Hochschule
Zittau/Görlitz
UNIVERSITY OF APPLIED SCIENCES

Faculty of
MECHANICAL ENGINEERING
Department of
TECHNICAL THERMODYNAMICS

Property Library for R134a

FluidLAB
with LibR134a
for MATLAB®

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Property Library for the Calculation

of R134a

FluidLAB for MATLAB®

LibR134a

Contents

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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_LibR134a.zip"

Including the following files:

FluidLAB_LibR134a_Setup.exe	- Installation program for the FluidLAB Add-On for use in MATLAB®
LibR134a.dll	- Dynamic Link Library for R134a for use in MATLAB®
FluidLAB_LibR134a_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_LibR134a_x64.zip"

Including the following files and folders:

Files:

Setup.exe	- Self-extracting and self-installing program for FluidLAB
FluidLAB_LibR134a_64_Setup.msi	- Installation program for the FluidLAB Add-On for use in MATLAB®
LibR134a.dll	- Dynamic Link Library for R134a for use in MATLAB®
FluidLAB_LibR134a_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 LibR134a as parameter	Property or Function	Unit of the result
$a = f(p,t,x)$	a_ptx_R134a	A_PTX_R134A(P,T,X)	C_A_PTX_R134A(A,P,T,X)	Thermal diffusivity	m^2/s
$c_p = f(p,t,x)$	cp_ptx_R134a	CP_PTX_R134A(P,T,X)	C_CP_PTX_R134A(CP,P,T,X)	Specific isobaric heat capacity	kJ/(kg K)
$c_v = f(p,t,x)$	cv_ptx_R134a	CV_PTX_R134A(P,T,X)	C_CV_PTX_R134A(CV,P,T,X)	Specific isochoric heat capacity	kJ/(kg K)
$\eta = f(p,t,x)$	eta_ptx_R134a	ETA_PTX_R134A(P,T,X)	C_ETA_PTX_R134A(ETA,P,T,X)	Dynamic viscosity	Pa s
$h = f(p,t,x)$	h_ptx_R134a	H_PTX_R134A(P,T,X)	C_H_PTX_R134A(H,P,T,X)	Specific enthalpy	kJ/kg
$\kappa = f(p,t,x)$	kappa_ptx_R134a	KAP_PTX_R134A(P,T,X)	C_KAP_PTX_R134A(KAP,P,T,X)	Isentropic exponent	-
$\lambda = f(p,t,x)$	lambda_ptx_R134a	LAM_PTX_R134A(P,T,X)	C_LAM_PTX_R134A(LAM,P,T,X)	Thermal conductivity	W/m K
$\nu = f(p,t,x)$	ny_ptx_R134a	NY_PTX_R134A(P,T,X)	C_NY_PTX_R134A(NY,P,T,X)	Kinematic viscosity	m^2/s
$p_s = f(t)$	ps_t_R134a	PS_T_R134A(T)	C_PS_T_R134A(PS,T)	Vapor pressure from temperature	Bar
$Pr = f(p,t,x)$	Pr_ptx_R134a	PR_PTX_R134A(P,T,X)	C_PR_PTX_R134A(PR,P,T,X)	*Prandtl*-Number	-
$\rho = f(p,t,x)$	rho_ptx_R134a	RHO_PTX_R134A(P,T,X)	C_RHO_PTX_R134A(RHO,P,T,X)	Density	kg/m^3
$s = f(p,t,x)$	s_ptx_R134a	S_PTX_R134A(P,T,X)	C_S_PTX_R134A(S,P,T,X)	Specific entropy	kJ/(kg K)
$\sigma = f(t)$	sigma_t_R134a	SIGMA_T_R134A(T)	C_SIGMA_T_R134A(SIGMA,T)	Surface tension	N/m
$t = f(p,h)$	t_ph_R134a	T_PH_R134A(P,H)	C_T_PH_R134A(T,P,H)	Backward function: Temperature from pressure and enthalpy	°C
$t = f(p,s)$	t_ps_R134a	T_PS_R134A(P,S)	C_T_PS_R134A(T,P,S)	Backward function: Temperature from pressure and entropy	°C
$t_s = f(p)$	ts_p_R134a	TS_P_R134A(P)	C_TS_P_R134A(TS,P)	Saturation temperature from pressure	°C
$u = f(p,t,x)$	u_ptx_R134a	U_PTX_R134A(P,T,X)	C_U_PTX_R134A(U,P,T,X)	Specific internal energy	kJ/kg
$v = f(p,t,x)$	v_ptx_R134a	V_PTX_R134A(P,T,X)	C_V_PTX_R134A(V,P,T,X)	Specific volume	m^3/kg
$w = f(p,t,x)$	w_ptx_R134a	W_PTX_R134A(P,T,X)	C_W_PTX_R134A(W,P,T,X)	Isentropic speed of sound	m/s^2
$x = f(p,h)$	x_ph_R134a	X_PH_R134A(P,H)	C_X_PH_R134A(X,P,H)	Backward function: Vapor fraction from pressure and enthalpy	kg/kg
$x = f(p,s)$	x_ps_R134a	X_PS_R134A(P,S)	C_X_PS_R134A(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 range: from $t(p,\rho_{\text{max}})$ to 181.85 °C

Pressure range: from p_t = 0.000389564 bar to 700 bar

Reference state

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

Details on the vapor fraction *x*

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

Single-phase region

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

Wet-steam region

If the state point to be calculated is located in the wet steam region, a value for x between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for x. When calculating wet steam either the given value for t and p = -1000 or the given value for p and t = -1000 and in both cases the value for x between 0 and 1 must be entered.

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

Wet steam region: Temperature ranges from t_t = –103.30 °C to t_c = 101.03 °C

Pressure ranges from p_t = 0. 000389564 bar to p_c = 40.566 bar

Hint:

If the calculation results in –1000, the values entered represent a state point beyond the range of validity of LibR134a. For further information on each function and its range of validity see Chapter 3. The same information may also be accessed via the online help pages.

2 Application of FluidLAB in MATLAB®

The FluidLAB Add-In has been developed to calculate thermodynamic properties in MATLAB® more conveniently. Within MATLAB® it enables the direct call of functions relating to R134a from the LibR134a property library.

2.1 Installing FluidLAB

Installing FluidLAB including LibR134a for 32-bit MATLAB®

This section describes the installation of FluidLAB LibR134a 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_LibR134a.zip", you will see the folder

CD_FluidLAB_LibR134a

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_LibR134a_Docu_Eng.pdf
FluidLAB_LibR134a_Setup.exe
LibR134a.dll.

In order to run the installation of FluidLAB including, the LibR134a property library, double-click on the file

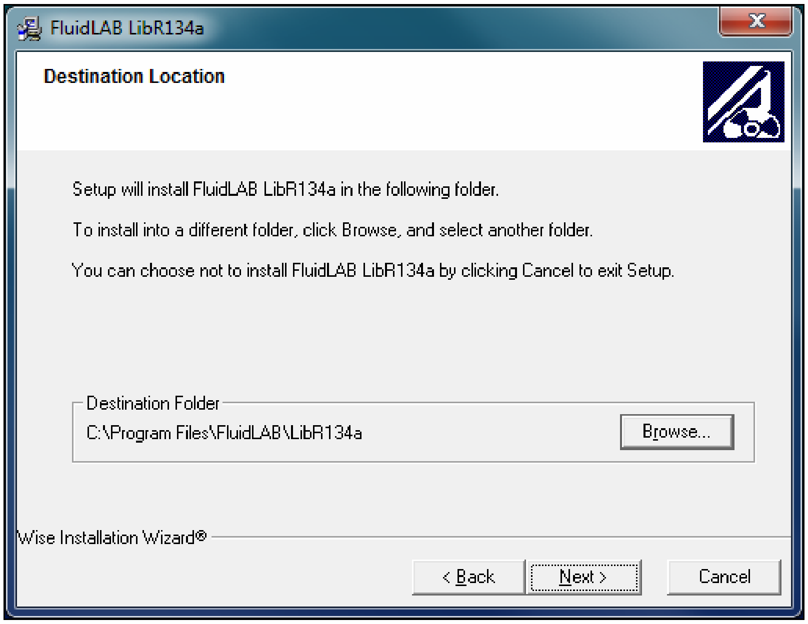
FluidLAB_LibR134a_Setup.exe.

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\LibR134a	(for English version of Windows)
C:\Programme\FluidLAB\LibR134a	(for German version of Windows).

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



FluidLAB LibR134a

Destination Location

Setup will install FluidLAB LibR134a in the following folder.

To install into a different folder, click Browse, and select another folder.

You can choose not to install FluidLAB LibR134a by clicking Cancel to exit Setup.

Destination Folder: C:\Program Files\FluidLAB\LibR134a

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" pops up. 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 for LibR134a into the directory:

C:\Program Files\FluidLAB\LibR134a (for English version of Windows)
C:\Programme\FluidLAB\LibR134a (for German version of Windows)):

advapi32.dll
Dformd.dll
Dforrt.dll
INSTALL.LOG
LibR134a.dll
LC.dll
msvcp60.dll
msvcrt.dll
Unwise.exe
Unwise.ini

Now, you have to overwrite the file "LibR134a.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 "LibR134a.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\LibR134a (for English version of Windows)
C:\Programme\FluidLAB\LibR134a (for German version of Windows))

and insert the file "LibR134a.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 "LibR134a.dll" successfully and the property functions are available in MATLAB.

Installing FluidLAB including LibR134a for 64-bit MATLAB®

This section describes the installation of FluidLAB LibR134a.

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_LibR134a_x64.zip", you will see the folder

CD_FluidLAB_LibR134a

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

Open this folder by double-clicking on it.

In this folder you will see the following files

FluidLAB_LibR134a_Docu_Eng.pdf
FluidLAB_LibR134a_64_Setup.msi
LibR134a.dll
Setup.exe

and folders

/vcredist_x64
/WindowsInstaller3_1.

In order to run the installation of FluidLAB including, the LibR134a property library, double-click on the file

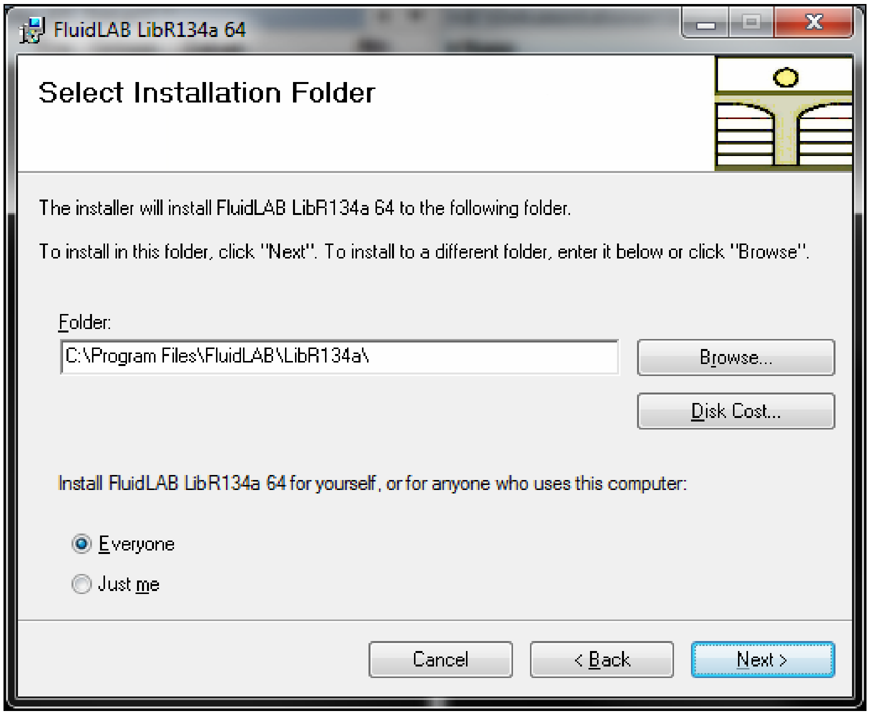
Setup.exe.

Installation of FluidLAB LibR134a 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\LibR134a	(for English version of Windows)
C:\Programme\FluidLAB\LibR134a	(for German version of Windows)

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



The installer will install FluidLAB LibR134a 64 to the following folder.

To install in this folder, click "Next". To install to a different folder, enter it below or click "Browse".

Folder: C:\Program Files\FluidLAB\LibR134a\

Install FluidLAB LibR134a 64 for yourself, or for anyone who uses this computer:

● Everyone
○ Just me

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 LibR134a 64 has been successfully installed." Confirm this by clicking the "Close" button.

The installation program has copied the following files for LibR134a into the directory

"C:\Program Files\FluidLAB\LibR134a" (for English version of Windows)
"C:\Programme\FluidLAB\LibR134a" (for German version of Windows):

capt_ico_big.ico
LC.dll
LibR134a.dll
libifcoremd.dll
libiomp5md.dll
libmmd.dll

Now, you have to overwrite the file "LibR134a.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 "LibR134a.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\LibR134a" (for English version of Windows)
"C:\Programme\FluidLAB\LibR134a" (for German version of Windows))

and insert the file "LibR134a.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 "LibR134a.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 LibR134a into the directory

"C:\Program Files\FluidLAB\LibR134a" (for English version of Windows)
"C:\Programme\FluidLAB\LibR134a" (for German version of Windows):

- Dynamic Link Library "LibR134a.dll" and other necessary system DLL files.
- MATLAB®-Interface-Program for calculable functions

a_ptx_R134a
cp_ptx_R134a
cv_ptx_R134a
eta_ptx_R134a
h_ptx_R134a
kappa_ptx_R134a
lambda_ptx_R134a
ny_ptx_R134a
Pr_ptx_R134a
ps_t_R134a
rho_ptx_R134a
s_ptx_R134a
t_ph_R134a
t_ps_R134a
ts_p_R134a
u_ptx_R134a
v_ptx_R134a
w_ptx_R134a
x_ph_R134a
x_ps_R134a

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

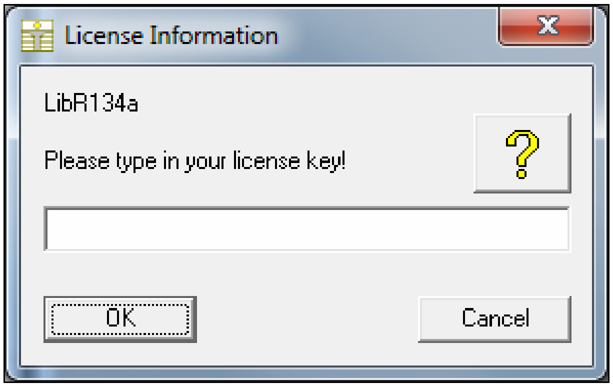
.mexw64

into your LibR134a directory (the standard being

"C:\Program Files\FluidLAB\LibR134a" (for English version of Windows)
"C:\Programme\FluidLAB\LibR134a" (for German version of Windows)).

2.2 Licensing the LibR134a 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 LibR134a (see figure below).

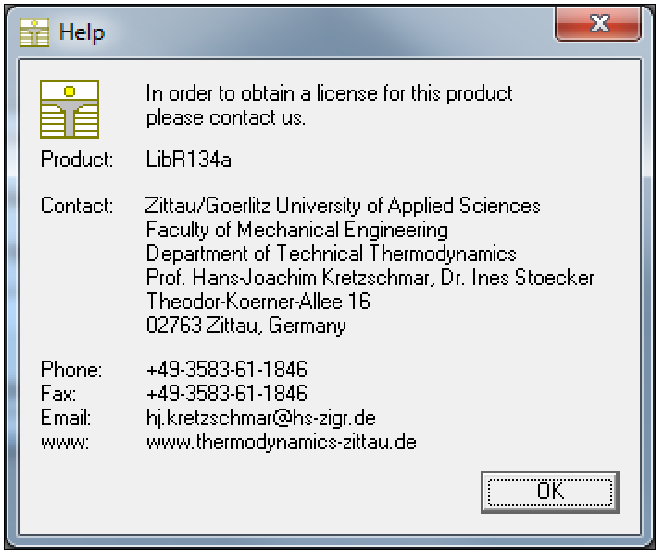


LibR134a

Please type in your license key!

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:



In order to obtain a license for this product
please contact us.

Product: LibR134a

Contact: Zittau/Goerlitz University of Applied Sciences
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Figure 2.4: "Help" window

If you do not enter a valid license it is still possible to use MATLAB® by clicking "Cancel". In this case, the LibR134a property library will display the result "–11111111" for every calculation.

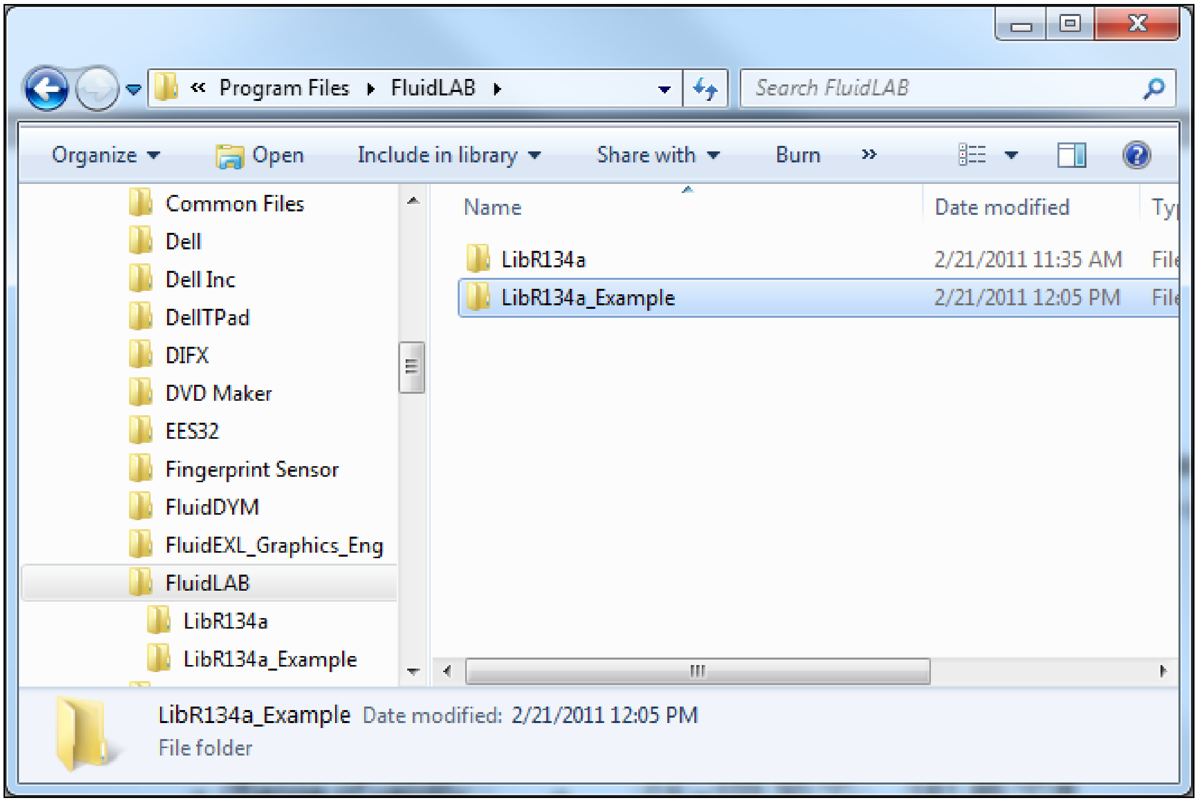
The "License Information" window will appear every time you use FluidLAB LibR134a until you enter a license code to complete registration. If you decide not to use FluidLAB LibR134a, you can uninstall the program following the instructions given in section 2.5 of this User’s Guide.

2.3 Example: Calculation of $h = f(p,t,x)$ 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* 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 easier viewing. Click the "Views" button and select "Details."
- Switch into the program directory of FluidLAB, in which you will find the folder "\LibR134a"; it is generally saved under: "C:\Program Files\FluidLAB"
- Create the folder "\LibR134a_Example" by clicking on "File" in the Explorer® menu, then "New" in the menu which appears and afterwards selecting "Folder". Name the new folder "\LibR134a_Example."
- You will now see the following window:



Name	Date modified	Ty
LibR134a	2/21/2011 11:35 AM	File
LibR134a_Example	2/21/2011 12:05 PM	File

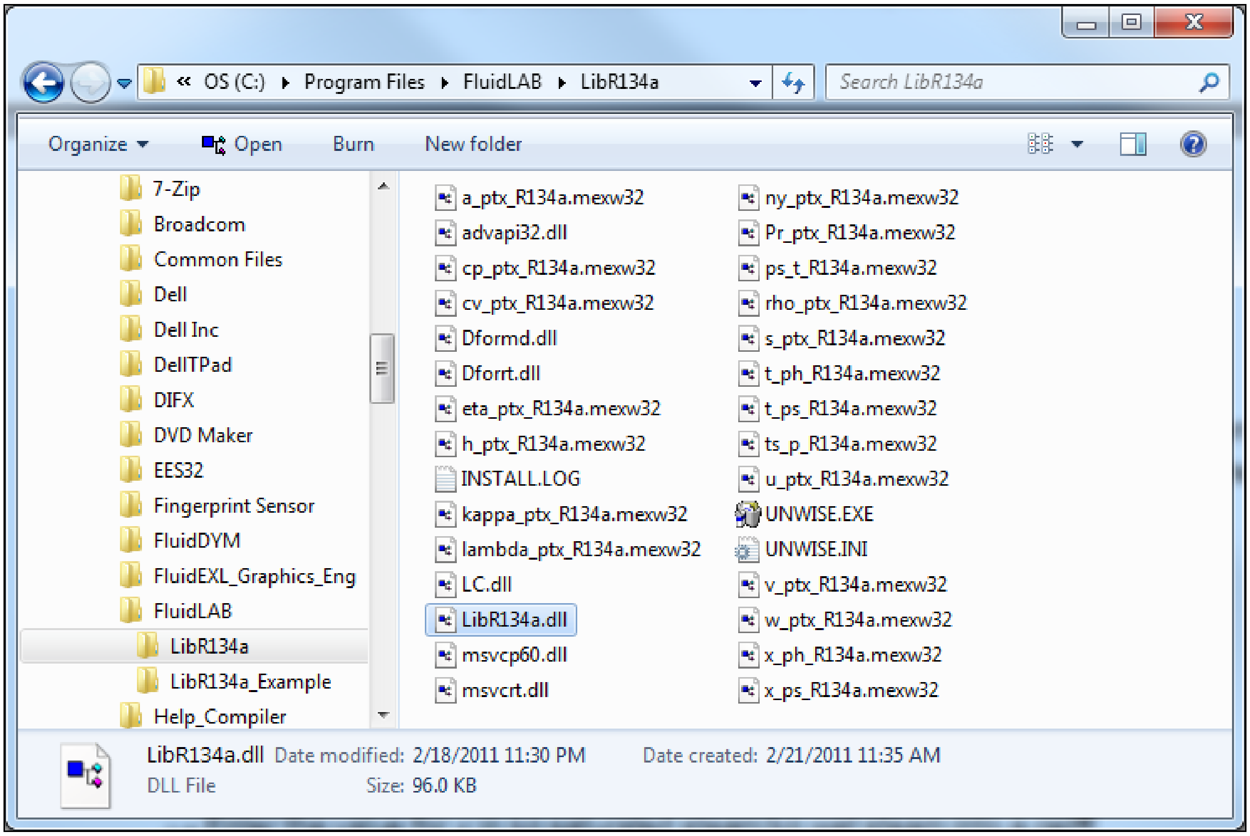
LibR134a_Example Date modified: 2/21/2011 12:05 PM
File folder

Figure 2.5: Folders "LibR134a" and "LibR134a_Example"

- Switch into the directory "\LibR134a" within "\FluidLAB", the standard being

"C:\Program Files\FluidLAB\LibR134a"	(for English version of Windows)
"C:\Programme\FluidLAB\LibR134a"	(for German version of Windows))."

- You will see the following window:



LibR134a.dll Date modified: 2/18/2011 11:30 PM Date created: 2/21/2011 11:35 AM
DLL File Size: 96.0 KB

Figure 2.6: Contents of the folder "LibR134a"

If you have installed the <u>32-bit version</u> of LibR134a you will now have to copy the following files into the directory

"C:\Program Files\FluidLAB\LibR134a_Example" (for English version of Windows)
"C:\Programme\FluidLAB\LibR134a_Example" (for German version of Windows)

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

- The following files are needed:
  - "h_ptx_97.mexw32"
  - "LibR134a.dll"
  - "libifcoremdd.dll"
  - "libmmd.dll"
  - "libmmdd.dll"
  - "msvcr71d.dll"
  - "dforrt.dll.dll"
  - "msvcrt.dll"
- Click the file "h_ptx_R134a.mexw32", then click "Edit" in the upper menu bar and select "Copy".
- Switch into the directory

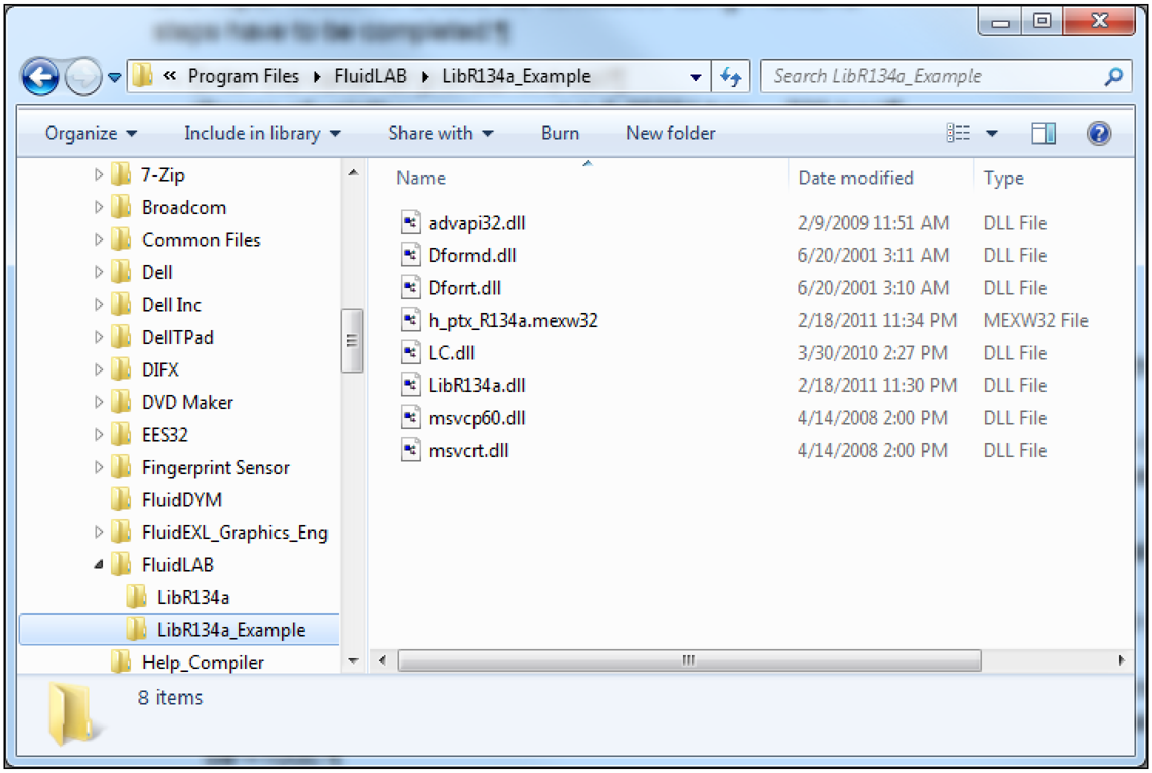
  "C:\Program Files\FluidLAB\LibR134a_Example" (for English version of Windows)
  "C:\Programme\FluidLAB\LibR134a_Example" (for German version of Windows),

click "Edit" and select "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:



Name	Date modified	Type
advapi32.dll	2/9/2009 11:51 AM	DLL File
Dformd.dll	6/20/2001 3:11 AM	DLL File
Dforrt.dll	6/20/2001 3:10 AM	DLL File
h_ptx_R134a.mexw32	2/18/2011 11:34 PM	MEXW32 File
LC.dll	3/30/2010 2:27 PM	DLL File
LibR134a.dll	2/18/2011 11:30 PM	DLL File
msvcp60.dll	4/14/2008 2:00 PM	DLL File
msvcrt.dll	4/14/2008 2:00 PM	DLL File

Figure 2.7: Contents of the folder "LibR134a_Example"

If you have installed the 64-bit version of LibR134a you will now have to copy the following files into the directory

"C:\Program Files\FluidLAB\LibR134a_Example" (for English version of Windows)

"C:\Programme\FluidLAB\LibR134a_Example" (for German version of Windows)

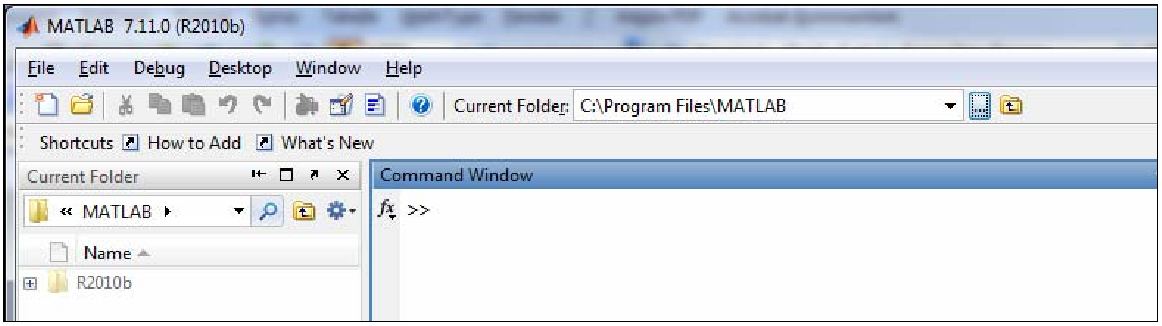
in order to calculate the function $h = f(p,t,x)$.

- The following six files are needed:
  - "h_ptx_R134a.mexw64"
  - "LC.dll"
  - "LibR134a.dll"
  - "libifcoremd.dll"
  - "libiomp5.dll"
  - "libmmd.dll."
- Click the file "h_ptx_R134a.mexw64", then click "Edit" in the upper menu bar and select "Copy."
- Switch into the directory

"C:\Program Files\FluidLAB\LibR134a_Example" (for English version of Windows)
"C:\Programme\FluidLAB\LibR134a_Example" (for German version of Windows),

click "Edit" and then "Paste."

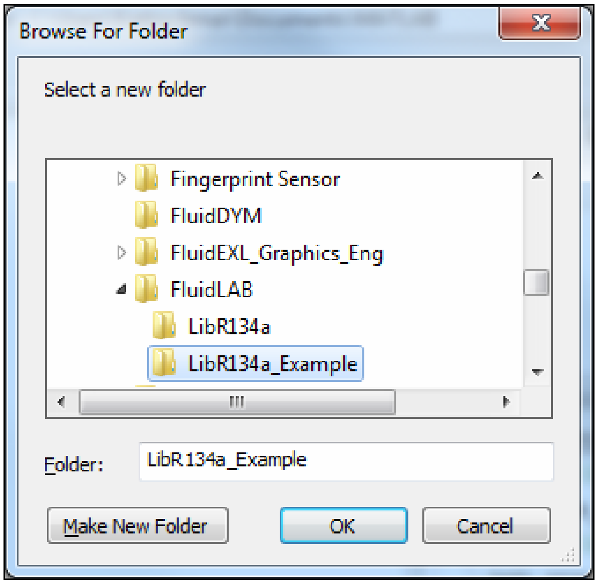
- Repeat these steps in order to copy the other files listed above. You may also select all the above-named files and then copy them as a group (press the Control button to enable multiple markings).
- Now, start MATLAB (if you have not started it before).
- Click the button marked in the next figure in order to open the folder "\LibR134a_Example" in the "Current Folder" window.



Current Folder: C:\Program Files\MATLAB

Figure 2.8: Selection of the working directory

- Find and select the directory "C:\Program Files\FluidLAB\LibR134a_Example" in the pop-up menu (see the following figure).



Folder: LibR134a_Example

Figure 2.9: Choosing the "LibR134a_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 "Desktop", then select "Editor". Now click on the "New Script" button in the Editor Window.
- 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.

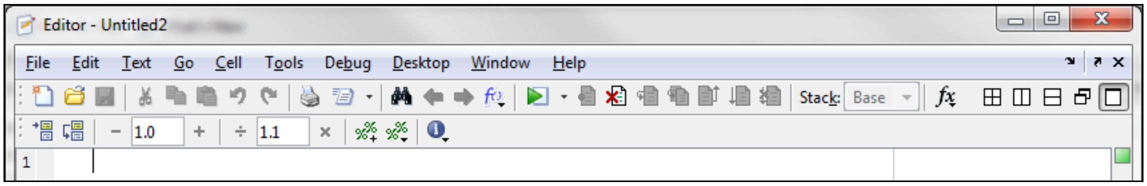
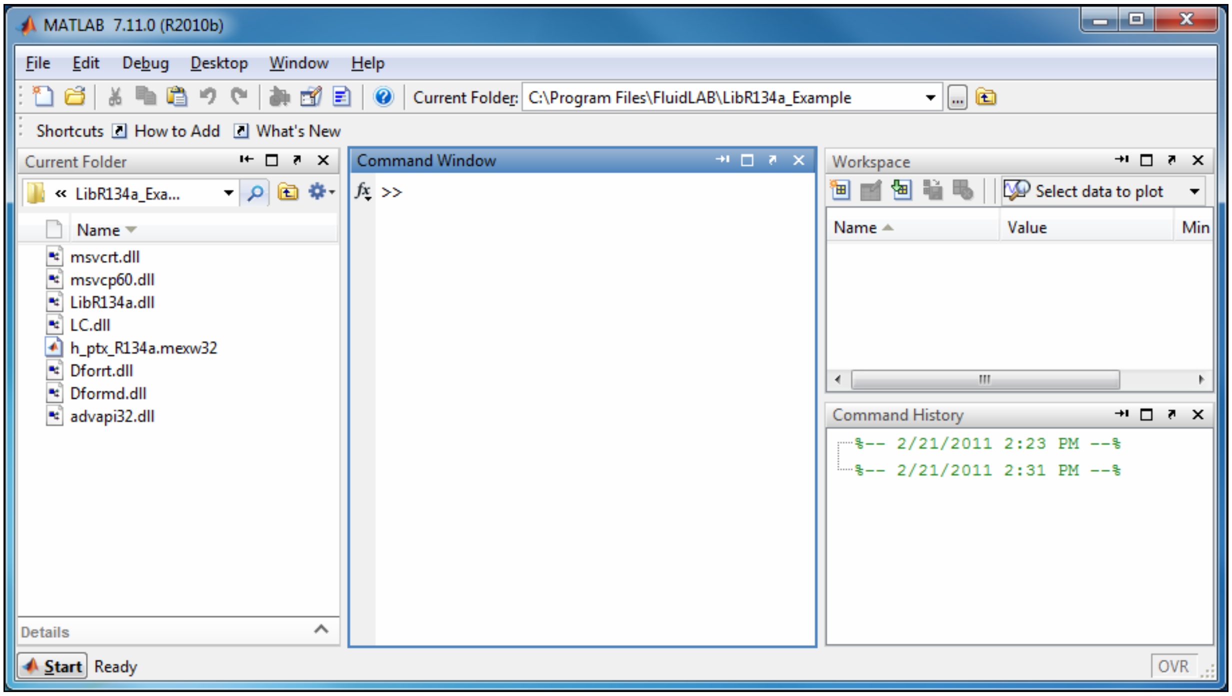


Figure 2.10: Embedding the "Editor" window

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



```
%-- 2/21/2011 2:23 PM --%
%-- 2/21/2011 2:31 PM --%
```

Figure 2.11: Embedded "Editor" window

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

Text to be written:	Explanation:
`% h_ptx_R134a.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 in kg/kg`	
`%%`	paragraph separation
`h=h_ptx_R134a(p,t,x)`	function call
`%%`	paragraph separation

- Remarks:
  - The program interprets the first line, starting with "%," to be a data description in "Current Directory."
  - Paragraph separations which are mandatory are marked with "%%". This also serves to separate the declaration of variables and calculation instructions.

- The words which are printed in green, start with "%" and come after the variables are comments. They are not in fact absolutely necessary, but they are very helpful for your overview and to make the process more easily understood.
- Omit the semicolons after the numerical values if you wish to see the result for *h* and the input parameters.

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

- First operand: Value for *p* = 10
  (Range of validity: *p* = 0.00391 bar ... 700 bar)
- Second operand: Value for *t* = 25 °C
  (Range of validity: *t* = –103.30 °C ... 181.85 °C)
- Third operand: Value for *x* = -1 kg/kg

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:

If the state point to be calculated is located in the single-phase region (liquid or superheated steam), e. g., pressure *p* and temperature *t* are given, 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, plus the value for *x* between 0 and 1 must be entered.

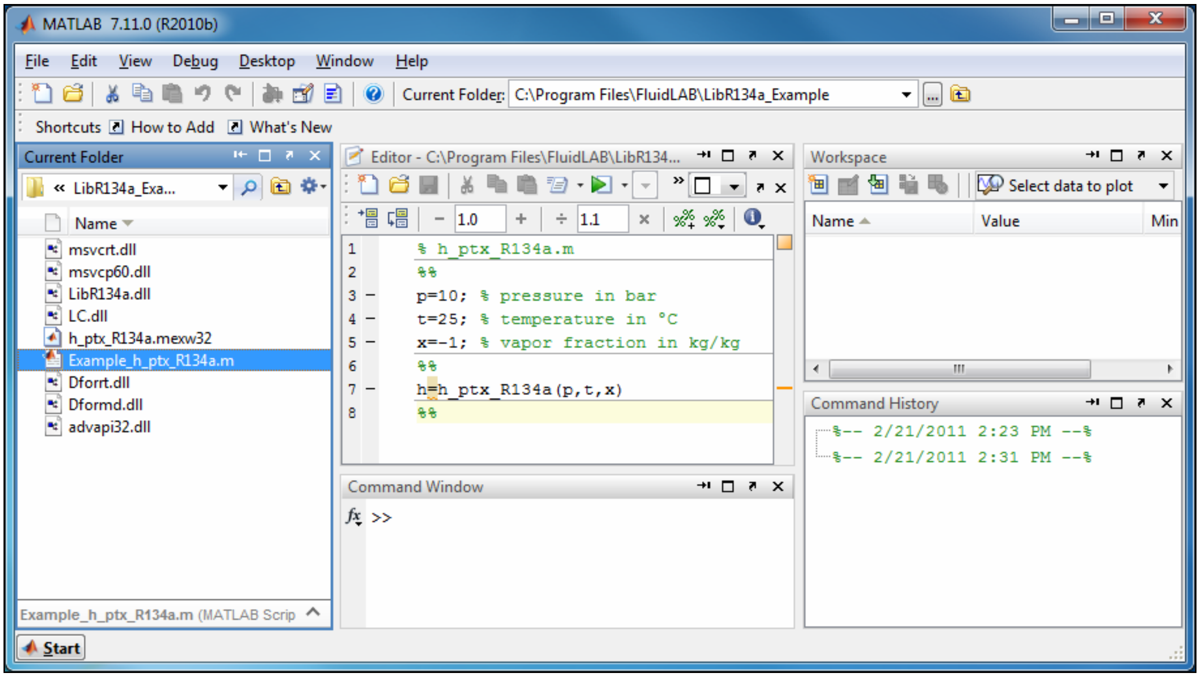
If *p* and *t* and *x* are entered as given values, the program considers *p* and *t* to be appropriate to represent the vapor pressure curve. If this is not the case the enthalpy calculated later will result in -1000.

(Vapor pressure curve of R134a: $t(p, \rho_{\max} = 1550\ \mathrm{kg/m^3})$ ... t_c = 101.03 °C
p_t = 0.00389564 bar ... p_c = 40.566 bar)

- Save the "M-File" by clicking the "File" button and then click "Save As...".
- The menu "Save file as:" appears; In this menu, the folder name "LibR134a_Example" must be displayed in the "Save in:" field.
- Next to "File name" you have to type "Example_h_ptx_R134a.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_R134a.m" in this case. Otherwise an error message will appear during the calculation.

- You will now see the following window:



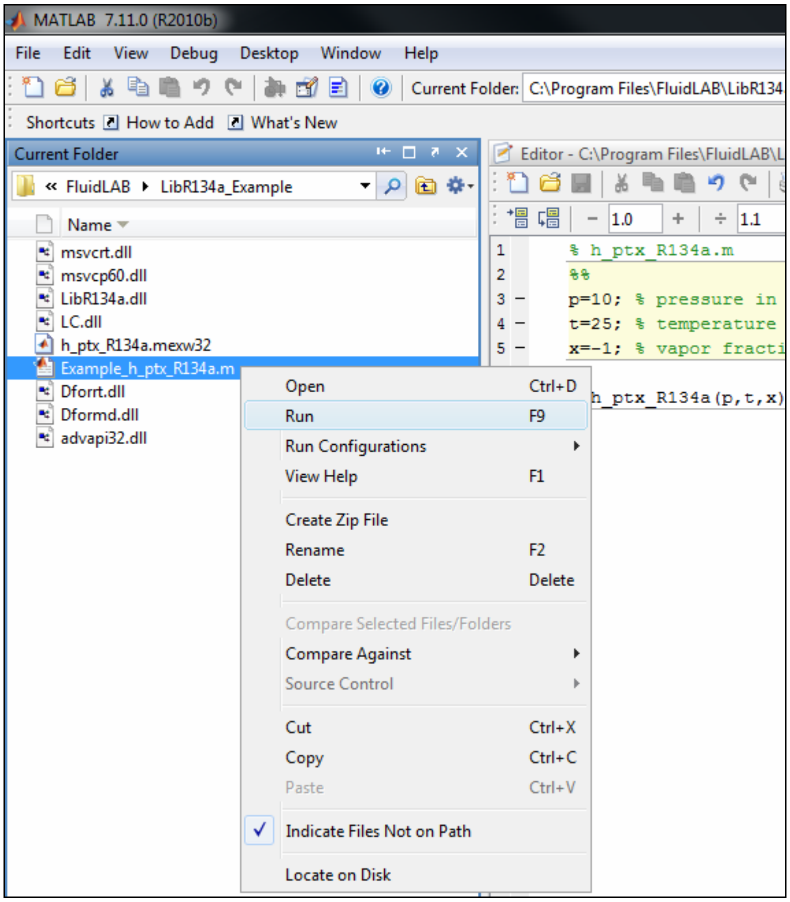
```
% h_ptx_R134a.m
%%
p=10; % pressure in bar
t=25; % temperature in °C
x=-1; % vapor fraction in kg/kg
%%
h=h_ptx_R134a(p,t,x)
%%
```

```
%-- 2/21/2011 2:23 PM --%
%-- 2/21/2011 2:31 PM --%
```

```
>>
```

Figure 2.12: "Example_h_ptx_R134a.m" M-file

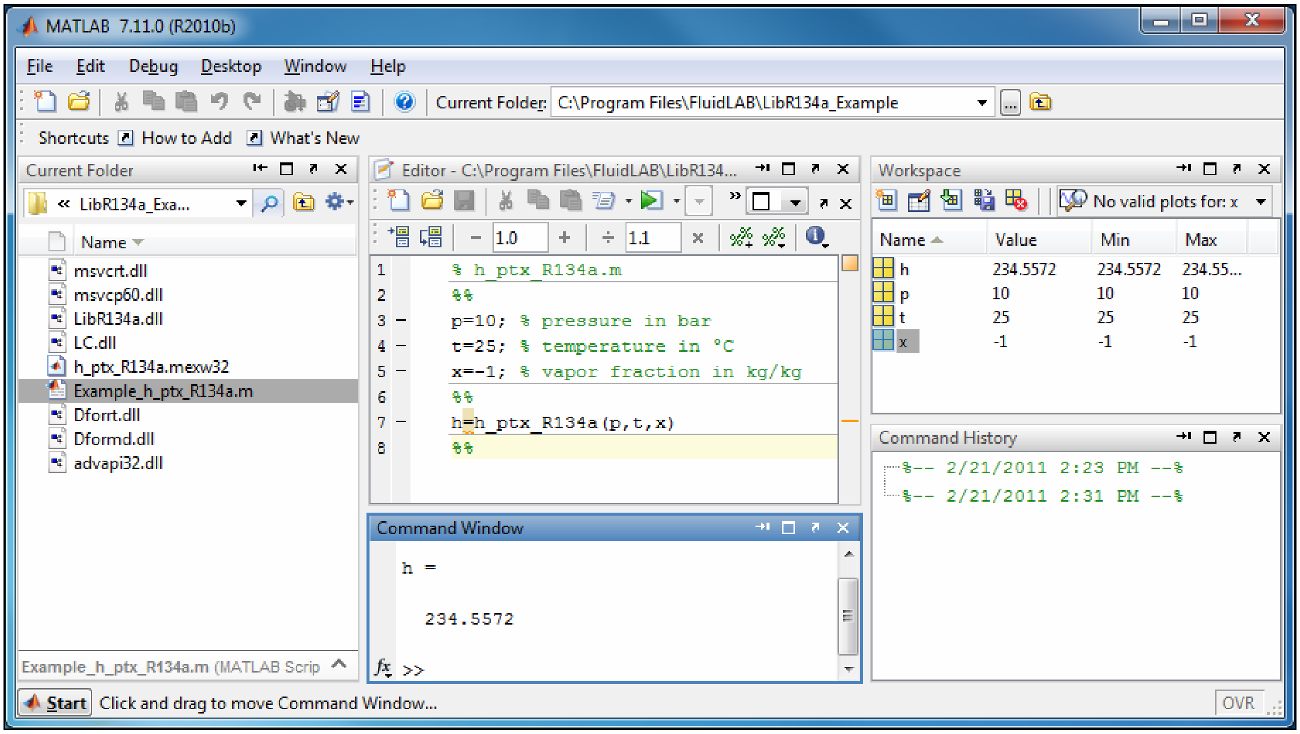
- Within the "Current Folder" window, the file "Example_h_ptx_R134a.m" appears.
- Right-click on this file and select "Run" in the menu which appears (see next figure).



```
% h_ptx_R134a.m
%%
p=10; % pressure in
t=25; % temperature
x=-1; % vapor fracti
h_ptx_R134a(p,t,x)
```

Figure 2.13: Running the "Example_h_ptx_R134a.m" M-file

- You will see the following window:



```
% h_ptx_R134a.m
%%
p=10; % pressure in bar
t=25; % temperature in °C
x=-1; % vapor fraction in kg/kg
%%
h=h_ptx_R134a(p,t,x)
%%
```

```
h =

   234.5572

>>
```

Name	Value	Min	Max
h	234.5572	234.5572	234.55...
p	10	10	10
t	25	25	25
x	-1	-1	-1

```
%-- 2/21/2011 2:23 PM --%
%-- 2/21/2011 2:31 PM --%
```

Figure 2.14: MATLAB® with calculated result

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

⇒ The result in our sample calculation here is: "h = 234.5572". 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 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\LibR134a_Example," and you may use it as a basis for further calculations using FluidLAB.

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

- Start MATLAB® (if you have not started it already).
- Click the button marked in the following image in order to open the folder "\LibR134a_Example" in the window "Current Folder."

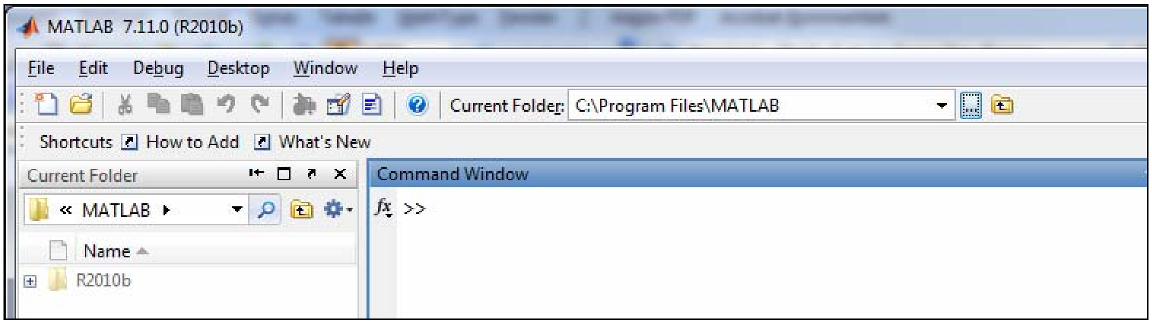
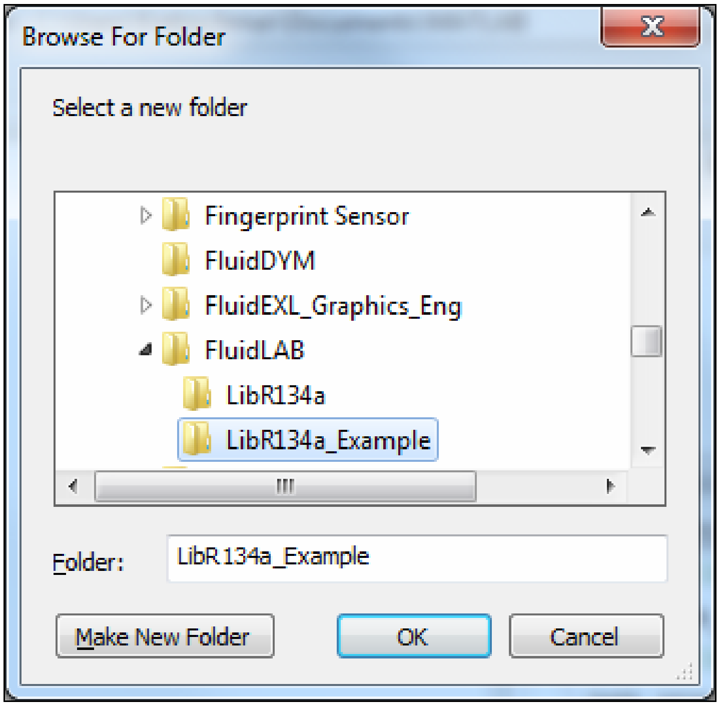


Figure 2.15: Selection of the working directory

- Find and select the directory

"C:\Program Files\FluidLAB\LibR134a_Example"	(for English version of Windows)
"C:\Programme\FluidLAB\LibR134a_Example"	(for German version of Windows)

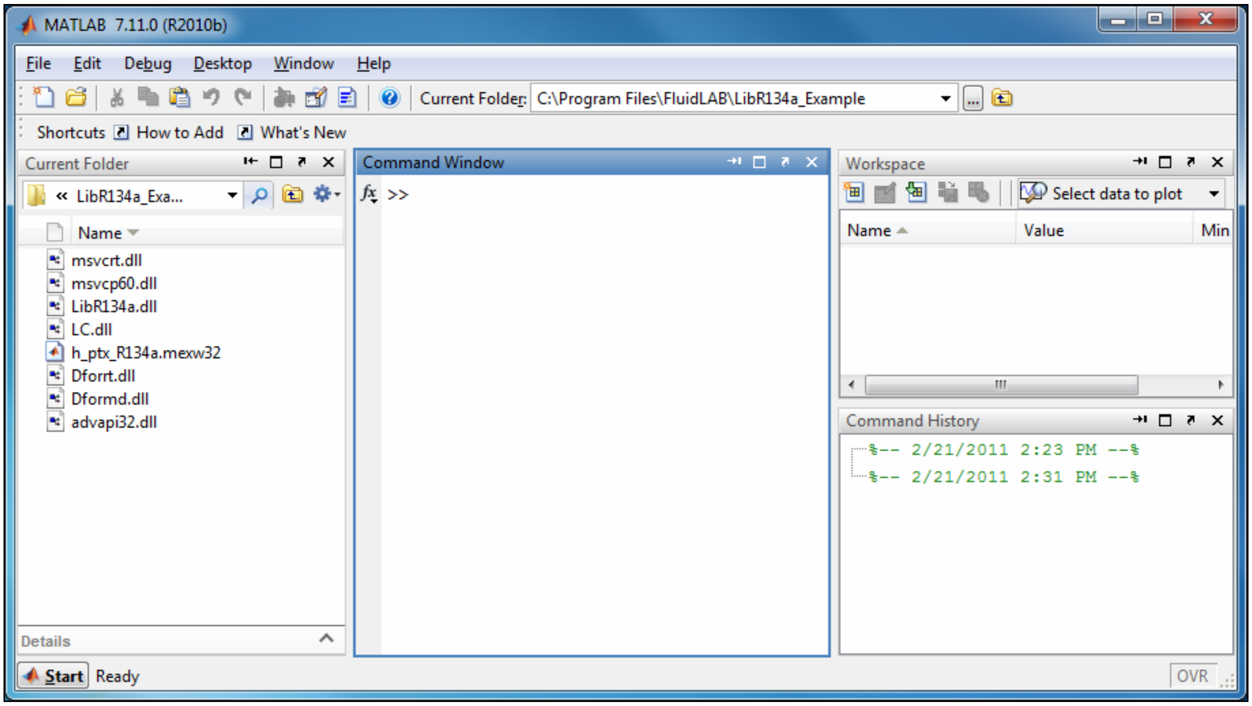
in the menu which appears (see the following figure).



Folder: LibR134a_Example

Figure 2.16: Choosing the "LibR134a_Example" folder

- Confirm your selection by clicking the "OK" button.
- You will see the following window:



Current Folder: C:\Program Files\FluidLAB\LibR134a_Example

msvcrt.dll
msvcp60.dll
LibR134a.dll
LC.dll
h_ptx_R134a.mexw32
Dforrt.dll
Dformd.dll
advapi32.dll

```
>>
```

```
%-- 2/21/2011 2:23 PM --%
%-- 2/21/2011 2:31 PM --%
```

Figure 2.17: MATLAB® with necessary files

Corresponding to the table of the property functions in Chapter 1 you have to call up the function "**h_ptx_R134a**" as follows for calculating *h* = f(*p*,*t*,*x*).

Write "**h=h_ptx_R134a(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* = 0.00391 bar ... 700 bar)
- Second operand: Value for *t* = 25 °C
  (Range of validity: *t* = –103.30 °C ... 181.85 °C)
- Third operand: Value for *x* = -1

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:

If the state point to be calculated is located in the single-phase region (liquid or superheated steam), e. g., pressure *p* and temperature *t* are given, x = –1 must be entered as a pro-forma value.

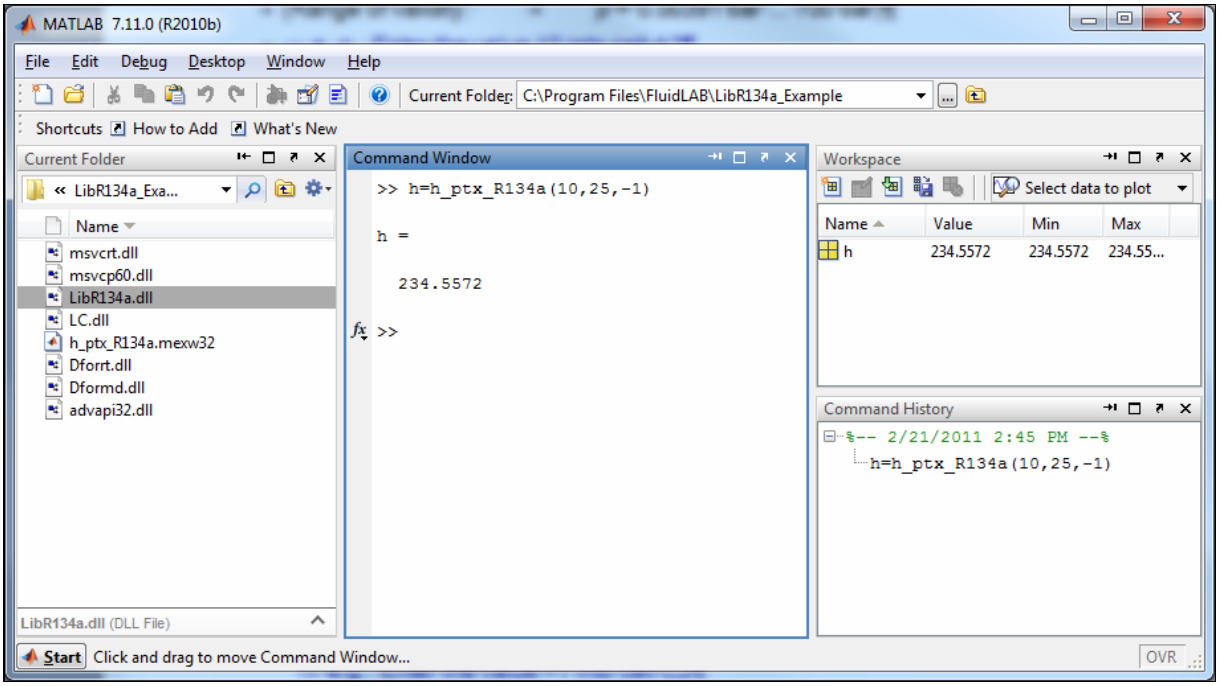
If the state point to be calculated is located in the wet steam region, a value for *x* between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered.

When calculating wet steam either the given value for *t* and p = -1000 or the given value for *p* and t = -1000, plus the value for *x* between 0 and 1 must be entered.

If *p* and *t* and *x* are entered as given values, the program considers *p* and *t* to be appropriate to represent the vapor pressure curve. If this is not the case the enthalpy calculated later will result in -1000.

(Vapor pressure curve of R134a: $t(p, \rho_{\text{max}} = 1550\ \text{kg/m}^3)$ ... t_c = 101.03 °C
p_t = 0.00389564 bar ... p_c = 40.566 bar)

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



Current Folder: C:\Program Files\FluidLAB\LibR134a_Example

« LibR134a_Exa...

Name
msvcrt.dll
msvcp60.dll
LibR134a.dll
LC.dll
h_ptx_R134a.mexw32
Dforrt.dll
Dformd.dll
advapi32.dll

```
>> h=h_ptx_R134a(10,25,-1)

h =

   234.5572

>>
```

Name	Value	Min	Max
h	234.5572	234.5572	234.55...

```
%-- 2/21/2011 2:45 PM --%
   h=h_ptx_R134a(10,25,-1)
```

Figure 2.18: MATLAB® with calculated result

⇒ In the "Command Window" you will see the result "h = 234.5572". 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.

2.5 Removing FluidLAB including LibR134a

To remove the property library LibR134a from your hard disk drive in Windows®, click "Start" in the Windows® task bar, select "Settings" and click "Control Panel".

Now double-click on "Add or Remove Programs". In the list box of the "Add or Remove Programs" window that appears select "FluidLAB LibR134a" 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 LibR134a installed, the directory "FluidLAB" will be removed as well.

3. Program Documentation

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

Function Name:	**a_ptx_R134a**
Subroutine with function value: for call from Fortran:	**REAL*8 FUNCTION A_PTX_R134A(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL:	**INTEGER*4 FUNCTION C_A_PTX_R134A(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

A_PTX_R134A, A or **a_ptx_R134a** – Thermal diffusivity $a = \frac{\lambda * v}{c_p}$ in m²/s

Range of validity

Temperature range:	from - 73.15 °C to 176.85 °C
Pressure range:	from 0.00389564 bar to 700 bar
Density range:	from 0.00105455 kg/m^3 to 1550 kg/m^3

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 range	from $t = -73.15$ °C to $t_c = 101.03$ °C
Pressure range	from $p_t = 0.00389564$ bar to $p_c = 40.566$ bar

Results for wrong input values

Result **A_PTX_R134A, A = -1000** or **a_ptx_R134a = -1000** for input values:

Single phase region: $(x = -1)$	$p > 700$ bar or $p < 0.00389564$ bar or $t > 181.85$°C or $t < -103.3$ °C or $\rho > 1550$ m^3/kg
Saturation lines:	at $p = -1000$ and $t > 101.03$ °C or $t < 73.15$°C at $t = -1000$ and $p > 40.566$ bar or $p < 0.00389564$bar or at $p > 40.566$ bar or $p < 0.00389564$ bar and $t > 101.03$ °C or $t < -103.3$ °C

References: [16], [23]

Specific Isobaric Heat Capacity $c_p = \mathrm{f}(p, t, x)$

Function Name:	**cp_ptx_R134a**
Subroutine with function value: for call from Fortran:	**REAL*8 FUNCTION CP_PTX_R134A(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL:	**INTEGER*4 FUNCTION C_CP_PTX_R134A(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

CP_PTX_R134A, **CP** or **cp_ptx_R134a** – Specific isobaric heat capacity c_p in $\mathrm{kJ/(kg\ K)}$

Range of validity

Temperature range: from $t(p, \rho_{\max} = 1550\ \mathrm{kg/m^3})$ to 181.85 °C

Pressure range: from 0.00389564 bar to 700 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* <u>and</u> p = -1000, or the given value for *p* <u>and</u> t = -1000, plus the value for *x* (x = 0 or x = 1). If *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the vapor pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Saturated liquid and saturated vapor line :

Temperature range	from $t(p, \rho_{\max} = 1550\ \mathrm{kg/m^3})$ to $t_\mathrm{c} = 101.03\ °\mathrm{C}$
Pressure range	from $p_\mathrm{t} = 0.00389564$ bar to $p_\mathrm{c} = 40.566$ bar

Results for wrong input values

Result **CP_PTX_R134A, CP = -1000**, or **cp_ptx_R134a = -1000** for input values:

Single phase region: $(x = -1)$	*p* > 700 bar or *p* < 0.00389564bar or $t > 181.85°\mathrm{C}$ or $t < t(p, \rho_{\max} = 1550\ \mathrm{kg/m^3})$ or $\rho > 1550\ \mathrm{kg/m^3}$
Saturation lines:	at *p* = -1000 and *t* > 101.03 °C or $t < t(p, \rho_{\max} = 1550\ \mathrm{kg/m^3})$ at *t* = -1000 and *p* > 40.566 bar or *p* < 0.00389564 bar or at *p* > 40.566 bar or *p* < 0.00389564 bar and *t* > 101.03 °C or $t < t(p, \rho_{\max} = 1550\ \mathrm{kg/m^3})$

References: [16]

Specific Isochoric Heat Capacity $c_v = \mathrm{f}(p,t,x)$

Function Name:	**cv_ptx_R134a**
Subroutine with function value: for call from Fortran:	**REAL*8 FUNCTION CV_PTX_R134A(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL:	**INTEGER*4 FUNCTION C_CV_PTX_R134A(CV,P,T,X)** REAL*8 CV,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

CV_PTX_R134A, **CV** or **cv_ptx_R134a** – Specific isochoric heat capacity c_v in $\mathrm{kJ}/(\mathrm{kg\ K})$

Range of validity

Temperature range:	from $t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$ to 181.85 °C
Pressure range:	from 0.00389564 bar to 700 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. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Saturated liquid and saturated vapor line :

Temperature range	from $t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$ to $t_{\mathrm{c}} = 101.03\ ^\circ\mathrm{C}$
Pressure range	from $p_{\mathrm{t}} = 0.00389564$ bar to $p_{\mathrm{c}} = 40.566$ bar

Results for wrong input values

Result **CV_PTX_R134A, CV = -1000** or **cv_ptx_R134a = -1000** for input values:

Single phase region: $(x = -1)$	$p > 700$ bar or $p < 0.00389564$ bar or $t > 181.85^\circ\mathrm{C}$ or $t < t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$ or $\rho > 1550\ \mathrm{m^3/kg}$
Saturation lines:	at $p = -1000$ and $t > 101.03$ °C or $t < t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$ at $t = -1000$ and $p > 40.566$ bar or $p < 0.00389564$ bar or at $p > 40.566$ bar or $p < 0.00389564$ bar and $t > 101.03$ °C or $t < t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$

References: [16]

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

Function Name:	**eta_ptx_R134a**
Subroutine with function value: for call from Fortran:	**REAL*8 FUNCTION ETA_PTX_R134A(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL:	**INTEGER*4 FUNCTION C_ETA_PTX_R134A(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

ETA_PTX_R134A, **ETA** or **eta_ptx_R134a** – Dynamic viscosity η in Pa s

Range of validity

Temperature range:	from $t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$ to 181.85 °C
Pressure range:	from 0.00389564 bar to 700 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 = -1, or the given value for *p* and t = -1, plus the value for *x* (x = 0 or x = 1). If *p* and *t* and *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the vapor pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Saturated liquid and saturated vapor line :

Temperature range	from $t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$ to $t_{\mathrm{c}} = 101.03\ ^{\circ}\mathrm{C}$
Pressure range	from $p_{\mathrm{t}} = 0.00389564$ bar to $p_{\mathrm{c}} = 40.566$ bar

Results for wrong input values

Result **ETA_PTX_R134A, ETA = -1000** or **eta_ptx_R134a = -1000** for input values:

Single phase region: $(x = -1)$	p > 700 bar or p < 0.00389564 bar or $t > 181.85\,^{\circ}\mathrm{C}$ or $t < t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$ or $\rho > 1550\ \mathrm{m^3/kg}$
Saturation lines:	at p = -1000 and t > 101.03 °C or $t < t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$ at t = -1000 and p > 40.566 bar or p < 0.00389564 bar or at p > 40.566 bar or p < 0.00389564 bar and t > 101.03 °C or $t < t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$

References: [16], [22]

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

Function Name:	**h_ptx_R134a**
Subroutine with function value: for call from Fortran:	**REAL*8 FUNCTION H_PTX_R134A(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL:	**INTEGER*4 FUNCTION C_H_PTX_R134A(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

H_PTX_R134A, **H** or **h_ptx_R134a** - Specific enthalpy h in kJ/kg

Range of validity

Temperature range:	from $t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$ to 181.85 °C
Pressure range:	from 0.00389564 bar to 700 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. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Saturated liquid and saturated vapor line :

Temperature range	from $t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$ to $t_{\mathrm{c}} = 101.03\ ^\circ\mathrm{C}$
Pressure range	from $p_{\mathrm{t}} = 0.00389564$ bar to $p_{\mathrm{c}} = 40.566$ bar

Results for wrong input values

Result **H_PTX_R134A, H = -1000** or **eta_ptx_R134a = -1000** for input values:

Single phase region: $(x = -1)$	p > 700 bar or p < 0.00389564 bar or $t > 181.85\,^\circ\mathrm{C}$ or $t < t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$ or $\rho > 1550\ \mathrm{m^3/kg}$
Saturation lines:	at p = -1000 and t > 101.03 °C or $t < t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$ at t = -1000 and p > 40.566 bar or p < 0.00389564 bar or at p > 40.566 bar or p < 0.00389564 bar and t > 101.03 °C or $t < t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$

References: [16]

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

Function Name:	**kappa_ptx_R134a**
Subroutine with function value: for call from Fortran:	**REAL*8 FUNCTION KAP_PTX_R134A(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL:	**INTEGER*4 FUNCTION C_KAP_PTX_R134A(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

KAP_PTX_R134A, **KAP** or **kappa_ptx_R134a** – Isentropic exponent $\kappa = \dfrac{w^2}{p^*v}$

Range of validity

Temperature range:	from $t(p,\rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$ to 181.85 °C
Pressure range:	from 0.00389564 bar to 700 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. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Saturated liquid and saturated vapor line :

Temperature range	from $t(p,\rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$ to $t_{\mathrm{c}} = 101.03\ ^{\circ}\mathrm{C}$
Pressure range	from $p_{\mathrm{t}} = 0.00389564$ bar to $p_{\mathrm{c}} = 40.566$ bar

Results for wrong input values

Result **KAP_PTX_R134A**, **KAP = -1000** or **kappa_ptx_R134a = -1000** for input values:

Single phase region: $(x = -1)$	$p > 700$ bar or $p < 0.00389564$ bar or $t > 181.85^{\circ}\mathrm{C}$ or $t < t(p,\rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$ or $\rho > 1550\ \mathrm{m^3/kg}$
Saturation lines:	at p = -1000 and t > 101.03 °C or $t < t(p,\rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$ at t = -1000 and p > 40.566 bar or p < 0.00389564 bar or at p > 40.566 bar or p < 0.00389564 bar and t > 101.03 °C or $t < t(p,\rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$

References: [16]

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

Function Name:	**lambda_ptx_R134a**
Subroutine with function value: for call from Fortran:	**REAL*8 FUNCTION LAM_PTX_R134A(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL:	**INTEGER*4 FUNCTION C_LAM_PTX_R134A(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

LAM_PTX_R134A, **LAM** or **lambda_ptx_R134a** – Thermal conductivity λ in W / m K

Range of validity

Temperature range:	from - 73.15 °C to 176.85 °C
Pressure range:	from 0.00389564 bar to 700 bar
Density range:	from 0.00105455 kg /m^3 to 1550 kg / m^3

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. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Saturated liquid and saturated vapor line :

Temperature range	from $t = -103.30$ °C to $t_c = 101.03$ °C
Pressure range	from $p_t = 0.00389564$ bar to $p_c = 40.566$ bar

Results for wrong input values

Result **LAM_PTX_R134A, LAM = - 1000** or **lambda_ptx_R134a = -1000** for input values:

Single phase region: $(x = -1)$	p > 700 bar or p < 0.00389564 bar or $t > 181.85$°C or $t < -103.3$ °C or $\rho > 1550$ m^3 / kg
Saturation lines:	at p = -1000 and t > 101.03 °C or t < 73.15°C at t = -1000 and p > 40.566 bar or p < 0.00389564 bar or at p > 40.566 bar or p < 0.00389564 bar and t > 101.03 °C or t < -103.30 °C

References: [16], [23]

Kinematic Viscosity $\nu = \mathrm{f}\left(p,t,x\right)$

Function Name:	**ny_ptx_R134a**
Subroutine with function value: for call from Fortran:	**REAL*8 FUNCTION NY_PTX_ R134A(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL:	**INTEGER*4 FUNCTION C_NY _PTX_ R134A(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

NY_PTX_ R134A, **NY** or **ny_ptx_ R134a** – Kinematic viscosity $\nu = \eta * v$ in m^2/s

Range of validity

Temperature range:	from - 73.15 °C to 181.85 °C
Pressure range:	from 0.00389564 bar to 700 bar
Density range:	from $0.00105455\ \mathrm{m}^3/\mathrm{kg}$ to $1550\ \mathrm{m}^3/\mathrm{kg}$

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. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Saturated liquid and saturated vapor line :

Temperature range	from $t = -103.30$ °C to $t_\mathrm{c} = 101.03$ °C
Pressure range	from $p_\mathrm{t} = 0.00389564$ bar to $p_\mathrm{c} = 40.566$ bar

Results for wrong input values

Result **NY_PTX_ R134A, NY= -1000** or **ny_ptx_ R134a = -1000** for input values:

Single phase region: $(x = -1)$	p > 700 bar or p < 0.00389564 bar or $t > 181.85$°C or $t < -103.3$ °C or $\rho > 1550\ \mathrm{m}^3/\mathrm{kg}$
Saturation lines:	at p = -1000 and t > 101.03 °C or t < 73.15°C at t = -1000 and p > 40.566 bar or p < 0.00389564 bar or at p > 40.566 bar or p < 0.00389564 bar and t > 101.03 °C or t < -103.30 °C

References: [16], [22]

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

Function Name:	**Pr_ptx_R134a**
Subroutine with function value: for call from Fortran:	**REAL*8 FUNCTION PR_PTX_R134A(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL:	**INTEGER*4 FUNCTION C_PR _PTX_R134A(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

PR _PTX _R134A, **PR** or **Pr _ptx _R134a** – Prandtl – Number $\Pr = \frac{\eta * c_p}{\lambda}$

Range of validity

Temperature range:	from - 73.15 °C to 181.85 °C
Pressure range:	from 0.00389564 bar to 700 bar
Density range:	from $0.0010545\,5\ \mathrm{m}^3/\mathrm{kg}$ to $1550\ \mathrm{m}^3/\mathrm{kg}$

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. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Saturated liquid and saturated vapor line :

Temperature range	from $t = -103.30$ °C to $t_c = 101.03$ °C
Pressure range	from $p_t = 0.00389564$ bar to $p_c = 40.566$ bar

Results for wrong input values

Result **PR_PTX_ R134A, PR= -1000** or **Pr_ptx_ R134a = -1000** for input values:

Single phase region:	*p* > 700 bar or *p* < 0.00389564 bar or
$(x = -1)$	$t > 181.85$°C or $t < -103.3$ °C or $\rho > 1550\ \mathrm{m}^3/\mathrm{kg}$
Saturation lines:	at *p* = -1000 and *t* > 101.03 °C or *t* < -73.15°C at *t* = -1000 and *p* > 40.566 bar or *p* < 0.00389564 bar or at *p* > 40.566 bar or *p* < 0.00389564 bar and *t* > 101.03 °C or *t* < -103.30 °C

References: [16], [22], [23]

Vapor Pressure $p_s = f(t)$

Function Name:	**ps_t_R134a**
Subroutine with function value: for call from Fortran:	**REAL*8 FUNCTION PS_T_ R134A(T)** REAL*8 T
Subroutine with parameter: for call from DLL:	**INTEGER*4 FUNCTION C_PS_T_ R134A(PS,T)** REAL*8 PS,T

Input Values:

T - Temperature *t* in °C

Result

PS_T_ R134A, **PS** or **ps_t_ R134a** – Vapor pressure p_s in bar

Range of validity

Temperature range: from $t(p, \rho_{max} = 1550\ \text{kg/m}^3)$ to 101.03 °C

Results for wrong input values

Result **PS_T_ R134A, PS = -1000** or **ps_t_ R134a = -1000** for input values:

$t > 101.03$ °C or $t < t(p, \rho_{max} = 1550\ \text{kg/m}^3)$

References: [16]

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

Function Name:	**rho_ptx_ R134a**
Subroutine with function value: for call from Fortran:	**REAL*8 FUNCTION RHO_PTX_ R134A(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL:	**INTEGER*4 FUNCTION C_RHO_PTX_ R134A(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

RHO_PTX_R134A, **RHO** or **rho_ptx_R134a** – Density ρ in $\mathrm{kg/m^3}$

Range of validity

Temperature range:	from $t(p, \rho_{\max} = 1550\ \mathrm{kg/m^3})$ to 181.85 °C
Pressure range:	from 0.00389564 bar to 700 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.If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Saturated liquid and saturated vapor line :

Temperature range	from $t(p, \rho_{\max} = 1550\ \mathrm{kg/m^3})$ to $t_c = 101.03\ °\mathrm{C}$
Pressure range	from $p_t = 0.00389564$ bar to $p_c = 40.566$ bar

Results for wrong input values

Result **RHO_PTX_R134a, RHO= -1000** or **rho_ptx_R134a = -1000** for input values:

Single phase region: $(x = -1)$	$p > 700$ bar or $p < 0.00389564$ bar or $t > 181.85°\mathrm{C}$ or $t < t(p, \rho_{\max} = 1550\ \mathrm{kg/m^3})$ or $\rho > 1550\ \mathrm{m^3/kg}$
Saturation lines:	at $p = -1000$ and $t > 101.03$ °C or $t < -73.15$°C at $t = -1000$ and $p > 40.566$ bar or $p < 0.00389564$ bar or at $p > 40.566$ bar or $p < 0.00389564$ bar and $t > 101.03$ °C or $t < t(p, \rho_{\max} = 1550\ \mathrm{kg/m^3})$

References: [16]

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

Function Name:	**s_ptx_R134a**
Subroutine with function value: for call from Fortran:	**REAL*8 FUNCTION S_PTX_R134A(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL:	**INTEGER*4 FUNCTION C_S_PTX_R134A(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

S_PTX_R134A, **S** or **s_ptx_R134a** - Specific entropy *s* in kJ/kg K

Range of validity

Temperature range:	from $t(p, \rho_{\max} = 1550\ \mathrm{kg/m^3})$ to 181.85 °C
Pressure range:	from 0.00389564 bar to 700 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.

If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Saturated liquid and saturated vapor line :

Temperature range	from $t(p, \rho_{\max} = 1550\ \mathrm{kg/m^3})$ to $t_c = 101.03$ °C
Pressure range	from $p_t = 0.00389564$ bar to $p_c = 40.566$ bar

Results for wrong input values

Result **S_PTX_R134A, S = -1000** or **s_ptx_R134a = -1000** for input values:

Single phase region: $(x = -1)$	$p > 700$ bar or $p < 0.00389564$ bar or $t > 181.85$°C or $t < -73.15$ °C or $\rho > 1550\ \mathrm{m^3/kg}$
Saturation lines:	at $p = -1000$ and $t > 101.03$ °C or $t < -73.15$°C at $t = -1000$ and $p > 40.566$ bar or $p < 0.00389564$ bar or at $p > 40.566$ bar or $p < 0.00389564$ bar and $t > 101.03$ °C or $t < t(p, \rho_{\max} = 1550\ \mathrm{kg/m^3})$

References: [16]

Surface Tension $\sigma = \mathrm{f}(t)$

Function Name:	**sigma_t_R134a**
Subroutine with function value: for call from Fortran:	**REAL*8 FUNCTION SIGMA_T_R134A(T)** REAL*8 T
Subroutine with parameter: for call from DLL:	**INTEGER*4 FUNCTION C_SIGMA_T_R134A(SIGMA,T)** REAL*8 SIGMA,T

Input Values:

T - Temperature *t* in °C

Result

SIGMA_T_R134A, **SIGMA** or **sigma_t_R134a** – Surface tension σ in N/m

Range of validity

Temperature range: from - 103.30 °C to 181.85 °C

Results for wrong input values

Result **SIGMA_T_R134A, SIGMA= -1000** or **sigma_t_R134a = -1000** for input values:

References: [16], [22]

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

Function Name: **t_ph_R134a**

Subroutine with function value: **REAL*8 FUNCTION T_PH_R134A(P,H)**
for call from Fortran: REAL*8 P,H

Subroutine with parameter: **INTEGER*4 FUNCTION C_T _PH_R134A(T,P,H)**
for call from DLL: REAL*8 T,P,H

Input Values:

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

Result

T_PH_R134A, **T** or **t_ph_R134a** - Temperature t in °C

Range of validity

Temperature range: from $t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$ to 181.85 °C

Pressure range: from 0.00389564 bar to 700 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 $p_{\mathrm{t}} = 0.00389564$ bar to $p_{\mathrm{c}} = 40.566$ bar

Results for wrong input values

Result **T_PH_R134A**, **T = -1000** or **t_ph_R134a = -1000** for input values:

Single phase region: $p > 700$ bar or $p < 0.00389564$ bar or
$(x = -1)$ $t > 181.85$°C or $t < t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$ or $\rho > 1550\ \mathrm{m^3/kg}$
Saturation lines: at $p > 70.54$ bar or $p < 0.00389564$ bar or
$t > 101.03$ °C or $t < t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$

References: [16]

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

Function Name: **t_ps_R134a**

Subroutine with function value: **REAL*8 FUNCTION T_PS_R134A(P,S)**
for call from Fortran: REAL*8 P,S

Subroutine with parameter: **INTEGER*4 FUNCTION C_T_PS_R134A(T,P,S)**
for call from DLL: REAL*8 T,P,S

Input Values:

P - Pressure *p* in bar

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

Result

T_PS_R134A, **T** or **t_ps_R134a** - Temperature *t* in °C

Range of validity

Temperature range: from $t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$ to 181.85 °C

Pressure range: from 0.00389564 bar to 700 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 $p_{\mathrm{t}} = 0.00389564$ bar to $p_{\mathrm{c}} = 40.566$ bar

Results for wrong input values

Result **T_PS_R134A**, **T = -1000** or **t_ps_R134a = -1000** for input values:

Single phase region: $p > 700$ bar or $p < 0.00389564$ bar or
$(x = -1)$ $t > 18185°\mathrm{C}$ or $t < t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$ or $\rho > 1550\ \mathrm{m^3/kg}$
Saturation lines: at $p > 70.54$ bar or $p < 0.00389564$ bar or
$t > 101.03$ °C or $t < t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$

References: [16]

Saturation Temperature $t_s = f(p)$

Function Name:	**ts_p_R134a**
Subroutine with function value: for call from Fortran:	**REAL*8 FUNCTION TS_P_R134A(P)** REAL*8 P
Subroutine with parameter: for call from DLL:	**INTEGER*4 FUNCTION C_TS_P_R134A(TS,P)** REAL*8 TS,P

Input Values:

P - Pressure *p* in bar

Result

TS_P_R134A, **TS** or **ts_p_R134a** – Saturation temperature t_s in °C

Range of validity

Pressure range: from 0.00389564 bar to 40.566 bar

Results for wrong input values

Result **TS_P_R134A**, **TS = -1000** or **ts_p_R134a = -1000** for input values:

$p < 0.00389564$ bar or $p > 40.566$ bar

References: [16]

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

Function Name:	**u_ptx_R134a**
Subroutine with function value: for call from Fortran:	**REAL*8 FUNCTION U_PTX_R134A(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL:	**INTEGER*4 FUNCTION C_U_PTX_R134A(U,P,T,X)** REAL*8 U,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

U_PTX_R134A, **U** or **u_ptx_R134a** - Specific internal energy *u* in kJ/kg

Range of validity

Temperature range: from $t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$ to 181.85 °C

Pressure range: from 0.00389564 bar to 700 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. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Saturated liquid and saturated vapor line :

Temperature range from $t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$ to $t_c = 101.03$ °C

Pressure range from $p_t = 0.00389564$ bar to $p_c = 40.566$ bar

Results for wrong input values

Result **U_PTX_R134A, U = -1000** or **u_ptx_R134a = -1000** for input values:

Single phase region: *p* > 700 bar or *p* < 0.00389564 bar or

$(x = -1)$ $t > 181.85$°C or $t < t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$ or $\rho > 1550\ \mathrm{m^3/kg}$

Saturation lines: at *p* = -1000 and *t* > 101.03 °C or *t* < -73.15°C

at *t* = -1000 and *p* > 40.566 bar or *p* < 0.00389564 bar or

at *p* > 40.566 bar or *p* < 0.00389564 bar and

t > 101.03 °C or $t < t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$

References: [16]

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

Function Name:	**v_ptx_R134a**
Subroutine with function value: for call from Fortran:	**REAL*8 FUNCTION V_PTX_R134A(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL:	**INTEGER*4 FUNCTION C_V_PTX_R134A(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

V_PTX_R134A, **V** or **v_ptx_R134a** – Specific volume v in m^3/kg

Range of validity

Temperature range:	from $t(p, \rho_{max} = 1550\ kg/m^3)$ to 181.85 °C
Pressure range:	from 0.00389564 bar to 700 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. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Saturated liquid and saturated vapor line :

Temperature range	from $t(p, \rho_{max} = 1550\ kg/m^3)$ to $t_c = 101.03$ °C
Pressure range	from $p_t = 0.00389564$ bar to $p_c = 40.566$ bar

Results for wrong input values

Result **V_PTX_R134A, V = -1000** or **v_ptx_R134a = -1000** for input values:

Single phase region: $(x = -1)$	p > 700 bar or p < 0.00389564 bar or $t > 181.85$°C or $t < t(p, \rho_{max} = 1550\ kg/m^3)$ or $\rho > 1550\ m^3/kg$
Saturation lines:	at p = -1000 and t > 101.03 °C or t < -73.15°C at t = -1000 and p > 40.566 bar or p < 0.00389564 bar or at p > 40.566 bar or p < 0.00389564 bar and t > 101.03 °C or $t < t(p, \rho_{max} = 1550\ kg/m^3)$

References: [16]

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

Function Name:	**w_ptx_R134a**
Subroutine with function value: for call from Fortran:	**REAL*8 FUNCTION W_PTX_R134A(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL:	**INTEGER*4 FUNCTION C_W_PTX_R134A(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

W_PTX_R134A, **W** or **w_ptx_R134a** - Speed of sound *w* in m/s

Range of validity

Temperature range:	from $t(p, \rho_{\text{max}} = 1550\ \text{kg/m}^3)$ to 181.85 °C
Pressure range:	from 0.00389564 bar to 700 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 range	from $t(p, \rho_{\text{max}} = 1550\ \text{kg/m}^3)$ to $t_c = 101.03\ ^\circ\text{C}$
Pressure range	from $p_t = 0.00389564$ bar to $p_c = 40.566$ bar

Results for wrong input values

Result **W_PTX_R134A, W = -1000** or **w_ptx_R134a = -1000** for input values:

Single phase region: $(x = -1)$	*p* > 700 bar or *p* < 0.00389564 bar or $t > 181.85^\circ\text{C}$ or $t < t(p, \rho_{\text{max}} = 1550\ \text{kg/m}^3)$ or $\rho > 1550\ \text{m}^3/\text{kg}$
Saturation lines:	at *p* = -1000 and *t* > 101.03 °C or *t* < -73.15°C at *t* = -1000 and *p* > 40.566 bar or *p* < 0.00389564 bar or at *p* > 40.566 bar or *p* < 0.00389564 bar and *t* > 101.03 °C or $t < t(p, \rho_{\text{max}} = 1550\ \text{kg/m}^3)$

References: [16]

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

Function Name:	**x_ph_R134a**
Subroutine with function value: for call from Fortran:	**REAL*8 FUNCTION X_PH_R134A(P,H)** REAL*8 P,H
Subroutine with parameter: for call from DLL:	**INTEGER*4 FUNCTION C_X_PH_R134A(T,P,H)** REAL*8 X,P,H

Input Values:

P - Pressure *p* in bar

H - Specific enthalpy *h* in kJ/kg

Result

X_PH_R134A, **X** or **x_ph_R134a** - Vapor fraction *x* in (kg saturated steam/kg wet steam)

Range of validity

Temperature range:	from $t(p, \rho_{\text{max}} = 1550\ \text{kg/m}^3)$ to 181.85 °C
Pressure range:	from 0.00389564 bar to 700 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 *u* 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 $p_t = 0.00389564$ bar to $p_c = 40.566$ bar

Results for wrong input values

Result **X_PH_R134A**, **X = -1** or **x_ph_R134a = -1** for input values:

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

$p <$ 40.566 bar or $p >$ 0.00389564 bar

References: [16]

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

Function Name:	**x_ps_R134a**
Subroutine with function value: for call from Fortran:	**REAL*8 FUNCTION X_PS_R134A(P,S)** REAL*8 P,S
Subroutine with parameter: for call from DLL:	**INTEGER*4 FUNCTION C_X_PS_R134A(X,P,S)** REAL*8 X,P,S

Input Values:

P - Pressure *p* in bar

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

Result

X_PS_R134A, **X** or **x_ps_R134a** - Vapor fraction *x* in (kg saturated steam/kg wet steam)

Range of validity

Temperature range: from $t(p, \rho_{\mathrm{max}} = 1550\ \mathrm{kg/m^3})$ to 101.03 °C

Pressure range: from 0.00389564 bar to 700 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. 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 $p_{\mathrm{t}} = 0.00389564$ bar to $p_{\mathrm{c}} = 40.566$ bar

Results for wrong input values

Result **X_PS_R134A**, **X = -1** or **x_ps_R134a = -1** for input values:

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

$p <$ 40.566 bar or $p >$ 0.00389564 bar

References: [16]

ZITTAU/GOERLITZ UNIVERSITY OF APPLIED SCIENCES
Department of Technical Thermodynamics
www.thermodynamics-zittau.de

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

Water and Steam

Library LibIF97

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

Humid Combustion Gas Mixtures

Library LibHuGas

Model: Ideal mixture of the real fluids:

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

and of the ideal gases:

SO_2, CO, Ne (Scientific Formulation of Bücker et al.)

Consideration of:

Dissociation from VDI 4670 and Poynting effect

Humid Air

Library LibHuAir

Model: Ideal mixture of the real fluids:

- Dry Air from Lemmon et al.
- Steam, water and ice from IAPWS-IF97 and IAPWS-06

Consideration of:

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

Carbon Dioxide including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1994)

Seawater

Library LibSeaWa

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

Consideration of:

- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

Dry Air including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Nitrogen

Library LibN2

Formulation of Span et al. (2000)

Hydrogen

Library LibH2

Formulation of Leachman et al. (2007)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth (1995)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of Bücker et al. (2003)

n-Butane

Library LibButane_n

Formulation of Bücker et al. (2003)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

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

Helmholtz energy equation for the mixing term

(also useable for calculating Kalina Cycle)

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

$C_2H_6O_2$	Ethylene glycol
$C_3H_8O_2$	Propylene glycol
C_2H_5OH	Ethyl alcohol
CH_3OH	Methyl alcohol
$C_3H_8O_3$	Glycerol
K_2CO_3	Potassium carbonate
$CaCl_2$	Calcium chloride
$MgCl_2$	Magnesium chloride
NaCl	Sodium chloride
$C_2H_3KO_2$	Potassium acetate

Formulation of the International Institute of Refrigeration (1997)

Siloxanes as ORC Working Fluids

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

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

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

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

Formulation of Colonna et al. (2006)

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

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

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

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

Formulation of Colonna et al. (2008)

Propane

Library LibPropane

Formulation of Lemmon et al. (2007)

Methanol

Library LibCH3OH

Formulation of de Reuck and Craven (1993)

Ethanol

Library LibC2H5OH

Formulation of Schroeder et al. (2012)

Helium

Library LibHe

Formulation of Arp et al. (1998)

Hydrocarbons

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

Isopentane **C_5H_{12}** **Library LibC5H12_ISO**

Neopentane **C_5H_{12}** **Library LibC5H12_NEO**

Isohexane **C_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**

Dinitrogen monooxide **N_2O** **Library LibN2O**

Sulfur dioxide **SO_2** **Library LibSO2**

Acetone **C_3H_6O** **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

For more information please contact:

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Fax.: +49-3583-61-1846

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives can be calculated.

---

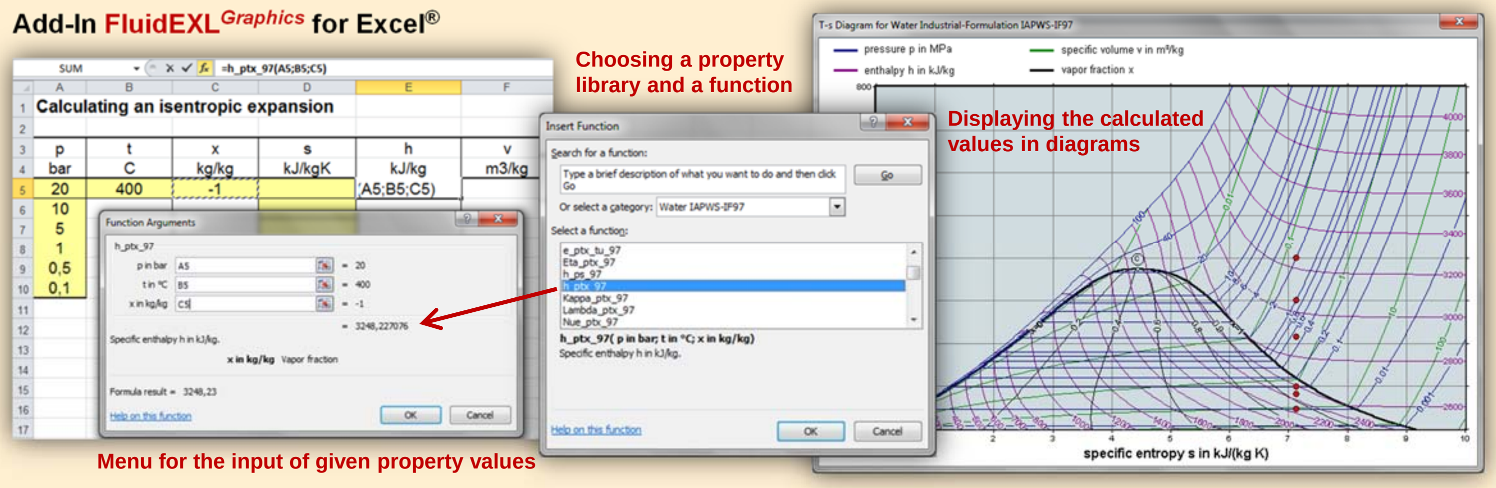
[a] Not all of these property functions are available in all property libraries.

www.thermodynamic-property-libraries.com

ZITTAU/GOERLITZ UNIVERSITY OF APPLIED SCIENCES
Department of Technical Thermodynamics
www.thermodynamics-zittau.de

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

Add-In FluidEXL*Graphics* for Excel®


Choosing a property library and a function

Displaying the calculated values in diagrams

Menu for the input of given property values

=h_ptx_97(A5;B5;C5)

Calculating an isentropic expansion

p	t	x	s	h	v
bar	C	kg/kg	kJ/kgK	kJ/kg	m3/kg
20	400	-1		(A5;B5;C5)	
10					
5					
1					
0,5					
0,1					

Or select a category: Water IAPWS-IF97

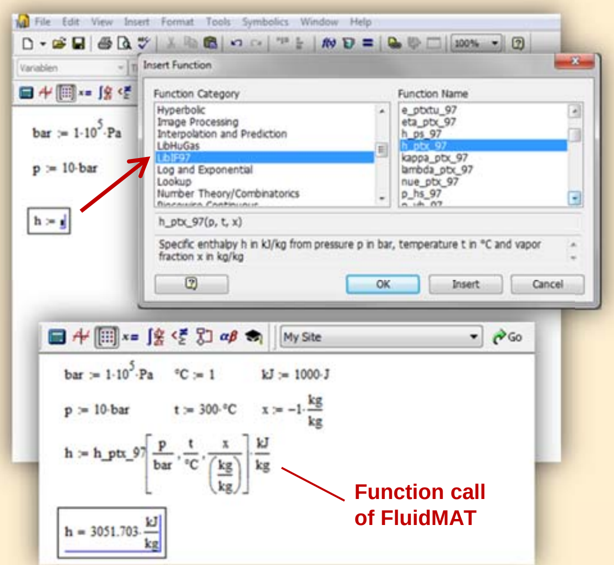
h_ptx_97(p in bar; t in °C; x in kg/kg)
Specific enthalpy h in kJ/kg.

p in bar A5 = 20
t in °C B5 = 400
x in kg/kg C5 = -1
= 3248,227076

Formula result = 3248,23

Add-In FluidMAT for Mathcad®

The property libraries can be used in Mathcad®.


Function call of FluidMAT

h_ptx_97(p, t, x)

Specific enthalpy h in kJ/kg from pressure p in bar, temperature t in °C and vapor fraction x in kg/kg

$bar := 1\cdot10^5\cdot Pa$ $\quad °C := 1 \quad kJ := 1000\cdot J$

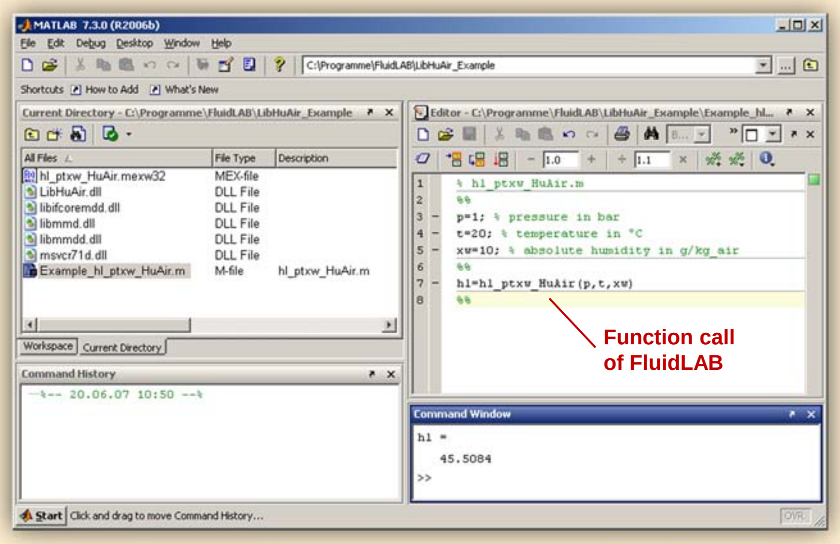
$p := 10\cdot bar \quad t := 300\cdot °C \quad x := -1\cdot\frac{kg}{kg}$

$h := h\_ptx\_97\left(\frac{p}{bar}, \frac{t}{°C}, \frac{x}{\left(\frac{kg}{kg}\right)}\right)\cdot\frac{kJ}{kg}$

$h = 3051.703\cdot\frac{kJ}{kg}$

Add-In FluidLAB for MATLAB®

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


Function call of FluidLAB

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

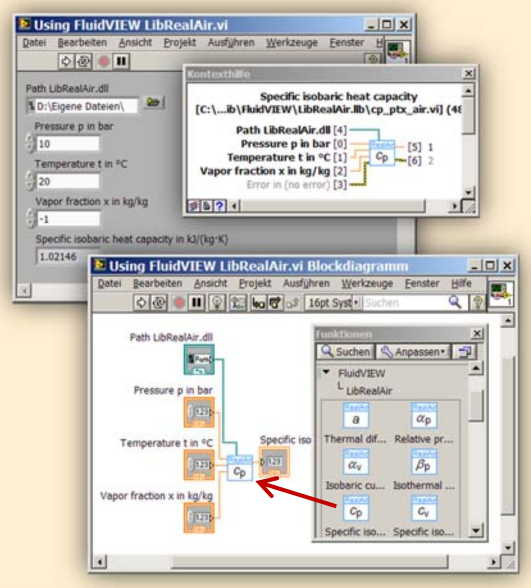
```
hl =

   45.5084

>>
```

Add-On FluidVIEW for LabVIEW®

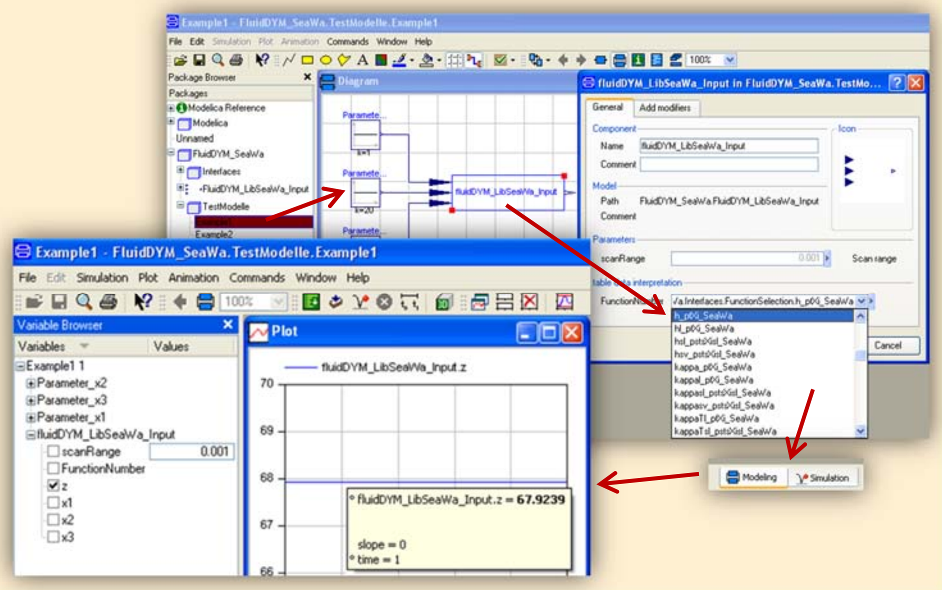
The property functions can be calculated in LabVIEW®.


Specific isobaric heat capacity
Path LibRealAir.dll
Pressure p in bar
Temperature t in °C
Vapor fraction x in kg/kg
Error in (no error)

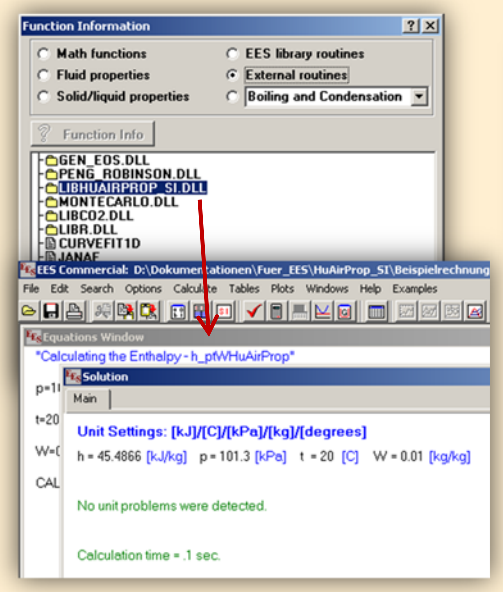
Path LibRealAir.dll: D:\Eigene Dateien\
Pressure p in bar: 10
Temperature t in °C: 20
Vapor fraction x in kg/kg: -1
Specific isobaric heat capacity in kJ/(kg·K): 1.02146

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

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


fluidDYM_LibSeaWa_Input.z = 67.9239
slope = 0
time = 1

Add-In **FluidEES** for Engineering Equation Solver®



"Calculating the Enthalpy - h_ptWHuAirProp"

Unit Settings: [kJ]/[C]/[kPa]/[kg]/[degrees]

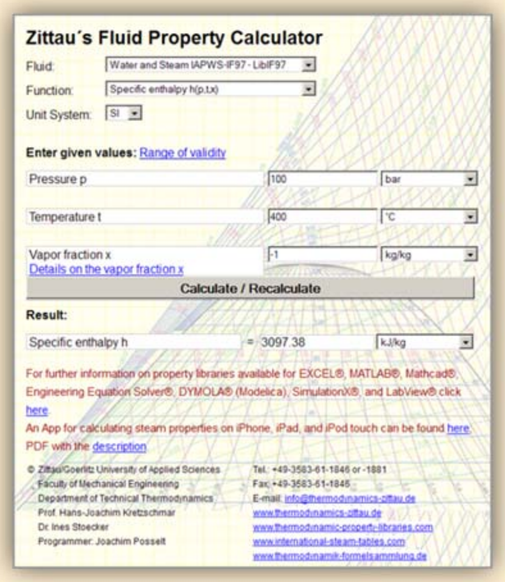
h = 45.4866 [kJ/kg] p = 101.3 [kPa] t = 20 [C] W = 0.01 [kg/kg]

No unit problems were detected.

Calculation time = .1 sec.

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

Online Property Calculator at www.thermodynamics-zittau.de



Fluid: Water and Steam IAPWS-IF97 - LibIF97

Function: Specific enthalpy h(p,t,x)

Unit System: SI

Enter given values: Range of validity

Pressure p: 100 bar

Temperature t: 400 °C

Vapor fraction x: -1 kg/kg

Details on the vapor fraction x

Result:

Specific enthalpy h = 3097.38 kJ/kg

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

An App for calculating steam properties on iPhone, iPad, and iPod touch can be found here.

PDF with the description

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www.thermodynamic-property-libraries.com
www.international-steam-tables.com
www.thermodynamik-formelsammlung.de

Property Software for Pocket Calculators

FluidCasio

fx 9750 G II

CFX 9850
fx-GG20

CFX 9860 G
Graph 85

ALGEBRA
FX 2.0

FluidHP

HP 48

HP 49

FluidTI

TI Nspire CX CAS
TI Nspire CAS

TI 83
TI 84
TI 89

TI Voyage 200

TI 92

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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.

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

www.thermodynamic-property-libraries.com

5. References

[1] Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam IAPWS-IF97.
IAPWS Sekretariat, Dooley, B, EPRI, Palo Alto CA (1997)

[2] Wagner, W.; Kruse, A.:
Zustandsgrößen von Wasser und Wasserdampf.
Springer-Verlag, Berlin (1998)

[3] Wagner, W.; Cooper, J.R.; Dittmann, A.; Kijima, J.; Kretzschmar, H.-J.; Kruse, A.; Mareš, R.; Oguchi, K.; Sato, H.; Stöcker, I.; Šifner, O.; Takaishi, Y.; Tanishita, I.; Trübenbach, J.; Willkommen, Th.:
The IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam.
ASME Journal of Eng. for Gas Turbines and Power 122 (2000) Nr. 1, S. 150-182

[4] Kretzschmar, H.-J.; Stöcker, I.; Klinger, J.; Dittmann, A.:
Calculation of Thermodynamic Derivatives for Water and Steam Using the New Industrial Formulation IAPWS-IF97.
in: Steam, Water and Hydrothermal Systems: Physics and Chemistry Meeting the Needs of Industry, Proceedings of the 13th International Conference on the Properties of Water and Steam, Eds. P.G. Hill et al., NRC Press, Ottawa, 2000

[5] Kretzschmar, H.-J.:
Mollier h,s-Diagramm.
Springer-Verlag, Berlin (1998)

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FZR Forschungszentrum, Rossendorf/Dresden	10/2003
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