Hochschule Zittau/Görlitz
UNIVERSITY OF APPLIED SCIENCES

Faculty of
MECHANICAL ENGINEERING
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TECHNICAL THERMODYNAMICS

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

FluidEXL*Graphics*

with LibHuAir

for Excel®

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

LibHuAir

FluidEXL *Graphics*

Contents

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0. Package Contents

0.1 Zip files for 32-bit Office®

The following zip files are delivered for your computer running a 32-bit Office® version.

English zip-file "CD_FluidEXL_Graphics_LibHuAir_Eng.zip" including the following files:

FluidEXL_Graphics_Eng_Setup.exe	- English installation program for the Add-In FluidEXL*Graphics* for use in Excel®
FluidEXL_Graphics_Eng.xla	- English Add-In for FluidEXL*Graphics*
LibHuAir.dll	- Dynamic link library for application in Windows® programs
LibHuAir_Eng.hlp	- English help file for the LibHuAir library
FluidEXL_Graphics_LibHuAir_Docu_Eng.pdf	- User's Guide

German zip-file "CD_FluidEXL_Graphics_LibHuAir.zip" including the following files:

FluidEXL_Graphics_Setup.exe	- German installation program for the Add-In FluidEXL*Graphics* for use in Excel®
FluidEXL_Graphics.xla	- German Add-In for FluidEXL*Graphics*
LibHuAir.dll	- Dynamic link library for application in Windows® programs
LibHuAir.hlp	- German help file for the LibHuAir library
FluidEXL_Graphics_LibHuAir_Docu_Eng.pdf	- User's Guide

0.2 Zip files for 64-bit Office®

The following zip files are delivered for your computer running a 64-bit Office® version.

English zip file "CD_FluidEXL_Graphics_LibHuAir_x64_Eng.zip" including the following files and folders:

Files:

FluidEXL_Graphics_LibHuAir_Docu_Eng.pdf	- User's Guide
FluidEXL_Graphics_Eng.xla	- FluidEXL*Graphics* Add-In
FluidEXL_Graphics_Eng_64_Setup.msi	- Self-extracting and self-installing program
LibHuAir.dll	- Dynamic link library for use in Windows® programs
LibHuAir_Eng.hlp	- English help file for the LibHuAir library
Setup.exe	- Self-extracting and self-installing

	program for FluidEXL^{Graphics}

Folders:

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

German zip file "CD_FluidEXL_Graphics_LibHuAir_x64.zip" including the following files and folders:

Files:

FluidEXL_Graphics_LibHuAir_Docu_Eng.pdf	- User's Guide
FluidEXL_Graphics.xla	- FluidEXL^{Graphics} Add-In
FluidEXL_Graphics_64_Setup.msi	- Self-extracting and self-installing program
LibHuAir.dll	- Dynamic link library for use in Windows® programs
LibHuAir.hlp	- German help file for the LibHuAir library
Setup.exe	- Self-extracting and self-installing program for FluidEXL^{Graphics}

Folders:

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

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 $(0 < x_w \leq x_{ws})$:

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 $0\,°C \leq t \leq 800\,°C$ 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 $t \geq 0.01°C$
  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 $p_{ds}(p,t) = f(p,t) \cdot p_s(t)$

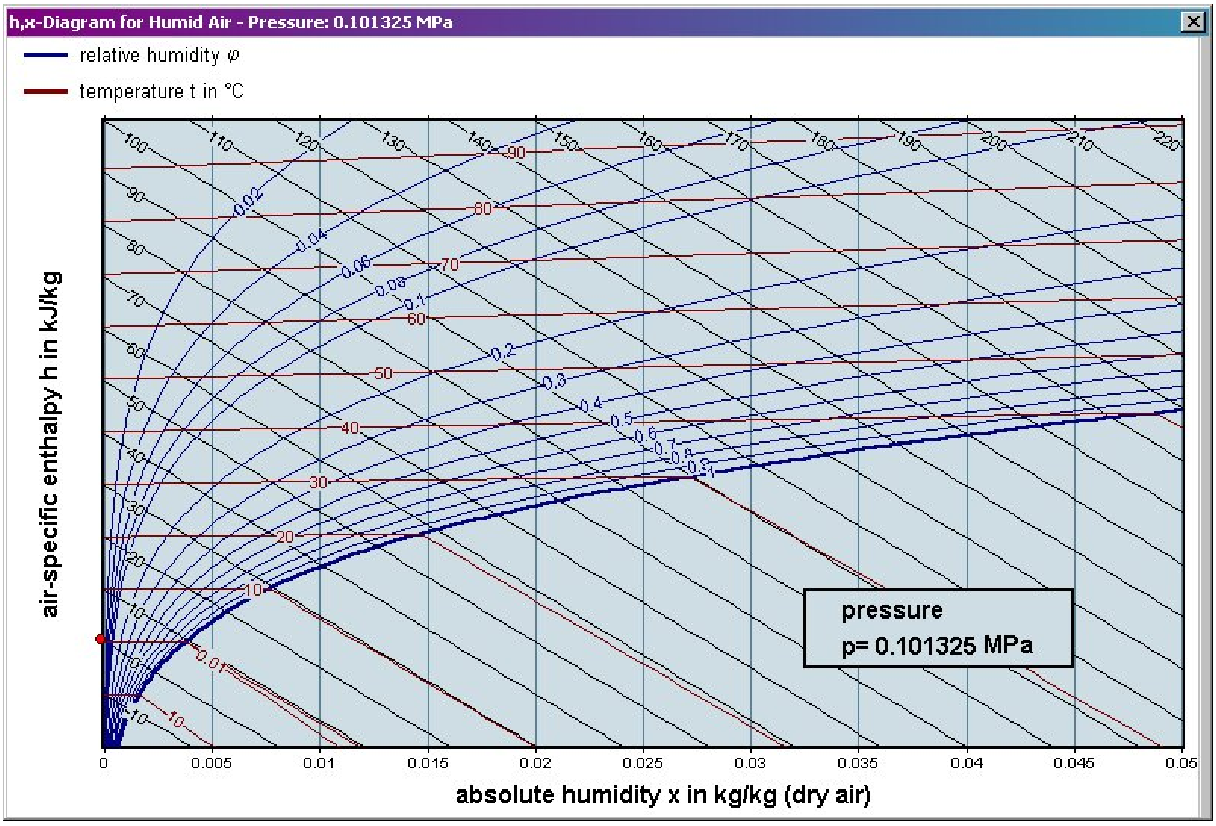
- $f(p,T)$ from Herrmann et al. [25], [26],
- $p_s(t)$ for $t \geq 273.16$ K from IAPWS - IF97 [1], [2], [3], [4],
- $p_s(t)$ for $t < 273.15$ K from IAPWS-08 [16], [17].

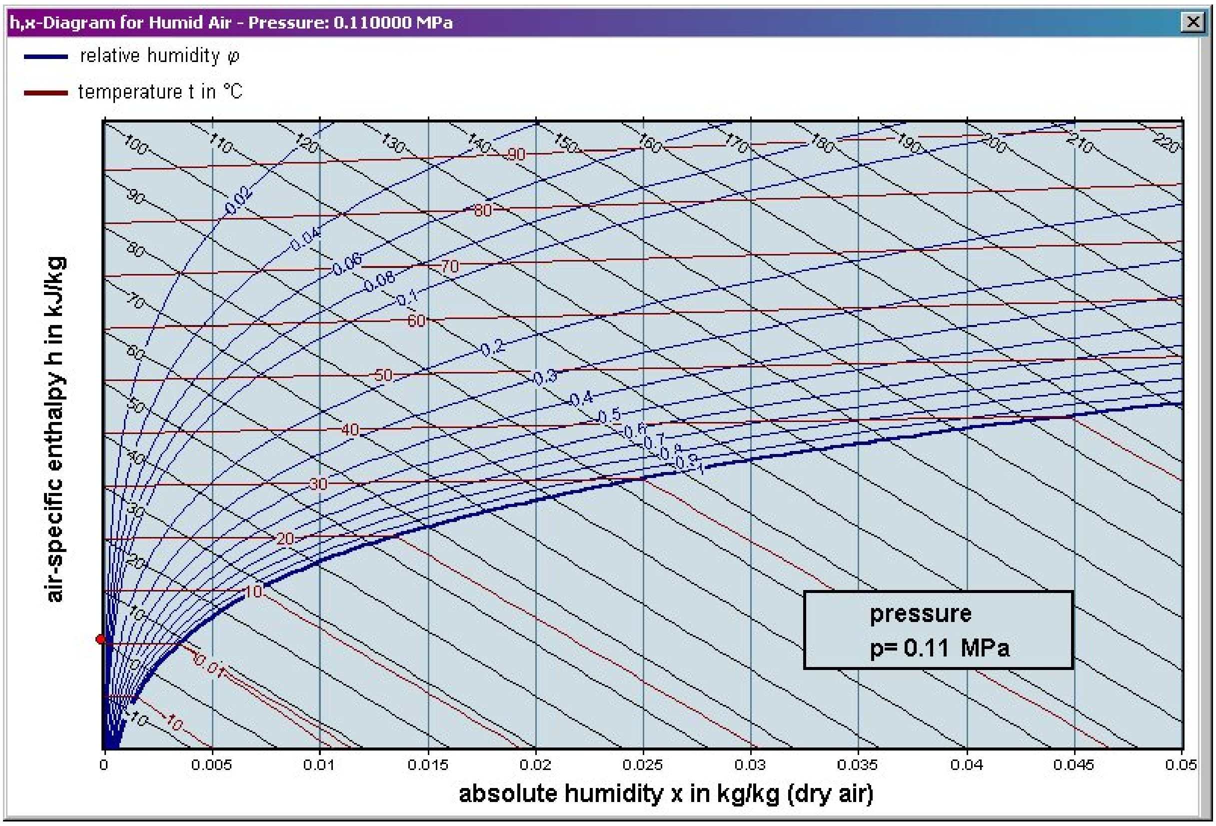
1.2 Thermodynamic Diagrams

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 FluidEXL*Graphics* in Excel®

The FluidEXL*Graphics* Add-In has been developed to calculate thermophysical properties in Excel® more conveniently. Within Excel®, it enables the direct call of functions relating to humid air from the LibHuAir property library. Furthermore, the program enables representation of the calculated values in various thermodynamic diagrams.

2.1 Installing FluidEXL*Graphics*

If FluidEXL*Graphics* has not yet been installed or if there is a version installed which has been delivered before June 2010, please complete the initial installation procedure described below.

If FluidEXL*Graphics* has already been installed in a version which has been delivered after June 2010, you simply need to copy the files which belong to the LibHuAir library. In this case, follow the subsection "Adding the LibHuAir Library."

Installing FluidEXL*Graphics* for 32-bit Office®

Complete the following steps for initial installation of FluidEXL*Graphics*.

Before you begin, it is best to uninstall any trial version or full version of FluidEXL*Graphics* delivered before April 2010.

After you have downloaded and extracted the zip-file

"CD_FluidEXL_Graphics_LibHuAir_Eng.zip" (for English version of Windows),
"CD_FluidEXL_Graphics_LibHuAir.zip" (for German version of Windows)

you will see the folder

CD_FluidEXL_Graphics_LibHuAir_Eng (for English version of Windows)
CD_FluidEXL_Graphics_LibHuAir (for German version of Windows)

in your Windows Explorer®, Norton Commander® or any other similar program you may be using.

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

Within this folder you will see the following files:

FluidEXL_Graphics_LibHuAir_Docu_Eng.pdf
FluidEXL_Graphics_LibHuAir_Setup.exe (for German version of Windows)
FluidEXL_Graphics_LibHuAir_Eng_Setup.exe (for German version of Windows)
FluidEXL_Graphics.xla (for German version of Windows)
FluidEXL_Graphics_Eng.xla (for English version of Windows)
LibHuAir.dll
LibHuAir.hlp (for German version of Windows)
LibHuAir_Eng.hlp (for English version of Windows).

In order to run the installation of FluidEXL*Graphics* including the LibHuAir property library double-click the file

FluidEXL_Graphics_LibHuAir_Eng_Setup.exe (for English version of Windows)
FluidEXL_Graphics_LibHuAir_Setup.exe (for German version of Windows)

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, "Choose Destination Location", the default path offered automatically for the installation of FluidEXL*Graphics* is

C:\Program Files\FluidEXL_Graphics_Eng	(for English version of Windows)
C:\Programme\FluidEXL_Graphics	(for German version of Windows)

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

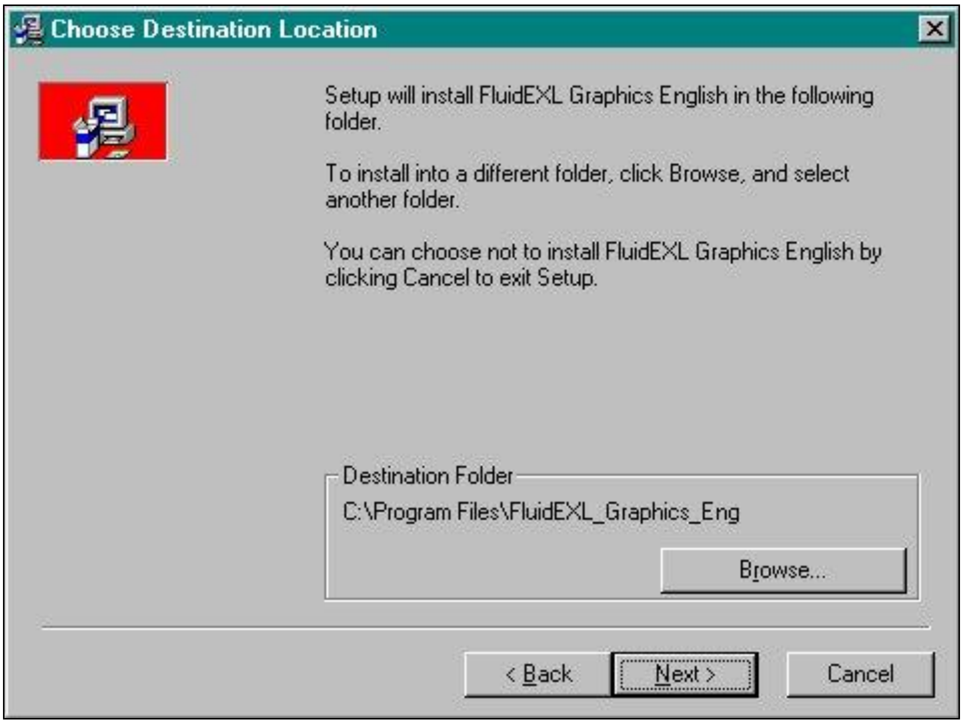


Figure 2.1: Choose Destination Location

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

After FluidEXL*Graphics* has been installed, the sentence "FluidEXL Graphics LibHuAir has been successfully installed." will be shown. Confirm this by clicking the "Finish" button.

The installation of FluidEXL*Graphics* has been completed.

During the installation process the following files

advapi32.dll	UNWISE.EXE
Dformd.dll	LC.dll
Dforrt.dll	msvcrt.dll
INSTALL_EXL.LOG	msvcp60.dll

FluidEXL_Graphics_Eng.xla	(for English version of Windows)
FluidEXL_Graphics.xla	(for German version of Windows)

have been copied into the chosen destination folder, in the standard case

C:\Program Files\FluidEXL_Graphics_Eng	(for English version of Windows)
C:\Programme\FluidEXL_Graphics	(for German version of Windows)

In the next step, the following files from the extracted folder

CD_FluidEXL_Graphics_LibHuAir_Eng (for English version of Windows)
CD_FluidEXL_Graphics_LibHuAir (for German version of Windows)

must be copied into the chosen destination folder (the standard being

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
C:\Programme\FluidEXL_Graphics (for German version of Windows)

using an appropriate program such as Explorer or Norton Commander:

FluidEXL_Graphics_Eng.xla (for English version of Windows)
FluidEXL_Graphics.xla (for German version of Windows)
LibHuAir.dll
LibHuAir_Eng.hlp (for English version of Windows)
LibHuAir.hlp (for German version of Windows).

Installing FluidEXL*Graphics* for 64-bit Office®

Complete the following steps for initial installation of FluidEXL*Graphics*.
Before you begin, it is best to uninstall any trial version or full version of FluidEXL*Graphics* delivered before June 2010.
After you have downloaded and extracted the zip-file

"CD_FluidEXL_Graphics_LibHuAir_x64_Eng.zip" (for English version of Windows)
"CD_FluidEXL_Graphics_LibHuAir_x64.zip" (for German version of Windows)

you will see the folder

CD_FluidEXL_Graphics_LibHuAir_Eng (for English version of Windows)
CD_FluidEXL_Graphics_LibHuAir (for German version of Windows)

in your Windows Explorer, Norton Commander etc.

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

Within this folder you will see the following files

FluidEXL_Graphics_LibHuAir_Docu_Eng
FluidEXL_Graphics_Eng.xla (for English version of Windows)
FluidEXL_Graphics_Eng.xla (for German version of Windows)
FluidEXL_Graphics_Eng_Setup_64.msi (for English version of Windows)
FluidEXL_Graphics_Setup_64.msi (for German version of Windows)
LibHuAir.dll
LibHuAir_Eng.hlp (for English version of Windows)
LibHuAir.hlp (for German version of Windows)
Setup.exe

and the folders

vcredist_x64
WindowsInstaller3_1.

In order to run the installation of FluidEXL*Graphics* double-click the file

Setup.exe.

If the "Microsoft Visual C++ 2010 x64 Redistributable Pack" is not running on your computer yet, installation will start with a window noting that the "Visual C++ 2010 runtime library (x64)" will be installed on your machine (see figure below).

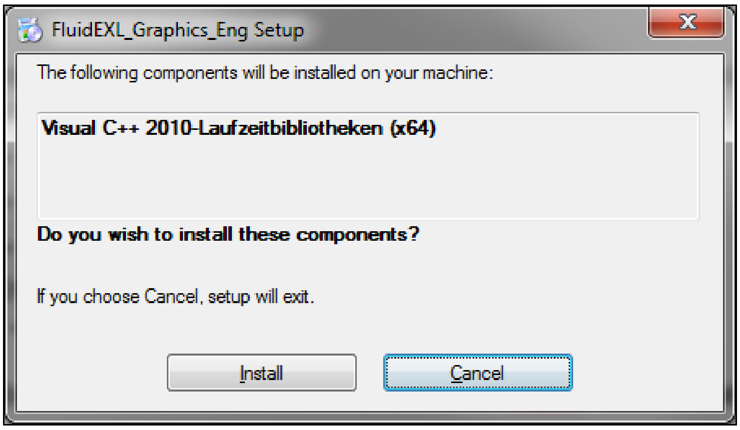


Figure 2.2: Installing the "Visual C++ 2010 runtime library (x64)"

Click on "Install" to continue.

In the following window you are required to accept the Microsoft® license terms to install the "Microsoft Visual C++ 2010 x64 Redistributable Pack" by ticking the box next to "I have read and accept the license terms" (see figure below).

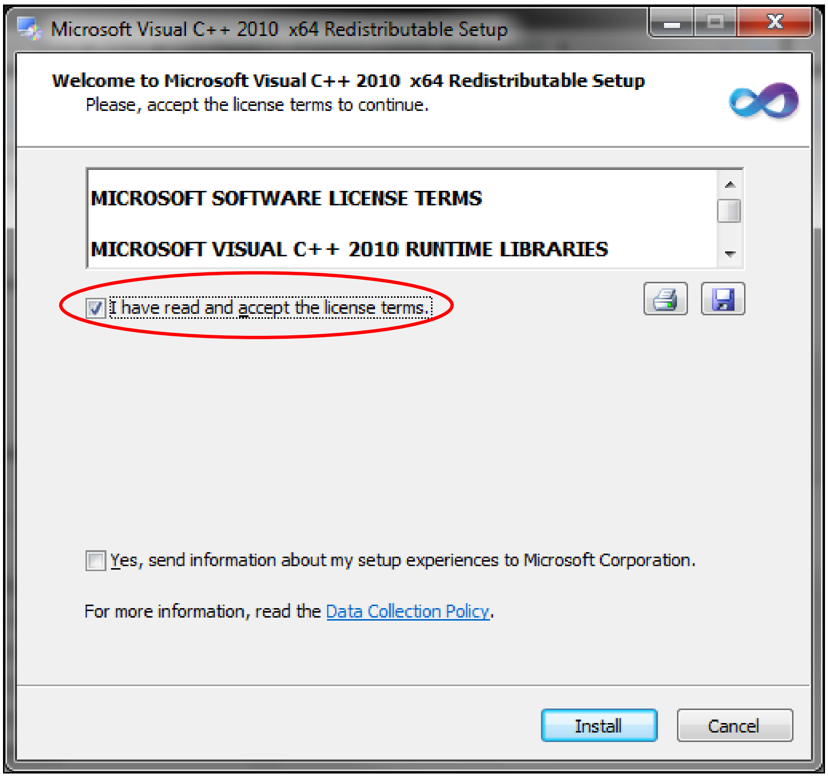


Figure 2.3: Accepting the license terms

Now click on "Install" to continue installation.

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

Now the installation of FluidEXL_Graphics_Eng_64 starts with a window noting that the installer will guide you through the installation. Click the "Next >" button to continue.

In the following dialog box, "Select Installation Folder," the default path offered automatically for the installation of FluidEXL^{Graphics} is

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
C:\Programme\FluidEXL_Graphics (for German version of Windows).

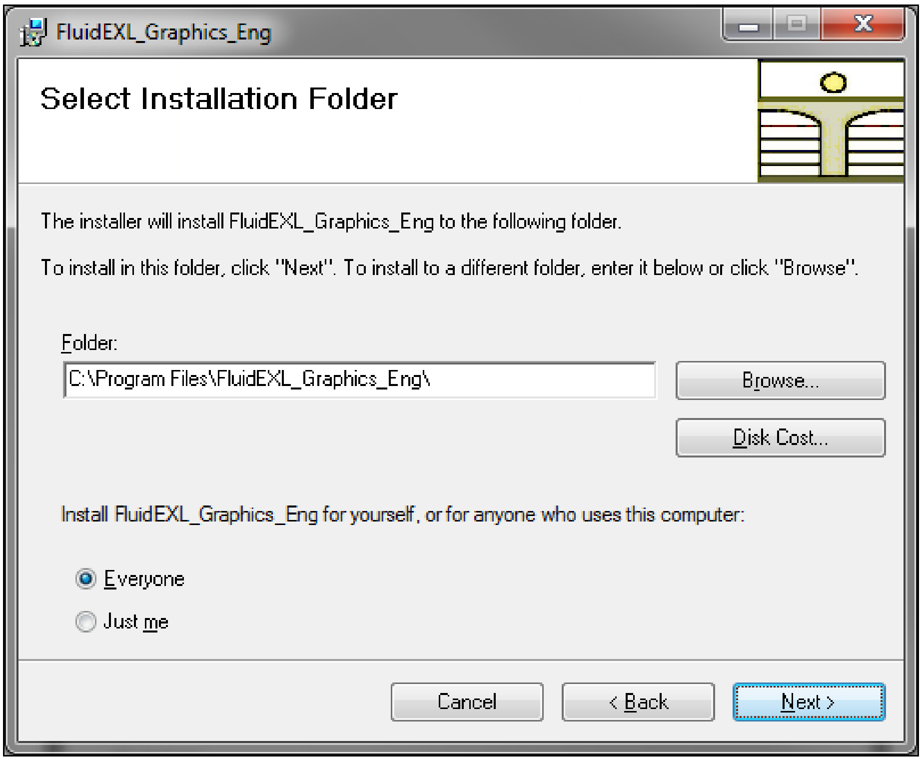


Figure 2.4: Choosing the Installation Folder of FluidEXL^{Graphics}

Finally, click on "Next >" to continue installation; click "Next >" again in the "Confirm Installation" window which follows in order to start the installation of FluidEXL^{Graphics}.

After FluidEXL^{Graphics} has been installed, you will see the sentence "FluidEXL_Graphics_Eng has been successfully installed." Confirm this by clicking the "Close" button.

During the installation process the following files will have been copied into the destination folder chosen, the standard being C:\Program Files\FluidEXL_Graphics_Eng:

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

In addition, the two subdirectories \FORMULATION97 and \FLuft were created in the destination folder.

In the next step, the files below, found on your CD, must be copied into the chosen destination folder (the standard being C:\Program Files\FluidEXL_Graphics_Eng) using an appropriate program such as Explorer or Norton Commander:

FluidEXL_Graphics_Eng.xla (for English version of Windows)
FluidEXL_Graphics.xla (for German version of Windows)

LibHuAir.dll
LibHuAir_Eng.hlp (for English version of Windows).
LibHuAir.hlp (for German version of Windows).

2.2 Registering FluidEXL*Graphics* as Add-In in Excel®

Registering FluidEXL*Graphics* as Add-In in Excel®, versions 2003 or earlier

After the installation of FluidEXL*Graphics*, the program must be registered as an Add-In in Excel®. In order to do so, start Excel and carry out the following steps:

- Click "Tools" in the upper Menu bar in Excel
- Here, click the "Add-Ins..." menu item

After a short delay, the dialog box "Add-Ins" will appear

- Click "Browse..."
- In the following dialog box, click your chosen destination folder (the standard being
  C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
  C:\Programme\FluidEXL_Graphics (for German version of Windows))
- Here click the file
  "FluidEXL_Graphics_Eng.xla" (for English version of Windows) or
  "FluidEXL_Graphics.xla" (for German version of Windows)

  and afterwards click "OK".

Now, the entry

"FluidEXL Graphics Eng" (for English version of Windows)
"FluidEXL Graphics" (for German version of Windows)

occurs in the Add-Ins list.

Note:

As long as the check box next to the file name

"FluidEXL Graphics Eng" (for English version of Windows) or
"FluidEXL Graphics" (for German version of Windows),

is ticked, this Add-In will be loaded automatically every time you start Excel until you untick the box by clicking on it again.

- In order to register FluidEXL*Graphics* as an Add-In click "OK" in the "Add-Ins" dialog box.

Now, the new FluidEXL*Graphics* menu bar will appear in the upper menu area of your Excel screen, marked with a red circle in the next figure.

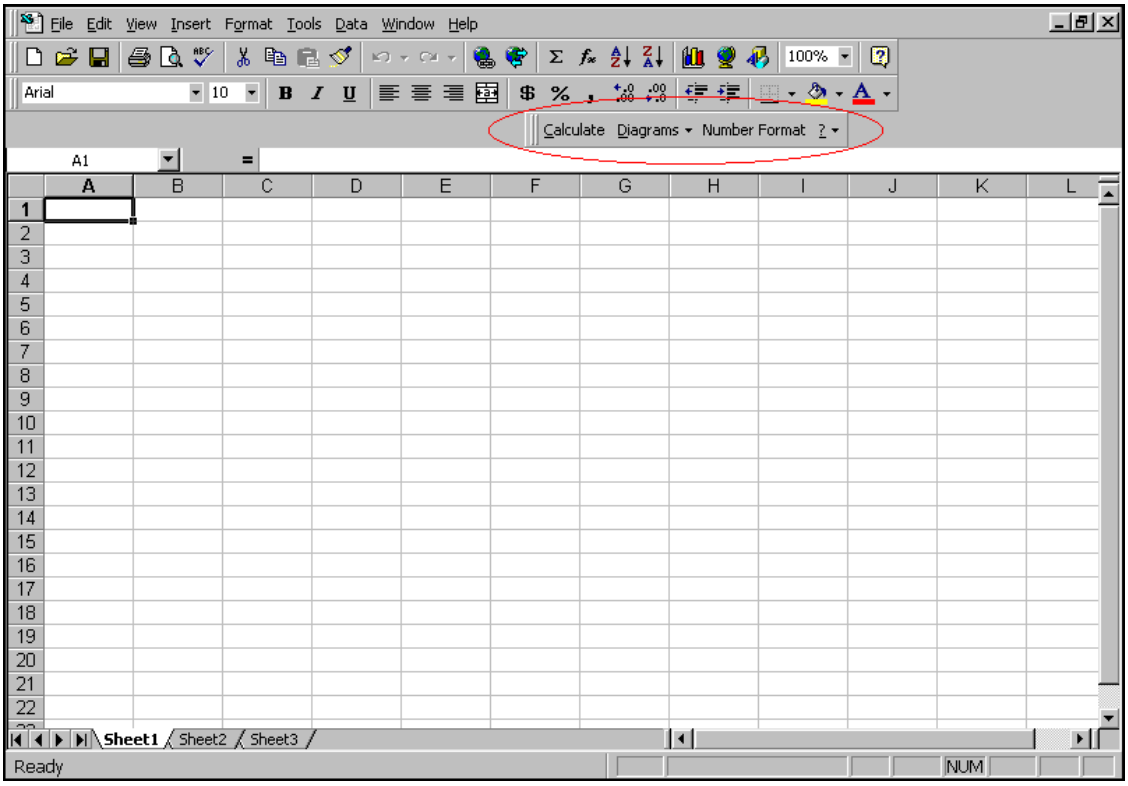


Figure 2.5: Menu bar of FluidEXL*Graphics*

Registering FluidEXL*Graphics* as Add-In in Excel® 2007 (or later versions)

After installation in Windows®, FluidEXL*Graphics* must be registered in Excel® as from version 2007 as an Add-In. For this, start Excel and carry out the following steps:

- Click the Windows Office button in the upper left corner of Excel
- Click on the "Excel Options" button in the menu which appears (see figure below)

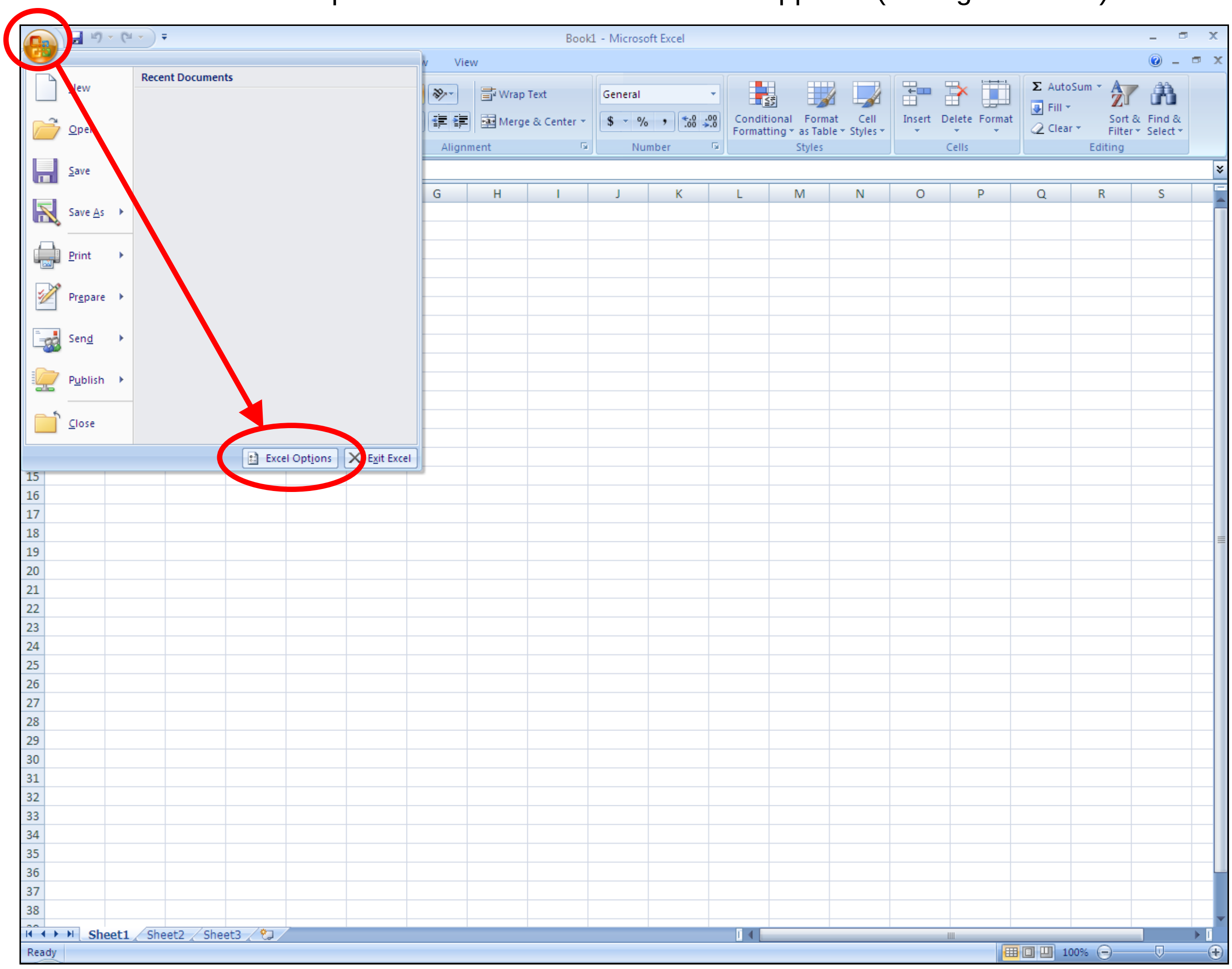


Figure 2.6: Registering FluidEXL*Graphics* as Add-In in Excel® 2007

- Click on "Add-Ins" in the next menu

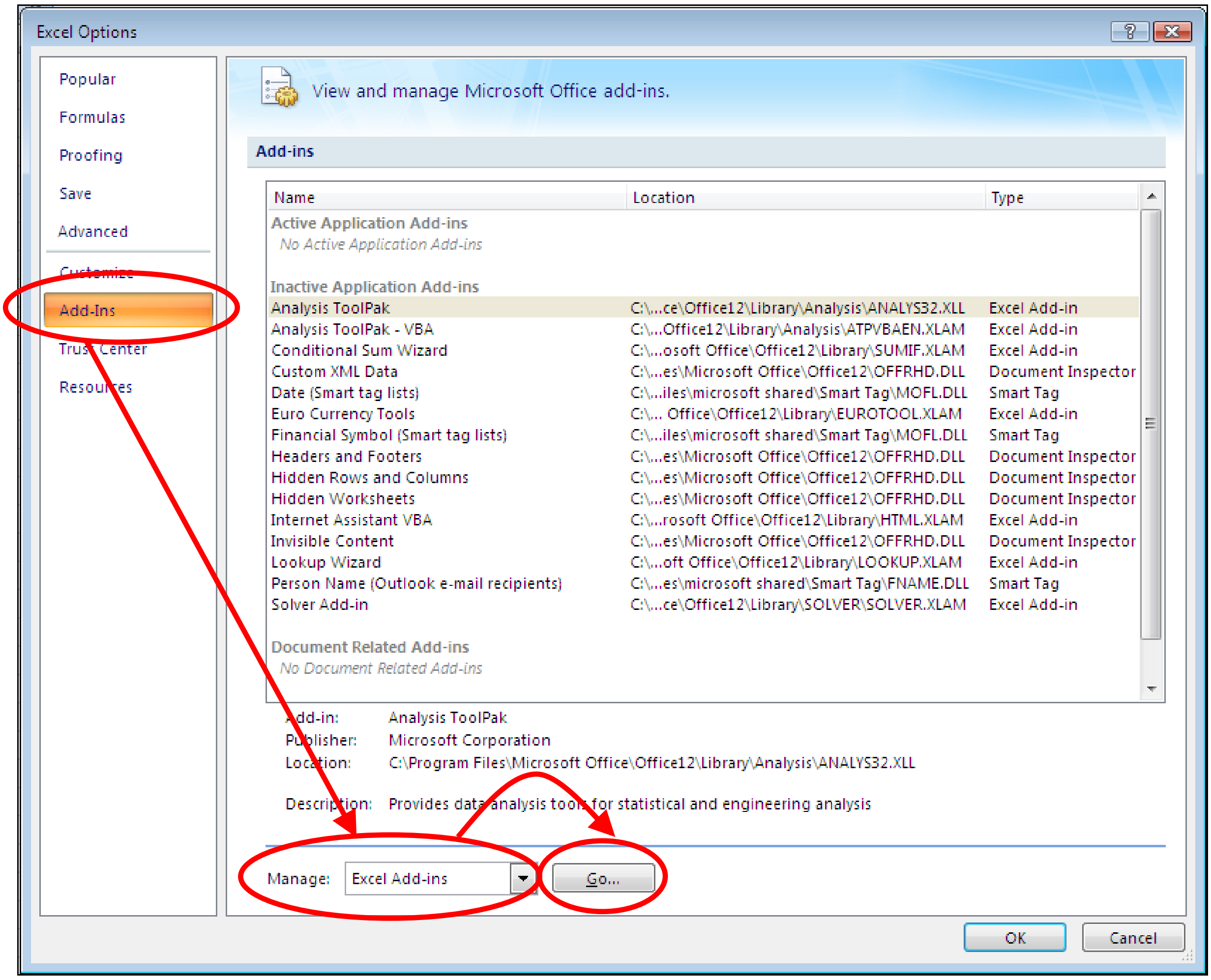


Figure 2.7: Dialog window "Excel Options"

- Should it not be shown in the list automatically, choose and click on "Excel Add-ins" (found next to "Manage:" in the lower area of the menu)
- Then click the "Go…" button
- Click "Browse" in the following window and locate the destination folder, in the standard case C:\Program Files\FluidEXL_Graphics_Eng; within that folder click on the file named

  "FluidEXL_Graphics_Eng.xla" (for English version of Windows)
  "FluidEXL_Graphics.xla" (for German version of Windows)

  and then click the "OK" button.

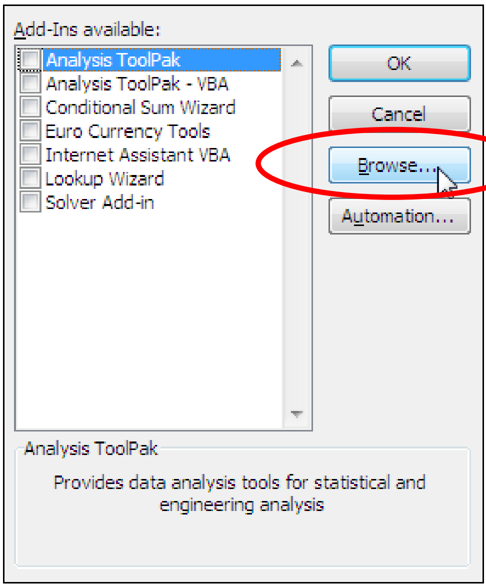


Figure 2.8: Dialog window "Add-Ins available"

- Now, "FluidEXL Graphics Eng" is shown in the Add-Ins list.
  (If a check-mark is situated in the box next to the name "FluidEXL Graphics", this Add-In will automatically be loaded whenever Excel starts. This will continue to occur unless the check-mark is removed from the box by clicking on it.)

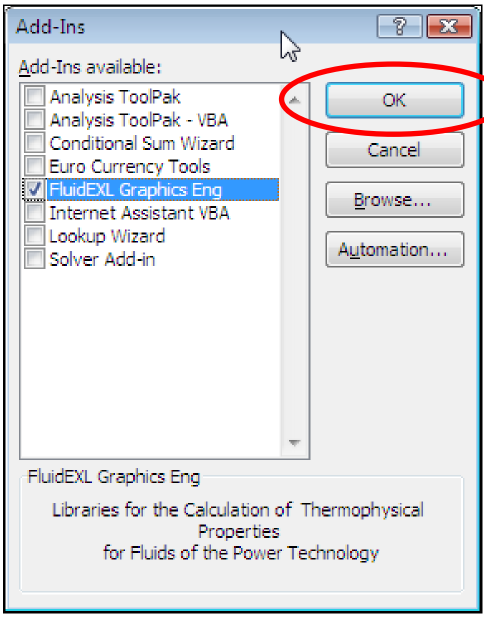


Figure 2.9: Dialog window "Add-Ins"

- In order to register the Add-In click the "OK" button in the "Add-Ins" window.

In order to use FluidEXL*Graphics* in the following example, click on the menu item "Add-Ins" which is shown in the next image.

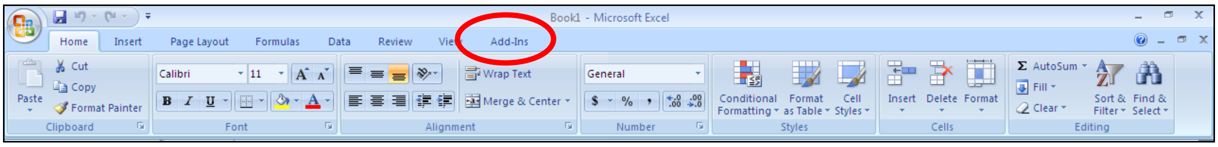


Figure 2.10: Menu item "Add-Ins"

In the upper menu region of Excel, the FluidEXL$^{\mathit{Graphics}}$ menu bar will appear as marked with the red circle in the next image.

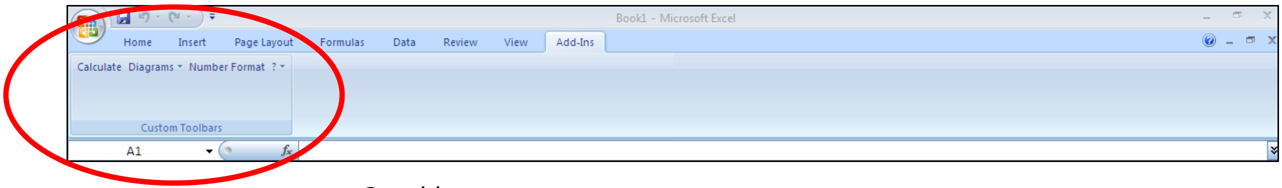


Figure 2.11: FluidEXL$^{\mathit{Graphics}}$ menu bar

Installation of FluidEXL$^{\mathit{Graphics}}$ in Excel as from version 2007 is now finished. FluidEXL$^{\mathit{Graphics}}$ can be used analogous to the description of Excel until version 2007.

Adding the LibHuAir Library (FluidEXL$^{\mathit{Graphics}}$ is already installed)

If FluidEXL$^{\mathit{Graphics}}$ has already been installed in the June 2010 version you only have to copy the following files provided in the extracted folder you only have to copy the following files provided in the extracted folder

CD_FluidEXL_Graphics_LibHuAir	(for German version of Windows)
CD_FluidEXL_Graphics_LibHuAir_Eng	(for English version of Windows)

into the folder you have chosen for the installation of FluidEXL$^{\mathit{Graphics}}$ (the standard being

C:\Program Files\FluidEXL_Graphics_Eng	(for English version of Windows®) or
C:\Programme\FluidEXL_Graphics	(for German version of Windows)),

using an appropriate program such as Explorer, Windows or Norton Commander:

FluidEXL_Graphics_Eng.xla	(for English version of Windows)
FluidEXL_Graphics.xla	(for German version of Windows)
LibHuAir.dll	
LibHuAir_Eng.hlp	(for English version of Windows)
LibHuAir.hlp	(for German version of Windows)

From within Excel you can now select the "Humid Air LibHuAir" DLL library property functions via the FluidEXL$^{\mathit{Graphics}}$ menu bar (the example calculation can be found in chapter 2.5 on page 2/20).

2.3 The FluidEXL$^{\mathit{Graphics}}$ Help System

As mentioned earlier, FluidEXL$^{\mathit{Graphics}}$ also provides detailed online help functions.
If you are running Windows Vista or Windows 7, please note the paragraph
"Using the FluidEXL$^{\mathit{Graphics}}$ Online-Help in Windows Vista or Windows 7."
For general information in Excel®:

- Click on "?" and then "Help" in the FluidEXL$^{\mathit{Graphics}}$ menu bar.

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

- Click "Calculate" in the FluidEXL$^{\mathit{Graphics}}$ menu bar.
- Click on the "Humid Air LibHuAir" library under "Or select a category:" in the "Insert Function" window which will appear.
- Click the "Help on this function" button in the lower left-hand edge of the "Insert Function" window.
- If the "Office Assistant" is active, first double-click "Help on this feature" and in the next

menu click "Help on selected function".

If the

"LibHuAir_Eng.hlp" (for English version of Windows)
"LibHuAir.hlp" (for German version of Windows)

function help cannot be found, confirm the question whether you want to look for it yourself with "Yes". Search and click on the "LibHuAir_Eng.hlp"/"LibHuAir.hlp" file in the installation menu of FluidEXL$^{\mathit{Graphics}}$ in the window which is opened, in the standard case

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows) or

C:\Programme\FluidEXL_Graphics (for English version of Windows),

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

Using the FluidEXL$^{\mathit{Graphics}}$ 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:

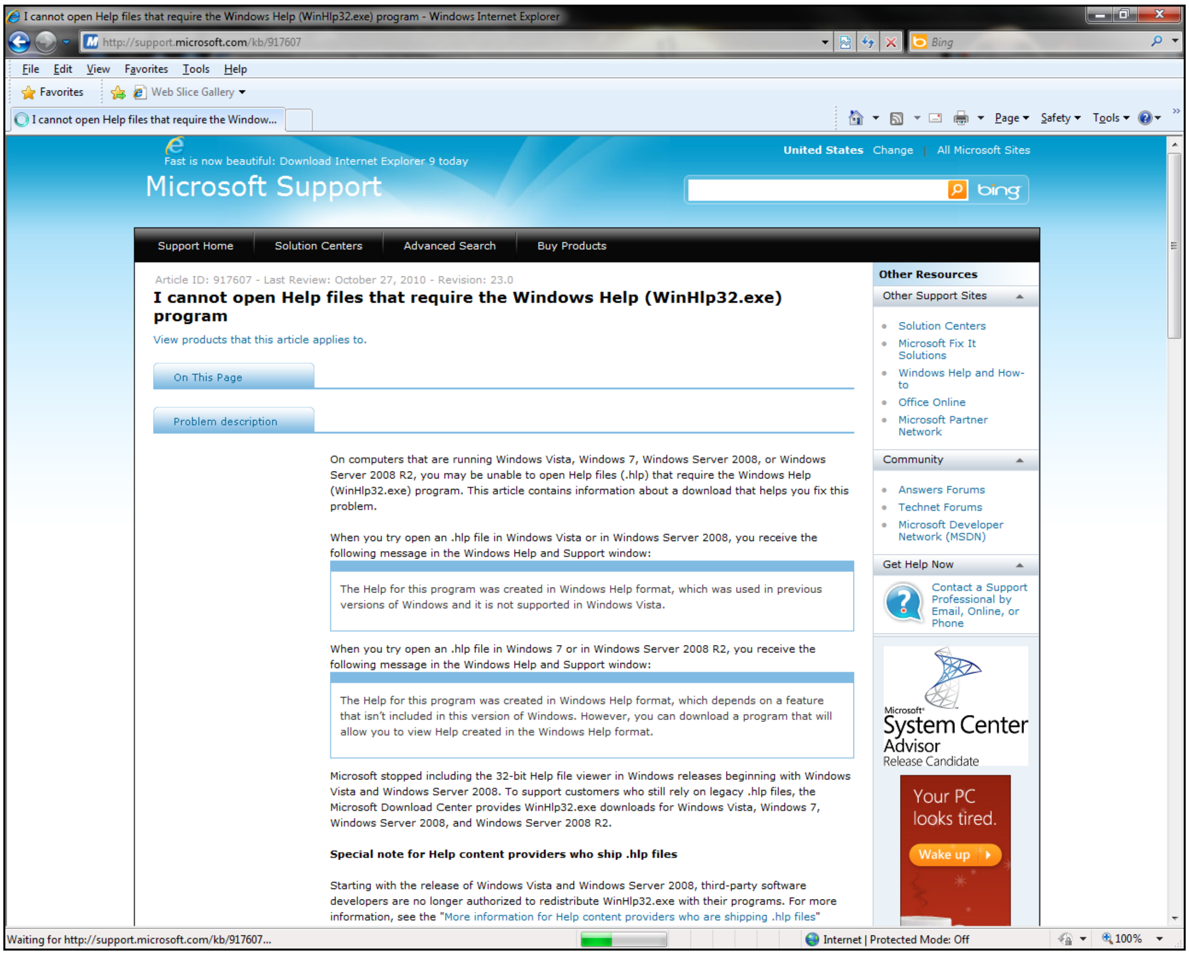


Figure 2.9: Microsoft® Support web page

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 analogous for Windows® Vista.

Click on the link "Windows Help program (WinHlp32.exe) for Windows 7" (see Figure 2.10).

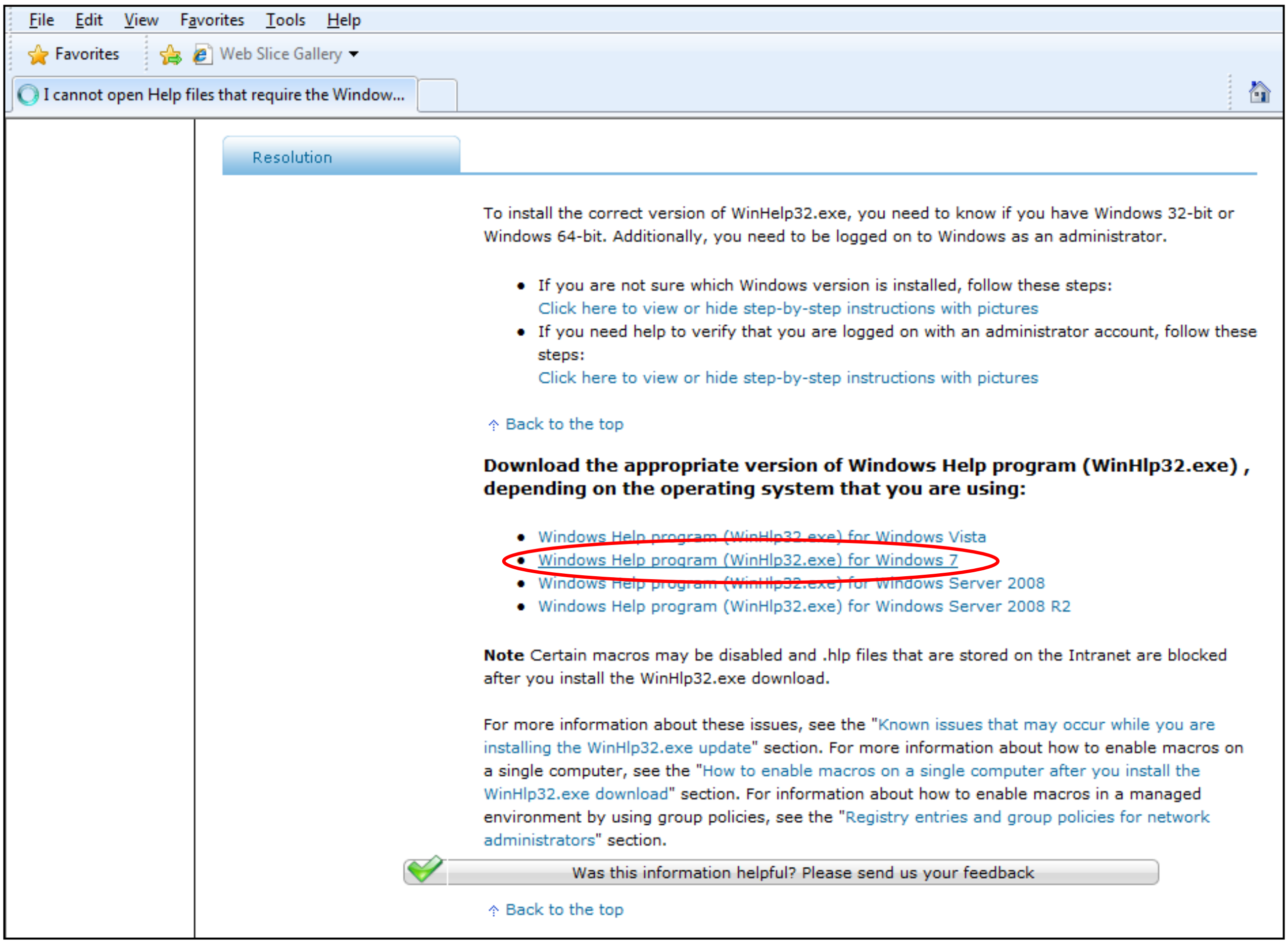


Figure 2.10: Selecting your Windows version

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 2.11).

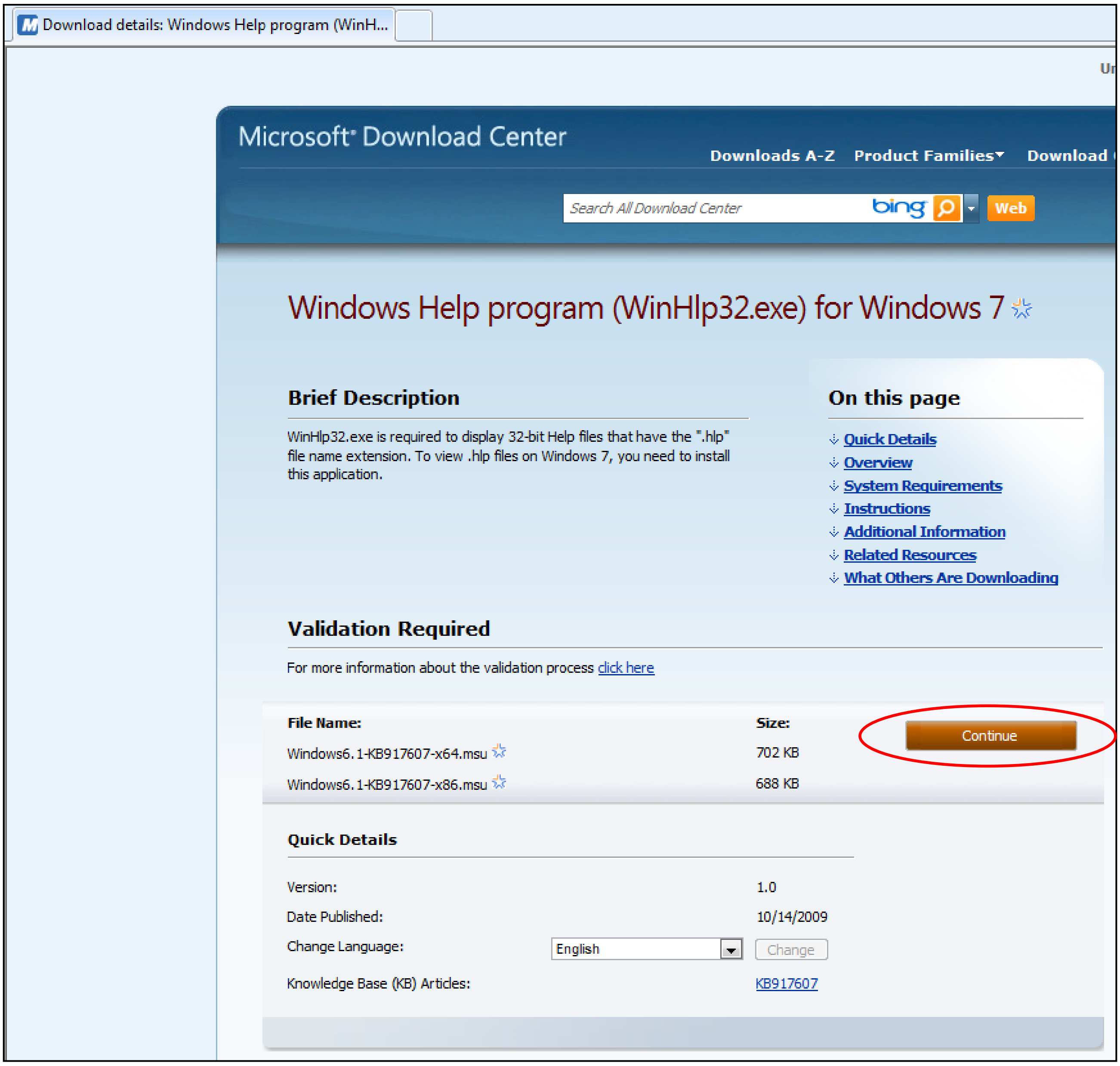


Figure 2.11: Microsoft® Download Center

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 2.12).

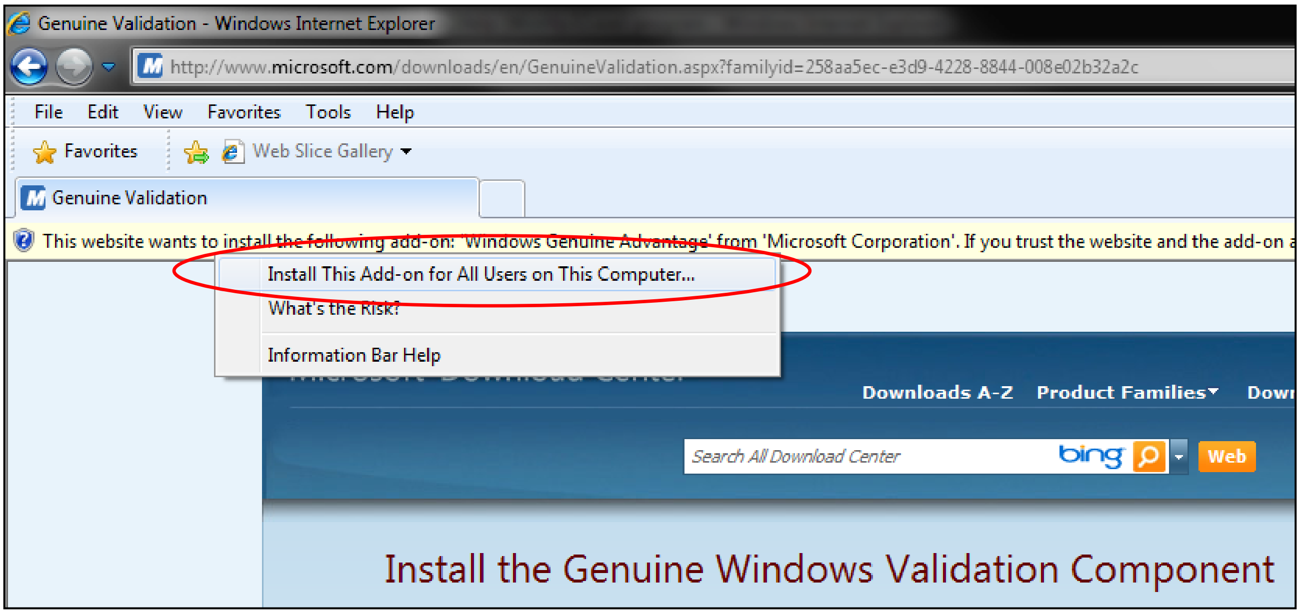


Figure 2.12: Installing the Genuine Windows Validation Component

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 2.13).

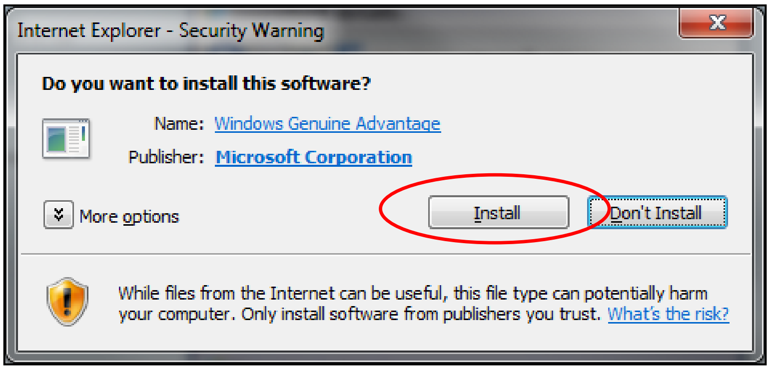


Figure 2.13: Internet Explorer – Security Warning

After the validation has been carried out you will be able to download the appropriate version of Windows Help program (see Figure 2.14).

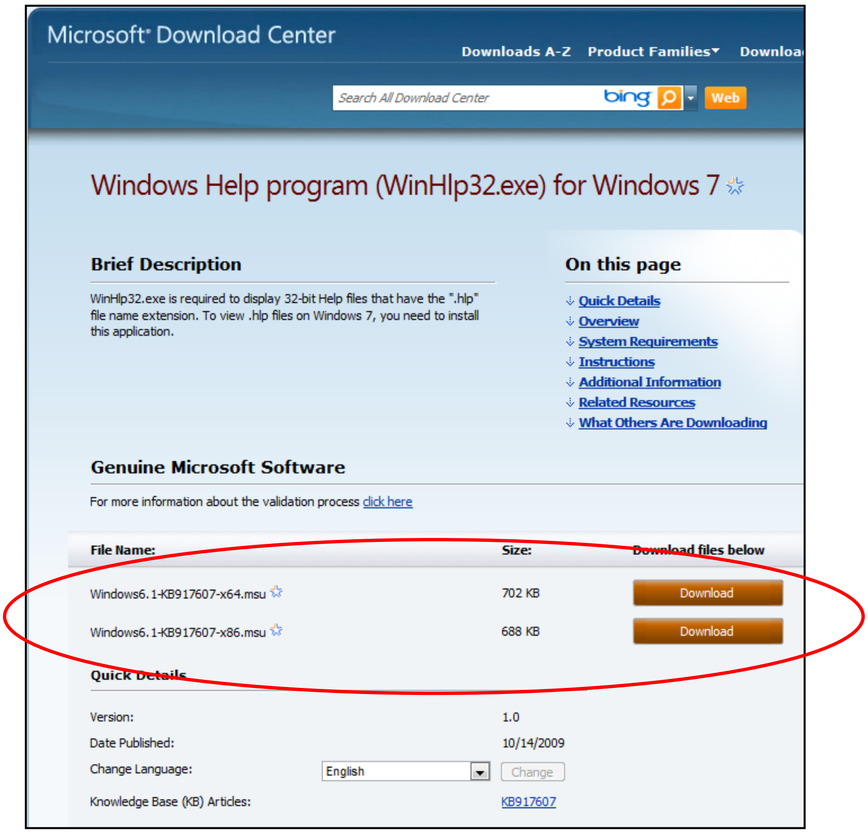


Figure 2.14: Downloading the Windows Help program

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.

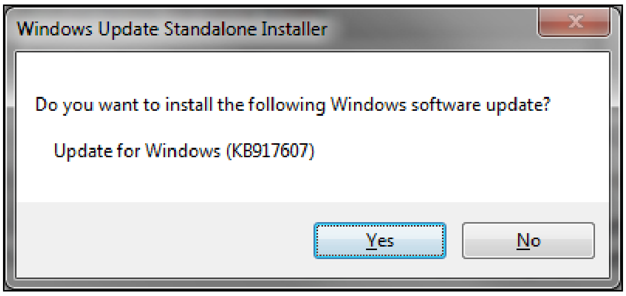


Figure 2.15: Windows Update Standalone Installer

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 2.16)

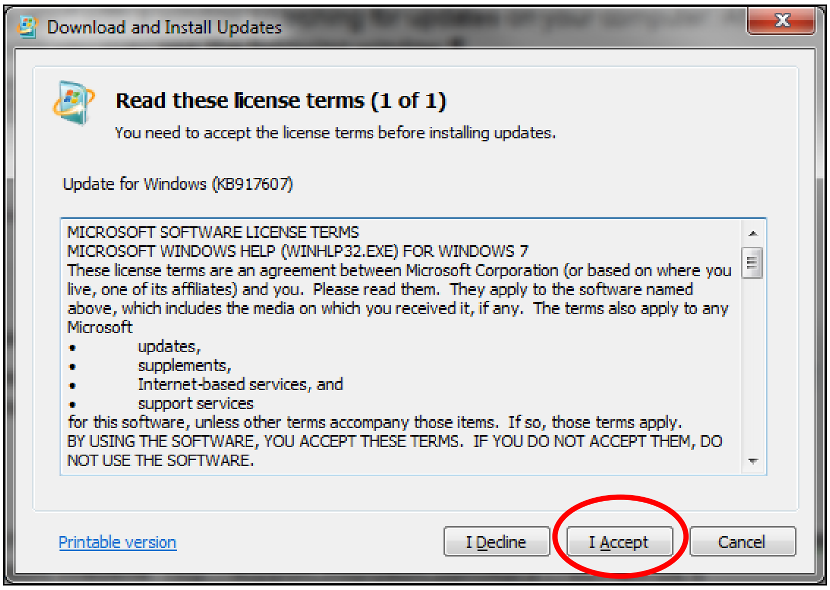


Figure 2.16: Windows License Terms

Installation starts once you have clicked the "I Accept" button (see Figure 2.17).

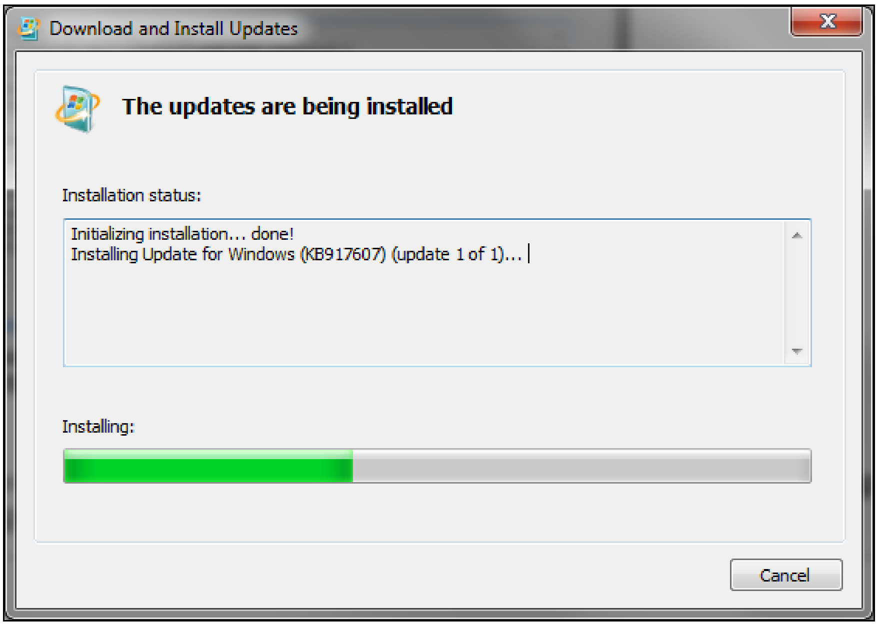


Figure 2.17: Installation process

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.

2.4 Licensing the LibHuAir Property Library

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

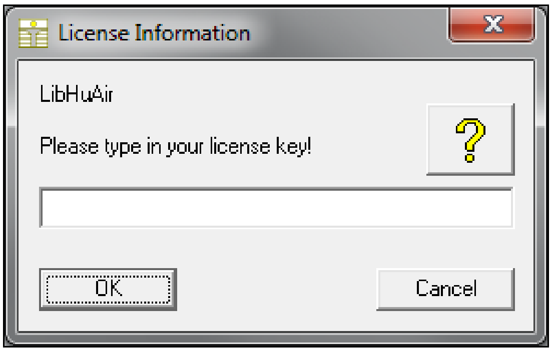


Figure 2.18: "License Information" window

Here you are asked to type in the license key which you have obtained from 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:

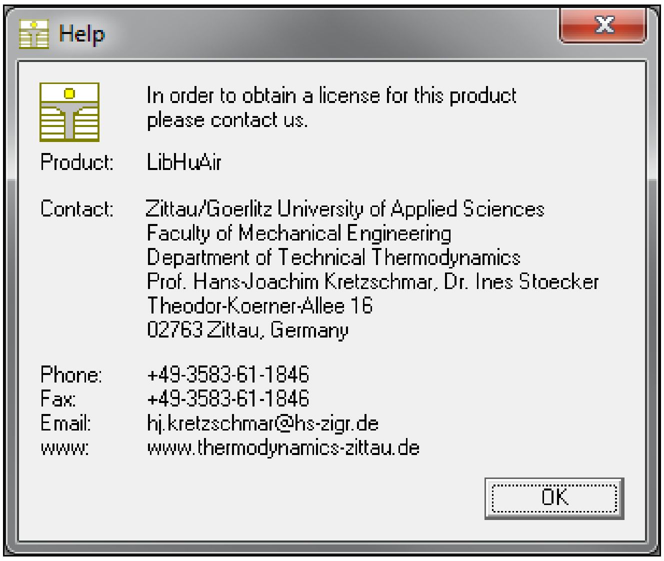


Figure 2.19: "Help" window

If you do not enter a valid license it is still possible to start Excel® 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 start Excel® unless you uninstall FluidEXL*Graphics* according to the description in section 2.3 of this User's Guide.
Should you not wish to license the LibHuAir property library, you have to delete the files

LibHuAir.dll	
LibHuAir.hlp	(for German version of Windows)
LibHuAir_Eng.hlp	(for English version of Windows)

in the installation folder of FluidEXL*Graphics* (the standard being

C:\Program Files\FluidEXL_Graphics_Eng	(for English version of Windows)
C:\Program Files\FluidEXL_Graphics	(for German version of Windows))

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

With this procedure the LibHuAir property library has been licensed.

2.5 Example: Calculation of $h_l = f(p,t,x_w)$

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, using FluidEXL*Graphics*. The following description relates to Excel 97. The procedure is analogous for Excel 2000 and XP.

Carry out the following steps:

- Start Excel®
- Enter the value for p in bar into a cell
  (Range of validity: p = 6.112 mbar ... 1000 bar)

  ⇒ e.g.: Enter the value 1.01325 into cell A1
- Enter the value for t in °C into cell
  (Range of validity: t = -143.15°C ... 1726.85°C)

  ⇒ e.g.: Enter the value 20 into cell B1
- Enter the value for x_W in g_{Water}/kg_{Air} (dry Air) into a cell
  (Range of validity: $x_W \geq 0$ g/kg_{Air})

  ⇒ e.g.: Enter the value 10 into cell C1
- Click the cell in which the air specific enthalpy h_l
  in kJ/kg_{Air} is to be displayed

  ⇒ e.g.: click on the cell D1
- Click "Calculate" in the menu bar of FluidEXL*Graphics*.
  The "Insert Function" window appears as shown in the next figure

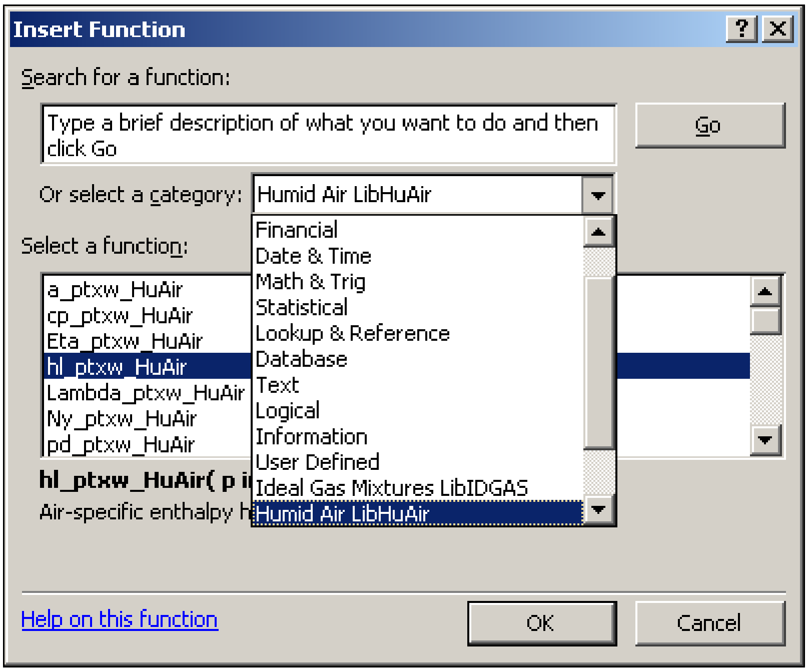


Figure 2.20: Choice of library and function name

- Search and click the "Humid Air LibHuAir" library next to "Or select a category:" in the upper part of the window.

- Search and click the "hl_ptxw_HuAir" function under "Select a function:" right below.

- Click the "OK" button
  The "Function Arguments" menu for the "hl_ptxw_HuAir" function, as shown in figure 2.21, appears.

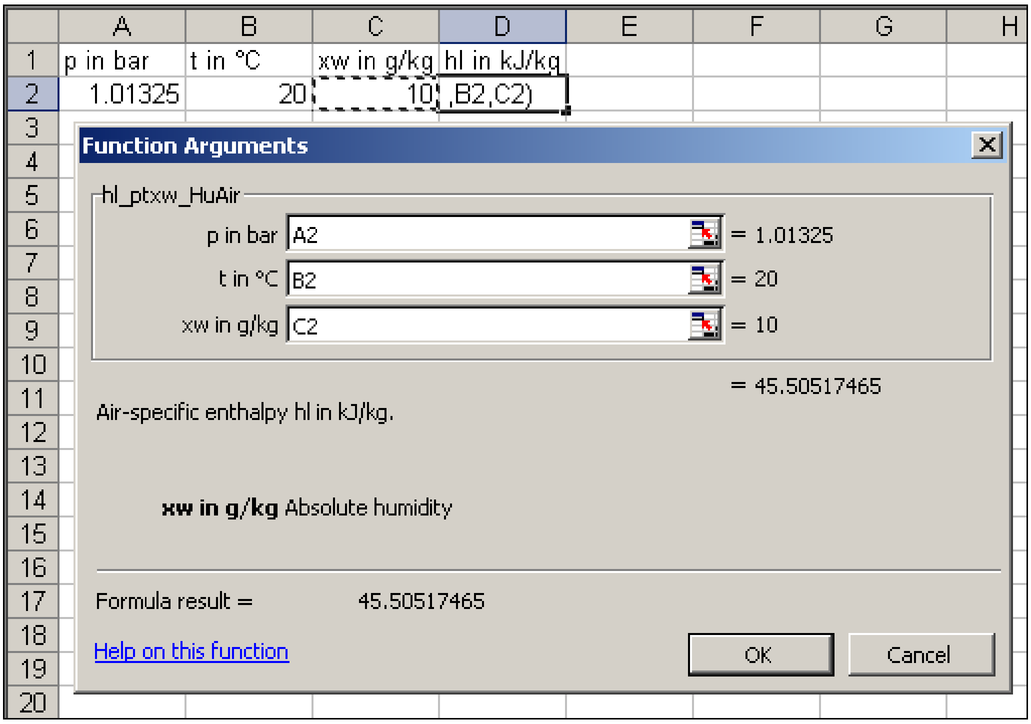


Figure 2.21: Input menu for the function

- The cursor is now situated on the line next to "p in bar". You can now enter the value for the mixture pressure *p* either by clicking the cell which contains the value for *p* or by typing the number of the cell or by entering the value for *p* directly into the window.

  ⇒ e. g.: Click the cell A1

- Situate the cursor on the line next to "t in °C". You can now enter the value for the temperature either by clicking the cell which contains the value for *t* or by typing the number of the cell or by entering the value for *t* directly into the window.

  ⇒ e. g.: Type B1 into the line next to "t in °C"

- Situate the cursor on the line next to "x_w in g/kg". You can now enter the value for the absolute humidity x_w either by clicking the cell which contains the value for x_w or by typing the number of the cell or by entering the value for x_w directly into the window.

  ⇒ e. g.: Click the cell C1

- Click the "Finish" button

The result for h_l in kJ/kg$_{Air}$ appears in the cell selected above.

⇒ The result in our sample calculation here is: h_l = 45.50517465.

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

You can now arbitrarily change the values for p, t or x_w in the appropriate cells. The enthalpy h_l is recalculated and updated every time you change the data. This shows that the Excel® data flow and the DLL calculations are working together successfully.

Hint:

If the input values entered are located outside the range of validity or if they do not fit together the result for the calculated function will always be -1 or -1000.

For further property functions calculable in FluidEXL*Graphics* see the function table in Chapter 1.

Number Formats

When using FluidEXL*Graphics* you have the option of choosing special number formats in advance.
Changes can be made as follows:

- Click the cell or select and click on the cells you wish to format.
  (In empty cells the new format will be applied once a value has been entered.)
- Click "Number Format" in the FluidEXL*Graphics* menu bar.
- Select the desired number format in the dialog box which appears:

"STD – Standard":	Insignificant zeros behind the decimal point are not shown.
"FIX – Fixed Number of Digits":	All set decimal places are shown, including insignificant zeros.
"SCI – Scientific Format":	Numbers are always shown in the exponential form with the set number of decimal places.

- Set the "Number of decimal places" by entering the number into the appropriate window.
- Confirm this by clicking the "OK" button.

As an example, the table below shows the three formats for the number 1.230 adjusted for three decimal places:

STD	1.23
FIX	1.230
SCI	1.230E+00

This formatting can also be applied to cells which have already been calculated.

2.6 Representation of Calculated Properties in Thermodynamic Diagrams

In the following section, the calculated state point is to be represented in thermodynamic diagrams with the help of FluidEXL*Graphics*. Calculations can be represented in the following diagrams:

- *h-x* Diagram p = 0.101325 MPa

- *h-x* Diagram p = 0.11 MPa

In order to represent the calculated values in a *h-x* diagram for p = 0.101325 MPa, for example, the absolute humidity and specific entropy values for the point to be represented must be marked.

- Click on the cell with the value for *h* (as *h* is the ordinate in the diagram)

  ⇒ e. g.: Click the cell D1

- Hold down the "Ctrl" key and simultaneously click the cell with the value for x_w (as x_w is the abscissa in the diagram)

  ⇒ e. g.: Hold down the "Ctrl" key and click the cell C1

  Note:

  The value pairs to be depicted (Y,X) here (h, x_w) must always be located in the same row or column.

- As displayed in the next figure, click "Diagrams" in the FluidEXL*Graphics* menu bar and choose "h-x Diagram 0.101325 MPa" in the drop-down menu

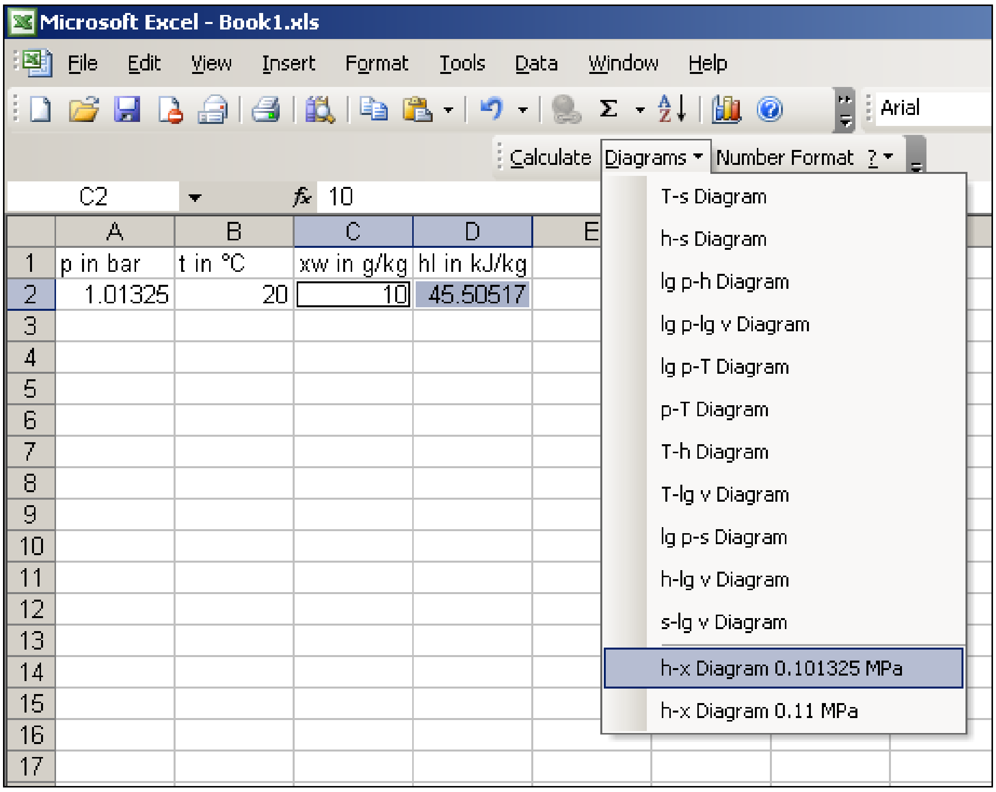


Figure 2.22: Marking the values and choosing the diagram

The *h-x* diagram shown in the figure below will appear. The calculated state point is marked as a red point.

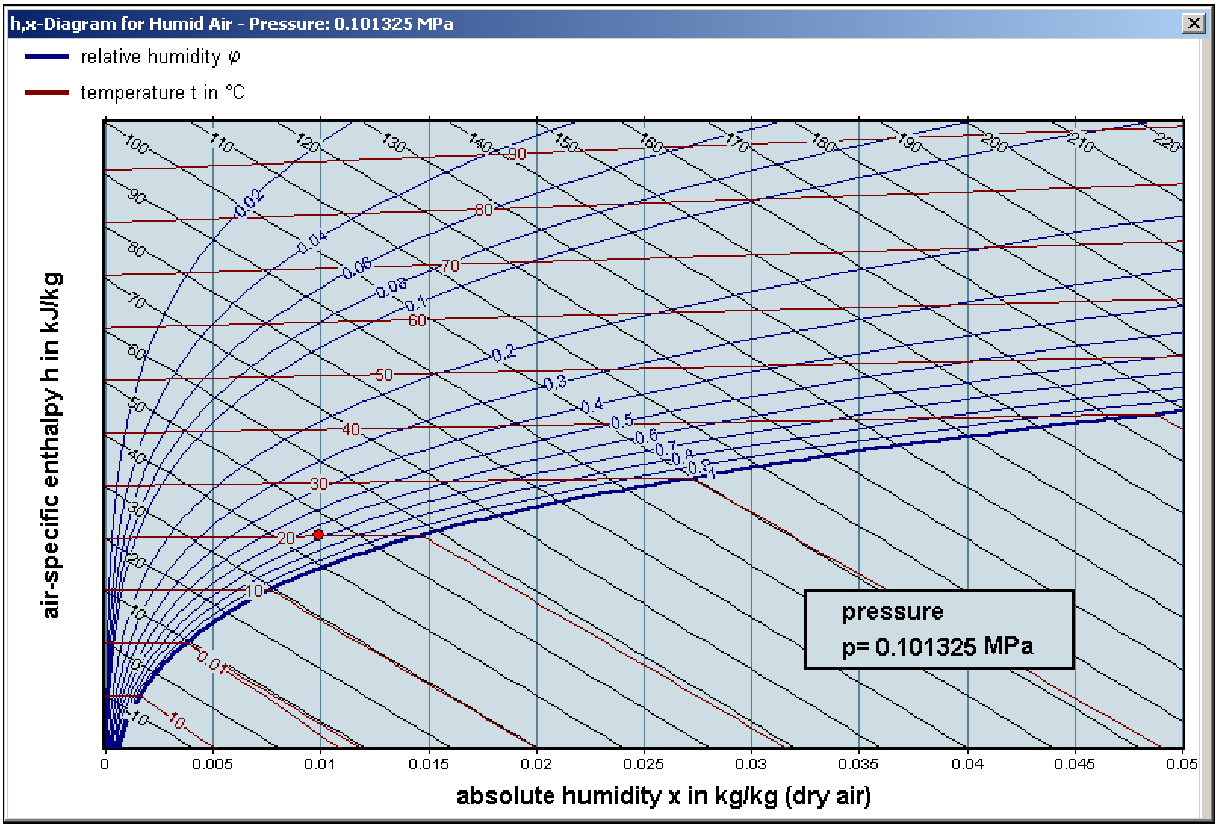


Figure 2.23: *h-x* Diagram including the state point

Note:

If the coloring is distorted you need to increase the amount of colors displayed on the screen by Windows® to more than 256 colors. The preferences can be set within Windows by going to "Control Panel" and then under "Screen".

To close the *h-x* diagram, click on the "x" in the upper-right hand corner of the *h-x* Diagram window.

Note - Diagrams with various state points:

If you calculate various state points, they can be represented in one selected diagram. To do this, first mark with the cursor those values which are to represent the values of y in the diagram. Afterwards, hold down the "Ctrl" key and mark the corresponding values which are to represent the values of x in the diagram. Note once more that all value pairs which should be represented (Y,X) must be located in one row in Excel®. Proceed as described above.

Note - Diagrams without any state points:

If you wish to have a look at a diagram without performing a calculation, mark two empty cells located in one row and select a diagram.

Printing the Diagrams

The state diagrams can be printed with the help of Word®, which also belongs to the Office suite®.

- When the selected diagram is on the screen, hold down the "Alt" key and press the "Print" key briefly.
  (This keyboard shortcut copies the current window, e.g., the diagram, into the Windows clipboard where it is ready to be pasted into other Windows® application programs.)
- Start Word by clicking "Start" in the Windows task bar, then "Programs", and then "Microsoft Word".
- As the diagram is to be printed in landscape format, change the (now loaded) Word application window into the landscape format.
  In order to do so, click "File" in the upper menu bar of Word, and then "Page Setup". Click "Margins" in the window which now appears, then "Landscape". Confirm this change by clicking "OK".
- In order to paste the diagram out of the Windows clipboard, click "Edit" in the upper menu bar of Word, and then "Paste".
  The diagram out of FluidEXL*Graphics* appears in the Word application window and is ready to save and/or print.
- Start the printing process by clicking "File" in the upper menu bar of Word, and then "Print". Proceed as usual in the "Print" window which appears.

The diagram will be printed in the A4 landscape format, if you do not change the preferences.
In order to continue working in Excel, click "Microsoft Excel - …" in the Windows task bar.

Proceed in the same way to print further diagrams.

2.6 Removing FluidEXL*Graphics*

Should you wish to remove only the LibHuAir library, delete the files

LibHuAir.dll
LibHuAir_Eng.hlp (for English version of Windows)
LibHuAir.hlp (for German version of Windows)

in the directory selected for the installation of FluidEXL*Graphics* (in the standard case

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
C:\Programme\FluidEXL_Graphics (for German version of Windows),

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

Unregistering FluidEXL*Graphics* as Add-In in Excel®, versions 2003 or earlier

To remove FluidEXL*Graphics* completely, proceed as follows: First, the registration of

FluidEXL_Graphics_Eng.xla (for English version of Windows®) or
FluidEXL_Graphics.xla (for German version of Windows)

has to be canceled in Excel.

In order to do that, click "Tools" in the upper menu bar of Excel and here "Add-Ins…". Untick the box on the left-hand side of

"FluidEXL Graphics Eng" (for English version of Windows) or
"FluidEXL Graphics" (for German version of Windows)

in the window that appears and click the "OK" button. The additional menu bar of FluidEXL*Graphics* disappears from the upper part of the Excel window. Afterwards, we recommend closing Excel.

Click "View" in the upper menu bar of Excel, then "Toolbars" and then "Customize…" in the list box which appears.

"FluidEXL Graphics Eng" (for English version of Windows) or
"FluidEXL Graphics" (for German version of Windows)

is situated at the bottom of the "Toolbars" entries, which must be selected by clicking on it. Delete the entry by clicking "Delete". You will be asked whether you really want to delete the toolbar – click "OK". Afterwards, we recommend closing Excel.

Within the next step delete the files

LibHuGas.dll
LibHuGas_Eng.hlp (for English version of Windows®)
LibHuGas.hlp (for German version of Windows)

in the directory selected for the installation of FluidEXL*Graphics* (in the standard case

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
C:\Programme\FluidEXL_Graphics (for German version of Windows)),

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

In order to remove FluidEXL*Graphics* from Windows and the hard disk drive, 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/Remove Programs" window that appears select

"FluidEXL Graphics Eng" (for English version of Windows) or

"FluidEXL Graphics" (for German version of Windows)

by clicking on it and click the "Add/Remove…" button. In the following dialog box click "Automatic" and thereafter "Next >". Click "Finish" in the "Perform Uninstall" window. Answer the question whether all shared components shall be removed with "Yes to All". Finally, close the "Add/Remove Programs" and "Control Panel" windows.

Now FluidEXL*Graphics* has been removed.

Unregistering FluidEXL*Graphics* as Add-In in Excel® 2007 (or later versions)

In order to unregister the FluidEXL*Graphics* Add-In in Excel® 2007 start Excel and carry out the following commands:

- Click the Windows Office® button in the upper left corner of Excel
- Click on the "Excel Options" button in the menu which appears

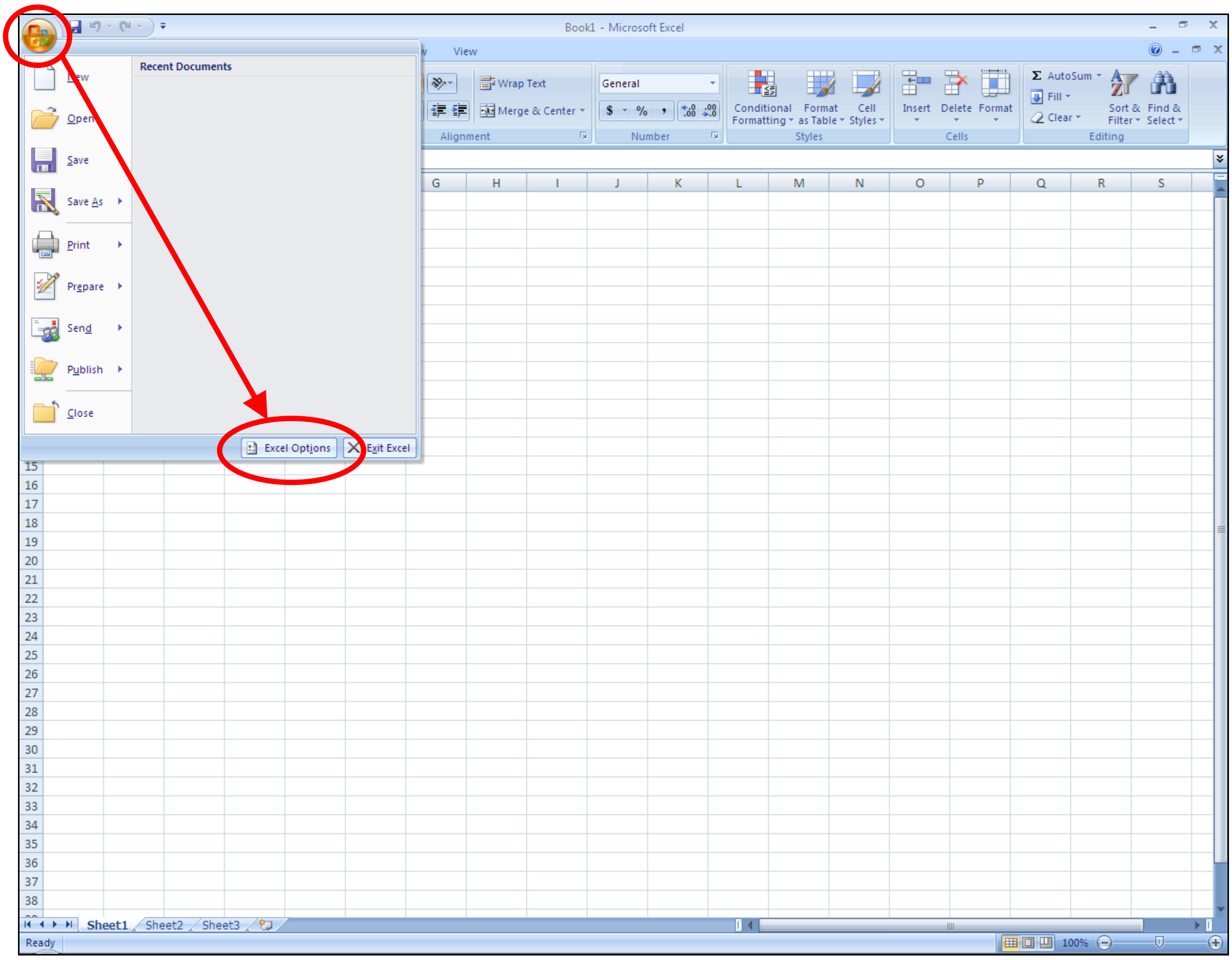


Figure 2.24: Unregistering FluidEXL*Graphics* as Add-In in Excel® 2007

- Click on "Add-Ins" in the next menu

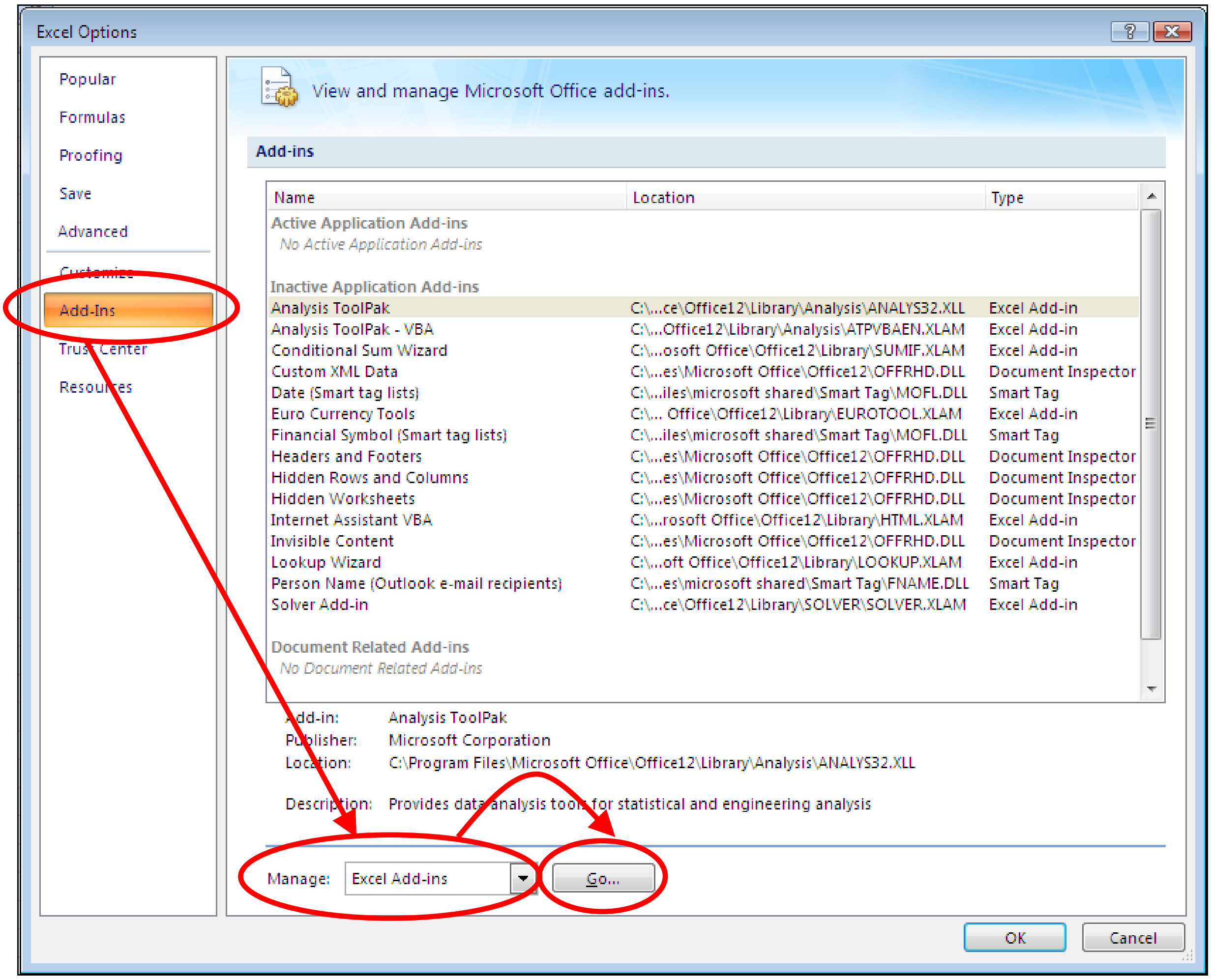


Figure 2.25: Dialog window "Add-Ins"

- If it is not shown in the list automatically, choose and click "Excel Add-ins" next to "Manage:" in the lower area of the menu
- Afterwards click the "Go…" button
- Remove the checkmark in front of

  "FluidEXL Graphics Eng" (for English version of Windows)
  "FluidEXL Graphics" (for German version of Windows)

in the window which now appears. Click the "OK" button to confirm your entry.

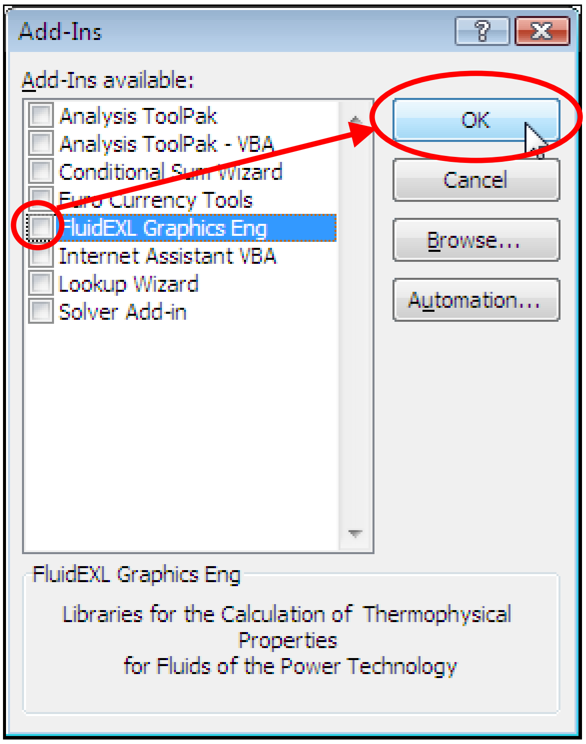


Figure 2.26: Dialog window "Add-Ins"

In order to remove FluidEXL*Graphics* from Windows and the hard drive, 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

"FluidEXL Graphics Eng"	(for English version of Windows)
"FluidEXL Graphics"	(for German version of Windows)

by clicking on it and then clicking the "Add/Remove…" button.

Click "Automatic" in the following dialog box and then the "Next >" button.

Click "Finish" in the "Perform Uninstall" window.

Answer the question of whether all shared components should be removed with "Yes to All." Finally, close the "Add or Remove Programs" and "Control Panel" windows.

Now FluidEXL*Graphics* has been completely removed from your computer.

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 $\nu = \dfrac{\eta}{\rho} = \eta \cdot v$
- 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 $\xi_l = 1 - \frac{x_w}{1 + x_w}$

Result for wrong input values:

Xil_xw_HuAir , Xil = - 1

Mass Fraction of Water $\xi_W = f(x_w)$

Function Name:

Xiw_xw_HuAir

Fortran Programs:

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

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

Input values:

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

Result:

Xiw_xw_HuAir, Xiw - Mass fraction of water

Range of Validity:

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

Comments:

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

Result for wrong input values:

Xiw_xw_HuAir, Xiw = - 1

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

Function Name:

xw_ptPhi_HuAir

Fortran Programs:

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

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

Input values:

p - Mixture pressure p in bar

t - Temperature t in °C

Phi - Relative humidity in %

Result:

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

Range of Validity:

Temperature t : from -143.15°C to $t_{critical}$ = 373,946°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 $\geq$ 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 $t \leq$ 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 $t \geq 0.01$°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 ≥ 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 $t \geq 0.01°C$ 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

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:

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

- 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_2O	F_2	Propane
N_2	SO_2	NH_3	Iso-Butane
O_2	H_2	Methane	n-Butane
CO	H_2S	Ethane	Benzene
CO_2	OH	Ethylene	Methanol
Air			

Consideration of:

- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

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 Bücker et al. (2003)

n-Butane

Library LibButane_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 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_5H_{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 monooxide N_2O **Library LibN2O**

Sulfur dioxide SO_2 **Library LibSO2**

Acetone C_3H_6O **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

For more information please contact:

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives can be calculated.

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

www.thermodynamic-property-libraries.com

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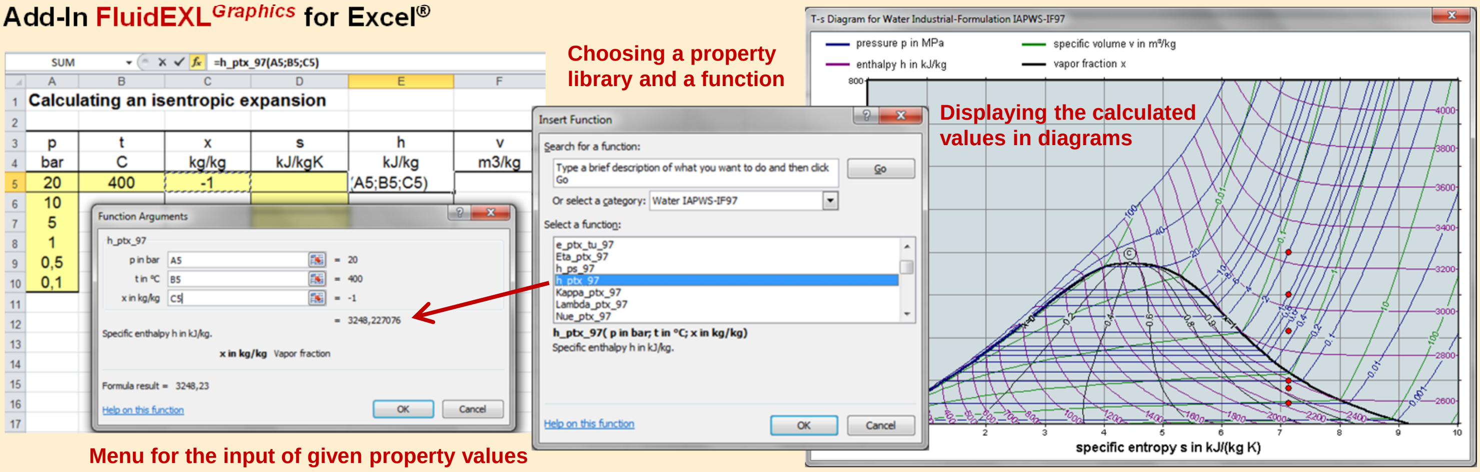
www.thermodynamics-zittau.de

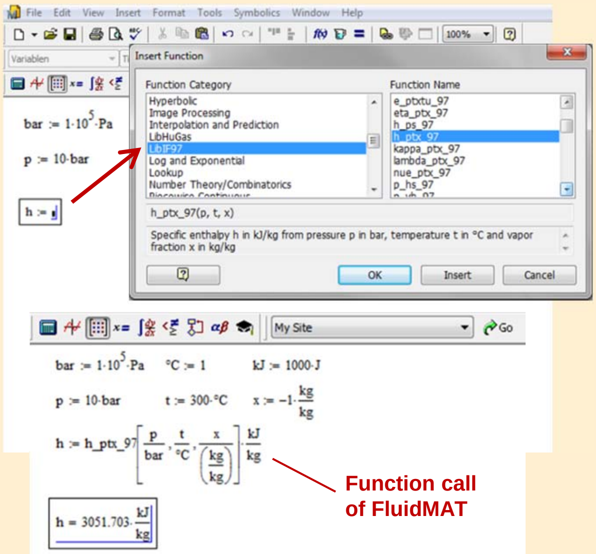
Property Software for Calculating Heat Cycles, Boilers, Turbines, and Refrigerators

Add-In FluidEXL *Graphics* for Excel®



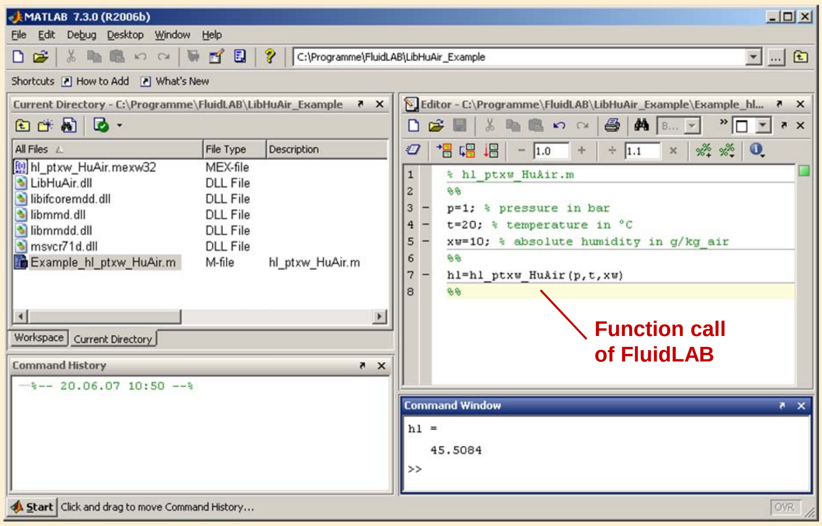
Add-In FluidMAT for Mathcad®

The property libraries can be used in Mathcad®.



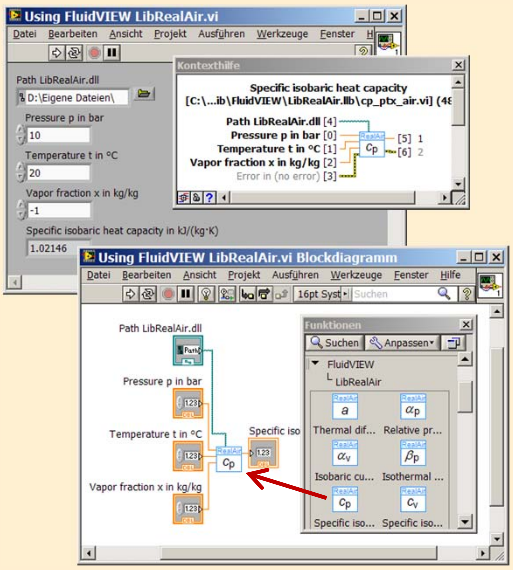
Add-In FluidLAB for MATLAB®

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



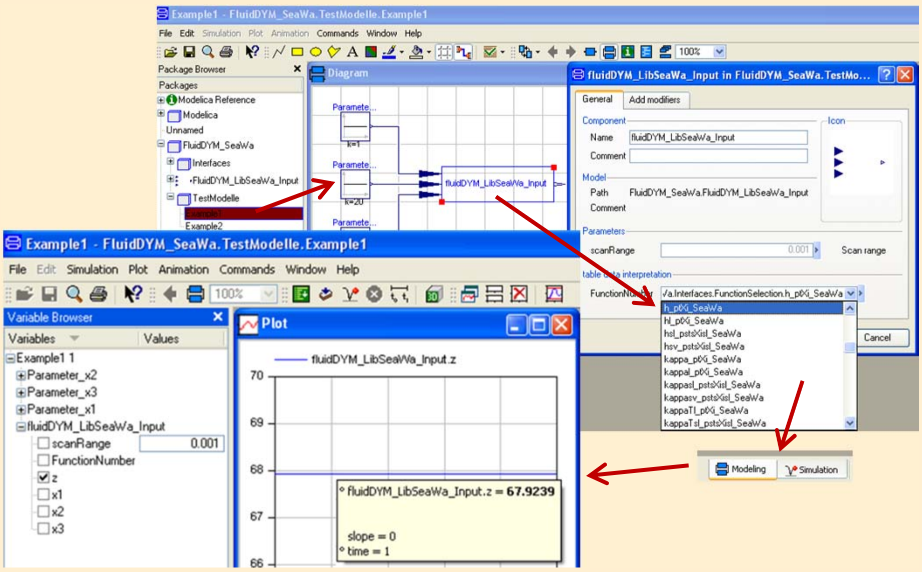
Add-On FluidVIEW for LabVIEW®

The property functions can be calculated in LabVIEW®.

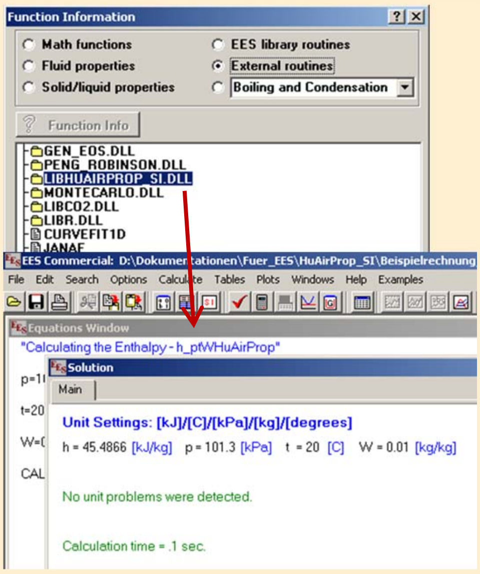


Add-In FluidDYM for DYMOLA® (Modelica) and SimulationX®

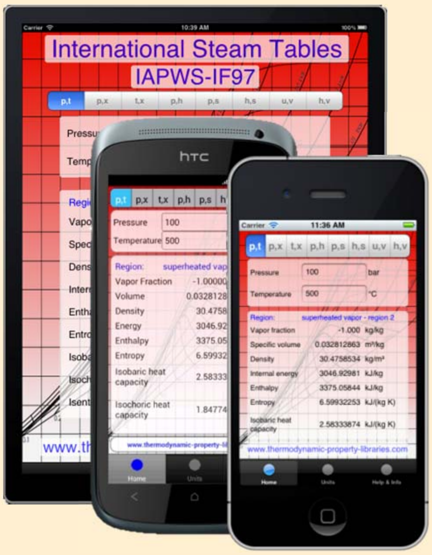
The property functions can be called in DYMOLA® and SimulationX®



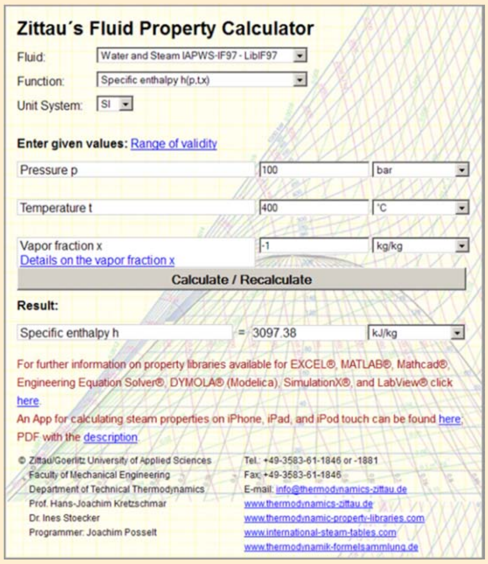
Add-In FluidEES for Engineering Equation Solver®



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



Online Property Calculator at www.thermodynamics-zittau.de



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

For more information please contact:

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives can be calculated.

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

www.thermodynamic-property-libraries.com

5. References

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6. Satisfied Customers

Date: 10/2011

The following companies and institutions use the property libraries

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

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SPG TECH, Montreuil Cedex, France	09/2011
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2010

Umweltinstitut Neumarkt	12/2010
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2006

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eta Energieberatung, Pfaffenhofen	02/2005
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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
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SorTech, Halle	11/2004
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STORA ENSO Sachsen, Eilenburg	12/2004
Technical University of Cottbus, Chair in Power Plant Engineering	12/2004
Freudenberg Service, Weinheim	12/2004

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Rietschle Energieplaner, Winterthur, Switzerland	02/2003
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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
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Erfurt University of Applied Sciences, Department of Supply Engineering	12/2003
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2002

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