Property Library for Iso-Butane

FluidLAB
with LibButane_Iso
for MATLAB®

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Property Software for Iso-Butane

FluidLAB for MATLAB®

LibButane_iso

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0. Package Contents

0.1 Zip file for 32-bit MATLAB®

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

"CD_FluidLAB_LibButan_iso.zip"

Including the following files:

FluidLAB_LibButan_iso_Setup.exe	- Installation program for the FluidLAB Add-On for use in MATLAB®
LibButan_iso.dll	- Dynamic Link Library for helium for use in MATLAB®
FluidLAB_LibButan_iso_Docu_Eng.pdf	- User's Guide

0.2 Zip file for 64-bit MATLAB®

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

"CD_FluidLAB_LibButan_iso_x64.zip"

Including the following files and folders:

Files:

Setup.exe	- Self-extracting and self-installing program for FluidLAB
FluidLAB_LibButan_iso_64.msi	- Installation program for the FluidLAB Add-On for use in MATLAB®
LibButan_iso.dll	- Dynamic Link Library for helium for use in MATLAB®
FluidLAB_LibButan_iso_Docu_Eng.pdf	- User's Guide

Folders:

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

1. Property Functions

Functional Dependence	Function Name	Call from Fortran program	Call in DLL LibButan_iso as parameter	Property or Function	Unit of the result
$a = f(p,t,x)$	a_ptx_BUTI	APTXBUTI(P,T,X)	C_APTXBUTI(A,P,T,X)	Thermal diffusivity	m^2/s
$c_p = f(p,t,x)$	cp_ptx_BUTI	CPPTXBUTI(P,T,X)	C_CPPTXBUTI(CP,P,T,X)	Specific isobaric heat capacity	kJ/(kg K)
$\eta = f(p,t,x)$	eta_ptx_BUTI	ETAPTXBUTI(P,T,X)	C_ETAPTXBUTI(ETA,P,T,X)	Dynamic viscosity	Pa s
$h = f(p,t,x)$	h_ptx_BUTI	HPTXBUTI(P,T,X)	C_HPTXBUTI(H,P,T,X)	Specific enthalpy	kJ/kg
$\kappa = f(p,t,x)$	kappa_ptx_BUTI	KAPTXBUTI(P,T,X)	C_KAPTXBUTI(KAP,P,T,X)	Isentropic exponent	-
$\lambda = f(p,t,x)$	lambda_ptx_BUTI	LAMPTXBUTI(P,T,X)	C_LAMPTXBUTI(LAM,P,T,X)	Thermal conductivity	W/(m K)
$\nu = f(p,t,x)$	ny_ptx_BUTI	NYPTXBUTI(P,T,X)	C_NYPTXBUTI(NY,P,T,X)	Kinematic viscosity	m^2/s
$p_{mel} = f(t)$	pmel_t_BUTI	PMELBUTI(T)	C_PMELBUTI(PMEL,T)	Melting pressure from temperature	bar
$p_s = f(t)$	ps_t_BUTI	PSTBUTI(T)	C_PSTBUTI(PS,T)	Vapor pressure from temperature	bar
$Pr = f(p,t,x)$	Pr_ptx_BUTI	PRPTXBUTI(P,T,X)	C_PRPTXBUTI(PR,P,T,X)	*Prandtl*-Number	-
$\rho = f(p,t,x)$	rho_ptx_BUTI	ROPTXBUTI(P,T,X)	C_ROPTXBUTI(RHO,P,T,X)	Density	kg/m^3
$s = f(p,t,x)$	s_ptx_BUTI	SPTXBUTI(P,T,X)	C_SPTXBUTI(S,P,T,X)	Specific entropy	kJ/(kg K)
$t = f(p,h)$	t_ph_BUTI	TPHBUTI(P,H)	C_TPHBUTI(T,P,H)	Backward function: Temperature from pressure and enthalpy	°C
$t = f(p,s)$	t_ps_BUTI	TPSBUTI(P,S)	C_TPSBUTI(T,P,S)	Backward function: Temperature from pressure and entropy	°C
$t_{mel} = f(p)$	tmel_p_BUTI	TMELBUTI(P)	C_TMELBUTI(TMEL,P)	Melting temperature from pressure	°C
$t_s = f(p)$	ts_p_BUTI	TSPBUTI(P)	C_TSPBUTI(TS,P)	Saturation temperature from pressure	°C
$u = f(p,t,x)$	u_ptx_BUTI	UPTXBUTI(P,T,X)	C_UPTXBUTI(U,P,T,X)	Specific internal energy	kJ/kg
$v = f(p,t,x)$	v_ptx_BUTI	VPTXBUTI(P,T,X)	C_VPTXBUTI(V,P,T,X)	Specific volume	m^3/kg

Functional Dependence	Function Name	Call from Fortran program	Call in DLL LibButan_iso as parameter	Property or Function	Unit of the result
w = f(*p*,*t*,*x*)	w_ptx_BUTI	WPTXBUTI(P,T,X)	C_WPTXBUTI(W,P,T,X)	Isentropic speed of sound	m/s
x = f(*p*,*h*)	x_ph_BUTI	XPHBUTI(P,H)	C_XPHBUTI(X,P,H)	Backward function: Vapor fraction from pressure and enthalpy	kg/kg
x = f(*p*,*s*)	x_ps_BUTI	XPSBUTI(P,S)	C_XPSBUTI(X,P,S)	Backward function: Vapor fraction from pressure and entropy	kg/kg

Units: t in °C

p in bar

x in (kg of saturated steam)/(kg wet steam)

Range of validity:

Temperature t: from $t_{mel}(p)$ to 301.85 °C

Pressure p: from $p_t = 2.19 \times 10^{-7}$ bar to 350 bar

Reference state

h = 200 kJ/kg and s = 1 kJ/(kg K) at t = 0 °C on the boiling curve (x = 0)

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 = -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.

Wet steam region: Temperature from t_t = –159.42 °C to t_c = 134.66 °C

Pressure from $p_t = 2.19 \times 10^{-7}$ bar to 36.29 bar

Note!

If the input values are located outside the range of validity, the result for the calculated function will always be –1000. You can find more exact details on every function and its corresponding range of validity in the enclosed program documentation in chapter 3.

2 Application of FluidLAB in MATLAB

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

2.1 Installing FluidLAB

Installing FluidLAB including LibButane_iso for 32-bit MATLAB®

This section describes the installation of FluidLAB LibButane_iso for a 32-bit version of MATLAB®.

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

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

CD_FluidLAB_LibButane_iso

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

Open this folder by double-clicking on it.

In this folder you will see the following files:

FluidLAB_LibButane_iso_Docu_Eng.pdf
FluidLAB_LibButane_iso_Setup.exe
LibButan_iso.dll.

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

FluidLAB_LibButane_iso_Setup.exe.

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

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

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

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

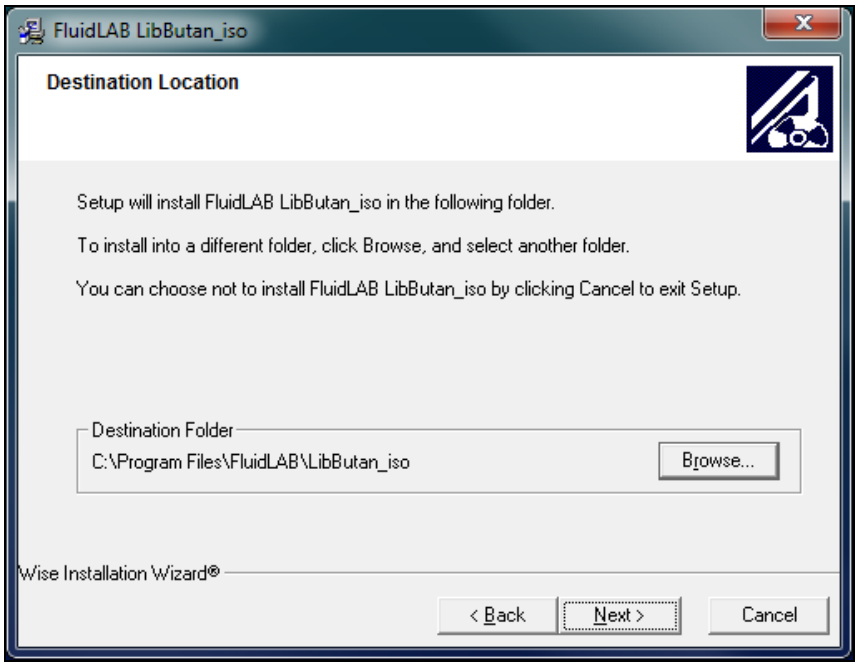

Figure 2.1: "Destination Location"

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

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

The installation program has copied the following files:

capt_ico_big.ico	LC.dll
libifcoremd.dll	limmd.dll
libiomp5md.dll	LibButan_iso.dll

for LibButane_iso into the directory

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

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

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

To do this, open the CD in "My Computer" and click on the file "LibButan_iso.dll" in order to highlight it.

Then click on the "Edit" menu in your Explorer and select "Copy".

Now, open your FluidLAB directory (the standard being

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

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

and insert the file "LibButan_iso.dll" by clicking the "Edit" menu in your Explorer and then select "Paste". Answer the question whether you want to replace the file by clicking the "Yes" button. Now, you have overwritten the file "LibButan_iso.dll" successfully and the property functions are available in MATLAB.

Installing FluidLAB including LibButane_iso for 64-bit MATLAB®

This section describes the installation of FluidLAB LibButane_iso.

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

After you have downloaded and extracted the zip-file "CD_FluidLAB_LibButane_iso_x64.zip", you will see the folder

CD_FluidLAB_LibButane_iso

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

Open this folder by double-clicking on it.

In this folder you will see the following two files:

FluidLAB_LibButane_iso_Docu_Eng.pdf
FluidLAB_LibButane_iso_64_Setup.msi
LibButan_iso.dll
Setup.exe.

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

Setup.exe.

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

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

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

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

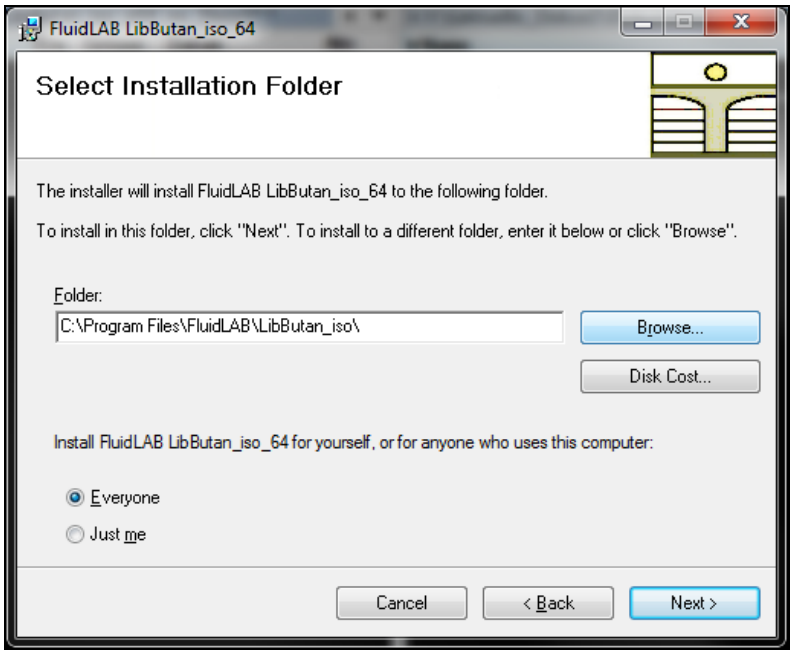

Figure 2.2: "Select Installation Folder"

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

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

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

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

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

Now, you have to overwrite the file "LibButan_iso.dll" in your FluidLAB directory with the file of the same name provided on your CD with FluidLAB.
To do this, open the CD in "My Computer" and click on the file "LibButan_iso.dll" in order to highlight it. Then click on the "Edit" menu in your Explorer and select "Copy".
Now, open your FluidLAB directory (the standard being C:\Program Files\FluidLAB\LibButane_iso) and insert the file "LibButan_iso.dll" by clicking the "Edit" menu in your Explorer and then select "Paste". Answer the question whether you want to replace the file by clicking the "Yes" button. Now, you have overwritten the file "LibButan_iso.dll" successfully and the property functions are available in MATLAB.

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

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

- Dynamic link library "LibButan_iso.dll" and other necessary system DLL files.

- MATLAB®-Interface-Program for calculable functions

a_ptx_BUTI	s_ptx_BUTI
cp_ptx_BUTI	t_ph_BUTI
eta_ptx_BUTI	t_ps_BUTI
h_ptx_BUTI	tmel_p_BUTI
kappa_ptx_BUTI	ts_p_BUTI
lambda_ptx_BUTI	u_ptx_BUTI
ny_ptx_BUTI	v_ptx_BUTI
pmel_t_BUTI	w_ptx_BUTI
ps_t_BUTI	x_ph_BUTI
Pr_ptx_BUTI	x_ps_BUTI
rho_ptx_BUTI	

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

The 32-bit installation program has copied function files with the file extension
.mexw32
and the 64-bit installation program has copied function files with the file extension
.mexw64
into your LibButane_iso directory (the standard being
C:\Program Files\FluidLAB\LibButane_iso (for English version of Windows)
C:\Programme\FluidLAB\LibButane_iso (for German version of Windows).

2.2 Licensing the LibButane_iso Property Library

The licensing procedure must be carried out when the prompt message appears. In this case, you will see the "License Information" window for LibButane_iso (see figure below).

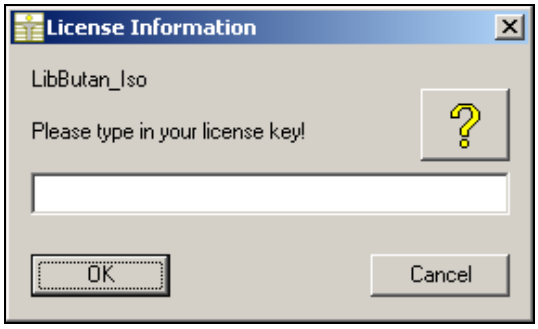

Figure 2.3: "License Information" window

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

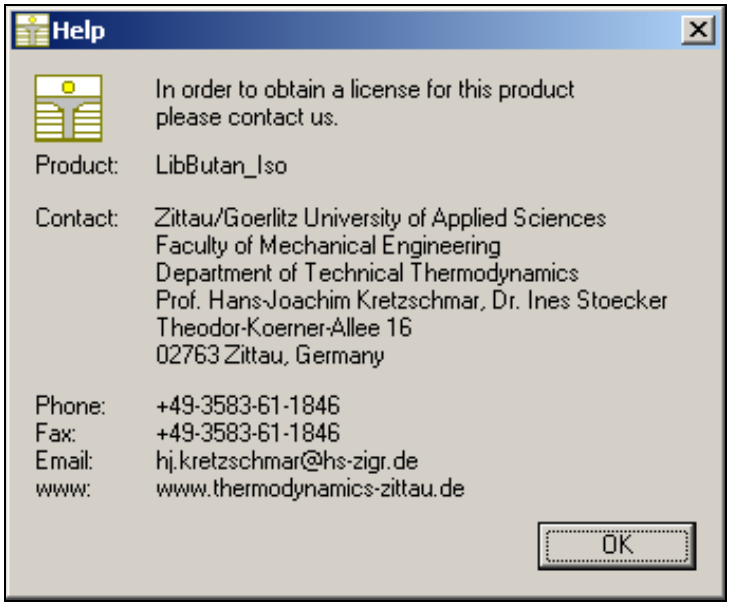

Figure 2.4: "Help" window

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

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

2.3 Example: Calculation of the Specific Enthalpy *h* = f(*p*,*t*,*x*) for LibButane_Iso in an M-File

Now we will calculate, step by step, the specific enthalpy *h* as a function of pressure *p*, temperature *t* and vapor fraction *x* for Iso-Butane using FluidLAB.

Please carry out the following instructions:

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

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

- Create the folder "\LibButane_iso_Example". Click "File", then click "New" in the pop-up menu and afterwards select "Folder". Name the new folder "\LibButane_iso_Example ".
- You will see the following window:

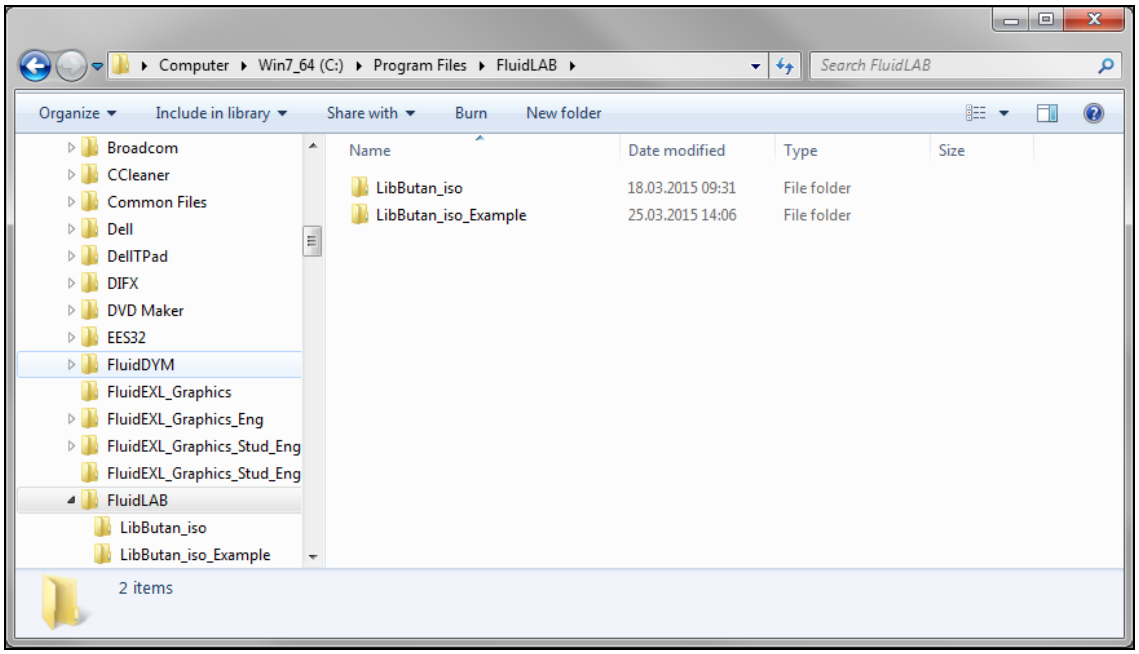

Figure 2.5: Folders "LibButane_iso" and "LibButane_iso_Example"

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

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

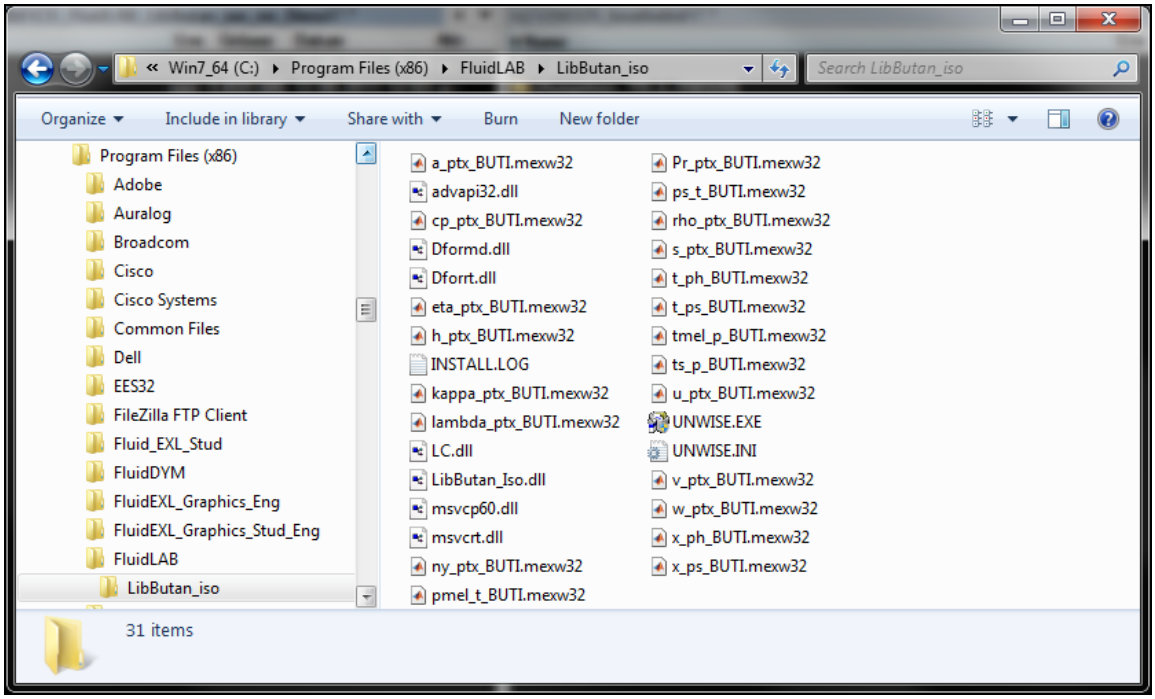

Figure 2.6: Contents of the folder "LibButane_iso" (32-bit version)

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

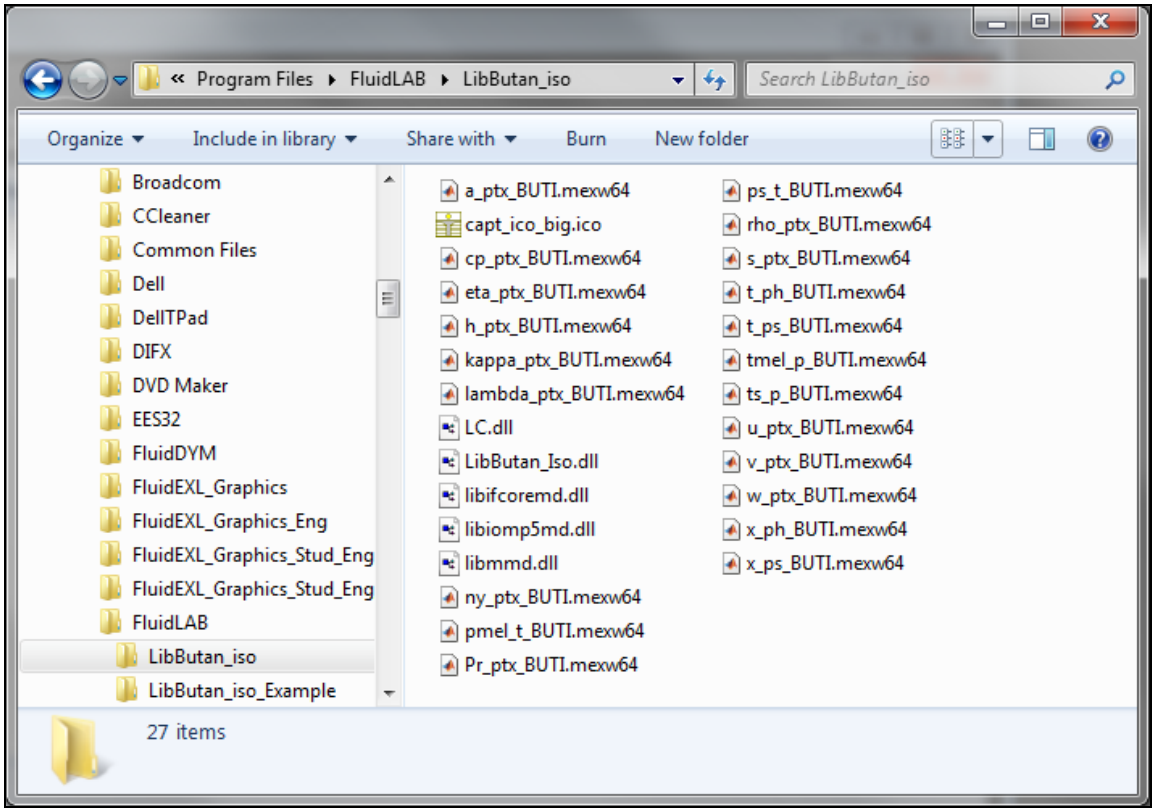

Figure 2.7: Contents of the folder "LibButane_iso" (64-bit version)

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

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

in order to calculate the function $h = f(p,t,x)$.

- The following files are needed:
  - "advapi32.dll"
  - "Dformd.dll"
  - "Dforrt.dll"
  - "h_ptx_BUTI.mexw32"
  - "LibButan_iso.dll"
  - "LC.dll.dll"
  - "msvcp60.dll"
  - "msvcrt.dll"
- Click the file "h_ptx_BUTI.mexw32", then click "Edit" in the upper menu bar and select "Copy".
- Switch into the directory

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

  click "Edit" and select "Paste".
- Repeat these steps in order to copy the other files listed above.
- You will see the following window:

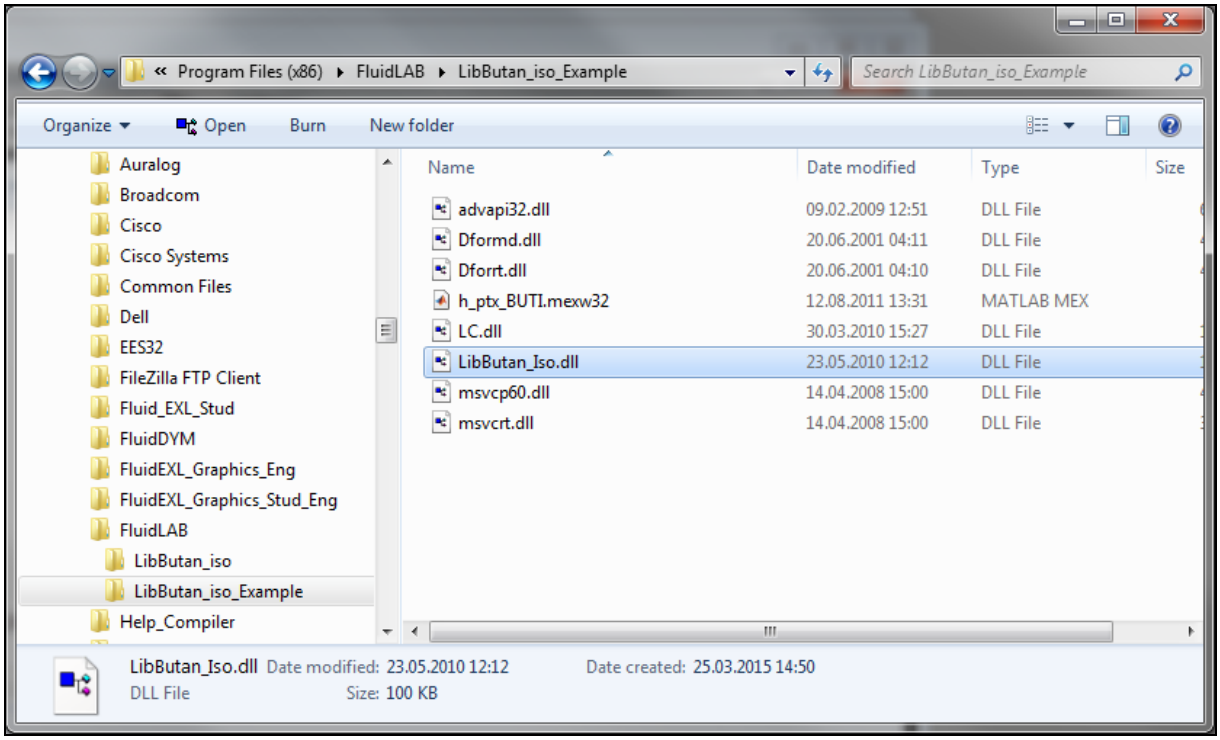

Figure 2.8: Contents of the folder "LibButane_iso_Example" (32-bit)

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

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

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

in order to calculate the function $h = f(p,t,x)$.

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

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

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

click "Edit" and then "Paste."

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

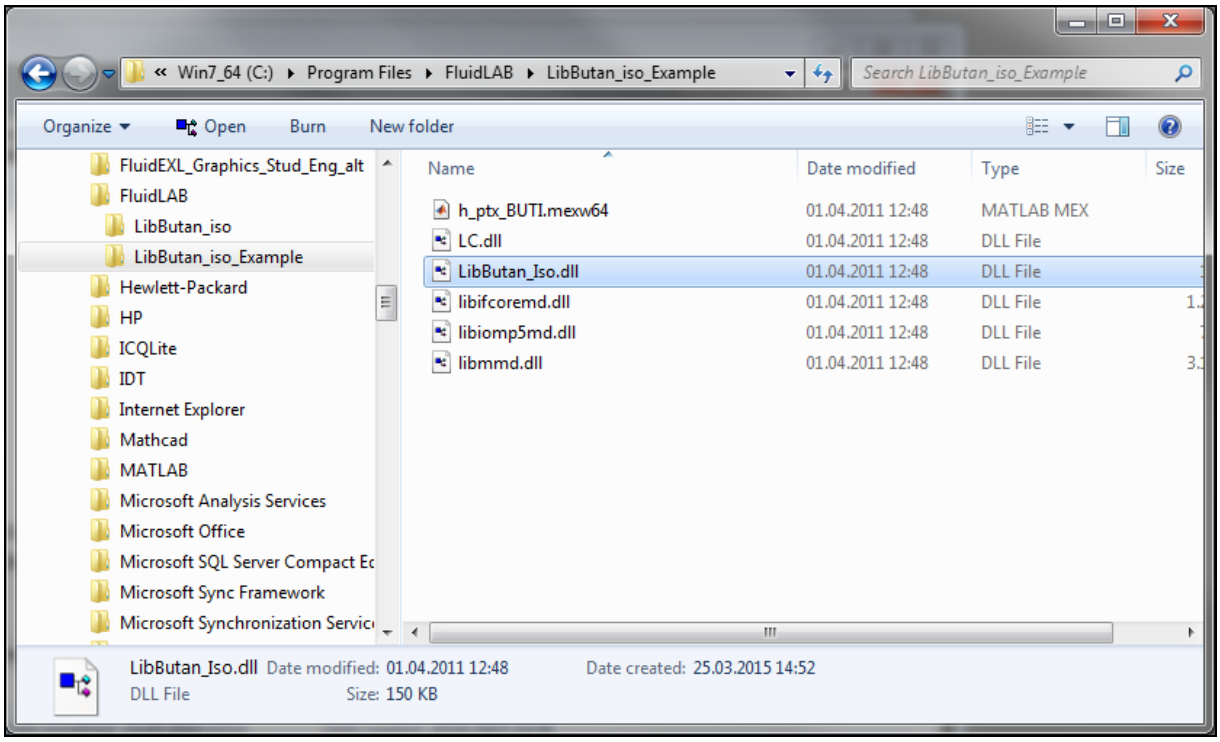

Figure 2.9: Contents of the folder "LibButan_iso_Example" (64-bit)

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

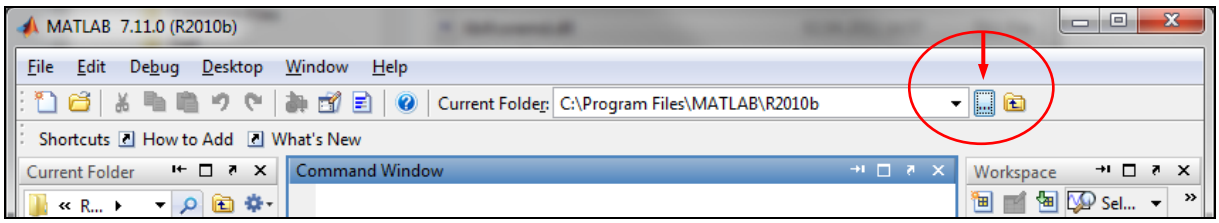

Figure 2.10: Selection of the working directory

- Find and select the directory

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

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

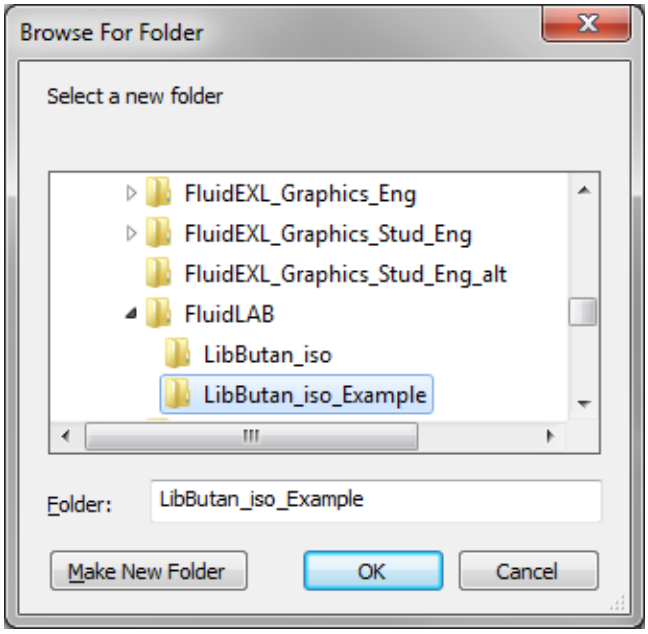

Figure 2.11: Choosing the "LibButan_iso_Example" folder

- Confirm your selection by clicking the "OK" button.
- First of all you need to create an M–File in MATLAB®. Within MATLAB® click "File", then select "New" and afterwards click "M-File" in MATLAB 2006 or earlier versions or click "Script" in MATLAB R2010 or later versions.
- If the "Editor" window appears as a separate window, you can embed it into MATLAB® by clicking the insertion arrow (see next figure) in order to obtain a better view.

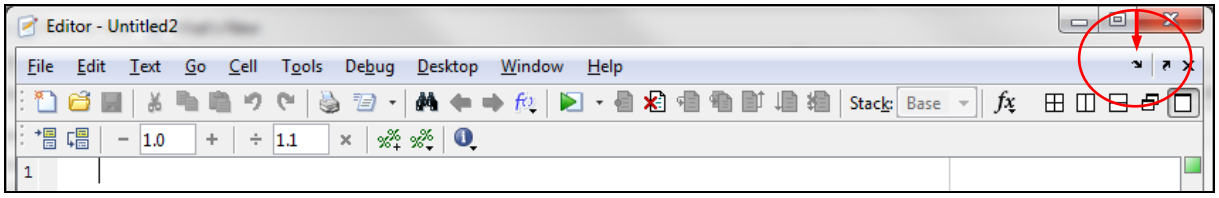

Figure 2.12: Embedding the "Editor" window

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

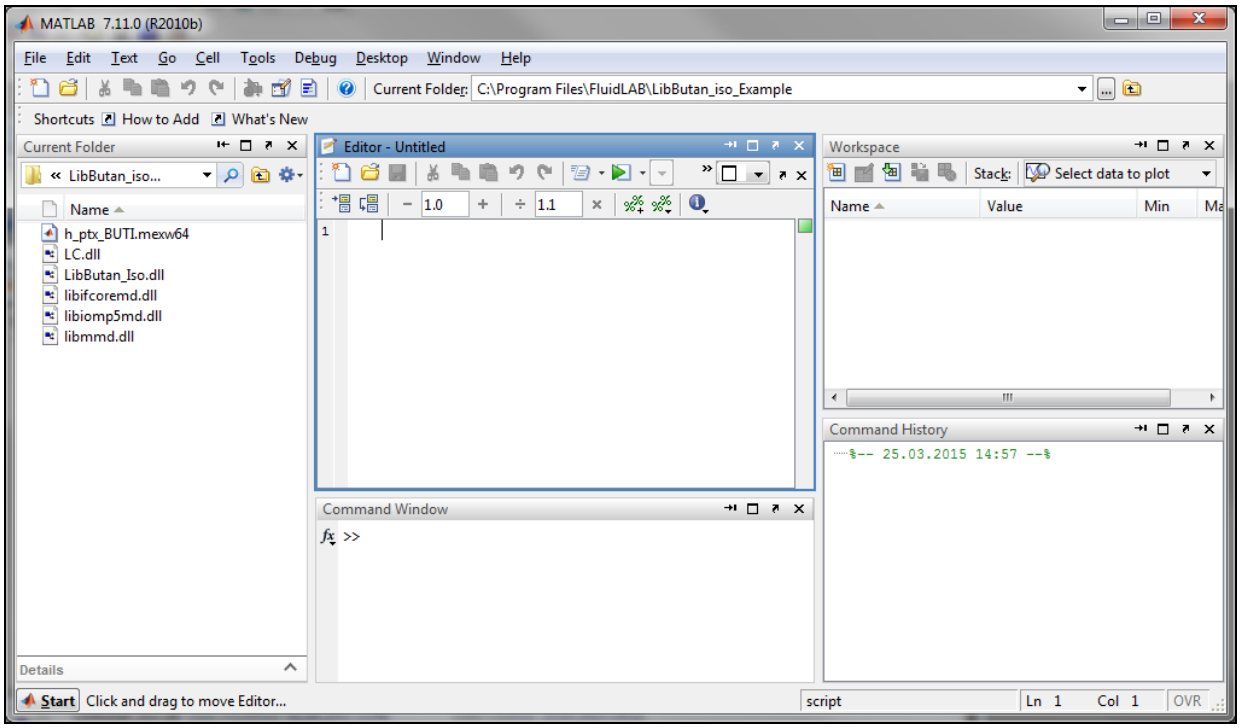

Figure 2.13: Embedded "Editor" window

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

Text to be written:	Explanation:
`% h_ptx_BUTI.m`	file name as comment
`%%`	paragraph separation
`p=10;  % pressure in bar`	declaration of the variables pressure, temperature, art and composition of mixture
`t=25;  % temperature in °C`	
`x=-1;  % vapor fraction of Iso-Butane in kg/kg`	
`%%`	paragraph separation
`h=h_ptx_BUTI(p,t,x)`	function call
`%%`	paragraph separation

- Remarks:

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

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

- First operand: Value for p = 10 bar
  (Range of validity: p_t = 2.19 x 10^{-7} bar … 350 bar)
- Second operand: Value for t = 25 °C
  (Range of validity: $t = t_{mel}(p)$ … 301.85 °C)
- Third operand: Value for x = -1 in kg saturated steam/kg wet steam)

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.
Here the backward functions will also result in x = –1.

Wet-steam region

When calculating wet steam, a value between 0 and 1 (x = 0 for boiling 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*. 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 *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1000.

(Saturation line of Iso-Butane: t_t = –159.42 °C ... t_c = 134.66 °C
p_t = 2.19 x 10^{-7} bar … p_c = 36.29 bar)

- Save the "M-File" by clicking the "File" button and then click "Save As...".
- The menu "Save file as:" appears; therein the folder name "LibButan_iso_Example" must be displayed next to "Save in:"
- Next to "File name" you have to type "Example_h_ptx_BUTI.m" and afterwards click the "Save" button.

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

- You will now see the following window:

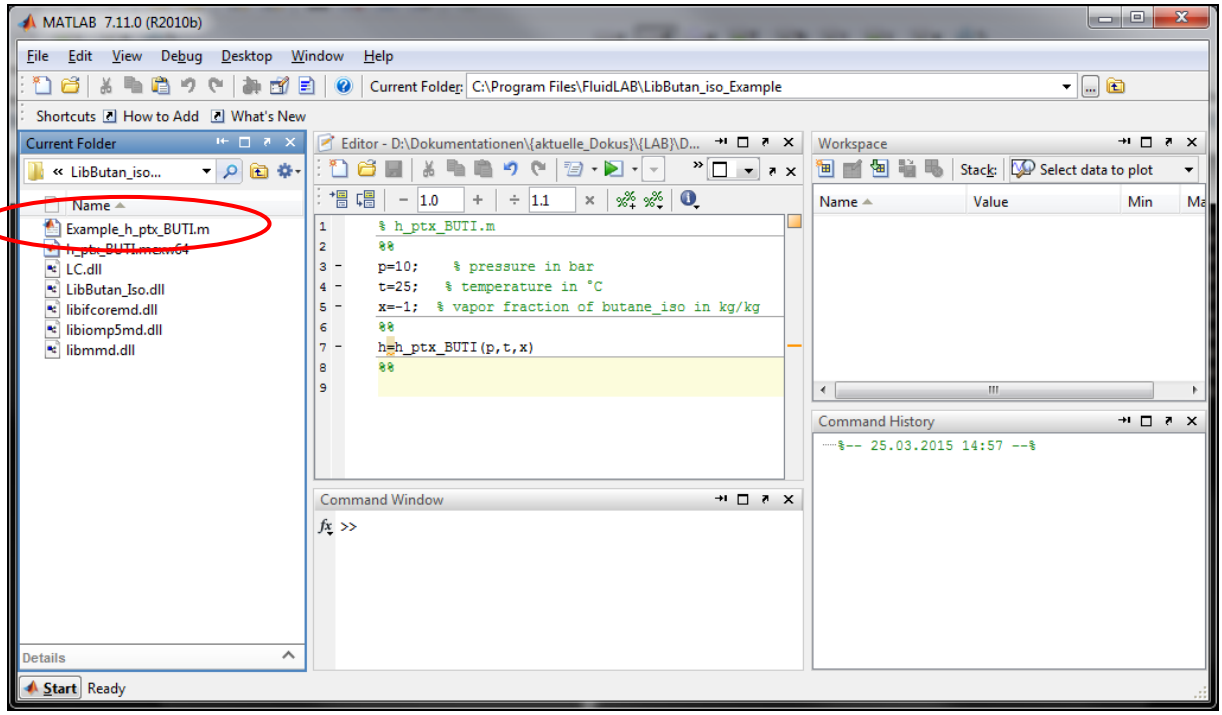

Figure 2.14: "Example_h_ptx_BUTI.m" M-file

- Within the "Current Directory" window the file "Example_h_ptx_BUTI.m" appears.
- Right-click this file and select "Run" in the menu which appears (see next Figure).

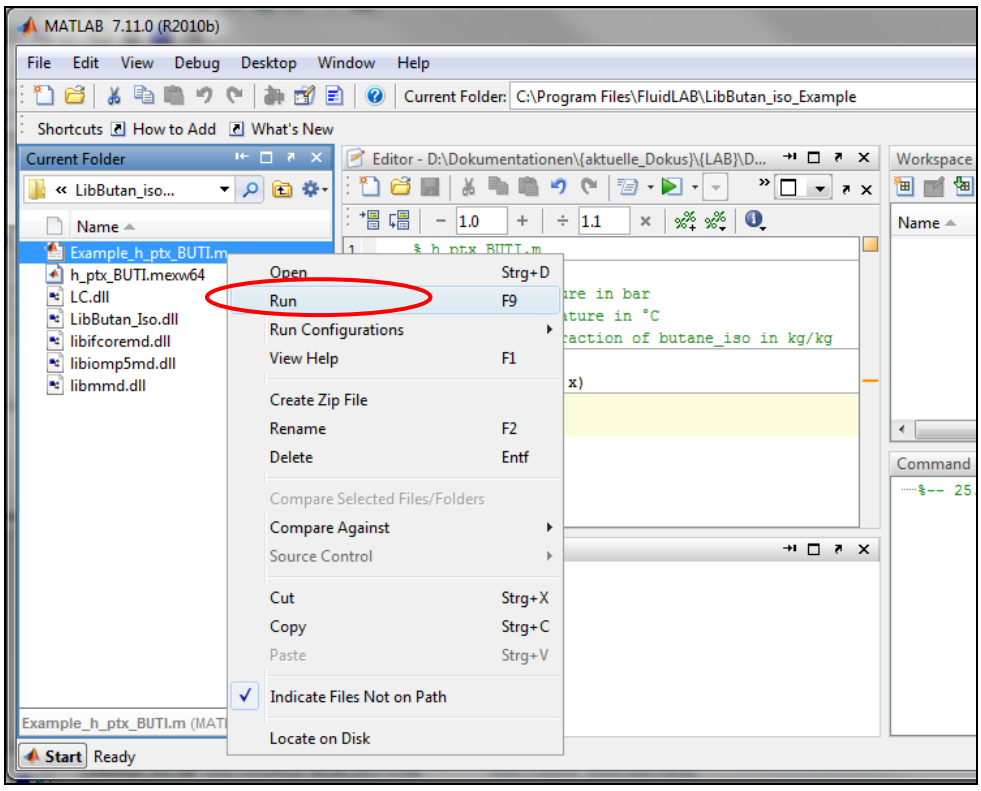

Figure 2.15: Running the "Example_h_ptx_BUTI.m" M-file

- You will see the following window:

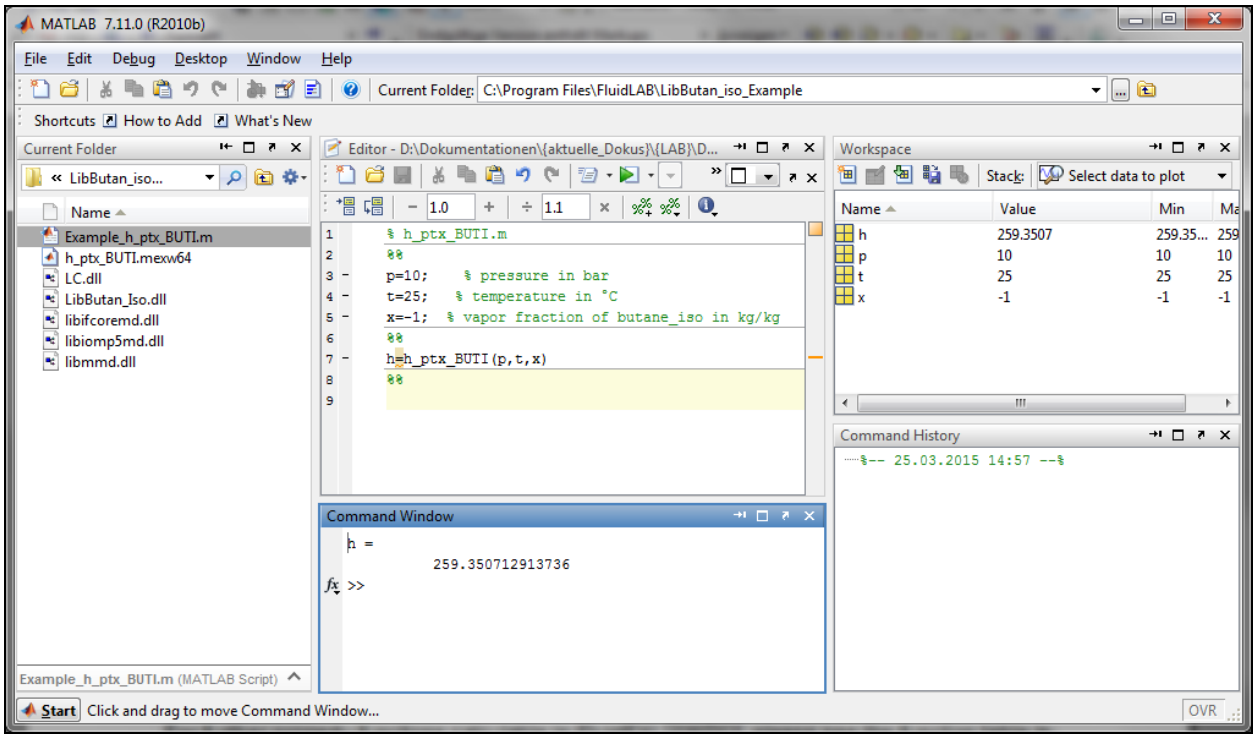

Figure 2.16: MATLAB® with calculated result

The result for *h* appears in the "Command Window".

⇒ The result in our sample calculation here is: "h = 259.350712913736 kJ/kg kJ/kg".
The corresponding unit is kJ/kg (see table of the property functions in Chapter 1).

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

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

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

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

Hint!

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

2.4 Example: Calculation of the Specific Enthalpy *h* = f(*p*,*t*,*x*) for Seawater in the Command Window

- Please follow the instructions from page 2/6 to 2/9.
- Start MATLAB® (if you have not started it already).
- Click the button marked in the following figure in order to open the folder "\LibButan_iso_Example" in the window "Current Directory".

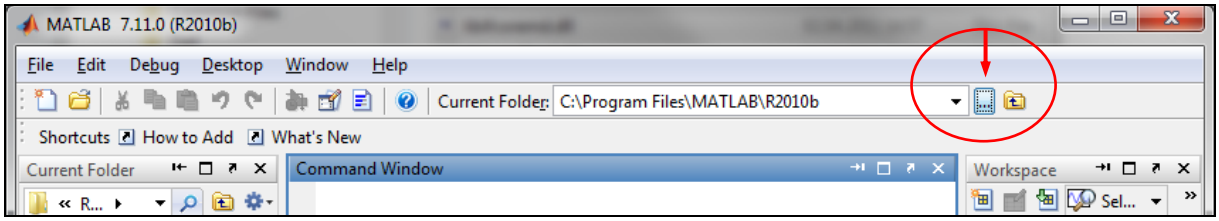

Figure 2.17: Selection of the working directory

- Find and select the directory

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

  in the menu that appears (see figure below).

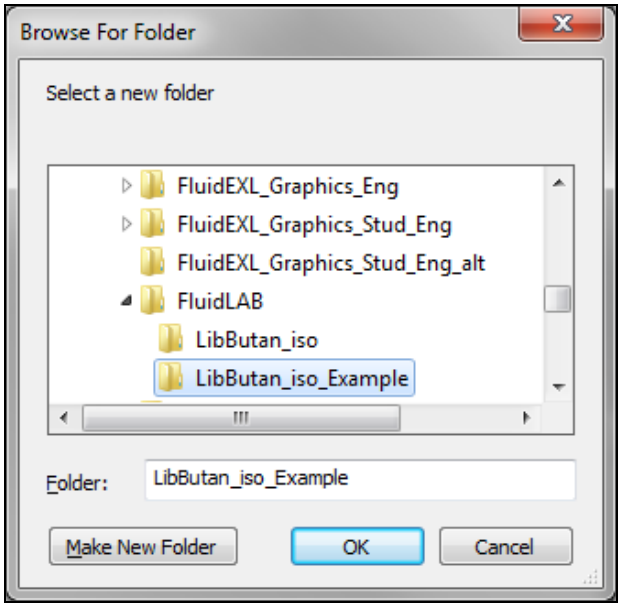

Figure 2.18: Choosing the "LibButan_iso_Example" folder

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

- You will see the following window:

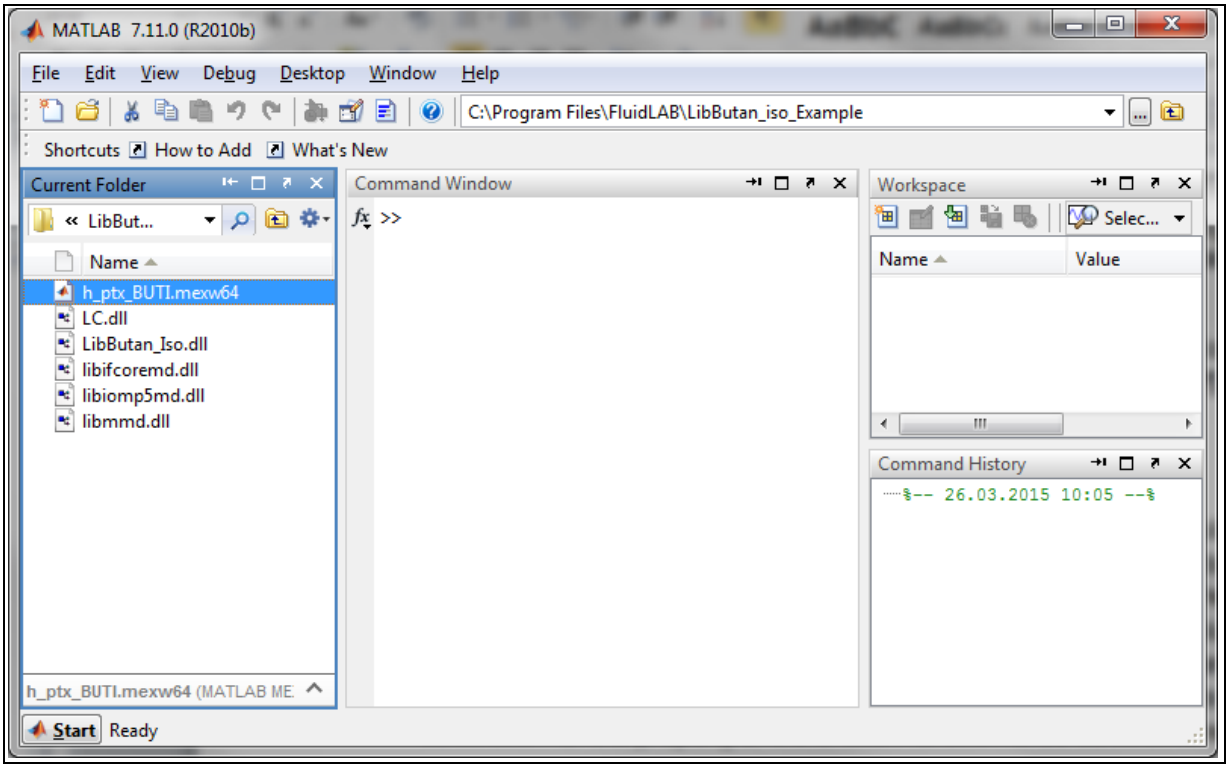

Figure 2.19: MATLAB® with necessary files

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

- Write "**h=h_ptx_BUTI(10,25,-1)**" within the "Command Window".

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

- First operand: Value for *p* = 10 bar
  (Range of validity: *p* = 0.01 bar ... 800 bar)
- Second operand: Value for *t* = 25 °C
  (Range of validity: *t* = -6°C … 220°C
- Third operand: Value for *x* = -1 in kg saturated steam/kg wet steam)

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.
Here the backward functions will also result in x = –1.

Wet-steam region

When calculating wet steam, a value between 0 and 1 (x = 0 for boiling 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*. 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 *p* and

t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1000.

(Saturation line of Iso-Butane: t_t = –159.42 °C ... t_c = 134.66 °C
p_t = 2.19 x 10^{-7} bar … p_c = 36.29 bar)

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

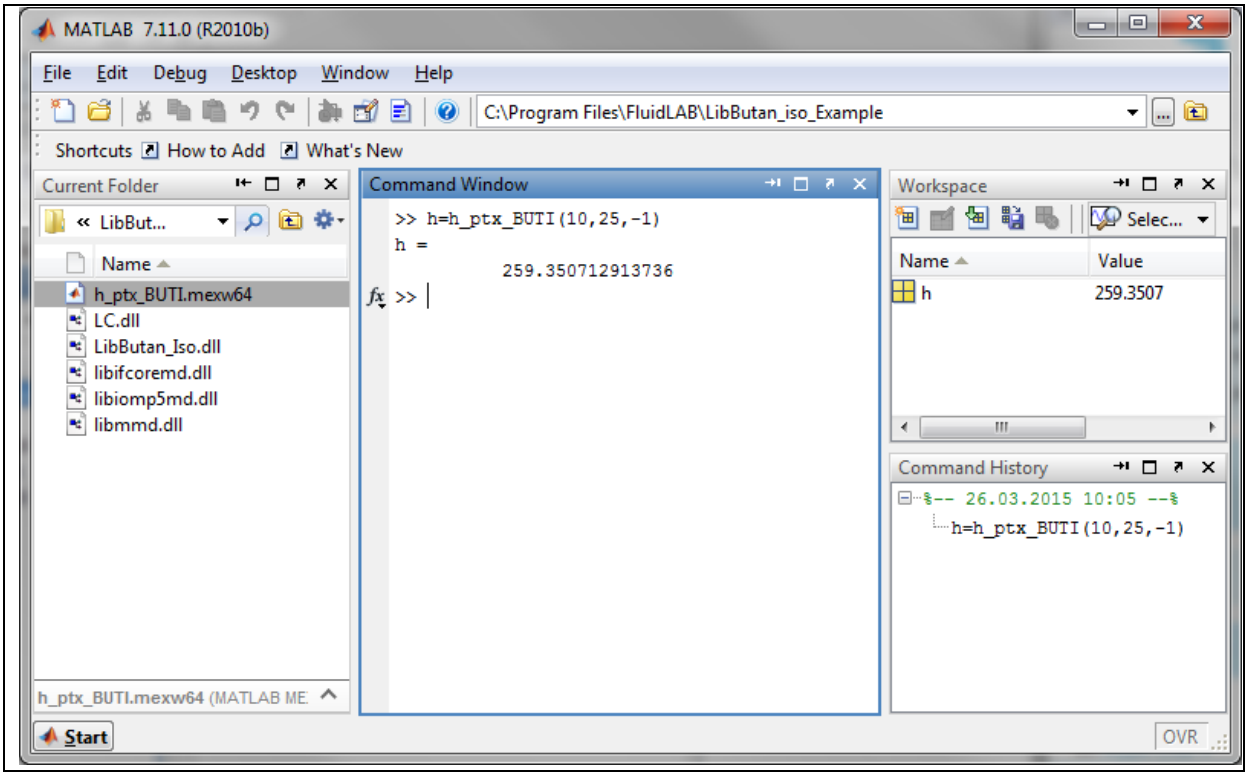

Figure 2.20: MATLAB® with calculated result

⇒ In the "Command Window" you will see the result "h = 259.350712913736kJ/kg ".
The corresponding unit is kJ/kg (see table of the property functions in chapter 1).

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

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

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

Note:

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

2.5 Using FluidLAB with SIMULINK

To use the functions of FluidLAB with the simulation program SIMULINK you have to start SIMULINK in MATLAB® by clicking on Simulink in the upper menu bar shown in Figure 2.19.

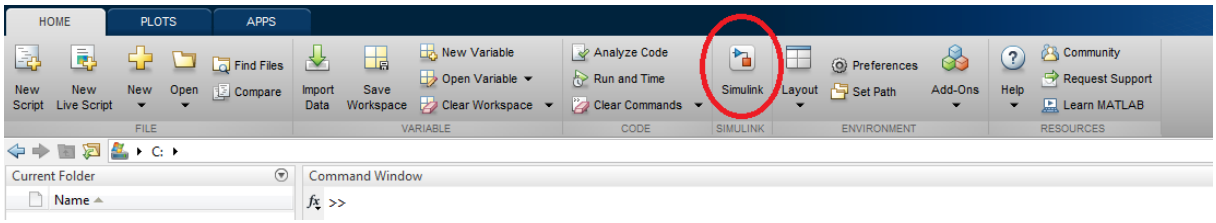

Figure 2.21: Starting Simulink

Then choose a blank model or a simulation in which you would like to use FluidLAB. Now you need to add a MATLAB function block that you can find in the library browser shown in Figure 2.22.

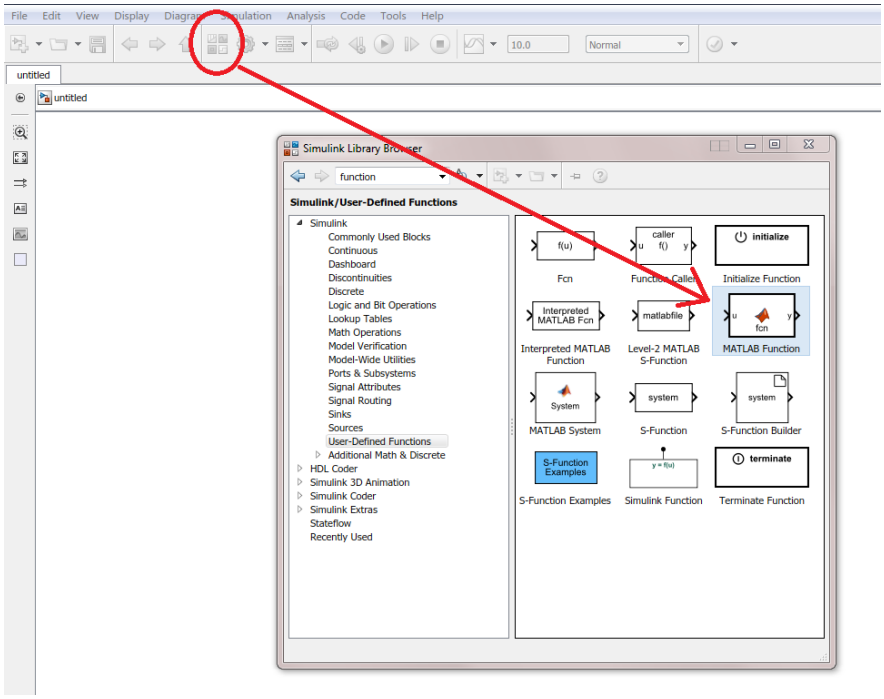

Figure 2.22: Simulink library browser and choosing a MATLAB Function

By dragging and dropping you can drag a Simulink block in your model. The function needs inputs and output that you can find in the Simulink library browser under sources and sinks. For this example constants were taken for the inputs and a display block were taken for outputting.

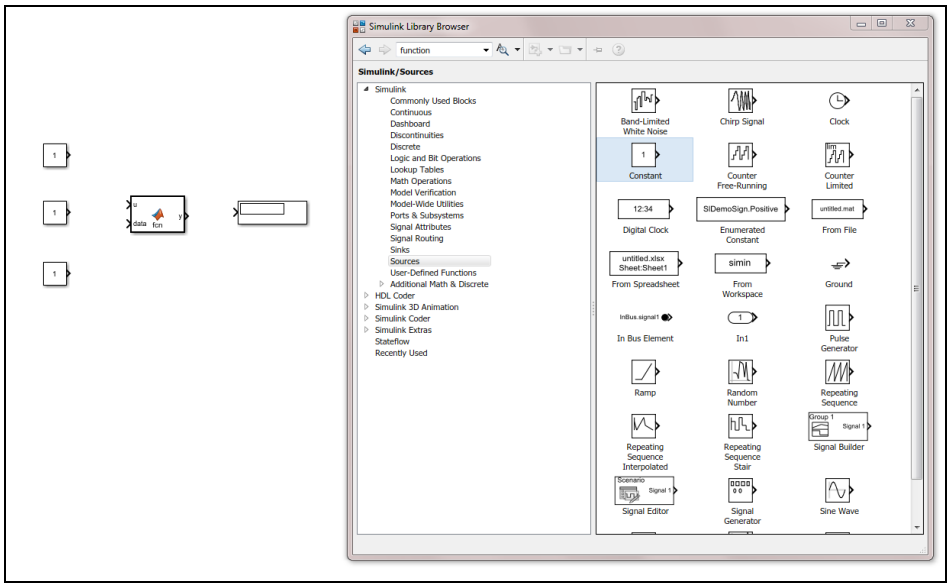

Figure 2.23: Inputs and outputs of the example

Now you have to link inputs and outputs to the MATLAB function block. By pressing and holding the left mouse button on the arrow of a block, you can draw a line and drag it to the MATLAB function block. With this method you can link all blocks together.

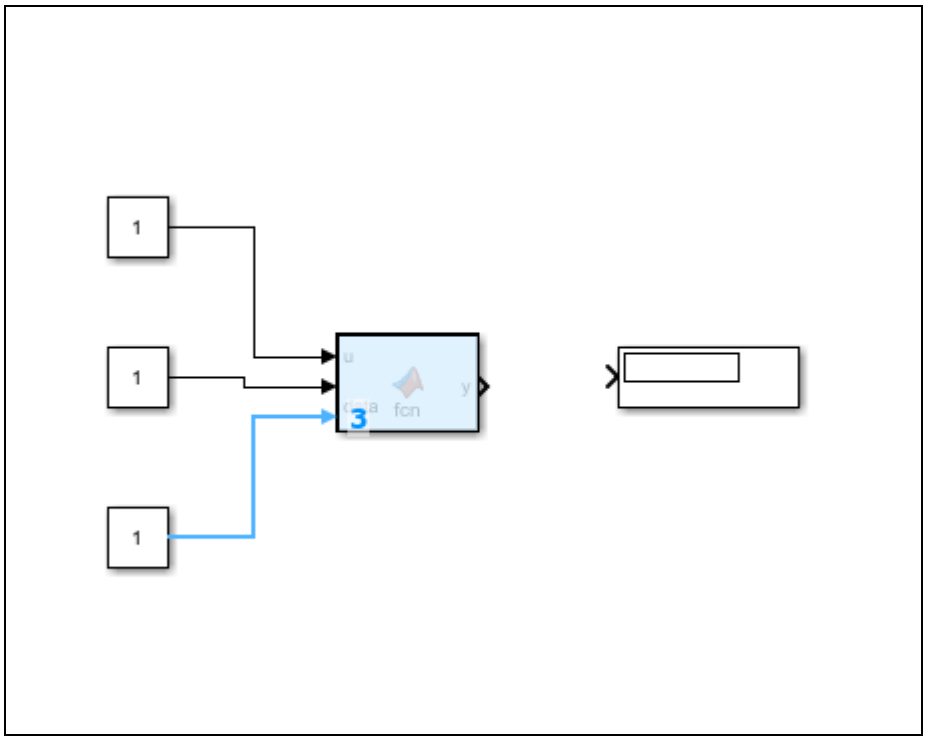

Figure 2.24: Linking blocks in Simulink

You can define the value of a constant block by double-click on them. If you want to calculate the example use the values you can find in section 2.3 and 2.4. With a double-click on the MATLAB function block you can define the function in MATLAB®. The following source code is for the example calculation and the table below describes the source code closer. You can adapt these few lines to call all other function of FluidLAB.

```
function h = fcn(p, t, x)
coder.extrinsic('addpath');
```

```
coder.extrinsic('h_ptx_BUTI');
addpath('C:\Program Files\FluidLAB\LibButane_Iso');
h = h_ptx_BUTI(p,t,x);
```

Matlab source code	Explanation
`function h = fcn(p, t, x)`	function header, you can define the function name and the inputs like p, t and x of the example
`coder.extrinsic('addpath');`	necessary to add a path
`coder.extrinsic('h_ptx_BUTI');`	Choose the function name of the FluidLAB function
`addpath('C:\Program Files\FluidLAB\LibButane_Iso');`	Add the installation path of FluidLAB
`h = h_ptx_BUTI(p,t,x);`	Linking the FluidLAB function to the MATLAB function block

You can copy and paste the sourcecode in MATLAB® or write it into the MATLAB® editor. The simulation will start by clicking the run button in Matlab or Simulink and you can see the example in the display block of the simulation which is shown in figure 2.23.

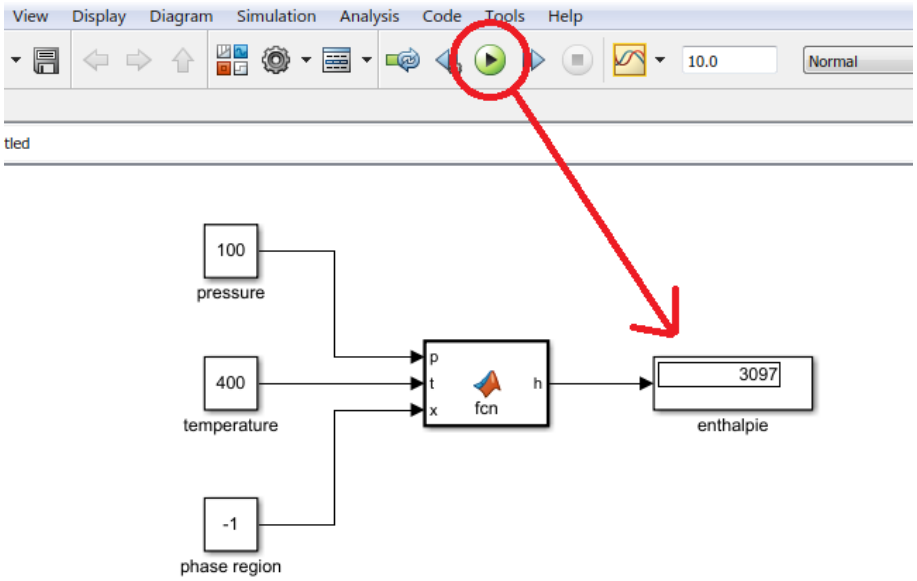

Figure 2.25: Starting the simulation and result of the calculation

Your result is may an other than shown in figure 2.25. If you want to calculate the example please use the values from section 2.3 and 2.4.

2.5 Removing FluidLAB including LibButane_iso

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

Now double-click on "Add or Remove Programs".

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

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

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

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

Now, FluidLAB has been removed.

If there is no library other than LibButane_iso installed, the directory "FluidLAB" will be removed as well.

3. Program Documentation

Thermal Diffusivity *a* = f(*p*,*t*,*x*)

Function Name:	**a_ptx_BUTI**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION APTXBUTI(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_APTXBUTI(A,P,T,X)** REAL*8 A,P,T,X

Input Values

P – Pressure *p* in bar

T - Temperature *t* in °C

X – Vapor fraction *x* (kg of saturated steam)/(kg wet steam)

Result

APTXBUTI, **A** or **a_ptx_BUTI** – Thermal diffusivity $a = \frac{\lambda * v}{c_p}$ in m^2 / s

Range of validity

Temperature range: from t_{mel} to 301.85°C

Pressure range: from $p_t = 2.19 \times 10^{-7}$ bar to 350 bar

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 = -1000, or the given value for *p* and t = -1000, 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_t = -159.42 °C to t_c = 134.66 °C

Pressure ranges from p_t = 2.19 x 10^{-7} bar to p_c = 36.29 bar)

Results for wrong input values

Result **APTXBUTI = –1000**, **A = –1000** or **a_ptx_BUTI = –1000** for input values

Single phase region: ($x = -1$)
$p > 350$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or
$t > 301.85$°C or $t < t_{mel}$

Boiling or dew curve:
at $p = -1000$ and $t > t_c = 134.66$°C or $t < t_t = -159.42$°C

at $t = -1000$ and $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or

at $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar and
$t > t_c = 134.66$°C or $t < t_t = -159.42$°C

References: [22], [25], [27]

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

Function Name:	**cp_ptx_BUTI**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION CPPTXBUTI(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_CPPTXBUTI(CP,P,T,X)** REAL*8 CP,P,T,X

Input Values

P – Pressure p in bar

T - Temperature t in °C

X – Vapor fraction x (kg of saturated steam)/(kg wet steam)

Result

CPTXBUTI, **CP** or **cp_ptx_BUTI** – Specific isobaric heat capacity c_p in kJ/(kg K)

Range of validity

Temperature range: from t_{mel} to 301.85°C

Pressure range: from $p_t = 2.19 \times 10^{-7}$ bar to 350 bar

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 = -1000, or the given value for p and t = -1000, 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_t = -159.42 °C to t_c = 134.66 °C

Pressure ranges from p_t = 2.19 x 10^{-7} bar to p_c = 36.29 bar)

Results for wrong input values

Result **CPPTXBUTI = –1000**, **CP = –1000** or **cp_ptx_BUTI = –1000** for input values

Single phase region: (x = –1)	$p > 350$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or $t > 301.85$°C or $t < t_{mel}$
Boiling or dew curve:	at $p = -1000$ and $t > t_c = 134.66$°C or $t < t_t = -159.42$°C
	at $t = -1000$ and $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or
	at $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar and $t > t_c = 134.66$°C or $t < t_t = -159.42$°C

References: [22], [25]

Dynamic Viscosity η = f(p,t,x)

Function Name:	**eta_ptx_BUTI**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION ETAPTXBUTI(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_ETAPTXBUTI(ETA,P,T,X)** REAL*8 ETA,P,T,X

Input Values

P – Pressure p in bar

T - Temperature t in °C

X – Vapor fraction x (kg of saturated steam)/(kg wet steam)

Result

ETAPTXBUTI, **ETA** or **eta_ptx_BUTI** – Dynamic viscosity η in Pa s

Range of validity

Temperature range: from t_{mel} to 301.85°C

Pressure range: from $p_t = 2.19 \times 10^{-7}$ bar to 350 bar

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 = -1000, or the given value for p and t = -1000, 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_t = -159.42 °C to t_c = 134.66 °C

Pressure ranges from p_t = 2.19 x 10^{-7} bar to p_c = 36.29 bar)

Results for wrong input values

Result **ETAPTXBUTI= –1000**, **ETA = –1000** or **eta_ptx_BUTI = –1000** for input values

Single phase region: (x = –1)	$p > 350$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or $t > 301.85$°C or $t < t_{mel}$
Boiling or dew curve:	at $p = -1000$ and $t > t_c = 134.66$°C or $t < t_t = -159.42$°C
	at $t = -1000$ and $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or
	at $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar and $t > t_c = 134.66$°C or $t < t_t = -159.42$°C

References: [22], [25], [26]

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

Function Name:	**h_ptx_BUTI**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION HPTXBUTI(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_HPTXBUTI(H,P,T,X)** REAL*8 H,P,T,X

Input Values

P – Pressure *p* in bar

T - Temperature *t* in °C

X – Vapor fraction *x* (kg of saturated steam)/(kg wet steam)

Result

HPTXBUTI, **H** or **h_ptx_BUTI** - Specific enthalpy *h* in kJ/kg

Range of validity

Temperature range: from t_{mel} to 301.85°C

Pressure range: from $p_t = 2.19 \times 10^{-7}$ bar to 350 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:

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 = -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.

(Boiling and dew curve: Temperature ranges from t_t = -159.42°C to t_c = 134.66 °C

Pressure ranges from p_t = 2.19 x 10^{-7} bar to p_c = 36.29 bar)

Results for wrong input values

Result **HPTXBUTI = –1000**, **H = –1000** or **h_ptx_BUTI = –1000** for input values

Single phase region: (x = –1)	$p > 350$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or $t > 301.85$°C or $t < t_{mel}$
Boiling or dew curve:	at $p = -1000$ and $t > t_c = 134.66$°C or $t < t_t = -159.42$°C
	at $t = -1000$ and $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or
	at $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar and $t > t_c = 134.66$°C or $t < t_t = -159.42$°C

References: [22], [25]

Isentropic Exponent κ = f(p,t,x)

Function Name:	**kappa_ptx_BUTI**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION KAPTXBUTI(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_KAPTXBUTI(KAP,P,T,X)** REAL*8 KAP,P,T,X

Input Values

P – Pressure p in bar

T - Temperature t in °C

X – Vapor fraction x (kg of saturated steam)/(kg wet steam)

Result

KAPPTXBUTI, **KAP** or **kappa_ptx_BUTI** – Isentropic exponent $\kappa = \frac{w^2}{p^*v}$

Range of validity

Temperature range: from t_{mel} to 301.85°C

Pressure range: from $p_t = 2.19 \times 10^{-7}$ bar to 350 bar

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 = -1000, or the given value for p and t = -1000, 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_t = -159.42 °C to t_c = 134.66 °C

Pressure ranges from $p_t = 2.19 \times 10^{-7}$ bar to p_c = 36.29 bar)

Results for wrong input values

Result **KAPTXBUTI**, **KAP = –1000** or **kappa_ptx_BUTI = –1000** for input values

Boiling or dew curve: at p = –1000 and $t > tc$ = 134.66 °C or $t < t_t$ = –159.42 °C

Single phase region: (x = –1)
$p > 350$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or
$t > 301.85$°C or $t < t_{mel}$

Boiling or dew curve:
at $p = -1000$ and $t > t_c = 134.66$°C or $t < t_t = -159.42$°C

at $t = -1000$ and $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or

at $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar and
$t > t_c = 134.66$°C or $t < t_t = -159.42$°C

References: [22], [25]

Thermal Conductivity λ = f(*p*,*t*,*x*)

Function Name:	**lambda_ptx_BUTI**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION LAMPTXBUTI(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_LAMPTXBUTI(LAM,P,T,X)** REAL*8 LAM,P,T,X

Input Values

P – Pressure *p* in bar

T - Temperature *t* in °C

X – Vapor fraction *x* (kg of saturated steam)/(kg wet steam)

Result

LAMPTXBUTI, **LAM** or **lambda_ptx_BUTI** – Thermal conductivity λ in W / m K

Range of validity

Temperature range: from t_{mel} to 301.85°C

Pressure range: from $p_t = 2.19 \times 10^{-7}$ bar to 350 bar

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 = -1000, or the given value for *p* and t = -1000, 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_t = -159.42 °C to t_c = 134.66 °C

Pressure ranges from p_t = 2.19 x 10^{-7} bar to p_c = 36.29 bar)

Results for wrong input values

Result **LAMPTXBUTI = –1000**, **LAM = –1000** or **lambda_ptx_BUTI = –1000** for input values

Single phase region: ($x = -1$)
$p > 350$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or
$t > 301.85$°C or $t < t_{mel}$

Boiling or dew curve:
at $p = -1000$ and $t > t_c = 134.66$°C or $t < t_t = -159.42$°C

at $t = -1000$ and $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or

at $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar and
$t > t_c = 134.66$°C or $t < t_t = -159.42$°C

References: [22], [25], [27]

Kinematic Viscosity ν = f(p,t,x)

Function Name:	**ny_ptx_BUTI**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION NYPTXBUTI(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_NYPTXBUTI(NY,P,T,X)** REAL*8 NY,P,T,X

Input Values

P – Pressure p in bar

T - Temperature t in °C

X – Vapor fraction x (kg of saturated steam)/(kg wet steam)

Result

NYPTXBUTI, **NY** or **ny_ptx_BUTI** – Kinematic viscosity $\nu = \eta \cdot v$ in m^2/s

Range of validity

Temperature range: from t_{mel} to 301.85°C

Pressure range: from $p_t = 2.19 \times 10^{-7}$ bar to 350 bar

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 = -1000, or the given value for p and t = -1000, 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_t = -159.42 °C to t_c = 134.66 °C

Pressure ranges from p_t = 2.19 x 10^{-7} bar to p_c = 36.29 bar)

Results for wrong input values

Result **NYPTXBUTI = –1000**, **NY = –1000** or **ny_ptx_BUTI = –1000** for input values

Single phase region: (x = –1)	$p > 350$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or $t > 301.85$°C or $t < t_{mel}$
Boiling or dew curve:	at $p = -1000$ and $t > t_c = 134.66$°C or $t < t_t = -159.42$°C
	at $t = -1000$ and $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or
	at $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar and $t > t_c = 134.66$°C or $t < t_t = -159.42$°C

References: [22], [25], [26]

Melting Pressure p_{mel} = f(t)

Function Name:	**pmel_t_BUTI**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION PMELBUTI(T)** REAL*8 T
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_PMELBUTI(PMEL,T)** REAL*8 PMEL,P,T,X

Input Values

T - Temperature t in °C

Result

PMELTBUTI, **PMEL** or **pmel_t_BUTI** – Melting pressure p_{mel} in bar

Range of validity

Temperature range: from $t_t = -159.42$°C to -147.751°C

Results for wrong input values

Result **PMELBUTI = –1000**, **PMEL = –1000** or **pmel_t_BUTI = –1000** for input values

$t < t_t = -159.42$°C or $t > -147.751$°C

References: [22], [25]

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

Function Name:	**Pr_ptx_BUTI**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION PRPTXBUTI(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_PRPTXBUTI(PR,P,T,X)** REAL*8 PR,P,T,X

Input Values

P – Pressure *p* in bar

T - Temperature *t* in °C

X – Vapor fraction *x* (kg of saturated steam)/(kg wet steam)

Result

PRPTXBUTI, **PR** or **Pr_ptx_BUTI** – Prandtl – Number $\mathrm{Pr} = \frac{\eta * c_p}{\lambda}$

Range of validity

Temperature range: from t_{mel} to 301.85°C

Pressure range: from $p_t = 2.19 \times 10^{-7}$ bar to 350 bar

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 = -1000, or the given value for *p* and t = -1000, 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_t = -159.42 °C to t_c = 134.66 °C

Pressure ranges from p_t = 2.19 x 10^{-7} bar to p_c = 36.29 bar)

Results for wrong input values

Result **PRPTXBUTI = –1000**, **PR = –1000** or **Pr_ptx_BUTI = –1000** for input values

Single phase region: ($x = -1$)
$p > 350$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or
$t > 301.85$°C or $t < t_{mel}$

Boiling or dew curve:
at $p = -1000$ and $t > t_c = 134.66$°C or $t < t_t = -159.42$°C
at $t = -1000$ and $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or
at $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar and
$t > t_c = 134.66$°C or $t < t_t = -159.42$°C

References: [22], [25], [26], [27]

Vapor Pressure p_S = f(t)

Function Name:	**ps_t_BUTI**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION PSTBUTI(T)** REAL*8 T
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_PSTBUTI(PS,T)** REAL*8 PS,T

Input Values

T - Temperature t in °C

Result

PSTBUTI, **PS** or **ps_t_BUTI** – Vapor pressure p_S in bar

Range of validity

Temperature range: from $t_t = -159.42$°C to $t_c = 134.66$°C

Results for wrong input values

Result **PSTBUTI = –1000**, **PS = –1000** or **ps_t_BUTI = –1000** for input values

$t < t_t = -159.42$°C or $t > t_c = 134.66$°C

References: [22], [25]

Density ρ = f(p,t,x)

Function Name:	**rho_ptx_BUTI**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION ROPTXBUTI(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_ROPTXBUTI(RHO,P,T,X)** REAL*8 RHO,P,T,X

Input Values

P – Pressure p in bar

T - Temperature t in °C

X – Vapor fraction x (kg of saturated steam)/(kg wet steam)

Result

RHOPTXBUTI, **RHO** or **rho_ptx_BUTI** – Density ρ in kg / m^3

Range of validity

Temperature range: from t_{mel} to 301.85°C

Pressure range: from $p_t = 2.19 \times 10^{-7}$ bar to 350 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:

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 = -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.

(Boiling and dew curve: Temperature ranges from t_t = -159.42°C to t_c = 134.66 °C

Pressure ranges from p_t = 2.19 x 10^{-7} bar to p_c = 36.29 bar)

Results for wrong input values

Result **ROPTXBUTI = –1000**, **RHO = –1000** or **rho_ptx_BUTI = –1000** for input values

Single phase region: (x = –1)	$p > 350$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or $t > 301.85$°C or $t < t_{mel}$
Boiling or dew curve:	at $p = -1000$ and $t > t_c = 134.66$°C or $t < t_t = -159.42$°C
	at $t = -1000$ and $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or
	at $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar and $t > t_c = 134.66$°C or $t < t_t = -159.42$°C

References: [22], [25]

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

Function Name:	**s_ptx_BUTI**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION SPTXBUTI(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_SPTXBUTI(S,P,T,X)** REAL*8 S,P,T,X

Input Values

P – Pressure *p* in bar

T - Temperature *t* in °C

X – Vapor fraction *x* (kg of saturated steam)/(kg wet steam)

Result

SPTXBUTI, **S** or **s_ptx_BUTI** - Specific entropy *s* in kJ/kg K

Range of validity

Temperature range: from t_{mel} to 301.85°C

Pressure range: from $p_t = 2.19 \times 10^{-7}$ bar to 350 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:

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 = -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.

(Boiling and dew curve: Temperature ranges from t_t = -159.42°C to t_c = 134.66 °C

Pressure ranges from p_t = 2.19 x 10^{-7} bar to p_c = 36.29 bar)

Results for wrong input values

Result **SPTXBUTI = –1000**, **S = –1000** or **s_ptx_BUTI = –1000** for input values

Single phase region: (x = –1)	$p > 350$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or $t > 301.85$°C or $t < t_{mel}$
Boiling or dew curve:	at $p = -1000$ and $t > t_c = 134.66$°C or $t < t_t = -159.42$°C
	at $t = -1000$ and $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or
	at $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar and $t > t_c = 134.66$°C or $t < t_t = -159.42$°C

References: [22], [25]

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

Function Name:	**t_ph_BUTI**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION TPHBUTI(P,H)** REAL*8 P,H
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_TPHBUTI(T,P,H)** REAL*8 T,P,H

Input Values

P – Pressure *p* in bar

H - Specific enthalpy *h* in kJ/kg

Result

TPHBUTI, **T** or **t_ph_BUTI** – Temperature *t* in °C

Range of validity

Temperature range: from t_{mel} to 301.85°C

Pressure range: from $p_t = 2.19 \times 10^{-7}$ bar to 350 bar

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_t = 2.19 x 10^{-7} bar to p_c = 36.29 bar

Results for wrong input values

Result **T_PH_BUTI**, **T = –1000** or **t_ph_BUTI = –1000** for input values

Single phase region: (x = –1)	$p > 350$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or at result $t > 301.85$°C, $t < t_t = -159.42$°C or $t < t_{mel}(p)$
Boiling or dew curve:	at $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or at result $t > t_c = 134.66$°C or $t < t_t = -159.42$°C

References: [22], [25]

Backward function: Temperature *t* = f(*p*,*s*)

Function Name:	**t_ps_BUTI**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION TPSBUTI(P,S)** REAL*8 P,S
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_TPSBUTI(T,P,S)** REAL*8 T,P,S

Input Values

P – Pressure *p* in bar

S - Specific entropy *s* in kJ/(kg K)

Result

TPSBUTI, **T** or **t_ps_BUTI** – Temperature *t* in °C

Range of validity

Temperature range: from t_{mel} to 301.85°C

Pressure range: from $p_t = 2.19 \times 10^{-7}$ bar to 350 bar

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_t = 2.19 x 10^{-7} bar to p_c = 36.29 bar

Results for wrong input values

Result **T_PS_BUTI, T = –1000** or **t_ps_BUTI = –1000** for input values

Single phase region: (x = –1)	$p > 350$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or at result $t > 301.85$°C, $t < t_t = -159.42$°C or $t < t_{mel}(p)$
Boiling or dew curve:	at $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or at result $t > t_c = 134.66$°C or $t < t_t = -159.42$°C

References: [22], [25]

Saturation Temperature t_S = f(p)

Function Name:	**ts_p_BUTI**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION TSPBUTI(P)** REAL*8 P
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_TSPBUTI(TS,P)** REAL*8 TS,P

Input Values

P – Pressure p in bar

Result

TSPBUTI, **TS** or **ts_p_BUTI** - Saturation temperature t_S in °C

Range of validity

Pressure range: from $p_t = 2.19 \times 10^{-7}$ bar to $p_c = 36.29$ bar

Results for wrong input values

Result **TSPBUTI = –1000**, **TS = –1000** or **ts_p_BUTI = –1000** for input values

$p < p_t = 2.19 \times 10^{-7}$ bar or $p > p_c = 36.29$ bar

References: [22], [25]

Melting Temperature $t_{mel} = f(p)$

Function Name:	**tmel_p_BUTI**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION TMELBUTI(P)** REAL*8 P
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_TMELBUTI(TMEL,P)** REAL*8 TMEL,P

Input Values

P – Pressure p in bar

Result

TMELPBUTI, **TMEL** or **tmel_p_BUTI** - Melting temperature t_{mel} in °C

Range of validity

Pressure range: from $p_t = 2.19 \times 10^{-7}$ bar to 350 bar

Results for wrong input values

Result **TMELBUTI = –1000**, **TMEL = –1000** or **tmel_p_BUTI = –1000** for input values

$p < p_t = 2.19 \times 10^{-7}$ bar or $p > p_c = 36.29$ bar

References: [22], [25]

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

Function Name:	**u_ptx_BUTI**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION UPTXBUTI(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_UPTXBUTI(H,P,T,X)** REAL*8 H,P,T,X

Input Values

P – Pressure *p* in bar

T - Temperature *t* in °C

X – Vapor fraction *x* (kg of saturated steam)/(kg wet steam)

Result

UPTXBUTI, **H** or **u_ptx_BUTI** - Specific internal energy *u* in kJ/kg

Range of validity

Temperature range: from t_{mel} to 301.85°C

Pressure range: from $p_t = 2.19 \times 10^{-7}$ bar to 350 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:

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 = -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.

(Boiling and dew curve: Temperature ranges from t_t = -159.42°C to t_c = 134.66 °C

Pressure ranges from p_t = 2.19 x 10^{-7} bar to p_c = 36.29 bar)

Results for wrong input values

Result **UPTXBUTI = –1000**, **H = –1000** or **u_ptx_BUTI = –1000** for input values

Single phase region: (x = –1)	$p > 350$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or $t > 301.85$°C or $t < t_{mel}$
Boiling or dew curve:	at $p = -1000$ and $t > t_c = 134.66$°C or $t < t_t = -159.42$°C
	at $t = -1000$ and $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or
	at $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar and $t > t_c = 134.66$°C or $t < t_t = -159.42$°C

References: [22], [25]

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

Function Name:	**v_ptx_BUTI**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION VPTXBUTI(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_VPTXBUTI(V,P,T,X)** REAL*8 V,P,T,X

Input Values

P – Pressure p in bar

T - Temperature t in °C

X – Vapor fraction x (kg of saturated steam)/(kg wet steam)

Result

VPTXBUTI, **V** or **v_ptx_BUTI** - Specific volume v in m^3/kg

Range of validity

Temperature range: from t_{mel} to 301.85°C

Pressure range: from $p_t = 2.19 \times 10^{-7}$ bar to 350 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:

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 = -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.

(Boiling and dew curve: Temperature ranges from t_t = -159.42°C to t_c = 134.66 °C

Pressure ranges from p_t = 2.19 x 10^{-7} bar to p_c = 36.29 bar)

Results for wrong input values

Result **VPTXBUTI = –1000**, **H = –1000** or **v_ptx_BUTI = –1000** for input values

Single phase region: (x = –1)	$p > 350$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or $t > 301.85$°C or $t < t_{mel}$
Boiling or dew curve:	at $p = -1000$ and $t > t_c = 134.66$°C or $t < t_t = -159.42$°C
	at $t = -1000$ and $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or
	at $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar and $t > t_c = 134.66$°C or $t < t_t = -159.42$°C

References: [22], [25]

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

Function Name:	**w_ptx_BUTI**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION WPTXBUTI(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_WPTXBUTI(W,P,T,X)** REAL*8 W,P,T,X

Input Values

P – Pressure *p* in bar

T - Temperature *t* in °C

X – Vapor fraction *x* (kg of saturated steam)/(kg wet steam)

Result

WPTXBUTI, **W** or **w_ptx_BUTI** – Speed of sound *w* in m/s

Range of validity

Temperature range: from t_{mel} to 301.85°C

Pressure range: from $p_t = 2.19 \times 10^{-7}$ bar to 350 bar

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 = -1000, or the given value for *p* and t = -1000, 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_t = -159.42 °C to t_c = 134.66 °C

Pressure ranges from p_t = 2.19 x 10^{-7} bar to p_c = 36.29 bar)

Results for wrong input values

Result **WPTXBUTI = –1000** or **w_ptx_BUTI = –1000** for input values

Single phase region: ($x = -1$)
$p > 350$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or
$t > 301.85$°C or $t < t_{mel}$

Boiling or dew curve:
at $p = -1000$ and $t > t_c = 134.66$°C or $t < t_t = -159.42$°C

at $t = -1000$ and $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar or

at $p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar and
$t > t_c = 134.66$°C or $t < t_t = -159.42$°C

References: [22], [25]

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

Function Name:	**x_ph_BUTI**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION XPHBUTI(P,H)** REAL*8 P,H
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_XPHBUTI(T,P,H)** REAL*8 X,P,H

Input Values

P – Pressure *p* in bar

H - Specific enthalpy *h* in kJ/kg

Result

XPHBUTI, **X** or **x_ph_BUTI** – Vapor fraction *x* in (kg saturated steam/kg wet steam)

Range of validity

Temperature range: from t_{mel} to 301.85°C

Pressure range: from $p_t = 2.19 \times 10^{-7}$ bar to 350 bar

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_t = 2.19 x 10^{-7} bar to p_c = 36.29 bar

Results for wrong input values

Result **X_PH_BUTI**, **X =** –1 or **x_ph_BUTI =** –1 for input values

In case the point of state is located in the single phase region

$p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar

References: [22], [25]

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

Function Name:	**x_ps_BUTI**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION XPSBUTI(P,S)** REAL*8 P,S
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_XPSBUTI(X,P,S)** REAL*8 X,P,S

Input Values

P – Pressure *p* in bar

S - Specific entropy in kJ/(kg K)

Result

XPSBUTI, **X** or **x_ps_BUTI** – Vapor fraction *x* in (kg saturated steam/kg wet steam)

Range of validity

Temperature range: from t_{mel} to 301.85°C

Pressure range: from $p_t = 2.19 \times 10^{-7}$ bar to 350 bar

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of *v*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_t = 2.19 x 10^{-7} bar to p_c = 36.29 bar

Results for wrong input values

Result **X_PS_BUTI**, **X =** –1 or **x_ps_BUTI =** –1 for input values

In case the point of state is located in the single phase region

$p > p_c = 36.29$ bar or $p < p_t = 2.19 \times 10^{-7}$ bar

References: [22], [25]

KCE

KCE-ThermoFluidProperties
www.thermofluidprop.com

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

Water and Steam

Library LibIF97

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

Library LibSBTL_IF97
Library LibSBTL_95

Extremely fast property calculations according to the IAPWS Guideline 2015
Spline-based Table Look-up Method (SBTL)
applied to the Industrial Formulation IAPWS-IF97 and to the Scientific Formulation IAPWS-95
for Computational Fluid Dynamics and simulating non-stationary processes

Humid Combustion Gas Mixtures

Library LibHuGas

Model: Ideal mixture of the real fluids:

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

and of the ideal gases:
SO_2, CO, Ne
(Scientific Formulation of Bücker et al.)

Consideration of:
- Dissociation from VDI 4670
- Poynting effect

Humid Air

Library LibHuAir

Model: Ideal mixture of the real fluids:
- Dry air from Lemmon et al.
- Steam, water and ice from IAPWS-IF97 and IAPWS-06

Consideration of:
- Condensation and freezing of steam
- Dissociation from VDI 4670
- Poynting effect from ASHRAE RP-1485

Carbon Dioxide Including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1996)

Seawater

Library LibSeaWa

IAPWS Industrial Formulation 2013

Ice

Library LibICE

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

Ideal Gas Mixtures

Library LibIdGasMix

Model: Ideal mixture of the ideal gases:

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

Consideration of:
- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:
- Dissociation from the VDI Guideline 4670

Humid Air

Library ASHRAE LibHuAirProp

Model: Virial equation from ASHRAE Report RP-1485 for real mixture of the real fluids:
- Dry air
- Steam

Consideration of:
- Enhancement of the partial saturation pressure of water vapor at elevated total pressures

www.ashrae.org/bookstore

Dry Air Including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth et al. (1993)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of Bücker and Wagner (2006)

n-Butane

Library LibButane_n

Formulation of Bücker and Wagner (2006)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

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

Helmholtz energy equation for the mixing term

(also useable for calculating the Kalina Cycle)

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

$C_2H_6O_2$	Ethylene glycol
$C_3H_8O_2$	Propylene glycol
C_2H_5OH	Ethanol
CH_3OH	Methanol
$C_3H_8O_3$	Glycerol
K_2CO_3	Potassium carbonate
$CaCl_2$	Calcium chloride
$MgCl_2$	Magnesium chloride
NaCl	Sodium chloride
$C_2H_3KO_2$	Potassium acetate
$CHKO_2$	Potassium formate
LiCl	Lithium chloride
NH_3	Ammonia

Formulation of the International Institute of Refrigeration (IIR 2010)

Ethanol
Library LibC2H5OH
Formulation of
Schroeder (2012)

Methanol
Library LibCH3OH
Formulation of
de Reuck and Craven (1993)

Propane
Library LibPropane
Formulation of
Lemmon et al. (2009)

Siloxanes as ORC Working Fluids

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

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

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

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

Formulation of Colonna et al. (2006)

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

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

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

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

Formulation of Colonna et al. (2008)

Nitrogen and Oxygen
Libraries
LibN2 and LibO2
Formulations of Span et al. (2000)
and Schmidt and Wagner (1985)

Hydrogen
Library LibH2
Formulation of
Leachman et al. (2009)

Helium
Library LibHe
Formulation of
Arp et al. (1998)

Hydrocarbons

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

Isopentane C_5H_{12} **Library LibC5H12_ISO**

Neopentane C_5H_{12} **Library LibC5H12_NEO**

Isohexane C_6H_{14} **Library LibC6H14**

Toluene C_7H_8 **Library LibC7H8**

Formulation of Lemmon and Span (2006)

Further Fluids

Carbon monoxide **CO** **Library LibCO**

Carbonyl sulfide **COS** **Library LibCOS**

Hydrogen sulfide H_2S **Library LibH2S**

Nitrous oxide N_2O **Library LibN2O**

Sulfur dioxide SO_2 **Library LibSO2**

Acetone C_3H_6O **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

For more information please contact:

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Phone: +49-351-27597860
Mobile: +49-172-7914607
Fax: +49-3222-4262250

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives can be calculated.

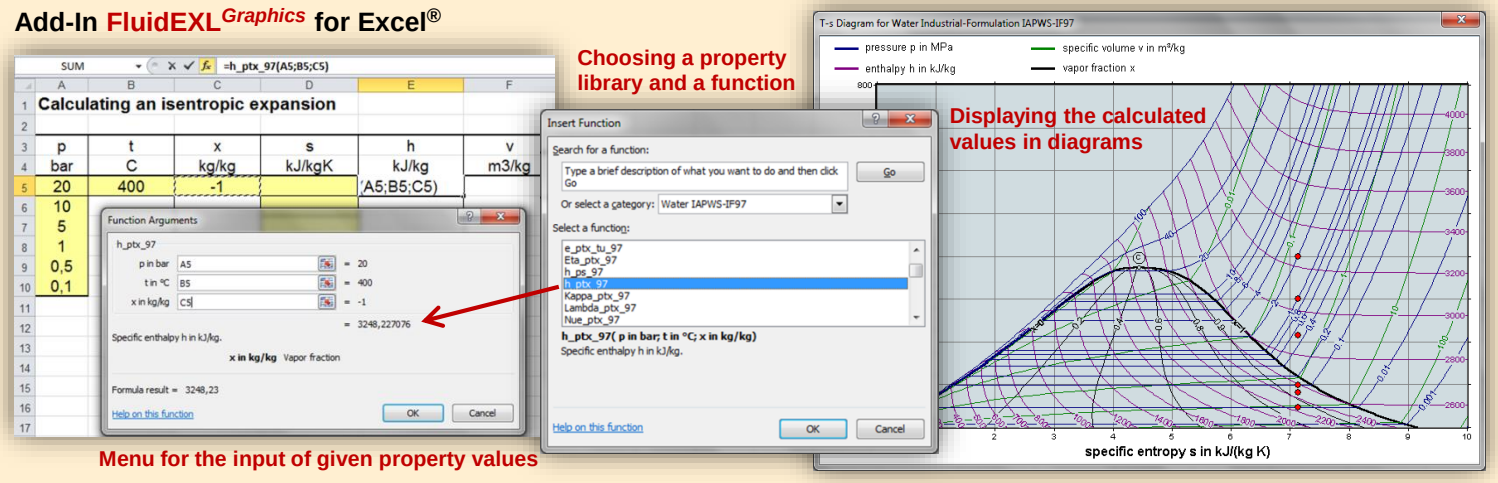
[a] Not all of these property functions are available in all property libraries.

KCE

KCE-ThermoFluidProperties
www.thermofluidprop.com

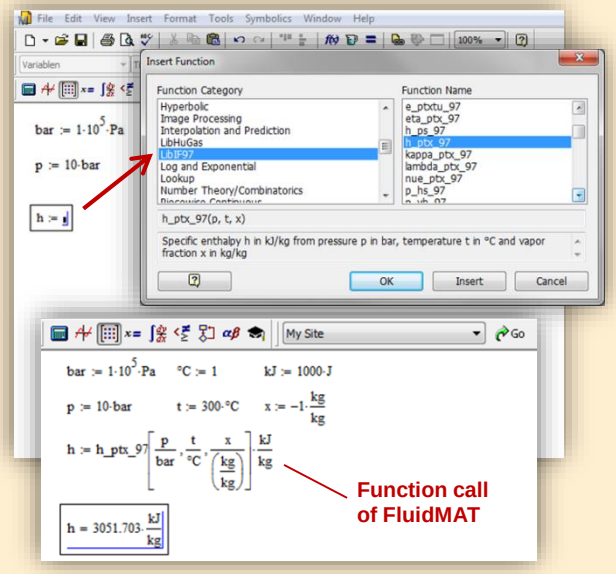
Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

Add-In FluidEXL*Graphics* for Excel®



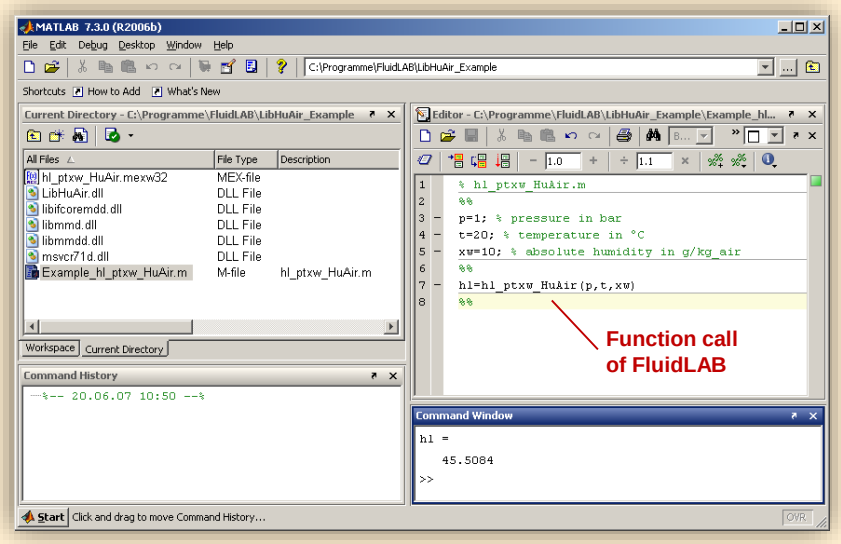
Add-In FluidMAT for Mathcad®

The property libraries can be used in Mathcad®.



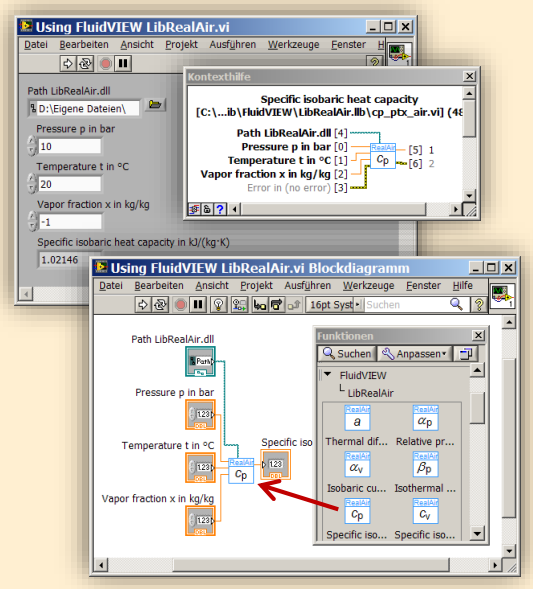
Add-In FluidLAB for MATLAB®

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



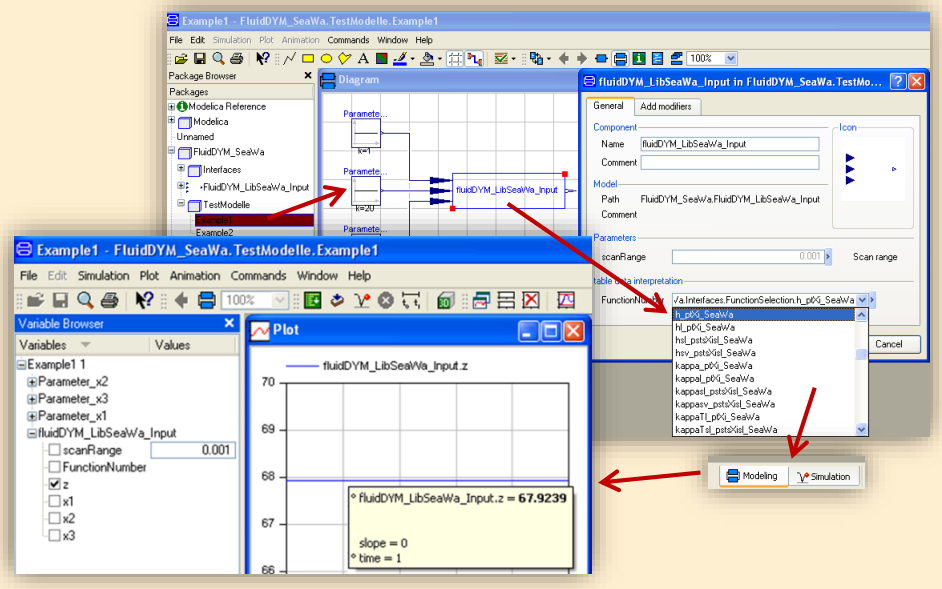
Add-On FluidVIEW for LabVIEW™

The property functions can be calculated in LabVIEW™.

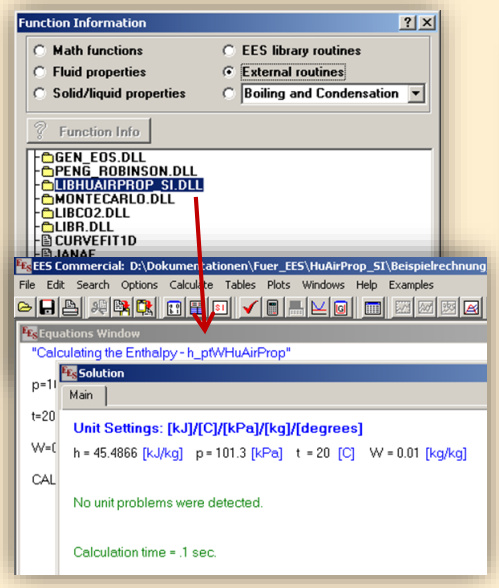


Add-In FluidDYM for DYMOLA® (Modelica) and SimulationX®

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

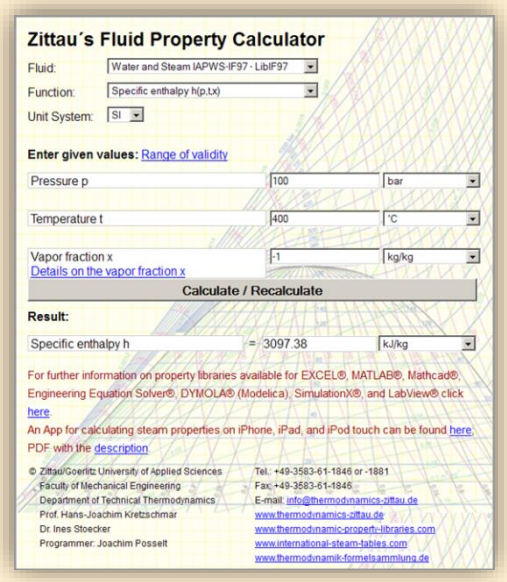


Add-In FluidEES for Engineering Equation Solver®



App International Steam Tables for iPhone, iPad, iPod touch, Android Smartphones and Tablets

Online Property Calculator at www.thermofluidprop.com



Property Software for Pocket Calculators

FluidCasio

fx 9750 G II

CFX 9850
fx-GG20

CFX 9860 G
Graph 85

ALGEBRA
FX 2.0

FluidHP

HP 48 HP 49

FluidTI

TI Nspire CX CAS
TI Nspire CAS

TI 83
TI 84
TI 89

TI Voyage 200

TI 92

For more information please contact:

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives can be calculated.

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

www.thermofluidprop.com

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6. Satisfied Customers

Date: 05/2018

The following companies and institutions use the property libraries

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2018

Universität Madrid, Madrid, Spanien	05/2018
HS Zittau/ Görlitz, Fakultät Wirtschaft, Zittau	05/2018
HS Niederrhein, Krefeld	05/2018
GRS, Köln	03/2018
RONAL AG, Härklingen, Schweiz	02/2018
Ingenieurbüro Leipert, Riegelsberg	02/2018
AIXPROCESS, Aachen	02/2018
KRONES, Neutraubling	02/2018
Doosan Lentjes, Ratingen	01/2018

2017

Compact Kältetechnik, Dresden	12/2017
Endress + Hauser Messtechnik GmbH +Co. KG, Hannover	12/2017
TH Mittelhessen, Gießen	11/2017
Haarslev Industries, Søndersø, Denmark	11/2017
Hochschule Zittau/Görlitz, Fachgebiet Energiesystemtechnik	11/2017
ATESTEO, Alsdorf	10/2017
Wijbenga, PC Geldermalsen, Netherlands	10/2017
Fels-Werke GmbH, Elbingerode	10/2017
KIT Karlsruhe, Institute für Neutronenphysik und Reaktortechnik	09/2017
Air-Consult, Jena	09/2017
Papierfabrik Koehler, Oberkirch	09/2017
ZWILAG, Würenlingen, Switzerland	09/2017
TLK-Thermo Universität Braunschweig, Braunschweig	08/2017
Fichtner IT Consulting AG, Stuttgart	07/2017
Hochschule Ansbach, Ansbach	06/2017
RONAL, Härkingen, Switzerland	06/2017
BORSIG Service, Berlin	06/2017

BOGE Kompressoren, Bielefeld	06/2017
STEAG Energy Services, Zwingenberg	06/2017
CES clean energy solutions, Wien, Austria	04/2017
Princeton University, Princeton, USA	04/2017
B2P Bio-to-Power, Wadersloh	04/2017
TU Dresden, Institute for Energy Engineering, Dresden	04/2017
SAINT-GOBAIN, Vaujours, France	03/2017
TU Bergakademie Freiberg, Chair of Thermodynamics, Freiberg	03/2017
SCHMIDT + PARTNER, Therwil, Switzerland	03/2017
KAESER Kompressoren, Gera	03/2017
F&R, Praha, Czech Republic	03/2017
ULT Umwelt-Lufttechnik, Löbau	02/2017
JS Energie & Beratung, Erding	02/2017
Kelvion Brazed PHE, Nobitz-Wilchwitz	02/2017
MTU Aero Engines, München	02/2017
Hochschule Zittau/Görlitz, IPM	01/2017
CombTec ProCE, Zittau	01/2017
SHELL Deutschland Oil, Wesseling	01/2017
MARTEC Education Center, Frederikshaven, Denmark	01/2017
SynErgy Thermal Management, Krefeld	01/2017

2016

BOGE Druckluftsysteme, Bielefeld	12/2016
BFT Planung, Aachen	11/2016
Midiplan, Bietigheim-Bissingen	11/2016
BBE Barnich IB	11/2016
Wenisch IB,	11/2016
INL, Idaho Falls	11/2016
TU Kältetechnik, Dresden	11/2016
Kopf SynGas, Sulz	11/2016
INTVEN, Bellevne (USA)	11/2016
DREWAG Dresden, Dresden	10/2016
AGO AG Energie+Anlagen, Kulmbach	10/2016
Universität Stuttgart, ITW, Stuttgart	09/2016
Pöyry Deutschland GmbH, Dresden	09/2016
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BASF über Fichtner IT Consulting AG	09/2016
B+B Engineering GmbH, Magdeburg	09/2016
Wilhelm Büchner Hochschule, Pfungstadt	08/2016

Webasto Thermo & Comfort SE, Gliching	08/2016
TU Dresden, Dresden	08/2016
Endress+Hauser Messtechnik GmbH+Co. KG, Hannover	08/2016
D + B Kältetechnik, Althausen	07/2016
Fichtner IT Consulting AG, Stuttgart	07/2016
AB Electrolux, Krakow, Poland	07/2016
ENEXIO Germany GmbH, Herne	07/2016
VPC GmbH, Vetschau/Spreewald	07/2016
INWAT, Lodz, Poland	07/2016
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Planungsbüro Waidhas GmbH, Chemnitz	07/2016
EEB Enerko, Aldershoven	07/2016
IHEBA Naturenergie GmbH & Co. KG, Pfaffenhofen	07/2016
SSP Kälteplaner AG, Wolfertschwenden	07/2016
EEB ENERKO Energiewirtschaftliche Beratung GmbH, Berlin	07/2016
BOGE Kompressoren Otto BOGE GmbH & Co KG, Bielefeld	06/2016
Universidad Carlos III de Madrid, Madrid, Spain	04/2016
INWAT, Lodzi, Poland	04/2016
Planungsbüro WAIDHAS GmbH, Chemnitz	04/2016
STEAG Energy Services GmbH, Laszlo Küppers, Zwingenberg	03/2016
WULFF & UMAG Energy Solutions GmbH, Husum	03/2016
FH Bielefeld, Bielefeld	03/2016
EWT Eckert Wassertechnik GmbH, Celle	03/2016
ILK Institut für Luft- und Kältetechnik GmbH, Dresden	02/2016, 06/2016 (2x)
IEV KEMA - DNV GV – Energie, Dresden	02/2016
Allborg University, Department of Energie, Aalborg, Denmark	02/2016
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Institut für Luft- und Kältetechnik, Dresden	02/2016, 05/2016, 06/2016
Bosch, Stuttgart	02/2016
INL Idaho National Laboratory, Idaho, USA	11/2016, 01/2016
Friedl ID, Wien, Austria	01/2016
Technical University of Dresden, Dresden	01/2016

2015

EES Enerko, Aachen	12/2015
Ruldolf IB, Strau, Austria	12/2015
Allborg University, Department of Energie, Aalborg, Denmark	12/2015
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Steinbrecht IB, Berlin	11/2015
Universidad Carlos III de Madrid, Madrid, Spain	11/2015
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Bosch, Lohmar	10/2015
Team Turbo Machines, Rouen, France	09/2015
BTC – Business Technology Consulting AG, Oldenburg	07/2015
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ILK, Dresden	07/2015
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Technical University of Nuremberg	03/2014
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YESS-World, South Korea	03/2014
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Stadtwerke Neuburg	02/2014
COMPAREX, Leipzig for RWE Essen	02/2014
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DLR, Stuttgart	01/2014
Doosan Lentjes, Ratingen	01/2014
Technical University of Berlin	01/2014
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Technical University of Braunschweig	01/2014
M&M Turbinentechnik, Bielefeld	01/2014

2013

TRANTER-GmbH, Artern	12/2013
SATAKE, Shanghai, China	12/2013
VOITH, Kunshan, China	12/2013
ULT, Löbau	12/2013
MAN, Copenhagen, Dänemark	11/2013
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Haarslev Industries, Herlev, Dänemark	11/2013
STEAG, Herne	11/2013, 12/2013
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Wilhelm-Büchner HS, Darmstadt	10/2013

IAV, Chemnitz	10/2013
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PD-Energy, Bitterfeld	09/2013
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M&M Turbinentechnik, Bielefeld	08/2013
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TIG-Group, Husum	08/2013
COMPAREX, Leipzig	08/2013, 11/2013
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Siemens, Frankenthal	08/2013, 10/2013
	11/2013
VGB, Essen	07/2013, 11/2013
Brunner Energieberatung, Zurich, Switzerland	07/2013
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SPX Balcke-Dürr, Ratingen	05/2012, 07/2012
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SKW, Piesteritz	04/2012
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LAWI Power, Dresden	04/2012
Stadtwerke Leipzig	04/2012
SEITZ, Wetzikon, Switzerland	03/2012, 07/2012
M & M, Bielefeld	03/2012
Sennheiser, Wedemark	03/2012
SPG, Montreuil Cedex, France	02/2012
German Destilation, Sprendlingen	02/2012
Lopez, Munguia, Spain	02/2012
Endress & Hauser, Hannover	02/2012
Palo Alto Research Center, USA	02/2012
WIPAK, Walsrode	02/2012
Freudenberg, Weinheim	01/2012
Fichtner, Stuttgart	01/2012
airinotec, Bayreuth	01/2012, 07/2012
University Auckland, New Zealand	01/2012
VPC, Vetschau	01/2012
Franken Guss, Kitzingen	01/2012

2011

XRG-Simulation, Hamburg	12/2011
Smurfit Kappa PPT, AX Roermond, Netherlands	12/2011
AWTEC, Zurich, Switzerland	12/2011
eins-energie, Bad Elster	12/2011
BeNow, Rodenbach	11/2011
Luzern University of Applied Sciences, Switzerland	11/2011
GMVA, Oberhausen	11/2011
CCI, Karlsruhe	10/2011
W.-Büchner University of Applied Sciences, Pfungstadt	10/2011
PLANAIR, La Sagne, Switzerland	10/2011
LAWI, Dresden	10/2011
Lopez, Munguia, Spain	10/2011
University of KwaZulu-Natal, Westville, South Africa	10/2011

Voith, Heidenheim	09/2011
SpgBe Montreal, Canada	09/2011
SPG TECH, Montreuil Cedex, France	09/2011
Voith, Heidenheim-Mergelstetten	09/2011
MTU Aero Engines, Munich	08/2011
MIBRAG, Zeitz	08/2011
RWE, Essen	07/2011
Fels, Elingerode	07/2011
Weihenstephan University of Applied Sciences	07/2011, 09/2011 10/2011
Forschungszentrum Juelich	07/2011
RWTH Aachen University	07/2011, 08/2011
INNEO Solutions, Ellwangen	06/2011
Caliqua, Basel, Switzerland	06/2011
Technical University of Freiberg	06/2011
Fichtner IT Consulting, Stuttgart	05/2011, 06/2011, 08/2011
Salzgitter Flachstahl, Salzgitter	05/2011
Helbling Beratung & Bauplanung, Zurich, Switzerland	05/2011
INEOS, Cologne	04/2011
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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
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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
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University of Halle-Merseburg, Department of USET Merseburg incorporated society	05/2006
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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

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TUEV Nord, Hannover	01/2005
J.H.K Plant Engineering and Service, Bremerhaven	01/2005
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FCIT, Stuttgart	01/2005
Energietechnik Leipzig (company license)	02/2005, 04/2005 07/2005
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Technical University of Dresden Professorship of Thermic Energy Machines and Plants	04/2005
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Stadtwerke Leipzig	07/2005
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Basel University of Applied Sciences, Department of Mechanical Engineering, Switzerland	10/2005

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HEW-Kraftwerk, Tiefstack	06/2004
h s energieanlagen, Freising	07/2004
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Physikalisch Technische Bundesanstalt (PTB), Braunschweig	08/2004
Mainova Frankfurt	08/2004
Rietschle Energieplaner, Winterthur, Switzerland	08/2004
MAN Turbo Machines, Oberhausen	09/2004
TUEV Sued, Dresden	10/2004
STEAG Kraftwerk, Herne	10/2004, 12/2004
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VEO Vulkan Energiewirtschaft Oderbruecke, Eisenhuettenstadt	11/2003
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Technical University of Graz, Department of Thermal Engineering, Austria	11/1999
Ostendorf Engineering, Gummersbach	12/1999

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Technical University of Cottbus, Chair in Power Plant Engineering	05/1998
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SCA Hygiene Products, Munich	10/1998
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