After the validation has been carried out you will be able to download the appropriate version of Windows Help program (see Figure 2.7).

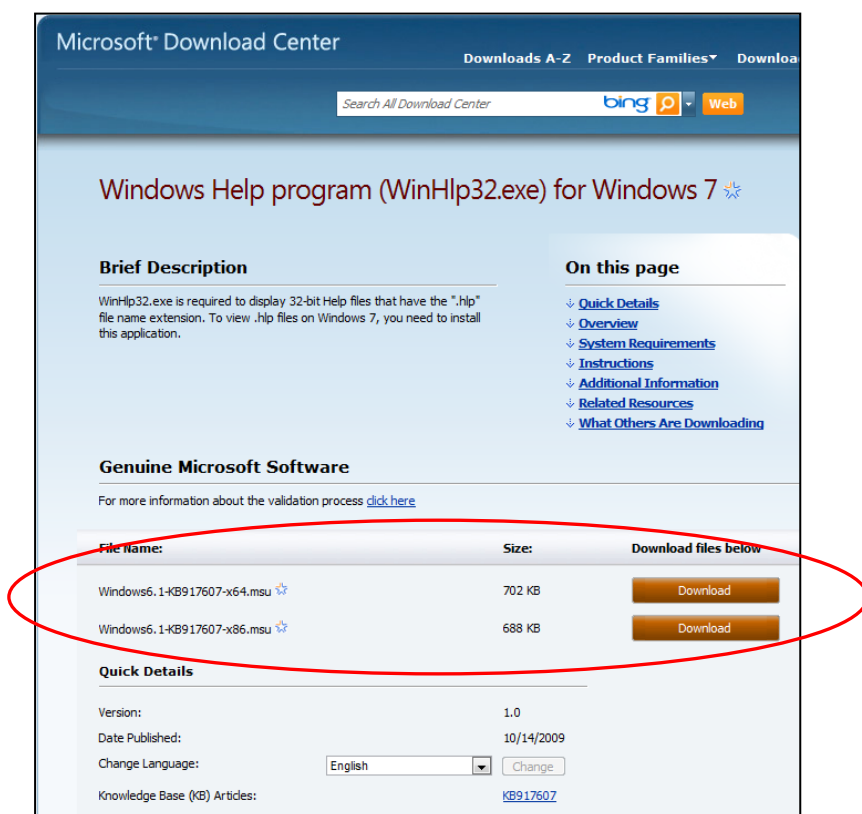


Figure 2.7: Downloading the Windows Help program

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

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

Windows6.1-KB917607-x64.msu.

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

Windows6.1-KB917607-x86.msu.

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

Windows6.1-KB917607-x64.msu (for 64-bit operating system)

Windows6.1-KB917607-x86.msu. (for 32-bit operating system).

Installation starts with a window searching for updates on your computer. After the program has finished searching you may see the following window.

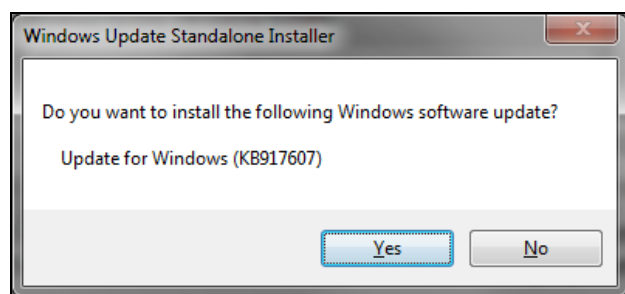


Figure 2.8: Windows Update Standalone Installer

In this case, the installation can be continued by clicking the "Yes" button.

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

In the next window you have to accept the Microsoft license terms before installing the update by clicking on "I Accept" (see Figure 2.9)

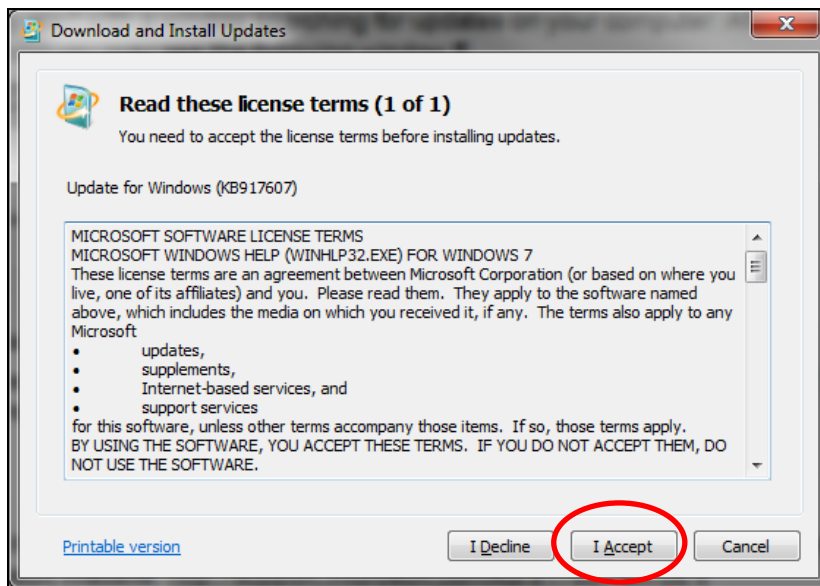


Figure 2.9: Windows License Terms

Installation starts once you have clicked the "I Accept" button (see Figure 2.10).

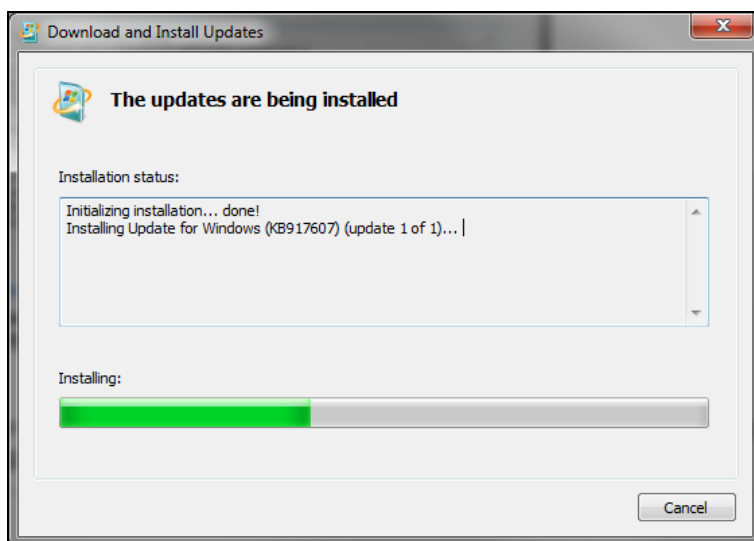


Figure 2.10: Installation process

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

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

2.3 Licensing the LibHuAir Property Library

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

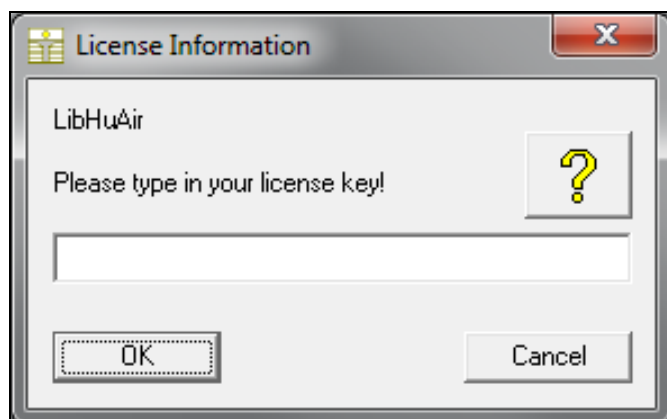


Figure 2.11: "License Information" window

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

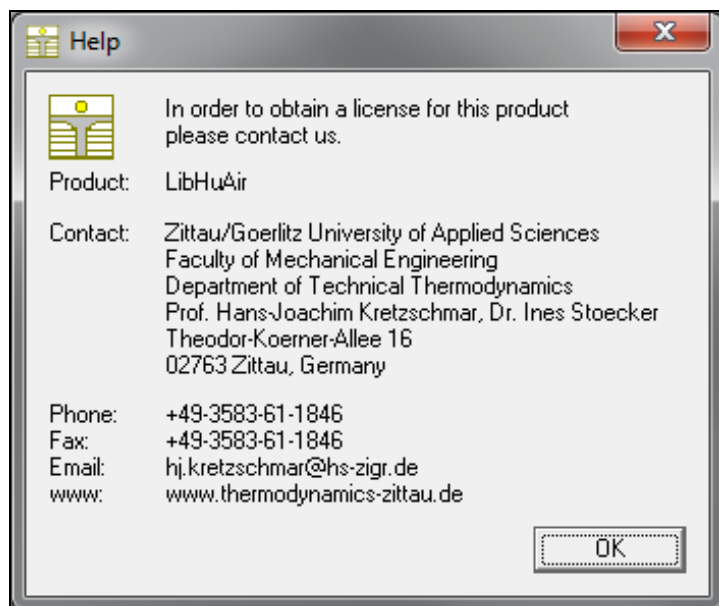


Figure 2.12: "Help" window

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

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

With this procedure the LibHuAir property library has been licensed.

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

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

How to perform a calculation with FluidEES:

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

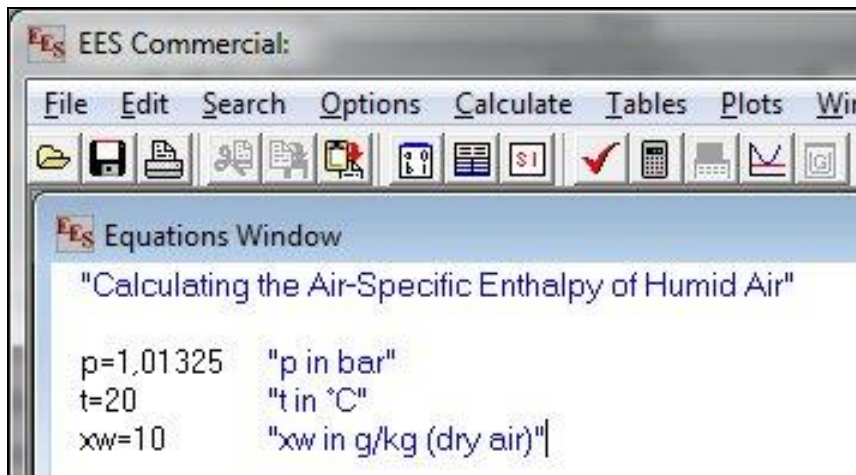


Figure 2.13: Preparing an EES® sheet for the calculation

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

Note:

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

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

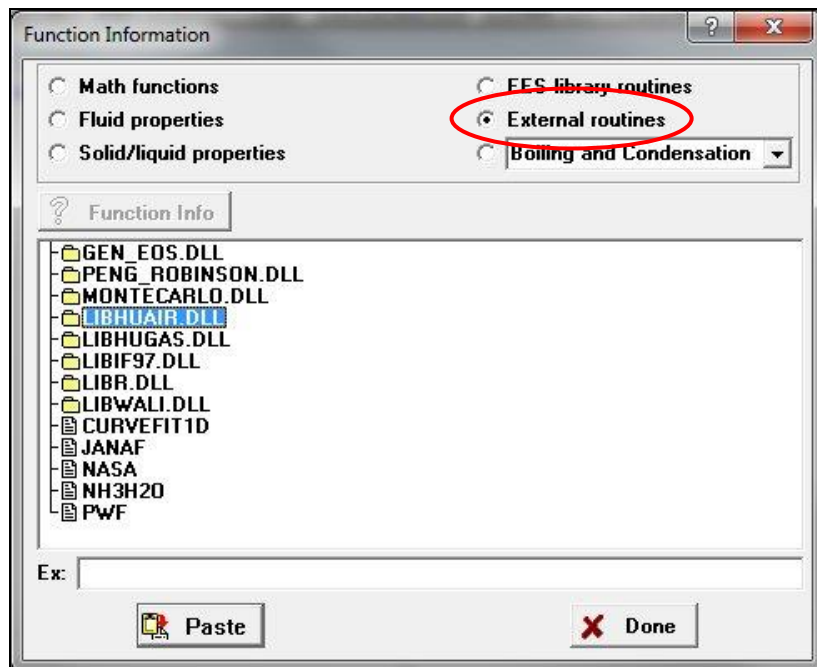


Figure 2.14: "Function Information" window offering different libraries (routines)

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

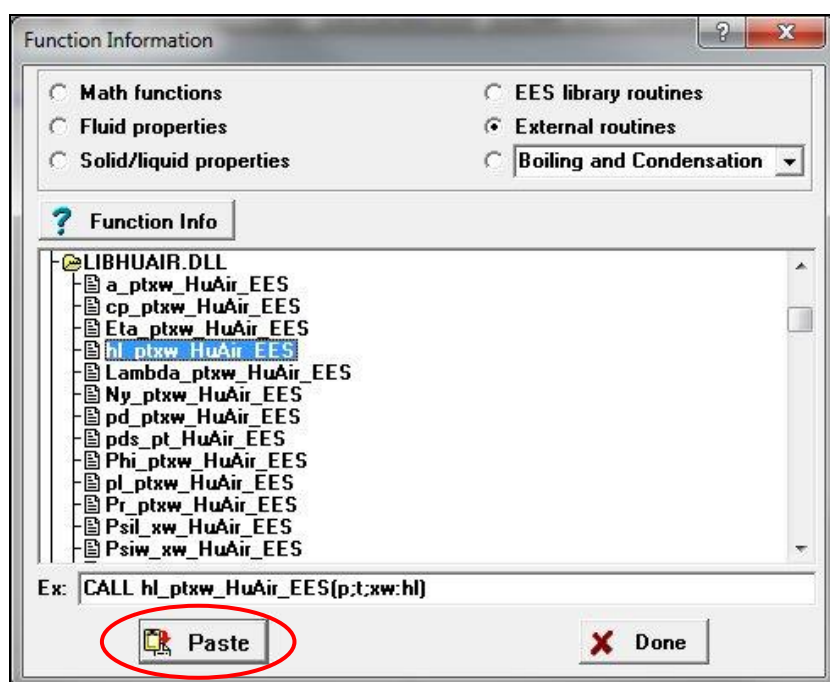


Figure 2.15: Selecting the "hl_ptxw_HuAir_EES" function

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

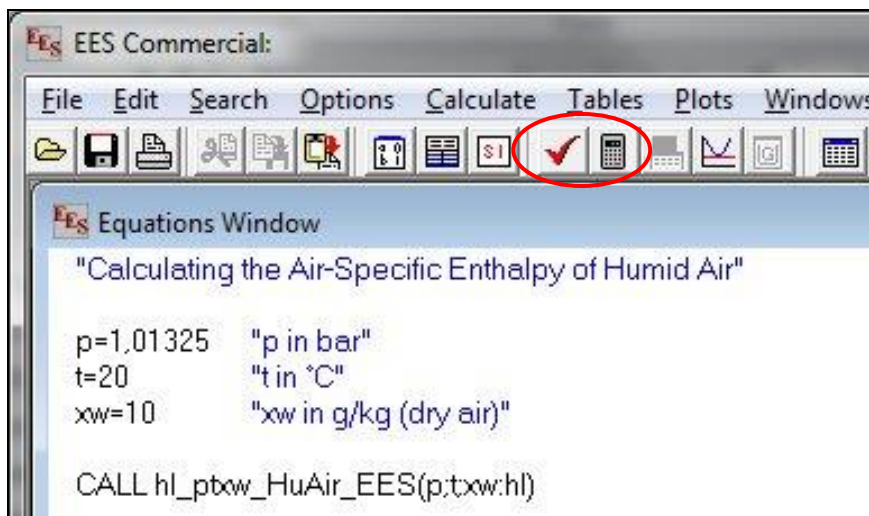


Figure 2.16: "Equations Window" with the call of the property function

- Now, you can check the syntax of the instructions in the "Equations Window" by clicking the  symbol in the upper menu bar of EES®. The program tests whether or not the syntax is correct (e.g. dots as decimal separators versus commas). Confirm the "Information" window which appears by clicking the "OK" button.
- Then click the  symbol in the upper menu bar of EES® to start the calculation.
- Soon you will see the "Calculations Completed" window. Leave this window by clicking the "Continue" button.
- The result for the specific enthalpy h appears in the "Solution" window (see Figure 2.17).

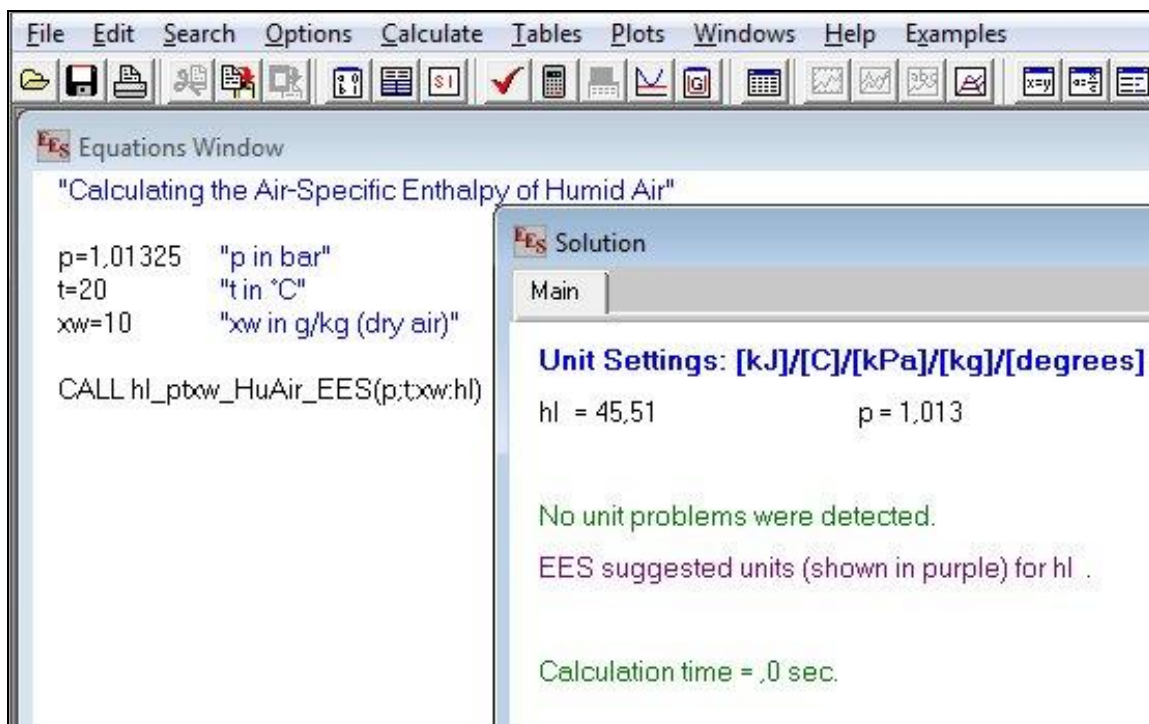


Figure 2.17: "Solution" window showing the result

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

⇒ The result in our sample calculation here is: "h = 45.51".

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

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

2.5 Removing FluidEES LibHuAir

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 "FluidEES LibHuAir" by clicking on it and click the "Change/Remove" button.

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

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

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

"FluidEES LibHuAir" has now been removed.

3. Program Documentation

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

Function Name:

a_ptxw_HuAir

Fortran Programs:

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

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

Input Values:

p - Mixture pressure p in bar

t - Temperature t in °C

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

Result:

a_ptxw_HuAir, a - Thermal diffusivity in m²/s

Range of Validity:

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

Mixture pressure p : from 6.112 mbar to 165.29 bar

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

Comments:

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

Results for wrong input values:

a_ptxw_HuAir, a = - 1

References:

Dry Air:

λ from *Lemmon* et al. [15]

c_p from *Lemmon* et al. [14]

ρ from *Lemmon* et al. [14]

Steam in humid air and liquid droplets in fog:

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

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

ρ from IAPWS-IF97 [1], [2], [3], [4]
for $t < 0.01^\circ\text{C}$ from IAPWS-06 [18], [19]

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

Function Name:

cp_ptxw_HuAir

Fortran Programs:

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

Input Values:

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

Result:

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

Range of Validity:

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

Comments:

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

Results for wrong input values:

cp_ptxw_HuAir, cp = -1

References:

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

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

Function Name:

Eta_ptxw_HuAir

Fortran Programs:

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

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

Input values:

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

Result:

Eta_ptxw_HuAir, Eta - Dynamic viscosity in Pa s

Range of Validity:

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

Comments:

- Model of ideal mixture of real fluids
- Neglect of ice crystals in ice fog ($t < 0.01^\circ\text{C}$ 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
- For temperatures greater than 500°C, the dissociation is taken into consideration

Result for wrong input values:

hl_ptxw_HuAir, hl = -1000

References:

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

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

Lambda_ptxw_HuAir

Fortran Programs:

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

Input values:

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

Result:

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

Range of Validity:

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

Comments:

- Model of ideal mixture of real fluids

Result for wrong input values:

Lambda_ptxw_HuAir, Lambda = -1

References:

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

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

Ny_ptxw_HuAir

Fortran Programs:

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

Input values:

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

Result:

Ny_ptxw_HuAir, Ny - Kinematic viscosity in m²/s

Range of Validity:

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

Comments:

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

Result for wrong input values:

Ny_ptxw_HuAir, Ny = -1

References:

Dry Air:

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

Steam in humid air and liquid droplets in fog:

η for $0^\circ\text{C} \leq t \leq 800^\circ\text{C}$ 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 $p_d = p_{ds}(p, t)$
- Saturation vapor pressure at saturation $p_{ds} = f \cdot p_s(t)$
with $p_{ds}(p, t)$ for $t \geq 0.01^\circ\text{C}$ - vapor pressure of water
 for $t < 0.01^\circ\text{C}$ - sublimation pressure of water
- Result for pure steam, liquid water and water ice: $p_d = 0$

Result for wrong input values:

pd_ptxw_HuAir, pd = -1

References:

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

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 $t_{\text{S}}(p, p_{\text{d}})$
(boiling temperature of water in gas mixtures)

Mixture pressure p : from 6.112 mbar to 165.29 bar

Comments:

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

Result for wrong input values:

pds_pt_HuAir, pds = -1

References:

f(p,t)	Herrmann et al. [25], [26]
p _S (t)	if t ≥ 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 $t_{\text{critical}} = 373,946^\circ\text{C}$ (critical temperature of water)

Mixture pressure p : from 6.112 mbar to 165.29 bar

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

Comments:

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

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

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

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

Result for wrong input values:

Phi_ptxw_HuAir, Phi = - 1

References:

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

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

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

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

pl_ptxw_HuAir

Fortran Programs:

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

Input values:

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

Result:

pl_ptxw_HuAir, pl - Partial pressure of air in bar

Range of Validity:

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

Comments:

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

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

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

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

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

Result for wrong input values:

pl_ptxw_HuAir, pl = -1

References:

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

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

Pr_ptxw_HuAir

Fortran Programs:

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

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

Input values:

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

Result:

Pr_ptxw_HuAir, Pr - *Prandtl*-number

Range of Validity:

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

Comments:

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

Result for wrong input values:

Pr_ptxw_HuAir , Pr = - 1

References:

Dry Air:

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

Steam in humid air and liquid droplets in fog:

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

Dissociation:

- from VDI Guideline 4670 [13]

Mole Fraction of Air $\psi_l = f(x_w)$
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 $\psi_l = 1 - \frac{R_w \cdot x_w}{R(1 + x_w)}$

Result for wrong input values:

Psil_xw_HuAir, Psil = - 1

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

Psiw_xw_HuAir

Fortran Programs:

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

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

Input values:

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

Result:

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

Range of Validity:

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

Comments:

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

Result for wrong input values:

Psiw_xw_HuAir , Psiw = - 1

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

Rho_ptxw_HuAir

Fortran Programs:

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

Input values:

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

Result:

Rho_ptxw_HuAir, Rho - Density in kg/m³

Range of Validity:

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

Comments:

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

Result for wrong input values:

Rho_ptxw_HuAir, Rho = -1

References:

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

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

sl_ptxw_HuAir

Fortran Programs:

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

Input values:

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

Result:

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

Range of Validity:

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

Comments:

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

Result for wrong input values:

sl_ptxw_HuAir, sl = - 1000

References:

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

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

`t_phlxw_HuAir`

Fortran Programs:

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

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

Input values:

- `p` - Mixture pressure p in bar
- `hl` - Air-specific enthalpy in $\text{kJ/kg}_{\text{Air}}$
- `xw` - Absolute humidity x_w in g/kg_{Air}

Result:

`t_phlxw_HuAir, t` - Temperature in $^{\circ}\text{C}$

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 : $\geq 0 \text{ g/kg}_{\text{Air}}$

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
- `sl` - Air-specific entropy in $\text{kJ}/(\text{kg}_{\text{Air}} \text{ K})$
- `xw` - Absolute humidity x_w in $\text{g}/\text{kg}_{\text{Air}}$

Result:

`t_pslxw_HuAir, t` - Temperature in $^{\circ}\text{C}$

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 : $\geq 0 \text{ g}/\text{kg}_{\text{Air}}$

Comments:

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

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

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

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

Result for wrong input values:

`t_pslxw_HuAir, t = -1000`

References:

Dry Air:

from *Lemmon* et al. [22]

Steam in humid air and liquid droplets in fog:

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

Ice crystals in fog:

from IAPWS-06 [18], [19]

Dissociation:

from VDI Guideline 4670 [13]

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

tf_ptxw_HuAir

Fortran Programs:

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

Input values:

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

Result:

tf_ptxw_HuAir, tf - Wet bulb temperature in °C

Range of Validity:

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

Comments:

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

Result for wrong input values:

tf_ptxw_HuAir, tf = - 1000

References:

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

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

tTau_pxw_HuAir

Fortran Programs:

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

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

Input values:

p - Mixture pressure p in bar

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

Result:

tdew_pxw_HuAir, tdew - Dew point temperature in °C

Range of Validity:

Mixture pressure p : from 6.112 mbar to 165.29 bar

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

Comments:

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

$t_\tau = t_{\text{sub}}(p, p_d)$ 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
- 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
`xw` - 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`, X_{iw} - 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`, $X_{iw} = -1$

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

Comments:

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

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

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

Result for wrong input values:

xw_ptPhi_HuAir, $x_w = -1$

References:

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

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

xw_ptpd_HuAir

Fortran Programs:

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

Input values:

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

Result:

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

Range of Validity:

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

Comments:

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

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

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

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

Result for wrong input values:

xw_ptpd_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:

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

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

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

Result for wrong input values:

xw_ptTau_HuAir, $x_w = -1$

References:

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

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

xw_pttf_HuAir

Fortran Programs:

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

Input values:

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

Result:

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

Range of Validity:

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

Comments:

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

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

Result for wrong input values:

xw_pttf_HuAir, $x_w = -1$

References:

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

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

xw_ptvl_HuAir

Fortran Programs:

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

Input values:

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

Result:

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

Range of Validity:

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

Comments:

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

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

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

Result for wrong input values:

xw_ptvl_HuAir, $x_w = -1$

References:

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

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

xws_pt_HuAir

Fortran Programs:

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

Input values:

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

Result:

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

Range of Validity:

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

Comments:

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

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

Result for wrong input values:

xws_pt_HuAir, $x_{ws} = -1$

References:

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



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

Water and Steam

Library LibIF97

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

Humid Combustion Gas Mixtures

Library LibHuGas

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

Humid Air

Library LibHuAir

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

Carbon Dioxide including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1994)

Seawater

Library LibSeaWa

IAPWS Formulation 2008 of Feistel and IAPWS-IF97

Ice

Library LibICE

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

Ideal Gas Mixtures

Library LibIdGasMix

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

- Consideration of:
- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

- Consideration of:
- Dissociation from the VDI Guideline 4670

Dry Air including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Nitrogen

Library LibN2

Formulation of Span et al. (2000)

Hydrogen

Library LibH2

Formulation of Leachman et al. (2007)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth (1995)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of Bucker et al. (2003)

n-Butane

Library LibButane_n

Formulation of Bucker et al. (2003)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

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

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

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

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

Formulation of the International Institute of Refrigeration (1997)

Siloxanes as ORC Working Fluids

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

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

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

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

Formulation of Colonna et al. (2006)

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

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

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

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

Formulation of Colonna et al. (2008)

Propane

Library LibPropane

Formulation of Lemmon et al. (2007)

Methanol

Library LibCH3OH

Formulation of de Reuck and Craven (1993)

Ethanol

Library LibC2H5OH

Formulation of Schroeder et al. (2012)

Helium

Library LibHe

Formulation of Arp et al. (1998)

Hydrocarbons

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

Isopentane C_5H_{12} **Library LibC5H12_ISO**

Neopentane C_5H_{12} **Library LibC5H12_NEO**

Isohexane C_6H_{14} **Library LibC5H14**

Toluene C_7H_8 **Library LibC7H8**

Formulation of Lemmon and Span (2006)

Further Fluids

Carbon monoxide CO **Library LibCO**

Carbonyl sulfide COS **Library LibCOS**

Hydrogen sulfide H_2S **Library LibH2S**

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

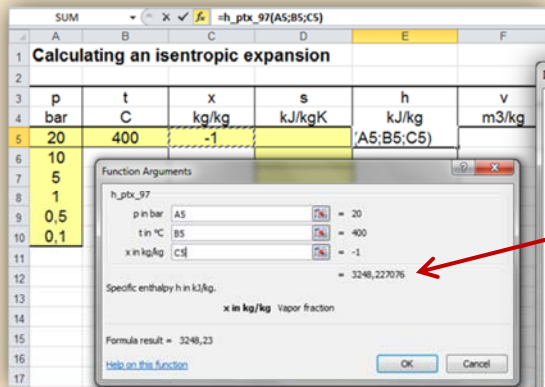
- Partial derivatives can be calculated.

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

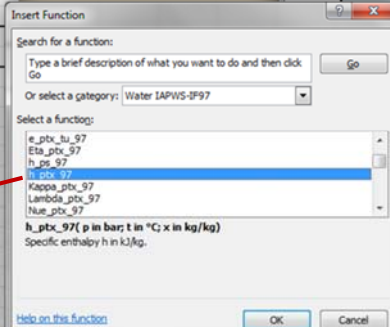


Property Software for Calculating Heat Cycles, Boilers, Turbines, and Refrigerators

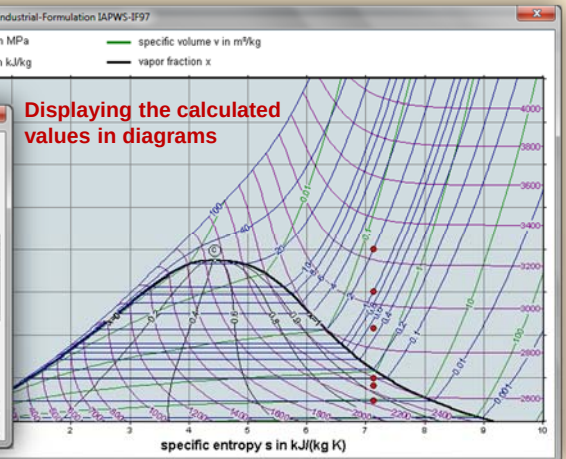
Add-In FluidEXL^{Graphics} for Excel[®]



Choosing a property library and a function



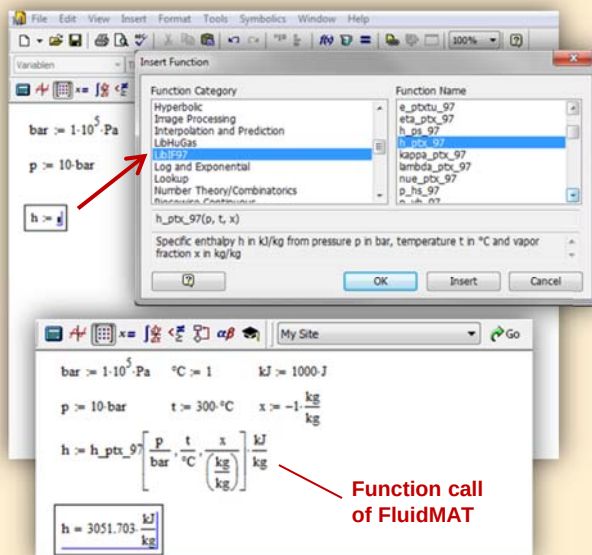
Displaying the calculated values in diagrams



Menu for the input of given property values

Add-In FluidMAT for Mathcad[®]

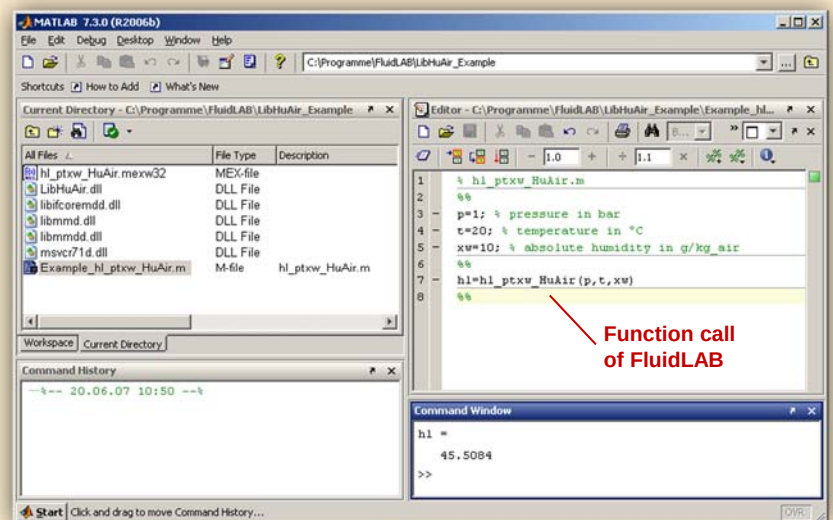
The property libraries can be used in Mathcad[®].



Function call of FluidMAT

Add-In FluidLAB for MATLAB[®]

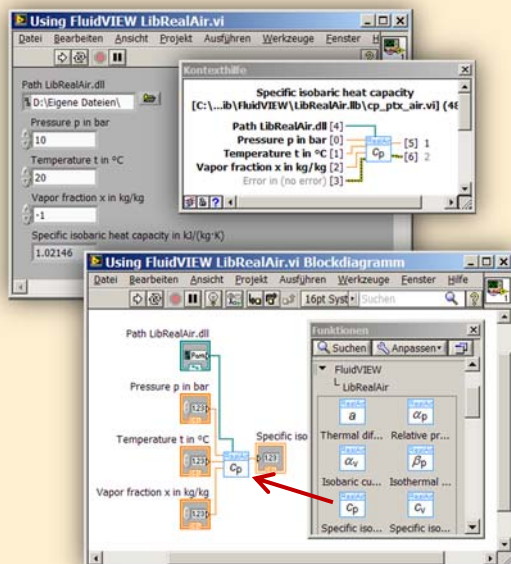
Using the Add-In FluidLAB the property functions can be called in MATLAB[®].



Function call of FluidLAB

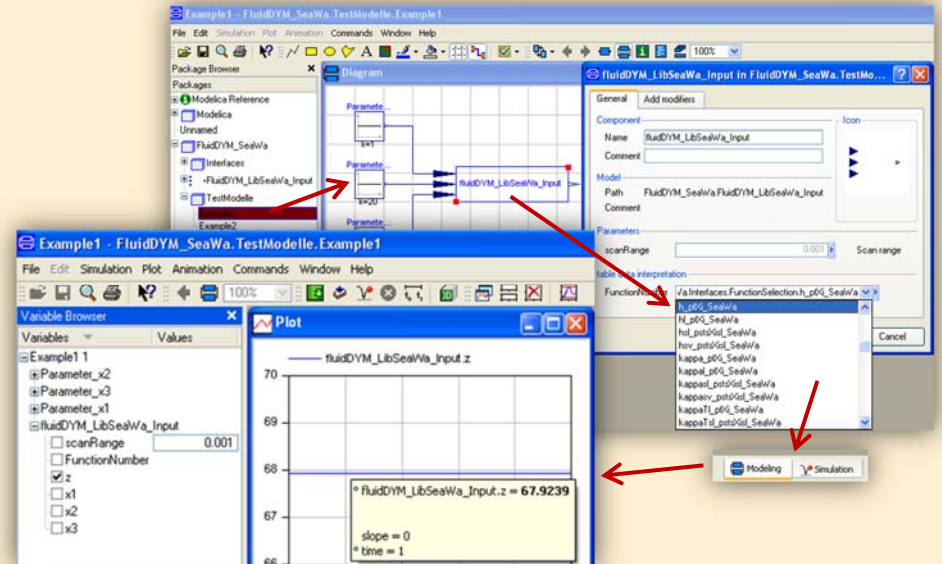
Add-On FluidVIEW for LabVIEW[®]

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

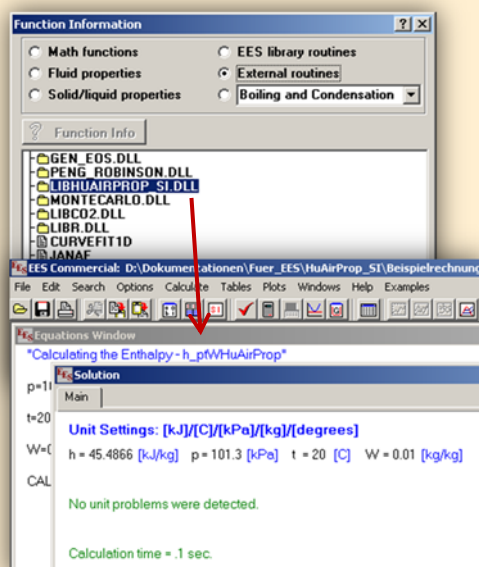


Add-In FluidDYM for DYMOLA[®] (Modelica) and SimulationX[®]

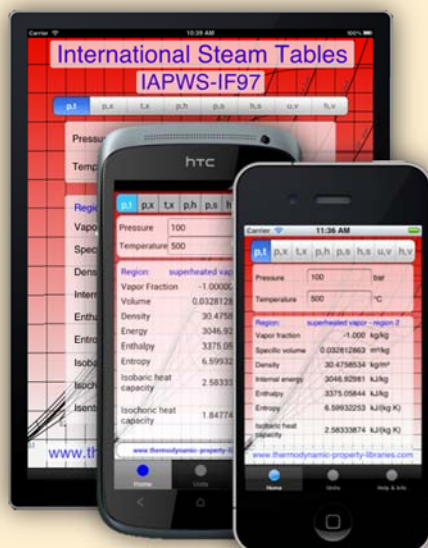
The property functions can be called in DYMOLA[®] and SimulationX[®].



Add-In FluidEES for Engineering Equation Solver®



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



Online Property Calculator at www.thermodynamics-zittau.de

Zittau's Fluid Property Calculator

Fluid:

Function:

Unit System:

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

Pressure p: bar

Temperature t: °C

Vapor fraction x: kg/kg

Calculate / Recalculate

Result:

Specific enthalpy h = 3097.38 kJ/kg

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

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

PDF with the [description](#)

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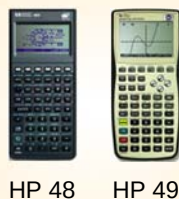
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www.international-steam-tables.com
www.thermodynamic-formelsammlung.de

Property Software for Pocket Calculators

FluidCasio



FluidHP



FluidTI



For more information please contact:

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

Thermodynamic Properties

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

Transport Properties

- Dynamic viscosity η
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Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives can be calculated.

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

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6. Satisfied Customers

Date: 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
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Fels, Elingerode	07/2011
Weihenstephan University of Applied Sciences	07/2011, 09/2011, 10/2011
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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
InfraServ, Gendorf	05/2002
SoftSolutions, Muehlhausen (company license)	05/2002
DREWAG, Dresden (company license)	05/2002
SOFBID, Zwingenberg (general EBSILON program license)	06/2002
Kleemann Engineering, Dresden	06/2002
Caliqua, Basel, Switzerland (company license)	07/2002
PCK Raffinerie, Schwedt (group license)	07/2002
Fischer-Uhrig Engineering, Berlin	08/2002
Fichtner Consulting & IT, Stuttgart (company licenses and distribution)	08/2002
Stadtwerke Duisburg	08/2002

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

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 (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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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 (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

1997

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