



Hochschule
Zittau/Görlitz
UNIVERSITY OF APPLIED SCIENCES

Faculty of
MECHANICAL ENGINEERING
Department of
TECHNICAL THERMODYNAMICS

Property Library for Standard Dry Air

FluidEXL *Graphics*
with LibRealAir
for Excel[®]

Prof. Hans-Joachim Kretzschmar
Dr. Ines Stoecker
Ines Jaehne
Matthias Kunick
Georg Doleisch von Dolsperg

Property Library for Standard Dry Air Including DLL and Add-In for Excel®

FluidEXL *Graphics* LibRealAir

Contents

- 0. Package Contents
- 1. Property Functions
 - 1.1 Range of Validity
 - 1.2 Functions
 - 1.3 Thermodynamic Diagrams
- 2. Application of FluidEXL *Graphics* in Excel®
 - 2.1 Installing FluidEXL *Graphics*
 - 2.2 Registering FluidEXL *Graphics* as Add-In in Excel®
 - 2.3 The FluidEXL *Graphics* Help System
 - 2.4 Licensing the LibRealAir Property Library
 - 2.5 Example: Calculation of $h = f(p, t, x)$ and $s = f(p, t, x)$
 - 2.6 Removing FluidEXL *Graphics*
- 3. Program Documentation
- 4. Property Libraries for Calculating Heat Cycles, Boilers, Turbines, and Refrigerators
- 5. References
- 6. Satisfied Customers

© Zittau/Goerlitz University of Applied Sciences, Germany
Faculty of Mechanical Engineering
Department of Technical Thermodynamics
Prof. Hans-Joachim Kretzschmar
Dr. Ines Stoecker
Phone: +49-3583-61-1846 or -1881
Fax: +49-3583-61-1846
E-mail: hj.kretzschmar@hs-zigr.de
Internet: www.thermodynamics-zittau.de

0. Package Contents

0.1 Zip files for 32-bit Windows®

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

English zip file "CD_FluidEXL_Graphics_LibRealAir_Eng.zip" including the following files:

FluidEXL_Graphics_Eng_Setup.exe	- English installation program for the Add-In FluidEXL <i>Graphics</i> for use in Excel®
FluidEXL_Graphics_Eng.xla	- English Add-In for FluidEXL <i>Graphics</i>
LibRealAir.dll	- Dynamic Link Library for use in Windows programs
LibRealAir.hlp	- Help file for the LibRealAir property library
FluidEXL_Graphics_LibRealAir_Docu_Eng.pdf	- User's Guide

German zip file "CD_FluidEXL_Graphics_LibRealAir.zip" including the following files:

FluidEXL_Graphics_Setup.exe	- German installation program for the Add-In FluidEXL <i>Graphics</i> for application in Excel®.
FluidEXL_Graphics.xla	- German Add-In for FluidEXL <i>Graphics</i>
LibRealAir.dll	- Dynamic Link Library for use in Windows® programs
LibRealAir.hlp	- Help file for the LibRealAir property library
FluidEXL_Graphics_LibRealAir_Docu_Eng.pdf	- User's Guide

0.2 Zip files for 64-bit Windows®

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

English zip file "CD_FluidEXL_Graphics_LibRealAir_x64_Eng.zip" including the following files and folders:

Files:

FluidEXL_Graphics_LibRealAir_Docu_Eng.pdf	- User's Guide
FluidEXL_Graphics_Eng.xla	- English FluidEXL <i>Graphics</i> Add-In
FluidEXL_Graphics_Eng_64_Setup.msi	- Self-extracting and self-installing program
LibRealAir.dll	- Dynamic link library for use in Windows® programs

LibRealAir.hlp	- Help file for the LibRealAir property library
Setup.exe	- Self-extracting and self-installing program for FluidEXL <i>Graphics</i>

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_LibRealAir_x64.zip" including the following files and folders:

Files:

FluidEXL_Graphics_LibRealAir_Docu_Eng.pdf	- User's Guide
FluidEXL_Graphics.xla	- German FluidEXL <i>Graphics</i> Add-In
FluidEXL_Graphics_64_Setup.msi	- Self-extracting and self-installing program
LibRealAir.dll	- Dynamic link library for use in Windows® programs
LibRealAir.hlp	- Help file for the LibRealAir property library
Setup.exe	- Self-extracting and self-installing program for FluidEXL <i>Graphics</i>

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 Range of Validity

The LibRealAir property library uses the thermodynamic property formulation for standard dry air released by *LEMMON* et al. [1], [2]. Whereas the atmospheric air is a mixture of fluids including nitrogen, oxygen, argon, carbon dioxide, steam, and other trace elements. The standard air this formulation is based on is dry and contains no carbon dioxide or trace elements. Due to the fact that the caused change is less than the experimental error in the measurements, this assumption has been made [1]. The composition is given in Table 1.1.

Table 1.1: Composition of air with N₂, O₂ and Ar as constituents

Component name	Chemical symbol	Mole fraction
Nitrogen	N ₂	0.7812
Oxygen	O ₂	0.2096
Argon	Ar	0.0092

The LibRealAir property library is valid for liquid, steam and supercritical air. This includes temperatures from 59.75 K (-213.4 °C) at the solidification point on the saturated liquid line to 2000 K (1726.85 °C) and pressures from 0.00001 bar to 20000 bar. The range of validity of the LibRealAir property library is shown in Figure 1.1 and Figure 1.3. Values for the points marked on these Figures are listed in Table 1.2 and Table 1.3.

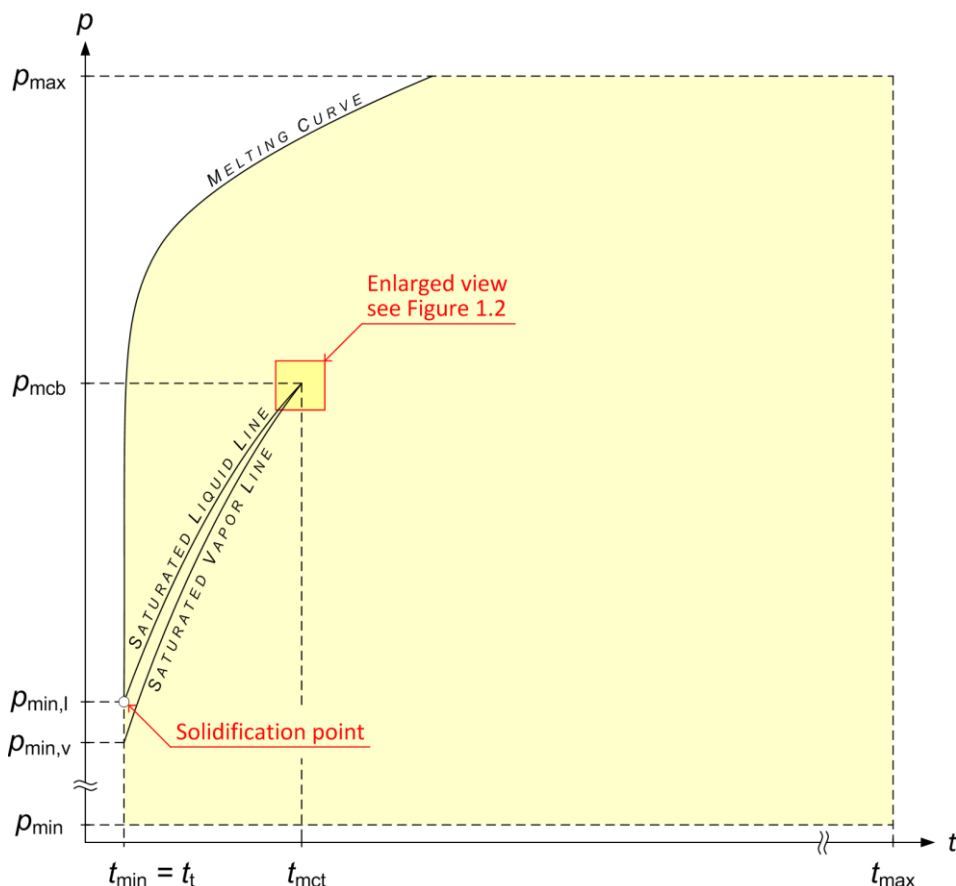


Figure 1.1: Entire range of validity in an $\lg p$, $\lg t$ – diagram
(see Figure 1.2 for an enlarged view of the critical region phase boundaries)

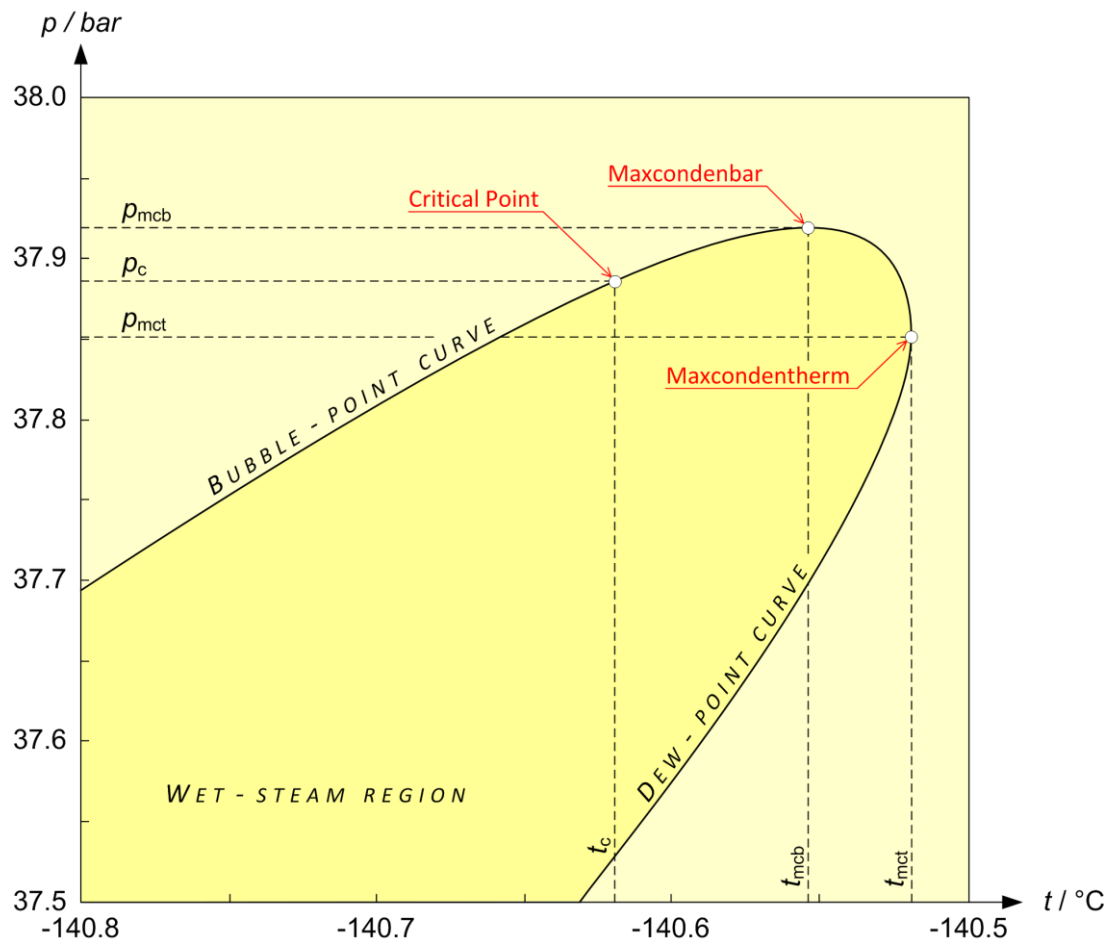


Figure 1.2: Enlarged view of the critical region phase boundaries in an p, t -diagram

Owing to the different boiling point temperatures of the mixture components in the p, T -diagram the saturation lines (liquid and vapor) of air do not overlap. In addition to the critical point a state point of maximum temperature (maxcondentherm) and a state point of maximum pressure (maxcondenbar) were determined on the saturation line. The maxcondentherm, maxcondenbar and critical point properties of air are shown in Table 1.3.

Table 1.2: Range of validity

Pressure	Abbreviations	Values in bar
Minimum pressure	$p_{\min}$	$1 \cdot 10^{-5}$
Minimum pressure on the dew-point curve	$p_{\min, l}$	0.024316
Minimum pressure on the bubble-point curve	$p_{\min, v}$	0.052646
Maximum pressure	$p_{\max}$	20000
Temperature	Abbreviations	Values in °C
Minimum temperature eq. triple point temperature	$t_{\min} = t_t$	-213.4
Maximum temperature	$t_{\max}$	1726.85
Specific Volume	Abbreviations	Values in m ³ /kg
Minimum specific volume	$v_{\min}$	0.00071991
Minimum specific volume on the bubble point curve	$v_{\min, l}$	0.00104112
Maximum specific volume on the dew-point curve	$v_{\max, v}$	7.037519
Maximum specific volume	$v_{\max}$	574234.252

Table 1.3: Maxcondentherm, maxcondenbar and critical point of air
(calculated with the formulation by LEMMON et al.)

Condition	Pressure in bar	Temperature in °C	Spec. volume in m ³ /kg
Maxcondentherm (mct)	37.8502	-140.5188	0.003323
Maxcondenbar (mcb)	37.9195	-140.5539	0.003018
Critical point (c)	37.8869	-140.6194	0.002853

Figure 1.3 shows the entire range of validity for the equation in an p, v -diagram. An enlarged view of the critical region phase boundaries in an p, v -diagram is shown in Figure 1.4.

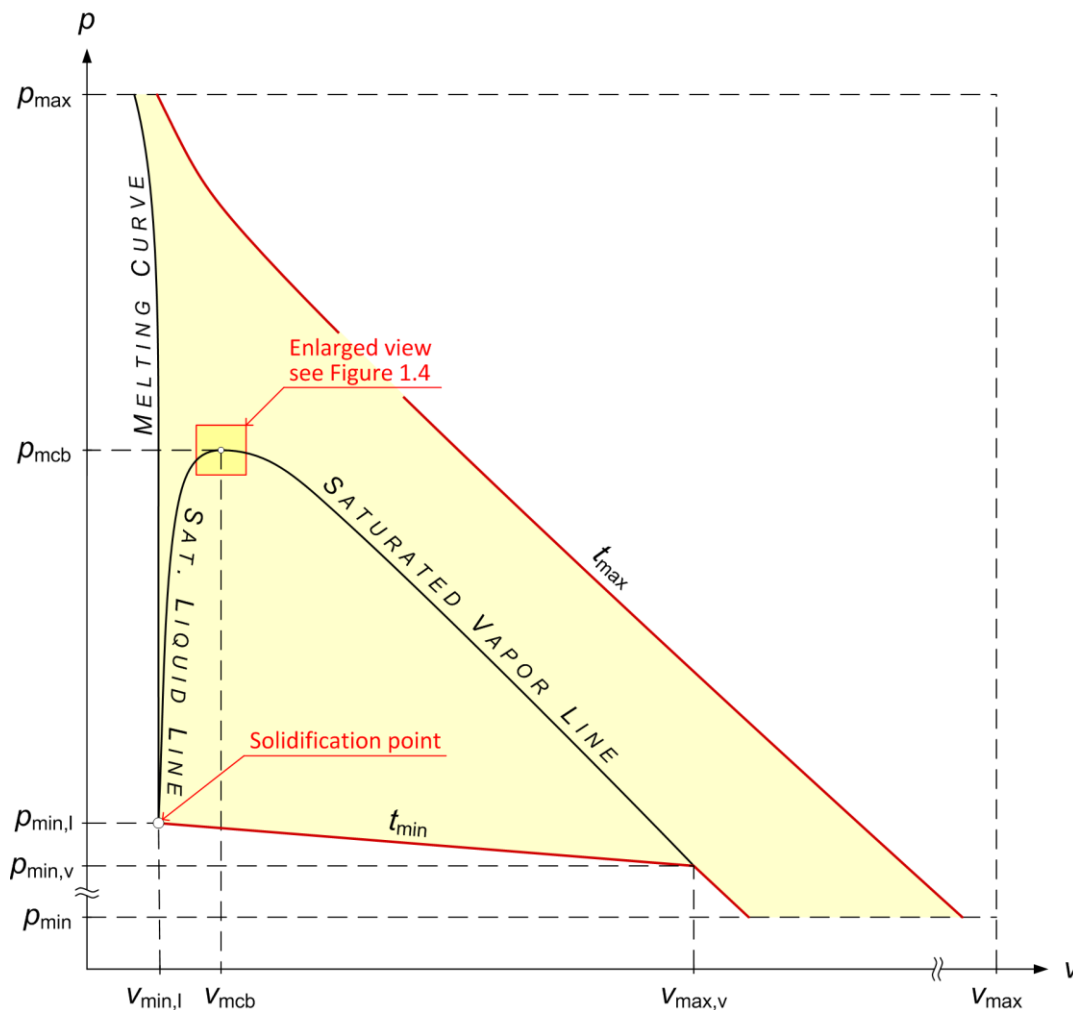


Figure 1.3: Entire range of validity in an $\lg p, \lg v$ - diagram

All sub-programs and functions can be applied in the entire range of validity of the LibRealAir. The call of the equation of state for each calculation region will be carried out within the program. The sub-programs of the LibRealAir DLL and the functions of the Add-In are listed in the following section.

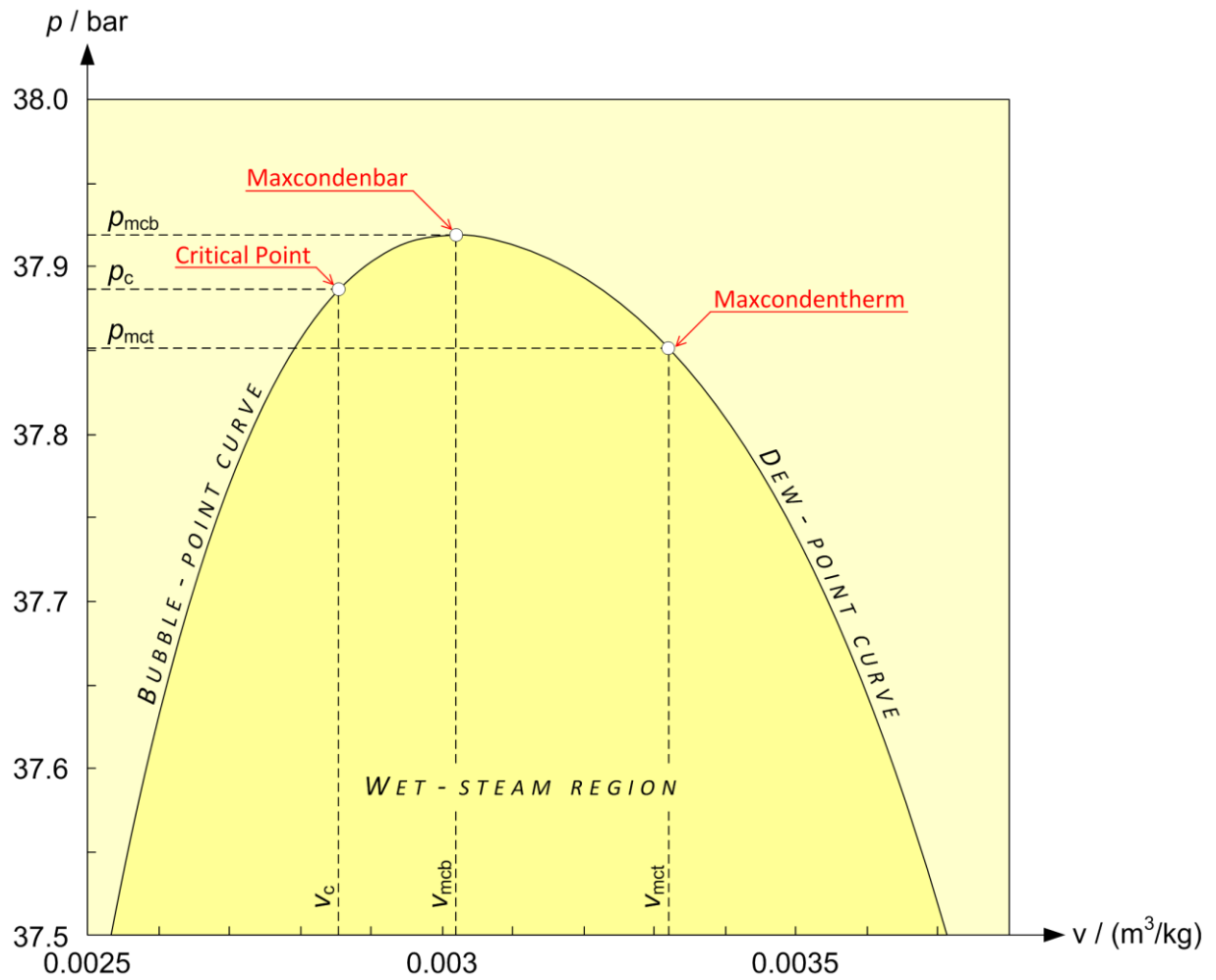


Figure 1.4: Enlarged view of the critical region phase boundaries in an p, v -diagram

1.2 Functions

Functional dependence	Function Name	Call from DLL LibRealAir, Result as Parameter	Property or Function	Unit of the Result
$a = f(p, t, x)$	a_ptx_air	= APTXAIR(P,T,X)	Thermal diffusivity	m ² /s
$\alpha_p = f(p, t, x)$	alphap_ptx_air	= ALPHAPPTXAIR(P,T,X)	Relative pressure coefficient	1/K
$\alpha_v = f(p, t, x)$	alphav_ptx_air	= ALPHAVPTXAIR(P,T,X)	Isobaric cubic expansion coefficient	1/K
$\beta_p = f(p, t, x)$	betap_ptx_air	= BETAPPTXAIR(P,T,X)	Isothermal stress coefficient	kg/m ³
$c_p = f(p, t, x)$	cp_ptx_air	= CPPTXAIR(P,T,X)	Specific isobaric heat capacity	kJ/(kg·K)
$c_v = f(p, t, x)$	cv_ptx_air	= CVPTXAIR(P,T,X)	Specific isochoric heat capacity	kJ/(kg·K)
$\eta = f(p, t, x)$	eta_ptx_air	= ETAPTXAIR(P,T,X)	Dynamic viscosity	Pa·s
$h = f(p, t, x)$	h_ptx_air	= HPTXAIR(P,T,X)	Specific enthalpy	kJ/kg
$\kappa = f(p, t, x)$	kappa_ptx_air	= KAPPAPTXAIR(P,T,X)	Isentropic exponent	-
$\kappa_T = f(p, t, x)$	kappat_ptx_air	= KAPPATPTXAIR(P,T,X)	Isothermal compressibility	1/kPa
$\lambda = f(p, t, x)$	lambda_ptx_air	= LAMBDAPTXAIR(P,T,X)	Thermal conductivity	W/(m·K)
$\nu = f(p, t, x)$	nu_ptx_air	= NUPTXAIR(P,T,X)	Kinematic viscosity	m ² /s
$p_{\text{mel}} = f(t)$	pmel_t_air	= PMELTAIR(T)	Pressure on the melting curve	bar
$Pr = f(p, t, x)$	prandtl_ptx_air	= PRANDTLPTXAIR(P,T,X)	Prandtl number	-
$p_{\text{sl}} = f(t)$	psl_t_air	= PSLTAIR(T)	Pressure on the saturated liquid line	bar
$p_{\text{sv}} = f(t)$	psv_t_air	= PSVTAIR(T)	Pressure on the saturated vapor line	bar
$\rho = f(p, t, x)$	rho_ptx_air	= RHOPTXAIR(P,T,X)	Density	kg/m ³
$s = f(p, t, x)$	s_ptx_air	= SPTXAIR(P,T,X)	Specific entropy	kJ/(kg·K)
$t_{\text{mel}} = f(p)$	tmel_p_air	= TMELPAIR(P)	Temperature on the melting curve	°C
$t = f(p, h)$	t_ph_air	= TPHAIR(P,H)	Backward function: Temperature from pressure and enthalpy	°C
$t = f(p, s)$	t_ps_air	= TPSAIR(P,S)	Backward function: Temperature from pressure and entropy	°C
$t_{\text{sl}} = f(p)$	tsl_p_air	= TSLPAIR(P)	Temperature on the saturated liquid line	°C
$t_{\text{sv}} = f(p)$	tsv_p_air	= TSVPAIR(P)	Temperature on the saturated vapor line	°C
$u = f(p, t, x)$	u_ptx_air	= UPTXAIR(P,T,X)	Specific internal energy	kJ/kg
$v = f(p, t, x)$	v_ptx_air	= VPTXAIR(P,T,X)	Specific volume	m ³ /kg
$w = f(p, t, x)$	w_ptx_air	= WPTXAIR(P,T,X)	Speed of sound	m/s
$x = f(p, h)$	x_ph_air	= XPHAIR(P,H)	Backward function: Vapor fraction from pressure and enthalpy	kg/kg
$x = f(p, s)$	x_ps_air	= XPSAIR(P,S)	Backward function: Vapor fraction from pressure and entropy	kg/kg

Units:

Temperature	t in °C
Pressure	p in bar
Vapor fraction	x in kg saturated steam/kg wet steam

Range of validity of LibRealAir:

Temperature: from -213.4 °C (59.75 K) to 1726.85 °C (2000 K)
 Pressure: from 0.00001 bar to 20000 bar

Details on the vapor fraction x and on the calculation of wet steam:

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

Single phase region

If the state point to be calculated is located in the single-phase region (liquid or superheated steam) $x = -1$ must be entered as a pro-forma value.

Wet steam region

When calculating wet steam, a value between 0 and 1 ($x = 0$ for saturated liquid, $x = 1$ for saturated steam) must be entered. It is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. When p and t and x are entered as given values, the program will consider whether p and t fit together. If it is not the case the calculation for the property of the chosen function to be calculated results in -1000 . In this case, the backward functions result in the appropriate value between 0 and 1 for x .

Boundaries for wet steam region

The boundaries for the wet steam region are

$$t_t = -213.4 \text{ °C}; \quad p_{\min,l} = 0.052646 \text{ bar}; \quad p_{\min,v} = 0.024316 \text{ bar}$$

$$t_{mct} = -140.5188 \text{ °C}; \quad p_{mcb} = 37.9195 \text{ bar}.$$

They are illustrated in Figure 1.1 and Figure 1.2 and listed in Table 1.2 and Table 1.3.

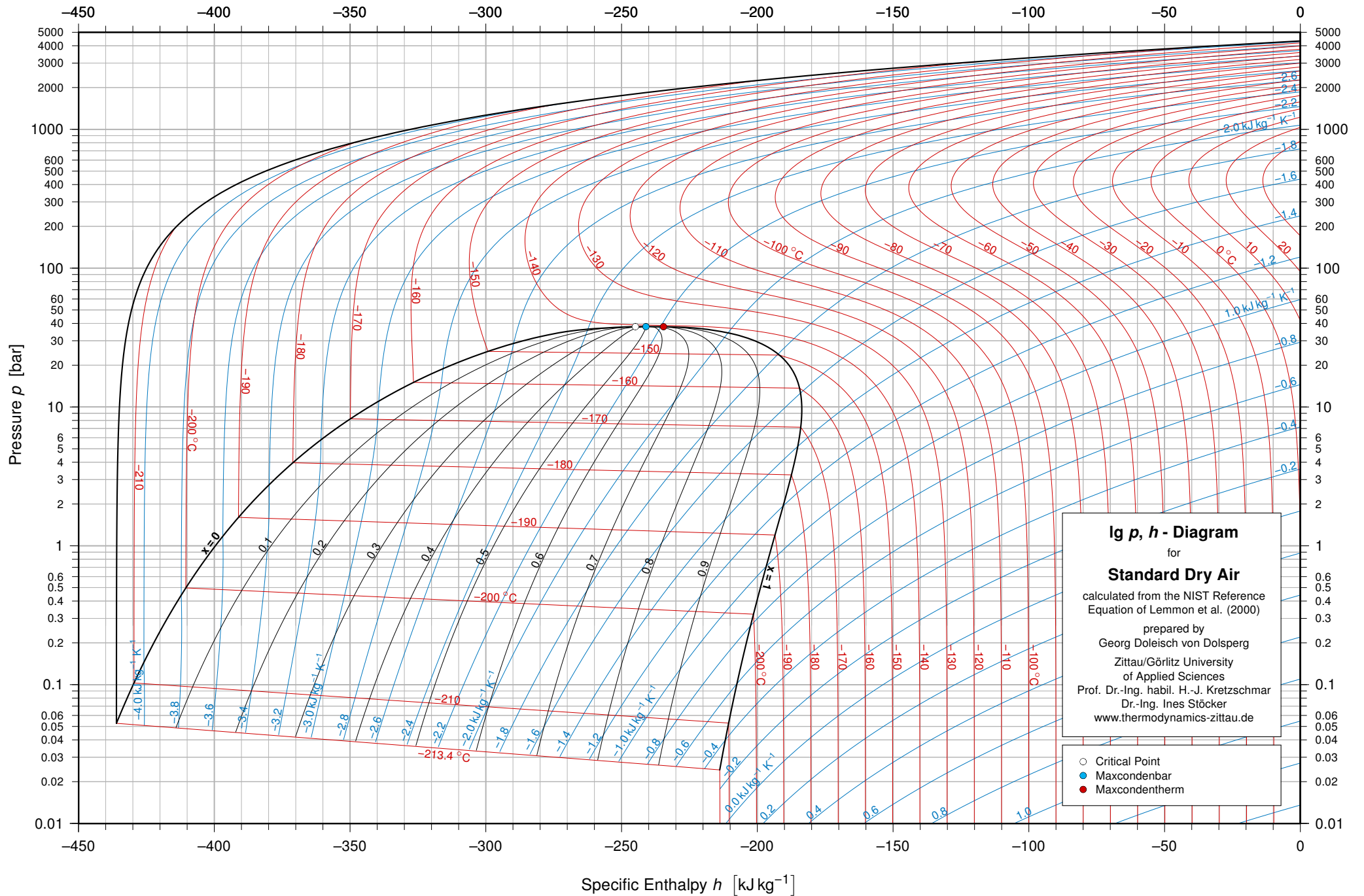
Note:

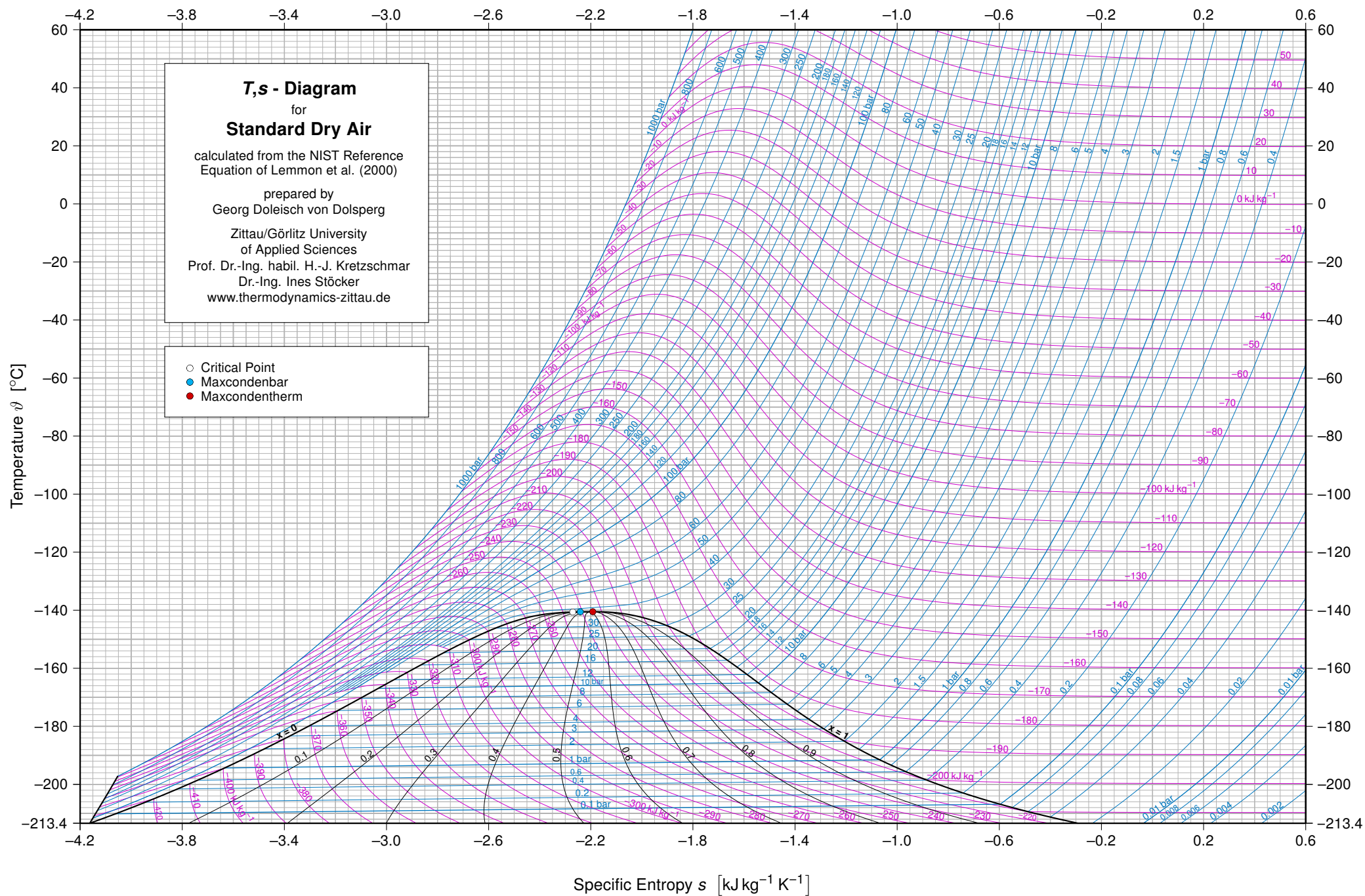
If the calculation results in -1000 , the values entered represent a state point beyond the range of validity. For further information on each function and its range of validity see Chapter 3. The same information may also be accessed via the online help pages.

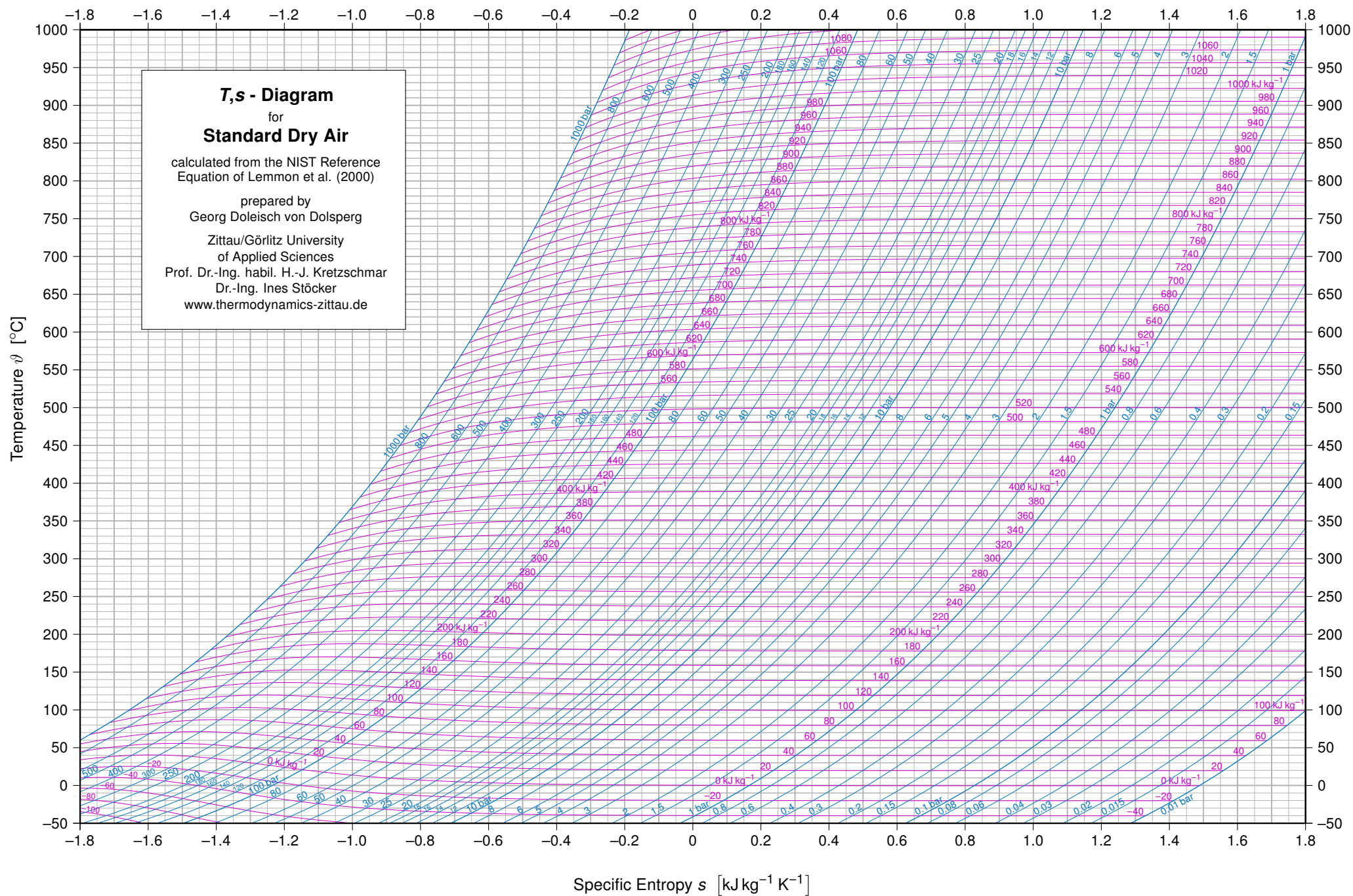
1.3 Thermodynamic Diagrams

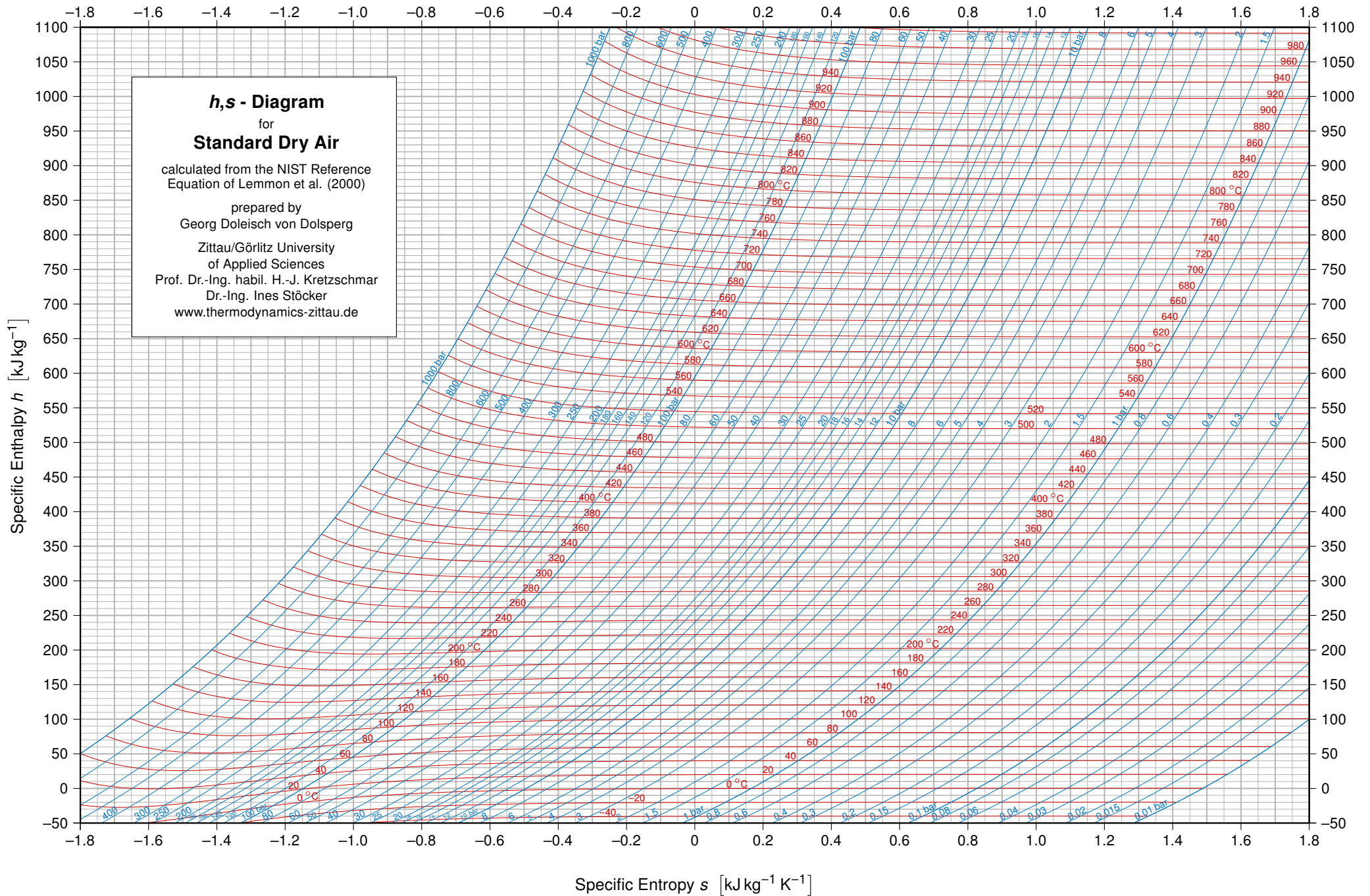
The next pages provide the following thermodynamic diagrams showing the properties of standard dry air.

- **lg p,h -diagram** from
 $p = 0.01 \text{ bar}$ to $p = 5000 \text{ bar}$,
 $t = -213.4 \text{ °C}$ to $t = 0 \text{ °C}$ and
 $\Delta h = 450 \text{ kJ/kg}$
- **T,s -diagram** from
 $t = -213.4 \text{ °C}$ to $t = 60 \text{ °C}$,
 $p = 0.01 \text{ bar}$ to $p = 1000 \text{ bar}$ and
 $\Delta s = 4.8 \text{ kJ/(kg·K)}$
- **T,s -diagram** from
 $t = -50 \text{ °C}$ to $t = 1000 \text{ °C}$,
 $p = 0.01 \text{ bar}$ to $p = 1000 \text{ bar}$ and
 $\Delta s = 3.6 \text{ kJ/(kg·K)}$
- **h,s -diagram** from
 $t = -40 \text{ °C}$ to $t = 1000 \text{ °C}$,
 $p = 0.01 \text{ bar}$ to $p = 1000 \text{ bar}$ and
 $\Delta s = 3.6 \text{ kJ/(kg·K)}$









2. Application of FluidEXL^{Graphics} in Excel[®]

The FluidEXL^{Graphics} Add-In has been developed to calculate thermodynamic properties in Excel more conveniently. Within Excel[®], it enables the direct call of functions relating to standard dry air from the LibRealAir property library.

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 LibRealAir library. In this case, follow the subsection "Adding the LibRealAir Library" on page 2/11.

Installing FluidEXL^{Graphics} for 32-bit Windows[®]

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_LibRealAir_Eng.zip"	(for English version of Windows)
"CD_FluidEXL_Graphics_LibRealAir.zip"	(for German version of Windows)

you will see the folder

CD_FluidEXL_Graphics_LibRealAir_Eng	(for English version of Windows)
CD_FluidEXL_Graphics_LibRealAir	(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_Eng_Setup.exe	(for English version of Windows)
FluidEXL_Graphics_Setup.exe	(for German version of Windows)
FluidEXL_Graphics_Eng.xla	(for English version of Windows)
FluidEXL_Graphics.xla	(for German version of Windows)
FluidEXL_Graphics_LibRealAir_Docu_Eng.pdf	
LibRealAir.dll	
LibRealAir.hlp.	

In order to run the installation of FluidEXL^{Graphics} double-click the file

FluidEXL_Graphics_Eng_Setup.exe	(for English version of Windows)
FluidEXL_Graphics_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 "Continue" button.

In the following dialog box, "Choose Destination Location", the default path offered automatically for the installation of FluidEXL^{Graphics} is

C:\Program Files\FuildEXL_Graphics_Eng	(for English version of Windows)
C:\Programme\FuildEXL_Graphics	(for German version of Windows).

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

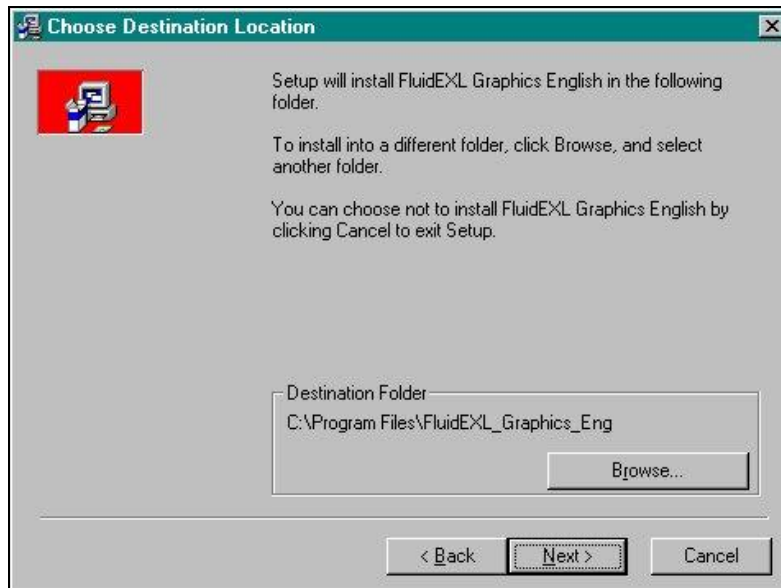


Figure 2.1: Choose Destination Location

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 English has been successfully installed."

will be shown. Confirm this by clicking the "Finish" button. During the installation process the following files

Advapi32.dll	LC.dll
DFORMD.dll	Msvcp60.dll
Dforrt.dll	Msvcrt.dll
UNWISE.EXE	UNWISE.INI
INSTALL_EXL.LOG	

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

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

from the extracted folder

CD_FluidEXL_Graphics_LibRealAir_Eng	(for English version of Windows)
CD_FluidEXL_Graphics_LibRealAir	(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 Windows Explorer or Norton Commander.

Installing FluidEXL *Graphics* for 64-bit Windows®

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_LibRealAir_x64_Eng.zip" (for English version of Windows)
 "CD_FluidEXL_Graphics_LibRealAir_x64.zip" (for German version of Windows)

you will see the folder

CD_FluidEXL_Graphics_LibRealAir_Eng (for English version of Windows)
 CD_FluidEXL_Graphics_LibRealAir (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_LibRealAir_Docu
 FluidEXL_Graphics_Eng.xla (for English version of Windows)
 FluidEXL_Graphics.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)
 LibRealAir.dll
 LibRealAir.hlp
 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).

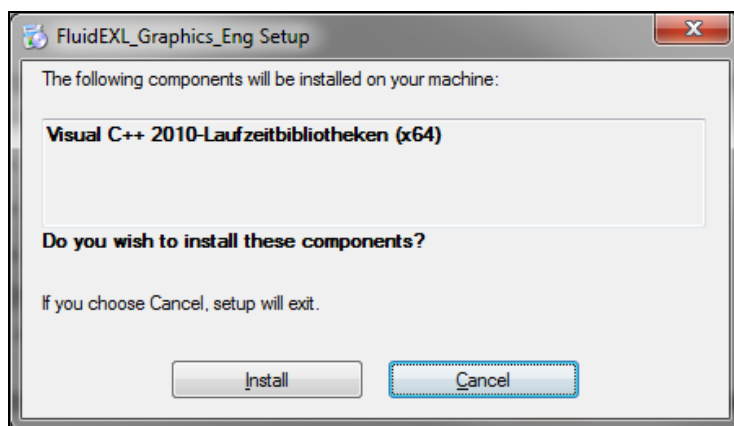


Figure 2.2: Installing the "Visual C++ 2010 runtime library (x64)"

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).

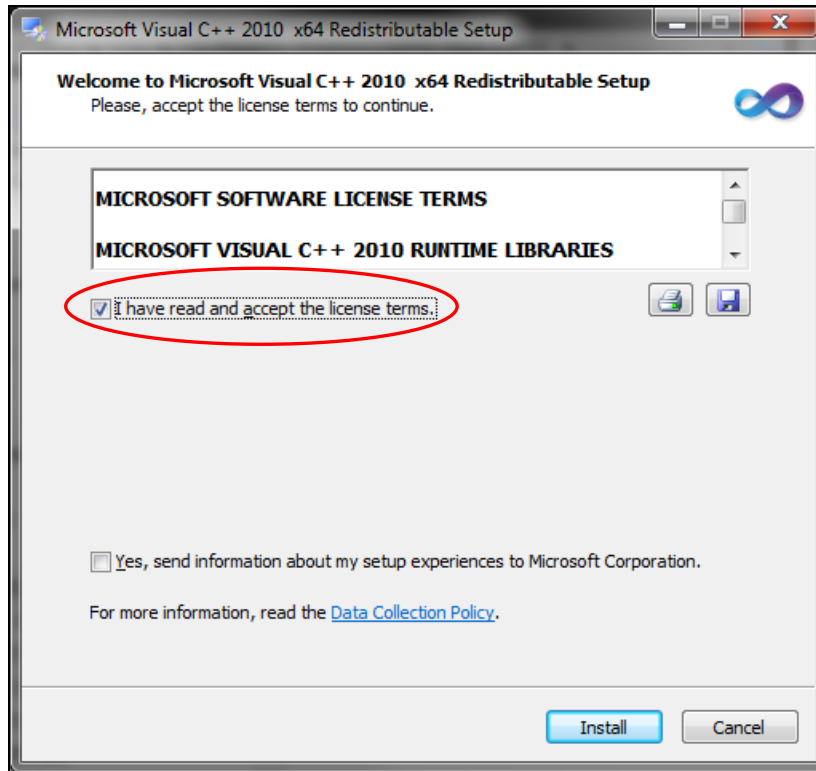


Figure 2.3: Accepting the license terms

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).

By clicking the "Browse..." button, you can change the installation directory before installation (see Figure 2.4).

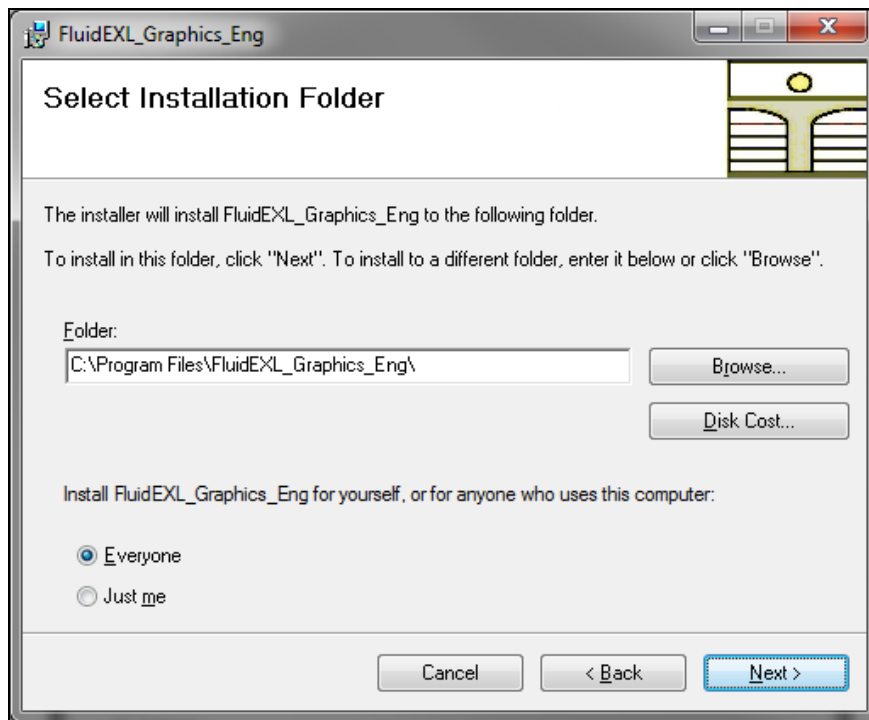


Figure 2.4: Choosing the Installation Folder of FluidEXL *Graphics*

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

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

will have been copied into the destination folder chosen, the standard being

C:\Program Files\FuildEXL_Graphics_Eng	(for English version of Windows)
C:\Programme\FuildEXL_Graphics	(for German version of Windows)..

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

In the next step, the files below,

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

found in your CD folder, must be copied into the chosen destination folder (the standard being

C:\Program Files\FuildEXL_Graphics_Eng	(for English version of Windows)
C:\Programme\FuildEXL_Graphics	(for German version of Windows))

using an appropriate program such as Explorer or Norton Commander.

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 of Excel[®].
- Here, click the "Add-Ins..." menu item.
After a short delay the "Add-Ins" dialog box will appear.
- Click "Browse...."
- In the following dialog box, choose your chosen destination folder (the standard being

C:\Program Files\FuildEXL_Graphics_Eng	(for English version of Windows)
C:\Programme\FuildEXL_Graphics	(for German version of Windows))

here select

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

will appear in the Add-Ins list.

Note:

As long as the check box next to the file name "FluidEXL Graphics Eng" is checked, this Add-In will be loaded automatically every time you start Excel[®] until you unmark 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 Figure 2.5.

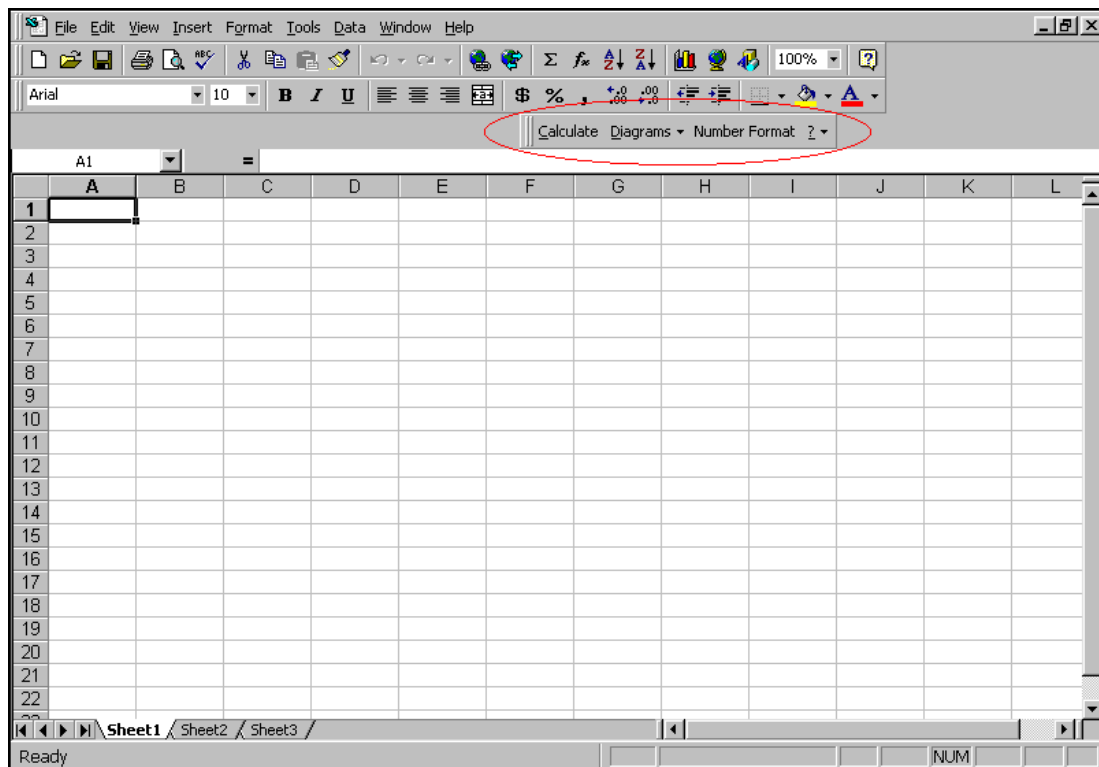


Figure 2.5: Menu bar of FluidEXL*Graphics*

From within Excel you can now select the "LibRealAir" DLL library property functions via this menu bar (see part 2.5 on page 2/19).

Registering FluidEXL^{Graphics} as Add-In in Excel[®] 2007 (or later versions)

After installation in Windows[®], FluidEXL^{Graphics} must be registered in Excel[®] versions 2007 and later as an Add-In. To do this, start Excel[®] and carry out the following steps:

- Click the Windows Office[®] button in the upper left hand corner of Excel[®]
- Click on the "Excel Options" button in the menu which appears (see Figure 2.6)

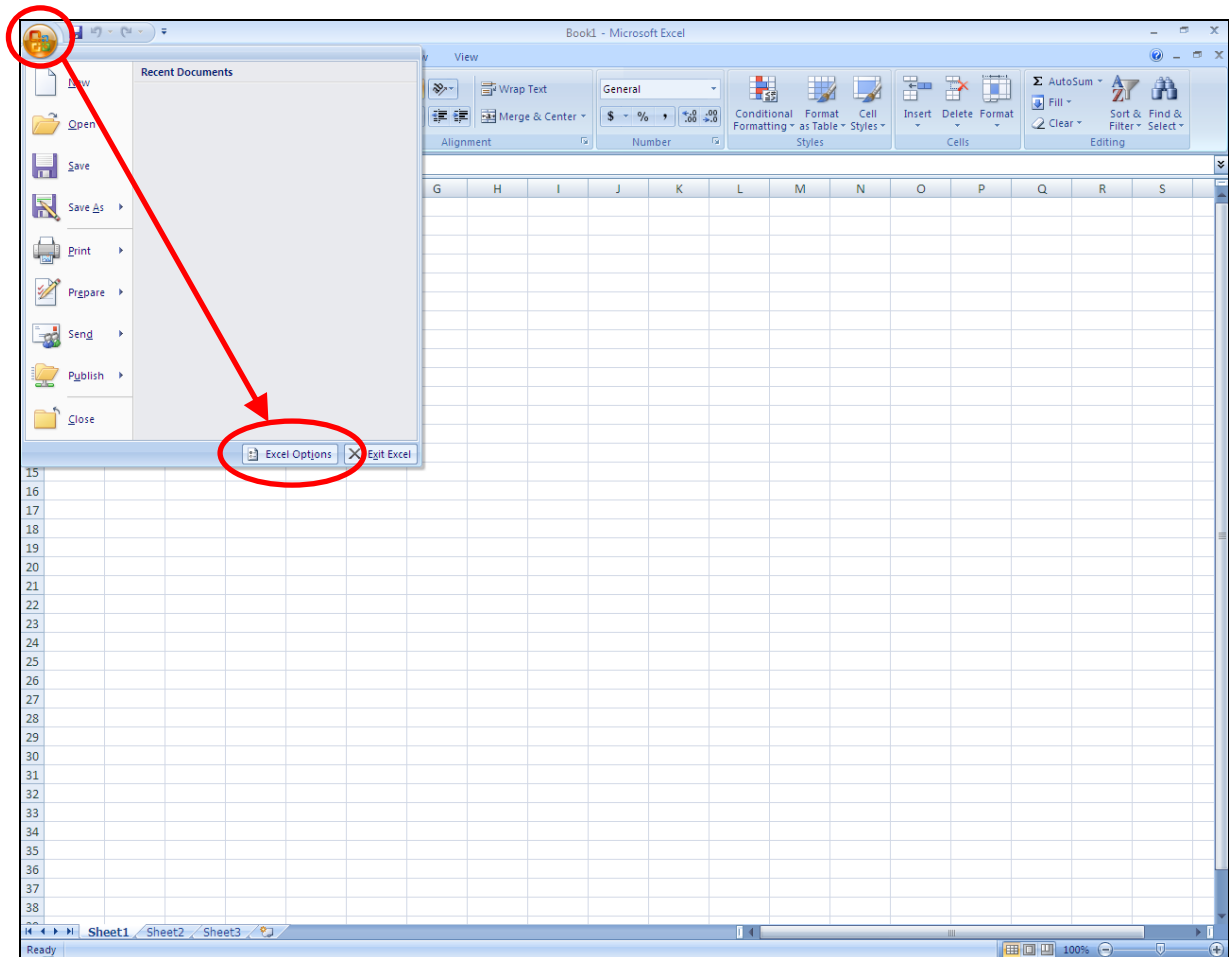


Figure 2.6: Registering FluidEXL^{Graphics} as Add-In in Excel[®] 2007

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

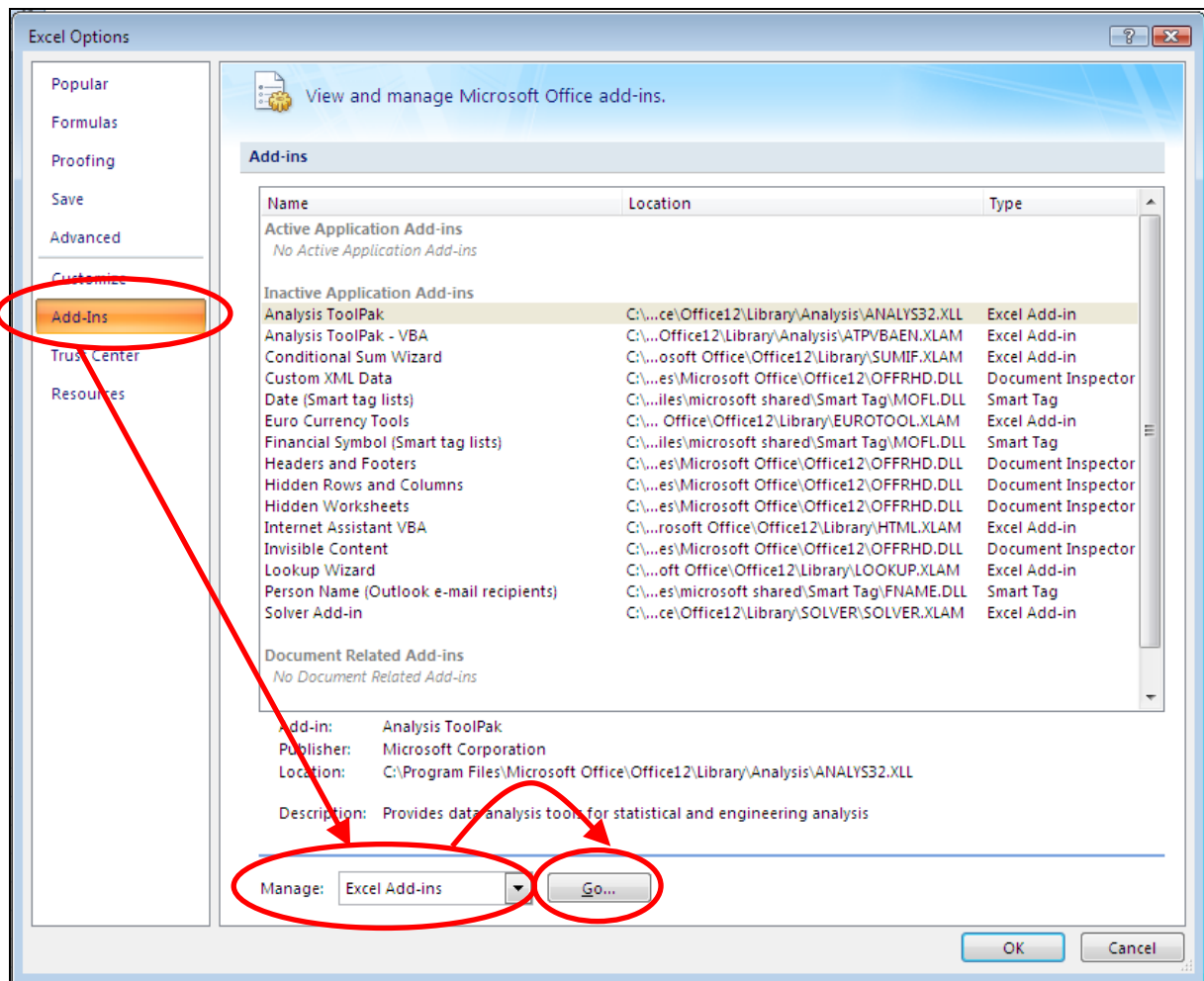


Figure 2.7: Dialog window "Excel Options"

- Should it not be shown in the list automatically, select "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, generally

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

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 hit "OK."

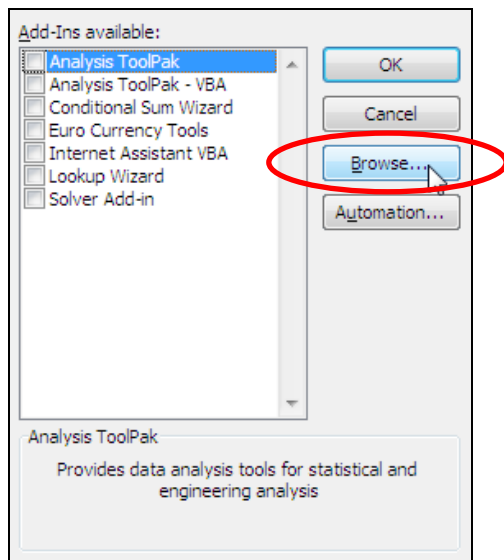


Figure 2.8: Dialog window "Add-Ins available"

- Now, "FluidEXL Graphics Eng" will be shown in your list of Add-Ins.
(If a check-mark is situated in the box next to the name "FluidEXL Graphics Eng," 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.)

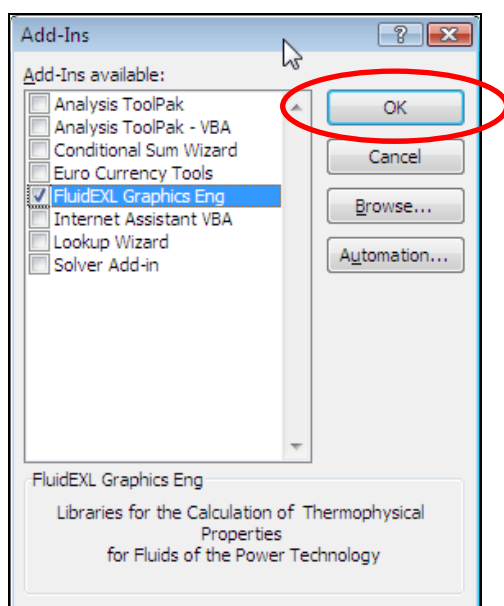


Figure 2.9: Dialog window "Add-Ins"

- 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" shown in Figure 2.10.

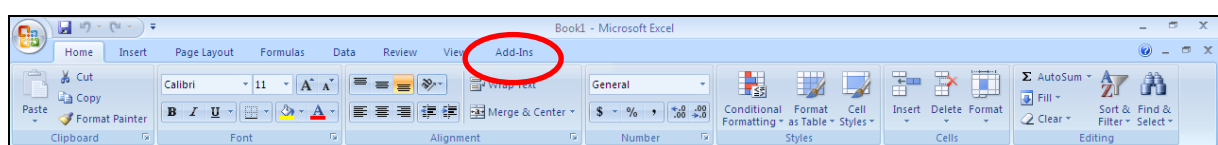


Figure 2.10: Menu item "Add-Ins"

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

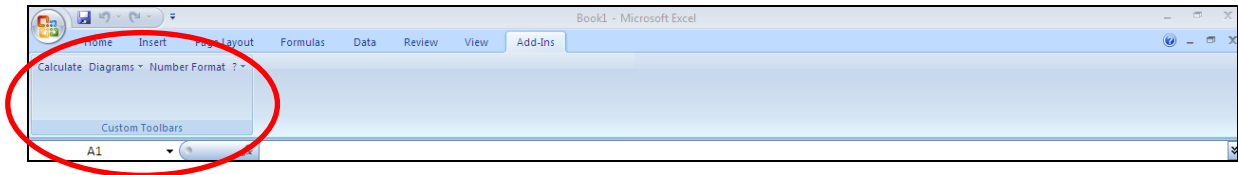


Figure 2.11: FluidEXL^{Graphics} menu bar

Installation of FluidEXL^{Graphics} in Excel[®] (versions 2007 and later) is now finished. FluidEXL^{Graphics} can be used analogous to the description for using with earlier Excel[®] versions.

Adding the LibRealAir Library (FluidEXL^{Graphics} is already installed)

If FluidEXL^{Graphics} has already been installed in the June 2010 version, you only have to copy the following files

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

provided in the extracted folder

CD_FluidEXL_Graphics_LibRealAir_Eng	(for English version of Windows)
CD_FluidEXL_Graphics_LibRealAir	(for German version of Windows)

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

C:\Program Files\FuildEXL_Graphics_Eng	(for English version of Windows)
C:\Programme\FuildEXL_Graphics	(for German version of Windows)

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

From within Excel you can now select the "LibRealAir" DLL library property functions for nitrogen via this menu bar (the example calculation can be found in chapter 2.5 on page 2/19).

2.3 The FluidEXL^{Graphics} Help System

As mentioned earlier, FluidEXL^{Graphics} also provides detailed online help functions. If you are running Windows Vista or Windows 7, please note the paragraph "Using the FluidEXL^{Graphics} Online-Help in Windows Vista or Windows 7."

For general information in Excel[®] click on "?" and then "Help" in the FluidEXL^{Graphics} menu bar. Information on individual property functions may be accessed via the following steps:

- Click "Calculate" in the FluidEXL^{Graphics} menu bar.
- Click on the "Standard Dry Air LibRealAir" 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 LibRealAir.hlp function help cannot be found, confirm the question whether you want to look for it yourself with "Yes". Select the LibRealAir.hlp file in the installation folder of FluidEXL^{Graphics} in the window which is opened, in the standard case

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

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

Using the FluidEXL^{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 2.12: 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 2.13).

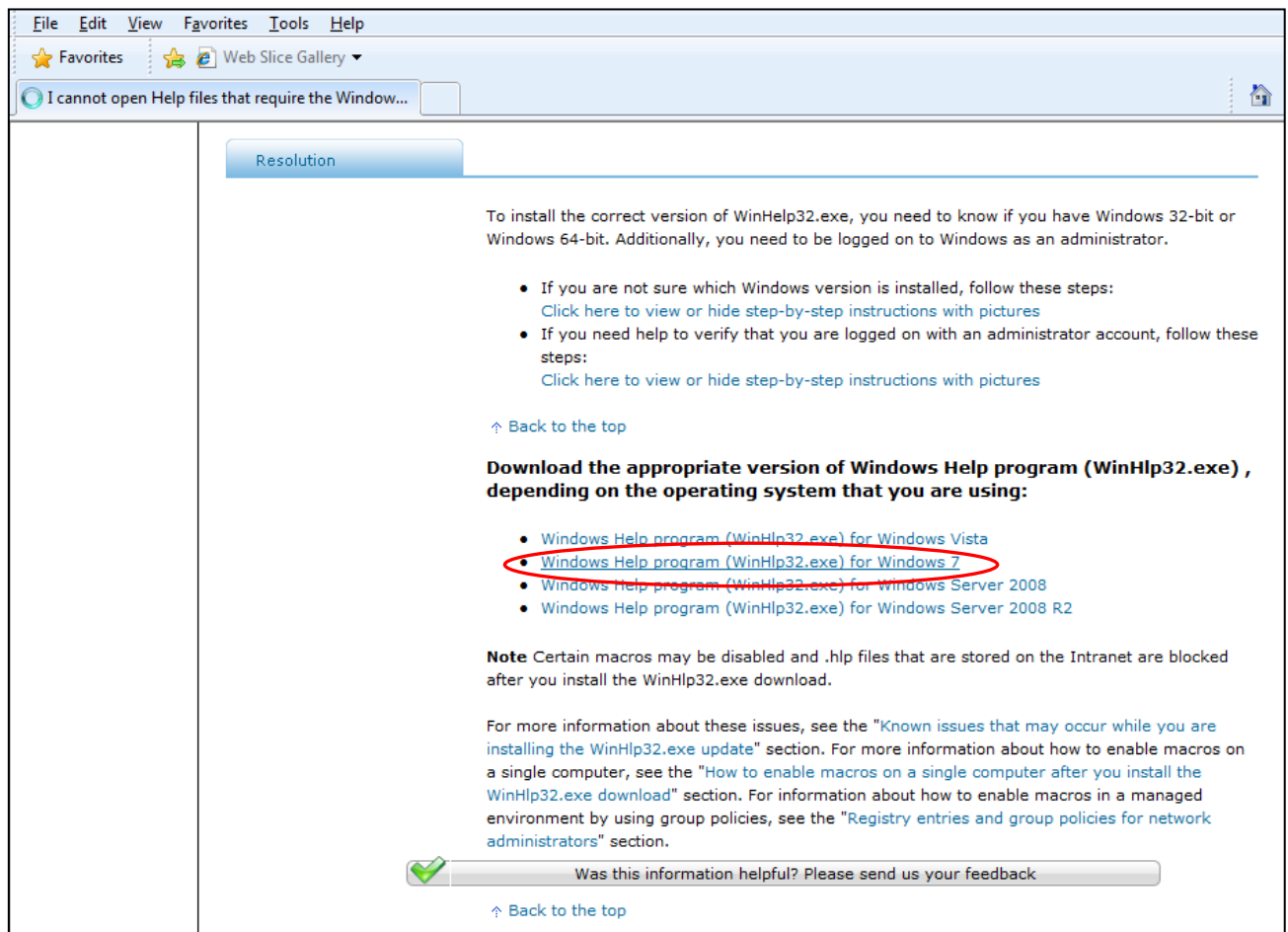


Figure 2.13: Selecting your Windows version

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 2.14).

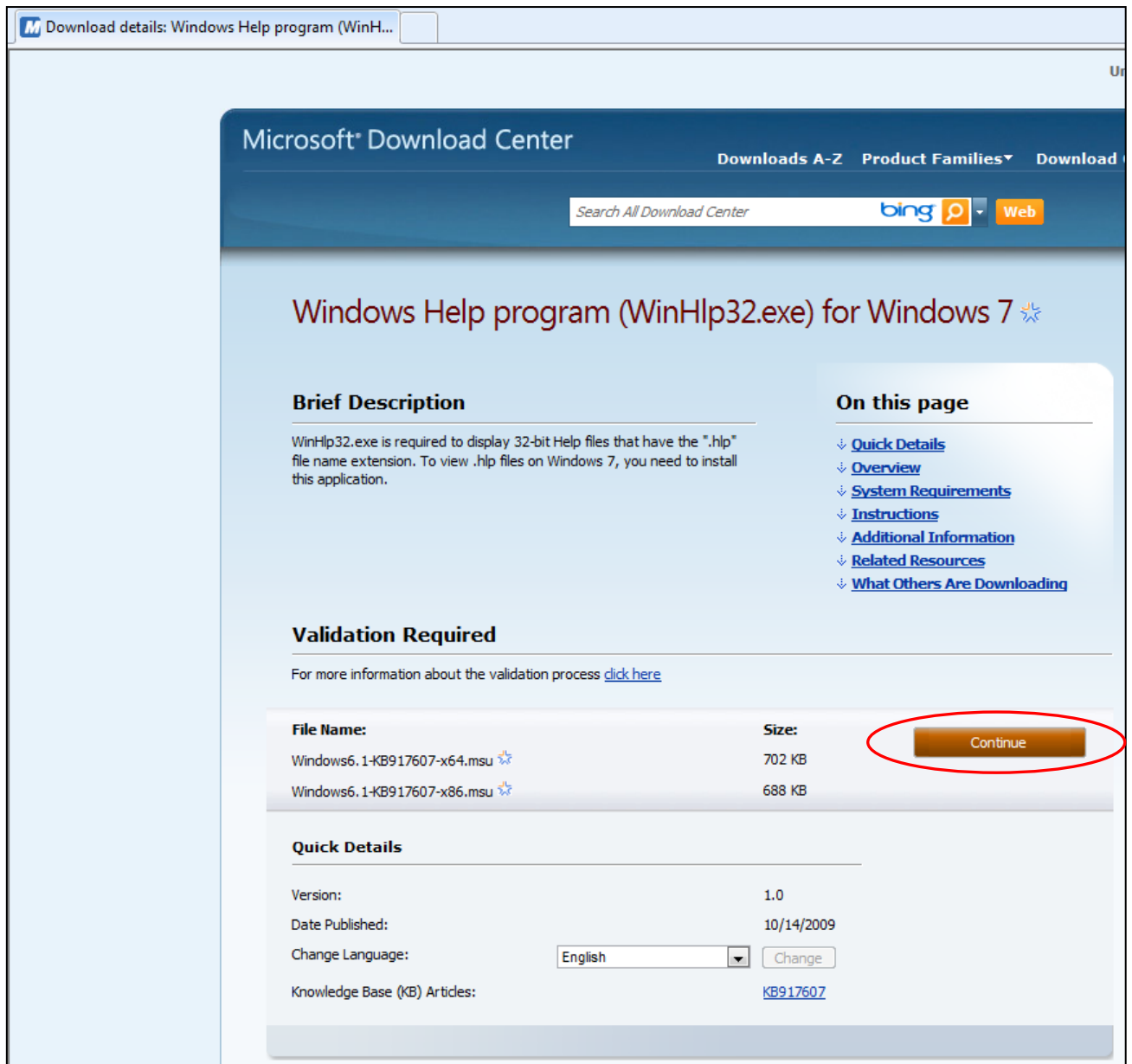


Figure 2.14: Microsoft® Download Center

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 2.15).

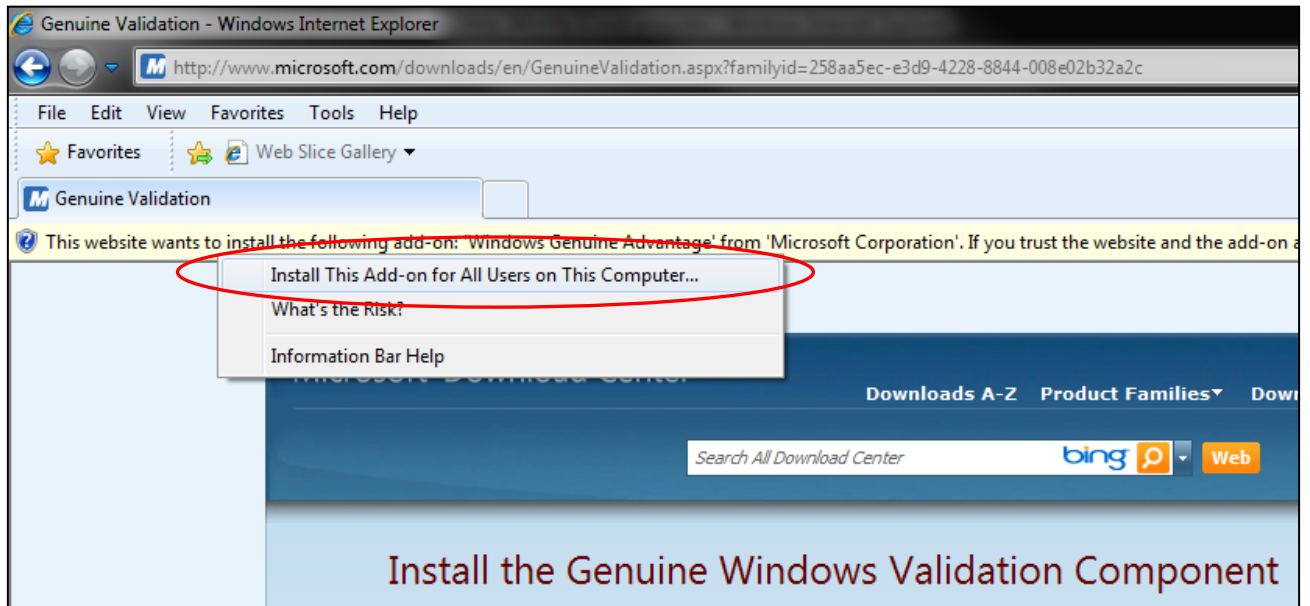


Figure 2.15: Installing the Genuine Windows Validation Component

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 2.16).

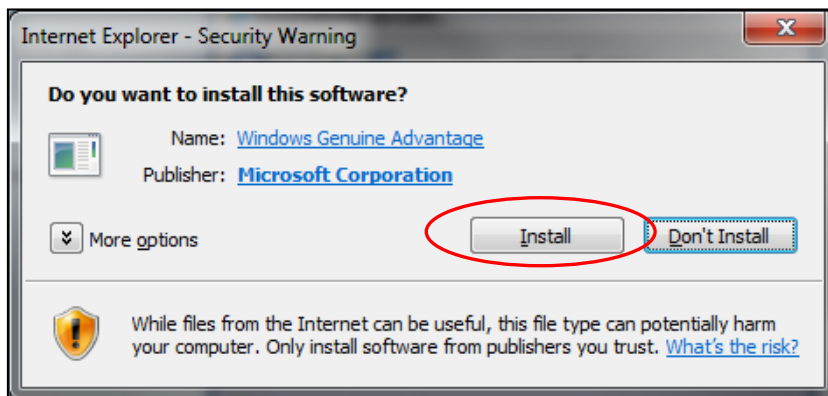


Figure 2.16: Internet Explorer – Security Warning

After the validation has been carried out you will be able to download the appropriate version of Windows Help program (see Figure 2.17).

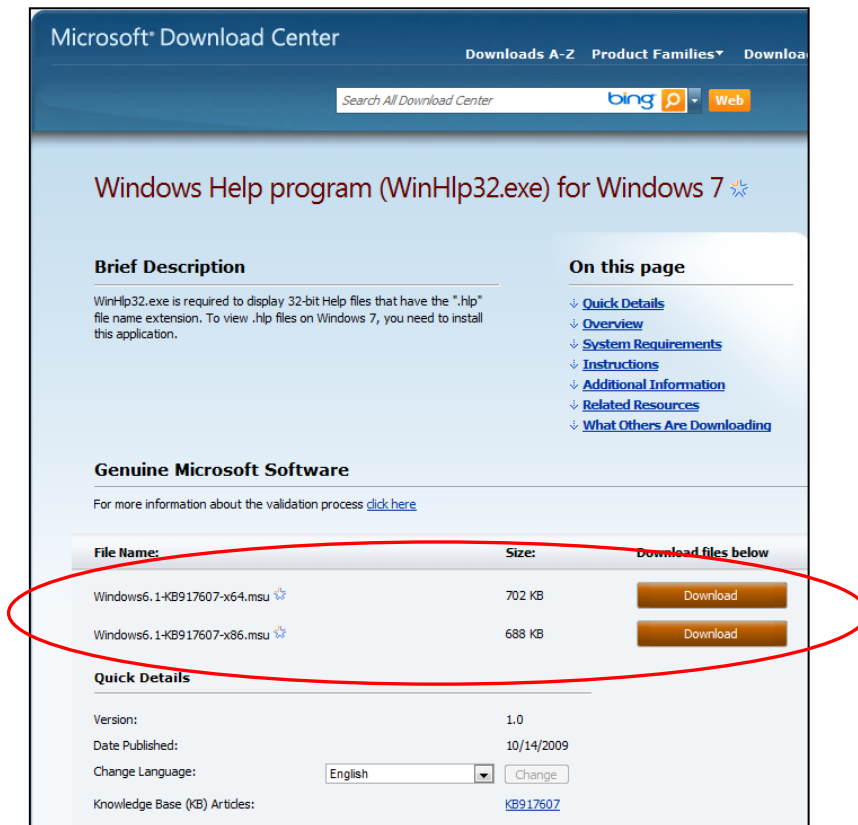


Figure 2.17: Downloading the Windows Help program

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.

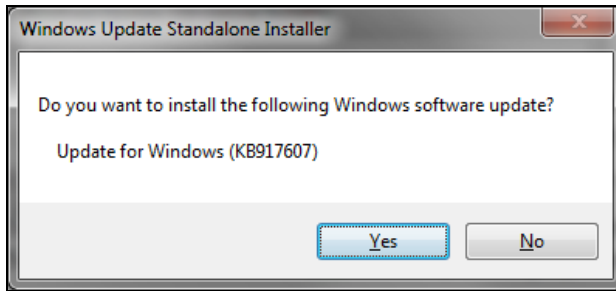


Figure 2.18: Windows Update Standalone Installer

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 2.19)

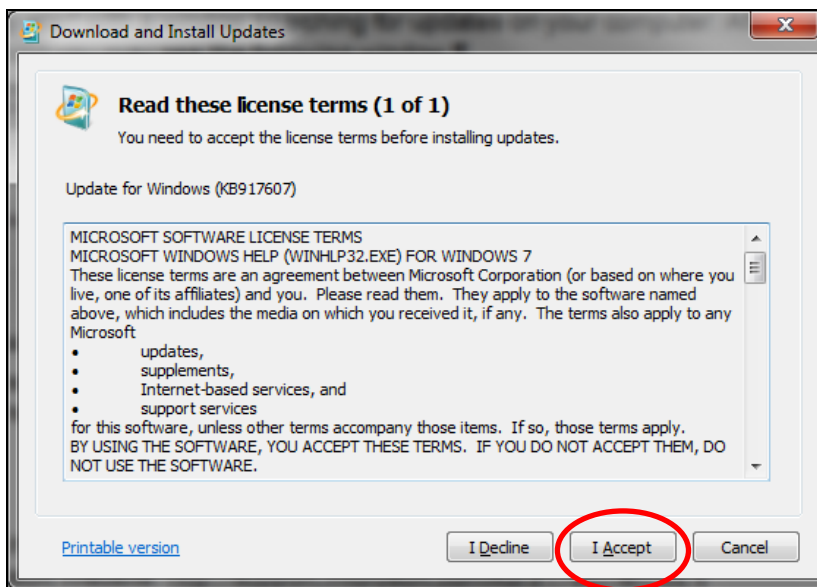


Figure 2.19: Windows License Terms

Installation starts once you have clicked the "I Accept" button (see Figure 2.20).

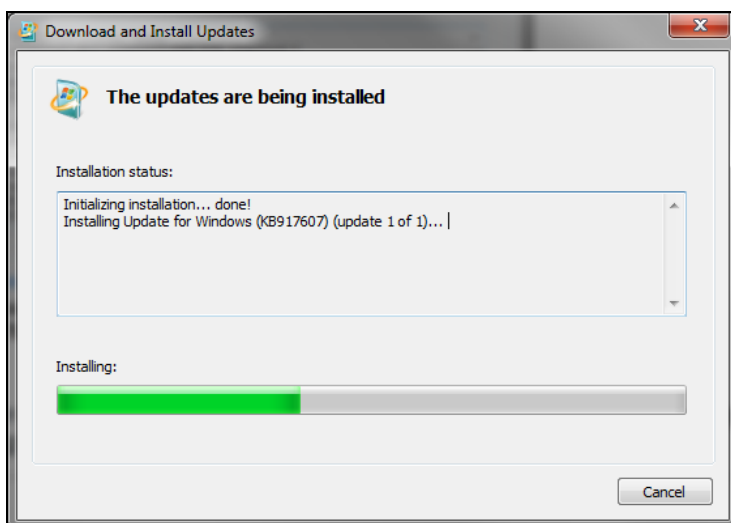


Figure 2.20: Installation process

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 LibRealAir Property Library

The licensing procedure has to be carried out when Excel[®] starts up and a FluidEXL^{Graphics} prompt message appears. In this case, you will see the "License Information" window (see figure below).

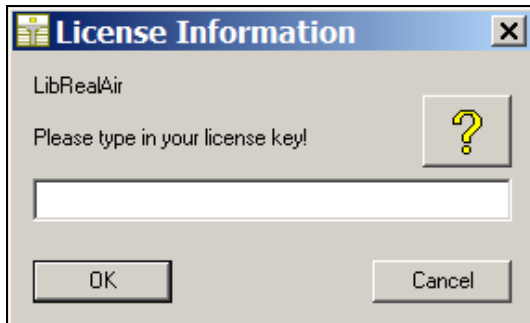


Figure 2.21: "License Information" window

Here you will have to type in the license key which you have obtained from the Zittau/Goerlitz University of Applied Sciences. You can find contact information on the "Content" page of this User's Guide or by clicking the yellow question mark in the "License Information" window. Then the following window will appear:

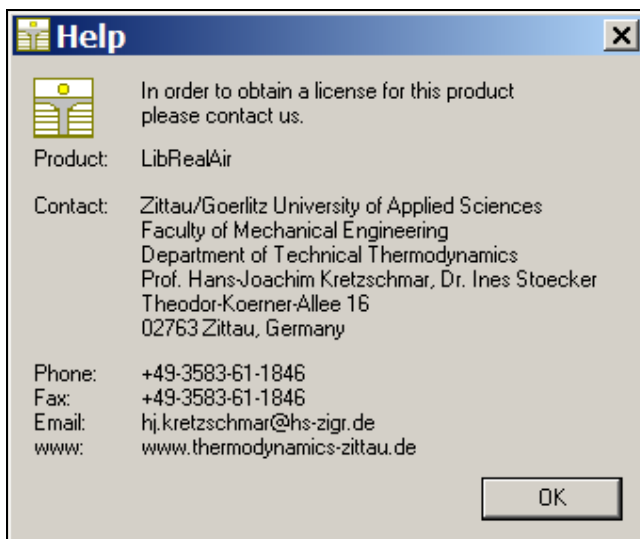


Figure 2.22: "Help" window

If you do not enter a valid license it is still possible to start Excel by clicking "Cancel" twice. In this case, the LibRealAir 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 2.6 of this User's Guide. Should you not wish to license the LibRealAir property library, you have to delete the files

LibRealAir.dll
LibRealAir.hlp

in the installation folder of FluidEXL^{Graphics} (the standard being

C:\Program Files\FuildEXL_Graphics_Eng (for English version of Windows)
C:\Programme\FuildEXL_Graphics (for German version of Windows))

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

2.5 Example: Calculation of $h = f(p, t, x)$ and $s = f(p, t, x)$

Now we will calculate, step by step, the specific enthalpy h as a function of pressure p , temperature t , and vapor fraction x , using FluidEXL *Graphics*.

- Start Excel®
- Enter a value for p in bar in a cell
(Range of validity corresponding to LEMMON: $p = 0.00001 \dots 20000$ bar)
⇒ e. g.: Enter the value 10 into cell A2
- Enter a value for t in °C in a cell
(Range of validity corresponding to LEMMON: $t = -213.4 \dots 1726.85^\circ\text{C}$)
⇒ e. g.: Enter the value 20 into cell B2

- Enter a value for x in kg saturated steam/kg wet steam in a cell

Since the wet steam region is calculated automatically by the subprograms, the following fixed details on the vapor fraction x are to be considered when the value for x is entered:

Single-phase region

If the state point to be calculated is located in the single-phase region (liquid or superheated steam) $x = -1$ must be entered as a pro-forma value.

Wet-steam region

If the state point to be calculated is located in the wet steam region, a value for x between 0 and 1 ($x = 0$ for saturated liquid, $x = 1$ for saturated steam) must be entered.

When calculating wet steam either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value for x between 0 and 1 must be entered.

If p and t and x are entered as given values, the program considers p and t to be appropriate to represent the vapor pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in -1000 .

⇒ e.g.: Enter -1 into the C2 cell.

- Click the cell in which the enthalpy h in kJ/kg is to be displayed.
⇒ e.g.: Click the D2 cell.
- Click "Calculate" in the menu bar of FluidEXL *Graphics*.
Now the "Insert Function" window appears (see next figure).

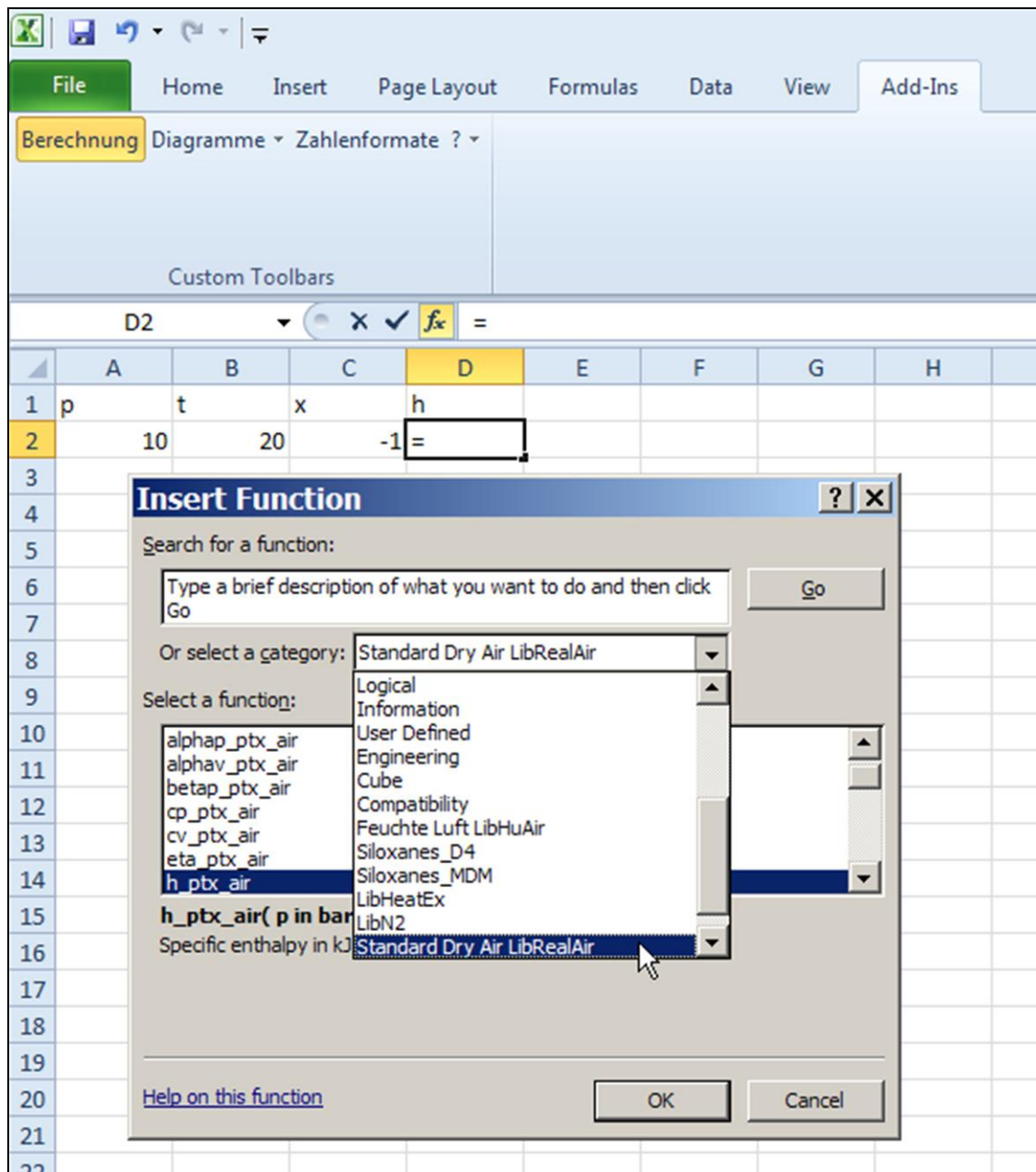


Figure 2.23: Choice of library and function name

- Search and click the "Standard Dry Air LibRealAir" library under "Or select a category:" in the upper part of the window.
- Search and click the `h_ptx_air` function under "Select a function:" right below.

Here it is possible to get more information on the range of validity, measuring units, error responses, etc. by clicking the "Help on this function" button.

- Click "OK".
The window shown in the next figure will now appear.

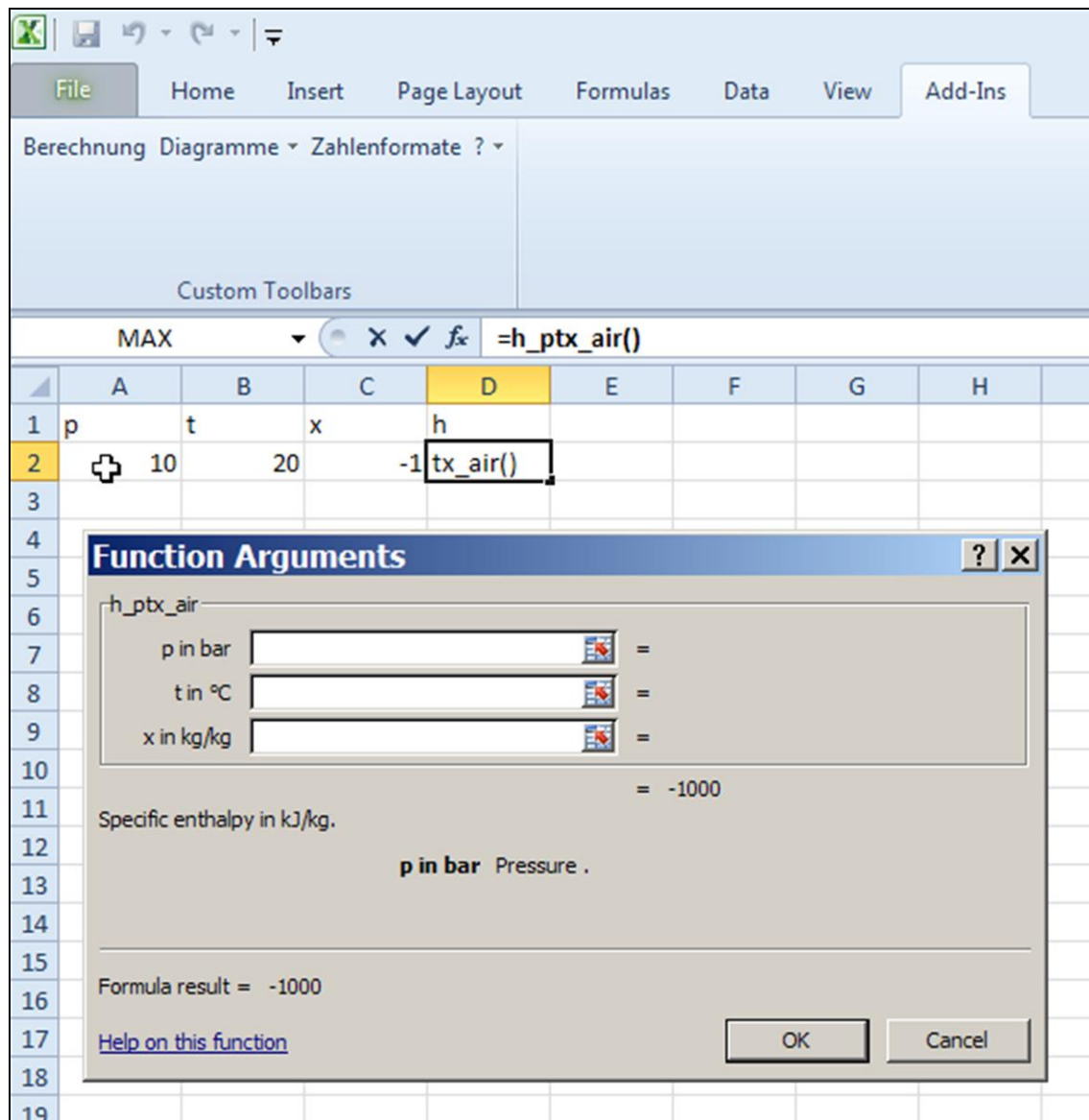


Figure 2.24: Input menu for the function

- The Cursor is now situated on the line next to "p in bar". You can now enter the value for p either by clicking the cell with the value for p , by entering the name of the cell with the value for p , or by entering the value for p directly.

⇒ e. g.: Click on the cell A2

- Situate the cursor next to "t in °C" and enter the value for t by clicking the cell with the value for t , by entering the name of the cell with the value for t , or by entering the value for t directly.

⇒ e. g.: Type B2 into the window next to "t in °C"

- Situate the cursor next to "x in kg/kg" and enter the value for x by clicking the cell with the value for x , by entering the name of the cell with the value for x , or by entering the value for x directly.

⇒ e. g.: Click on the cell C2

The window should now look like the following figure:

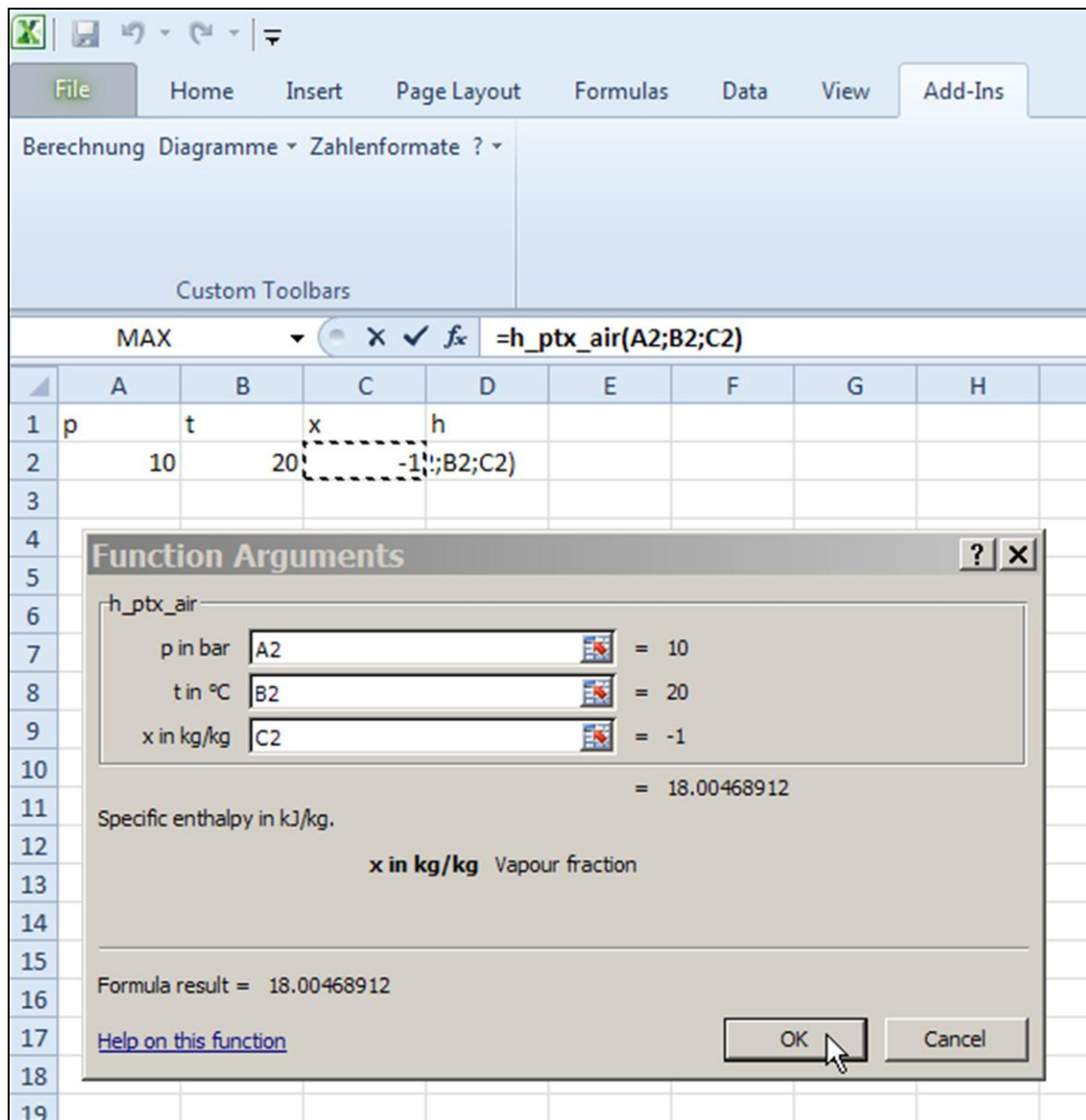


Figure 2.25: Input menu showing the result

- Click the "OK" button.
The result for h in kJ/kg appears in the cell selected above.

⇒ The result for h in our sample calculation here is: 18.00468912 kJ/kg.

The calculation of $h = f(p, t, x)$ has thus been completed. Correspondingly, the specific entropy $s = f(p, t, x)$ can be calculated with the same values for p , t , and x .

Click the cell in which the entropy s in kJ/(kg·K) is to be displayed.

⇒ e.g.: Click the cell E2.

Click "Calculate" in the menu bar of FluidEXL *Graphics*.
The "Insert Function" window will appear.

Because of the previous calculation, the "Standard Dry Air LibRealAir" library under "Or select a category:" will be marked automatically.

Search for and click on the `s_ptx_air` function under "Select a function:" in the center of the window.

Click "OK".

The "Function Arguments" window appears.

Enter the cell name with the value of p next to "p in bar", or click on the cell with the value of p .

Situate the cursor next to "t in °C", click and enter the cell name with the value of t , or click on the cell with the value of t .

Situate the cursor next to "x in kg/kg", click and enter the cell name with the value of x , or click on the cell with the value of x .

Click "OK".

The result for s in kJ/kg K appears in the cell selected above.

⇒ The result for s in our sample calculation here is: -0.430733041 in kJ/(kg·K).

The calculation of $s = f(p, t, x)$ has been carried out. You can now arbitrarily change the values for p , T , or x in the appropriate cells. The specific enthalpy and the specific entropy are recalculated and updated every time you change the data. This shows that the Excel® data flow and the DLL calculations are working together successfully.

Note:

If the calculation results in -1 , this indicates that the values entered are located outside the range of validity of *LEMMON*. More detailed information on each function and its range of validity is available in Chapter 3.

For further property functions calculable in FluidEXL^{Graphics}, see the function table in Chapter 1.

2.6 Removing FluidEXL *Graphics*

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

LibRealAir.dll
LibRealAir.hlp

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

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

has to be cancelled 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)
"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.

If the FluidEXL *Graphics* menu bar does not disappear, take the following steps:

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)
"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".

Within the next step delete the files

LibRealAir.dll,
LibRealAir.hlp

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

C:\Program Files\FuildEXL_Graphics_Eng (for English version of Windows)
C:\Programme\FuildEXL_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)
"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

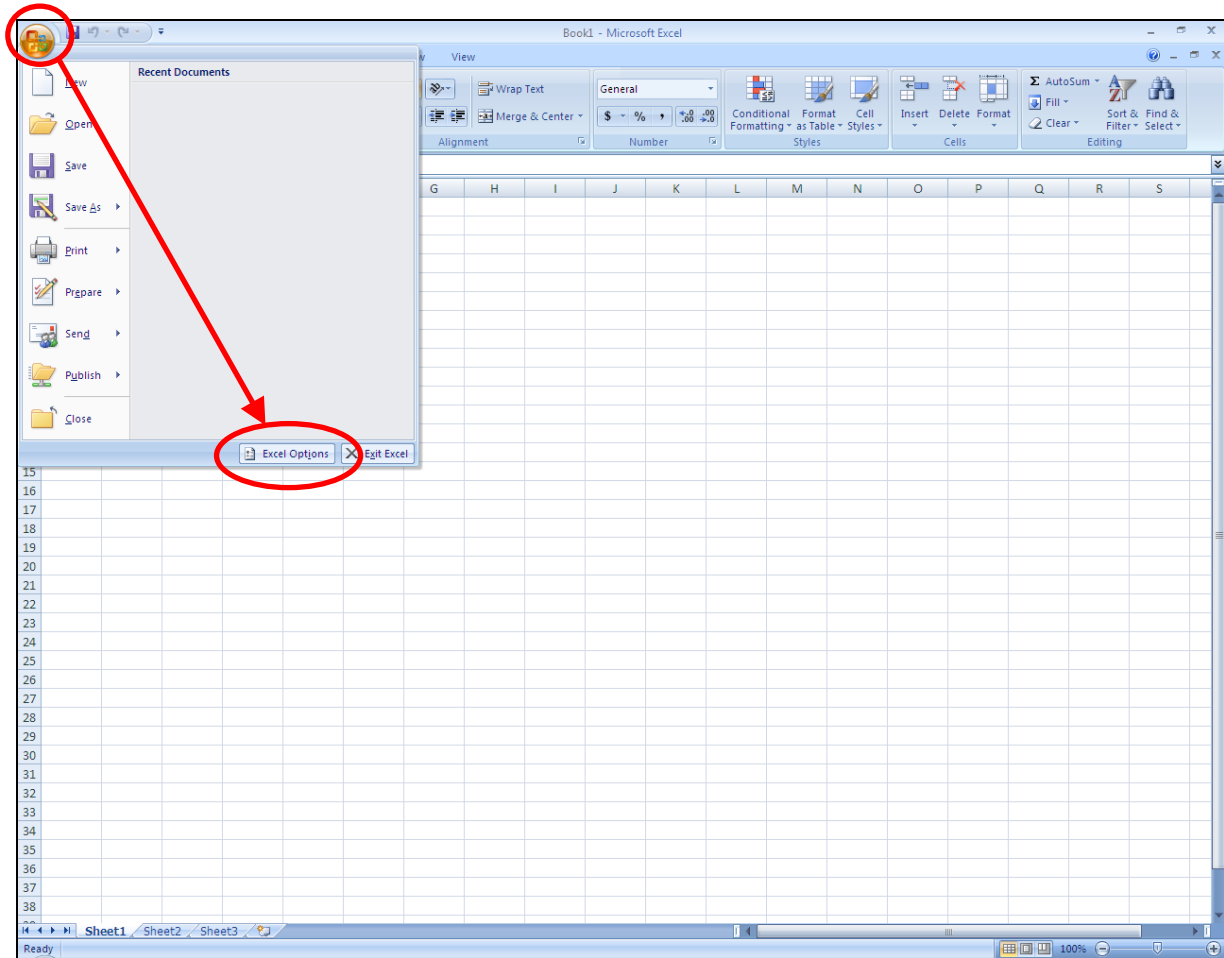


Figure 2.26: Unregistering FluidEXL *Graphics* as Add-In in Excel® 2007

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

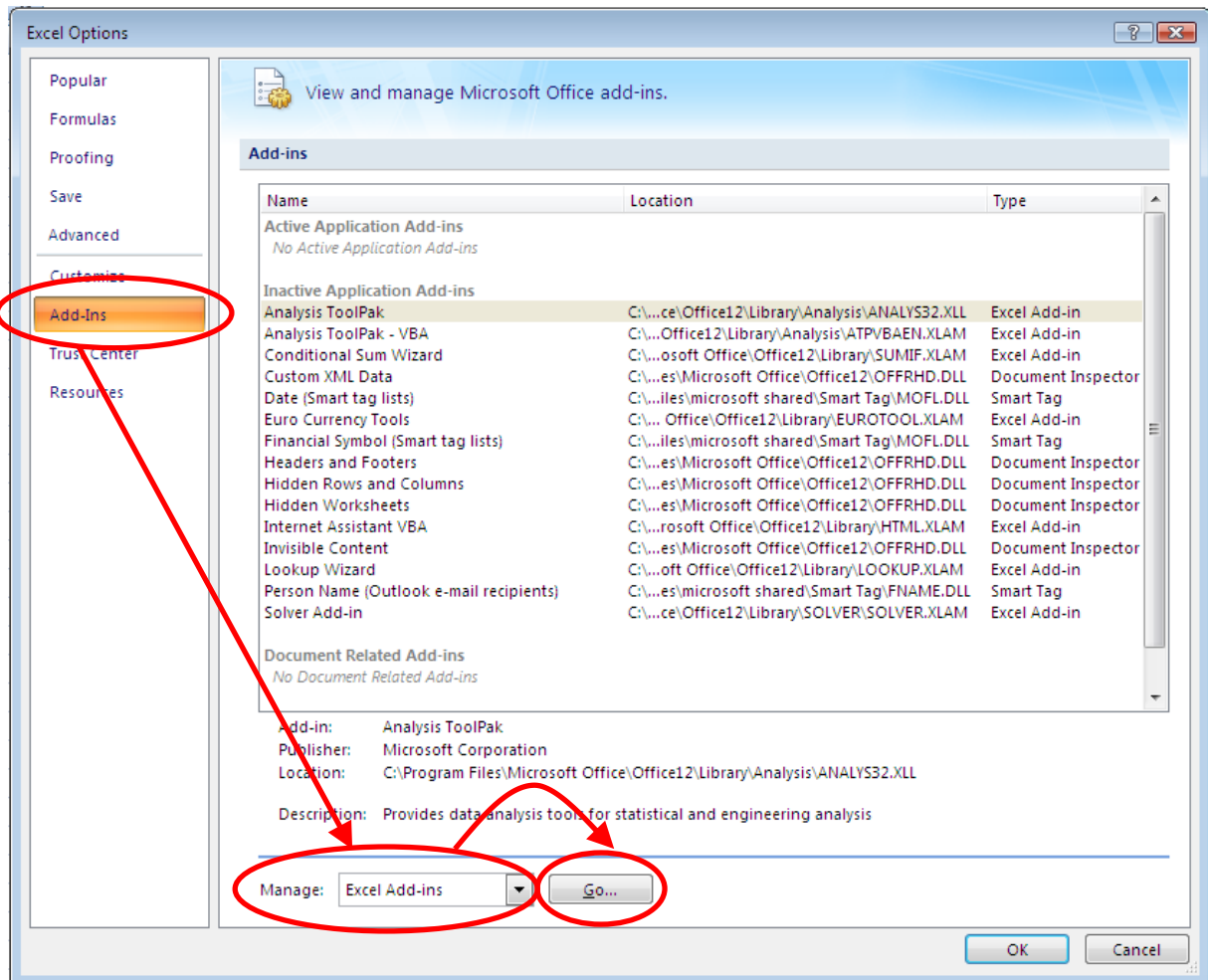


Figure 2.27: Dialog window "Add-Ins"

- If it is not shown in the list automatically, chose 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.

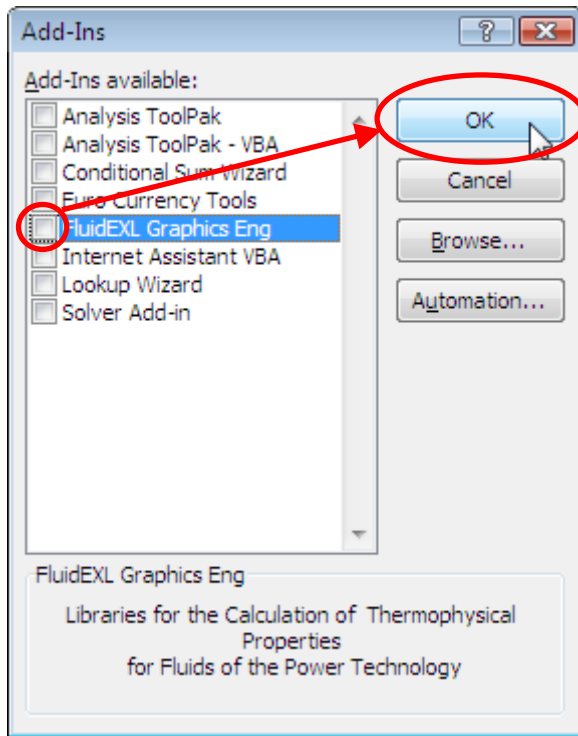


Figure 2.28: Dialog window "Add-Ins"

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 $a = f(p, t, x)$

Function Name: **a_ptx_air**
 Subroutine with function value: **REAL*8 FUNCTION APTXAIR(P,T,X)**
 Variable Types: **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

a_ptx_air or **APTXAIR** - Thermal diffusivity $a = \frac{\lambda}{\rho \cdot c_p} = \frac{\lambda \cdot v}{c_p}$

Range of validity

Temperature range: from -213.4 °C (59.75 K) to 1726.85 °C (2000 K)
 Pressure range: from 0.00001 bar to 20000 bar

Details on the vapor fraction x

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

Single phase region

If the state point to be calculated is located in the single phase region (liquid or superheated steam) $x = -1$ must be entered as a pro-forma value.

Saturation lines

If the state point to be calculated is located on the saturated liquid line, the value 0 has to be entered for x . When calculating saturated steam (saturated vapor line) $x = 1$ has to be entered. The calculation for x values between 0 and 1 is not possible. It is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x (0 or 1). When p and t and x are entered as given values, the program will consider whether p and t fit together. If it is not the case the calculation of the function a will result in -1000 .

Boundaries for wet steam region

The boundaries for the wet steam region are illustrated in Figure 1.1 and Figure 1.2.

Results for wrong input values

The result is **a_ptx_air = -1000** or **APTXAIR = -1000** for the following input values:

Single phase region: $p > p_{\max} = 20000$ or $p < p_{\min} = 0.00001$ bar or
 ($x = -1$) $t > t_{\max} = 1726.85$ °C or $t < t_{\min} = -213.4$ °C or $t < t_{\text{mel}}(p)$
 Saturated liquid line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188$ °C or $t < t_{\min} = -213.4$ °C or
 ($x = 0$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\text{min},l} = 0.052646$ bar or

at $p < p_{\text{mcb}} = 37.9195 \text{ bar}$ and $p > p_{\text{min,l}} = 0.052646 \text{ bar}$ and
 $|t - t_{\text{sl}}(p)| > 0.1 \text{ K}$

Saturated vapor line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188 \text{ °C}$ or $t < t_{\text{min}} = -213.4 \text{ °C}$ or
 ($x = 1$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195 \text{ bar}$ or $p < p_{\text{min,v}} = 0.024316 \text{ bar}$ or
 at $p < p_{\text{mcb}} = 37.9195 \text{ bar}$ and $p > p_{\text{min,v}} = 0.024316 \text{ bar}$ and
 $|t - t_{\text{sv}}(p)| > 0.1 \text{ K}$

References

[1], [2]

Relative Pressure Coefficient $\alpha_p = f(p, t, x)$

Function Name: **alphap_ptx_air**
 Subroutine with function value: **REAL*8 FUNCTION ALPHAPPTXAIR(P,T,X)**
 Variable Types: **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

alphap_ptx_air or **ALPHAPPTXAIR** – Relative pressure coefficient $\alpha_p = -\frac{1}{p} \left(\frac{\partial p}{\partial T} \right)_v$ in 1/K

Range of validity

Temperature range: from -213.4 °C (59.75 K) to 1726.85 °C (2000 K)
 Pressure range: from 0.00001 bar to 20000 bar

Details on the vapor fraction x

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

Single phase region

If the state point to be calculated is located in the single phase region (liquid or superheated steam) $x = -1$ must be entered as a pro-forma value.

Saturation lines

If the state point to be calculated is located on the saturated liquid line, the value 0 has to be entered for x . When calculating saturated steam (saturated vapor line) $x = 1$ has to be entered. The calculation for x values between 0 and 1 is not possible. It is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x (0 or 1). When p and t and x are entered as given values, the program will consider whether p and t fit together. If it is not the case the calculation of the function α_p will result in -1000 .

Boundaries for wet steam region

The boundaries for the wet steam region are illustrated in Figure 1.1 and Figure 1.2.

Results for wrong input values

Result **alphap_ptx_air** = **-1000** or **ALPHAPPTXAIR** = **-1000** for the following input values:

Single phase region: $p > p_{\max} = 20000$ or $p < p_{\min} = 0.00001$ bar or
 ($x = -1$) $t > t_{\max} = 1726.85$ °C or $t < t_{\min} = -213.4$ °C or $t < t_{\text{mel}}(p)$

Saturated liquid line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188$ °C or $t < t_{\min} = -213.4$ °C or
 ($x = 0$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\min, \text{l}} = 0.052646$ bar or
 at $p < p_{\text{mcb}} = 37.9195$ bar and $p > p_{\min, \text{l}} = 0.052646$ bar and
 $|t - t_{\text{sl}}(p)| > 0.1\text{K}$

Saturated vapor line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188 \text{ °C}$ or $t < t_{\text{min}} = -213.4 \text{ °C}$ or
 ($x = 1$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195 \text{ bar}$ or $p < p_{\text{min,v}} = 0.024316 \text{ bar}$ or
 at $p < p_{\text{mcb}} = 37.9195 \text{ bar}$ and $p > p_{\text{min,v}} = 0.024316 \text{ bar}$ and
 $|t - t_{\text{sv}}(p)| > 0.1 \text{ K}$

Reference

[1]

Isobaric Cubic Expansion Coefficient $\alpha_v = f(p, t, x)$

Function Name: **alphav_ptx_air**
 Subroutine with function value: **REAL*8 FUNCTION ALPHAVPTXAIR(P,T,X)**
 Variable Types: **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

alphav_ptx_air or **ALPHAVPTXAIR**

Isobaric cubic expansion coefficient $\alpha_v = \frac{1}{\rho} \left(\frac{\partial \rho}{\partial p} \right)_T \left(\frac{\partial p}{\partial T} \right)_\rho$ in 1/K

Range of validity

Temperature range: from -213.4 °C (59.75 K) to 1726.85 °C (2000 K)
 Pressure range: from 0.00001 bar to 20000 bar

Details on the vapor fraction x

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

Single phase region

If the state point to be calculated is located in the single phase region (liquid or superheated steam) $x = -1$ must be entered as a pro-forma value.

Saturation lines

If the state point to be calculated is located on the saturated liquid line, the value 0 has to be entered for x . When calculating saturated steam (saturated vapor line) $x = 1$ has to be entered. The calculation for x values between 0 and 1 is not possible. It is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x (0 or 1). When p and t and x are entered as given values, the program will consider whether p and t fit together. If it is not the case the calculation of the function α_v will result in -1000 .

Boundaries for wet steam region

The boundaries for the wet steam region are illustrated in Figure 1.1 and Figure 1.2.

Results for wrong input values

Result **alphav_ptx_air** = **-1000** or **ALPHAVPTXAIR** = **-1000** for the following input values:

Single phase region: $p > p_{\max} = 20000$ or $p < p_{\min} = 0.00001$ bar or
 ($x = -1$) $t > t_{\max} = 1726.85$ °C or $t < t_{\min} = -213.4$ °C or $t < t_{\text{mel}}(p)$

Saturated liquid line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188$ °C or $t < t_{\min} = -213.4$ °C or
 ($x = 0$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\text{min,l}} = 0.052646$ bar or

at $p < p_{\text{mcb}} = 37.9195 \text{ bar}$ and $p > p_{\text{min,l}} = 0.052646 \text{ bar}$ and
 $|t - t_{\text{sl}}(p)| > 0.1 \text{ K}$

Saturated vapor line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188 \text{ °C}$ or $t < t_{\text{min}} = -213.4 \text{ °C}$ or
 ($x = 1$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195 \text{ bar}$ or $p < p_{\text{min,v}} = 0.024316 \text{ bar}$ or
 at $p < p_{\text{mcb}} = 37.9195 \text{ bar}$ and $p > p_{\text{min,v}} = 0.024316 \text{ bar}$ and
 $|t - t_{\text{sv}}(p)| > 0.1 \text{ K}$

Reference

[1]

Isothermal Stress Coefficient $\beta_p = f(p, t, x)$

Function Name: **betap_ptx_air**
 Subroutine with function value: **REAL*8 FUNCTION BETAPPTXAIR(P,T,X)**
 Variable Types: **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

betap_ptx_air or **BETAPPTXAIR** – Isothermal stress coefficient $\beta_p = \frac{\rho^2}{p} \left(\frac{\partial p}{\partial \rho} \right)_T$ in kg / m³

Range of validity

Temperature range: from -213.4 °C (59.75 K) to 1726.85 °C (2000 K)
 Pressure range: from 0.00001 bar to 20000 bar

Details on the vapor fraction x

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

Single phase region

If the state point to be calculated is located in the single phase region (liquid or superheated steam) $x = -1$ must be entered as a pro-forma value.

Saturation lines

If the state point to be calculated is located on the saturated liquid line, the value 0 has to be entered for x . When calculating saturated steam (saturated vapor line) $x = 1$ has to be entered. The calculation for x values between 0 and 1 is not possible. It is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x (0 or 1). When p and t and x are entered as given values, the program will consider whether p and t fit together. If it is not the case the calculation of the function β_p will result in -1000 .

Boundaries for wet steam region

The boundaries for the wet steam region are illustrated in Figure 1.1 and Figure 1.2.

Results for wrong input values

Result **betap_ptx_air** = **-1000** or **BETAPPTXAIR** = **-1000** for the following input values:

Single phase region: $p > p_{\max} = 20000$ or $p < p_{\min} = 0.00001$ bar or
 ($x = -1$) $t > t_{\max} = 1726.85$ °C or $t < t_{\min} = -213.4$ °C or $t < t_{\text{mel}}(p)$

Saturated liquid line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188$ °C or $t < t_{\min} = -213.4$ °C or
 ($x = 0$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\text{min,l}} = 0.052646$ bar or
 at $p < p_{\text{mcb}} = 37.9195$ bar and $p > p_{\text{min,l}} = 0.052646$ bar and
 $|t - t_{\text{sl}}(p)| > 0.1\text{K}$

Saturated vapor line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188 \text{ °C}$ or $t < t_{\text{min}} = -213.4 \text{ °C}$ or
 ($x = 1$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195 \text{ bar}$ or $p < p_{\text{min,v}} = 0.024316 \text{ bar}$ or
 at $p < p_{\text{mcb}} = 37.9195 \text{ bar}$ and $p > p_{\text{min,v}} = 0.024316 \text{ bar}$ and
 $|t - t_{\text{sv}}(p)| > 0.1 \text{ K}$

Reference

[1]

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

Function Name: **cp_ptx_air**
 Subroutine with function value: **REAL*8 FUNCTION CPPTXAIR(P,T,X)**
 Variable Types: **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

cp_ptx_air or **CPPTXAIR** – Specific isobaric heat capacity c_p in kJ/(kg·K)

Range of validity

Temperature range: from -213.4 °C (59.75 K) to 1726.85 °C (2000 K)
 Pressure range: from 0.00001 bar to 20000 bar

Details on the vapor fraction x

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

Single phase region

If the state point to be calculated is located in the single phase region (liquid or superheated steam) $x = -1$ must be entered as a pro-forma value.

Saturation lines

If the state point to be calculated is located on the saturated liquid line, the value 0 has to be entered for x . When calculating saturated steam (saturated vapor line) $x = 1$ has to be entered. The calculation for x values between 0 and 1 is not possible. It is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x (0 or 1). When p and t and x are entered as given values, the program will consider whether p and t fit together. If it is not the case the calculation of the function c_p will result in -1000 .

Boundaries for wet steam region

The boundaries for the wet steam region are illustrated in Figure 1.1 and Figure 1.2.

Results for wrong input values

Result **cp_ptx_air** = **-1000** or **CPPTXAIR** = **-1000** for the following input values:

Single phase region: $p > p_{\max} = 20000$ or $p < p_{\min} = 0.00001$ bar or
 ($x = -1$) $t > t_{\max} = 1726.85$ °C or $t < t_{\min} = -213.4$ °C or $t < t_{\text{mel}}(p)$

Saturated liquid line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188$ °C or $t < t_{\min} = -213.4$ °C or
 ($x = 0$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\min, l} = 0.052646$ bar or
 at $p < p_{\text{mcb}} = 37.9195$ bar and $p > p_{\min, l} = 0.052646$ bar and
 $|t - t_{\text{sl}}(p)| > 0.1\text{K}$

Saturated vapor line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188 \text{ °C}$ or $t < t_{\text{min}} = -213.4 \text{ °C}$ or
 ($x = 1$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195 \text{ bar}$ or $p < p_{\text{min,v}} = 0.024316 \text{ bar}$ or
 at $p < p_{\text{mcb}} = 37.9195 \text{ bar}$ and $p > p_{\text{min,v}} = 0.024316 \text{ bar}$ and
 $|t - t_{\text{sv}}(p)| > 0.1 \text{ K}$

Reference

[1]

Specific Isochoric Heat Capacity $c_v = f(p, t, x)$

Function Name: **cv_ptx_air**
 Subroutine with function value: **REAL*8 FUNCTION CVPTXAIR(P,T,X)**
 Variable Types: **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

cv_ptx_air or **CVPTXAIR** – Specific isochoric heat capacity c_v in kJ/(kg·K)

Range of validity

Temperature range: from -213.4 °C (59.75 K) to 1726.85 °C (2000 K)
 Pressure range: from 0.00001 bar to 20000 bar

Details on the vapor fraction x

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

Single phase region

If the state point to be calculated is located in the single phase region (liquid or superheated steam) $x = -1$ must be entered as a pro-forma value.

Saturation lines

If the state point to be calculated is located on the saturated liquid line, the value 0 has to be entered for x . When calculating saturated steam (saturated vapor line) $x = 1$ has to be entered. The calculation for x values between 0 and 1 is not possible. It is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x (0 or 1). When p and t and x are entered as given values, the program will consider whether p and t fit together. If it is not the case the calculation of the function c_v will result in -1000 .

Boundaries for wet steam region

The boundaries for the wet steam region are illustrated in Figure 1.1 and Figure 1.2.

Results for wrong input values

Result **cv_ptx_air** = **-1000** or **CVPTXAIR** = **-1000** for the following input values:

Single phase region: $p > p_{\max} = 20000$ or $p < p_{\min} = 0.00001$ bar or
 ($x = -1$) $t > t_{\max} = 1726.85$ °C or $t < t_{\min} = -213.4$ °C or $t < t_{\text{mel}}(p)$

Saturated liquid line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188$ °C or $t < t_{\min} = -213.4$ °C or
 ($x = 0$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\min, l} = 0.052646$ bar or
 at $p < p_{\text{mcb}} = 37.9195$ bar and $p > p_{\min, l} = 0.052646$ bar and
 $|t - t_{\text{sl}}(p)| > 0.1$ K

Saturated vapor line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188 \text{ °C}$ or $t < t_{\text{min}} = -213.4 \text{ °C}$ or
 ($x = 1$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195 \text{ bar}$ or $p < p_{\text{min,v}} = 0.024316 \text{ bar}$ or
 at $p < p_{\text{mcb}} = 37.9195 \text{ bar}$ and $p > p_{\text{min,v}} = 0.024316 \text{ bar}$ and
 $|t - t_{\text{sv}}(p)| > 0.1 \text{ K}$

Reference

[1]

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

Function Name: **eta_ptx_air**
 Subroutine with function value: **REAL*8 FUNCTION ETAPTXAIR(P,T,X)**
 Variable Types: **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

eta_ptx_air or **ETAPTXAIR** – Dynamic viscosity η in Pa·s

Range of validity

Temperature range: from -213.4 °C (59.75 K) to 1726.85 °C (2000 K)
 Pressure range: from 0.00001 bar to 20000 bar

Details on the vapor fraction x

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

Single phase region

If the state point to be calculated is located in the single phase region (liquid or superheated steam) $x = -1$ must be entered as a pro-forma value.

Saturation lines

If the state point to be calculated is located on the saturated liquid line, the value 0 has to be entered for x . When calculating saturated steam (saturated vapor line) $x = 1$ has to be entered. The calculation for x values between 0 and 1 is not possible. It is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x (0 or 1). When p and t and x are entered as given values, the program will consider whether p and t fit together. If it is not the case the calculation of the function η will result in -1000 .

Boundaries for wet steam region

The boundaries for the wet steam region are illustrated in Figure 1.1 and Figure 1.2.

Results for wrong input values

Result **eta_ptx_air** = **-1000** or **ETAPTXAIR** = **-1000** for the following input values:

Single phase region: $p > p_{\max} = 20000$ or $p < p_{\min} = 0.00001$ bar or
 ($x = -1$) $t > t_{\max} = 1726.85$ °C or $t < t_{\min} = -213.4$ °C or $t < t_{\text{mel}}(p)$

Saturated liquid line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188$ °C or $t < t_{\min} = -213.4$ °C or
 ($x = 0$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\text{min,l}} = 0.052646$ bar or
 at $p < p_{\text{mcb}} = 37.9195$ bar and $p > p_{\text{min,l}} = 0.052646$ bar and
 $|t - t_{\text{sl}}(p)| > 0.1$ K

Saturated vapor line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188 \text{ °C}$ or $t < t_{\text{min}} = -213.4 \text{ °C}$ or
 ($x = 1$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195 \text{ bar}$ or $p < p_{\text{min,v}} = 0.024316 \text{ bar}$ or
 at $p < p_{\text{mcb}} = 37.9195 \text{ bar}$ and $p > p_{\text{min,v}} = 0.024316 \text{ bar}$ and
 $|t - t_{\text{sv}}(p)| > 0.1 \text{ K}$

References

[1], [2]

Specific Enthalpy $h = f(p, t, x)$

Function Name: **h_ptx_air**
 Subroutine with function value: **REAL*8 FUNCTION HPTXAIR(P,T,X)**
 Variable Types: **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

h_ptx_air or **HPTXAIR** – Specific enthalpy h in kJ/kg

Range of validity

Temperature range: from -213.4 °C (59.75 K) to 1726.85 °C (2000 K)
 Pressure range: from 0.00001 bar to 20000 bar

Details on the vapor fraction x and on the calculation of wet steam

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

Single phase region

If the state point to be calculated is located in the single phase region (liquid or superheated steam) $x = -1$ must be entered as a pro-forma value.

Wet steam region

When calculating wet steam, a value between 0 and 1 ($x = 0$ for saturated liquid, $x = 1$ for saturated steam) must be entered. It is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. When p and t and x are entered as given values, the program will consider whether p and t fit together. If it is not the case the calculation of the function h will result in -1000 .

Boundaries for wet steam region

The boundaries for the wet steam region are illustrated in Figure 1.1 and Figure 1.2.

Results for wrong input values

Result **h_ptx_air** = **-1000** or **HPTXAIR** = **-1000** for the following input values:

Single phase region: $p > p_{\max} = 20000$ or $p < p_{\min} = 0.00001$ bar or
 ($x = -1$) $t > t_{\max} = 1726.85$ °C or $t < t_{\min} = -213.4$ °C or $t < t_{\text{mel}}(p)$

Saturated liquid line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188$ °C or $t < t_{\min} = -213.4$ °C or
 ($x = 0$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\min, l} = 0.052646$ bar or
 at $p < p_{\text{mcb}} = 37.9195$ bar and $p > p_{\min, l} = 0.052646$ bar and
 $|t - t_{\text{sl}}(p)| > 0.1$ K

Saturated vapor line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188$ °C or $t < t_{\min} = -213.4$ °C or
 ($x = 1$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\min, v} = 0.024316$ bar or

at $p < p_{\text{mcb}} = 37.9195 \text{ bar}$ and $p > p_{\text{min,v}} = 0.024316 \text{ bar}$ and
 $|t - t_{\text{sv}}(p)| > 0.1 \text{ K}$

Reference

[1]

Isentropic Exponent $\kappa = f(p, t, x)$

Function Name: **kappa_ptx_air**
 Subroutine with function value: **REAL*8 FUNCTION KAPPTXAIR(P,T,X)**
 Variable Types: **REAL*8 P,T,X**

Input values

P - Pressure p in bar

T - Temperature t in °C

X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

kappa_ptx_air or **KAPPTXAIR** – Isentropic exponent $\kappa = -\frac{v}{p} \left(\frac{\partial p}{\partial v} \right)_s = \frac{w^2}{p \cdot v}$

Range of validity

Temperature range: from -213.4 °C (59.75 K) to 1726.85 °C (2000 K)

Pressure range: from 0.00001 bar to 20000 bar

Details on the vapor fraction x

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

Single phase region

If the state point to be calculated is located in the single phase region (liquid or superheated steam) $x = -1$ must be entered as a pro-forma value.

Saturation lines

If the state point to be calculated is located on the saturated liquid line, the value 0 has to be entered for x . When calculating saturated steam (saturated vapor line) $x = 1$ has to be entered. The calculation for x values between 0 and 1 is not possible. It is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x (0 or 1). When p and t and x are entered as given values, the program will consider whether p and t fit together. If it is not the case the calculation of the function κ will result in -1000 .

Boundaries for wet steam region

The boundaries for the wet steam region are illustrated in Figure 1.1 and Figure 1.2.

Results for wrong input values

Result **kappa_ptx_air** = **-1000** or **KAPPTXAIR** = **-1000** for the following input values:

Single phase region: $p > p_{\max} = 20000$ or $p < p_{\min} = 0.00001$ bar or

($x = -1$) $t > t_{\max} = 1726.85$ °C or $t < t_{\min} = -213.4$ °C or $t < t_{\text{mel}}(p)$

Saturated liquid line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188$ °C or $t < t_{\min} = -213.4$ °C or

($x = 0$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\min, l} = 0.052646$ bar or

at $p < p_{\text{mcb}} = 37.9195$ bar and $p > p_{\min, l} = 0.052646$ bar and

$|t - t_{\text{sl}}(p)| > 0.1$ K

Saturated vapor line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188 \text{ °C}$ or $t < t_{\text{min}} = -213.4 \text{ °C}$ or
 ($x = 1$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195 \text{ bar}$ or $p < p_{\text{min,v}} = 0.024316 \text{ bar}$ or
 at $p < p_{\text{mcb}} = 37.9195 \text{ bar}$ and $p > p_{\text{min,v}} = 0.024316 \text{ bar}$ and
 $|t - t_{\text{sv}}(p)| > 0.1 \text{ K}$

Reference

[1]

Isothermal Compressibility $\kappa_T = f(p, t, x)$

Function Name: **kappat_ptx_air**
 Subroutine with function value: **REAL*8 FUNCTION KAPPATPTXAIR(P,T,X)**
 Variable Types: **REAL*8 P,T,X**

Input values

P - Pressure p in bar

T - Temperature t in °C

X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

kappat_ptx_air or **KAPPATPTXAIR** - Isothermal compressibility $\kappa_T = -\frac{1}{v} \left(\frac{\partial v}{\partial p} \right)_T = v \left(\frac{\partial p}{\partial v} \right)_T^{-1}$

Range of validity

Temperature range: from -213.4 °C (59.75 K) to 1726.85 °C (2000 K)

Pressure range: from 0.00001 bar to 20000 bar

Details on the vapor fraction x

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

Single phase region

If the state point to be calculated is located in the single phase region (liquid or superheated steam) $x = -1$ must be entered as a pro-forma value.

Saturation lines

If the state point to be calculated is located on the saturated liquid line, the value 0 has to be entered for x . When calculating saturated steam (saturated vapor line) $x = 1$ has to be entered. The calculation for x values between 0 and 1 is not possible. It is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x (0 or 1). When p and t and x are entered as given values, the program will consider whether p and t fit together. If it is not the case the calculation of the function κ_T will result in -1000 .

Boundaries for wet steam region

The boundaries for the wet steam region are illustrated in Figure 1.1 and Figure 1.2.

Results for wrong input values

Result **kappat_ptx_air = -1000** or **KAPPATPTXAIR = -1000** for the following input values:

Single phase region: $p > p_{\max} = 20000$ or $p < p_{\min} = 0.00001$ bar or

($x = -1$) $t > t_{\max} = 1726.85$ °C or $t < t_{\min} = -213.4$ °C or $t < t_{\text{mel}}(p)$

Saturated liquid line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188 \text{ °C}$ or $t < t_{\text{min}} = -213.4 \text{ °C}$ or
 ($x = 0$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195 \text{ bar}$ or $p < p_{\text{min,l}} = 0.052646 \text{ bar}$ or
 at $p < p_{\text{mcb}} = 37.9195 \text{ bar}$ and $p > p_{\text{min,l}} = 0.052646 \text{ bar}$ and
 $|t - t_{\text{sl}}(p)| > 0.1 \text{ K}$

Saturated vapor line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188 \text{ °C}$ or $t < t_{\text{min}} = -213.4 \text{ °C}$ or
 ($x = 1$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195 \text{ bar}$ or $p < p_{\text{min,v}} = 0.024316 \text{ bar}$ or
 at $p < p_{\text{mcb}} = 37.9195 \text{ bar}$ and $p > p_{\text{min,v}} = 0.024316 \text{ bar}$ and
 $|t - t_{\text{sv}}(p)| > 0.1 \text{ K}$

Reference

[1]

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

Function Name: **lambda_ptx_air**
 Subroutine with function value: **REAL*8 FUNCTION LAMBDAPTXAIR(P,T,X)**
 Variable Types: **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

lambda_ptx_air or **LAMBDAPTXAIR** – Thermal conductivity λ in W/(m·K)

Range of validity

Temperature range: from -213.4 °C (59.75 K) to 1726.85 °C (2000 K)
 Pressure range: from 0.00001 bar to 20000 bar

Details on the vapor fraction x

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

Single phase region

If the state point to be calculated is located in the single phase region (liquid or superheated steam) $x = -1$ must be entered as a pro-forma value.

Saturation lines

If the state point to be calculated is located on the saturated liquid line, the value 0 has to be entered for x . When calculating saturated steam (saturated vapor line) $x = 1$ has to be entered. The calculation for x values between 0 and 1 is not possible. It is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x (0 or 1). When p and t and x are entered as given values, the program will consider whether p and t fit together. If it is not the case the calculation of the function λ will result in -1000 .

Boundaries for wet steam region

The boundaries for the wet steam region are illustrated in Figure 1.1 and Figure 1.2.

Results for wrong input values

Result **lambda_ptx_air** = **-1000** or **LAMBDAPTXAIR** = **-1000** for the following input values:

Single phase region: $p > p_{\max} = 20000$ or $p < p_{\min} = 0.00001$ bar or
 ($x = -1$) $t > t_{\max} = 1726.85$ °C or $t < t_{\min} = -213.4$ °C or $t < t_{\text{mel}}(p)$

Saturated liquid line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188$ °C or $t < t_{\min} = -213.4$ °C or
 ($x = 0$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\min, l} = 0.052646$ bar or
 at $p < p_{\text{mcb}} = 37.9195$ bar and $p > p_{\min, l} = 0.052646$ bar and
 $|t - t_{\text{sl}}(p)| > 0.1$ K

Saturated vapor line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188 \text{ °C}$ or $t < t_{\text{min}} = -213.4 \text{ °C}$ or
 ($x = 1$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195 \text{ bar}$ or $p < p_{\text{min,v}} = 0.024316 \text{ bar}$ or
 at $p < p_{\text{mcb}} = 37.9195 \text{ bar}$ and $p > p_{\text{min,v}} = 0.024316 \text{ bar}$ and
 $|t - t_{\text{sv}}(p)| > 0.1 \text{ K}$

References

[1], [2]

Kinematic Viscosity $\nu = f(p, t, x)$

Function Name: **nu_ptx_air**
 Subroutine with function value: **REAL*8 FUNCTION NUPTXAIR(P,T,X)**
 Variable Types: **REAL*8 P,T,X**

Input values

P - Pressure p in bar

T - Temperature t in °C

X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

nu_ptx_air or **NUPTXAIR** – Kinematic viscosity $\nu = \frac{\eta}{\rho} = \eta \cdot \nu$ in m²/s

Range of validity

Temperature range: from -213.4 °C (59.75 K) to 1726.85 °C (2000 K)

Pressure range: from 0.00001 bar to 20000 bar

Details on the vapor fraction x

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

Single phase region

If the state point to be calculated is located in the single phase region (liquid or superheated steam) $x = -1$ must be entered as a pro-forma value.

Saturation lines

If the state point to be calculated is located on the saturated liquid line, the value 0 has to be entered for x . When calculating saturated steam (saturated vapor line) $x = 1$ has to be entered. The calculation for x values between 0 and 1 is not possible. It is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x (0 or 1). When p and t and x are entered as given values, the program will consider whether p and t fit together. If it is not the case the calculation of the function ν will result in -1000 .

Boundaries for wet steam region

The boundaries for the wet steam region are illustrated in Figure 1.1 and Figure 1.2.

Results for wrong input values

Result **nu_ptx_air** = **-1000** or **NUPTXAIR** = **-1000** for the following input values:

Single phase region: $p > p_{\max} = 20000$ or $p < p_{\min} = 0.00001$ bar or

($x = -1$) $t > t_{\max} = 1726.85$ °C or $t < t_{\min} = -213.4$ °C or $t < t_{\text{mel}}(p)$

Saturated liquid line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188$ °C or $t < t_{\min} = -213.4$ °C or

($x = 0$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\min, l} = 0.052646$ bar or

at $p < p_{\text{mcb}} = 37.9195$ bar and $p > p_{\min, l} = 0.052646$ bar and

$|t - t_{\text{sl}}(p)| > 0.1$ K

Saturated vapor line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188 \text{ °C}$ or $t < t_{\text{min}} = -213.4 \text{ °C}$ or
 ($x = 1$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195 \text{ bar}$ or $p < p_{\text{min,v}} = 0.024316 \text{ bar}$ or
 at $p < p_{\text{mcb}} = 37.9195 \text{ bar}$ and $p > p_{\text{min,v}} = 0.024316 \text{ bar}$ and
 $|t - t_{\text{sv}}(p)| > 0.1 \text{ K}$

References

[1], [2]

Pressure on the Melting Curve $p_{\text{mel}} = f(t)$

Function Name: **pmel_t_air**
 Subroutine with function value: **REAL*8 FUNCTION PMELTAIR(T)**
 Variable Types: **REAL*8 T**

Input values

T - Temperature t in °C

Result

pmel_t_air or **PMELTAIR** – Pressure on the melting curve p_{mel} in bar

Range of validity

Temperature range: from $t_t = t_{\text{min}} = -213.4$ °C to $t_{\text{mel}}(20000 \text{ bar}) = -36.9508$ °C

Results for wrong input values

Result **pmel_t_air = -1000** or **PMELTAIR = -1000** for the following input values:

$t > t_{\text{mel}}(20000 \text{ bar}) = -36.9508$ °C or $t < t_{\text{min}} = -213.4$ °C or

Reference

[1]

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

Function Name: **prandtl_ptx_air**
 Subroutine with function value: **REAL*8 FUNCTION PRANDTLPTXAIR(P,T,X)**
 Variable Types: **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

prandtl_ptx_air or **PRANDTLPTXAIR** – Prandtl-number $Pr = \frac{\nu}{a} = \frac{\eta \cdot c_p}{\lambda}$

Range of validity

Temperature range: from -213.4 °C (59.75 K) to 1726.85 °C (2000 K)
 Pressure range: from 0.00001 bar to 20000 bar

Details on the vapor fraction x

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

Single phase region

If the state point to be calculated is located in the single phase region (liquid or superheated steam) $x = -1$ must be entered as a pro-forma value.

Saturation lines

If the state point to be calculated is located on the saturated liquid line, the value 0 has to be entered for x . When calculating saturated steam (saturated vapor line) $x = 1$ has to be entered. The calculation for x values between 0 and 1 is not possible. It is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x (0 or 1). When p and t and x are entered as given values, the program will consider whether p and t fit together. If it is not the case the calculation of the function Pr will result in -1000 .

Boundaries for wet steam region

The boundaries for the wet steam region are illustrated in Figure 1.1 and Figure 1.2.

Results for wrong input values

Result **prandtl_ptx_air** = **-1000** or **PRANDTLPTXAIR** = **-1000** for the following input values:

Single phase region: $p > p_{\max} = 20000$ or $p < p_{\min} = 0.00001$ bar or
 ($x = -1$) $t > t_{\max} = 1726.85$ °C or $t < t_{\min} = -213.4$ °C or $t < t_{\text{mel}}(p)$

Saturated liquid line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188$ °C or $t < t_{\min} = -213.4$ °C or
 ($x = 0$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\min, l} = 0.052646$ bar or
 at $p < p_{\text{mcb}} = 37.9195$ bar and $p > p_{\min, l} = 0.052646$ bar and
 $|t - t_{\text{sl}}(p)| > 0.1$ K

Saturated vapor line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188 \text{ °C}$ or $t < t_{\text{min}} = -213.4 \text{ °C}$ or
 ($x = 1$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195 \text{ bar}$ or $p < p_{\text{min,v}} = 0.024316 \text{ bar}$ or
 at $p < p_{\text{mcb}} = 37.9195 \text{ bar}$ and $p > p_{\text{min,v}} = 0.024316 \text{ bar}$ and
 $|t - t_{\text{sv}}(p)| > 0.1 \text{ K}$

References

[1], [2]

Pressure on the Saturated Liquid Line $p_{sl} = f(t)$

Function Name: **psl_t_air**
 Subroutine with function value: **REAL*8 FUNCTION PSLTAIR(T)**
 Variable Types: **REAL*8 T**

Input values

T - Temperature t in °C

Result

psl_t_air or **PSLTAIR** – Pressure on the saturated liquid line p_{sl} in bar

Range of validity

Temperature range: from $t_{\min} = -213.4$ °C to $t_{\text{mct}} = -140.5188$ °C

Details on the saturation lines

The boundaries for the wet steam region are illustrated in Figure 1.1 and Figure 1.2. In order that the function $p_{sv} = f(t)$ will not be double-valued in the critical region, the saturated vapor line ($x = 1$) is partially represented by the function $p_{sl} = f(t)$ calculating pressures on the saturated liquid line ($x = 0$). This concerns the segment between the critical point and the maxcondentherm point.

Results for wrong input values

Result **psl_t_air** = **-1000** or **PSLTAIR** = **-1000** for the following input values:

$t > t_{\text{mct}} = -140.5188$ °C or $t < t_{\min} = -213.4$ °C

Reference

[1]

Pressure on the Saturated Vapor Line $p_{sv} = f(t)$

Function Name: **psv_t_air**
 Subroutine with function value: **REAL*8 FUNCTION PSVTAIR(T)**
 Variable Types: **REAL*8 T**

Input values

T - Temperature t in °C

Result

psv_t_air or **PSVTAIR** – Pressure on the saturated vapor line p_{sv} in bar

Range of validity

Temperature range: from $t_{\min} = -213.4$ °C to $t_{\text{mct}} = -140.5188$ °C

Details on the saturation lines

The boundaries for the wet steam region are illustrated in Figure 1.1 and Figure 1.2. In order that the function $p_{sv} = f(t)$ will not be double-valued in the critical region, the saturated vapor line ($x = 1$) is partially represented by the function $p_{sl} = f(t)$ calculating pressures on the saturated liquid line ($x = 0$). This concerns the segment between the critical point and the maxcondentherm point.

Results for wrong input values

Result **psv_t_air** = **-1000** or **PSVTAIR** = **-1000** for the following input values:

$t > t_{\text{mct}} = -140.5188$ °C or $t < t_{\min} = -213.4$ °C

Reference

[1]

Density $\rho = f(p, t, x)$

Function Name: **rho_ptx_air**
 Subroutine with function value: **REAL*8 FUNCTION RHOPTXAIR(P,T,X)**
 Variable Types: **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

rho_ptx_air or **RHOPTXAIR** – Density $\rho = \frac{1}{v}$ in kg/m³

Range of validity

Temperature range: from -213.4 °C (59.75 K) to 1726.85 °C (2000 K)
 Pressure range: from 0.00001 bar to 20000 bar

Details on the vapor fraction x and on the calculation of wet steam

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

Single phase region

If the state point to be calculated is located in the single phase region (liquid or superheated steam) $x = -1$ must be entered as a pro-forma value.

Wet steam region

When calculating wet steam, a value between 0 and 1 ($x = 0$ for saturated liquid, $x = 1$ for saturated steam) must be entered. It is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. When p and t and x are entered as given values, the program will consider whether p and t fit together. If it is not the case the calculation of the function ρ will result in -1000 .

Boundaries for wet steam region

The boundaries for the wet steam region are illustrated in Figure 1.1 and Figure 1.2.

Results for wrong input values

Result **rho_ptx_air** = **-1000** or **RHOPTXAIR** = **-1000** for the following input values:

Single phase region: $p > p_{\max} = 20000$ or $p < p_{\min} = 0.00001$ bar or
 ($x = -1$) $t > t_{\max} = 1726.85$ °C or $t < t_{\min} = -213.4$ °C or $t < t_{\text{mel}}(p)$

Saturated liquid line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188$ °C or $t < t_{\min} = -213.4$ °C or
 ($x = 0$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\min, \text{l}} = 0.052646$ bar or
 at $p < p_{\text{mcb}} = 37.9195$ bar and $p > p_{\min, \text{l}} = 0.052646$ bar and
 $|t - t_{\text{sl}}(p)| > 0.1$ K

Saturated vapor line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188$ °C or $t < t_{\min} = -213.4$ °C or
 ($x = 1$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\min, \text{v}} = 0.024316$ bar or

at $p < p_{\text{mcb}} = 37.9195 \text{ bar}$ and $p > p_{\text{min,v}} = 0.024316 \text{ bar}$ and
 $|t - t_{\text{sv}}(p)| > 0.1 \text{ K}$

Reference

[1]

Specific Entropy $s = f(p, t, x)$

Function Name: **s_ptx_air**
 Subroutine with function value: **REAL*8 FUNCTION SPTXAIR(P,T,X)**
 Variable Types: **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

s_ptx_air or **SPTXAIR** – Specific entropy s in kJ/kg

Range of validity

Temperature range: from -213.4 °C (59.75 K) to 1726.85 °C (2000 K)
 Pressure range: from 0.00001 bar to 20000 bar

Details on the vapor fraction x and on the calculation of wet steam

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

Single phase region

If the state point to be calculated is located in the single phase region (liquid or superheated steam) $x = -1$ must be entered as a pro-forma value.

Wet steam region

When calculating wet steam, a value between 0 and 1 ($x = 0$ for saturated liquid, $x = 1$ for saturated steam) must be entered. It is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. When p and t and x are entered as given values, the program will consider whether p and t fit together. If it is not the case the calculation of the function s will result in -1000 .

Boundaries for wet steam region

The boundaries for the wet steam region are illustrated in Figure 1.1 and Figure 1.2.

Results for wrong input values

Result **s_ptx_air** = **-1000** or **SPTXAIR** = **-1000** for the following input values:

Single phase region: ($x = -1$)	$p > p_{\max} = 20000$ or $p < p_{\min} = 0.00001$ bar or $t > t_{\max} = 1726.85$ °C or $t < t_{\min} = -213.4$ °C or $t < t_{\text{mel}}(p)$
Saturated liquid line: ($x = 0$)	at $p = -1$ and $t > t_{\text{mct}} = -140.5188$ °C or $t < t_{\min} = -213.4$ °C or at $t = -1$ and $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\min, \text{l}} = 0.052646$ bar or at $p < p_{\text{mcb}} = 37.9195$ bar and $p > p_{\min, \text{l}} = 0.052646$ bar and $ t - t_{\text{sl}}(p) > 0.1$ K
Saturated vapor line: ($x = 1$)	at $p = -1$ and $t > t_{\text{mct}} = -140.5188$ °C or $t < t_{\min} = -213.4$ °C or at $t = -1$ and $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\min, \text{v}} = 0.024316$ bar or

at $p < p_{\text{mcb}} = 37.9195 \text{ bar}$ and $p > p_{\text{min,v}} = 0.024316 \text{ bar}$ and
 $|t - t_{\text{sv}}(p)| > 0.1 \text{ K}$

Reference

[1]

Temperature on the Melting Curve $t_{\text{mel}} = f(p)$

Function Name: **tmel_p_air**
 Subroutine with function value: **REAL*8 FUNCTION TMELPAIR(P)**
 Variable Types: **REAL*8 P**

Input values

P – Pressure p in bar

Result

tmel_p_air or **TMELPAIR** – Temperature on the melting curve t_{mel} in °C

Range of validity

Pressure range: from $p_t = p_{\text{min},I} = 0.052646$ bar to $p_{\text{max}} = 20000$ bar

Results for wrong input values

Result **tmel_t_air** = **-1000** or **TMELPAIR** = **-1000** for the following input values:

$p > p_{\text{max}} = 20000$ bar or $p < p_{\text{min},I} = 0.052646$ bar

Reference

[1]

Backward Function: Temperature $t = f(p, h)$

Function Name: **t_ph_air**
 Subroutine with function value: **REAL*8 FUNCTION TPHAIR(P,H)**
 Variable Types: **REAL*8 P,H**

Input values

P - Pressure p in bar
H - Specific enthalpy h in kJ/kg

Result

t_ph_air or **TPHAIR** – Temperature t in °C

Range of validity

Temperature range: from -213.4 °C (59.75 K) to 1726.85 °C (2000 K)
 Pressure range: from 0.00001 bar to 20000 bar

Details on the calculation of wet steam

The wet steam region is calculated automatically by the subprograms. Using the given values for p and h the program determines whether the state point to be calculated is located within the single phase region (liquid or superheated steam) or the wet steam region. After that, the calculation is carried out for the specific region.

The boundaries for the wet steam region are illustrated in Figure 1.1 and Figure 1.2.

Results for wrong input values

Result **t_ph_air = -1000** or **TPHAIR = -1000** for the following input values:

Single phase region: $p > p_{\max} = 20000$ or $p < p_{\min} = 0.00001$ bar or
 $t > t_{\max} = 1726.85$ °C or $t < t_{\min} = -213.4$ °C or $t < t_{\text{mel}}(p)$

Saturated liquid line: at $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\text{min,l}} = 0.052646$ bar or
 at result $t > t_{\text{mcb}} = -140.5539$ °C or $t < t_{\min} = -213.4$ °C

Saturated vapor line: at $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\text{min,v}} = 0.024316$ bar or
 at result $t > t_{\text{mcb}} = -140.5539$ °C or $t < t_{\min} = -213.4$ °C or

Reference

[1]

Backward Function: Temperature $t = f(p, s)$

Function Name: **t_ps_air**
 Subroutine with function value: **REAL*8 FUNCTION TPSAIR(P,S)**
 Variable Types: **REAL*8 P,S**

Input values

P - Pressure p in bar
S - Specific entropy s in kJ/(kg·K)

Result

t_ps_air or **TPSAIR** – Temperature t in °C

Range of validity

Temperature range: from -213.4 °C (59.75 K) to 1726.85 °C (2000 K)
 Pressure range: from 0.00001 bar to 20000 bar

Details on the calculation of wet steam

The wet steam region is calculated automatically by the subprograms. Using the given values for p and s the program determines whether the state point to be calculated is located within the single phase region (liquid or superheated steam) or the wet steam region. After that, the calculation is carried out for the specific region.

The boundaries for the wet steam region are illustrated in Figure 1.1 and Figure 1.2.

Results for wrong input values

Result **t_ps_air = -1000** or **TPSAIR = -1000** for the following input values:

Single phase region: $p > p_{\max} = 20000$ or $p < p_{\min} = 0.00001$ bar or
 $t > t_{\max} = 1726.85$ °C or $t < t_{\min} = -213.4$ °C or $t < t_{\text{mel}}(p)$

Saturated liquid line: at $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\text{mcb}} = 0.052646$ bar or
 at result $t > t_{\text{mcb}} = -140.5539$ °C or $t < t_{\min} = -213.4$ °C

Saturated vapor line: at $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\text{min,v}} = 0.024316$ bar or
 at result $t > t_{\text{mcb}} = -140.5539$ °C or $t < t_{\min} = -213.4$ °C or

Reference

[1]

Temperature on the Saturated Liquid Line $t_{sl} = f(p)$

Function Name: **tsl_p_air**
 Subroutine with function value: **REAL*8 FUNCTION TSLPAIR(P)**
 Variable Types: **REAL*8 P**

Input values

P - Pressure p in bar

Result

tsl_p_air or **TSLPAIR** – Temperature on the saturated liquid line t_{sl} in °C

Range of validity

Pressure range: from $p_{\min,l} = 0.052646$ bar to $p_{\text{mcb}} = 37.9195$ bar

Details on the saturation lines

The boundaries for the wet steam region are illustrated in Figure 1.1 and Figure 1.2. In order that the function $t_{sv} = f(p)$ will not be double-valued in the critical region, the saturated vapor line ($x = 1$) is partially represented by the function $t_{sl} = f(p)$ calculating temperatures on the saturated liquid line ($x = 0$). This concerns the segment between the critical point and the maxcondenbar point.

Results for wrong input values

Result **tsl_p_air** = **-1000** or **TSLPAIR** = **-1000** for the following input values:

$p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\min,l} = 0.052646$ bar

Reference

[1]

Temperature on the Saturated Vapor Line $t_{sv} = f(p)$

Function Name: **tsv_p_air**
 Subroutine with function value: **REAL*8 FUNCTION TSVPAIR(P)**
 Variable Types: **REAL*8 P**

Input values

P - Pressure p in bar

Result

tsv_p_air or **TSVPAIR** – Temperature on the saturated vapor line t_{sv} in °C

Range of validity

Pressure range: from $p_{\min,v} = 0.024316$ bar to $p_{\text{mcb}} = 37.9195$ bar

Details on the saturation lines

The boundaries for the wet steam region are illustrated in Figure 1.1 and Figure 1.2. In order that the function $t_{sv} = f(p)$ will not be double-valued in the critical region, the saturated vapor line ($x = 1$) is partially represented by the function $t_{sl} = f(p)$ calculating temperatures on the saturated liquid line ($x = 0$). This concerns the segment between the critical point and the maxcondenbar point.

Results for wrong input values

Result **tsv_p_air** = **−1000** or **TSVPAIR** = **−1000** for the following input values:

$p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\min,v} = 0.024316$ bar

Reference

[1]

Specific Internal Energy $u = f(p, t, x)$

Function Name: **u_ptx_air**
 Subroutine with function value: **REAL*8 FUNCTION UPTXAIR(P,T,X)**
 Variable Types: **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

u_ptx_air or **UPTXAIR** – Specific internal energy u in kJ/kg

Range of validity

Temperature range: from -213.4 °C (59.75 K) to 1726.85 °C (2000 K)
 Pressure range: from 0.00001 bar to 20000 bar

Details on the vapor fraction x and on the calculation of wet steam

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

Single phase region

If the state point to be calculated is located in the single phase region (liquid or superheated steam) $x = -1$ must be entered as a pro-forma value.

Wet steam region

When calculating wet steam, a value between 0 and 1 ($x = 0$ for saturated liquid, $x = 1$ for saturated steam) must be entered. It is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. When p and t and x are entered as given values, the program will consider whether p and t fit together. If it is not the case the calculation of the function u will result in -1000 .

Boundaries for wet steam region

The boundaries for the wet steam region are illustrated in Figure 1.1 and Figure 1.2.

Results for wrong input values

Result **u_ptx_air** = **-1000** or **UPTXAIR** = **-1000** for the following input values:

Single phase region: ($x = -1$)	$p > p_{\max} = 20000$ or $p < p_{\min} = 0.00001$ bar or $t > t_{\max} = 1726.85$ °C or $t < t_{\min} = -213.4$ °C or $t < t_{\text{mel}}(p)$
Saturated liquid line: ($x = 0$)	at $p = -1$ and $t > t_{\text{mct}} = -140.5188$ °C or $t < t_{\min} = -213.4$ °C or at $t = -1$ and $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\min, \text{l}} = 0.052646$ bar or at $p < p_{\text{mcb}} = 37.9195$ bar and $p > p_{\min, \text{l}} = 0.052646$ bar and $ t - t_{\text{sl}}(p) > 0.1$ K
Saturated vapor line: ($x = 1$)	at $p = -1$ and $t > t_{\text{mct}} = -140.5188$ °C or $t < t_{\min} = -213.4$ °C or at $t = -1$ and $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\min, \text{v}} = 0.024316$ bar or

at $p < p_{\text{mcb}} = 37.9195 \text{ bar}$ and $p > p_{\text{min,v}} = 0.024316 \text{ bar}$ and
 $|t - t_{\text{sv}}(p)| > 0.1 \text{ K}$

Reference

[1]

Specific Volume $v = f(p, t, x)$

Function Name: **v_ptx_air**
 Subroutine with function value: **REAL*8 FUNCTION VPTXAIR(P,T,X)**
 Variable Types: **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

v_ptx_air or **VPTXAIR** – Specific volume v in m³/kg

Range of validity

Temperature range: from -213.4 °C (59.75 K) to 1726.85 °C (2000 K)
 Pressure range: from 0.00001 bar to 20000 bar

Details on the vapor fraction x and on the calculation of wet steam

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

Single phase region

If the state point to be calculated is located in the single phase region (liquid or superheated steam) $x = -1$ must be entered as a pro-forma value.

Wet steam region

When calculating wet steam, a value between 0 and 1 ($x = 0$ for saturated liquid, $x = 1$ for saturated steam) must be entered. It is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. When p and t and x are entered as given values, the program will consider whether p and t fit together. If it is not the case the calculation of the function v will result in -1000 .

Boundaries for wet steam region

The boundaries for the wet steam region are illustrated in Figure 1.1 and Figure 1.2.

Results for wrong input values

Result **v_ptx_air = -1000** or **VPTXAIR = -1000** for the following input values:

Single phase region:	$p > p_{\max} = 20000$ or $p < p_{\min} = 0.00001$ bar or
($x = -1$)	$t > t_{\max} = 1726.85$ °C or $t < t_{\min} = -213.4$ °C or $t < t_{\text{mel}}(p)$
Saturated liquid line:	at $p = -1$ and $t > t_{\text{mct}} = -140.5188$ °C or $t < t_{\min} = -213.4$ °C or
($x = 0$)	at $t = -1$ and $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\min, \text{l}} = 0.052646$ bar or
	at $p < p_{\text{mcb}} = 37.9195$ bar and $p > p_{\min, \text{l}} = 0.052646$ bar and
	$ t - t_{\text{sl}}(p) > 0.1$ K
Saturated vapor line:	at $p = -1$ and $t > t_{\text{mct}} = -140.5188$ °C or $t < t_{\min} = -213.4$ °C or
($x = 1$)	at $t = -1$ and $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\min, \text{v}} = 0.024316$ bar or

at $p < p_{\text{mcb}} = 37.9195 \text{ bar}$ and $p > p_{\text{min,v}} = 0.024316 \text{ bar}$ and
 $|t - t_{\text{sv}}(p)| > 0.1 \text{ K}$

Reference

[1]

Isentropic Speed of Sound $w = f(p, t, x)$

Function Name: **w_ptx_air**
 Subroutine with function value: **REAL*8 FUNCTION WPTXAIR(P,T,X)**
 Variable Types: **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

w_ptx_air or **WPTXAIR** – Isentropic speed of sound w in m/s

Range of validity

Temperature range: from -213.4 °C (59.75 K) to 1726.85 °C (2000 K)
 Pressure range: from 0.00001 bar to 20000 bar

Details on the vapor fraction x

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

Single phase region

If the state point to be calculated is located in the single phase region (liquid or superheated steam) $x = -1$ must be entered as a pro-forma value.

Saturation lines

If the state point to be calculated is located on the saturated liquid line, the value 0 has to be entered for x . When calculating saturated steam (saturated vapor line) $x = 1$ has to be entered. The calculation for x values between 0 and 1 is not possible. It is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x (0 or 1). When p and t and x are entered as given values, the program will consider whether p and t fit together. If it is not the case the calculation of the function w will result in -1000 .

Boundaries for wet steam region

The boundaries for the wet steam region are illustrated in Figure 1.1 and Figure 1.2.

Results for wrong input values

Result **w_ptx_air** = **-1000** or **WPTXAIR** = **-1000** for the following input values:

Single phase region: $p > p_{\max} = 20000$ or $p < p_{\min} = 0.00001$ bar or
 ($x = -1$) $t > t_{\max} = 1726.85$ °C or $t < t_{\min} = -213.4$ °C or $t < t_{\text{mel}}(p)$
 Saturated liquid line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188$ °C or $t < t_{\min} = -213.4$ °C or
 ($x = 0$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195$ bar or $p < p_{\min, \text{l}} = 0.052646$ bar or
 at $p < p_{\text{mcb}} = 37.9195$ bar and $p > p_{\min, \text{l}} = 0.052646$ bar and
 $|t - t_{\text{sl}}(p)| > 0.1\text{K}$

Saturated vapor line: at $p = -1$ and $t > t_{\text{mct}} = -140.5188 \text{ °C}$ or $t < t_{\text{min}} = -213.4 \text{ °C}$ or
 ($x = 1$) at $t = -1$ and $p > p_{\text{mcb}} = 37.9195 \text{ bar}$ or $p < p_{\text{min,v}} = 0.024316 \text{ bar}$ or
 at $p < p_{\text{mcb}} = 37.9195 \text{ bar}$ and $p > p_{\text{min,v}} = 0.024316 \text{ bar}$ and
 $|t - t_{\text{sv}}(p)| > 0.1 \text{ K}$

References

[1], [2]

Backward Function: Vapor Fraction $x = f(p,h)$

Function Name: **x_ph_air**
 Subroutine with function value: **REAL*8 FUNCTION XPHAIR(P,H)**
 Variable Types: **REAL*8 P,H**

Input values

P - Pressure p in bar
H - Specific enthalpy h in kJ/kg

Result

x_ph_air or **XPHAIR** – Vapor fraction x in (kg saturated steam)/(kg wet steam)

Range of validity

Temperature range: from -213.4 °C (59.75 K) to 1726.85 °C (2000 K)
 Pressure range: from 0.00001 bar to 20000 bar

Details on the calculation of wet steam

The wet steam region is calculated automatically by the subprograms. Using the given values of p and h , the program determines whether the state point to be calculated is located within the single phase region (liquid or superheated steam) or the wet steam region. When the given state point is located in the wet steam region, x will be calculated, otherwise the result is set to $x = -1$

Results for wrong input values

Result **x_ph_air = -1** or **XPHAIR = -1** for the following input values:

$$p > p_{\text{mcb}} = 37.9195 \text{ bar or } p < p_{\text{min,v}} = 0.024316 \text{ bar}$$

Reference:

[1]

Backward Function: Vapor Fraction $x = f(p,s)$

Function Name: **x_ps_air**
 Subroutine with function value: **REAL*8 FUNCTION XPSAIR(P,S)**
 Variable Types: **REAL*8 P,S**

Input values

P - Pressure p in bar
S - Specific entropy s in kJ/(kg·K)

Result

x_ps_air or **XPSAIR** – Vapor fraction x in (kg saturated steam)/(kg wet steam)

Range of validity

Temperature range: from -213.4 °C (59.75 K) to 1726.85 °C (2000 K)
 Pressure range: from 0.00001 bar to 20000 bar

Details on the calculation of wet steam

The wet steam region is calculated automatically by the subprograms. Using the given values of p and s , the program determines whether the state point to be calculated is located within the single phase region (liquid or superheated steam) or the wet steam region. When the given state point is located in the wet steam region, x will be calculated, otherwise the result is set to $x = -1$

Results for wrong input values

Result **x_ps_air = -1** or **XPSAIR = -1** for the following input values:

$$p > p_{\text{mcb}} = 37.9195 \text{ bar or } p < p_{\text{min,v}} = 0.024316 \text{ bar}$$

Reference:

[1]



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

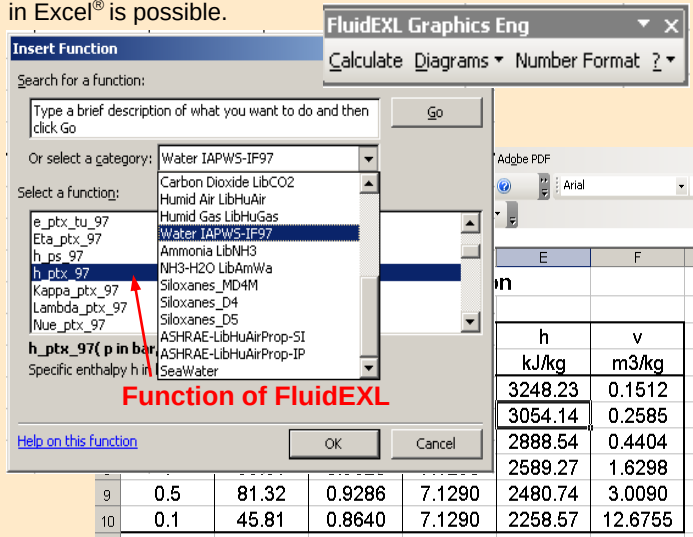
Steam, Water and Ice	Humid Combustion Gas Mixtures	Humid Air
Library LibIF97 - Industrial Formulation IAPWS-IF97 (Revision 2007) - Supplementary Standards - IAPWS-IF97-S01 - IAPWS-IF97-S03rev - IAPWS-IF97-S04 - IAPWS-IF97-S05 - IAPWS Revised Advisory Note No. 3 on Thermodyn. Derivatives (2008) - Ice from IAPWS-Formulation 2006	Library LibHuGas Ideal mixture of the real fluids: CO ₂ - Span and Wagner O ₂ - Schmidt and Wagner H ₂ O - IAPWS-95 Ar - Tegeler et al. N ₂ - Span et al. and of the ideal gases: SO ₂ , CO, Ne (scientific equations of Bucker et al.) Consideration of Dissociation from VDI 4670 and Poynting effect Library LibIDGAS Ideal gas mixture calculated from VDI-Guideline 4670	Library LibHuAir Ideal mixture of the real fluids: - Dry air from Lemmon et al. - Steam and water from IAPWS-95 Consideration of - Dissociation from VDI-Guideline 4670 - Poynting effect Library LibIdAir Ideal gas mixture (VDI-Guideline 4670)

Carbon Dioxide Library LibCO2 Formulation of Span and Wagner (1994)	Ideal Gas Mixtures Library LibIdGasMix 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 VDI-Guideline 4670	Seawater Library LibSeaWa IAPWS Formulation 2008 of Feistel and IAPWS-IF97
Hydrogen Library LibH2 Formulation of Leachman et al. (2007)		Ammonia Library LibNH3 Formulation of Tillner-Roth (1995)
Methanol Library LibCH3OH Formulation of de Reuck and Craven (1993)		Propane Library LibPropan Formulation of Lemmon et al. (2007)
Ethanol Library LibC2H5OH Formulation of Dillon and Pennoncello (2004)		Helium Library LibHe Formulation of McCarty and Arp (1990)
	Dry Air Library LibRealAir Formulation of Lemmon et al. (2000)	
	Nitrogen Library LibN2 Formulation of Span et al. (2000)	

Siloxanes as ORC Working Fluids	Mixtures for Absorption Processes	Refrigerants
C₆H₁₈OSi₂ Library LibMM C₈H₂₄O₄Si₄ Library LibD4 C₁₀H₃₀O₅Si₅ Library LibD5 C₁₂H₃₆O₆Si₆ Library LibD6 C₈H₂₄O₂Si₃ Library LibMDM C₁₀H₃₀O₃Si₄ Library LibMD2M C₁₂H₃₆O₄Si₅ Library LibMD3M C₁₄H₄₂O₅Si₆ Library LibMD4M Formulations of Colonna et al. (2006 and 2008)	Library LibAmWa Ammonia/Water Mixtures IAPWS Guideline 2001 of Tillner-Roth and Friend (1998) Helmholtz energy equation for the mixing term (useable for calculating Kalina Cycle) Library LibWaLi Water/Lithium Bromide Mixtures Formulation of Kim and Infante Ferreira (2004) Gibbs energy equation for the mixing term	Library LibR134a R134a Formulation of Tillner-Roth and Baehr (1994) Library LibButan_Iso Iso-Butane Formulation of Bucker et al. (2003) Library LibButan_n n-Butane Formulation of Bucker et al. (2003)

Add-In FluidEXL for Excel®

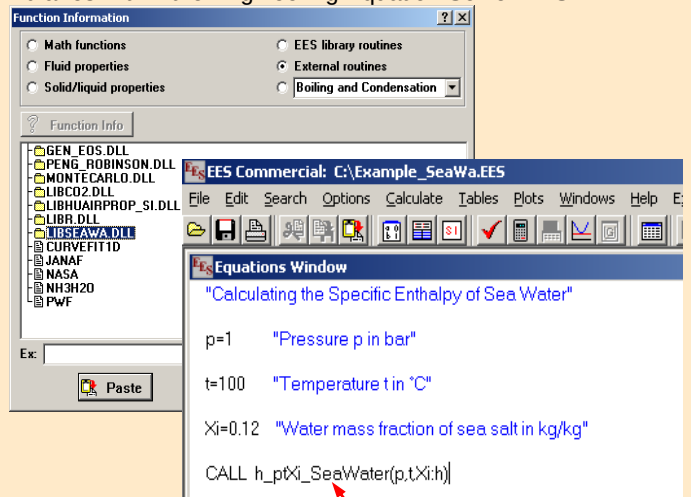
Using the Add-In FluidEXL a direct call of the property functions in Excel® is possible.



Function of FluidEXL

Add-In FluidEES for EES®

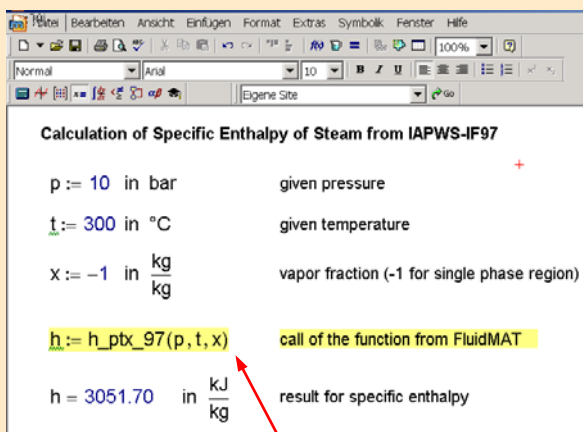
The Add-In FluidEES allows to call the functions of the property libraries within the Engineering Equation Solver EES®.



Function of FluidEES

Add-In FluidMAT for Mathcad®

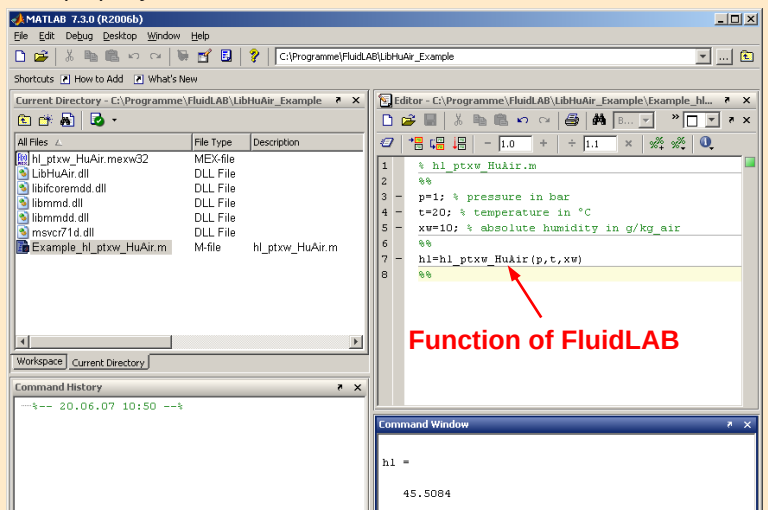
Using the Add-on FluidMAT, the functions of the property libraries can be used in Mathcad®.



Function of FluidMAT

Add-In FluidLAB for MATLAB®

The property functions can be called in MATLAB®.



Function of FluidLAB

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

Thermodynamic Properties

- Saturation 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

Thermodynamic Derivatives

- Partial derivatives can be calculated

Transport Properties

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

Backward Functions

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

For information please contact:

Zittau/Goerlitz University of Applied Sciences
Department of Technical Thermodynamics
Prof. Hans-Joachim Kretzschmar
Dr. Ines Stoecker
Theodor-Koerner-Allee 16
02763 Zittau, Germany

E-mail: hj.kretzschmar@hs-zigr.de
Internet: www.thermodynamics-zittau.de
Phone: +49-3583-61-1846
Fax.: +49-3583-61-1846

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

5. References

- [1] Lemmon, E. W.; Jacobsen, R. T.; Friend D. G.: *Thermodynamic Properties of Air and Mixtures of Nitrogen, Argon, and Oxygen From 60 to 2000 K at Pressures to 2000 MPa*. Journal of Physical and Chemical Reference Data, Volume 29, No. 3, 2000.
- [2] Lemmon, E. W.; Jacobsen, R. T.: *Viscosity and Thermal Conductivity Equations for Nitrogen, Oxygen, Argon, and Air*. International Journal of Thermophysics, Volume 25, No. 1, 2004.

6. Satisfied Customers

Date: 10/2011

The following companies and institutions use the property libraries

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

2011

Lopez, Munguia, Spain	10/2011
University of KwaZulu-Natal, Westville, South Africa	10/2011
Voith, Heidenheim	09/2011
SpgBe Montreal, Canada	09/2011
SPG TECH, Montreuil Cedex, France	09/2011
Voith, Heidenheim-Mergelstetten	09/2011
MTU Aero Engines, Munich	08/2011
MIBRAG, Zeitz	08/2011
RWE, Essen	07/2011
Fels, Elingerode	07/2011
Weihenstephan University of Applied Sciences	07/2011, 09/2011, 10/2011
Forschungszentrum Juelich	07/2011
RWTH Aachen University	07/2011, 08/2011
Voith, Zschopau	07/2011
INNEO Solutions, Ellwangen	06/2011
Caliqua, Basel, Switzerland	06/2011
Technical University of Freiberg	06/2011
Fichtner IT Consulting, Stuttgart	05/2011, 06/2011, 08/2011
Salzgitter Flachstahl, Salzgitter	05/2011
Helbling Beratung & Bauplanung, Zurich, Switzerland	05/2011
INEOS, Cologne	04/2011
Enseleit Consulting Engineers, Siebigerode	04/2011

Witt Consulting Engineers, Stade	03/2011
Helbling, Zurich, Switzerland	03/2011
MAN Diesel, Copenhagen, Denmark	03/2011
AGO, Kulmbach	03/2011
University of Duisburg	03/2011, 06/2011
CCP, Marburg	03/2011
BASF, Ludwigshafen	02/2011
ALSTOM Power, Baden, Switzerland	02/2011
Universität der Bundeswehr, Munich	02/2011
Calorifer, Elgg, Switzerland	01/2011
STRABAG, Vienna, Austria	01/2011
TUEV Sued, Munich	01/2011
ILK Dresden	01/2011
Technical University of Dresden	01/2011, 05/2011, 06/2011, 08/2011

2010

Umweltinstitut Neumarkt	12/2010
YIT Austria, Vienna, Austria	12/2010
MCI Innsbruck, Austria	12/2010
University of Stuttgart	12/2010
HS Cooler, Wittenburg	12/2010
Visteon, Novi Jicin, Czech Republic	12/2010
CompuWave, Brunntal	12/2010
Stadtwerke Leipzig	12/2010
MCI Innsbruck, Austria	12/2010
EVONIK Energy Services, Zwingenberg	12/2010
Caliqua, Basel, Switzerland	11/2010
Shanghai New Energy Resources Science & Technology, China	11/2010
Energieversorgung Halle	11/2010
Hochschule für Technik Stuttgart, University of Applied Sciences	11/2010
Steinmueller, Berlin	11/2010
Amberg-Weiden University of Applied Sciences	11/2010
AREVA NP, Erlangen	10/2010
MAN Diesel, Augsburg	10/2010
KRONES, Neutraubling	10/2010

Vaillant, Remscheid	10/2010
PC Ware, Leipzig	10/2010
Schubert Consulting Engineers, Weißenberg	10/2010
Fraunhofer Institut UMSICHT, Oberhausen	10/2010
Behringer Consulting Engineers, Tagmersheim	09/2010
Saacke, Bremen	09/2010
WEBASTO, Neubrandenburg	09/2010
Concordia University, Montreal, Canada	09/2010
Compañía Eléctrica de Sochagota, Bogota, Colombia	08/2010
Hannover University of Applied Sciences	08/2010
ERGION, Mannheim	07/2010
Fichtner IT Consulting, Stuttgart	07/2010
TF Design, Matieland, South Africa	07/2010
MCE, Berlin	07/2010, 12/2010
IPM, Zittau/Goerlitz University of Applied Sciences	06/2010
TUEV Sued, Dresden	06/2010
RWE IT, Essen	06/2010
Glen Dimplex, Kulmbach	05/2010, 07/2010 10/2010
Hot Rock, Karlsruhe	05/2010
Darmstadt University of Applied Sciences	05/2010
Voith, Heidenheim	04/2010
CombTec, Zittau	04/2010
University of Glasgow, Great Britain	04/2010
Universitaet der Bundeswehr, Munich	04/2010
Technical University of Hamburg-Harburg	04/2010
Vattenfall Europe, Berlin	04/2010
HUBER Consulting Engineers, Berching	04/2010
VER, Dresden	04/2010
CCP, Marburg	03/2010
Offenburg University of Applied Sciences	03/2010
Technical University of Berlin	03/2010
NIST Boulder CO, USA	03/2010
Technical University of Dresden	02/2010
Siemens Energy, Nuremberg	02/2010

Augsburg University of Applied Sciences	02/2010
ALSTOM Power, Baden, Switzerland	02/2010, 05/2010
MIT Massachusetts Institute of Technology Cambridge MA, USA	02/2010
Wieland Werke, Ulm	01/2010
Siemens Energy, Goerlitz	01/2010, 12/2010
Technical University of Freiberg	01/2010
ILK, Dresden	01/2010, 12/2010
Fischer-Uhrig Consulting Engineers, Berlin	01/2010

2009

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

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

2008

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

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

2007

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

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

2006

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

Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	05/2006
Fichtner Consulting & IT Stuttgart (company licenses and distribution)	05/2006
Suedzucker, Ochsenfurt	06/2006
M&M Turbine Technology, Bielefeld	06/2006
Feistel Engineering, Volkach	07/2006
ThyssenKrupp Marine Systems, Kiel	07/2006
Caliqua, Basel, Switzerland (company license)	09/2006
Atlas-Stord, Rodovre, Denmark	09/2006
Konstanz University of Applied Sciences, Course of Studies Construction and Development	10/2006
Siemens Power Generation, Duisburg	10/2006
Hannover University of Applied Sciences, Department of Mechanical Engineering	10/2006
Siemens Power Generation, Berlin	11/2006
Zikesch Armaturentechnik, Essen	11/2006
Wismar University of Applied Sciences, Seafaring Department	11/2006
BASF, Schwarzheide	12/2006
Enertech Energie und Technik, Radebeul	12/2006

2005

TUEV Nord, Hannover	01/2005
J.H.K Plant Engineering and Service, Bremerhaven	01/2005
Electrowatt-EKONO, Zurich, Switzerland	01/2005
FCIT, Stuttgart	01/2005
Energietechnik Leipzig (company license)	02/2005, 04/2005, 07/2005
eta Energieberatung, Pfaffenhofen	02/2005
FZR Forschungszentrum, Rossendorf/Dresden	04/2005
University of Saarbruecken	04/2005
Technical University of Dresden Professorship of Thermic Energy Machines and Plants	04/2005
Grenzebach BSH, Bad Hersfeld	04/2005
TUEV Nord, Hamburg	04/2005
Technical University of Dresden, Waste Management	05/2005
Siemens Power Generation, Goerlitz	05/2005

Duesseldorf University of Applied Sciences, Department of Mechanical Engineering and Process Engineering	05/2005
Redacom, Nidau, Switzerland	06/2005
Dumas Verfahrenstechnik, Hofheim	06/2005
Alensys Engineering, Erkner	07/2005
Stadtwerke Leipzig	07/2005
SaarEnergie, Saarbruecken	07/2005
ALSTOM ITC, Rugby, Great Britain	08/2005
Technical University of Cottbus, Chair in Power Plant Engineering	08/2005
Vattenfall Europe, Berlin (group license)	08/2005
Technical University of Berlin	10/2005
Basel University of Applied Sciences, Department of Mechanical Engineering, Switzerland	10/2005
Midiplan, Bietigheim-Bissingen	11/2005
Technical University of Freiberg, Chair in Hydrogeology	11/2005
STORA ENSO Sachsen, Eilenburg	12/2005
Energieversorgung Halle (company license)	12/2005
KEMA IEV, Dresden	12/2005

2004

Vattenfall Europe (group license)	01/2004
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

2000

SOFBID, Zwingenberg (general EBSILON program license)	01/2000
AG KKK - PGW Turbo, Leipzig	01/2000

PREUSSAG NOELL, Wuerzburg	01/2000
M&M Turbine Technology, Bielefeld	01/2000
IBR Engineering Reis, Nittendorf-Undorf	02/2000
GK, Hannover	03/2000
KRUPP-UHDE, Dortmund (company license)	03/2000
UMAG W. UDE, Husum	03/2000
VEAG, Berlin (group license)	03/2000
Thinius Engineering, Erkrath	04/2000
SaarEnergie, Saarbruecken	05/2000, 08/2000
DVO Data Processing Service, Oberhausen	05/2000
RWTH Aachen University	06/2000
VAUP Process Automation, Landau	08/2000
Knuerr-Lommatec, Lommatzsch	09/2000
AVACON, Helmstedt	10/2000
Compania Electrica, Bogota, Colombia	10/2000
G.U.N.T. Geraetebau, Barsbuettel (general license for training test benches)	11/2000
Steinhaus Informationssysteme, Datteln (general license for process data software)	12/2000

1999

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

1998

Technical University of Cottbus, Chair in Power Plant Engineering	05/1998
Fichtner Consulting & IT (CADIS information systems) Stuttgart (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