



Property Library for Standard Dry Air

**FluidDYM
with LibRealAir
for DYMOLA®**

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Property Software for Standard Dry Air LibRealAir

FluidDYM for DYMOLA®

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0 Package Contents

0.1 Zip file for 32-bit DYMOLA®

"CD_FluidDYM_LibCO2.zip"

Including the following files:

| | |
|---------------------------|---|
| FluidDYM_LibCO2_Setup.exe | Installation Program for the FluidDYM Add-In for use in DYMOLA® |
| LibCO2.dll | Dynamic Link Library f |
| FluidDYM_LibCO2_Docu.pdf | User's Guide |
| Folder "Users_Guide" | Includes the complete User's Guide |

0.2 Zip file for 64-bit MATLAB®

"CD_FluidDYM_LibCO2_64.zip"

Including the following files and folders:

Files:

| | |
|--------------------------|---|
| Setup.exe | - Self-extracting and self-installing program for FluidLAB |
| FluidDYM_LibCO2_64.msi | - Installation program for the FluidLAB Add-On for use in MATLAB® |
| LibCO2.dll | - Dynamic Link Library for carbon dioxide for use in MATLAB® |
| FluidLAB_LibCO2_Docu.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

1.1 Range of Validity

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

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

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

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

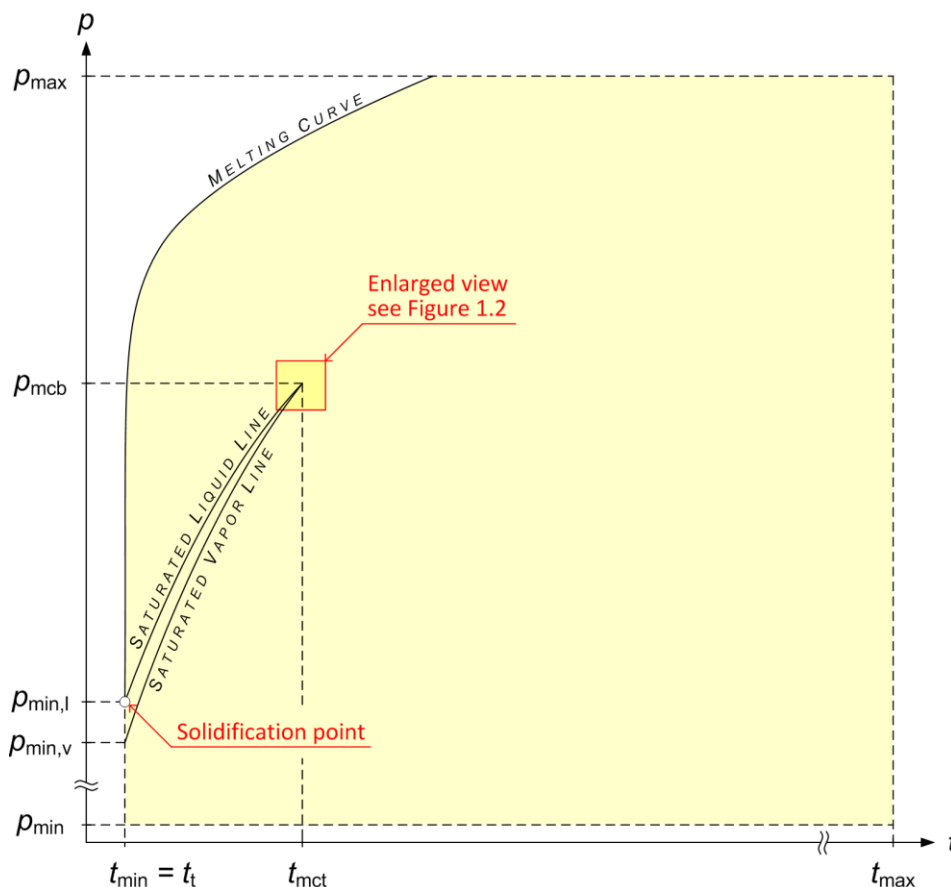


Figure 1.1: Entire range of validity in an $\lg p, \lg t$ – diagram
(see Figure 1.2 for an enlarged view of the critical region phase boundaries)

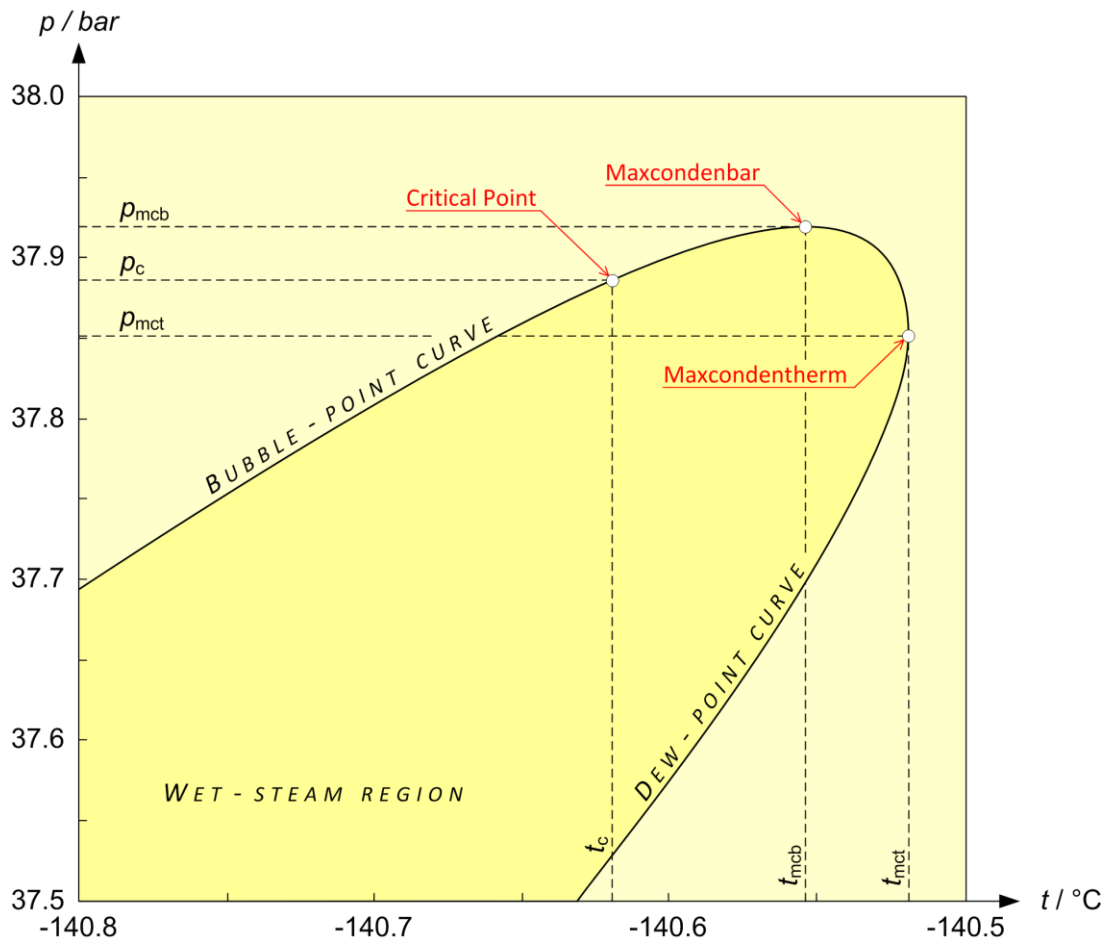


Figure 1.2: Enlarged view of the critical region phase boundaries in an p, t -diagram

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

Table 1.2: Range of validity

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

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

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

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

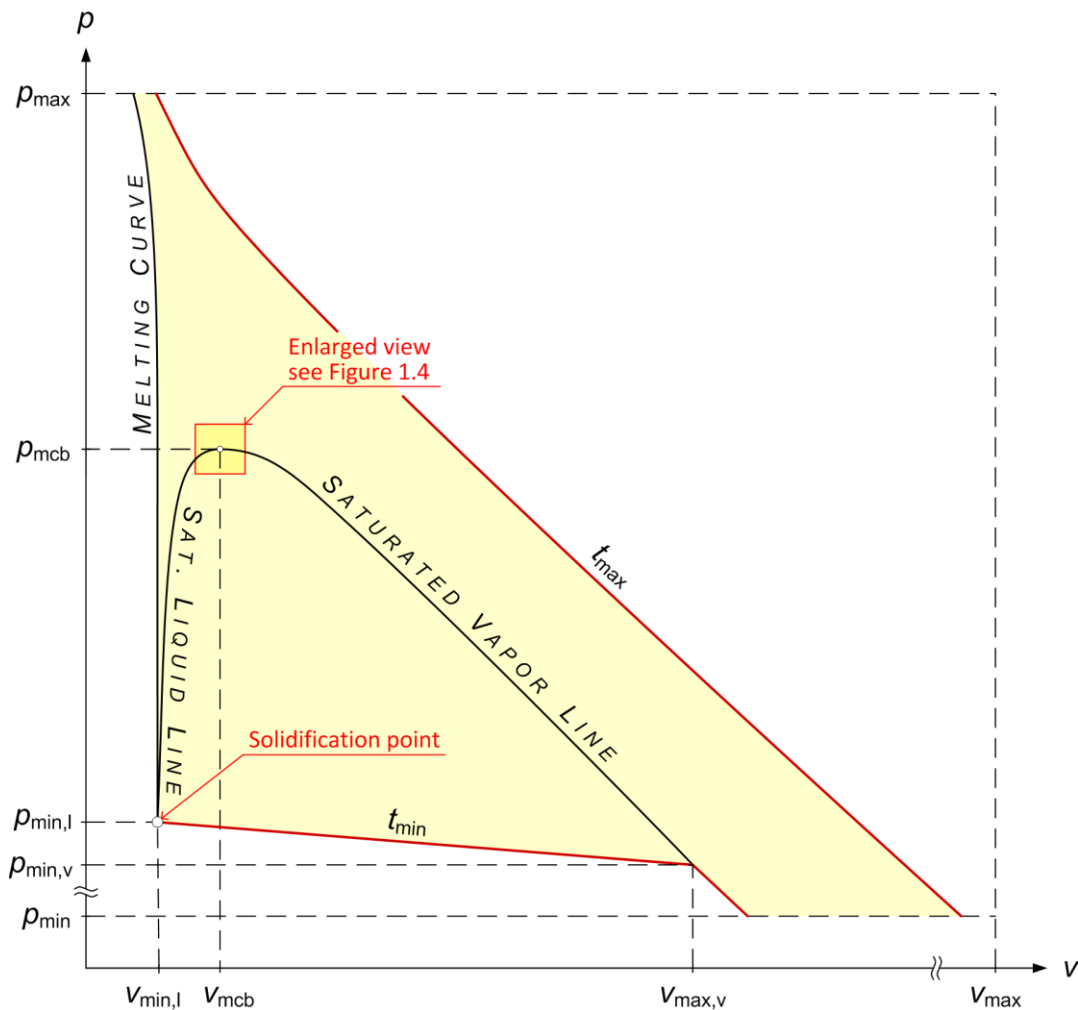


Figure 1.3: Entire range of validity in an $\lg p, \lg v$ - diagram

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

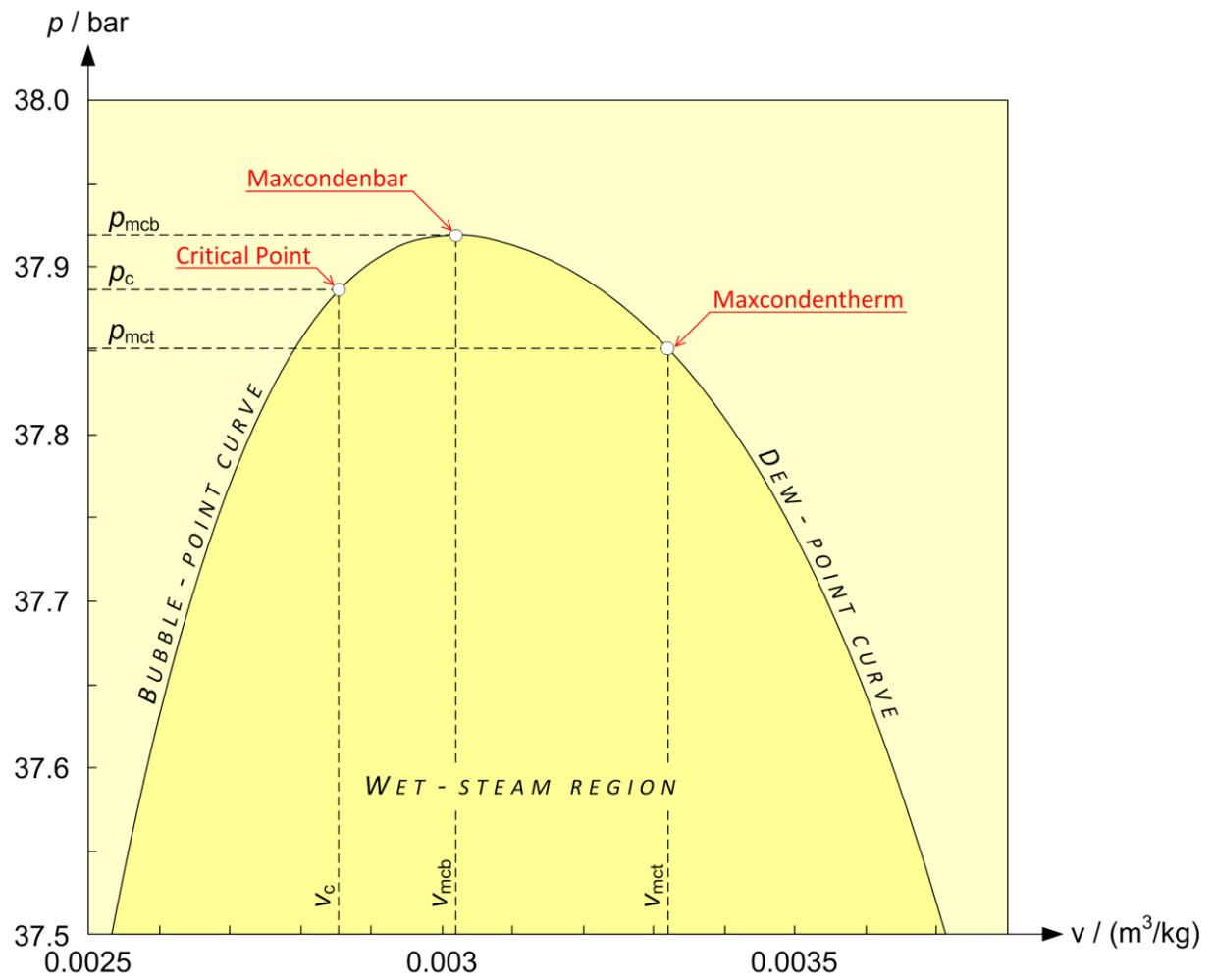


Figure 1.4: Enlarged view of the critical region phase boundaries in an p, v -diagram

1.2 Functions

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

Units:

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

Range of validity of LibRealAir:

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

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

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

Single phase region

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

Wet steam region

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

Boundaries for wet steam region

The boundaries for the wet steam region are

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

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

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

Note:

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

1.3 Thermodynamic Diagrams

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

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

2. Application of FluidDYM in Dymola®

The FluidDYM Add-In has been developed to calculate thermodynamic properties in Dymola® more conveniently. Within Dymola® it enables the direct call of functions relating to standard dry air from the LibRealAir property library. The 32-bit version of FluidDYM LibRealAir runs on both the 32-bit and 64-bit version of DYMOLA®.

2.1 Installing FluidDYM

In this section, the installation of FluidDYM and LibRealAir is described.

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_FluidDYM_LibRealAir.zip," (32-bit version)

"CD_FluidDYM_LibRealAir_64.zip," (64-bit version)

you will see the folder

CD_FluidDYM_LibRealAir (32-bit version)

CD_FluidDYM_LibRealAir_64 (64-bit version)

in your Windows Explorer®, Norton Commander® etc.

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

Within the folder for the **32-bit version** you will see the following files

FluidDYM_LibRealAir_Users_Guide.pdf

FluidDYM_LibRealAir_Setup.exe (32-bit version)

and the folder

"Users_Guide."

Within the folder for the **64-bit version** you will see the following files

FluidDYM_LibRealAir_Users_Guide.pdf

FluidDYM_LibRealAir_64_Setup.msi

Setup.exe

and the folder

"Users_Guide."

In order to run the installation of **32-bit** FluidDYM including the LibRealAir property library double-click the file

FluidDYM_LibRealAir_Setup.exe.

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

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

C:\Program Files\FluidDYM\LibRealAir.

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

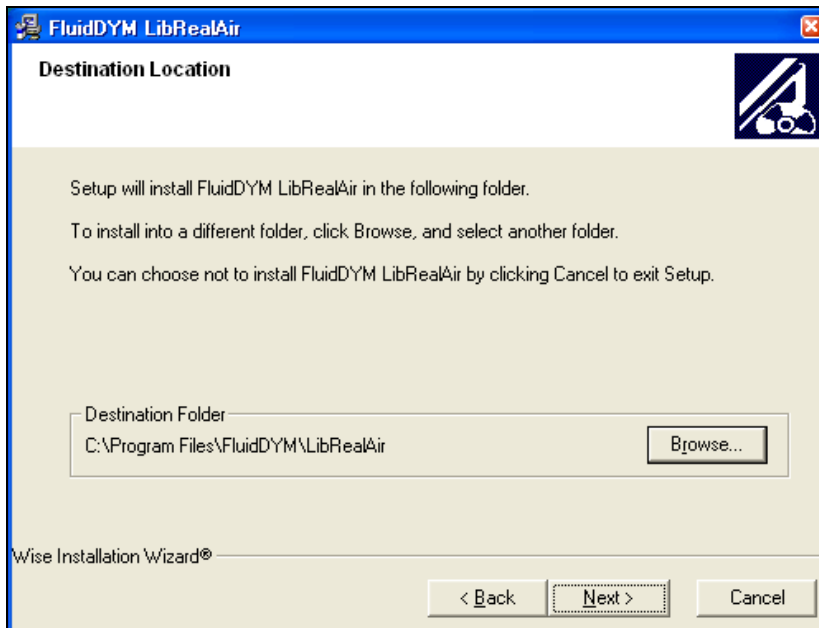


Figure 2.1: Dialog window "Destination Location"

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

After FluidDYM has been installed, you will see the sentence "FluidDYM LibRealAir has been successfully installed." Confirm this by clicking the "Finish" button.

The installation of FluidDYM 32-bit has been completed.

In order to run the installation of **64-bit** FluidDYM including the LibRealAir property library double-click the file

Setup.exe.

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

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

C:\Users\...\Documents\FuildDYM_64\LibRealAir.

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

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

After FluidDYM has been installed, you will see the sentence "FluidDYM LibRealAir has been successfully installed." Confirm this by clicking the "Finish" button.

The installation of FluidDYM 64-bit has been completed. The installation program has copied the following files into the directory

C:\Program Files\FluidDYM\LibRealAir (for English version of Windows)
 C:\Programme\FluidDYM\LibRealAir (for German version of Windows):

- Dynamic link library "LibRealAir.dll"
- Folder "Users_Guide"
- Link up Dynamic link library "LibRealAir_Dymola.dll" and other necessary system DLL files
- Library File "LibRealAir_Dymola.lib"
- Header File "LibRealAir_Dymola.h" and other necessary system DLL files
- Modelica File "FluidDYM_LibRealAir.mo", includes the following property functions:

| | |
|-----------------|-------------|
| a_ptx_air | psl_t_air |
| alphap_ptx_air | psv_t_air |
| alphav_ptx_air | rho_ptx_air |
| betap_ptx_air | s_ptx_air |
| cp_ptx_air | tmel_p_air |
| cv_ptx_air | t_ph_air |
| eta_ptx_air | t_ps_air |
| h_ptx_air | tsl_p_air |
| kappa_ptx_air | tsv_p_air |
| kappat_ptx_air | u_ptx_air |
| lambda_ptx_air | v_ptx_air |
| nu_ptx_air | w_ptx_air |
| pmel_t_air | x_ph_air |
| prandtl_ptx_air | x_ps_air |

Now, you have to overwrite the file "LibRealAir.dll" and the folder "Users_Guide" in your LibRealAir directory with the files of the same names provided in your CD folder with FluidDYM.

To do this, open the CD folder "CD_FluidDYM_LibRealAir" in "My Computer" and click on the file "LibRealAir.dll" in order to highlight it. Hold Ctrl and click on the folder "Users_Guide" to mark it as well.

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

Now, open your LibRealAir directory (the standard being

C:\Program Files\FluidDYM\LibRealAir (for English version of Windows)
 C:\Programme\FluidDYM\LibRealAir (for German version of Windows))

and insert the "LibRealAir.dll" and the "Users_Guide" folder by clicking the "Edit" menu in your Explorer and then select "Paste".

Answer the question whether you want to replace the files by clicking the "Yes" button. Now, you have overwritten the file "LibRealAir.dll" and the folder "Users_Guide" successfully.

2.2 Licensing the LibRealAir Property Library

The licensing procedure has to be carried out when Dymola® is running and a model simulation starts. In this case, you will see the "License Information" window (see Figure 2.2).

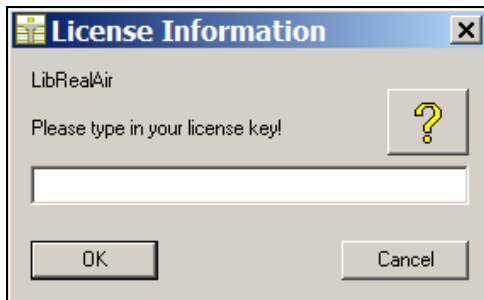


Figure 2.2: "License Information" window

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

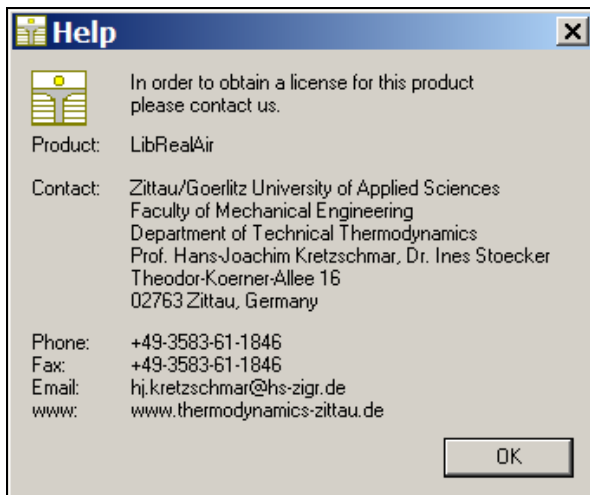


Figure 2.3: "Help" window

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

The "License Information" window will appear every time you start Dymola.

Should you not wish to license the LibRealAir property library, you have to uninstall the FluidDYM LibRealAir property library following the description in section 2.4 of this User's Guide.

2.3 Example: Calculation of $h = f(p, t, x)$

Now we will calculate, step by step, the specific enthalpy h of standard dry air as a function of pressure p , temperature t and vapor fraction x , using Dymola®.

Please carry out the following instructions:

- Start Windows Explorer®, Total Commander®, My Computer or another file manager program.
The description here refers to Windows Explorer.
- Your Windows Explorer should be set to Details for a better view. Click the "View" (Ansicht) button and select "Details".
- Switch into the program directory of FluidDYM in which you will find the folder "\LibRealAir"; the standard location is:

C:\Program Files\FluidDYM\LibRealAir (for English version of Windows)
 C:\Programme\FluidDYM\LibRealAir (for German version of Windows))
- Create the folder "\LibRealAir_Example" by clicking on "File" in the Explorer menu, then "New" in the menu which appears, and then selecting "Folder". Name the new folder "\LibRealAir_Example".
- You will see the following window:

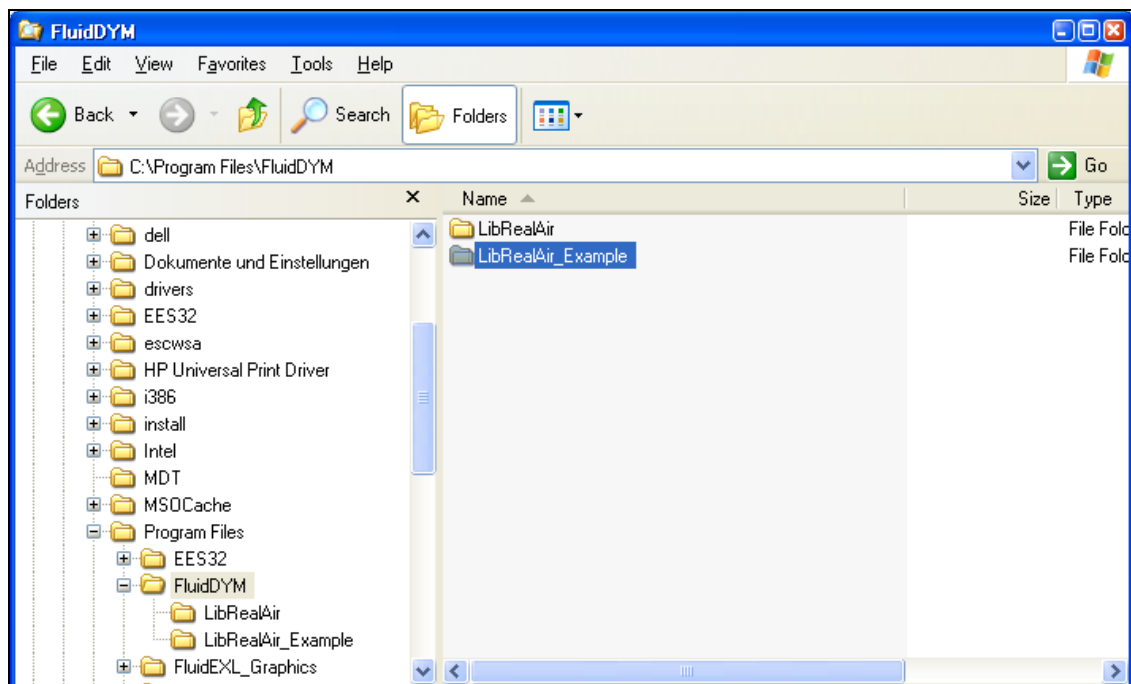


Figure 2.4: "LibRealAir_Example" and "LibRealAir" directory in FluidDYM

- Switch into the directory "\LibRealAir" within "\FluidDYM", the standard being:

C:\Program Files\FluidDYM\LibRealAir (for English version of Windows)
 C:\Programme\FluidDYM\LibRealAir (for German version of Windows)).

- You will see the following window:

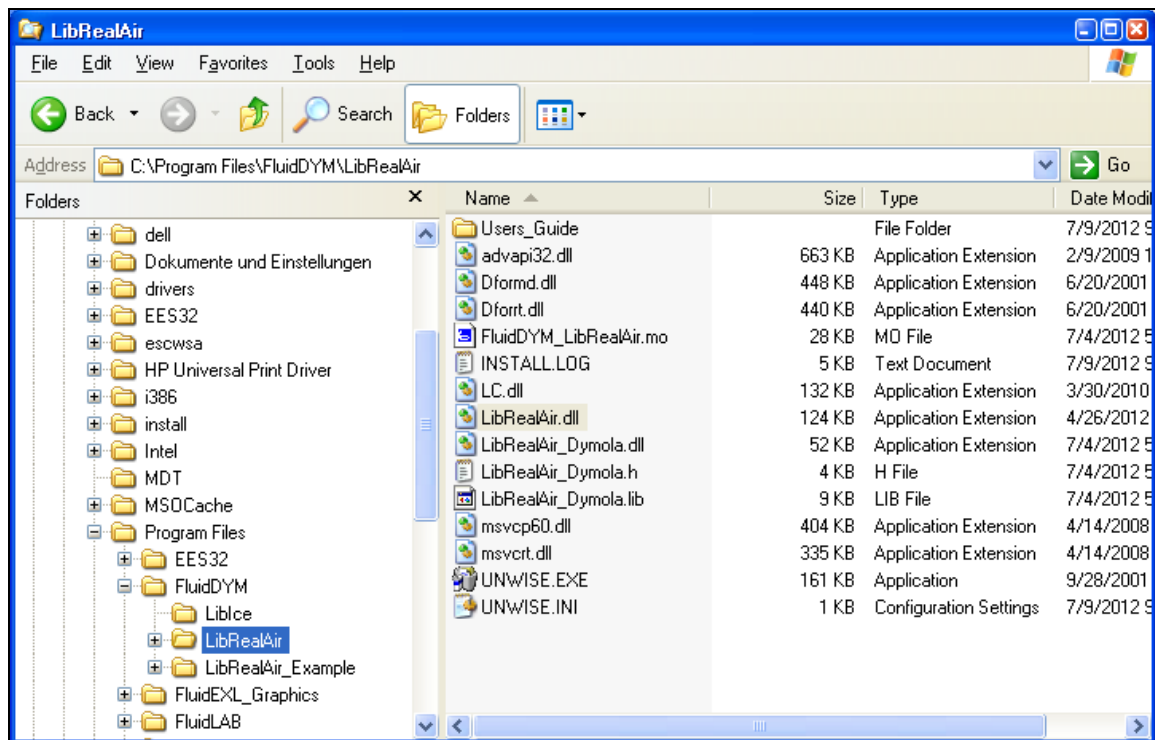


Figure 2.5: "LibRealAir" directory including installed files

In order to calculate the function $h = f(p, t, x)$, the following files are necessary. Copy them into the directory

C:\Program Files\FluidDYM\LibRealAir (for English version of Windows)
 C:\Programme\FluidDYM\LibRealAir (for German version of Windows)):

- "advapi32.dll"
- "Dformd.dll"
- "Dforrt.dll"
- "FluidDYM_LibRealAir.mo"
- "LC.dll"
- "LibRealAir.dll"
- "LibRealAir_Dymola.dll"
- "LibRealAir_Dymola.h"
- "LibRealAir_Dymola.lib"
- "msvc60.dll"
- "Msvcrt.dll"
- the folder "Users_Guide"

- Mark up these files, then click "Edit" in the upper menu bar and select "Copy".

- Switch into the directory

C:\Program Files\FluidDYM\LibRealAir_Example (for English version of Windows)
 C:\Programme\FluidDYM\LibRealAir_Example (for German version of Windows)),

click "Edit" and then "Paste".

- You will see the following window:

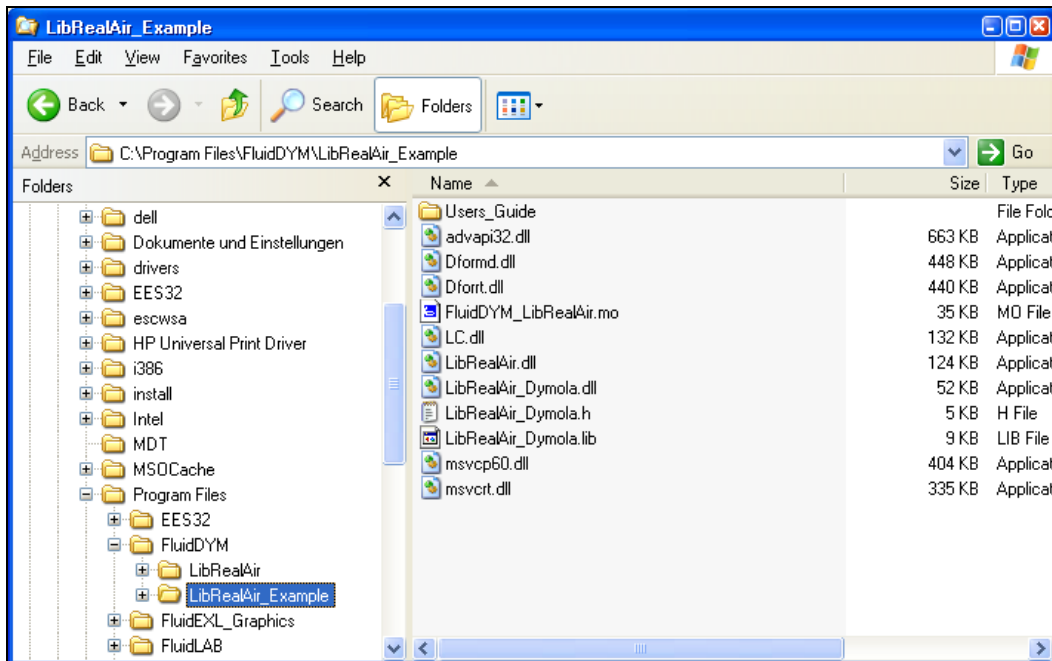


Figure 2.6: "LibRealAir_Example" directory including the newly-copied files

- Start Dymola®.
- Now click on "File" in the Dymola® menu bar and select "Open" (see Figure 2.7).

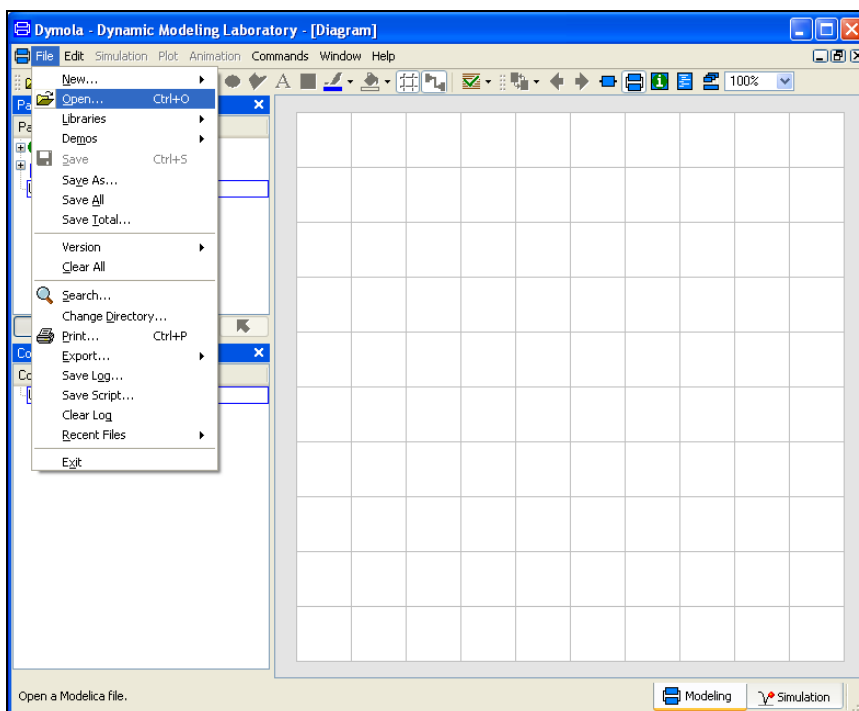


Figure 2.7: Selecting the menu entry "Open"

- Search and click on the directory
 "C:\Program Files\FluidDYM\LibRealAir_Example" (for English version of Windows)
 "C:\Programme\FluidDYM\LibRealAir_Example" (for German version of Windows)
 in the appearing menu.
- Select the "FluidDYM_LibRealAir.mo" file and click on the "Open" button (see Figure 2.8).

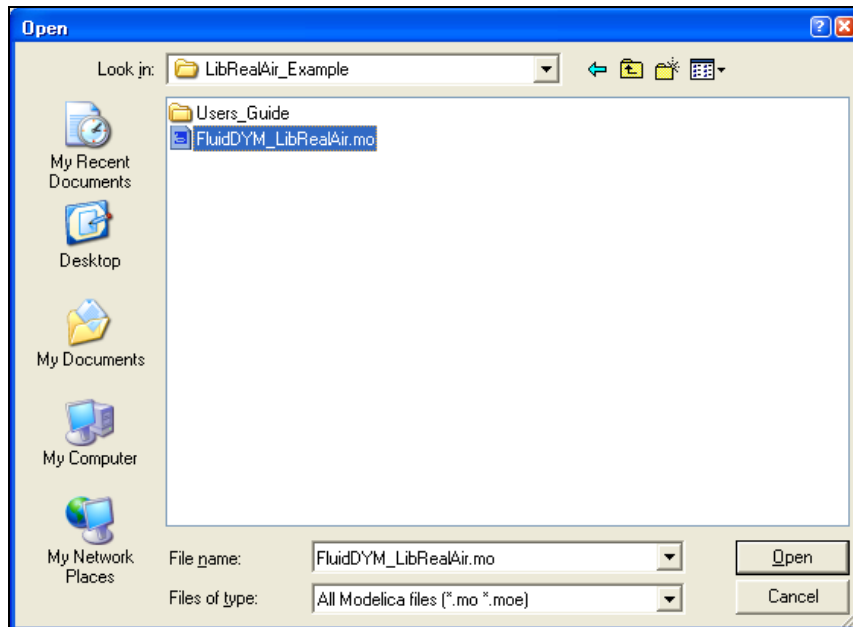


Figure 2.8: Selecting the "FluidDYM_LibRealAir.mo" file

- The library will be loaded by Dymola which may take a few seconds.
- After Dymola has finished loading the LibRealAir library, you will see the window shown in Figure 2.9.

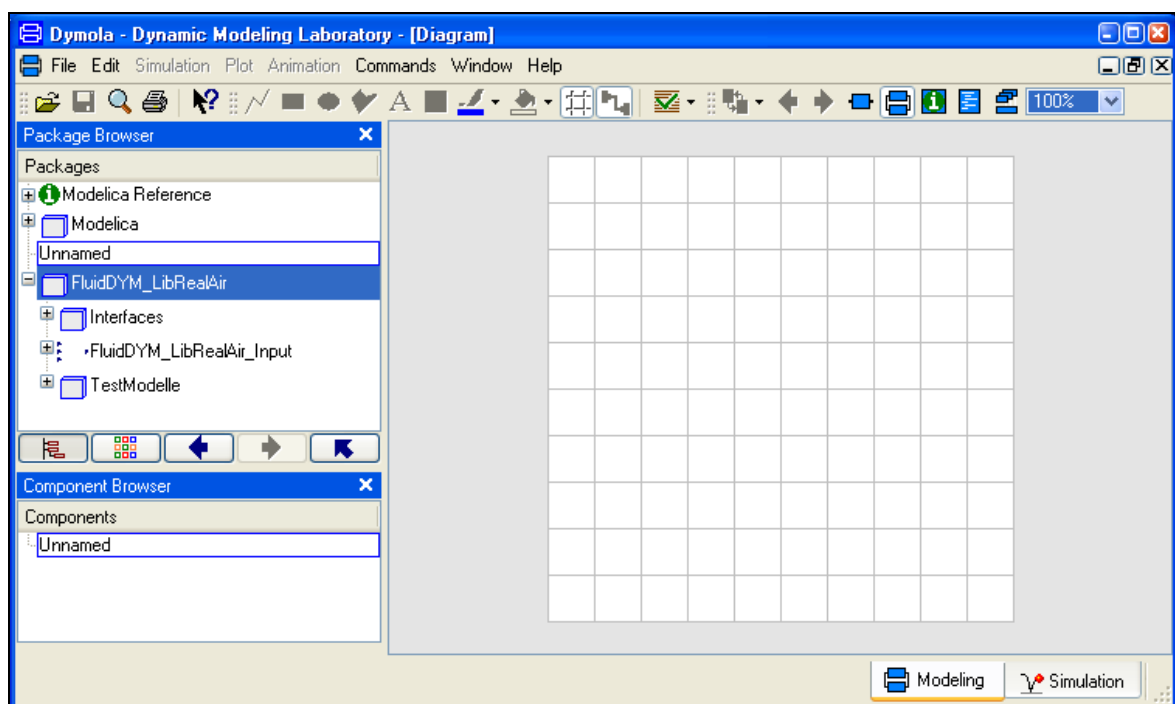


Figure 2.9: Dymola window after loading the "LibRealAir" library

- Now, click on "File" in the Dymola menu bar and select "Change Directory..." in order to open the folder "\\LibRealAir_Example" (see Figure 2.10).

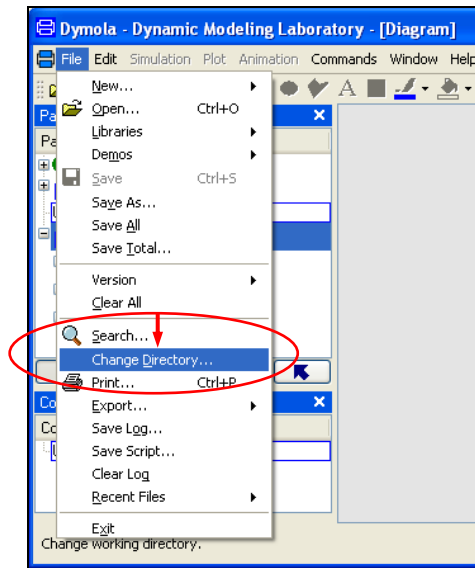


Figure 2.10: Selecting the menu entry "Change Directory..."

- Search and click on the directory
 - "C:\Program Files\FluidDYM\LibRealAir_Example" (for English version of Windows)
 - "C:\Programme\FluidDYM\LibRealAir_Example" (for German version of Windows)
 in the menu that appears (see Figure 2.11).

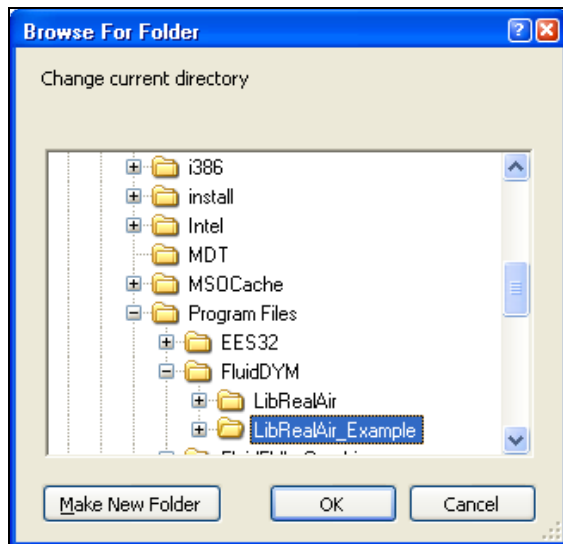



Figure 2.11: Selecting the "LibRealAir_Example" directory

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

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

- Click on the Dymola-Block "Testmodelle," which can be found in the FluidDYM_LibRealAir package in the "Package Browser" on the left hand side of the Dymola window. Here choose Example1 by double-clicking on it.

- Now click on the  button in the Dymola menu bar in order to switch to the Diagram Mode. You will see the following window:

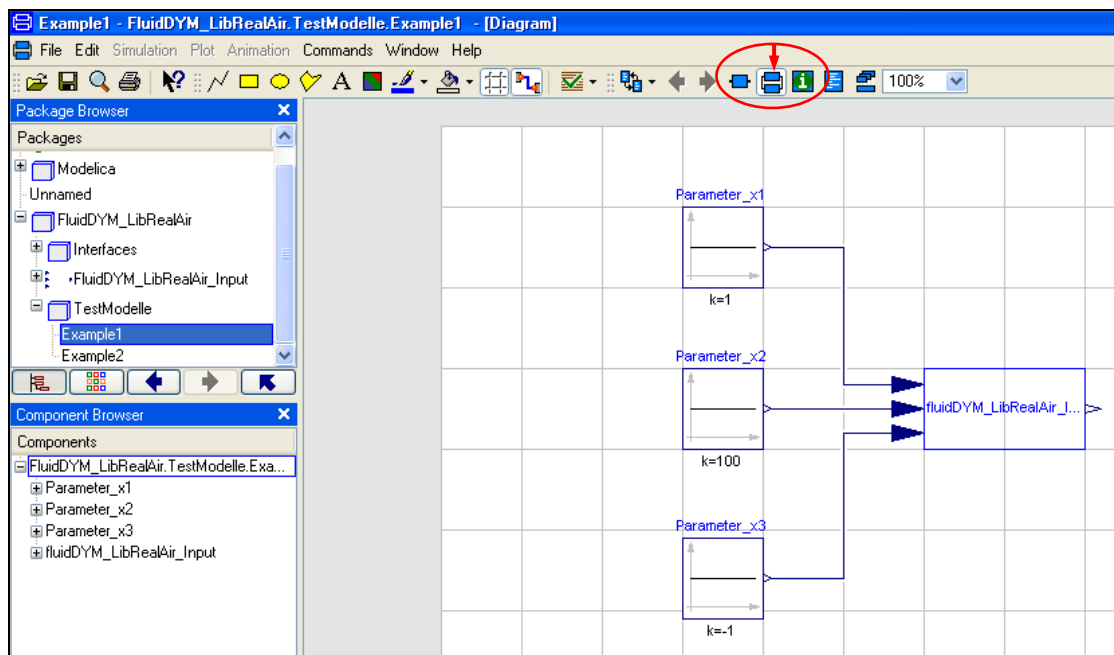


Figure 2.12: Dymola in Diagram Mode

- Now double-click on the "fluidDYM_LibRealAir_Input" block on the right hand side of the Dymola window.
- Search and click the "h_ptx_air" function next to "Function Number" in the menu that appears (see Figure 2.13).

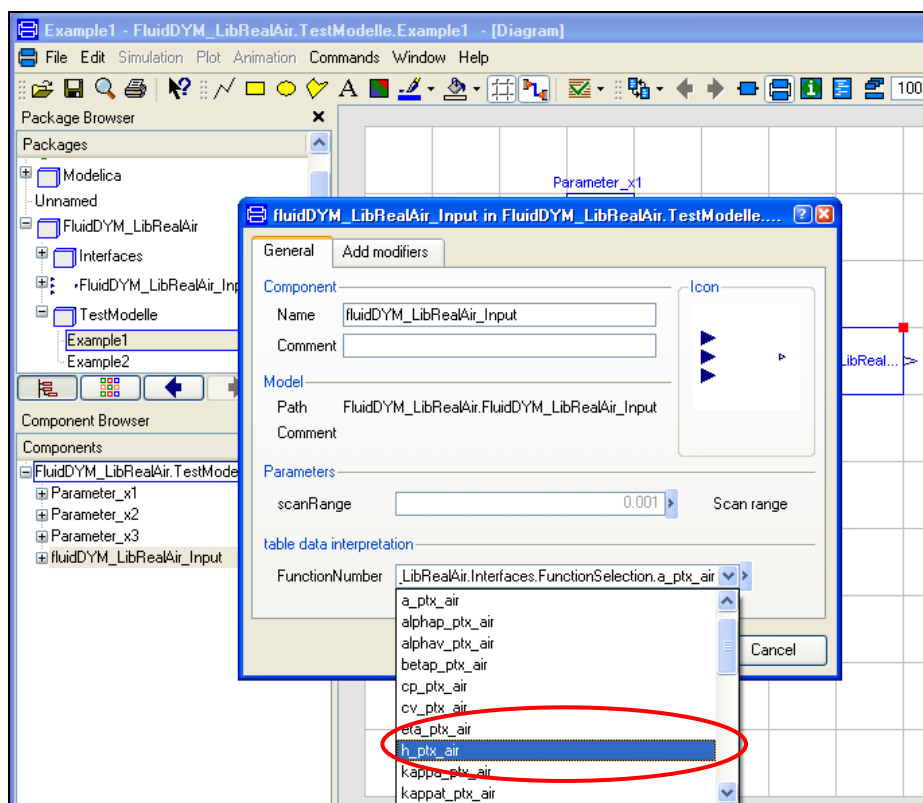


Figure 2.13: Choosing the function "h_ptx_air"

- You can set the scan range (how many times the property will be calculated per second) next to "scanRange". The preset value 0.001 means that the property will be calculated 1000 times per second. E.g. if you enter the value 1, the property will be calculated once per second. Do not change the preset value of 0.001 for our example calculation.

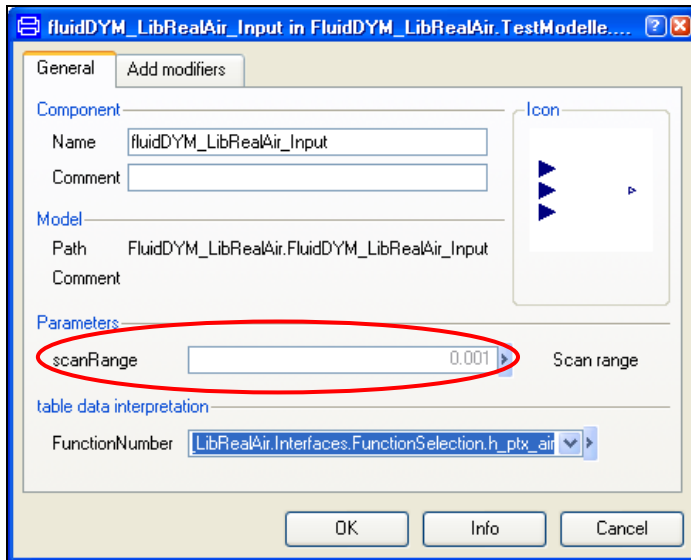


Figure 2.14: Setting the scan range

- Now we will configure the input parameters x_1 to x_3 , where x_1 represents the pressure p , x_2 represents the temperature t , and x_3 represents the vapor fraction x . When calculating a function with only one or two input parameters, the other input parameter(s) will not be defined.
- First, double click on the "Parameter_x1" block which represents the first input parameter, here the pressure p in bar.

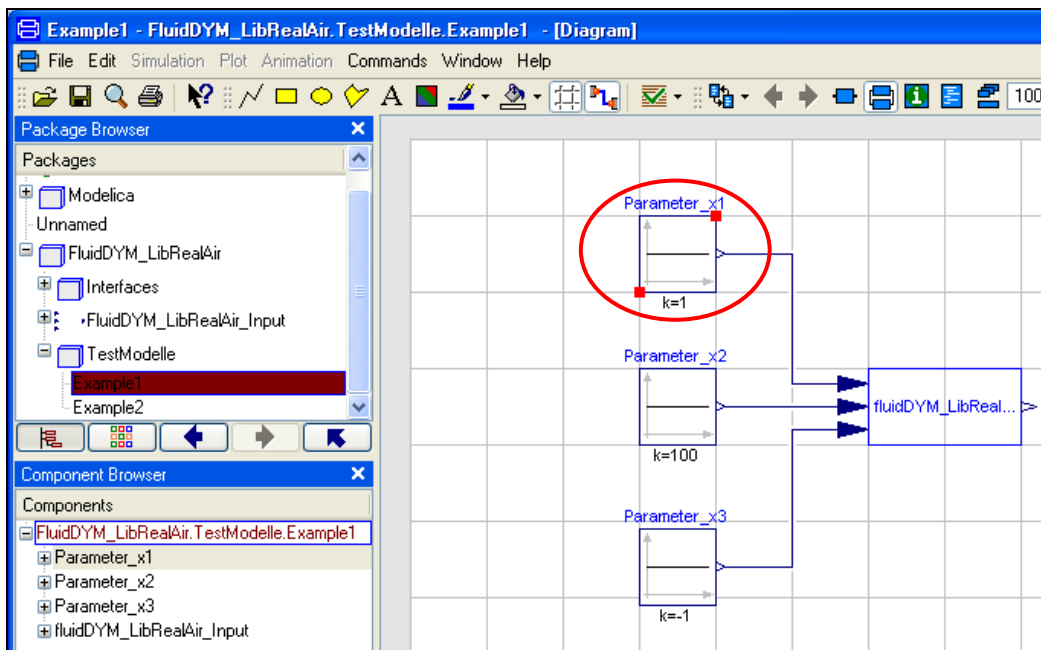


Figure 2.15: "Parameter_x1" block in Dymola

- Enter the value 10 on the line next to "k" in the dialog window which appears (Range of validity corresponding to *LEMMON*: $p = 0.00001 \dots 20000$ bar)

- Then click the "OK" button (see Figure 2.16).

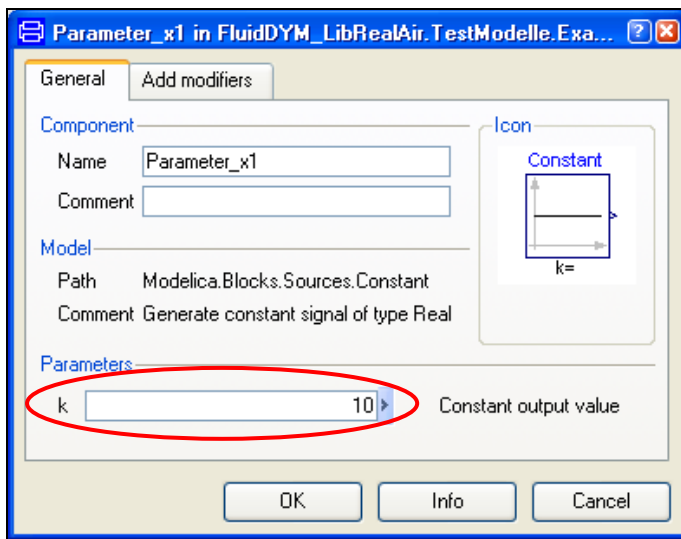


Figure 2.16: Entering the value for the pressure p

- Now, double click on the "Parameter_x2" block which represents the second input parameter, here the temperature t in $^{\circ}\text{C}$.
- Enter the value 20 on the line next to "k" in the dialog window which appears
(Range of validity corresponding to *LEMMON*: $t = -213.4 \dots 1726.85^{\circ}\text{C}$)
- Then click the "OK" button (see Figure 2.17).

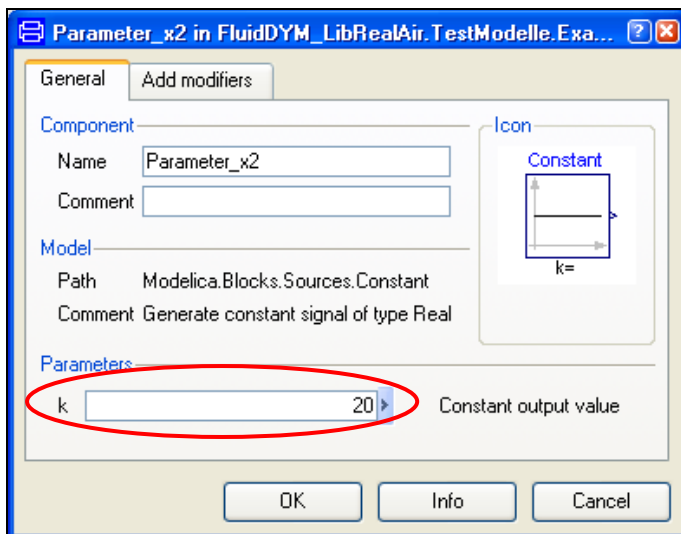


Figure 2.17: Entering the value for the temperature t

- Now, double click on the "Parameter_x3" block which represents the third input parameter, here the vapor fraction x in 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:

Single-phase region

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

Wet-steam region

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

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

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

- Enter the value -1 on the line next to "k" in the dialog window which appears
- Then click the "OK" button (see Figure 2.18)

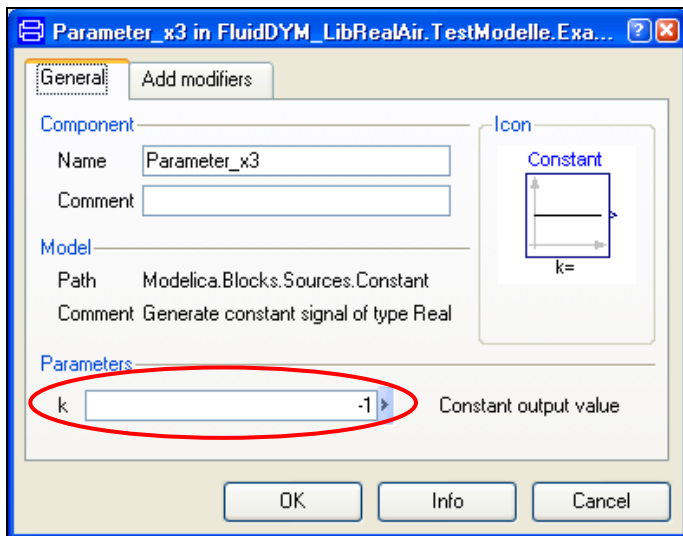
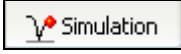


Figure 2.18: Entering the value for the vapor fraction x

All parameters have now been defined.

- Click on the  button in the lower right area of Dymola in order to switch into the "Simulation Mode".

In Figure 2.19 you can see how the Dymola "Simulation Mode" looks like.

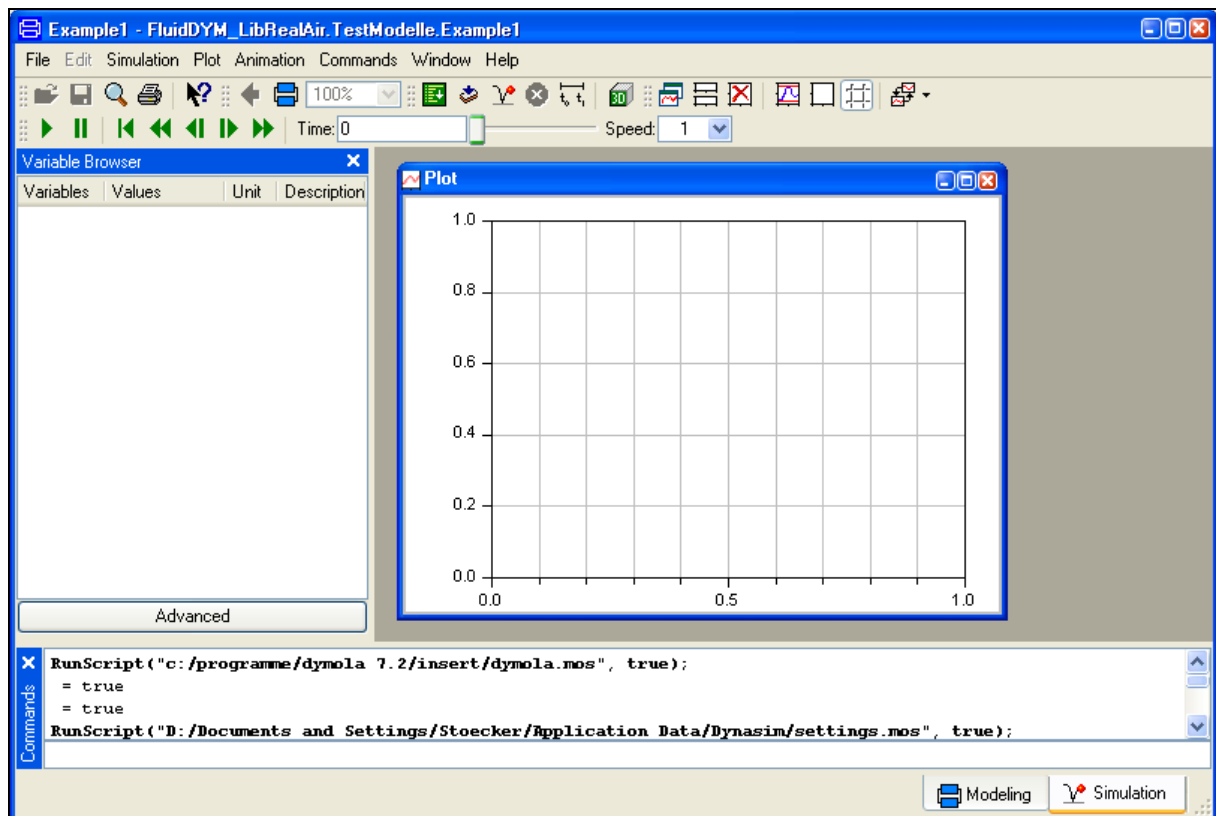



Figure 2.19: "Simulation Mode" window

- Click on the "Simulate" Button  in the Dymola menu bar to start the calculation. Now the model will be compiled and the simulation started.
- Afterwards you will see the following entries within the "Variable Browser" window in Dymola (see Figure 2.20):

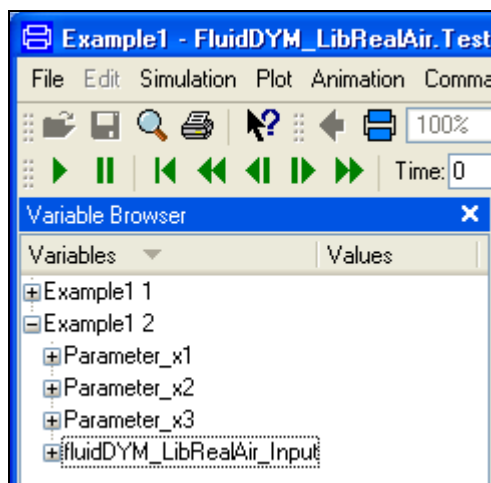


Figure 2.20: "Variable Browser" with new entries

IMPORTANT NOTICE:

Per default the 64-bit version of Dymola creates a 32-bit simulation process. If you want to create a 64-bit simulation process you must have installed the 64-bit version of FluidDYM and you now need to enter the following command into the command line of Dymola and confirm your entry by pressing the Enter key:

"Advanced.CompileWith64=2"

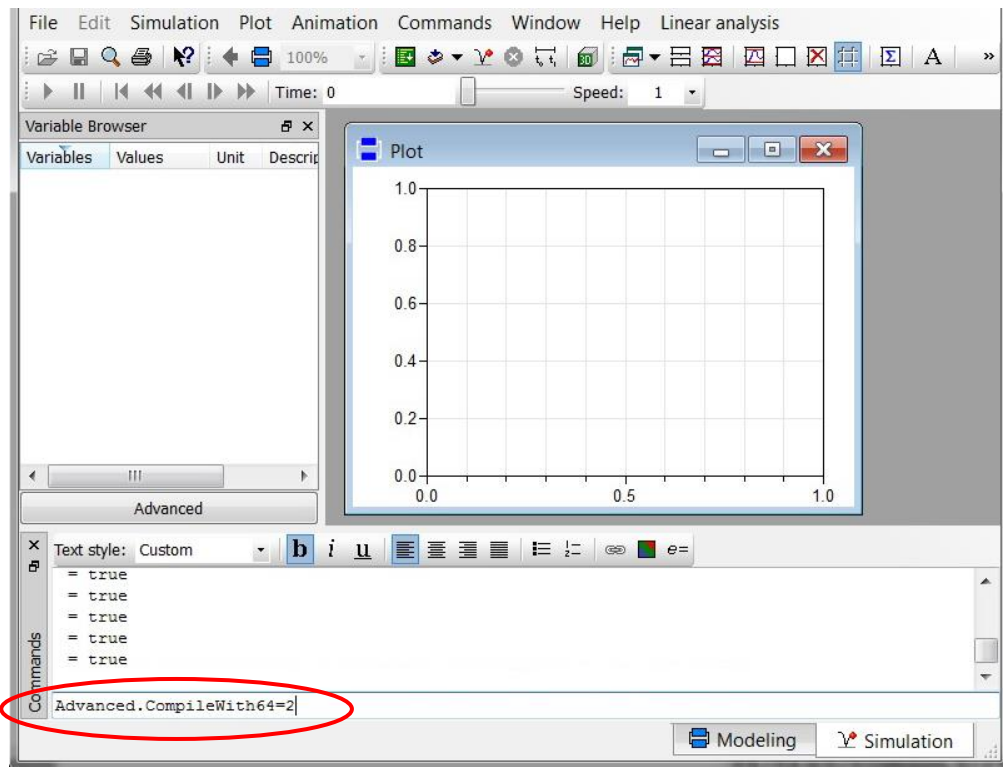



Figure 2.21: "Simulation Mode" window with 64-bit command

Now, your 64-bit Dymola creates 64-bit simulation processes with FluidDYM.

Please note that if you restart Dymola and want to create 64-bit simulation processes again, you will always have to enter this command anew.

For further information concerning this matter, please see the Dymola user's guide.

- By clicking on the "New Plot Window" button , a new diagram window will be opened.
- Click on "fluidDYM_LibRealAir_Input" within the "Variable Browser"; then you will see the input and output parameters "scanRange", "FunctionNumber", "z", "x1", "x2" and "x3" (see Figure 2.22).

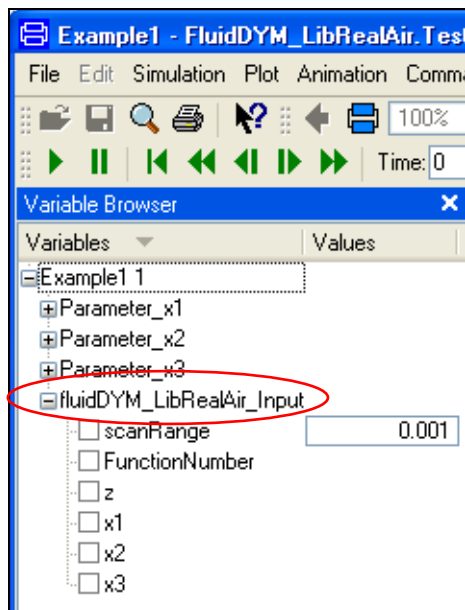


Figure 2.22: Parameters of "fluidDYM_LibRealAir_Input"

- After clicking on the output parameter "z", the calculated property will be represented graphically in the "PlotWindow".
- Move the mouse over the curve to see the result of the simulation at a specific point in time (see Figure 2.23).

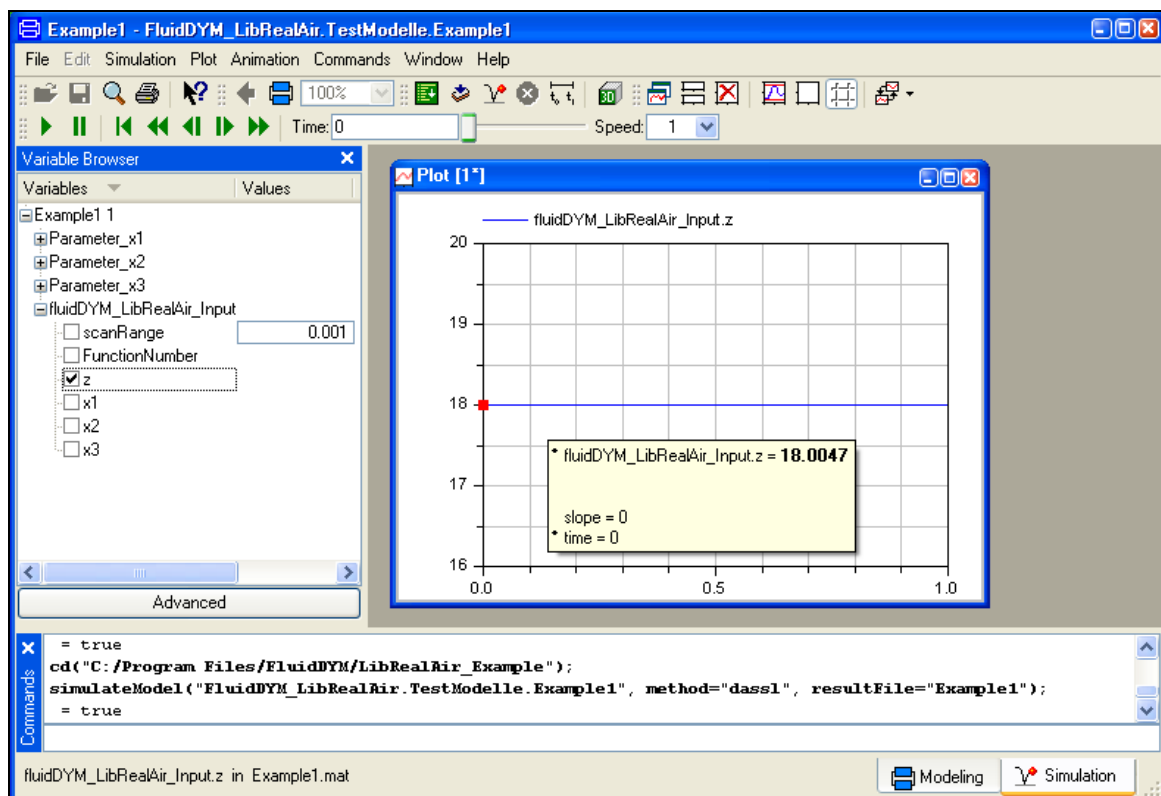



Figure 2.23: "DiagramWindow" showing the result

The result for h appears in the "DiagramWindow"


⇒ The result in our sample calculation here is: " $h = 18.0047$ ".

The corresponding unit is kJ/kg (see table of the property functions in Chapter 1).


- Now click on the Modeling button  in the lower right area of Dymola in order to switch into the "Modeling Mode". Here you can arbitrarily change the values for p , t , and x in the appropriate blocks.

Help Systems in Dymola®

Dymola® provides detailed help functions. You can choose to read the program documentation or the help page of a specific property function, as desired.

Within the "Modeling-Mode"  the help may be accessed via two different steps.

First we will show you how to access the program documentation of the property library.

- Make sure Dymola is set to the "Modeling-Mode".
- Now click the  button in the Dymola menu bar to choose the "Documentation Mode".
- Double-click on the "FluidDYM_LibRealAir" Block at the left and then click on "Users_Guide" (see Figure 2.24).

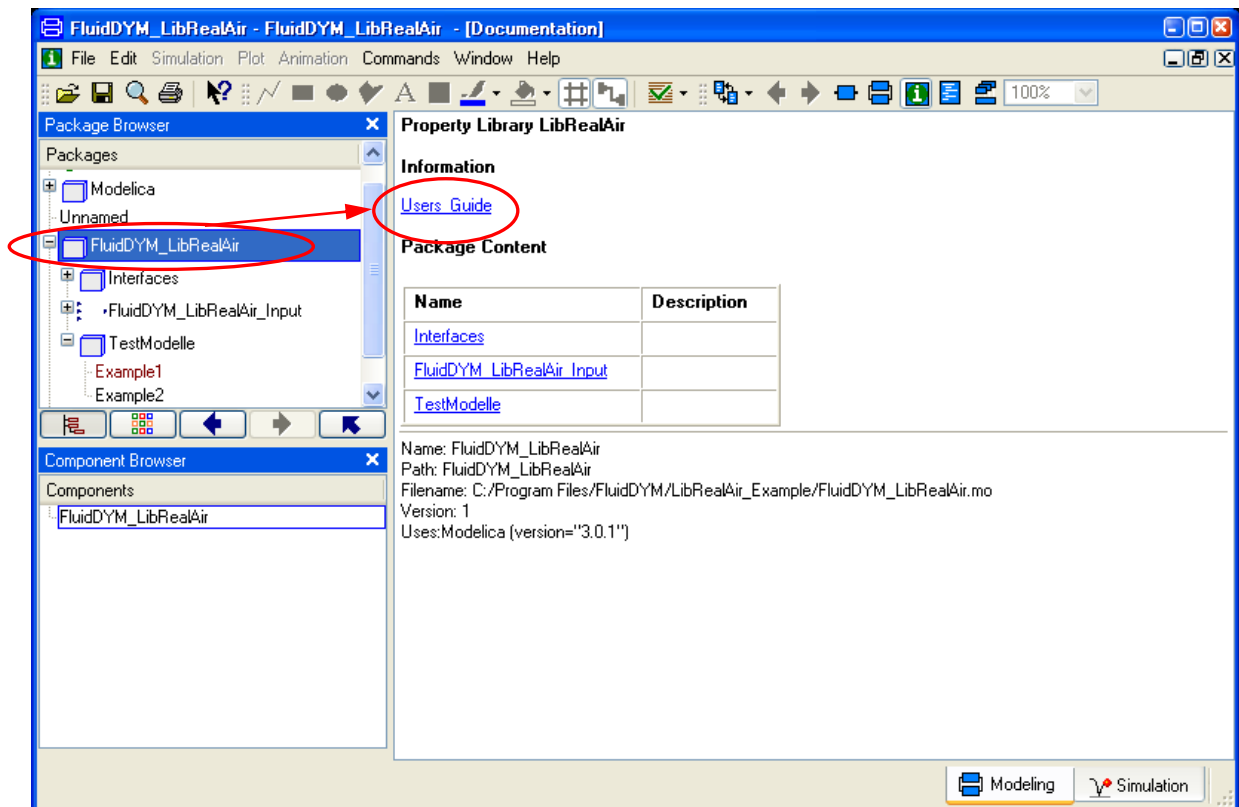



Figure 2.24: Selecting the "Users_Guide"

- The program documentation will be displayed within your default web browser.

Now, we will show you how to access the help page of a specific property function.

- Make sure Dymola is set to the "Modeling-Mode".
- Now click the  button in the Dymola menu bar to choose the "Documentation Mode".
- Double-click on the "FluidDYM_LibRealAir_Input" block on the left (see Figure 2.25).

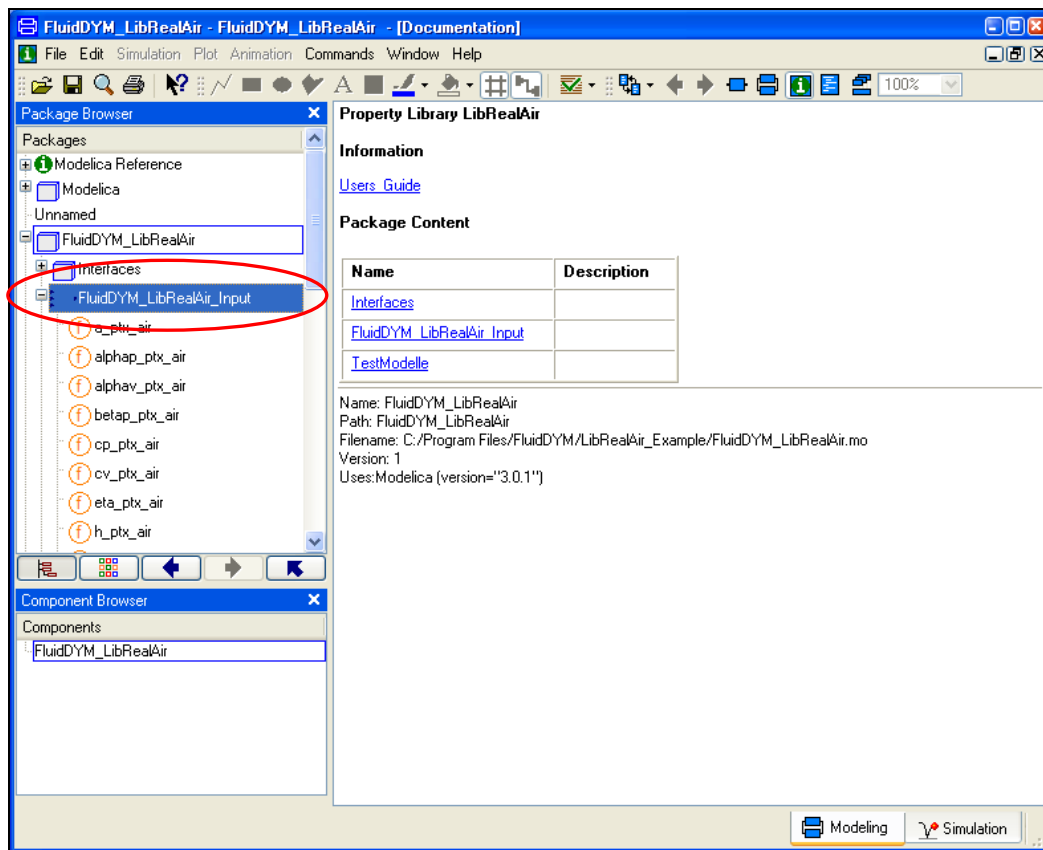


Figure 2.25: Selected "FluidDYM_LibRealAir_Input" Block

- Below "FluidDYM_LibRealAir_Input" you will see all functions of the LibRealAir property function (see Figure 2.25).
- Now select a function, e.g. "h_ptx_air", and then click on "Users_Guide" (see Figure 2.26).

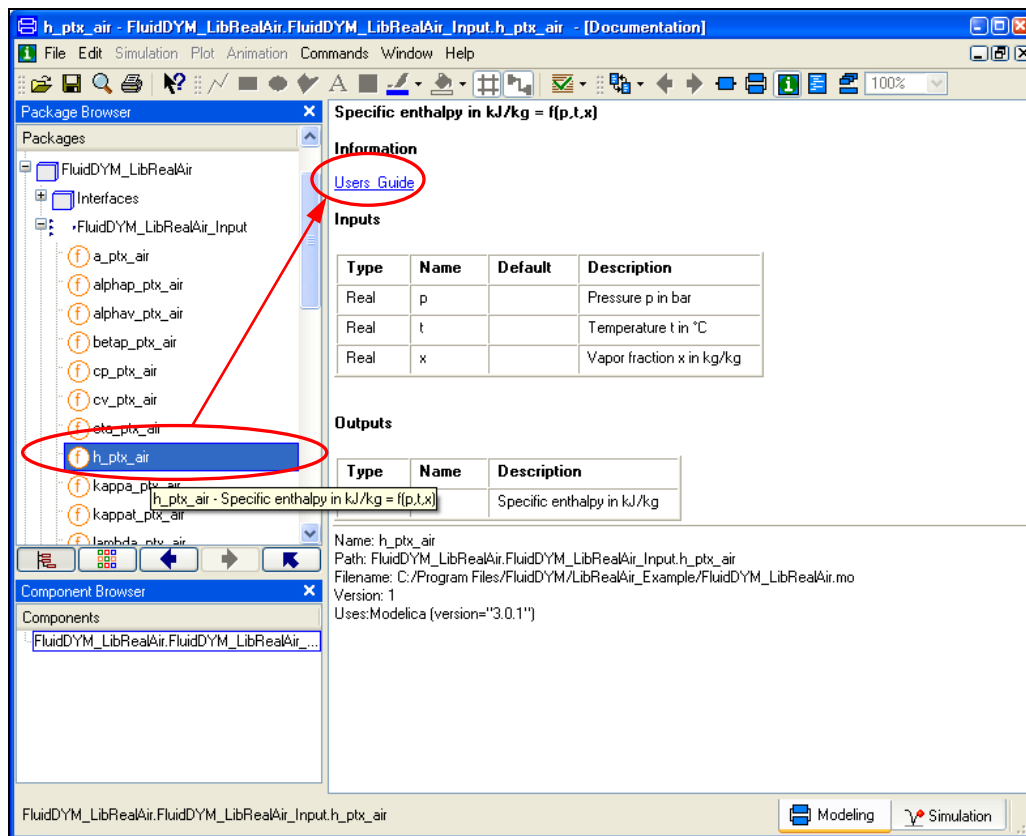


Figure 2.26: Marking the "h_ptx_air" function and selecting the "Users_Guide"

- You will now see the help page of the selected function, here "h_ptx_air", in your default web browser (see Figure 2.27).

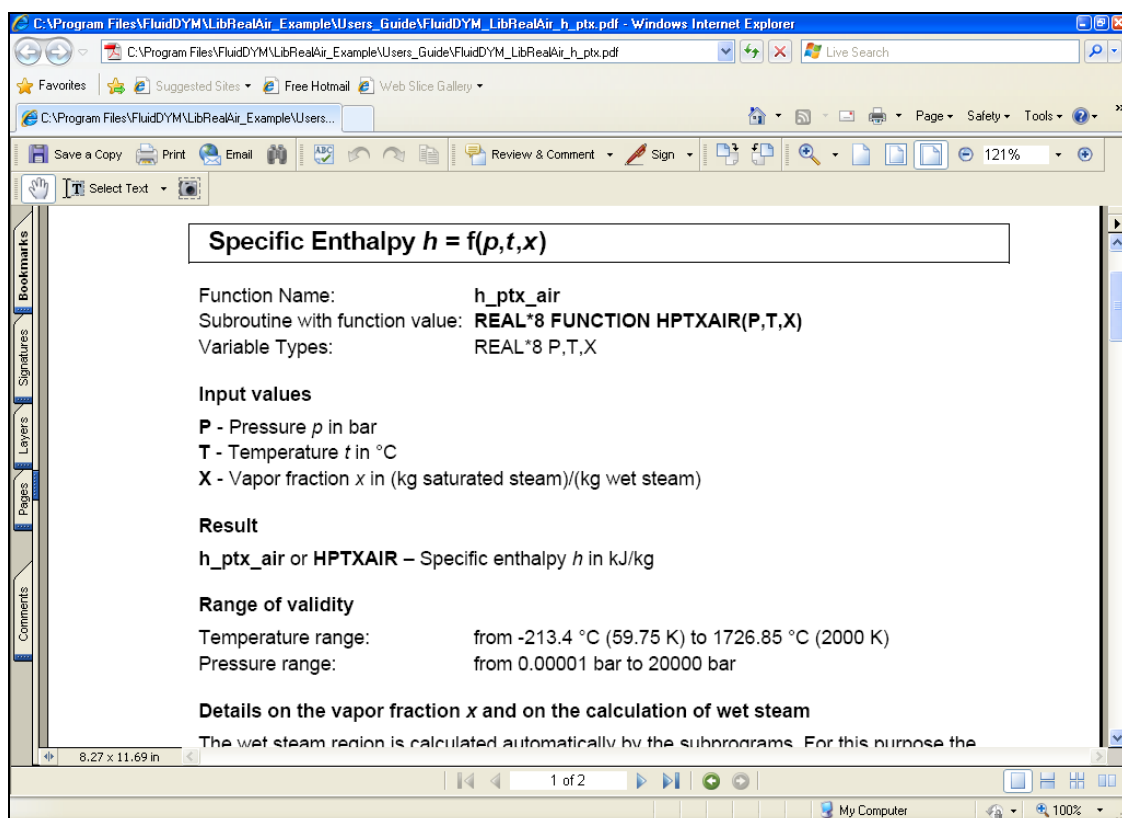


Figure 2.27: Help page of the function "h_ptx_air" in the web browser

2.4 Removing LibRealAir in Dymola

In order to remove the property library LibRealAir from your hard drive in Windows®, click "Start" in the lower task bar, then "Settings" and "Control Panel".

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

In the list box of the "Add or Remove Programs" menu which appears, select "FluidDYM LibRealAir" by clicking on it and then clicking the "Change/Remove" button.

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

Confirm the "Perform Uninstall" menu which appears by clicking the "Finish" button.

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

"FluidDYM LibRealAir" has now been removed.

If LibRealAir is the only library installed, the directory "FluidDYM" will be removed as well.

3. Program Documentation

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

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

Input values

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

Result

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

Range of validity

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

Details on the vapor fraction x

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

Single phase region

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

Saturation lines

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

Boundaries for wet steam region

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

Results for wrong input values

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

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

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

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

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

References

[1], [2]

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

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

Input values

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

Result

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

Range of validity

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

Details on the vapor fraction x

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

Single phase region

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

Saturation lines

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

Boundaries for wet steam region

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

Results for wrong input values

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

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

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

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

Reference

[1]

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

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

Input values

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

Result

alphav_ptx_air or **ALPHAVPTXAIR**

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

Range of validity

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

Details on the vapor fraction x

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

Single phase region

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

Saturation lines

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

Boundaries for wet steam region

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

Results for wrong input values

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

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

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

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

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

Reference

[1]

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

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

Input values

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

Result

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

Range of validity

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

Details on the vapor fraction x

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

Single phase region

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

Saturation lines

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

Boundaries for wet steam region

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

Results for wrong input values

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

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

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

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

Reference

[1]

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

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

Input values

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

Result

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

Range of validity

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

Details on the vapor fraction x

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

Single phase region

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

Saturation lines

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

Boundaries for wet steam region

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

Results for wrong input values

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

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

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

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

Reference

[1]

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

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

Input values

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

Result

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

Range of validity

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

Details on the vapor fraction x

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

Single phase region

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

Saturation lines

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

Boundaries for wet steam region

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

Results for wrong input values

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

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

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

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

Reference

[1]

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

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

Input values

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

Result

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

Range of validity

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

Details on the vapor fraction x

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

Single phase region

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

Saturation lines

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

Boundaries for wet steam region

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

Results for wrong input values

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

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

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

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

References

[1], [2]

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

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

Input values

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

Result

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

Range of validity

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

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

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

Single phase region

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

Wet steam region

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

Boundaries for wet steam region

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

Results for wrong input values

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

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

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

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

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

Reference

[1]

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

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

Input values

P - Pressure p in bar

T - Temperature t in °C

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

Result

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

Range of validity

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

Pressure range: from 0.00001 bar to 20000 bar

Details on the vapor fraction x

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

Single phase region

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

Saturation lines

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

Boundaries for wet steam region

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

Results for wrong input values

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

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

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

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

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

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

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

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

Reference

[1]

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

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

Input values

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

Result

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

Range of validity

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

Details on the vapor fraction x

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

Single phase region

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

Saturation lines

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

Boundaries for wet steam region

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

Results for wrong input values

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

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

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

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

Reference

[1]

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

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

Input values

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

Result

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

Range of validity

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

Details on the vapor fraction x

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

Single phase region

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

Saturation lines

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

Boundaries for wet steam region

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

Results for wrong input values

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

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

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

References

[1], [2]

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

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

Input values

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

Result

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

Range of validity

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

Details on the vapor fraction x

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

Single phase region

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

Saturation lines

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

Boundaries for wet steam region

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

Results for wrong input values

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

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

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

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

References

[1], [2]

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

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

Input values

T - Temperature t in °C

Result

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

Range of validity

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

Results for wrong input values

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

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

Reference

[1]

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

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

Input values

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

Result

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

Range of validity

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

Details on the vapor fraction x

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

Single phase region

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

Saturation lines

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

Boundaries for wet steam region

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

Results for wrong input values

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

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

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

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

References

[1], [2]

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

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

Input values

T - Temperature t in °C

Result

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

Range of validity

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

Details on the saturation lines

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

Results for wrong input values

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

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

Reference

[1]

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

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

Input values

T - Temperature t in °C

Result

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

Range of validity

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

Details on the saturation lines

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

Results for wrong input values

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

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

Reference

[1]

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

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

Input values

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

Result

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

Range of validity

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

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

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

Single phase region

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

Wet steam region

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

Boundaries for wet steam region

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

Results for wrong input values

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

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

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

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

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

Reference

[1]

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

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

Input values

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

Result

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

Range of validity

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

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

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

Single phase region

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

Wet steam region

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

Boundaries for wet steam region

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

Results for wrong input values

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

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

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

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

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

Reference

[1]

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

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

Input values

P – Pressure p in bar

Result

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

Range of validity

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

Results for wrong input values

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

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

Reference

[1]

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

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

Input values

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

Result

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

Range of validity

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

Details on the calculation of wet steam

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

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

Results for wrong input values

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

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

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

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

Reference

[1]

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

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

Input values

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

Result

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

Range of validity

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

Details on the calculation of wet steam

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

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

Results for wrong input values

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

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

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

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

Reference

[1]

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

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

Input values

P - Pressure p in bar

Result

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

Range of validity

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

Details on the saturation lines

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

Results for wrong input values

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

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

Reference

[1]

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

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

Input values

P - Pressure p in bar

Result

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

Range of validity

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

Details on the saturation lines

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

Results for wrong input values

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

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

Reference

[1]

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

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

Input values

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

Result

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

Range of validity

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

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

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

Single phase region

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

Wet steam region

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

Boundaries for wet steam region

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

Results for wrong input values

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

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

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

Reference

[1]

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

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

Input values

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

Result

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

Range of validity

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

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

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

Single phase region

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

Wet steam region

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

Boundaries for wet steam region

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

Results for wrong input values

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

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

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

Reference

[1]

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

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

Input values

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

Result

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

Range of validity

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

Details on the vapor fraction x

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

Single phase region

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

Saturation lines

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

Boundaries for wet steam region

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

Results for wrong input values

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

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

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

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

References

[1], [2]

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

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

Input values

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

Result

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

Range of validity

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

Details on the calculation of wet steam

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

Results for wrong input values

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

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

Reference:

[1]

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

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

Input values

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

Result

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

Range of validity

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

Details on the calculation of wet steam

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

Results for wrong input values

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

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

Reference:

[1]

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 Bucker 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 Bucker and Wagner (2006)

n-Butane

Library LibButane_n

Formulation of Bucker 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

| | |
|-----------------------------------|---------------------|
| $\text{C}_2\text{H}_6\text{O}_2$ | Ethylene glycol |
| $\text{C}_3\text{H}_8\text{O}_2$ | Propylene glycol |
| $\text{C}_2\text{H}_5\text{OH}$ | Ethanol |
| CH_3OH | Methanol |
| $\text{C}_3\text{H}_8\text{O}_3$ | Glycerol |
| K_2CO_3 | Potassium carbonate |
| CaCl_2 | Calcium chloride |
| MgCl_2 | Magnesium chloride |
| NaCl | Sodium chloride |
| $\text{C}_2\text{H}_3\text{KO}_2$ | 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 $C_{14}H_{42}O_6Si_6$ **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 **H₂S** **Library LibH2S**

Nitrous oxide **N₂O** **Library LibN2O**

Sulfur dioxide **SO₂** **Library LibSO2**

Acetone C_3H_6O **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

For more information please contact:

KCE-ThermoFluidProperties UG (limited liability) & Co. KG
Professor Hans-Joachim Kretschmar

Wallotstr. 3
01307 Dresden, Germany

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E-mail: info@thermofluidprop.com

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

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

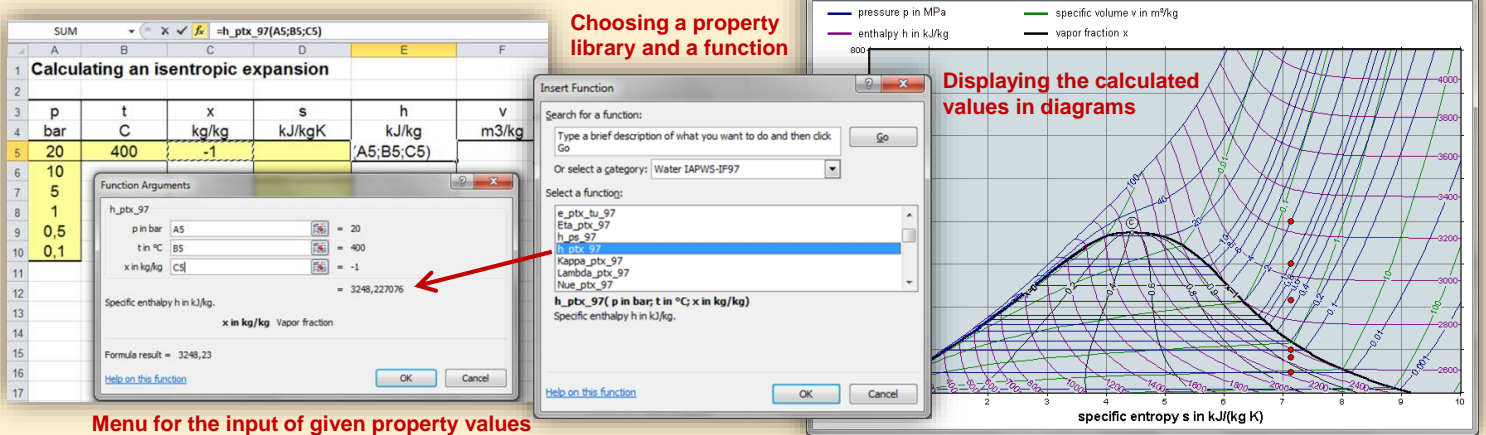
Thermodynamic Derivatives

- Partial derivatives can be calculated.

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

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

Add-In FluidEXL^{Graphics} for Excel[®]



Calculating an isentropic expansion

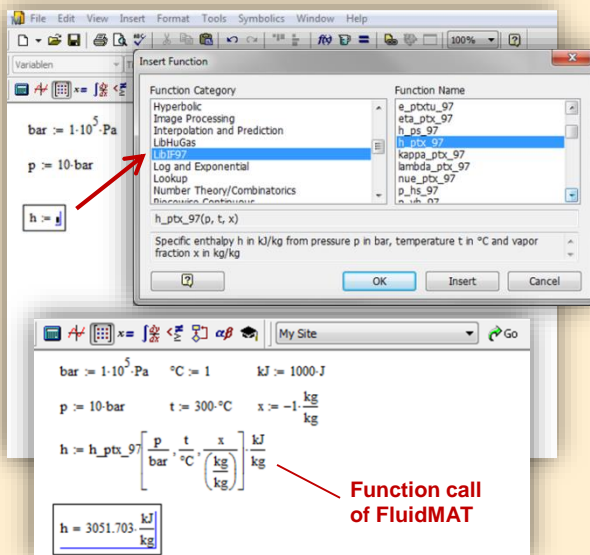
Choosing a property library and a function

Displaying the calculated values in diagrams

Menu for the input of given property values

Add-In FluidMAT for Mathcad[®]

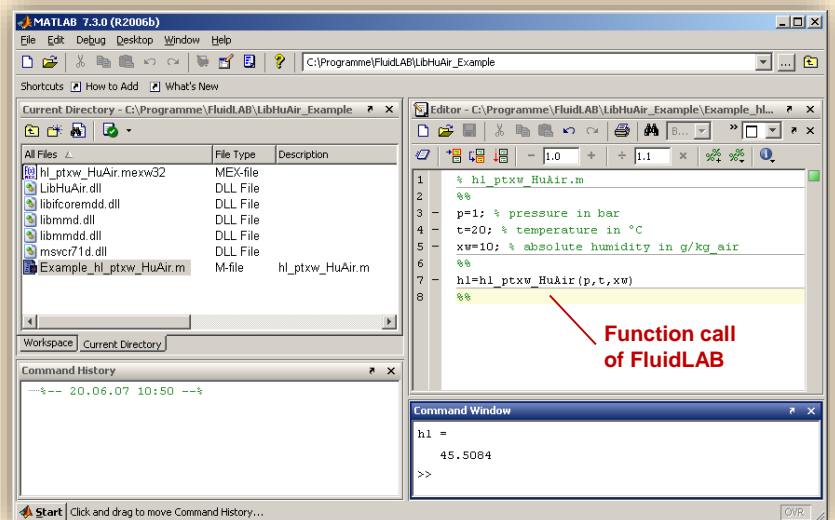
The property libraries can be used in Mathcad[®].



Function call of FluidMAT

Add-In FluidLAB for MATLAB[®]

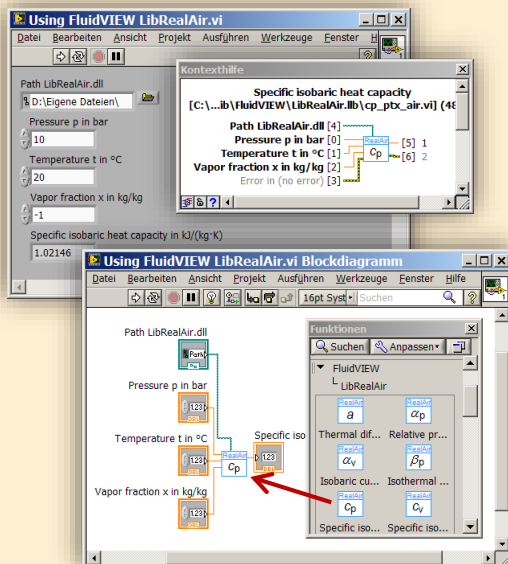
Using the Add-In FluidLAB the property functions can be called in MATLAB[®].



Function call of FluidLAB

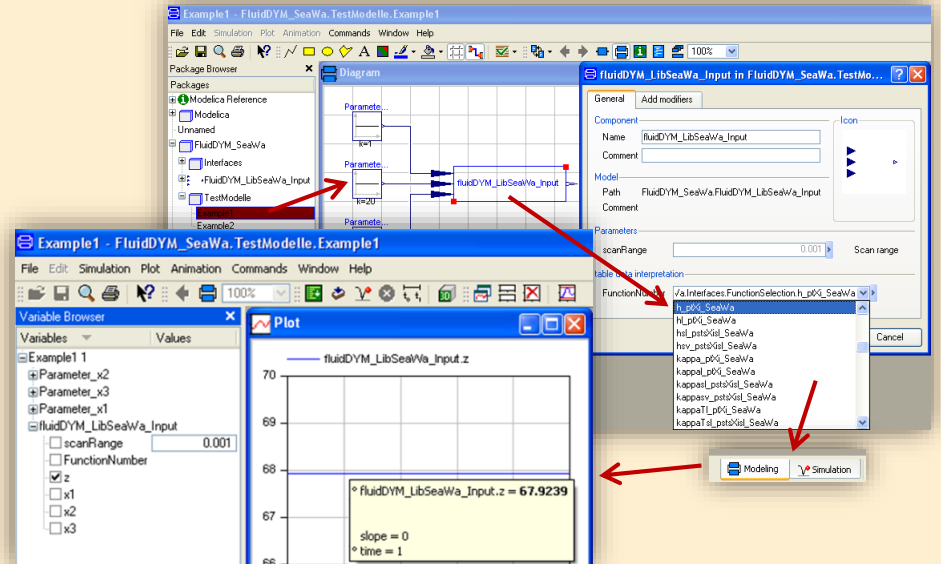
Add-On FluidVIEW for LabVIEW[™]

The property functions can be calculated in LabVIEW[™].

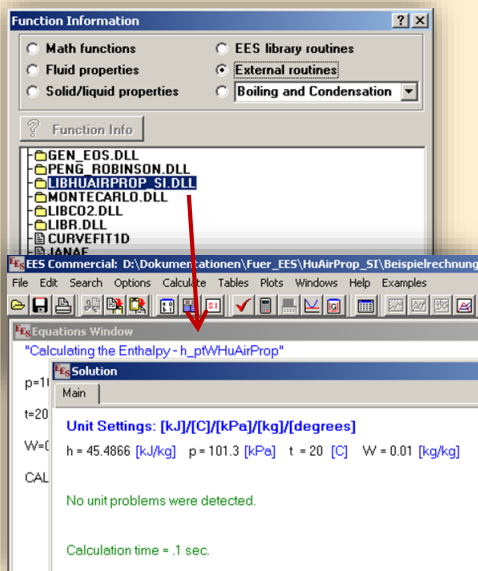


Add-In FluidDYM for DYMOLA[®] (Modelica) and SimulationX[®]

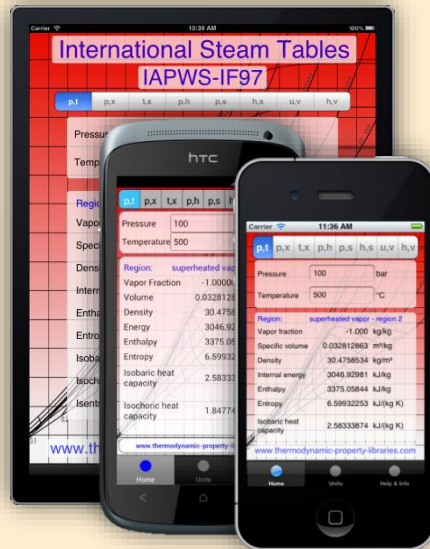
The property functions can be called in DYMOLA[®] and SimulationX[®].



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

Zittau's Fluid Property Calculator

Fluid:

Function:

Unit System:

Enter given values: [Range of validity](#)

Pressure p: bar

Temperature t: °C

Vapor fraction x: kg/kg

Calculate / Recalculate

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.thermofluidprop.com
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 83 TI 84 TI 89



TI Voyage 200



TI 92

For more information please contact:

KCE-ThermoFluidProperties UG (limited liability) & Co. KG
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01307 Dresden, Germany

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E-mail: info@thermofluidprop.com
Phone: +49-351-27597860
Mobile: +49-172-7914607
Fax: +49-3222-4262250

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.

5. References

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

6. Satisfied Customers

Date: 05/2018

The following companies and institutions use the property libraries

- FluidEXL *Graphics* for Excel®
- FluidLAB for MATLAB®
- FluidMAT for Mathcad®
- FluidEES for Engineering Equation Solver® EES
- FluidDYM for Dymola® (Modelica) and SimulationX®
- FluidVIEW for LabVIEW™.

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, Sønderød, 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 |

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|---|---------|
| 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 Braze 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, Bellevue (USA) | 11/2016 |
| DREWAG Dresden, Dresden | 10/2016 |
| AGO AG Energie+Anlagen, Kulmbach | 10/2016 |
| Universität Stuttgart, ITW, Stuttgart | 09/2016 |
| Pöry Deutschland GmbH, Dresden | 09/2016 |
| Siemens AG, Erlangen | 09/2016 |
| BASF über Fichtner IT Consulting AG | 09/2016 |
| B+B Engineering GmbH, Magdeburg | 09/2016 |
| Wilhelm Büchner Hochschule, Pfungstadt | 08/2016 |

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|---|---------------------------|
| 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 |
| E.ON SE, Düsseldorf | 07/2016 |
| 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 |
| G.A.M. Heat GmbH, Gräfenhainichen | 02/2016 |
| 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 |
| University of Lyubljana, Slovenia | 12/2015 |
| Steinbrecht IB, Berlin | 11/2015 |
| Universidad Carlos III de Madrid, Madrid, Spain | 11/2015 |
| STEAK, Essen | 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 |
| KIT Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen | 07/2015 |
| ILK, Dresden | 07/2015 |
| Schniewindt GmbH & Co. KG, Neuenwalde | 08/2015 |

2014

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| PROJEKTPLAN, Dohna | 04/2014 |
| Technical University of Vienna, Austria | 04/2014 |
| MTU Aero Engines AG, Munich | 04/2014 |
| GKS, Schweinfurt | 03/2014 |
| Technical University of Nuremberg | 03/2014 |
| EP-E, Niederstetten | 03/2014 |
| Rückert NatUrgas GmbH, Lauf | 03/2014 |
| YESS-World, South Korea | 03/2014 |
| ZAB, Dessau | 02/2014 |
| KIT-TVT, Karlsruhe | 02/2014 |
| Stadtwerke Neuburg | 02/2014 |
| COMPAREX, Leipzig for RWE Essen | 02/2014 |
| Technical University of Prague, Czech Republic | 02/2014 |
| HS Augsburg | 02/2014 |
| Envi-con, Nuremberg | 01/2014 |
| DLR, Stuttgart | 01/2014 |
| Doosan Lentjes, Ratingen | 01/2014 |
| Technical University of Berlin | 01/2014 |
| Technical University of Munich | 01/2014 |
| 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 |
| DREWAG, Dresden | 11/2013 |
| Haarslev Industries, Herlev, Dänemark | 11/2013 |
| STEAG, Herne | 11/2013, 12/2013 |
| Ingersoll-Rand, Oberhausen | 11/2013 |
| Wilhelm-Büchner HS, Darmstadt | 10/2013 |

| | |
|--|------------------|
| IAV, Chemnitz | 10/2013 |
| Technical University of Regensburg | 10/2013 |
| PD-Energy, Bitterfeld | 09/2013 |
| Thermofin, Heinsdorfergrund | 09/2013 |
| SHI, New Jersey, USA | 09/2013 |
| M&M Turbinentechnik, Bielefeld | 08/2013 |
| BEG-BHV, Bremerhaven | 08/2013 |
| TIG-Group, Husum | 08/2013 |
| COMPAREX, Leipzig | 08/2013, 11/2013 |
| for RWE Essen | 12/2013 |
| University of Budapest, Hungary | 08/2013 |
| Siemens, Frankenthal | 08/2013, 10/2013 |
| | 11/2013 |
| VGB, Essen | 07/2013, 11/2013 |
| Brunner Energieberatung, Zurich, Switzerland | 07/2013 |
| Technical University of Deggendorf | 07/2013 |
| University of Maryland, USA | 07/2013, 08/2013 |
| University of Princeton, USA | 07/2013 |
| NIST, Boulder, USA | 06/2013 |
| IGUS GmbH, Dresden | 06/2013 |
| BHR Bilfinger, Essen | 06/2013 |
| SÜDSALZ, Bad Friedrichshall | 06/2013, 12/2013 |
| Technician School of Berlin | 05/2013 |
| KIER, Gajeong-ro, Südkorea | 05/2013 |
| Schwing/Stetter GmbH, Memmingen | 05/2013 |
| Vattenfall, Berlin | 05/2013 |
| AUTARK, Kleinmachnow | 05/2013 |
| STEAG, Zwingenberg | 05/2013 |
| Hochtief, Düsseldorf | 05/2013 |
| University of Stuttgart | 04/2013 |
| Technical University -Bundeswehr, Munich | 04/2013 |
| Rerum Cognitio Forschungszentrum, Frankfurt | 04/2013 |
| Kältetechnik Dresden + Bremen, Alfhausen | 04/2013 |
| University Auckland, New Zealand | 04/2013 |
| MASDAR Institut, Abu Dhabi, United Arab Emirates | 03/2013 |
| Simpelkamp, Dresden | 02/2013 |
| VEO, Eisenhüttenstadt | 02/2013 |
| ENTEC, Auerbach | 02/2013 |
| Caterpillar, Kiel | 02/2013 |
| Technical University of Wismar | 02/2013 |
| Technical University of Dusseldorf | 02/2013 |

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|--|------------------|
| ILK, Dresden | 01/2013, 08/2013 |
| Fichtner IT, Stuttgart | 01/2013, 11/2013 |
| Schnepf Ingeniuerbüro, Nagold | 01/2013 |
| Schütz Engineering, Wadgassen | 01/2013 |
| Endress & Hauser, Reinach, Switzerland | 01/2013 |
| Oschatz GmbH, Essen | 01/2013 |
| frischli Milchwerke, Rehburg-Loccum | 01/2013 |

2012

| | |
|---|------------------|
| Voith, Bayreuth | 12/2012 |
| Technical University of Munich | 12/2012 |
| Dillinger Huette | 12/2012 |
| University of Stuttgart | 11/2012 |
| Siemens, Muehlheim | 11/2012 |
| Sennheiser, Hannover | 11/2012 |
| Oschatz GmbH, Essen | 10/2012 |
| Fichtner IT, Stuttgart | 10/2012, 11/2012 |
| Helbling Technik AG, Zurich, Switzerland | 10/2012 |
| University of Duisburg | 10/2012 |
| Rerum Cognitio Forschungszentrum, Frankfurt | 09/2012 |
| Pöry Deutschland GmbH, Dresden | 08/2012 |
| Extracciones, Guatemala | 08/2012 |
| RWE, Essen | 08/2012 |
| Weghaus Consulting Engineers, Wuerzburg | 08/2012 |
| GKS, Schweinfurt | 07/2012 |
| COMPAREX, Leipzig for RWE Essen | 07/2012 |
| GEA, Nobitz | 07/2012 |
| Meyer Werft, Papenburg | 07/2012 |
| STEAG, Herne | 07/2012 |
| GRS, Cologne | 06/2012 |
| Fichtner IT Consult, Chennai, India | 06/2012 |
| Siemens, Freiburg | 06/2012 |
| Nikon Research of America, Belmont, USA | 06/2012 |
| Niederrhein University of Applied Sciences, Krefeld | 06/2012 |
| STEAG, Zwingenberg | 06/2012 |
| Mainova, Frankfurt on Main via Fichtner IT Consult | 05/2012 |
| Endress & Hauser | 05/2012 |
| PEU, Espenheim | 05/2012 |
| Luzern University of Applied Sciences, Switzerland | 05/2012 |

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| BASF, Ludwigshafen (general license) via Fichtner IT Consult | 05/2012 |
| SPX Balcke-Dürr, Ratingen | 05/2012, 07/2012 |
| Gruber-Schmidt, Wien, Austria | 04/2012 |
| Vattenfall, Berlin | 04/2012 |
| ALSTOM, Baden | 04/2012 |
| SKW, Piesteritz | 04/2012 |
| TERA Ingegneria, Trento, Italy | 04/2012 |
| Siemens, Erlangen | 04/2012, 05/2012 |
| 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 Destillation, 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

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| 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 |

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| 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 |
| Enseleit Consulting Engineers, Siebigerode | 04/2011 |
| Witt Consulting Engineers, Stade | 03/2011 |
| Helbling, Zurich, Switzerland | 03/2011 |
| MAN Diesel, Copenhagen, Denmark | 03/2011 |
| AGO, Kulmbach | 03/2011 |
| University of Duisburg | 03/2011, 06/2011 |
| CCP, Marburg | 03/2011 |
| BASF, Ludwigshafen | 02/2011 |
| ALSTOM Power, Baden, Switzerland | 02/2011 |
| Universität der Bundeswehr, Munich | 02/2011 |
| Calorifer, Elgg, Switzerland | 01/2011 |
| STRABAG, Vienna, Austria | 01/2011 |
| TUEV Sued, Munich | 01/2011 |
| ILK Dresden | 01/2011 |
| Technical University of Dresden | 01/2011, 05/2011 06/2011, 08/2011 |

2010

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| Umweltinstitut Neumarkt | 12/2010 |
| YIT Austria, Vienna, Austria | 12/2010 |
| MCI Innsbruck, Austria | 12/2010 |

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| University of Stuttgart | 12/2010 |
| HS Cooler, Wittenburg | 12/2010 |
| Visteon, Novi Jicin, Czech Republic | 12/2010 |
| CompuWave, Brunntal | 12/2010 |
| Stadtwerke Leipzig | 12/2010 |
| MCI Innsbruck, Austria | 12/2010 |
| EVONIK Energy Services, Zwingenberg | 12/2010 |
| Caliqua, Basel, Switzerland | 11/2010 |
| Shanghai New Energy Resources Science & Technology, China | 11/2010 |
| Energieversorgung Halle | 11/2010 |
| Hochschule für Technik Stuttgart, University of Applied Sciences | 11/2010 |
| Steinmueller, Berlin | 11/2010 |
| Amberg-Weiden University of Applied Sciences | 11/2010 |
| AREVA NP, Erlangen | 10/2010 |
| MAN Diesel, Augsburg | 10/2010 |
| KRONES, Neutraubling | 10/2010 |
| Vaillant, Remscheid | 10/2010 |
| PC Ware, Leipzig | 10/2010 |
| Schubert Consulting Engineers, Weißenberg | 10/2010 |
| Fraunhofer Institut UMSICHT, Oberhausen | 10/2010 |
| Behringer Consulting Engineers, Tagmersheim | 09/2010 |
| Saacke, Bremen | 09/2010 |
| WEBASTO, Neubrandenburg | 09/2010 |
| Concordia University, Montreal, Canada | 09/2010 |
| Compañía Eléctrica de Sochagota, Bogota, Colombia | 08/2010 |
| Hannover University of Applied Sciences | 08/2010 |
| ERGION, Mannheim | 07/2010 |
| Fichtner IT Consulting, Stuttgart | 07/2010 |
| TF Design, Matieland, South Africa | 07/2010 |
| MCE, Berlin | 07/2010, 12/2010 |
| IPM, Zittau/Goerlitz University of Applied Sciences | 06/2010 |
| TUEV Sued, Dresden | 06/2010 |
| RWE IT, Essen | 06/2010 |
| Glen Dimplex, Kulmbach | 05/2010, 07/2010 |
| | 10/2010 |
| Hot Rock, Karlsruhe | 05/2010 |
| Darmstadt University of Applied Sciences | 05/2010 |
| Voith, Heidenheim | 04/2010 |
| CombTec, Zittau | 04/2010 |
| University of Glasgow, Great Britain | 04/2010 |
| Universitaet der Bundeswehr, Munich | 04/2010 |

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| 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 |

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| 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 |

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| 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

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| 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, | 07/2008 |
| Professorship of Building Services | |
| Technical University of Cottbus, | 07/2008, 10/2008 |
| Chair in Power Plant Engineering | |
| Ingersoll-Rand, Unicov, Czech Republic | 08/2008 |

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|---|------------------|
| 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

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| 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 |

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|---|------------------|
| 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

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| 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, | 02/2006 |
| Department of Thermal Fluid Flow Engines | |
| Technical University of Munich, | 02/2006 |
| Chair in Apparatus and Plant Engineering | |
| Energietechnik Leipzig (company license), | 02/2006 |
| Siemens Power Generation, Erlangen | 02/2006, 03/2006 |
| RWE Power, Essen | 03/2006 |
| WAETAS, Pobershau | 04/2006 |
| Siemens Power Generation, Goerlitz | 04/2006 |
| Technical University of Braunschweig, | 04/2006 |
| Department of Thermodynamics | |
| EnviCon & Plant Engineering, Nuremberg | 04/2006 |
| Brassel Engineering, Dresden | 05/2006 |
| University of Halle-Merseburg, | 05/2006 |
| Department of USET Merseburg incorporated society | |
| Technical University of Dresden, | 05/2006 |
| Professorship of Thermic Energy Machines and Plants | |
| Fichtner Consulting & IT Stuttgart (company licenses and distribution) | 05/2006 |
| Suedzucker, Ochsenfurt | 06/2006 |
| M&M Turbine Technology, Bielefeld | 06/2006 |
| Feistel Engineering, Volkach | 07/2006 |
| ThyssenKrupp Marine Systems, Kiel | 07/2006 |

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| Caliqua, Basel, Switzerland (company license) | 09/2006 |
| Atlas-Stord, Rodovre, Denmark | 09/2006 |
| Konstanz University of Applied Sciences, Course of Studies Construction and Development | 10/2006 |
| Siemens Power Generation, Duisburg | 10/2006 |
| Hannover University of Applied Sciences, Department of Mechanical Engineering | 10/2006 |
| Siemens Power Generation, Berlin | 11/2006 |
| Zikesch Armaturentechnik, Essen | 11/2006 |
| Wismar University of Applied Sciences, Seafaring Department | 11/2006 |
| BASF, Schwarzheide | 12/2006 |
| Enertech Energie und Technik, Radebeul | 12/2006 |

2005

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| TUEV Nord, Hannover | 01/2005 |
| J.H.K Plant Engineering and Service, Bremerhaven | 01/2005 |
| Electrowatt-EKONO, Zurich, Switzerland | 01/2005 |
| FCIT, Stuttgart | 01/2005 |
| Energietechnik Leipzig (company license) | 02/2005, 04/2005 |
| | 07/2005 |
| eta Energieberatung, Pfaffenhofen | 02/2005 |
| FZR Forschungszentrum, Rossendorf/Dresden | 04/2005 |
| University of Saarbruecken | 04/2005 |
| Technical University of Dresden | 04/2005 |
| Professorship of Thermic Energy Machines and Plants | |
| Grenzebach BSH, Bad Hersfeld | 04/2005 |
| TUEV Nord, Hamburg | 04/2005 |
| Technical University of Dresden, Waste Management | 05/2005 |
| Siemens Power Generation, Goerlitz | 05/2005 |
| Duesseldorf University of Applied Sciences, Department of Mechanical Engineering and Process Engineering | 05/2005 |
| Redacom, Nidau, Switzerland | 06/2005 |
| Dumas Verfahrenstechnik, Hofheim | 06/2005 |
| Alensys Engineering, Erkner | 07/2005 |
| Stadtwerke Leipzig | 07/2005 |
| SaarEnergie, Saarbruecken | 07/2005 |
| ALSTOM ITC, Rugby, Great Britain | 08/2005 |
| Technical University of Cottbus, Chair in Power Plant Engineering | 08/2005 |
| Vattenfall Europe, Berlin (group license) | 08/2005 |
| Technical University of Berlin | 10/2005 |
| Basel University of Applied Sciences, Department of Mechanical Engineering, Switzerland | 10/2005 |

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| Midiplan, Bietigheim-Bissingen | 11/2005 |
| Technical University of Freiberg, Chair in Hydrogeology | 11/2005 |
| STORA ENSO Sachsen, Eilenburg | 12/2005 |
| Energieversorgung Halle (company license) | 12/2005 |
| KEMA IEV, Dresden | 12/2005 |

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| Vattenfall Europe (group license) | 01/2004 |
| TUEV Nord, Hamburg | 01/2004 |
| University of Stuttgart, Institute of Thermodynamics and Heat Engineering | 02/2004 |
| MAN B&W Diesel A/S, Copenhagen, Denmark | 02/2004 |
| Siemens AG Power Generation, Erlangen | 02/2004 |
| Ulm University of Applied Sciences | 03/2004 |
| Visteon, Kerpen | 03/2004, 10/2004 |
| Technical University of Dresden, Professorship of Thermic Energy Machines and Plants | 04/2004 |
| Rerum Cognitio, Zwickau | 04/2004 |
| University of Saarbruecken | 04/2004 |
| Grenzebach BSH, Bad Hersfeld | 04/2004 |
| SOFBID Zwingenberg (general EBSILON program license) | 04/2004 |
| EnBW Energy Solutions, Stuttgart | 05/2004 |
| HEW-Kraftwerk, Tiefstack | 06/2004 |
| h s energieanlagen, Freising | 07/2004 |
| FCIT, Stuttgart | 08/2004 |
| Physikalisch Technische Bundesanstalt (PTB), Braunschweig | 08/2004 |
| Mainova Frankfurt | 08/2004 |
| Rietschle Energieplaner, Winterthur, Switzerland | 08/2004 |
| MAN Turbo Machines, Oberhausen | 09/2004 |
| TUEV Sued, Dresden | 10/2004 |
| STEAG Kraftwerk, Herne | 10/2004, 12/2004 |
| University of Weimar | 10/2004 |
| energeticals (e-concept), Munich | 11/2004 |
| SorTech, Halle | 11/2004 |
| Enertech EUT, Radebeul (company license) | 11/2004 |
| Munich University of Applied Sciences | 12/2004 |
| STORA ENSO Sachsen, Eilenburg | 12/2004 |
| Technical University of Cottbus, Chair in Power Plant Engineering | 12/2004 |
| Freudenberg Service, Weinheim | 12/2004 |

2003

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| Paper Factory, Utzenstorf, Switzerland | 01/2003 |
| MAB Plant Engineering, Vienna, Austria | 01/2003 |

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| Wulff Energy Systems, Husum | 01/2003 |
| Technip Benelux BV, Zoetermeer, Netherlands | 01/2003 |
| ALSTOM Power, Baden, Switzerland | 01/2003, 07/2003 |
| VER, Dresden | 02/2003 |
| Rietschle Energieplaner, Winterthur, Switzerland | 02/2003 |
| DLR, Leupholdhausen | 04/2003 |
| Emden University of Applied Sciences, Department of Technology | 05/2003 |
| Pettersson+Ahrends, Ober-Moerlen | 05/2003 |
| SOFBID ,Zwingenberg (general EBSILON program license) | 05/2003 |
| Ingenieurbuero Ostendorf, Gummersbach | 05/2003 |
| TUEV Nord, Hamburg | 06/2003 |
| Muenstermann GmbH, Telgte-Westbevern | 06/2003 |
| University of Cali, Colombia | 07/2003 |
| Atlas-Stord, Rodovre, Denmark | 08/2003 |
| ENERKO, Aldenhoven | 08/2003 |
| STEAG RKB, Leuna | 08/2003 |
| eta Energieberatung, Pfaffenhofen | 08/2003 |
| exergie, Dresden | 09/2003 |
| AWTEC, Zurich, Switzerland | 09/2003 |
| Energie, Timelkam, Austria | 09/2003 |
| Electrowatt-EKONO, Zurich, Switzerland | 09/2003 |
| LG, Annaberg-Buchholz | 10/2003 |
| FZR Forschungszentrum, Rossendorf/Dresden | 10/2003 |
| EnviCon & Plant Engineering, Nuremberg | 11/2003 |
| Visteon, Kerpen | 11/2003 |
| VEO Vulkan Energiewirtschaft Oderbruecke, Eisenhuettenstadt | 11/2003 |
| Stadtwerke Hannover | 11/2003 |
| SaarEnergie, Saarbruecken | 11/2003 |
| Fraunhofer-Gesellschaft, Munich | 12/2003 |
| Erfurt University of Applied Sciences, Department of Supply Engineering | 12/2003 |
| SorTech, Freiburg | 12/2003 |
| Mainova, Frankfurt | 12/2003 |
| Energieversorgung Halle | 12/2003 |

2002

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| Hamilton Medical AG, Rhaezuens, Switzerland | 01/2002 |
| Bochum University of Applied Sciences, Department of Thermo- and Fluid Dynamics | 01/2002 |
| SAAS, Possendorf/Dresden | 02/2002 |
| Siemens, Karlsruhe (general license for the WinIS information system) | 02/2002 |

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| FZR Forschungszentrum, Rossendorf/Dresden | 03/2002 |
| CompAir, Simmern | 03/2002 |
| GKS Gemeinschaftskraftwerk, Schweinfurt | 04/2002 |
| ALSTOM Power Baden, Switzerland (group licenses) | 05/2002 |
| InfraServ, Gendorf | 05/2002 |
| SoftSolutions, Muehlhausen (company license) | 05/2002 |
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| PCK Raffinerie, Schwedt (group license) | 07/2002 |
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| Stadtwerke Hannover | 09/2002 |
| Siemens Power Generation, Goerlitz | 10/2002 |
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| Bayer, Leverkusen | 11/2002 |
| Dillinger Huette, Dillingen | 11/2002 |
| G.U.N.T. Geraetebau, Barsbuettel | 12/2002 |
| (general license and training test benches) | |
| VEAG, Berlin (group license) | 12/2002 |

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| ALSTOM Power, Baden, Switzerland | 01/2001, 06/2001 12/2001 |
| KW2 B. V., Amersfoot, Netherlands | 01/2001, 11/2001 |
| Eco Design, Saitamaken, Japan | 01/2001 |
| M&M Turbine Technology, Bielefeld | 01/2001, 09/2001 |
| MVV Energie, Mannheim | 02/2001 |
| Technical University of Dresden, Department of Power Machinery and Plants | 02/2001 |
| PREUSSAG NOELL, Wuerzburg | 03/2001 |
| Fichtner Consulting & IT Stuttgart | 04/2001 |
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| SaarEnergie, Saarbruecken | 05/2001 |
| Siemens, Karlsruhe | 08/2001 |
| (general license for the WinIS information system) | |
| Neusiedler AG, Ulmerfeld, Austria | 09/2001 |

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| h s energieranlagen, Freising | 09/2001 |
| Electrowatt-EKONO, Zurich, Switzerland | 09/2001 |
| IPM Zittau/Goerlitz University of Applied Sciences (general license) | 10/2001 |
| eta Energieberatung, Pfaffenhofen | 11/2001 |
| ALSTOM Power Baden, Switzerland | 12/2001 |
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| SOFBID, Zwingenberg | 01/2000 |
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| AG KKK - PGW Turbo, Leipzig | 01/2000 |
| PREUSSAG NOELL, Wuerzburg | 01/2000 |
| M&M Turbine Technology, Bielefeld | 01/2000 |
| IBR Engineering Reis, Nittendorf-Undorf | 02/2000 |
| GK, Hannover | 03/2000 |
| KRUPP-UHDE, Dortmund (company license) | 03/2000 |
| UMAG W. UDE, Husum | 03/2000 |
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