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**Property Library for
the Industrial Formulation
IAPWS-IF97
for Water and Steam**

FluidEXL *Graphics*

LibIF97

**for Excel®
Student's Version**

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**Software for the Industrial Formulation IAPWS-IF97
of Water and Steam
Including DLL and Add-In for Excel®
FluidEXL^{Graphics}
LibIF97
Student's Version**

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0. Package Contents

0.1 Zip file for 32-bit Windows®

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

Zip-file "CD_FluidEXL_Graphics_LibIF97_Eng.zip" including the following files:

FluidEXL_Graphics_Stud_Eng_Setup.exe	- Self-extracting and self-installing program for FluidEXL ^{Graphics}
FluidEXL_Graphics_Stud_Eng.xla	- FluidEXL ^{Graphics} Add-In
LibIF97_Stud_Eng.hlp	- Help file for the LibIF97_Stud property library
LibIF97_Stud.dll	- Dynamic link library with functions for water and steam
FluidEXL_Graphics_LibIF97_Docu_Stud_Eng.pdf	- User's Guide

0.2 Zip file for 64-bit Windows®

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

Zip-file "CD_FluidEXL_Graphics_LibIF97_Stud_Eng_x64.zip" including the following files and folders:

Files:

FluidEXL_Graphics_LibIF97_Docu_Stud_Eng.pdf	- User's Guide
FluidEXL_Graphics_Stud_Eng.xla	- FluidEXL ^{Graphics} Add-In
FluidEXL_Graphics_Stud_Eng_64.msi	- Self-extracting and self-installing program
LibIF97_Stud.dll	- Dynamic link library with functions for water and steam
LibIF97_Stud_Eng.hlp	- Help file for the LibIF97_Stud property library
Setup.exe	- Self-extracting and self-installing program for FluidEXL ^{Graphics}

Folders:

vc_redist_x64	- Folder containing the "Microsoft Visual C++ 2010 x64 Redistributable Pack"
WindowsInstaller3_1	- Folder containing the "Microsoft Windows Installer"

1. Range of Validity and Program Library Structure

The International Association for the Properties of Water and Steam (IAPWS) issued the IAPWS-IF97 Industrial Formulation for Thermodynamic Properties of Water and Steam in 1997. This standard must be applied worldwide in final warranty calculations for power plants which use water and steam as working fluid.

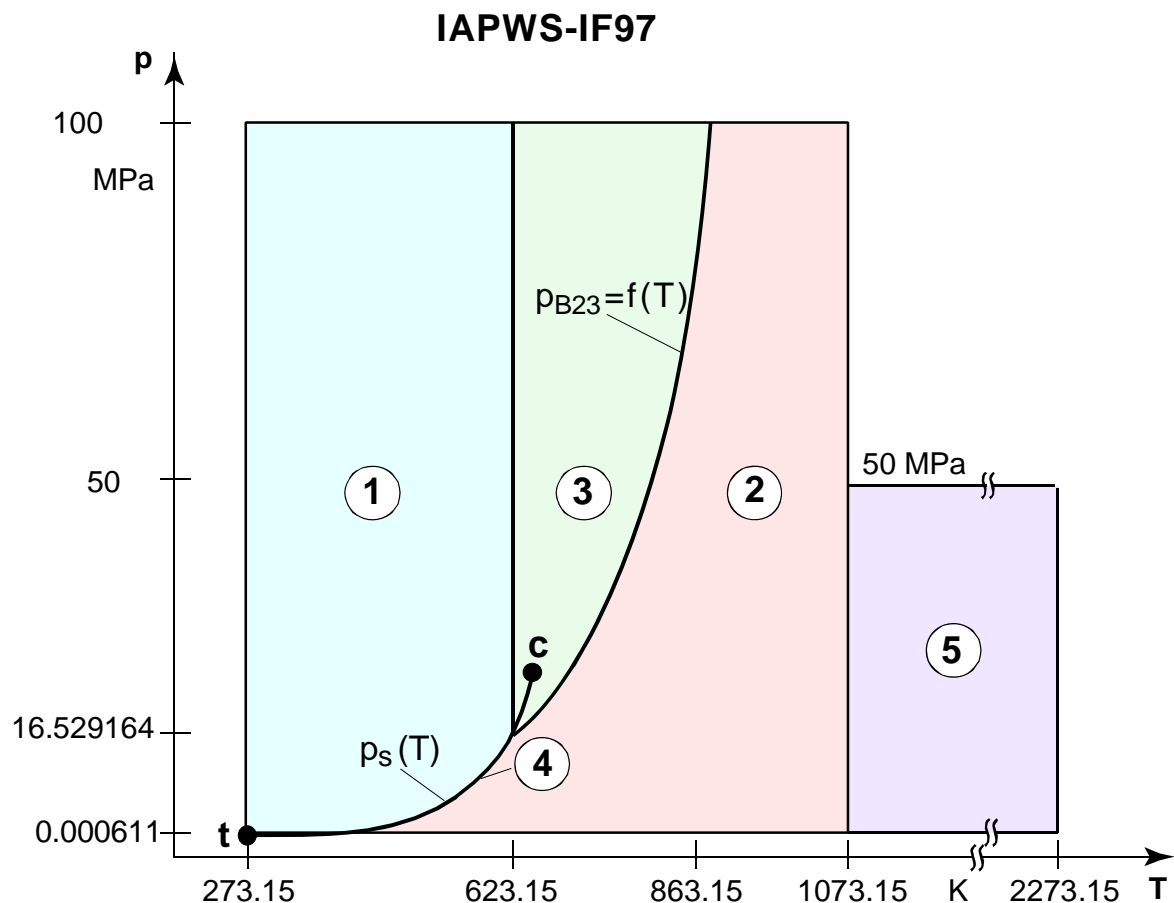
Figure 1 shows the range of validity of the equation set of the Industrial Formulation, fully named

"IAPWS Industrial Formulation 1997 for the Thermodynamic Properties
of Water and Steam",

abbreviated

"IAPWS-IF97".

The IAPWS-IF97 range of state includes temperatures from 273.15 K up to 1073.13 K at pressures from 0.000611 MPa to 100 MPa and up to 2273.15 K at pressures up to 50 MPa. Internally, the entire range of validity is divided into five calculation regions (see figure below). The fundamental equations of these regions are described in detail in the official IAPWS release [1], [2], and [3].



The students' version of the LibIF97 program library is valid for the regions 1 and 2, and for the wet steam region (region 4).

2. Property Functions of the Library

Functional Dependence	Function Name	Property or Function	Unit of the Function Value
$c_p = f(p, T, x)$	cp_pTx_97	Specific isobaric heat capacity	$\text{kJ/kg} \cdot \text{K}$
$\eta = f(p, T, x)$	eta_pTx_97	Dynamic viscosity	$\text{Pa} \cdot \text{s} = \text{kg/m} \cdot \text{s}$
$h = f(p, T, x)$	h_pTx_97	Specific enthalpy	kJ/kg
$\lambda = f(p, T, x)$	lambda_pTx_97	Thermal conductivity	W/m K
$p_s = f(T)$	ps_T_97	Saturation pressure from temperature	MPa
$s = f(p, T, x)$	s_pTx_97	Specific entropy	$\text{kJ/kg} \cdot \text{K}$
$T = f(p, h)$	T_ph_97	Backward function: temperature from pressure and specific enthalpy	K
$T = f(p, s)$	T_ps_97	Backward function: temperature from pressure and specific entropy	K
$T_s = f(p)$	Ts_p_97	Saturation temperature from pressure	K
$v = f(p, T, x)$	v_pTx_97	Specific volume	m^3/kg
$x = f(p, h)$	x_ph_97	Backward function: vapor fraction from pressure and specific enthalpy	kg/kg
$x = f(p, s)$	x_ps_97	Backward function: vapor fraction from pressure and specific entropy	kg/kg

Units:
 T in K
 p in MPa
 x in (kg saturated steam)/(kg wet steam)

The IAPWS-IF97 range of validity (regions 1, 2, 4, see Figure 1)

Temperature range: from 273.15 K to 1073.15 K

Pressure range: from 0.000611 MPa to 100 MPa

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

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. In this case, the backward functions result in the appropriate value between 0 and 1 for x . When calculating wet steam either the given value for T and $p = -1$ or the given value for p and $T = -1$ 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 this is not the case the calculation for the property of the chosen function results in -1 .

Wet steam region of the IAPWS-IF97:

Temperature ranges from $T = 273.15 \text{ K}$ to $T = 623.15 \text{ K}$

Pressure ranges from $p = 0.000611 \text{ MPa}$ to $p = 16.529 \text{ MPa}$

Note.

If the calculated value results in -1 (except for x), the values entered represent a state point beyond the range of validity of IAPWS-IF97. For further information on each function and its range of validity see Chapter 4. The same information may also be accessed via the online help pages.

3. 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 water and steam from the LibIF97_Stud property library. Furthermore, the program enables representation of the calculated values in various thermodynamic diagrams.

3.1 Installing FluidEXL *Graphics*

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 April 2010.

After you have downloaded and extracted the zip-file

"CD_FluidEXL_Graphics_LibIF97_Stud_Eng.zip"
you will see the folder

CD_FluidEXL_Graphics_LibIF97_Stud_Eng
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_Stud_Eng_Setup.exe
FluidEXL_Graphics_LibIF97_Docu_Stud_Eng
FluidEXL_Graphics_Stud_Eng.xla
LibIF97_Stud.dll
LibIF97_Stud_Eng.hlp.

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

FluidEXL_Graphics_Stud_Eng_Setup.exe.

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

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

C:\Program Files\FluidEXL_Graphics_Stud_Eng

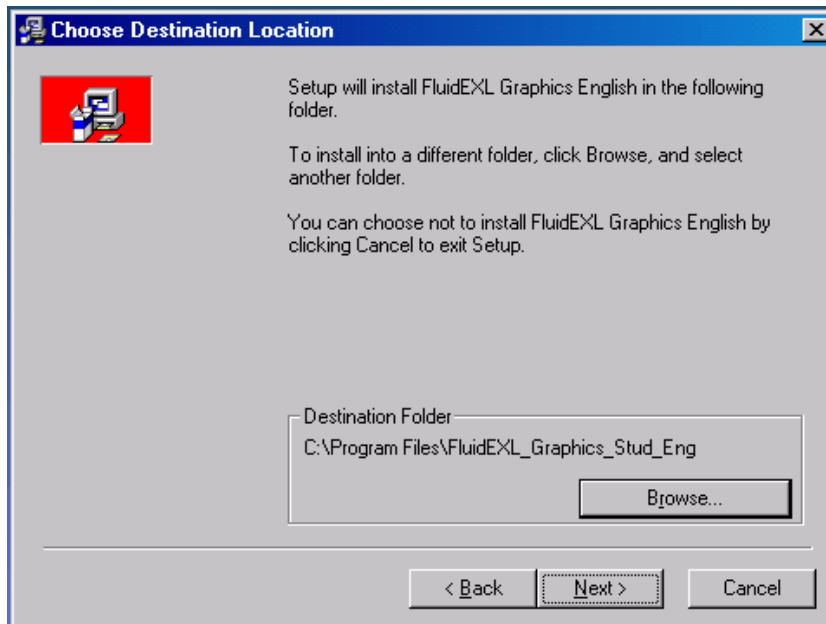


Figure 3.1: Choose Destination Location

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.

Close the windows "Add or Remove Program" and "Control Panel". The installation of FluidEXL *Graphics* has been completed.

During the installation process the following files have been copied into the chosen destination folder, in the standard case C:\Program Files\FuildEXL_Graphics_Stud_Eng:

Dforrt.dll
Msvcr7.dll
INSTALL_EXL.LOG
UNWISE.EXE
UNWISE.INI

In addition, the two subdirectories \FORMULATION97 and \FLuft have been compiled in the destination folder.

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

FluidEXL_Graphics_Stud_Eng.xla
LibIF97_Stud.dll
LibIF97_Stud_Eng.hlp.

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 April 2010.

After you have downloaded and extracted the zip-file

"CD_FluidEXL_Graphics_LibIF97_Stud_Eng_x64.zip"
you will see the folder

CD_FluidEXL_Graphics_LibIF97_Stud_Eng_x64
in your Windows Explorer, Norton Commander, etc.

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

Within this folder you will see the files

FluidEXL_Graphics_LibIF97_Docu_Stud_Eng
FluidEXL_Graphics_Stud_Eng.xla
FluidEXL_Graphics_Stud_Eng_64.msi
LibIF97_Stud.dll
LibIF97_Stud_Eng.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).

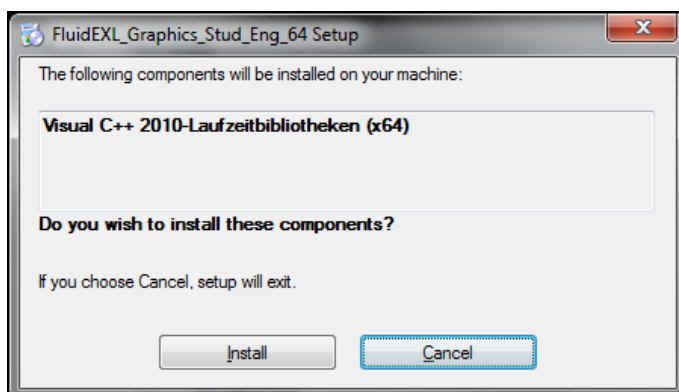


Figure 3.2: Installing the "Visual C++ 2010 runtime library (x64)"

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).

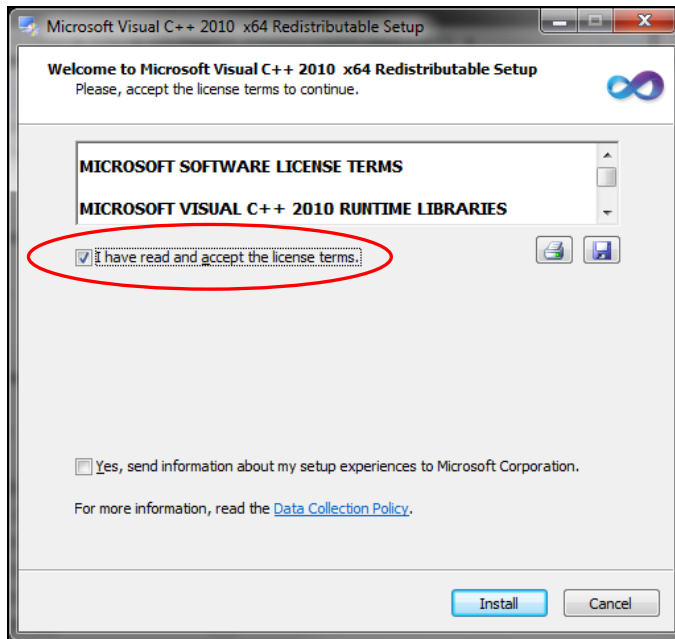


Figure 3.3: Accepting the license terms

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_Stud_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_Stud_Eng.

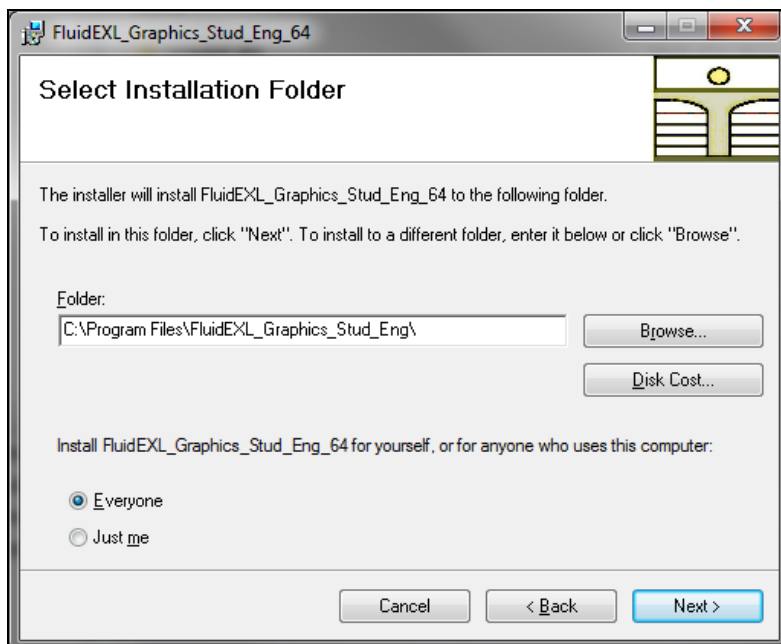


Figure 3.4: Choosing the Installation Folder of FluidEXL_Graphics

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_Stud_Eng_x64 has been successfully installed." Confirm this by clicking the "Close" button.

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

capt_ico_big.ico
libifcoremd.dll
libmmd.dll

In addition, the two subdirectories \FORMULATION97 and \FLuft will have been created in the destination folder.

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

FluidEXL_Graphics_Stud_Eng.xla
LibIF97_Stud.dll
LibIF97_Stud_Eng.hlp.

3.2 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 on "Add-Ins..." in the menu.

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_Stud_Eng)
here select "FluidEXL_Graphics_Stud_Eng.xla" and afterwards click "OK".
- Now, the entry "FluidEXL Graphics Eng" 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 the next figure.

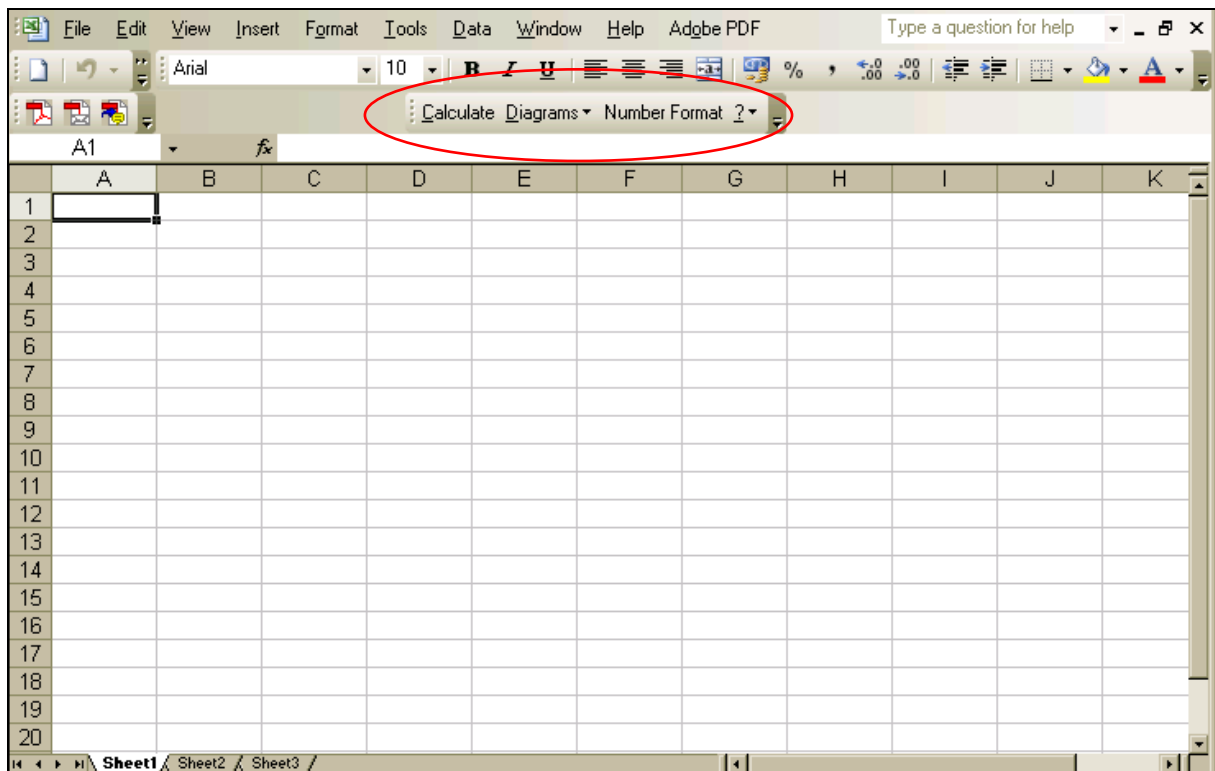


Figure 3.5: Menu bar of FluidEXLGraphics

From within Excel you can now select the "Water IAPWS-IF97" DLL library property functions via this menu bar (cf. part 2.4).

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

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

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

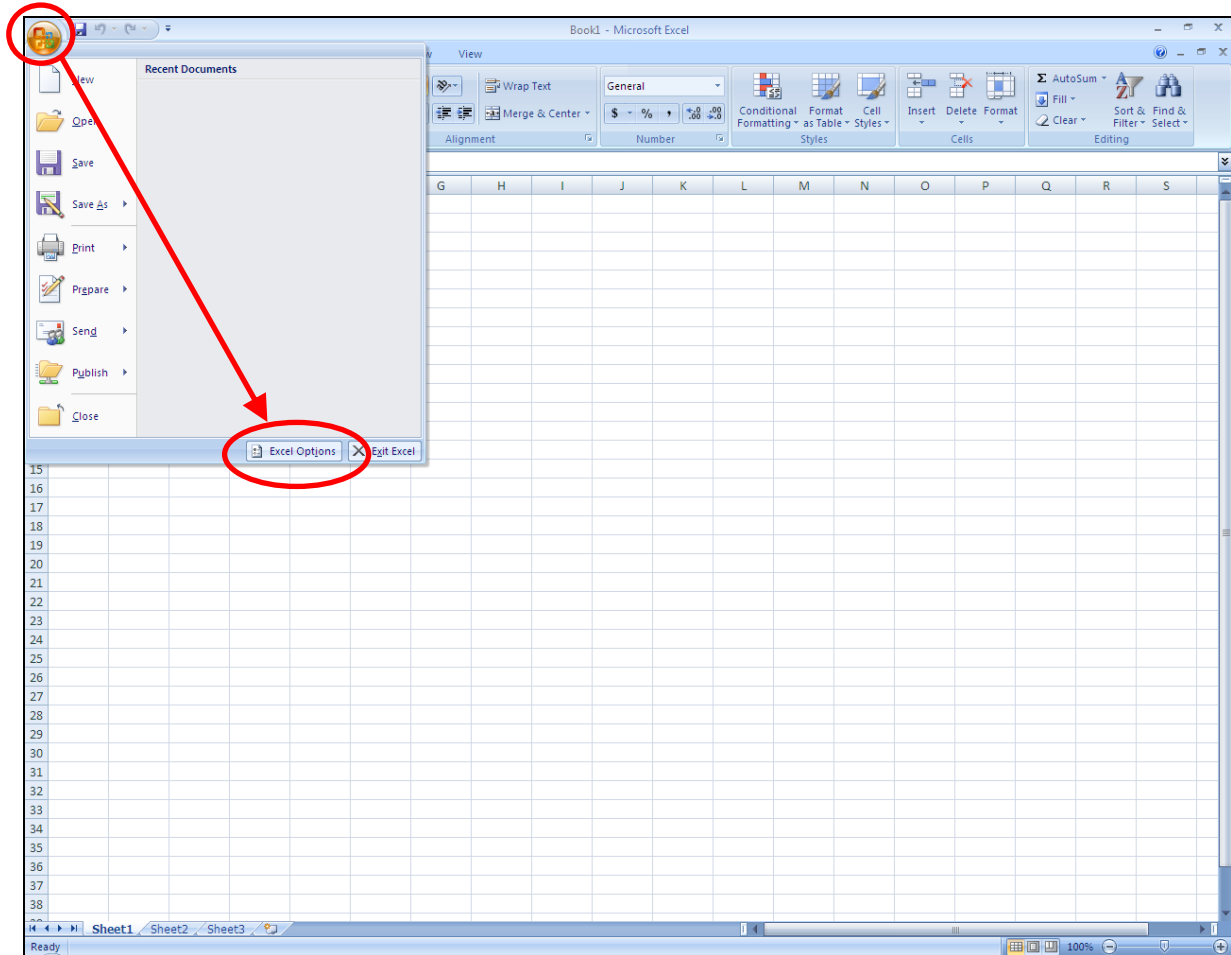


Figure 3.6: Registering FluidEXL *Graphics* as Add-In in Excel® 2007

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

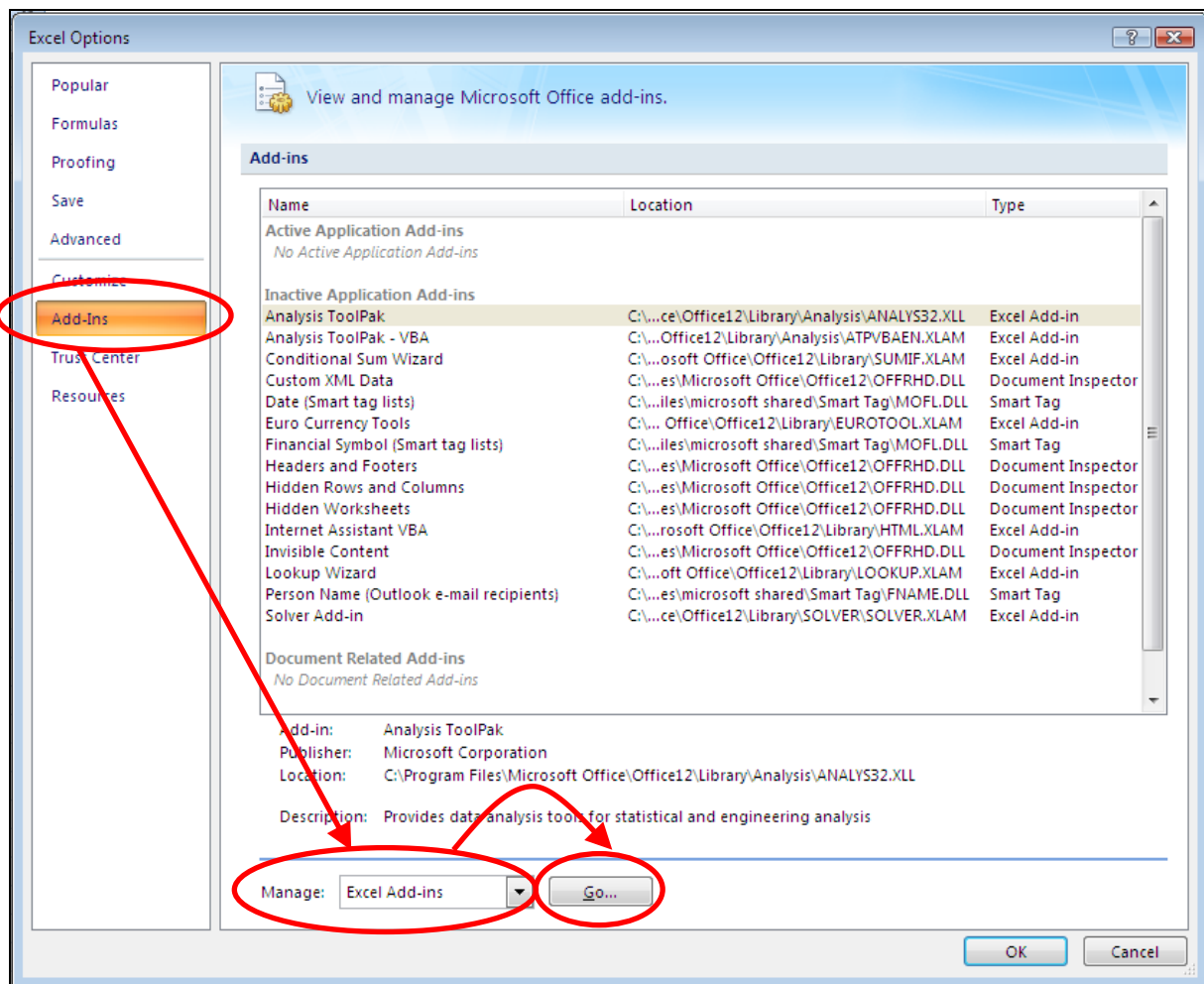


Figure 3.7: Dialog window "Excel Options"

- 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_Stud_Eng; within that folder click on the file named "FluidEXL_Graphics_Stud_Eng.xla" and then hit "OK."

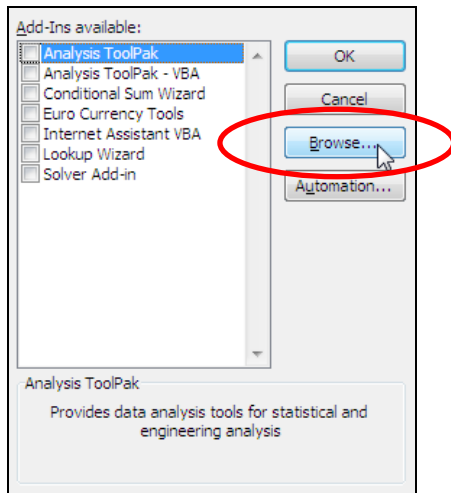


Figure 3.8: Dialog window "Add-Ins available"

- 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", 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.)

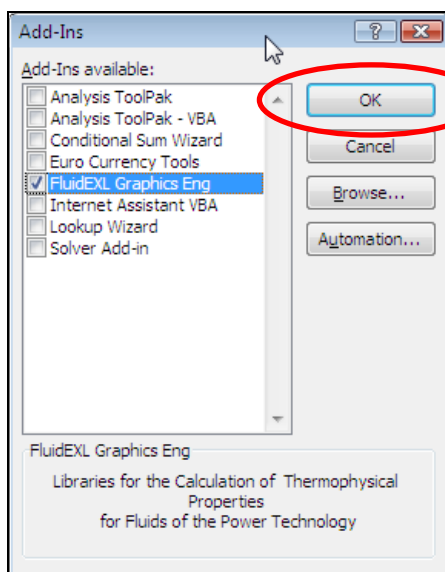


Figure 3.9: Dialog window "Add-Ins"

- 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 the next image.

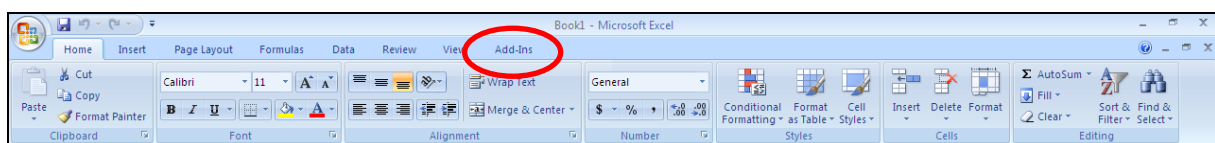


Figure 3.10: Menu item "Add-Ins"

In the upper menu region of Excel, the FluidEXL *Graphics* menu bar will appear as indicated by the red circle in the next figure.

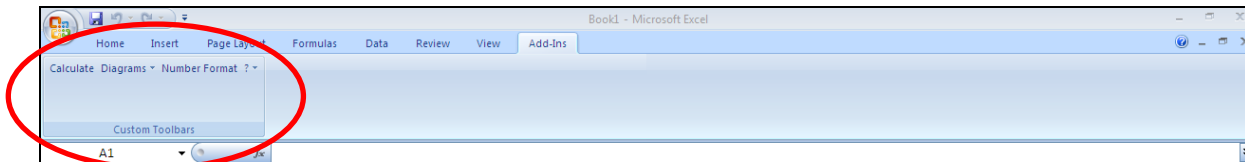


Figure 3.11: FluidEXL *Graphics* menu bar

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 LibIF97 Library (FluidEXL *Graphics* is already installed)

If FluidEXL *Graphics* has already been installed, you only have to copy the following files

FluidEXL_Graphics_Stud_Eng.xla

LibIF97_Stud.dll

LibIF97_Stud_Eng.hlp

provided in the extracted folder

CD_FluidEXL_Graphics_LibIF97_Stud_Eng

into the folder you have chosen for the installation of FluidEXL *Graphics* (the standard being

C:\Program Files\FuildEXL_Graphics_Stud_Eng

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

From within Excel you can now select the "Water IAPWS-IF97" DLL library property functions for water and steam via this menu bar (the example calculation can be found in chapter 3.4 on page 3/18).

3.3 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 "Help" in the FluidEXL *Graphics* menu bar.

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

- Click on "?" and then "Help" in the FluidEXL *Graphics* menu bar.
- Click on the "Water IAPWS-IF97" 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 LibIF97_Stud_Eng.hlp function help cannot be found, you will be asked whether you want to look for it yourself – answer with "Yes." Click on the LibIF97_Stud_Eng.hlp file in the installation menu of FluidEXL *Graphics* in the window which is opened, the standard being

C:\Program Files\FuildEXL_Graphics_Stud_Eng,

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 3.12: 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 3.13).

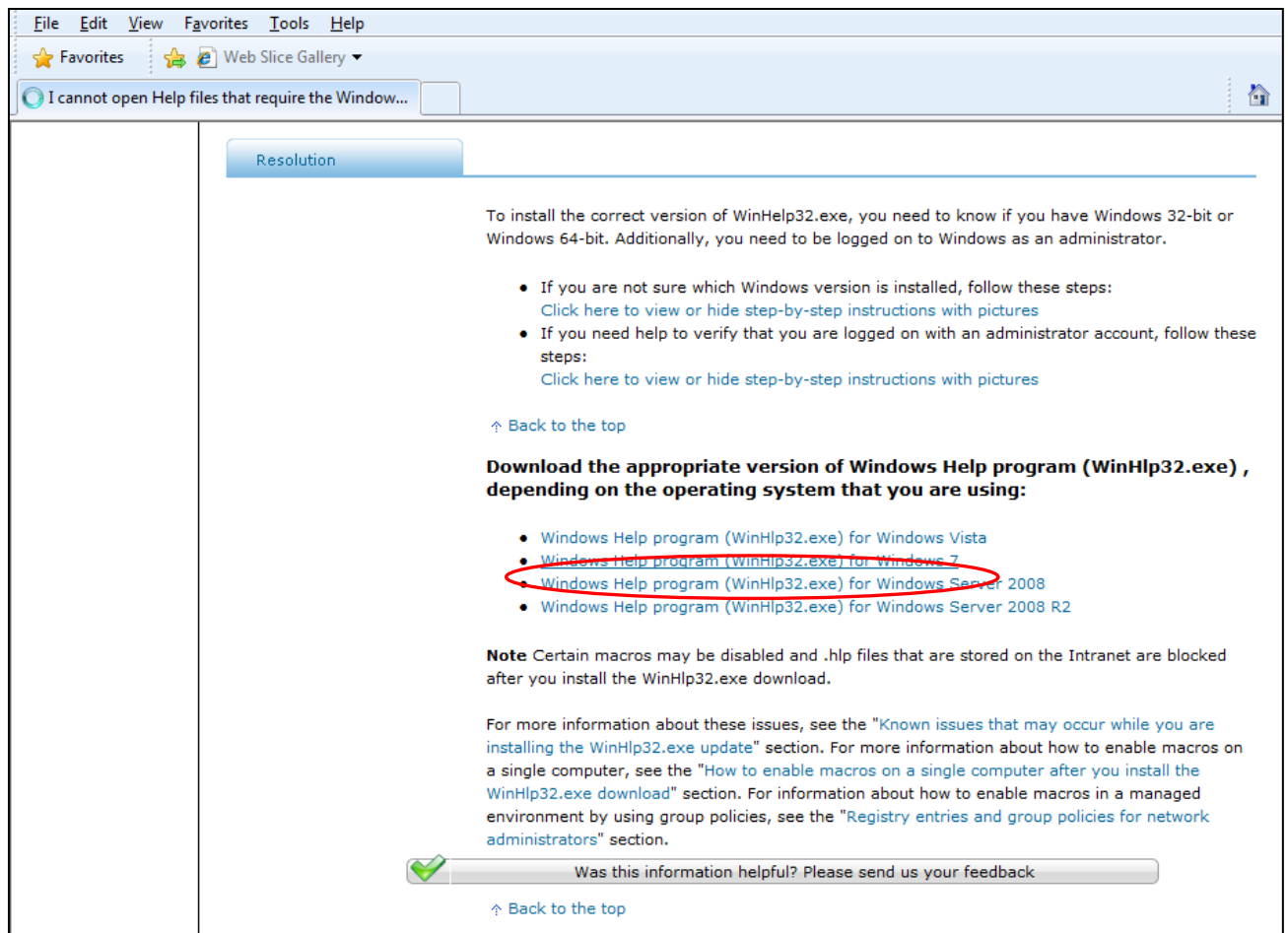


Figure 3.13: Selecting your Windows version

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 3.14).

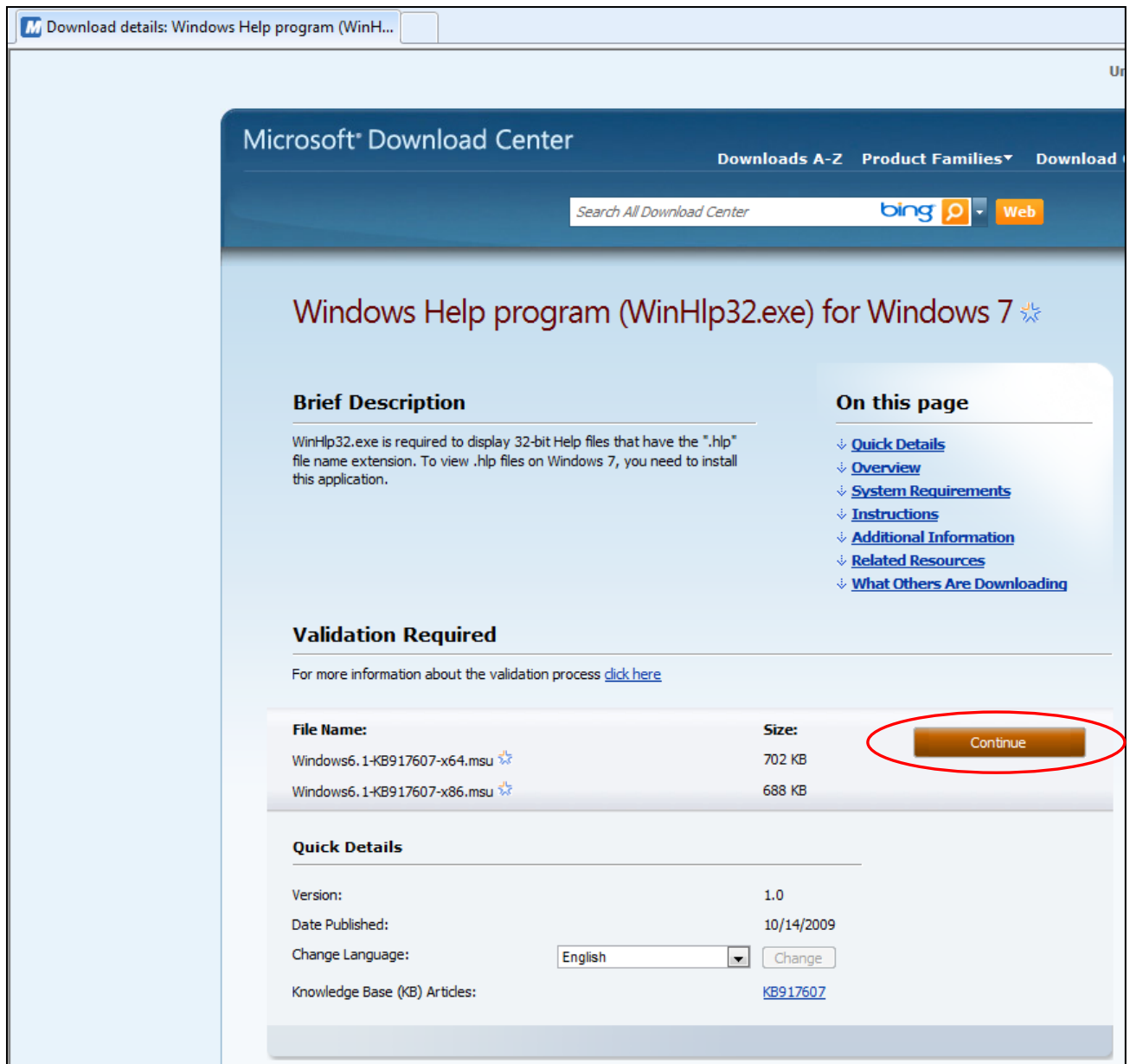


Figure 3.14: Microsoft® Download Center

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 3.15).

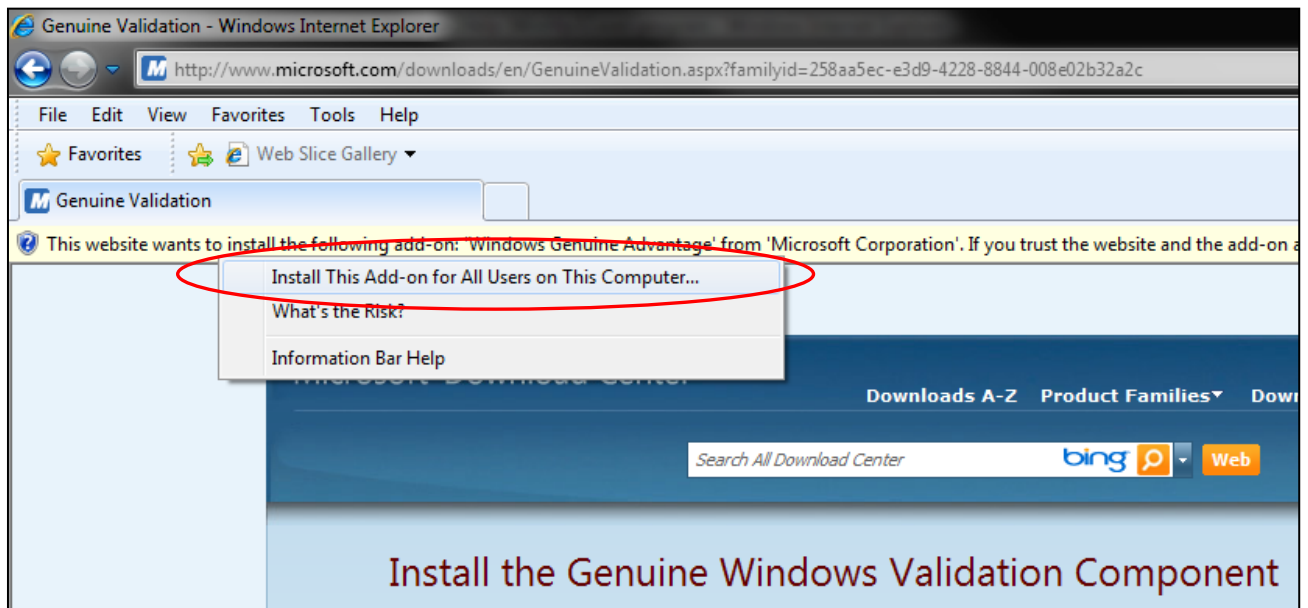


Figure 3.15: Installing the Genuine Windows Validation Component

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 3.16).

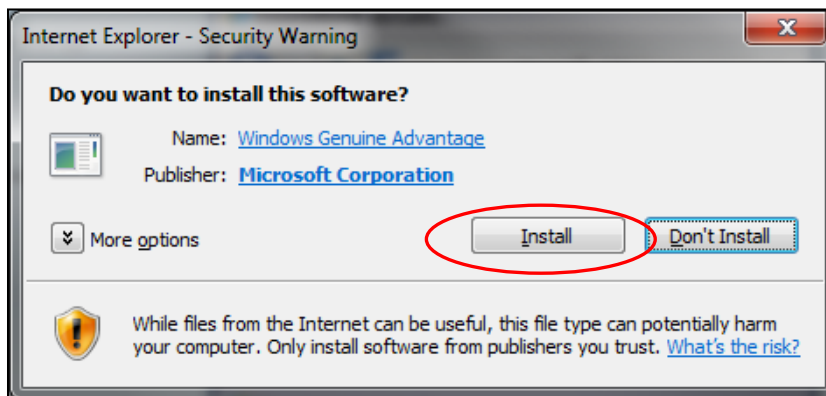


Figure 3.16: Internet Explorer – Security Warning

After the validation has been carried out you will be able to download the appropriate version of Windows Help program (see Figure 3.17).

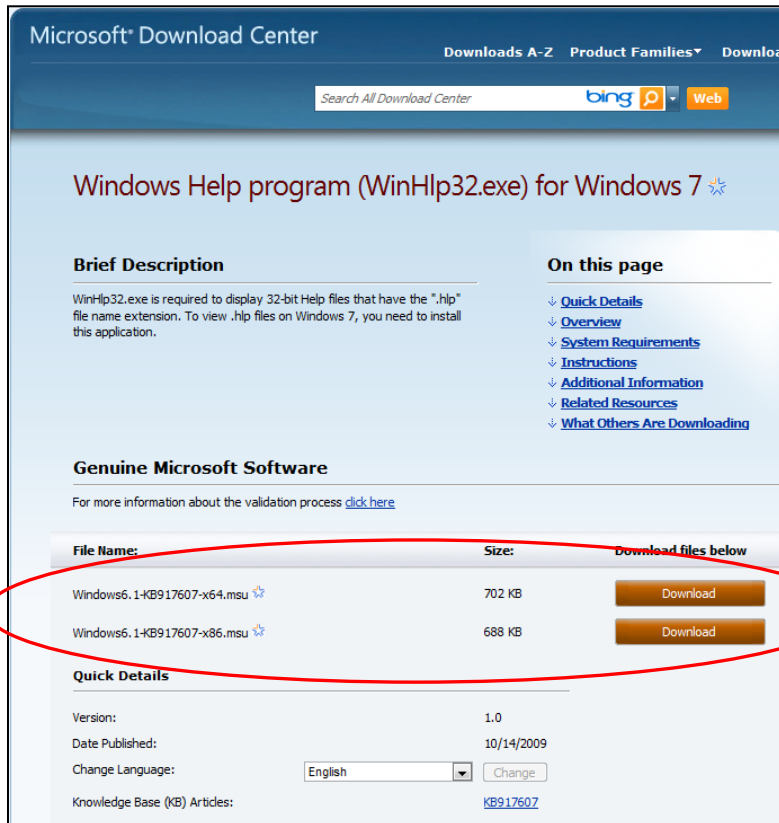


Figure 3.17: Downloading the Windows Help program

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.

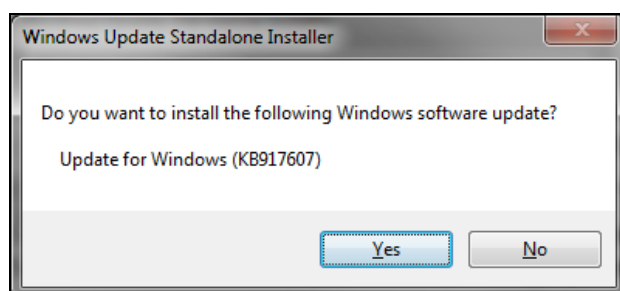


Figure 3.18: Windows Update Standalone Installer

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 3.19)

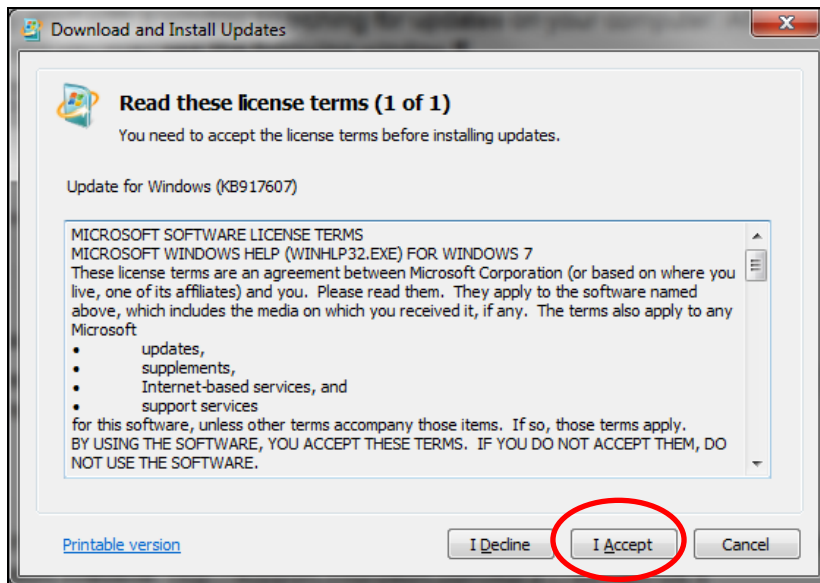


Figure 3.19: Windows License Terms

Installation starts once you have clicked the "I Accept" button (see Figure 3.20).

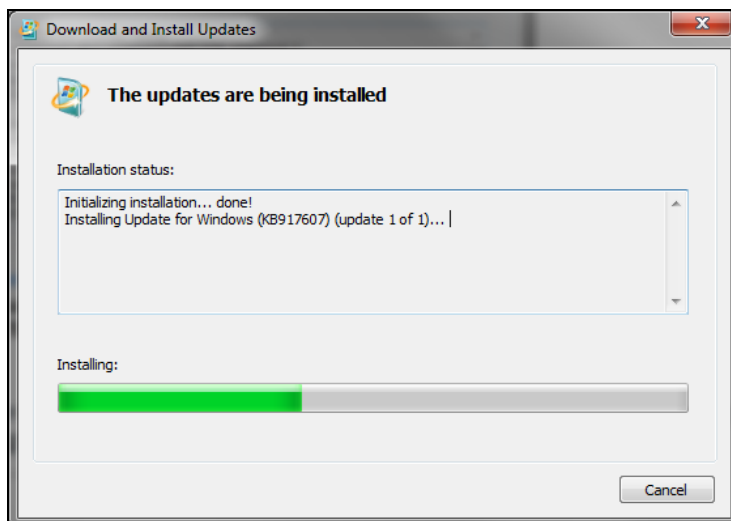


Figure 3.20: Installation process

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.

3.4 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 MPa into a cell.
(IF97 range of validity: $p = 0.0006112 \text{ MPa} \dots 100 \text{ MPa}$)
⇒ e.g.: Enter 10 into cell A2.
- Enter a value for T in K into a cell.
(IF97 range of validity: $T = 273.15 \dots 1073.15 \text{ K}$)
⇒ e.g.: Enter 673.15 into cell B2.

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

Since 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 $p = -1$ or the given value for p and $T = -1$ 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 -1 .

Wet-steam region of IAPWS-IF97: $T = 273.15 \text{ K} \dots T = 647.096 \text{ K}$
 $p = 0.0006112 \text{ MPa} \dots p = 22.064 \text{ MPa}$

⇒ e.g.: Enter -1 into cell C2.

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

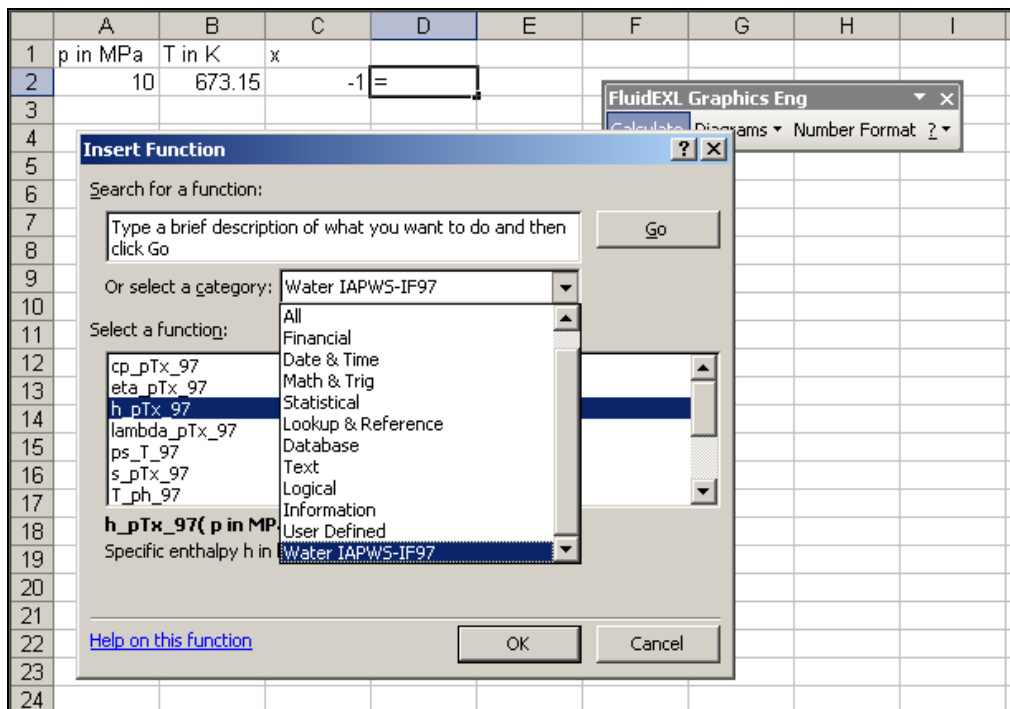


Figure 3.21: Choice of library and function name

- Next to "Or select a category:" in the upper part of the window scroll down to select the "Water IAPWS-IF97" library.
- Then click on h_pTx_97 under "Select a function:" directly below that.

Here it is possible to get more information on scope, 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.

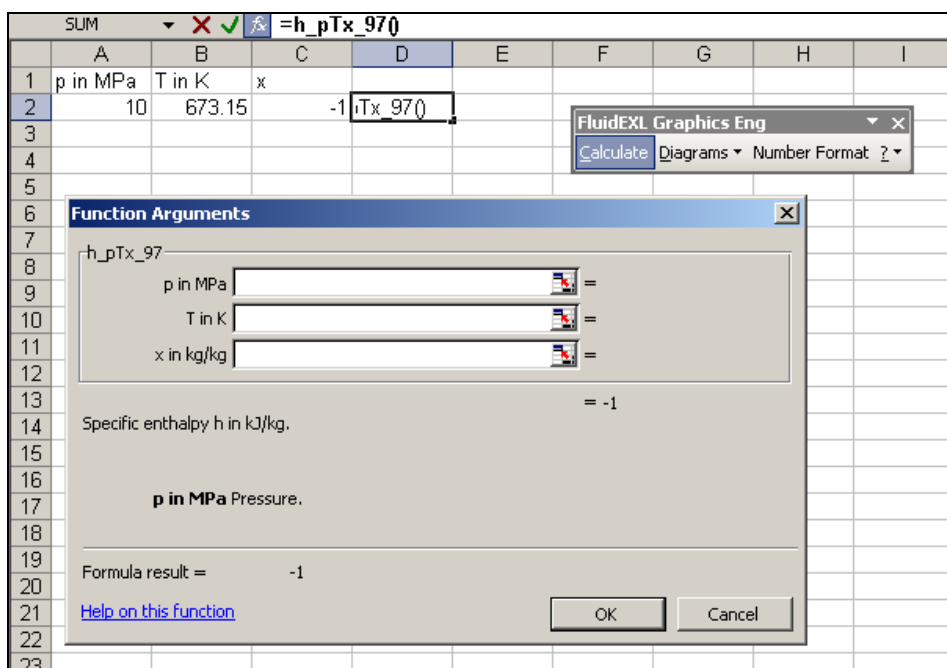


Figure 3.22: Input menu for the function

- The cursor is situated on the line next to "p in MPa". 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.
- Situate the cursor next to "T in K" 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.
- 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.

The window should now look as follows:

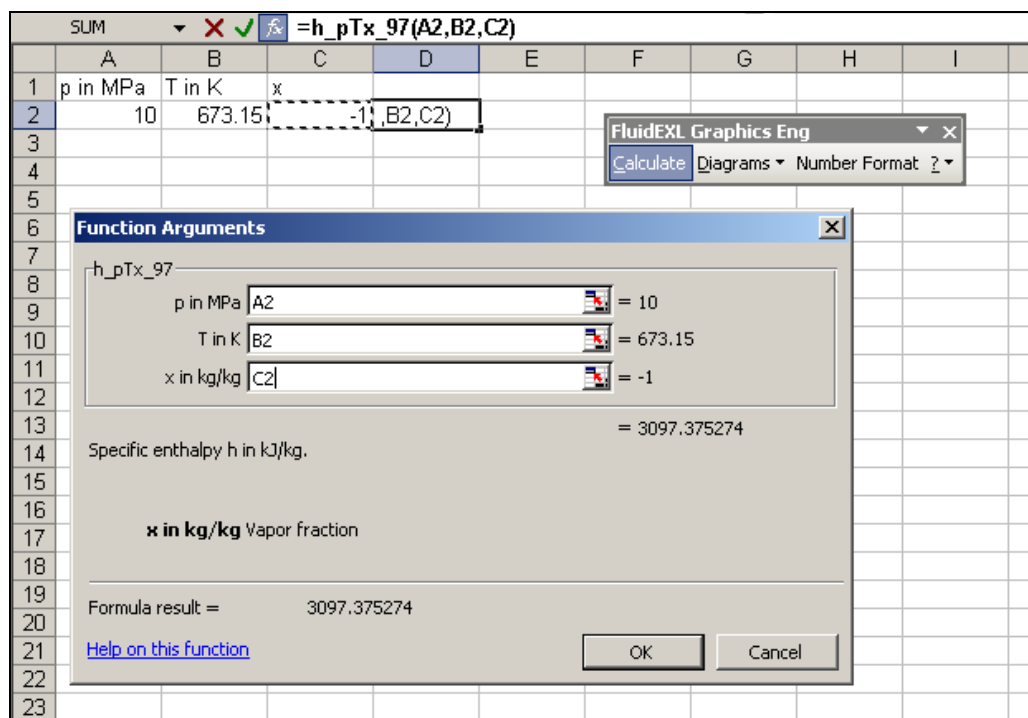


Figure 3.23: Input menu showing the result

- Click the "OK" button.

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

⇒ The result in our sample calculation here is: $h = 3097.375274$ 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 "Water IAPWS-IF97" library next to "Or select a category:" will be marked automatically.
- This time select the function s_{pTx_97} under "Select a function:" in the center of the window.

- Click "OK."
The "Function Arguments" window will appear.
- Enter the cell name with the value of p next to "p in MPa", or click on the cell where the value of p has been entered.
- Situate the cursor next to "T in K", 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 in our sample calculation here is: $s = 6.213928894$ 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 outside the range of validity of IF97. More detailed information on each function and its range of validity is available in Chapter 4.

For further property functions calculable in FluidEXL *Graphics*, see the function table in Chapter 2.

Number Formats

When using FluidEXL *Graphics* you have the option of choosing special number formats in advance.

Changes can be made as follows:

- Select the cell or cells you wish to format.
(In empty cells the new format will be applied once a value has been entered.)
- Click "Number Format" in the FluidEXL *Graphics* menu bar.
- Select the desired number format in the dialog box which appears:
 - "STD – Standard": Insignificant zeros behind the decimal point are not shown.
 - "FIX – Fixed Number of Digits": All set decimal places are shown, including insignificant zeros.
 - "SCI – Scientific Format": Numbers are always shown in the exponential form with the set number of decimal places.
- Set the "Number of decimal places" by entering the number into the appropriate window.
- Confirm this by clicking the "OK" button.

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

STD	1.23
FIX	1.230
SCI	1.230E+00

This formatting can also be applied "after-the-fact" to cells which have already been calculated.

3.5 Representation of Calculated Properties in Thermodynamic Diagrams

The following section describes how the calculated state point can be represented in thermodynamic diagrams with the help of FluidEXL *Graphics*. Calculations can be represented in the following diagrams:

- T - s diagram
- h - s diagram
- $lg\ p$ - h diagram
- $lg\ p$ - $lg\ v$ diagram
- $lg\ p$ - T diagram
- p - T diagram
- T - h diagram
- T - $lg\ v$ diagram
- $lg\ p$ - s diagram
- h - $lg\ v$ diagram
- s - $lg\ v$ diagram

In order to represent the calculated values, e.g. in a T - s diagram, the values of temperature and specific entropy must be marked for the point to be represented.

- Click on the cell with the value for T (as T is the ordinate in the diagram).
 ⇒ [Click cell B2 in our example.](#)

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

Note:

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

⇒ [For this example, hold down the "Ctrl" key and click on cell E2.](#)

- As displayed in the next figure, click "Diagrams" in the FluidEXL *Graphics* menu bar and choose "T-s diagram" in the drop-down menu.

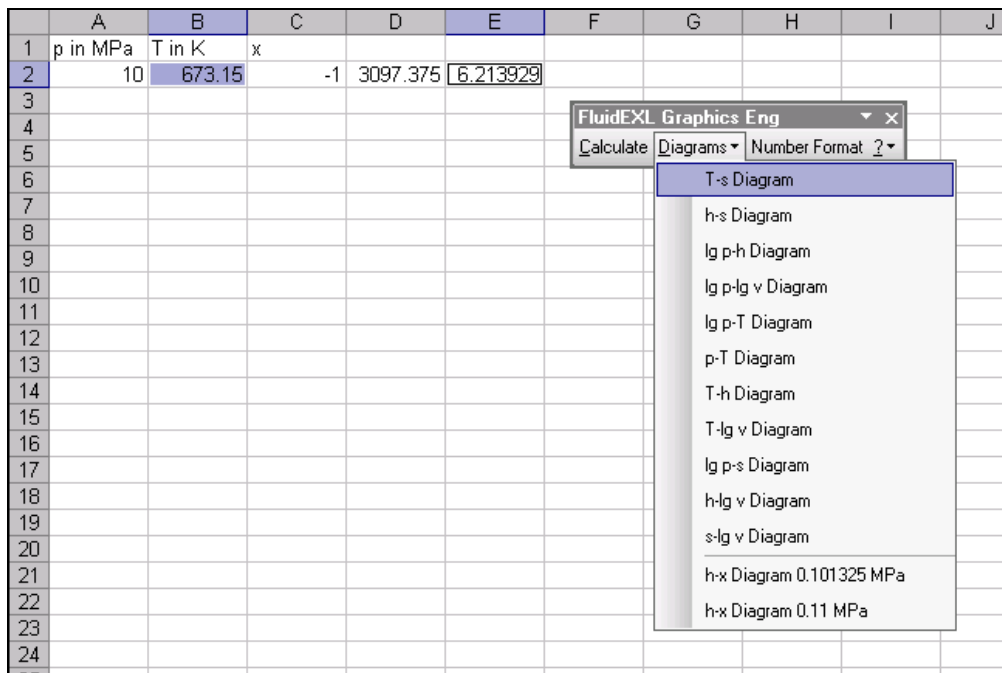


Figure 3.24: Marking the values and choice of the diagram

The T - s diagram shown in the figure below will appear. The calculated state point is marked as a red point.

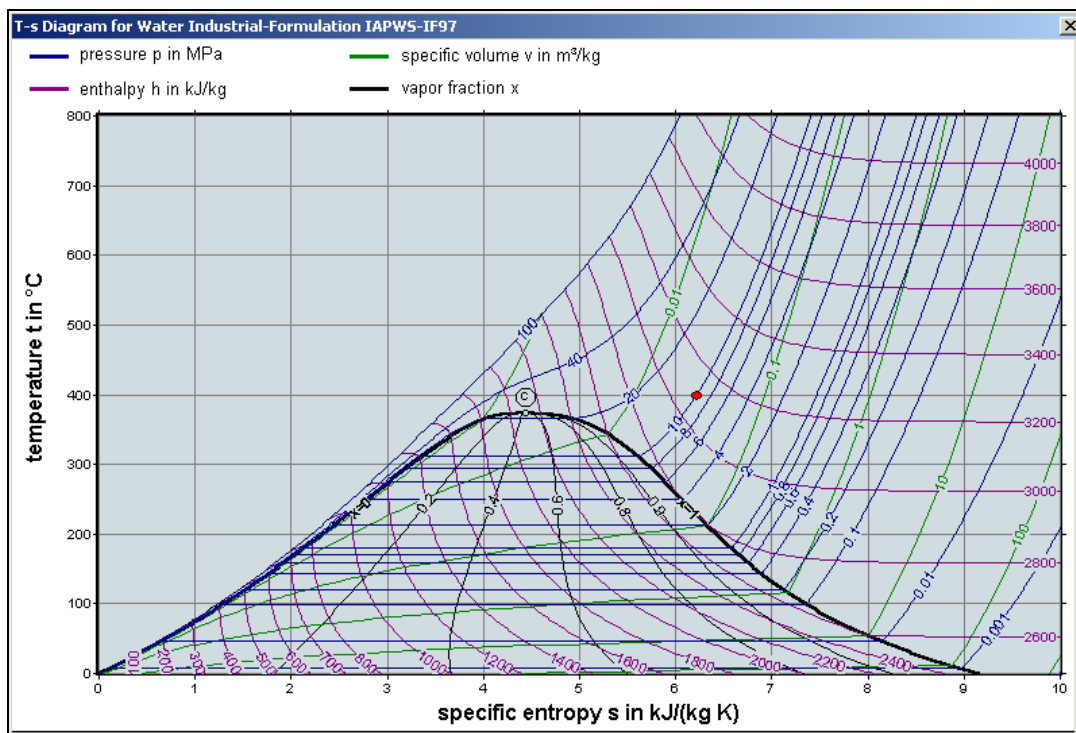


Figure 3.25: T - s Diagram including the state point

Note:

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

Proceed in the same way if you wish to represent values in the h - s diagram:

- Click the cell with the value for h .
⇒ Click on cell D2 in our example.
- Hold down the "Ctrl" key and simultaneously click on the cell with the value for s . Release the "Ctrl" key.
⇒ For this example, click on cell E2 while holding down the "Ctrl" key.
- Click "Diagrams" in the menu bar of FluidEXL *Graphics*, and click " h - s diagram" in the menu which appears.
In the h - s diagram then displayed, the state point is marked in red.

If the calculated state point should be represented in the $lg\ p$ - h diagram, mark the value of p first and then mark the value of h . Then proceed as above.

Note – Diagrams with various state points:

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

Note – Diagrams without any state points:

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

Printing Diagrams

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

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

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

Proceed in the same way to print further diagrams.

3.6 Removing FluidEXL *Graphics*

Should you wish to remove only the LibIF97_Stud library, delete the files

LibIF97_Stud.dll

LibIF97_Stud_Eng.hlp

in the directory selected for the installation of FluidEXL *Graphics* (the standard being C:\Program Files\FuildEXL_Graphics_Stud_Eng), 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 cancel the registration of FluidEXL_Graphics_Stud_Eng.xla in Excel[®].

In order to do that, click "Tools" in the upper menu bar of Excel and here "Add-Ins..." Unmark the box on the left-hand side of "FluidEXL Graphics Eng" in the window that appears and click the "OK" button. The additional menu bar of FluidEXL *Graphics* will disappear 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," situated at the bottom of the "Toolbars" entries, must be selected by clicking on it. Delete the entry manually by clicking "Delete". When asked whether you really want to delete the toolbar, click "OK."

As the next step, delete the files

LibIF97_Stud.dll

LibIF97_Stud_Eng.hlp

in the directory selected for the installation of FluidEXL *Graphics* (the standard being C:\Program Files\FuildEXL_Graphics_Stud_Eng), using an appropriate program such as Explorer[®] or Norton Commander.

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 Student English" by clicking on it and click the "Change/Remove..." button. In the following dialog box click "Automatic" and then "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 or 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 hand corner of Excel
- Click on the "Excel Options" button in the menu which pops up

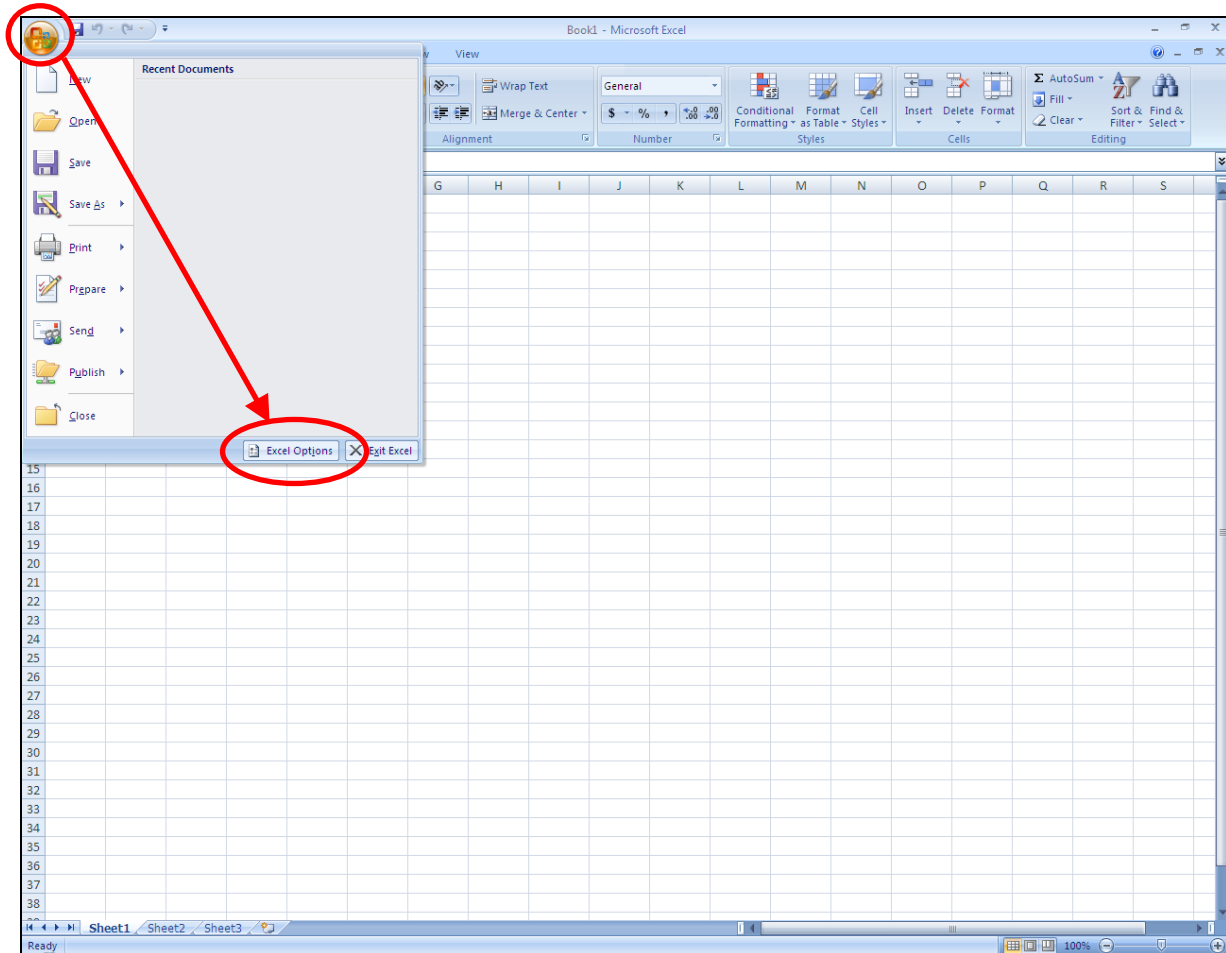


Figure 3.26: Unregistering FluidEXL *Graphics* as Add-In in Excel® 2007

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

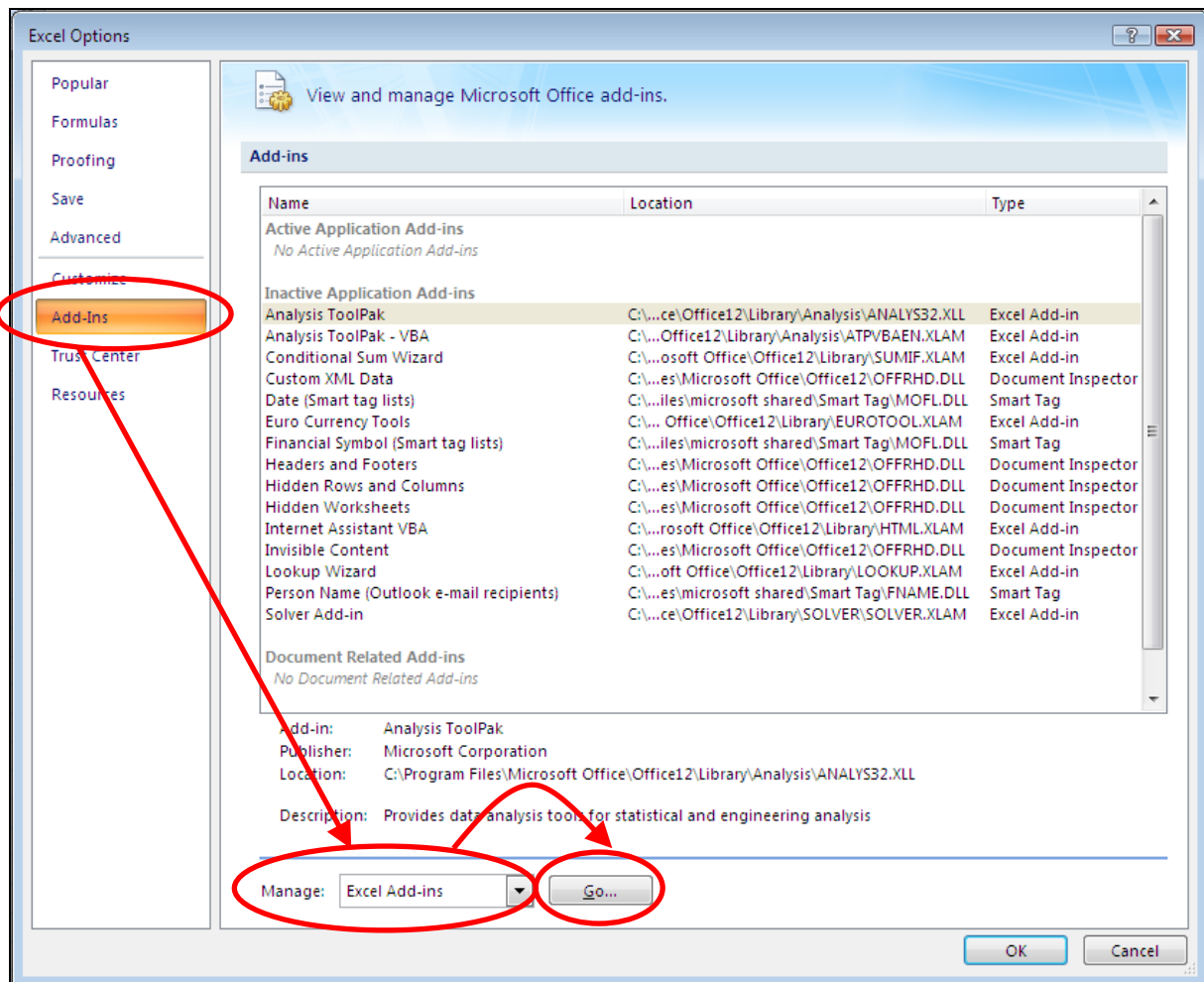


Figure 3.27: Dialog window "Add-Ins"

- If it is not shown in the list automatically, select "Excel Add-ins" next to "Manage:" in the lower area of the menu
- Then click the "Go..." button
- Remove the checkmark in front of "FluidEXL Graphics Eng" in the window which now appears. Click the "OK" button to confirm your entry.

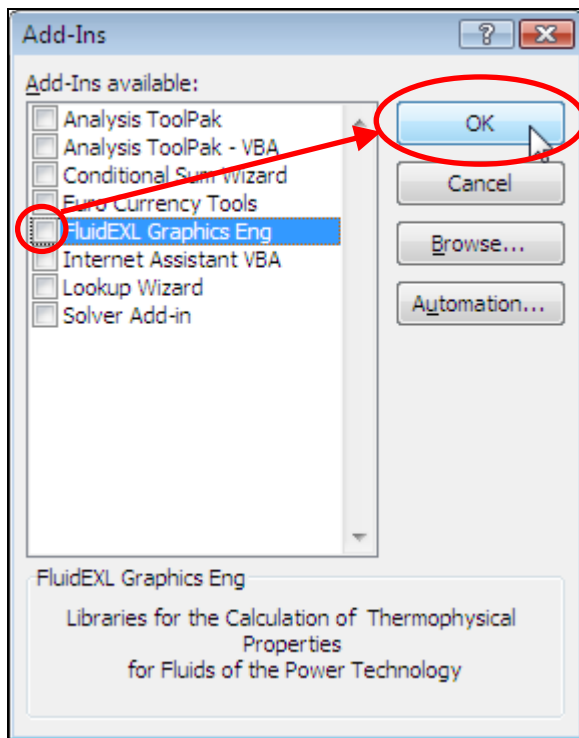


Figure 3.28: Dialog window "Add-Ins"

In order to remove FluidEXL *Graphics* from Windows[®] and from your hard drive, click "Start" in the lower task bar; then click "Settings" and "Control Panel."

Now, double-click "Add or Remove Programs," click on "FluidEXL Graphics Student English" by clicking on it and click the "Change/Remove..." button.

Mark "Automatic" and click the "Next >" button.

Now click the "Finish" button in the "Perform Uninstall" window.

Click "Yes to All" in the "Remove Shared Component" window.

Finally, the windows "Add or Remove Programs" and "Control Panel" should be closed.

Now FluidEXL *Graphics* has been removed.

4. Program Documentation

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

Function Name: **cp_pTx_97**
 Subprogram with value of the function: **REAL*8 FUNCTION CPPTX97(P,T,X)**
 For the call out of FORTRAN: **REAL*8 P,T,X**
 Subprogram with parameter: **INTEGER*4 FUNCTION C_CPPTX97(CP,P,T,X)**
 For the call out of the DLL: **REAL*8 CP,P,T,X**

Input values

p - Pressure p in MPa
T - Temperature T in K
x - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

CPPTX97, CP or **cp_pTx_97** - Specific isobaric heat capacity c_p in kJ/kg K

Range of validity

Temperature range: from 273.15 K to 1073.15 K
 Pressure range: from 0.000611 MPa to 100 MPa

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered.

When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for T and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and T and x are entered as given values, the program will consider p and T to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $T = 273.15$ K to $T = 647.096$ K

Pressure ranges from $p = 0.000611$ MPa to $p = 22.064$ MPa)

Results for wrong input values

Wrong input values(see below) result in **CPPTX97, CP = -1** or **cp_pTx_97 = -1**.

Single-phase region: $p > 100$ MPa or $p < 0.000611$ MPa or
 ($x = -1$) $T > 2273.15$ K or $T < 273.15$ K or
 $T > 1073.15$ K at $p > 10$ MPa

Saturated liquid or vapor line: at $p = -1$ and $T > 647.096$ K or $T < 273.15$ K or
 ($x = 0$ or $x = 1$) at $T = -1$ and $p > 22.064$ MPa or $p < 0.000611$ MPa or
 at $p > 22.064$ MPa or $p < 0.000611$ MPa
 and $T > 647.096$ K or $T < 273.15$ K
 at $|T - T_s(p)| > 0.1$ K

References: [1], [2], [3]

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

Function Name: **eta_pTx_97**
 Subprogram with value of the function: **REAL*8 FUNCTION ETAPTX97(P,T,X)**
 For the call out of FORTRAN: **REAL*8 P,T,X**
 Subprogram with parameter: **INTEGER*4 FUNCTION C_ETAPTX97(ETA,P,T,X)**
 For the call out of the DLL: **REAL*8 ETA,P,T,X**

Input values

p - Pressure p in MPa
T - Temperature T in K
x - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

ETAPTX97, ETA or eta_pTx_97 – Dynamic viscosity η in Pa s

Range of validity

Temperature range: from 273.15 K to 1073.15 K
 Pressure range: from 0.000611 MPa to 100 MPa

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered.

When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for T and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and T and x are entered as given values, the program will consider p and T to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $T = 273.15$ K to $T = 647.096$ K

Pressure ranges from $p = 0.000611$ MPa to $p = 22.064$ MPa)

Results for wrong input values

Wrong input values(see below) result in **ETAPTX97, ETA = - 1** or **eta_pTx_97 = - 1**.

Single-phase region: $p > 100$ MPa or $p < 0.000611$ MPa or
 ($x = - 1$) $T > 1073.15$ K or $T < 273.15$ K

Saturated liquid or vapor line:
 ($x = 0$ or $x = 1$) at $p = - 1$ and $T > 647.096$ K or $T < 273.15$ K or
 at $T = - 1$ and $p > 22.064$ MPa or $p < 0.000611$ MPa or
 at $p > 22.064$ MPa or $p < 0.000611$ MPa
 and $T > 647.096$ K or $T < 273.15$ K
 at $|T - T_s(p)| > 0.1$ K

References: [5], internal calculation of ρ or v corresponding to: [1], [2], [3]

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

Function Name: **h_pTx_97**

Subprogram with value of the function: **REAL*8 FUNCTION HPTX97(P,T,X)**
 For the call out of FORTRAN: **REAL*8 P,T,X**

Subprogram with parameter: **INTEGER*4 FUNCTION C_HPTX97(H,P,T,X)**
 For the call out of the DLL: **REAL*8 H,P,T,X**

Input values

p - Pressure p in MPa
T - Temperature T in K
x - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

HPTX97, H or h_pTx_97 - Specific enthalpy h in kJ/kg

Range of validity

Temperature range: from 273.15 K to 1073.15 K
 Pressure range: from 0.000611 MPa to 100 MPa

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:

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.

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 $p = -1$ or the given value for p and $T = -1$ 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 -1 .

(Wet steam region of the IAPWS-IF97:

Temperature ranges from $T = 273.15$ K to $T = 647.096$ K

Pressure ranges from $p = 0.000611$ MPa to $p = 22.064$ MPa)

Results for wrong input values

Wrong input values(see below) result in **HPTX97, H = - 1** or **h_pTx_97 = - 1**.

Single-phase region: $p > 100$ MPa or $p < 0.000611$ MPa or
 ($x = - 1$) $T > 2273.15$ K or $T < 273.15$ K or
 $T > 1073.15$ K at $p > 10$ MPa

Wet steam region: at $p = - 1$ and $T > 647.096$ K or $T < 273.15$ K or
 ($0 \leq x \leq 1$) at $T = - 1$ and $p > 22.064$ MPa or $p < 0.000611$ MPa or
 at $p > 22.064$ MPa or $p < 0.000611$ MPa
 and $T > 647.096$ K or $T < 273.15$ K
 at $|T - T_s(p)| > 0.1$ K

References: [1], [2], [3]

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

Function Name: **lambda_pTx_97**
 Subprogram with value of the function: **REAL*8 FUNCTION LAMPTX97(P,T,X)**
 For the call out of FORTRAN: **REAL*8 P,T,X**
 Subprogram with parameter: **INTEGER*4 FUNCTION C_LAMPTX97(LAM,P,T,X)**
 For the call out of the DLL: **REAL*8 LAM,P,T,X**

Input values

p - Pressure p in MPa
T - Temperature T in K
x - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

LAMPTX97, LAM or **lambda_pTx_97** - Thermal conductivity λ in W/m·K

Range of validity

Temperature range: from 273.15 K to 1073.15 K
 Pressure range: from 0.000611 MPa to 100 MPa

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered.

When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for T and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and T and x are entered as given values, the program will consider p and T to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $T = 273.15$ K to $T = 647.096$ K

Pressure ranges from $p = 0.000611$ MPa to $p = 22.064$ MPa)

Results for wrong input values

Wrong input values(see below) result in **LAMPTX97, LAM = - 1** or **lambda_pTx_97 = - 1**.

Single-phase region: $p > 100$ MPa or $p < 0.000611$ MPa or
 ($x = - 1$) $T > 1073.15$ K or $T < 273.15$ K

Saturated liquid or vapor line: at $p = - 1$ and $T > 647.096$ K or $T < 273.15$ K or
 ($x = 0$ or $x = 1$) at $T = - 1$ and $p > 22.064$ MPa or $p < 0.000611$ MPa or
 at $p > 22.064$ MPa or $p < 0.000611$ MPa
 and $T > 647.096$ K or $T < 273.15$ K
 at $|T - T_s(p)| > 0.1$ K

References: [4], internal calculation of ρ or v corresponding to: [1], [2], [3]

Saturation Pressure $p_s = f(T)$

Function Name: **ps_T_97**
 Subprogram with value of the function: **REAL*8 FUNCTION PST97(T)**
 For the call out of FORTRAN: **REAL*8 T**
 Subprogram with parameter: **INTEGER*4 FUNCTION C_PST97(PS,T)**
 For the call out of the DLL: **REAL*8 PS,T**

Input values

T - Temperature T in K

Result

PST97, PS or **ps_T_97** – Saturation pressure p_s in MPa

Range of validity

from $T = 273.15$ K to $T = 647.096$ K

Results for wrong input values

Wrong input values(see below) result in **PST97, PS = -1** or **ps_T_97 = -1**.
 $T < 273.15$ K or $T > 647.096$ K

References: [1], [2], [3]

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

Function Name: **s_pTx_97**
 Subprogram with value of the function: **REAL*8 FUNCTION SPTX97(P,T,X)**
 For the call out of FORTRAN: **REAL*8 P,T,X**
 Subprogram with parameter: **INTEGER*4 FUNCTION C_SPTX97(S,P,T,X)**
 For the call out of the DLL: **REAL*8 S,P,T,X**

Input values

p - Pressure p in MPa
T - Temperature T in K
x - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

SPTX97, S or **s_pTx_97** - Specific entropy s in kJ/kg K

Range of validity

Temperature range: from 273.15 K to 1073.15 K
 Pressure range: from 0.000611 MPa to 100 MPa

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:

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.

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 $p = -1$ or the given value for p and $T = -1$ 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 -1 .

(Wet steam region of the IAPWS-IF97:

Temperature ranges from $T = 273.15$ K to $T = 647.096$ K

Pressure ranges from $p = 0.000611$ MPa to $p = 22.064$ MPa)

Results for wrong input values

Wrong input values(see below) result in **SPTX97, S = - 1** or **s_pTx_97 = - 1**.

Single-phase region: $p > 100$ MPa or $p < 0.000611$ MPa or
 ($x = - 1$) $T > 2273.15$ K or $T < 273.15$ K or
 $T > 1073.15$ K at $p > 10$ MPa

Wet steam region: at $p = - 1$ and $T > 647.096$ K or $T < 273.15$ K or
 ($0 \leq x \leq 1$) at $T = - 1$ and $p > 22.064$ MPa or $p < 0.000611$ MPa or
 at $p > 22.064$ MPa or $p < 0.000611$ MPa
 and $T > 647.096$ K or $T < 273.15$ K
 at $|T - T_s(p)| > 0.1$ K

References: [1], [2], [3]

#K\$+ **Backward Function: Temperature $T = f(p, h)$**

Function Name: **T_ph_97**

Subprogram with value of the function: **REAL*8 FUNCTION TPH97(P,H)**
For the call out of FORTRAN: **REAL*8 P,H**

Subprogram with parameter: **INTEGER*4 FUNCTION C_TPH97(T,P,H)**
For the call out of the DLL: **REAL*8 T,P,H**

Input values

p - Pressure p in MPa
h - Specific enthalpy h in kJ/kg

Result

TPH97, T or T_ph_97 - Temperature T in K

Range of validity

Pressure range: from 0.000611 MPa to 100 MPa
Enthalpy range: corresponding to temperatures from 273.15 K to 1073.15 K

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of p and h the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of T in the appropriate region will be carried out.

Wet steam region: Pressure ranges from $p = 0.000611$ MPa to $p = 22.064$ MPa

Results for wrong input values

Wrong input values(see below) result in **TPH97, T = - 1** or **T_ph_97 = - 1**.

Single-phase region: $p > 100$ MPa or $p < 0.000611$ MPa or
when calculation results in $T > 2273.15$ K or $T < 273.15$ K or
 $T > 1073.15$ K at $p > 10$ MPa

Wet steam region: $p > 22.064$ MPa or $p < 0.000611$ MPa or
when calculation results in $T > 647.096$ K or $T < 273.15$ K

References: [1], [2], [3]

FUNC_97_200

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

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

+ SUCH:200

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

Function Name: **T_ps_97**
 Subprogram with value of the function: **REAL*8 FUNCTION TPS97(P,S)**
 For the call out of FORTRAN: **REAL*8 P,S**
 Subprogram with parameter: **INTEGER*4 FUNCTION C_TPS97(T,P,S)**
 For the call out of the DLL: **REAL*8 T,P,S**

Input values

p - Pressure p in MPa
s - Specific entropy s in kJ/kg K

Result

TPS97, T or T_ps_97 - Temperature T in K

Range of validity

Pressure range: from 0.000611 MPa to 100 MPa
 Enthalpy range: corresponding to temperatures from 273.15 K to 1073.15 K

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of p and s the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of T in the appropriate region will be carried out.

Wet steam region: Pressure ranges from $p = 0.000611$ MPa to $p = 22.064$ MPa

Results for wrong input values

Wrong input values(see below) result in **TPS97, T = - 1** or **T_ps_97 = - 1**.

Single-phase region: $p > 100$ MPa or $p < 0.000611$ MPa or
 when calculation results in $T > 2273.15$ K or $T < 273.15$ K or
 $T > 1073.15$ K at $p > 10$ MPa

Wet steam region: $p > 22.064$ MPa or $p < 0.000611$ MPa or
 when calculation results in $T > 647.096$ K or $T < 273.15$ K

References: [1], [2], [3]

Saturation Temperature $T_s = f(p)$

Function Name: **Ts_p_97**
Subprogram with value of the function: **REAL*8 FUNCTION TSP97(P)**
For the call out of FORTRAN: **REAL*8 P**
Subprogram with parameter: **INTEGER*4 FUNCTION C_TSP97(TS,P)**
For the call out of the DLL: **REAL*8 TS,P**

Input values

p - Pressure p in MPa

Result

TSP97, T or **Ts_p_97** - Saturation temperature T_s in K

Range of validity

from $p = 0.000611$ MPa to $p = 22.064$ MPa

Results for wrong input values

Wrong input values(see below) result in **TSP97, T = - 1** or **Ts_p_97 = - 1**.
 $p < 0.000611$ MPa or $p > 22.064$ MPa

References: [1], [2], [3]

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

Function Name: **v_pTx_97**

Subprogram with value of the function: **REAL*8 FUNCTION VPTX97(P,T,X)**
for the call out of FORTRAN: **REAL*8 P,T,X**

Subprogram with parameter: **INTEGER*4 FUNCTION C_VPTX97(V,P,T,X)**
for the call out of the DLL: **REAL*8 V,P,T,X**

Input values

p - Pressure p in MPa
T - Temperature T in K
x - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

VPTX97, V or v_pTx_97 - Specific volume v in m^3/kg

Range of validity

Temperature range: from 273.15 K to 1073.15 K
 Pressure range: from 0.000611 MPa to 100 MPa

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:

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.

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 $p = -1$ or the given value for p and $T = -1$ 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 -1 .

(Wet steam region of the IAPWS-IF97:

Temperature ranges from $T = 273.15 \text{ K}$ to $T = 647.096 \text{ K}$

Pressure ranges from $p = 0.000611 \text{ MPa}$ to $p = 22.064 \text{ MPa}$)

Results for wrong input values

Wrong input values(see below) result in **VPTX97, V = - 1** or **v_pTx_97 = - 1**.

Single-phase region: $p > 100 \text{ MPa}$ or $p < 0.000611 \text{ MPa}$ or
 ($x = - 1$) $T > 2273.15 \text{ K}$ or $T < 273.15 \text{ K}$ or
 $T > 1073.15 \text{ K}$ at $p > 10 \text{ MPa}$

Wet steam region: at $p = - 1$ and $T > 647.096 \text{ K}$ or $T < 273.15 \text{ K}$ or
 ($0 \leq x \leq 1$) at $T = - 1$ and $p > 22.064 \text{ MPa}$ or $p < 0.000611 \text{ MPa}$ or
 at $p > 22.064 \text{ MPa}$ or $p < 0.000611 \text{ MPa}$
 and $T > 647.096 \text{ K}$ or $T < 273.15 \text{ K}$
 at $|T - T_s(p)| > 0.1 \text{ K}$

References: [1], [2], [3]

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

Function Name: **x_ph_97**

Subprogram with value of the function: **REAL*8 FUNCTION XPH97(P,H)**
 For the call out of FORTRAN: **REAL*8 P,H**

Subprogram with parameter: **INTEGER*4 FUNCTION C_XPH97(X,P,H)**
 For the call out of the DLL: **REAL*8 X,P,H**

Input values

p - Pressure p in MPa

h - Specific enthalpy h in kJ/kg

Result

XPH97, X or x_ph_97 - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Range of Validity

Pressure range: from 0.000611 MPa to 100 MPa

Enthalpy range: corresponding to temperatures from 273.15 K to 1073.15 K

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of p and h the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. When calculating wet steam the value for x between 0 and 1 is calculated (0 for saturated liquid, 1 for saturated steam). If the state point to be calculated is located in the single-phase region the result $x = -1$ will be returned.

Wet steam region: Pressure ranges from $p = 0.000611$ MPa to $p = 22.064$ MPa

Results for wrong input values

Wrong input values(see below) result in **XPH97, X = -1** or **x_ph_97 = -1**.

If the state point to be calculated is located within the single-phase region
 $p > 22.064$ MPa or $p < 0.000611$ MPa

References: [1], [2], [3]

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

Function Name: **x_ps_97**

Subprogram with value of the function: **REAL*8 FUNCTION XPS97(P,S)**
 For the call out of FORTRAN: **REAL*8 P,S**

Subprogram with parameter: **INTEGER*4 FUNCTION C_XPS97(X,P,S)**
 For the call out of the DLL: **REAL*8 X,P,S**

Input values

p - Pressure p in MPa

s - Specific entropy s in kJ/kg K

Result

XPS97, X or x_ps_97 - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Range of validity

Pressure range: from 0.000611 MPa to 100 MPa

Entropy range: corresponding to temperatures from 273.15 K to 1073.15 K

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of p and s the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. When calculating wet steam the value for x between 0 and 1 is calculated (0 for saturated liquid, 1 for saturated steam). If the state point to be calculated is located in the single-phase region the result $x = -1$ will be returned.

Wet steam region: Pressure ranges from $p = 0.000611$ MPa to $p = 22.064$ MPa

Results for wrong input values

Wrong input values(see below) result in **XPS97, X = -1** or **x_ps_97 = -1**.

If the state point to be calculated is located within the single-phase region
 $p > 22.064$ MPa or $p < 0.000611$ MPa

References: [1], [2], [3]



5. 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 Bückner 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 Bückner et al. (2003) Library LibButan_n n-Butane Formulation of Bückner 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

	h	v
	kJ/kg	m³/kg
3248.23	0.1512	
3054.14	0.2585	
2888.54	0.4404	
2589.27	1.6298	
2480.74	3.0090	
2258.57	12.6755	

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

```

"Calculating the Specific Enthalpy of Sea Water"
p=1 "Pressure p in bar"
t=100 "Temperature t in °C"
Xi=0.12 "Water mass fraction of sea salt in kg/kg"
CALL h_ptx_97(p,t,Xi)
    
```

Add-In FluidMAT for Mathcad®

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

Function of FluidMAT

Calculation of Specific Enthalpy of Steam from IAPWS-IF97

$p := 10$ in bar given pressure

$t := 300$ in °C given temperature

$x := -1$ in $\frac{\text{kg}}{\text{kg}}$ vapor fraction (-1 for single phase region)

$h := h_{\text{ptx_97}}(p, t, x)$ call of the function from FluidMAT

$h = 3051.70$ in $\frac{\text{kJ}}{\text{kg}}$ result for specific enthalpy

Add-In FluidLAB for MATLAB®

The property functions can be called in MATLAB®.

Function of FluidLAB

```

% hl_ptxw_HuAir.m
%%
p=1; % pressure in bar
t=20; % temperature in °C
xw=10; % absolute humidity in g/kg air
%%
hl=hl_ptxw_HuAir(p,t,xw)
%%
    
```

Command Window

```

h1 =
45.5084
    
```

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

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

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

6. References

- [1] IAPWS Secretariat, Dooley, B., EPRI, Palo Alto CA (1997):
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- [2] Wagner, W.; Kretzschmar, H.-J. (2008):
International Steam Tables. Springer-Verlag, Berlin, www.international-steam-tables.com
- [3] Kretzschmar, H.-J. (2008):
Mollier h-s Diagram. Springer-Verlag, Berlin, www.international-steam-tables.com
- [4] IAPWS Secretariat, Dooley, B., EPRI, Palo Alto CA (1998):
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- [5] IAPWS Secretariat, Dooley, B., EPRI, Palo Alto CA (2003):
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