User's Guide

for

LibHuAirProp

Library of Psychrometric, Thermodynamic, and Transport Properties for *Real* Humid Air, Steam, Water, and Ice
I-P & SI Units

FluidDYM for DYMOLA®

Version 8.0

Based on ASHRAE Research Projects RP-1485 and RP-1767

Prepared by

THERMO FLUID PROPERTIES

www.thermofluidprop.com

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LibHuAirProp Product Information

Do you need property values for moist air in I-P or SI units in your daily work?

► Use the property library LibHuAirProp ◄

Do you need these properties in Excel®, MATLAB®, Mathcad®, Mathcad Prime®, Engineering Equation Solver®, LabVIEW™, DYMOLA®, or SimulationX®?

► Use the add-ins FluidEXL, FluidLAB, FluidMAT, FluidPRIME, FluidEES, FluidVIEW, or FluidDYM ◄

What properties can be calculated using this software?

► thermodynamic properties psychrometric functions ◄

► transport properties backward functions ◄

What range of state is covered by this property library?

► unsaturated and saturated moist air ◄

► supersaturated moist air (liquid fog and ice fog) ◄

► temperatures from −143.15°C (−225.67°F) to 350°C (662°F) ◄

► pressures from 0.01 kPa (0.00145 psi) to 10,000 kPa (1450.4 psi) ◄

What are the references of LibHuAirProp?

Tables for moist air properties in the 2009, 2013, and 2017 *ASHRAE Handbook of Fundamentals* were calculated using LibHuAirProp

Psychrometrics **1.3**

Table 2 Thermodynamic Properties of Moist Air at Standard Atmospheric Pressure, 101.325 kPa

Temp., °C	Humidity Ratio	Specific Volume, m^3/kg_{da}			Specific Enthalpy, kJ/kg_{da}			Specific Entropy, $kJ/(kg_{da} \cdot K)$		Temp., °C
t	W_s, kg_w/kg_{da}	v_{da}	v_{as}	v_s	h_{da}	h_{as}	h_s	s_{da}	s_s	t
–60	0.0000067	0.6027	0.0000	0.6027	–60.341	0.016	–60.325	–0.2494	–0.2494	–60
–59	0.0000076	0.6055	0.0000	0.6055	–59.335	0.018	–59.317	–0.2447	–0.2446	–59
–58	0.0000087	0.6084	0.0000	0.6084	–58.329	0.021	–58.308	–0.2400	–0.2399	–58
–57	0.0000100	0.6112	0.0000	0.6112	–57.323	0.024	–57.299	–0.2354	–0.2353	–57
–56	0.0000114	0.6141	0.0000	0.6141	–56.317	0.027	–56.289	–0.2307	–0.2306	–56
–55	0.0000129	0.6169	0.0000	0.6169	–55.311	0.031	–55.280	–0.2261	–0.2260	–55
–54	0.0000147	0.6198	0.0000	0.6198	–54.305	0.035	–54.269	–0.2215	–0.2213	–54
–53	0.0000167	0.6226	0.0000	0.6226	–53.299	0.040	–53.258	–0.2169	–0.2167	–53
–52	0.0000190	0.6255	0.0000	0.6255	–52.293	0.046	–52.247	–0.2124	–0.2121	–52
–51	0.0000215	0.6283	0.0000	0.6283	–51.287	0.052	–51.235	–0.2078	–0.2076	–51

Thermodynamic and psychrometric property algorithms from ASHRAE Research Project 1485

FINAL REPORT

ASHRAE RP-1485

Thermodynamic Properties of Real Moist Air, Dry Air, Steam, Water, and Ice

By S. Herrmann[a], H.-J. Kretzschmar[a], and D.P. Gatley[b]

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November 17, 2008 (Submitted to TC for review)

March 12, 2009 (Final with corrections)

January 18, 2017 (Last update)

(For the documentation of corrections and modifications see the Appendix)

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Thermodynamic Properties of Real Moist Air, Dry Air, Steam, Water, and Ice (RP-1485)

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Received February 14, 2009; accepted May 6, 2009

This paper is based on findings resulting from ASHRAE Research Project RP-1485.

This research updates the modeling of moist air as a real gas mixture using the virial equation of state. It includes the Hyland and Wexler model (1983a, 1983b) and considers the Nelson-Sauer model (2002). All new National Institute of Standards and Technology reference equations and the latest International Association for the Properties of Water and Steam (IAPWS) standards, as well as the current values for the molar masses and gas constants, have been incorporated. The deviations of the proposed model to the Hyland-Wexler and Nelson-Sauer models are very low at ambient pressures but increase with increasing pressures and temperatures. The range of validity of the new model is in pressure from 0.01 kPa up to 10 MPa, in temperature from –143.15°C up to 350°C, and in humidity ratio from 0 kg_w/kg_a up to 10 kg_w/kg_a. This model was used to produce moist air and H_2O saturation property tables for the psychrometric chapter in the 2009 ASHRAE Handbook—Fundamentals *(ASHRAE 2009). The paper summarizes ASHRAE Research Project 1485 (RP-1485).*

Transport property algorithms of moist air from ASHRAE Research Project 1767

FINAL REPORT

ASHRAE RP-1767

Transport Properties of Real Moist Air,
Dry Air, Steam, and Water

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December 31, 2018

Properties of dry air from the NIST Reference Equation of *Lemmon et al.* and properties of steam, water, and ice from the Industrial Formulation IAPWS-IF97, the Scientific Formulation IAPWS-95, and other current IAPWS formulations

Thermodynamic Properties of Air and Mixtures of Nitrogen, Argon, and Oxygen From 60 to 2000 K at Pressures to 2000 MPa

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Received June 28, 1999; revised manuscript received December 2, 1999

A thermodynamic property formulation for standard dry air based upon available experimental $p-\rho-T$, heat capacity, speed of sound, and vapor–liquid equilibrium data is presented. This formulation is valid for liquid, vapor, and supercritical air at temperatures from the solidification point on the bubble-point curve (59.75 K) to 2000 K at pressures up to 2000 MPa. In the absence of reliable experimental data for air above 873 K and 70

0047-2689/2000/29(3)/331/55/$37.00 331 J. Phys. Chem. Ref. Data, Vol. 29, No. 3, 2000

The International Association for the Properties of Water and Steam

Lucerne, Switzerland
August 2007

Revised Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam
(The revision only relates to the extension of region 5 to 50 MPa)

The International Association for the Properties of Water and Steam

Doorwerth, The Netherlands
September 2009

Revised Release on the IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use

Who are the authors of LibHuAirProp?

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Property Library for *Real* Humid Air, Steam, Water, and Ice

ASHRAE-LibHuAirProp

Contents

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0 Package Contents

0.1 Add-In for 32-bit version of DYMOLA®

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

ZIP file "CD_FluidDYM_ASHRAE_LibHuAirProp.zip" for DYMOLA®

The ZIP file contains the following files:

FluidDYM_ASHRAE_LibHuAirProp_Users_Guide.pdf	User's Guide
FluidDYM_ASHRAE_LibHuAirProp_Setup.exe	Installation program for the FluidDYM Add-In for use in DYMOLA®

0.2 Add-In for 64-bit version of DYMOLA®

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

ZIP file "CD_FluidDYM_ASHRAE_LibHuAirProp_64.zip" for DYMOLA®

The ZIP file contains the following files:

FluidDYM_ASHRAE_LibHuAirProp_Users_Guide.pdf	User's Guide
FluidDYM_ASHRAE_LibHuAirProp_64_Setup.msi	- Self-extracting and self-installing program
Setup.exe	- Installation program for the FluidDYM Add-In for use in DYMOLA®

Part I-P Units

1 Property Library ASHRAE-LibHuAirProp-IP

1.1 Function Overview

1.1.1 Function Overview for Real Moist Air

Functional Dependence	Function Name	Property or Function	Unit of the Result	Page
$a = \mathrm{f}(p,t,W)$	a_ptW_HAP_IP	Thermal diffusivity	ft²/s	3/2
$\alpha_\mathrm{p} = \mathrm{f}(p,t,W)$	alphap_ptW_HAP_IP	Relative pressure coefficient	1/°R	3/3
$\beta_\mathrm{p} = \mathrm{f}(p,t,W)$	betap_ptW_HAP_IP	Isothermal stress coefficient	lb/ft³	3/4
$c = \mathrm{f}(p,t,W)$	c_ptW_HAP_IP	Speed of sound	ft/s	3/5
$c_p = \mathrm{f}(p,t,W)$	cp_ptW_HAP_IP	Specific isobaric heat capacity	Btu/(lb·°R)	3/6
$c_v = \mathrm{f}(p,t,W)$	cv_ptW_HAP_IP	Specific isochoric heat capacity	Btu/(lb·°R)	3/7
$f = \mathrm{f}(p,t)$	f_pt_HAP_IP	Enhancement factor (decimal ratio)	-	3/8
$h = \mathrm{f}(p,t,W)$	h_ptW_HAP_IP	Air-specific enthalpy	$\mathrm{Btu/lb_a}$	3/9
$\eta = \mathrm{f}(p,t,W)$	Eta_ptW_HAP_IP	Dynamic viscosity	lb·s/ft²	3/10
$\kappa = \mathrm{f}(p,t,W)$	Kappa_ptW_HAP_IP	Isentropic exponent	-	3/11
$\lambda = \mathrm{f}(p,t,W)$	Lambda_ptW_HAP_IP	Thermal conductivity	Btu/(h·ft·°R)	3/12
$\nu = \mathrm{f}(p,t,W)$	Ny_ptW_HAP_IP	Kinematic viscosity	ft²/s	3/13
$p = \mathrm{f}(t,s,W)$	p_tsW_HAP_IP	Pressure of humid air	psi	3/14
$p = \mathrm{f}(z_\mathrm{ele})$	p_zele_HAP_IP	Pressure of humid air from elevation	psi	3/15
$p_\mathrm{Air} = \mathrm{f}(p,t,W)$	pAIR_ptW_HAP_IP	Partial pressure of dry air in moist air	psi	3/16
$p_\mathrm{H2O} = \mathrm{f}(p,t,W)$	pH2O_ptW_HAP_IP	Partial pressure of water vapor in moist air	psi	3/17
$p_\mathrm{H2Os} = \mathrm{f}(p,t)$	pH2Os_pt_HAP_IP	Partial saturation pressure of water vapour in moist air	psi	3/18

Functional Dependence	Function Name	Property or Function	Unit of the Result	Page
$\varphi = \mathrm{f}(p,t,W)$	phi_ptW_HAP_IP	Relative humidity (decimal ratio)	-	3/19
$Pr = \mathrm{f}(p,t,W)$	Pr_ptW_HAP_IP	PRANDTL number	-	3/20
$\psi_{\mathrm{Air}} = \mathrm{f}(W)$	PsiAir_W_HAP_IP	Mole fraction of dry air in moist air	$\mathrm{mol_a/mol}$	3/21
$\psi_{\mathrm{H2O}} = \mathrm{f}(W)$	PsiH2O_W_HAP_IP	Mole fraction of water vapor in moist air	$\mathrm{mol_w/mol}$	3/22
$\rho = \mathrm{f}(p,t,W)$	Rho_ptW_HAP_IP	Density	$\mathrm{lb/ft^3}$	3/23
$s = \mathrm{f}(p,t,W)$	s_ptW_HAP_IP	Air-specific entropy	$\mathrm{Btu/(lb_a \cdot °R)}$	3/24
$t = \mathrm{f}(p,h,\varphi)$	t_phphi_HAP_IP	Backward function: temperature from total pressure, air-specific enthalpy and relative humidity	°F	3/25
$t = \mathrm{f}(p,h,W)$	t_phW_HAP_IP	Backward function: temperature from total pressure, enthalpy and humidity ratio	°F	3/26
$t = \mathrm{f}(p,s,W)$	t_psW_HAP_IP	Backward function: temperature from total pressure, entropy and humidity ratio	°F	3/27
$t = \mathrm{f}(p,t_{\mathrm{wb}},W)$	t_ptwbW_HAP_IP	Backward function: temperature from total pressure, wet-bulb temperature and humidity ratio	°F	3/28
$t_{\mathrm{d}} = \mathrm{f}(p,W)$	td_pW_HAP_IP	Dew-point/frost-point temperature	°F	3/29
$t_{\mathrm{s}} = \mathrm{f}(p,p_{\mathrm{H2O}})$	ts_ppH2O_HAP_IP	Backward function: saturation temperature of water from total pressure and partial pressure of water vapor	°F	3/30
$t_{\mathrm{wb}} = \mathrm{f}(p,t,W)$	twb_ptW_HAP_IP	Wet-bulb/ice-bulb temperature	°F	3/31
$u = \mathrm{f}(p,t,W)$	u_ptW_HAP_IP	Air-specific internal energy	$\mathrm{Btu/lb_a}$	3/32
$v = \mathrm{f}(p,t,W)$	v_ptW_HAP_IP	Air-specific volume	$\mathrm{ft^3/lb_a}$	3/33
$W = \mathrm{f}(p,t,p_{\mathrm{H2O}})$	W_ptpH2O_HAP_IP	Humidity ratio from total pressure, temperature, and partial pressure of water vapor	$\mathrm{lb_w/lb_a}$	3/34
$W = \mathrm{f}(p,t,\varphi)$	W_ptphi_HAP_IP	Humidity ratio from total pressure, temperature, and relative humidity	$\mathrm{lb_w/lb_a}$	3/35
$W = \mathrm{f}(p,t_{\mathrm{d}})$	W_ptd_HAP_IP	Humidity ratio from total pressure and dew-point temperature	$\mathrm{lb_w/lb_a}$	3/36

Functional Dependence	Function Name	Property or Function	Unit of the Result	Page
$W = \mathrm{f}(p,t,t_{\mathrm{wb}})$	W_pttwb_HAP_IP	Humidity ratio from total pressure, (dry bulb) temperature, and wet-bulb temperature	lb_w/lb_a	3/37
$W_{\mathrm{s}} = \mathrm{f}(p,t)$	Ws_pt_HAP_IP	Saturation humidity ratio	lb_w/lb_a	3/38
$\xi_{\mathrm{Air}} = \mathrm{f}(W)$	XiAir_W_HAP_IP	Mass fraction of dry air in moist air	lb_a/lb	3/39
$\xi_{\mathrm{H2O}} = \mathrm{f}(W)$	XiH2O_W_HAP_IP	Mass fraction of water vapor in moist air	lb_w/lb	3/40
$Z = \mathrm{f}(p,t,W)$	Z_ptW_HAP_IP	Compression factor (decimal ratio)	-	3/41

Range of Validity of Thermodynamic Properties

Property	Range of Validity					
Pressure:	0.00145	≤	p	≤	1450.4	psi
Temperature:	–225.67	≤	t	≤	662	°F
Humidity ratio:	0	≤	W	≤	10	lb_w/lb_a
Relative humidity:	0	≤	φ	≤	1	(decimal ratio)
Dew-point temperature:	–225.67	≤	t_d	≤	662	°F
Wet-bulb temperature:	–225.67	≤	t_{wb}	≤	662	°F

Units

Symbol	Quantity	Unit
p	Pressure	psi
t	Temperature	°F
W	Humidity ratio	lb_w/lb_a (lb water / lb dry air)
φ	Relative humidity	(decimal ratio)
t_d	Dew point temperature	°F
t_{wb}	Wet bulb temperature	°F

Range of Validity of Transport Properties

Property	Range of Validity					
Pressure:	0.00145	≤	p	≤	1450.4	psi
Temperature:	–99.67	≤	t	≤	662	°F
Humidity ratio:	0	≤	W	≤	10	lb_w/lb_a
Relative humidity:	0	≤	φ	≤	1	(decimal ratio)

Molar Masses

Component	Molar Mass	Reference
Dry Air	63.859 lb/kmol	[17]
Water	39.7168998 lb/kmol	[5], [6]

Reference States

Property	Dry Air	Steam, Water, and Ice
Pressure	14.6959 psi	p_s(32.018°F) = 0.088714 psi
Temperature	32°F	32.018°F
Enthalpy	0 Btu/lb	0.00026301926 Btu/lb
Entropy	0 Btu/(lb·°R)	0 Btu/(lb·°R)

1.1.2 Function Overview for Steam and Water for Temperatures $t \geq 32°F$

Functional Dependence	Function Name	Property or Function	Unit of the Result	Page
$h_{liq} = f(p,t)$	hliq_pt_97_IP	Specific enthalpy of liquid water	Btu/lb	3/43
$h_{liq,s} = f(t)$	hliqs_t_97_IP	Specific enthalpy of saturated liquid water	Btu/lb	3/44
$h_{vap,s} = f(t)$	hvaps_t_97_IP	Specific enthalpy of saturated water vapor	Btu/lb	3/45
$p_s = f(t)$	ps_t_97_IP	Saturation pressure of water	psi	3/46
$s_{liq} = f(p,t)$	sliq_pt_97_IP	Specific entropy of liquid water	Btu/(lb·°R)	3/47
$s_{liq,s} = f(t)$	sliqs_t_97_IP	Specific entropy of saturated liquid water	Btu/(lb·°R)	3/48
$s_{vap,s} = f(t)$	svaps_t_97_IP	Specific entropy of saturated water vapor	Btu/(lb·°R)	3/49
$t_s = f(p)$	ts_p_97_IP	Saturation temperature of water	°F	3/50
$v_{liq} = f(p,t)$	vliq_pt_97_IP	Specific volume of liquid water	ft^3/lb	3/51
$v_{liq,s} = f(t)$	vliqs_t_97_IP	Specific volume of saturated liquid water	ft^3/lb	3/52
$v_{vap,s} = f(t)$	vvaps_t_97_IP	Specific volume of saturated water vapor	ft^3/lb	3/53

Range of Validity

Property	Range of Validity					
Pressure:	0.00145	≤	p	≤	1450.4	psi
Temperature:	32	≤	t	≤	662	°F

Reference State

Property	Water Vapor and Liquid Water
Pressure	p_s(32.018°F) = 0.088714 psi
Temperature	32.018°F
Enthalpy	0.00026301926 Btu/lb
Entropy	0 Btu/(lb·°R)

Units

Symbol	Quantity	Unit
p	Pressure	psi
t	Temperature	°F

1.1.3 Function Overview for Steam and Ice for Temperatures $t \leq 32°F$

Functional Dependence	Function Name	Property	Unit of the Result	Page
$h_{ice,sub} = f(t)$	hicesub_t_06_IP	Specific enthalpy of saturated ice	Btu/lb	3/55
$h_{vap,sub} = f(t)$	hvapsub_t_95_IP	Specific enthalpy of saturated water vapor	Btu/lb	3/56
$p_{mel} = f(t)$	pmel_t_08_IP	Melting pressure of ice	psi	3/57
$p_{sub} = f(t)$	psub_t_08_IP	Sublimation pressure of ice	psi	3/58
$s_{ice,sub} = f(t)$	sicesub_t_06_IP	Specific entropy of saturated ice	Btu/(lb·°R)	3/59
$s_{vap,sub} = f(t)$	svapsub_t_95_IP	Specific entropy of saturated water vapor	Btu/(lb·°R)	3/60
$t_{mel} = f(p)$	tmel_p_08_IP	Melting temperature of ice	°F	3/61
$t_{sub} = f(p)$	tsub_p_08_IP	Sublimation temperature of ice	°F	3/62
$v_{ice,sub} = f(t)$	vicesub_t_06_IP	Specific volume of saturated ice	ft^3/lb	3/63
$v_{vap,sub} = f(t)$	vvapsub_t_95_IP	Specific volume of saturated water vapor	ft^3/lb	3/64

Range of Validity

Property	Range of Validity					
Pressure:	p_{sub}(–225.67°F) = 1.7407E-12	≤	p	≤	1450.4	psi
Temperature:	–225.67	≤	t	≤	32	°F

Units

Symbol	Quantity	Unit
p	Pressure	psi
t	Temperature	°F

Reference State

Property	Water Vapor and Ice
Pressure	p_s(32.018°F) = 0.088714 psi
Temperature	32.018°F
Enthalpy	0.00026301926 Btu/lb
Entropy	0 Btu/(lb·°R)

1.2 Conversion of SI and I-P Units

Property		Conversion: SI Units → I-P Units	Conversion: I-P Units → SI Units	Units SI	Units I-P
Thermal diffusivity	a	$\frac{a_{IP}}{\frac{ft^2}{s}} = \frac{a_{SI}}{\frac{m^2}{s}} \times 10.76391042$	$\frac{a_{SI}}{\frac{m^2}{s}} = \frac{a_{IP}}{\frac{ft^2}{s}} \times 0.0929304$	m²/s	ft²/s
Relative pressure coefficient	α_p	$\frac{\alpha_{p,IP}}{\frac{1}{°R}} = \frac{\alpha_{p,SI}}{\frac{1}{K}} \times \frac{9}{5}$	$\frac{\alpha_{p,SI}}{\frac{1}{K}} = \frac{\alpha_{p,IP}}{\frac{1}{°R}} \times \frac{5}{9}$	1/K	1/°R
Isothermal stress coefficient	β_p	$\frac{\beta_{p,IP}}{\frac{lb}{ft^3}} = \frac{\beta_{p,SI}}{\frac{kg}{m^3}} \times 0.062428$	$\frac{\beta_{p,SI}}{\frac{kg}{m^3}} = \frac{\beta_{p,IP}}{\frac{lb}{ft^3}} \times 16.018463$	kg/m³	lb/ft³
Speed of sound	c	$\frac{c_{IP}}{\frac{ft}{s}} = \frac{c_{SI}}{\frac{m}{s}} \times 3.2808399$	$\frac{c_{SI}}{\frac{m}{s}} = \frac{c_{IP}}{\frac{ft}{s}} \times 0.3048$	m/s	ft/s
Specific isobaric heat capacity	c_p	$\frac{c_{p,IP}}{\frac{Btu}{lb\ °R}} = \frac{c_{p,SI}}{\frac{kJ}{kg\ K}} \times 0.2388459$	$\frac{c_{p,SI}}{\frac{kJ}{kg\ K}} = \frac{c_{p,IP}}{\frac{Btu}{lb\ °R}} \times 4.1868$	kJ/(kg·K)	Btu/(lb·°R)
Specific isochoric heat capacity	c_v	$\frac{c_{v,IP}}{\frac{Btu}{lb\ °R}} = \frac{c_{v,SI}}{\frac{kJ}{kg\ K}} \times 0.2388459$	$\frac{c_{v,SI}}{\frac{kJ}{kg\ K}} = \frac{c_{v,IP}}{\frac{Btu}{lb\ °R}} \times 4.1868$	kJ/(kg·K)	Btu/(lb·°R)
Dynamic viscosity	η	$\frac{\eta_{IP}}{\frac{lb\ s}{ft^2}} = \frac{\eta_{SI}}{\frac{Pa}{s}} \times 0.02088543$	$\frac{\eta_{SI}}{\frac{Pa}{s}} = \frac{\eta_{IP}}{\frac{lb\ s}{ft^2}} \times 47.880259$	Pa·s	lb·s/ft²
Enhancement factor	f	$f_{IP} = f_{SI}$	$f_{SI} = f_{IP}$	-	-

Property		Conversion: SI Units → I-P Units	Conversion: I-P Units → SI Units	Units SI	Units I-P
Air-specific enthalpy (moist air)	h	$\frac{h_{IP}}{\frac{Btu}{lb_a}} = \frac{h_{SI}}{\frac{kJ}{kg_a}} \times 0.4299226 + 7.68565365666$	$\frac{h_{SI}}{\frac{kJ}{kg_a}} = \left(\frac{h_{IP}}{\frac{Btu}{lb_a}} - 7.68565365666\right) \times 2.326$	kJ/kg_a	Btu/lb_a
Specific enthalpy (water, water vapor, ice)	h_w	$\frac{h_{IP}}{\frac{Btu}{lb}} = \frac{h_{SI}}{\frac{kJ}{kg}} \times 0.4299226$	$\frac{h_{SI}}{\frac{kJ}{kg}} = \frac{h_{IP}}{\frac{Btu}{lb}} \times 2.326$	kJ/kg	Btu/lb
Isentropic exponent	κ	$\kappa_{IP} = \kappa_{SI}$	$\kappa_{SI} = \kappa_{IP}$	-	-
Thermal conductivity	λ	$\frac{\lambda_{IP}}{\frac{Btu}{h\ ft\ °R}} = \frac{\lambda_{SI}}{\frac{W}{m\ K}} \times 0.57778932$	$\frac{\lambda_{SI}}{\frac{W}{m\ K}} = \frac{\lambda_{IP}}{\frac{Btu}{h\ ft\ °R}} \times 1.73073467$	W/(m·K)	Btu/(h·ft·°R)
Kinematic viscosity	ν	$\frac{\nu_{IP}}{\frac{ft^2}{s}} = \frac{\nu_{SI}}{\frac{m^2}{s}} \times 10.763910417$	$\frac{\nu_{SI}}{\frac{m^2}{s}} = \frac{\nu_{IP}}{\frac{ft^2}{s}} \times 0.092903040$	m^2/s	ft^2/s
Pressure	p	$\frac{p_{IP}}{psi} = \frac{p_{SI}}{kPa} \times 0.14503774$	$\frac{p_{SI}}{kPa} = \frac{p_{IP}}{psi} \times 6.894757$	kPa	psi
Relative humidity	φ	$\varphi_{IP} = \varphi_{SI}$	$\varphi_{SI} = \varphi_{IP}$	-	-
Prandtl number	Pr	$Pr_{IP} = Pr_{IP}$	$Pr_{SI} = Pr_{IP}$	-	-
Mole fraction	ψ	$\psi_{IP} = \psi_{SI}$	$\psi_{SI} = \psi_{IP}$	mol/mol	mol/mol
Density	ρ	$\frac{\rho_{IP}}{\frac{lb}{ft^3}} = \frac{\rho_{SI}}{\frac{kg}{m^3}} \times 0.062428$	$\frac{\rho_{SI}}{\frac{kg}{m^3}} = \frac{\rho_{IP}}{\frac{lb}{ft^3}} \times 16.018463$	kg/m^3	lb/ft^3
Air-specific entropy (moist air)	s	$\frac{s_{IP}}{\frac{Btu}{lb_a\ °R}} = \frac{s_{SI}}{\frac{kJ}{kg_a\ K}} \times 0.2388459 + 0.01616365106$	$\frac{s_{SI}}{\frac{kJ}{kg_a\ K}} = \left(\frac{s_{IP}}{\frac{Btu}{lb_a\ °R}} - 0.01616365106\right) \times 4.1868$	$kJ/(kg_a \cdot K)$	$Btu/(lb_a \cdot °R)$

Property	Conversion: SI Units → I-P Units	Conversion: I-P Units→ SI Units	Units SI	Units I-P
Specific entropy (water, water vapor, ice) s_w	$\frac{s_{IP}}{\frac{Btu}{lb_a\ °R}} = \frac{s_{SI}}{\frac{kJ}{kg_a\ K}} \times 0.23884589$	$\frac{s_{SI}}{\frac{kJ}{kg_a\ K}} = \frac{s_{IP}}{\frac{Btu}{lb_a\ °R}} \times 4.1868$	kJ/(kg$_a$·K)	Btu/(lb$_a$·°R)
Temperature t	$\frac{t_{IP}}{°F} = \frac{t_{SI}}{°C} \times \frac{9}{5} + 32$	$\frac{t_{SI}}{°C} = \left(\frac{t_{IP}}{°F} - 32\right) \times \frac{5}{9}$	°C	°F
Air-specific internal energy (moist air) u	$(u = h - pv)$ $\frac{u_{IP}}{\frac{Btu}{lb_a}} = \frac{h_{SI}}{\frac{kJ}{kg_a}} \times 0.4299226 + 7.68565365666 - \frac{p_{SI}}{kPa} \times 0.145037738 \cdot \frac{v_{SI}}{\frac{m^3}{kg_a}} \times 16.018453$	$(u = h - pv)$ $\frac{u_{SI}}{\frac{kJ}{kg_a}} = \left(\frac{h_{IP}}{\frac{Btu}{lb_a}} - 7.68565365666\right) \times 2.236 - \frac{p_{IP}}{psi} \times 6.894757293 \cdot \frac{v_{SIP}}{\frac{ft^3}{lb_a}} \times 0.062428$	kJ/kg$_a$	Btu/lb$_a$
Air-specific volume (moist air) v	$\frac{v_{IP}}{\frac{ft^3}{lb_a}} = \frac{v_{SI}}{\frac{m^3}{kg_a}} \times 16.018453$	$\frac{v_{SI}}{\frac{m^3}{kg_a}} = \frac{v_{IP}}{\frac{ft^3}{lb_a}} \times 0.062428$	m^3/kg$_a$	ft^3/lb$_a$
Specific volume (water, water vapor, ice) v_w	$\frac{v_{IP}}{\frac{ft^3}{lb}} = \frac{v_{SI}}{\frac{m^3}{kg}} \times 16.018453$	$\frac{v_{SI}}{\frac{m^3}{kg}} = \frac{v_{IP}}{\frac{ft^3}{lb}} \times 0.062428$	m^3/kg	ft^3/lb
Humidity ratio W	$W_{IP} = W_{SI}$	$W_{SI} = W_{IP}$	kg$_w$/kg$_a$	lb$_w$/lb$_a$
Mass fraction ξ	$\xi_{IP} = \xi_{SI}$	$\xi_{SI} = \xi_{IP}$	kg$_w$/kg	lb$_w$/lb
Compression factor Z	$Z_{IP} = Z_{SI}$	$Z_{SI} = Z_{IP}$	-	-

1.3 Calculation Algorithms

1.3.1 Algorithms for Real Moist Air

The properties of moist air are calculated from the modified Hyland-Wexler model given in Herrmann, Kretzschmar, and Gatley (HKG) [1], [2]. The modifications incorporate:

- the value for the universal molar gas constant from the CODATA standard by Mohr and Taylor [22]
- the value for the molar mass of dry air from Gatley et al. [17] and that of water from IAPWS-95 [5], [6]
- the calculation of the ideal-gas parts of the heat capacity, enthalpy, and entropy for dry air from the fundamental equation of Lemmon et al. [14]
- the calculation of the ideal-gas parts of the heat capacity, enthalpy, and entropy for water vapor from IAPWS-IF97 [7], [8], [9] for $t \geq 32°\text{F}$ and from IAPWS-95 [5], [6] for $t \leq 32°\text{F}$
- the calculation of the vapor-pressure enhancement factor from the equation given by the models of Hyland and Wexler [21]
- the calculation of the second and third molar virial coefficients B_{aa} and C_{aaa} for dry air from the fundamental equation of Lemmon et al. [14] according to Feistel et al. [24]
- the calculation of the second and third molar virial coefficients B_{ww} and C_{www} for water and steam from IAPWS-95 [5], [6] according to Feistel et al. [24]
- the calculation of the air-water second molar cross-virial coefficient B_{aw} from Harvey and Huang [15]
- the calculation of the air-water third molar cross-virial coefficients C_{aaw} and C_{aww} from Nelson and Sauer [12], [13]
- the calculation of the saturation pressure of water from IAPWS-IF97 [7], [8], [9] for $t \geq 32°\text{F}$ and of the sublimation pressure of water from IAPWS-08 [11] for $t \leq 32°\text{F}$
- the calculation of the isothermal compressibility of saturated liquid water from IAPWS-IF97 [7], [8], [9] for $t \geq 32°\text{F}$ and that of ice from IAPWS-06 [10] for $t \leq 32°\text{F}$ in the determination of the vapor-pressure enhancement factor
- the calculation of Henry's constant from the IAPWS Guideline 2004 [16] in the determination of the enhancement factor. The mole fractions for the three main components of dry air were taken from Lemmon et al. [14]. Argon was not considered in the calculation of Henry’s constant in the former research projects, but it is now the third component of dry air.

The transport properties of moist air are calculated from the model given in Herrmann et al. [3], [4].

1.3.2 Algorithms for Steam and Water for Temperatures $t \geq 32°F$

The *p-T* diagram in Fig. 1 shows the formulations used for water and water vapor. The temperature range above 32°F is covered by IAPWS-IF97 [7], [8], [9]:

- The saturation line is calculated from the IAPWS-IF97 saturation pressure equation $p_s^{97}(t)$ and saturation temperature equation $t_s^{97}(p)$.
- The properties in the liquid region including saturated-liquid line are calculated from the fundamental equation of the IAPWS-IF97 region 1.
- The properties in the vapor region including saturated-vapor line are calculated from the fundamental equation of the IAPWS-IF97 region 2.

1.3.3 Algorithms for Steam and Ice for Temperatures $t \leq 32°F$

- The sublimation curve is covered by the IAPWS-08 sublimation pressure equation $p_{subl}^{08}(t)$ [11] (see Fig. 1).
- The properties of ice including saturated ice are determined by the fundamental equation of the IAPWS-06 [10].
- The properties of vapor including saturated vapor are calculated from the fundamental equation of IAPWS-95 [5], [6].

1.3.4 Overview of the Applied Formulations for Steam, Water, and Ice

The following *p-T* diagram shows the used IAPWS Formulations and the ranges where they are applied.

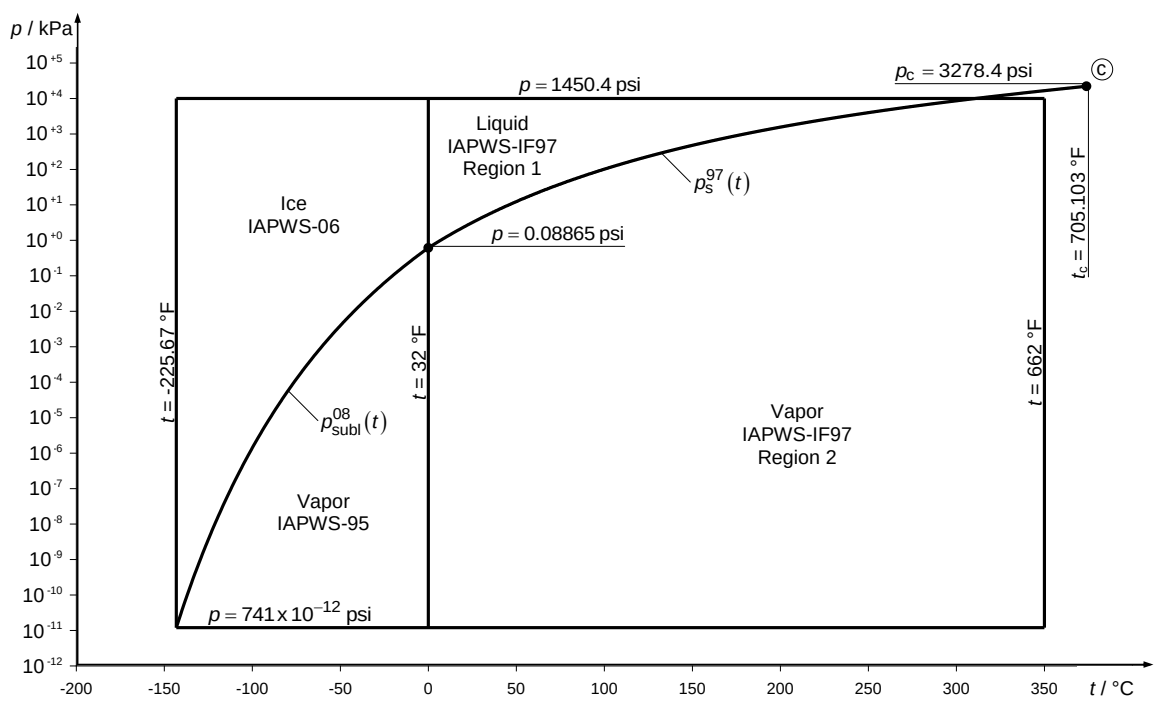


Figure 1: *p-T* diagram with used IAPWS formulations for steam, water, and ice.

2 Add-In FluidDYM for DYMOLA® for ASHRAE-LibHuAirProp-IP

2.1 Installing FluidDYM

The FluidDYM Add-In has been developed to calculate thermophysical properties in Dymola® more conveniently. Within Dymola®, it enables the direct call of functions relating to real moist air, steam, water, and ice from the ASHRAE-LibHuAirProp-IP property library.

The 32-bit version of FluidDYM LibHuAirProp runs on both the 32-bit and 64-bit version of Dymola®.

2.1.1 Installing FluidDYM including LibHuAirProp

In this section, the installation of FluidDYM and LibHuAirProp 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_ASHRE_LibHuAirProp.zip," (32-bit version)

"CD_FluidDYM_ASHRE_LibHuAirProp_64.zip," (64-bit version)

you will see the folder

CD_FluidDYM_ASHRAE_LibHuAirProp (32-bit version)

CD_FluidDYM_ASHRAE_LibHuAirProp_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_ASHRAE_LibHuAirProp_Users_Guide.pdf
FluidDYM_LibHuAirProp_32_Setup.msi
setup.exe.

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

FluidDYM_ASHRAE_LibHuAirProp_Users_Guide.pdf
FluidDYM_LibHuAirProp_64_Setup.msi
Setup.exe.

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

setup.exe.

If the "Microsoft Visual C++ 2010 x86 Redistributable" is not running on your computer yet, installation will start with a window noting that the "Visual C++ 2010 runtime library (x86)" will be installed on your machine (see Figure 2.1.1).

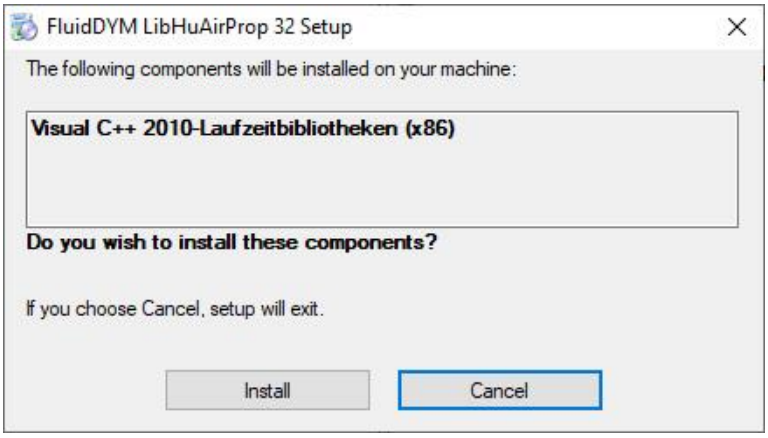


Figure 2.1.1: Installing the "Visual C++ 2010 runtime library (x86)"

Click on "Install" to continue.

Note.

If there is a newer version of "Microsoft Visual C++ 2010 x86 Redistributable" package installed on your computer than the one provided in this installation setup.exe will stop and is followed by an error message. In this case please start the installation again by double-clicking the file "FluidDYM_LibHuAirProp_32_Setup.msi" and skip the next three steps described in the User's Guide.

In the following window you are required to accept the Microsoft® license terms to install the "Microsoft Visual C++ 2010 x86 Redistributable" by ticking the box next to "I have read and accept the license terms" (see Figure 2.1.2).

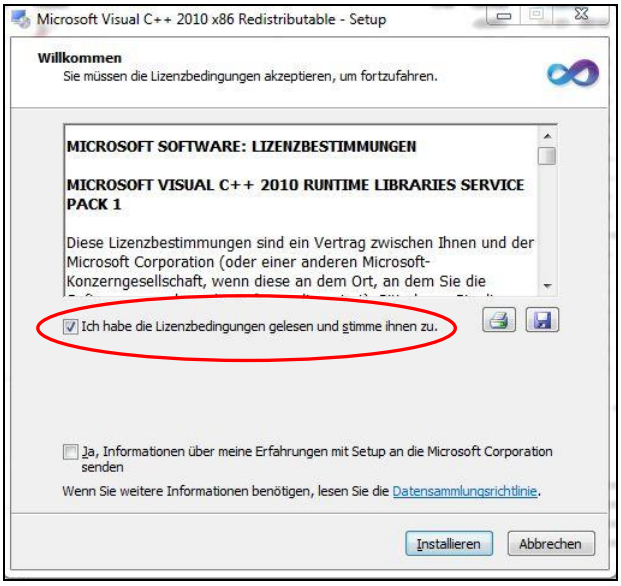


Figure 2.1.2: Accepting the license terms

Now click on "Install" to continue installation.

After the "Microsoft Visual C++ 2010 x86 Redistributable" has been installed, you will see the sentence "Microsoft Visual C++ 2010 x86 Redistributable has been installed." Confirm this by clicking "Finish."

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:\Uders\..\Documents\FluidDYM_32\LibHuAirProp.

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

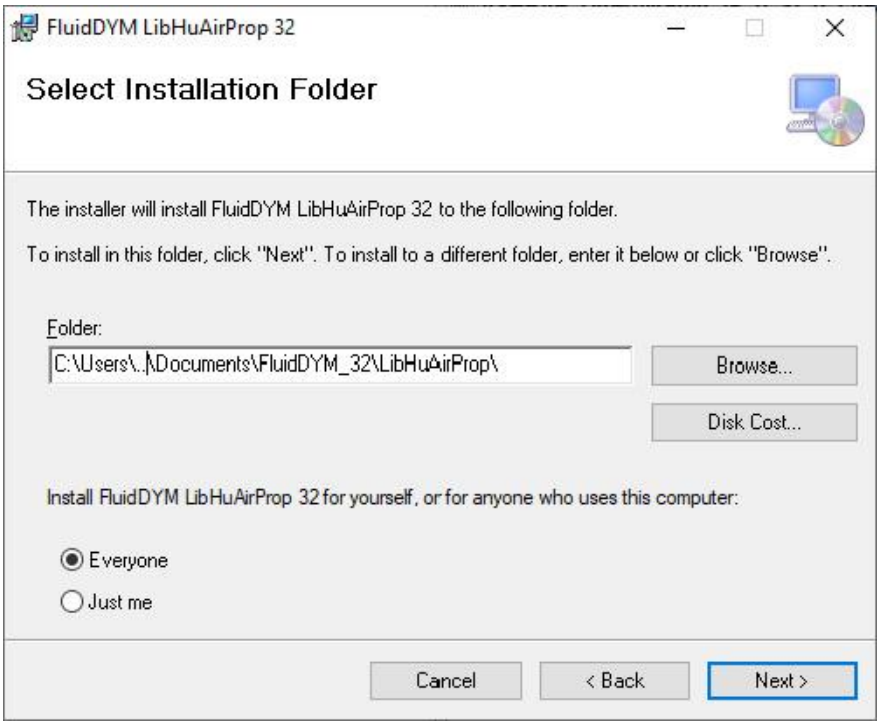


Figure 2.1.3: "Choose Destination Location"

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

After FluidDYM has been installed, you will see the sentence "FluidDYM LibHuAirProp 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 LibHuAirProp property library double-click the file

setup.exe.

If the "Microsoft Visual C++ 2010 x64 Redistributable Pack" is not running on your computer yet, installation will start with a window noting that the "Visual C++ 2010 runtime library (x64)" will be installed on your machine (see 2.1.4).

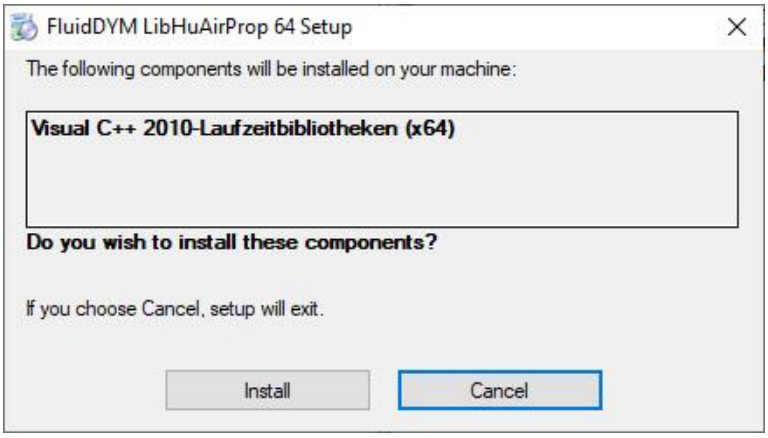


Figure 2.1.4: Installing the "Visual C++ 2010 runtime library (x64)"

Click on "Install" to continue.

Note.

If there is a newer version of "Microsoft Visual C++ 2010 x64 Redistributable" package installed on your computer than the one provided in this installation setup.exe will stop and is followed by an error message. In this case please start the installation again by double-clicking the file "FluidDYM_LibHuAirProp_64_Setup.msi" and skip the next three steps described in the User's Guide.

In the following window you are required to accept the Microsoft® license terms to install the "Microsoft Visual C++ 2010 x64 Redistributable Pack" by ticking the box next to "I have read and accept the license terms" (see Figure 2.1.5).

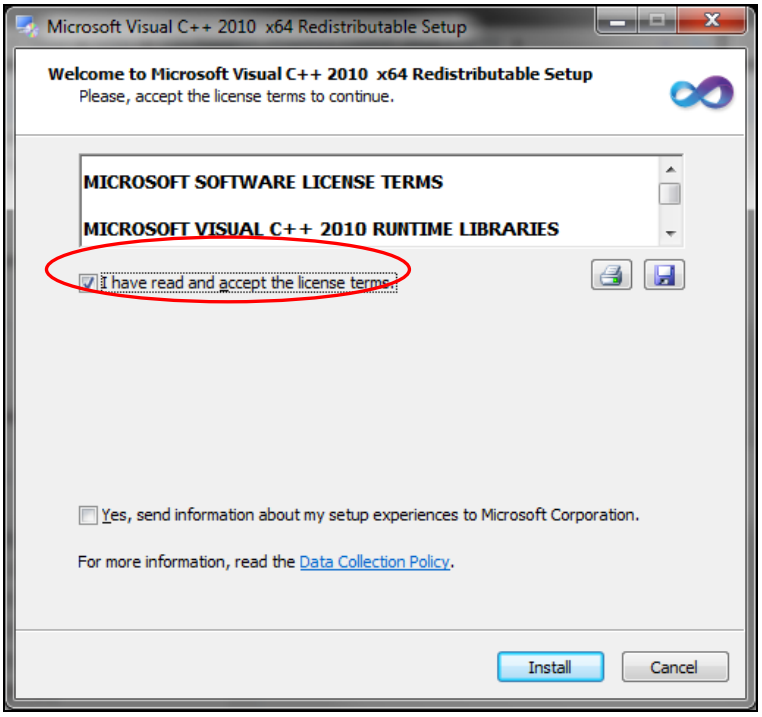


Figure 2.1.5: Accepting the license terms

Now click on "Install" to continue installation.

After the "Microsoft Visual C++ 2010 x64 Redistributable Pack" has been installed, you will see the sentence "Microsoft Visual C++ 2010 x64 Redistributable has been installed." Confirm this by clicking "Finish."

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\FluidDYM_64\LibHuAirProp.

By clicking the "Browse…" button, you can change the installation directory before installation (see figure below). If you change the installation directory, please add "\FluidDYM_64\LibHuAirProp\" after changing.

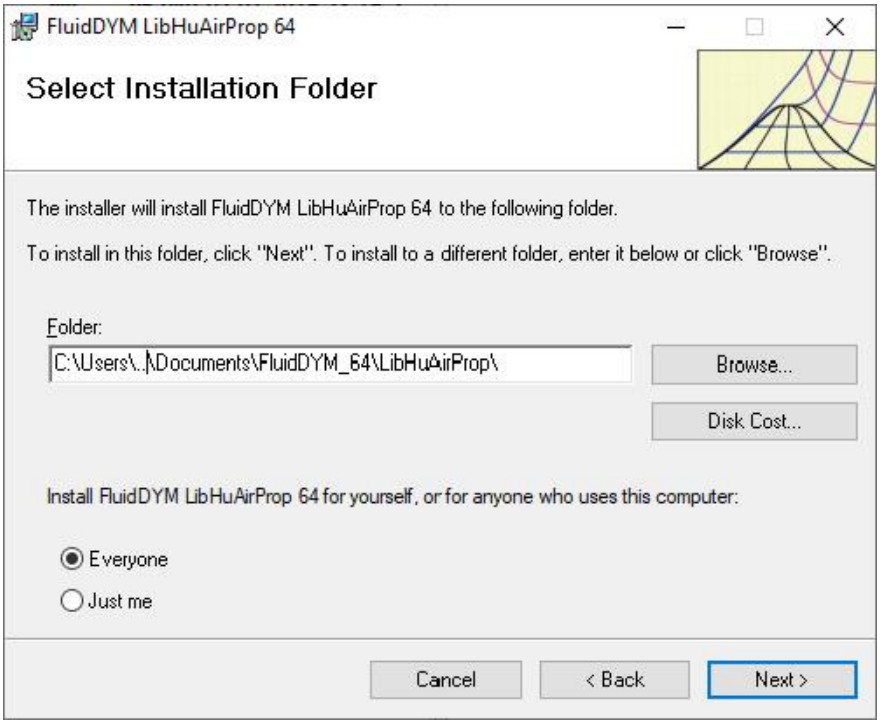


Figure 2.1.6: "Choose Destination Location"

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

After FluidDYM has been installed, you will see the sentence "FluidDYM LibHuAirProp 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 for both the I-P and the SI version into the directory chosen during the installation process:

- Dynamic link libraries "LibHuAirProp_IP.dll" and "LibHuAirProp_SI.dll"

- Link up dynamic link libraries "LibHuAirProp_IP_Dymola.dll", "LibHuAirProp_SI_Dymola.dll" and other necessary system DLL files

- Library files "LibHuAirProp_IP_Dymola.lib" and "LibHuAirProp_SI_Dymola.lib"

- Header files "LibHuAirProp_IP_Dymola.h", "LibHuAirProp_SI_Dymola.h"

- Modelica file "FluidDYM_LibHuAirProp_IP.mo" including the following property functions:

a_ptW_HAP_IP
alphap_ptW_HAP_IP
betap_ptW_HAP_IP
c_ptW_HAP_IP
cp_ptW_HAP_IP
cv_ptW_HAP_IP
f_pt_HAP_IP
h_ptW_HAP_IP
Eta_ptW_HAP_IP
Kappa_ptW_HAP_IP
Lambda_ptW_HAP_IP
Ny_ptW_HAP_IP
p_tsW_HAP_IP
p_zele_HAP_IP
pAIR_ptW_HAP_IP
pH2O_ptW_HAP_IP
pH2Os_pt_HAP_IP
phi_ptW_HAP_IP
Pr_ptW_HAP_IP
PsiAir_W_HAP_IP
PsiH2O_W_HAP_IP
Rho_ptW_HAP_IP
s_ptW_HAP_IP
t_phW_HAP_IP
t_psW_HAP_IP
t_ptwbW_HAP_IP
td_pW_HAP_IP
ts_ppH2Os_HAP_IP
twb_ptW_HAP_IP
u_ptW_HAP_IP
v_ptW_HAP_IP
W_ptpH2O_HAP_IP
W_ptphi_HAP_IP
W_ptd_HAP_IP
W_pttwb_HAP_IP
Ws_pt_HAP_IP
XiAir_W_HAP_IP
XiH2O_W_HAP_IP
Z_ptW_HAP_IP
hliq_pt_97_IP
hliqs_t_97_IP
hvaps_t_97_IP
ps_t_97_IP
sliq_pt_97_IP
sliqs_t_97_IP
svaps_t_97_IP
ts_p_97_IP
vliq_pt_97_IP
vliqs_t_97_IP
vvaps_t_97_IP
hicesub_t_06_IP
hvapsub_t_95_IP
pmel_t_08_IP
psub_t_08_IP
sicesub_t_06_IP
svapsub_t_95_IP
tmel_p_08_IP
tsub_p_08_IP
vicesub_t_06_IP
vvapsub_t_95_IP

- Modelica file "FluidDYM_LibHuAirProp_SI.mo" including the following property functions:

a_ptW_HAP_SI
alphap_ptW_HAP_SI
betap_ptW_HAP_SI
c_ptW_HAP_SI
cp_ptW_HAP_SI
cv_ptW_HAP_SI
f_pt_HAP_SI
h_ptW_HAP_SI
Eta_ptW_HAP_SI
Kappa_ptW_HAP_SI
Lambda_ptW_HAP_SI
Ny_ptW_HAP_SI
p_tsW_HAP_SI
p_zele_HAP_SI
pAIR_ptW_HAP_SI
pH2O_ptW_HAP_SI
pH2Os_pt_HAP_SI
phi_ptW_HAP_SI
PR_ptW_HAP_SI
PsiAir_W_HAP_SI
PsiH2O_W_HAP_SI
Rho_ptW_HAP_SI
s_ptW_HAP_SI
t_phW_HAP_SI
t_psW_HAP_SI
t_ptwbW_HAP_SI
td_pW_HAP_SI
ts_ppH2Os_HAP_SI
twb_ptW_HAP_SI
u_ptW_HAP_SI
v_ptW_HAP_SI
W_ptpH2O_HAP_SI
W_ptphi_HAP_SI
W_ptd_HAP_SI
W_pttwb_HAP_SI
Ws_pt_HAP_SI
XiAir_W_HAP_SI
XiH2O_W_HAP_SI
Z_ptW_HAP_SI
hliq_pt_97_SI
hliqs_t_97_SI
hvaps_t_97_SI
ps_t_97_SI
sliq_pt_97_SI
sliqs_t_97_SI
svaps_t_97_SI
ts_p_97_SI
vliq_pt_9_SI
vliqs_t_97_SI
vvaps_t_97_SI
hicesub_t_06_SI
hvapsub_t_95_SI
pmel_t_08_SI
psub_t_08_SI
sicesub_t_06_SI
svapsub_t_95_SI
tmel_p_08_SI
tsub_p_08_SI
vicesub_t_06_SI
vvapsub_t_95_SI

2.1.2 The FluidDYM Help System

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_HuAirProp_IP" block on the left and then click on "Users_Guide_IP" (see Figure 2.1.7).

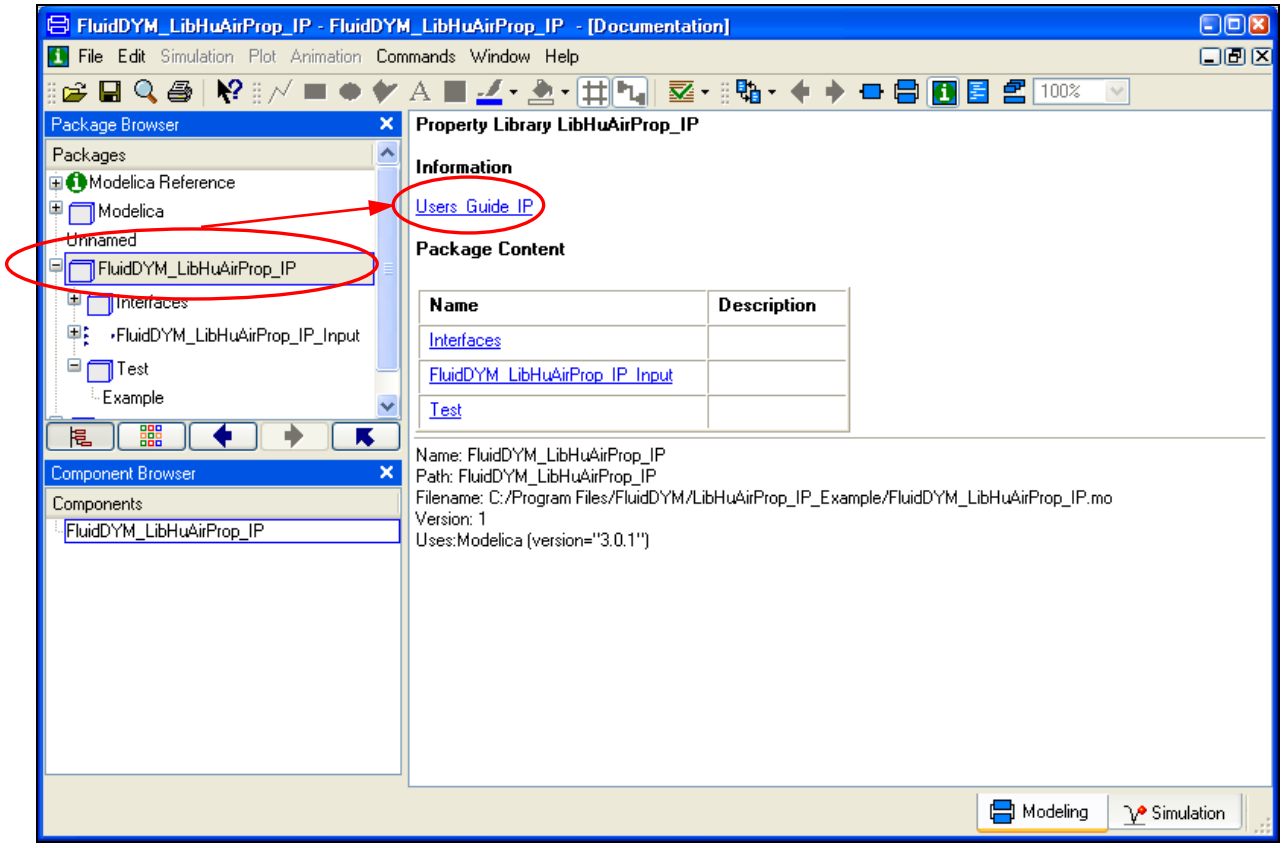


Figure 2.1.7: Selecting the "Users_Guide_IP"

- 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_LibHuAirProp_IP_Input" block on the left (see Figure 2.1.8).

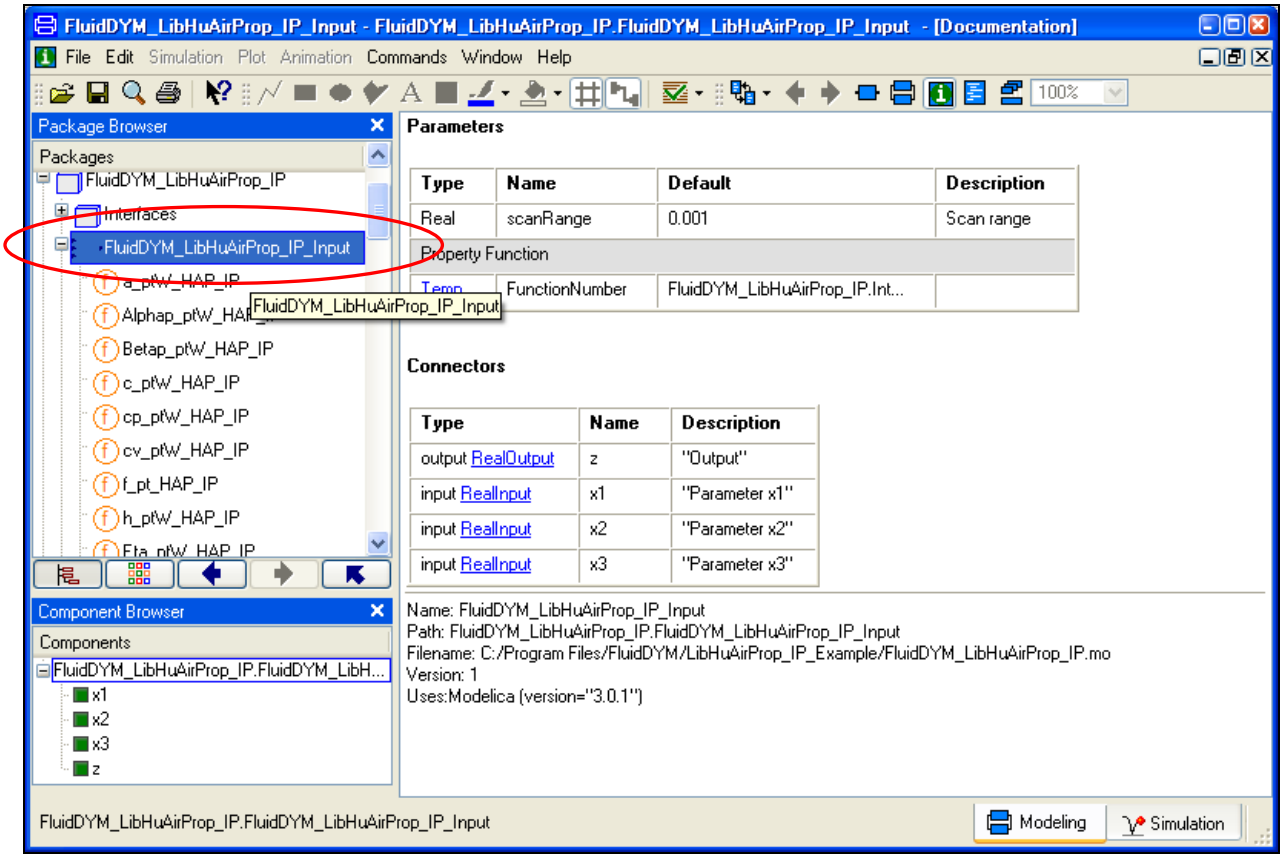


Figure 2.1.8: Selected "FluidDYM_LibHuAirProp_IP_Input" Block

- Below "FluidDYM_LibHuAirProp_IP_Input" you will see all functions of the LibHuAirProp_IP property function.
- Now select a function, e.g. "h_ptW_HAP_IP", and then click on "Users_Guide_IP" (see Figure 2.1.9).

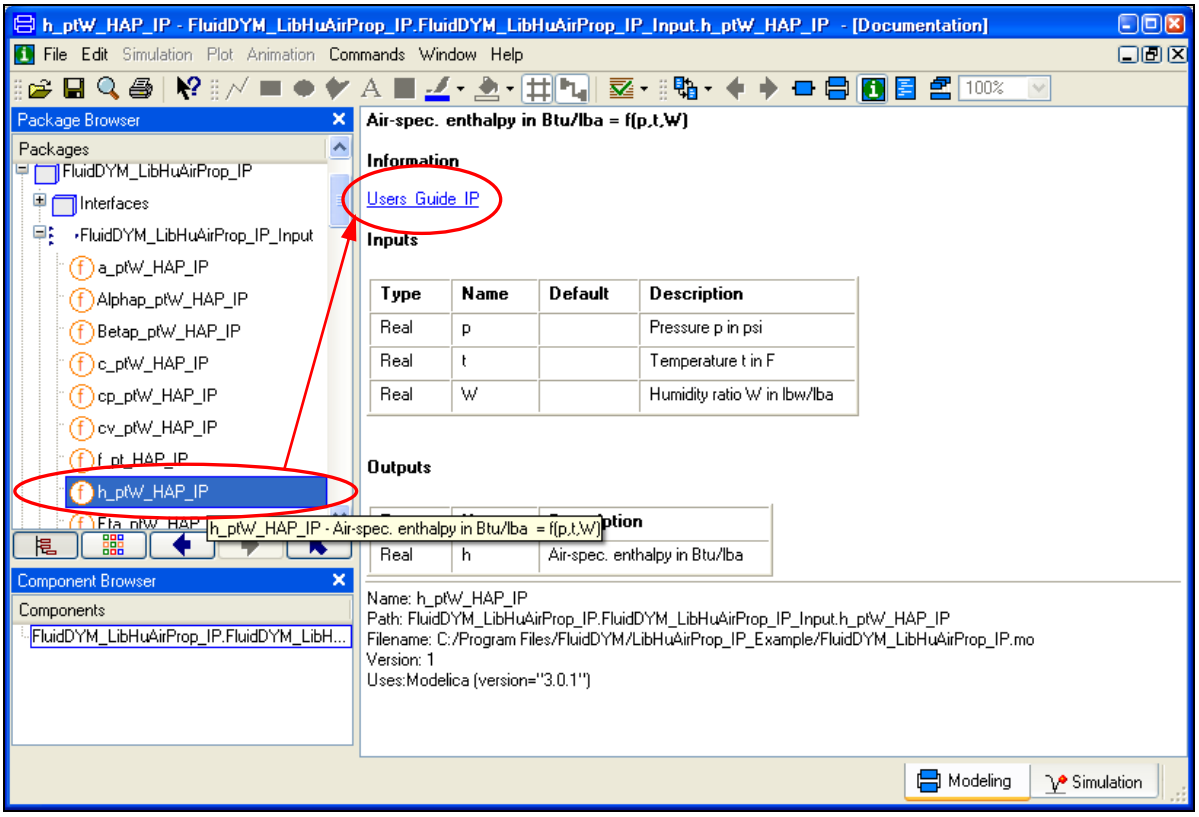


Figure 2.1.9: Marking the "h_ptW_HAP_IP" function and selecting the "Users_Guide_IP"

- You will now see the help page of the selected function, here "h_ptW_HAP_IP", in your default web browser (see Figure 2.1.10).

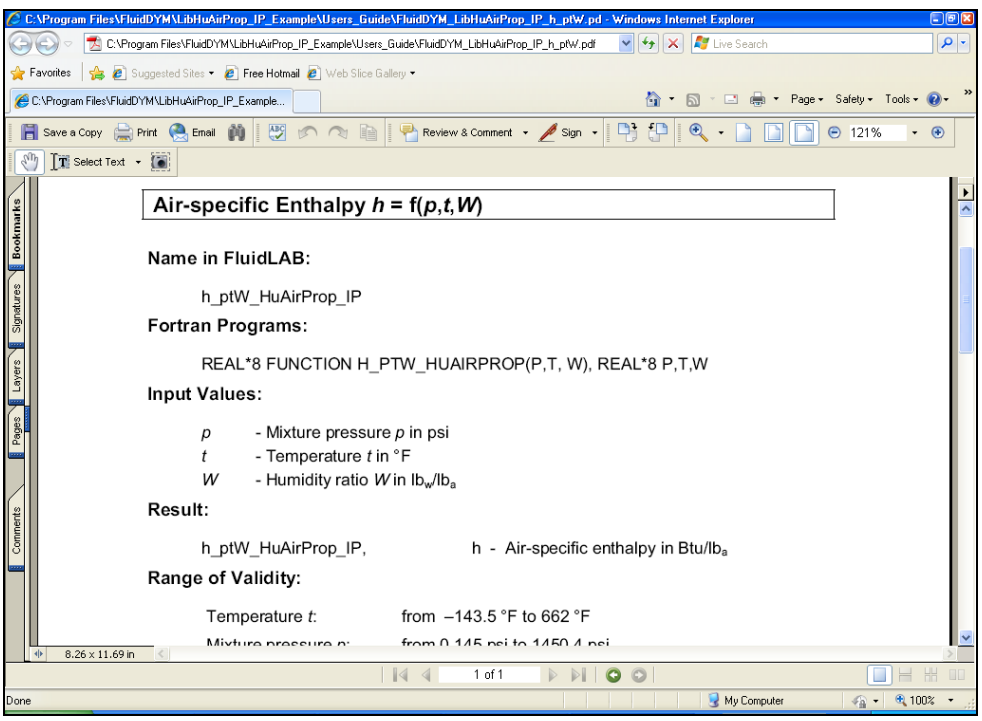


Figure 2.1.10: Help page of the function "h_ptW_HAP_IP" in the web browser

2.2 Licensing the LibHuAirProp Property Library

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

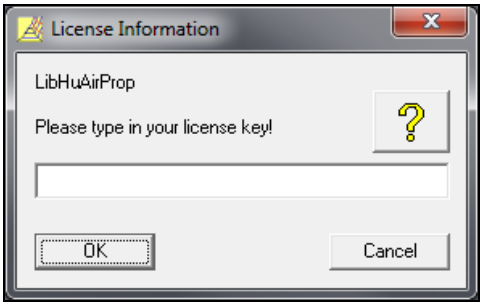


Figure 2.2.1: "License Information" window

Here you are asked to type in the license key, which you have obtained from Kretzschmar Consulting Engineers. If you do not have this, or have any questions, you will find contact information on the "Content" page of this User's Guide or by clicking the yellow question mark in the "License Information" window.

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

The "License Information" window will appear every time you use FluidDYM LibHuAirProp until you enter a license code to complete registration. If you decide not to use FluidDYM LibHuAirProp, you can uninstall the program following the instructions given in section 2.4 of this User's Guide.

With this procedure, both the LibHuAirProp-IP and LibHuAirProp-SI property libraries have been licensed.

2.3 Example: Calculation of *h* = f(*p*,*t*,*W*)

Now we will calculate, step by step, the specific enthalpy *h* of moist air as a function of pressure *p*, temperature *t* and humidity ratio *W*, 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" button and select "Details".
- Switch into the program directory of FluidDYM, which you specified during the installation, in which you will find the folder "\LibHuAirProp;"
- Create the folder "\LibHuAirProp_IP_Example" by clicking on "File" in the Explorer menu, then "New" in the menu which appears, and then selecting "Folder". Name the new folder "\LibHuAirProp_IP_Example".
- Switch into the directory "\LibHuAirProp" within "\FluidDYM_32" or "FluidDYM_64".

In order to calculate the function *h* = f(*p*,*t*,*W*), the following files are necessary.

For the **32-bit version of** FluidDYM copy these files into the example directory "C:\...\FluidDYM_32\LibHuAirProp_IP_Example":

- "advapi32.dll"
- "Dforrt.dll"
- "Dformd.dll"
- "FluidDYM_HuAirProp_IP.mo"
- "LCKCE.dll"
- "LibHuAirProp_IP.dll"
- "LibHuAirProp_IP_Dymola.dll"
- "LibHuAirProp_IP_Dymola.h"
- "LibHuAirProp_IP_Dymola.lib"
- "msvcp60.dll"
- "msvcrt.dll"
- "libifcoremd.dll"
- "libiocomp5md.dll"
- "libmmd.dll"
- the folder "Users_Guide_IP"

- Mark up these files, then click "Edit" in the upper menu bar and select "Copy".
- Switch into the directory "C:\...\FluidDYM_32\LibHuAirProp_IP_Example", click "Edit" and then "Paste".

For the **64-bit version** of FluidDYM copy these files into the folder "LibHuAirProp_IP_Example" in the installation directory:

- "FluidDYM_HuAirProp_IP.mo"
- "LCKCE.dll"
- "LibHuAirProp_IP.dll"
- "LibHuAirProp_IP_Dymola.dll"
- "LibHuAirProp_IP_Dymola.h"
- "LibHuAirProp_IP_Dymola.lib"
- "libifcoremd.dll"
- "libiocomp5md.dll"
- "libmmd.dll"
- the folder "Users_Guide_IP"

- Mark up these files, then click "Edit" in the upper menu bar and select "Copy".
- Switch into the directory "C:\...\FluidDYM_64\LibHuAirProp_IP_Example", click "Edit" and then "Paste".
- Start Dymola®.
- Now click on "File" in the Dymola® menu bar and select "Open" (see Figure 2.3.1).

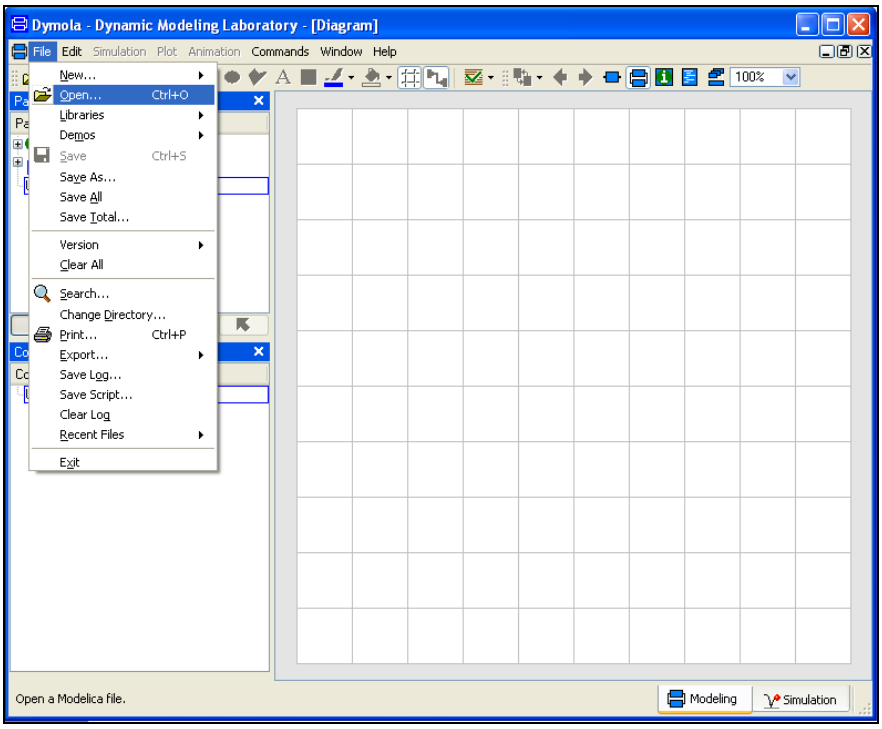


Figure 2.3.1: Selecting the menu entry "Open"

- Search and click on the directory "C:\...\LibHuAirProp_IP_Example" in the menu that appears.
- Select the "FluidDYM_LibHuAirProp_IP.mo" file and click on the "Open" button (see Figure 2.3.2)

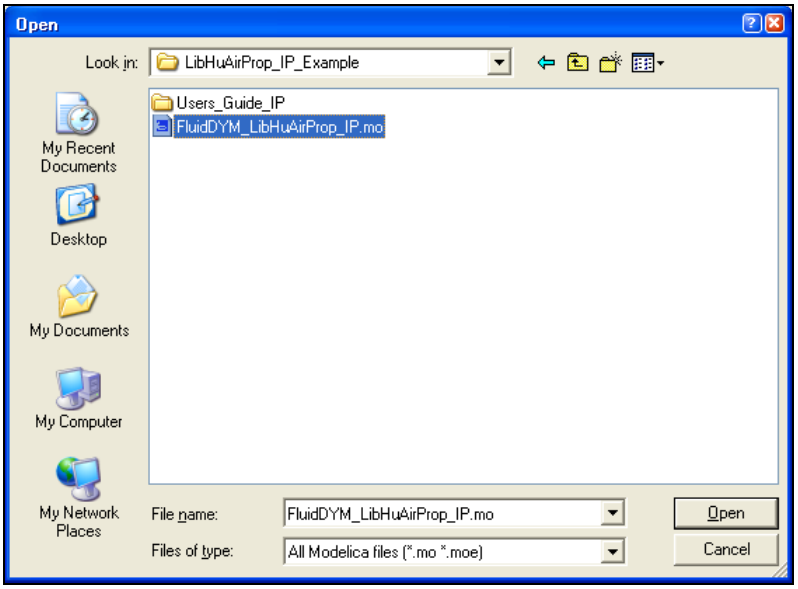


Figure 2.3.2: Selecting the *FluidDYM_HuAirProp_IP.mo* file

- The library will be loaded by Dymola® which may take a few seconds.
- After Dymola® has finished loading the LibHuAirProp_IP library, you will see the window shown in Figure 2.3.3.

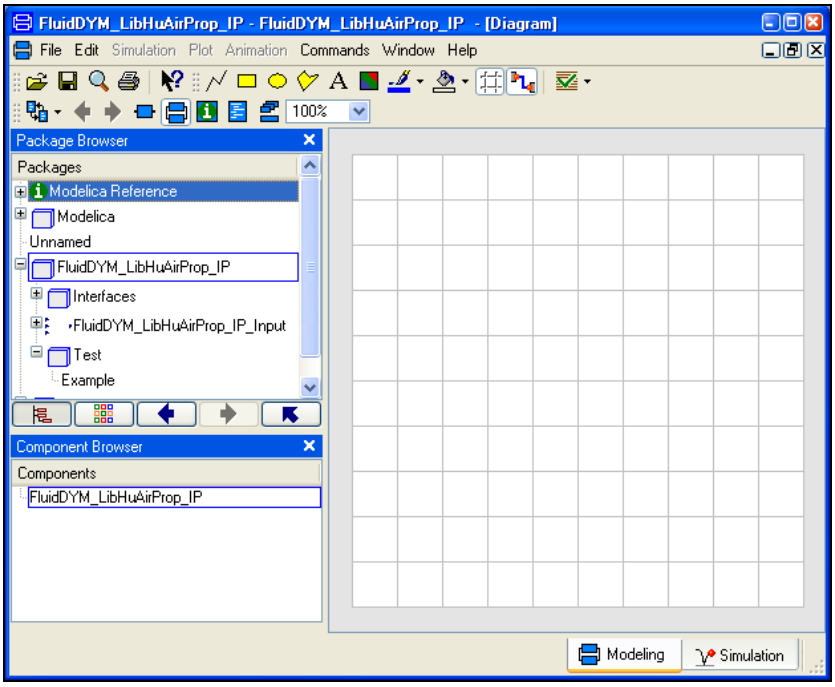


Figure 2.3.3: Dymola® window after loading the *LibHuAirProp_IP* library

- Now, click on "File" in the Dymola® menu bar and select "Change Directory…" in order to open the folder "\LibHuAirProp_IP_Example" (see Figure 2.3.4).

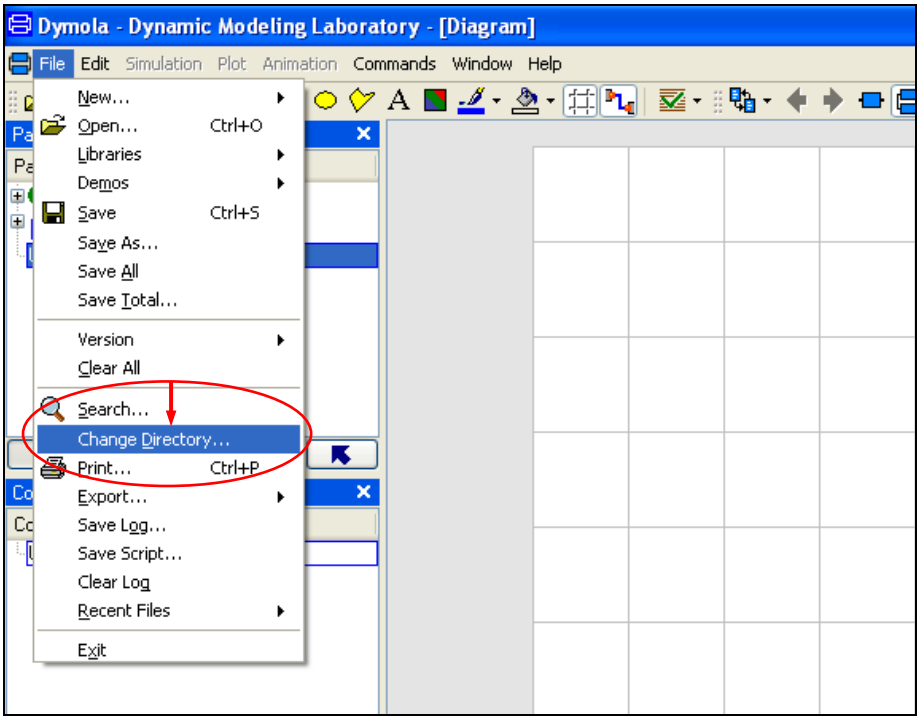


Figure 2.3.4: Selecting the menu entry "Change Directory…"

- Search and click on the directory "C:\...\LibHuAirProp_IP_Example" in the menu that appears (see figure below).

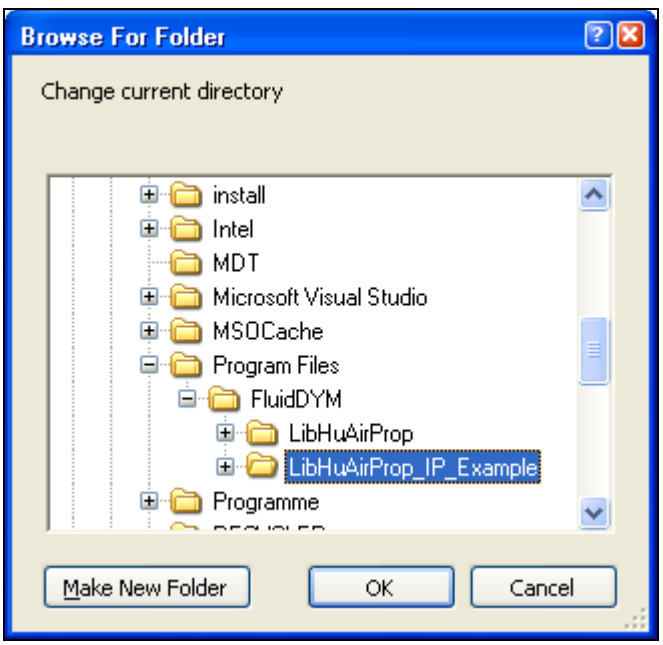


Figure 2.3.5: Selecting the *LibHuAirProp_IP_Example* directory

- 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_ptW_HAP_IP" as follows for calculating $h = f(p,t,W)$.

- Click on the Dymola® block "Test," which can be found in the FluidDYM_HuAirProp_IP package

in the "Package Browser" on the left hand side of the Dymola® window. Here choose Example 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:

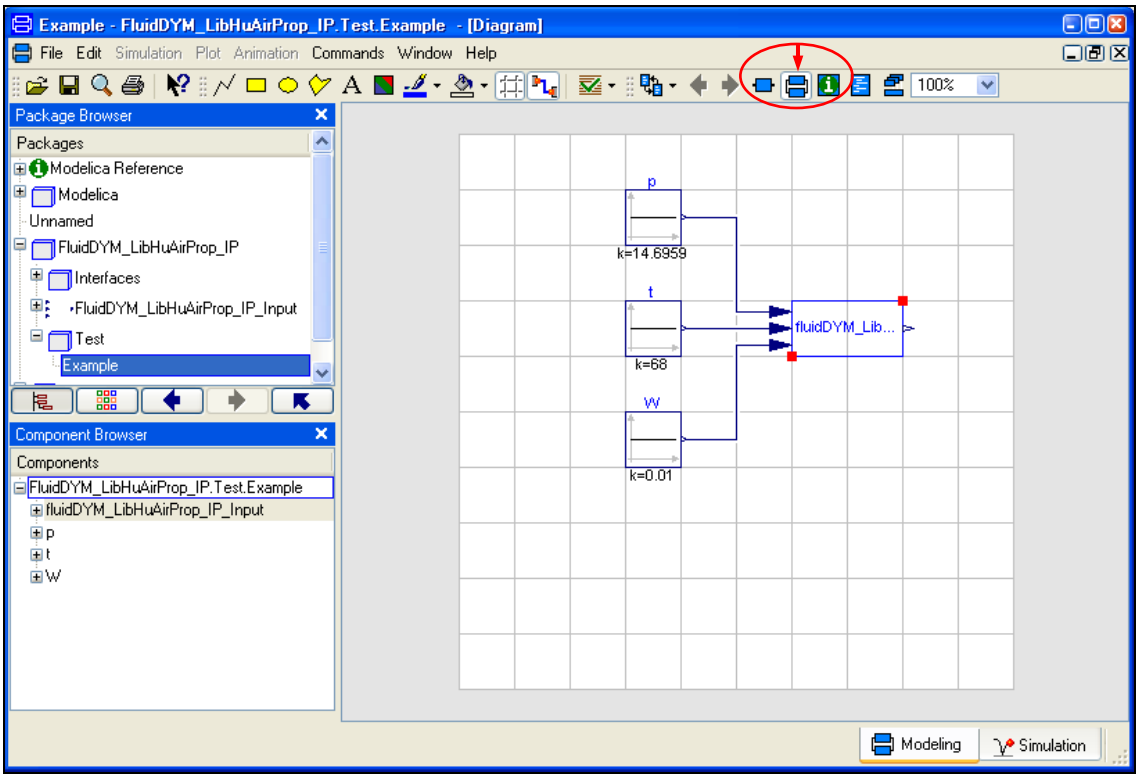


Figure 2.3.6: Dymola® in Diagram Mode

- Now double-click on the "fluidDYM_LibHuAirProp_IP_Input" block on the right hand side of the Dymola® window.
- Search and click the "h_ptW_HAP_IP" function next to "Function Number" in the menu that appears (see figure below).

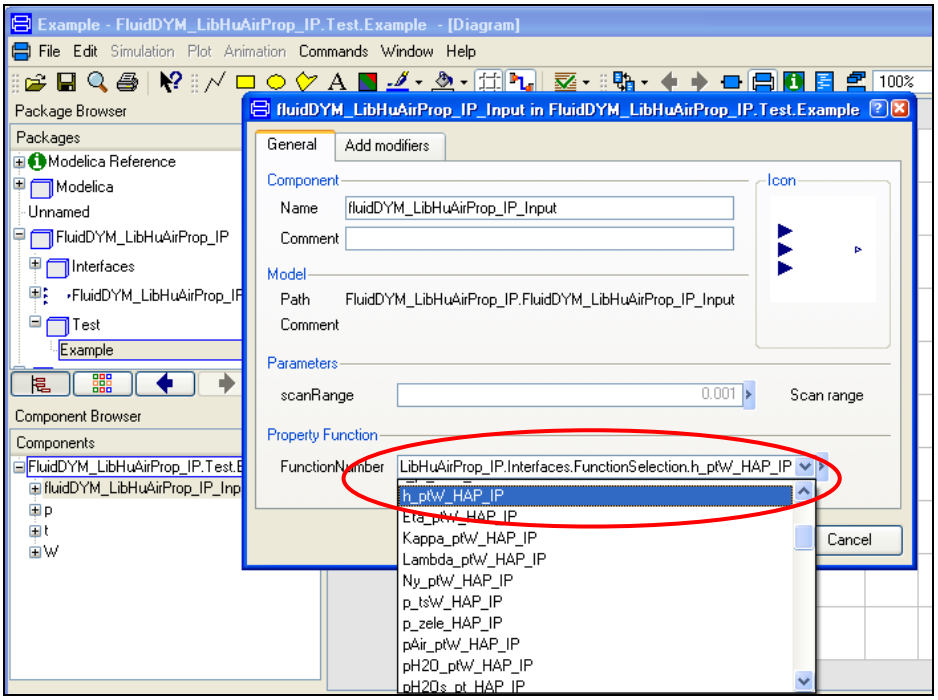


Figure 2.3.7: Choosing the function *h_ptW_HAP_IP*

- 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. If you enter the value 1, for example, the property will be calculated once per second. Do not change the preset value of 0.001 for our example calculation.

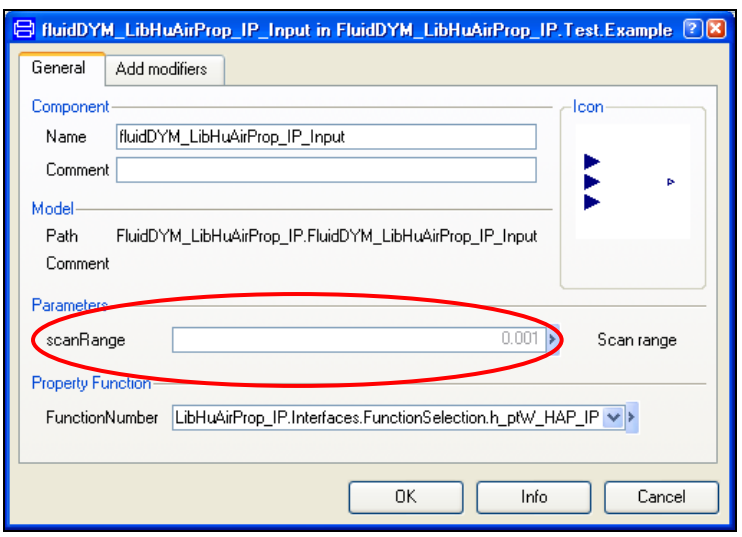


Figure 2.3.8: Setting the scan range

- Now we will configure the input parameters *p*, *t*, and *W*. When calculating a function with only two input parameters, the third input parameter will not be defined.
- First, double click on the "p" block which represents the first input parameter, here the pressure *p* in psi (see Figure 2.3.9).

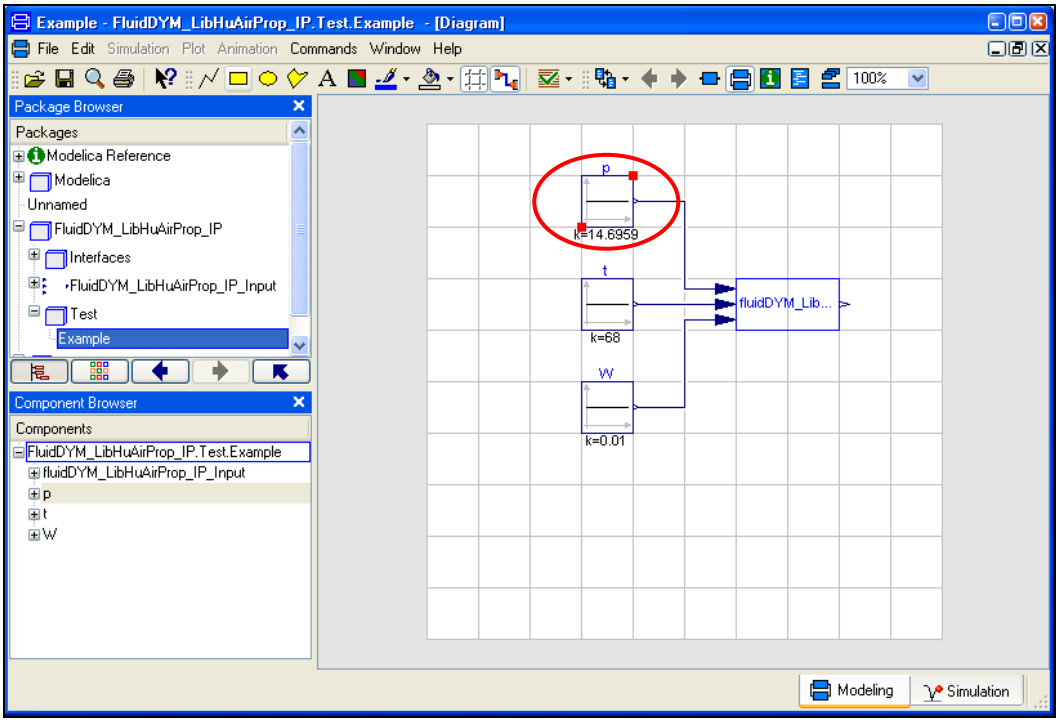


Figure 2.3.9: "Parameter *p* in psi" block in Dymola®

- Enter the value 14.6959 on the line next to "k" in the dialog window which appears and then click the "OK" button (see Figure 2.3.10).

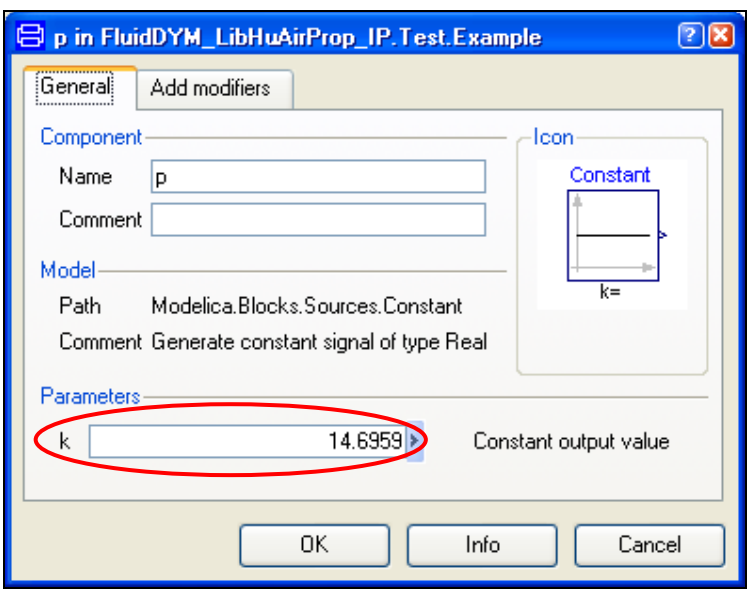


Figure 2.3.10: Entering the value for the pressure *p*

- Now, double click on the "t" block which represents the second input parameter, here the temperature *t* in °F.
- Enter the value 68 on the line next to "k" in the dialog window which appears and then click the "OK" button (see Figure 2.3.11).

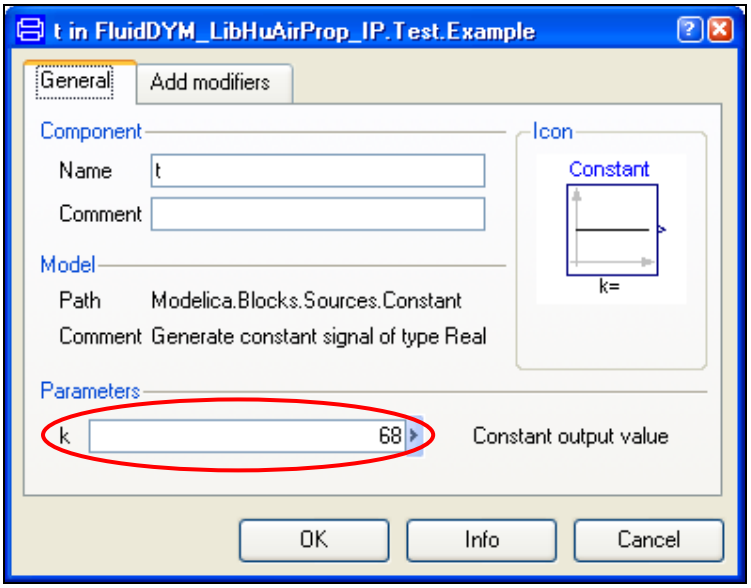


Figure 2.3.11: Entering the value for the temperature *t*

- Now, double click on the "W" block which represents the third input parameter, here the humidity ratio *W* in lb_w/lb_a.
- Enter the value 0.01 on the line next to "k" in the dialog window which appears and then click the "OK" button (see Figure 2.3.12).

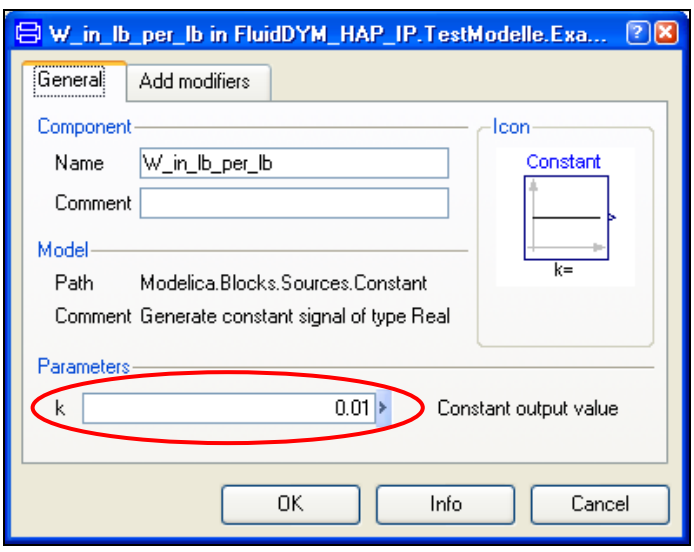
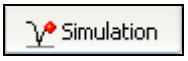


Figure 2.3.12: Entering the value for the humidity ratio *W*

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 2.3.13 you can see what the Dymola® "Simulation Mode" looks like.

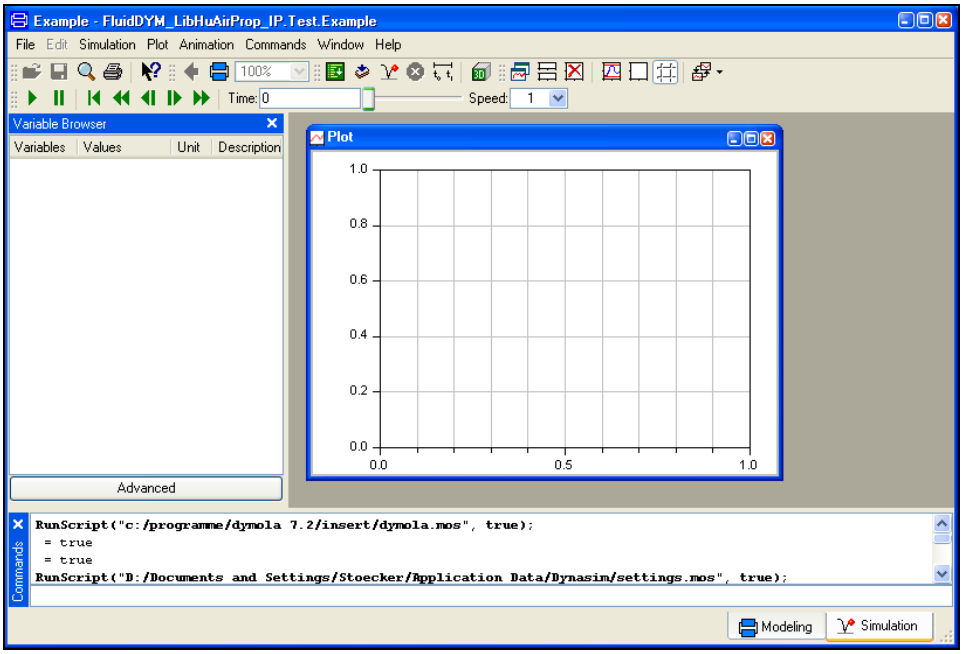


Figure 2.3.13: "Simulation Mode" window

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 LibHuAirProp 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"

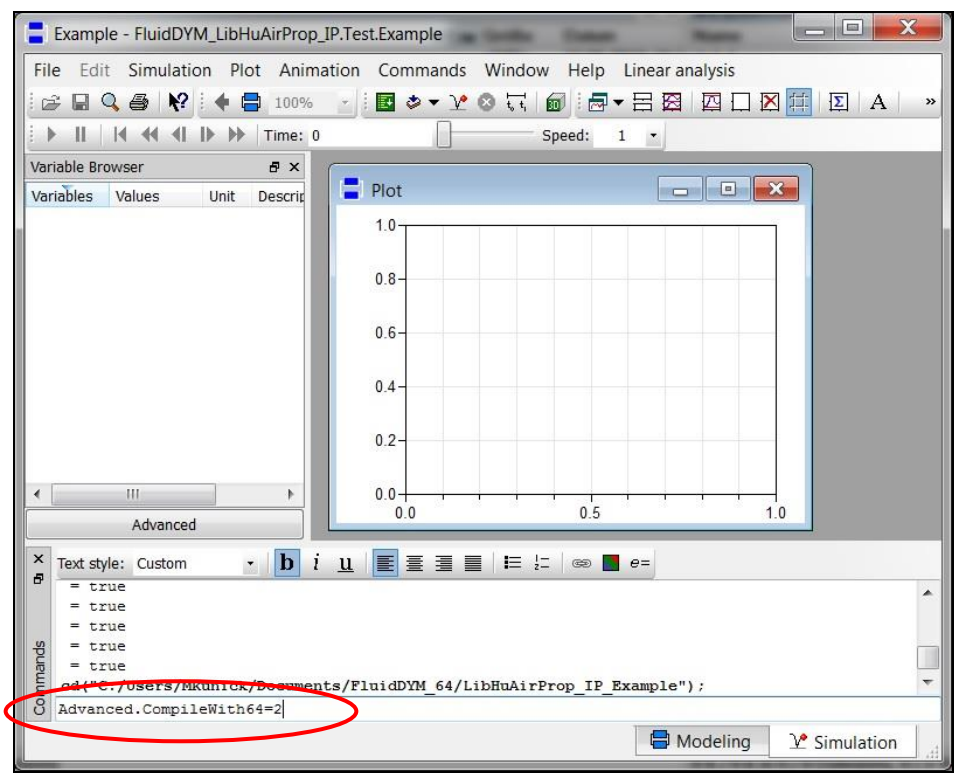


Figure 2.3.14: "Simulation Mode" window with 64-bit command

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

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.

- 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 2.3.15):

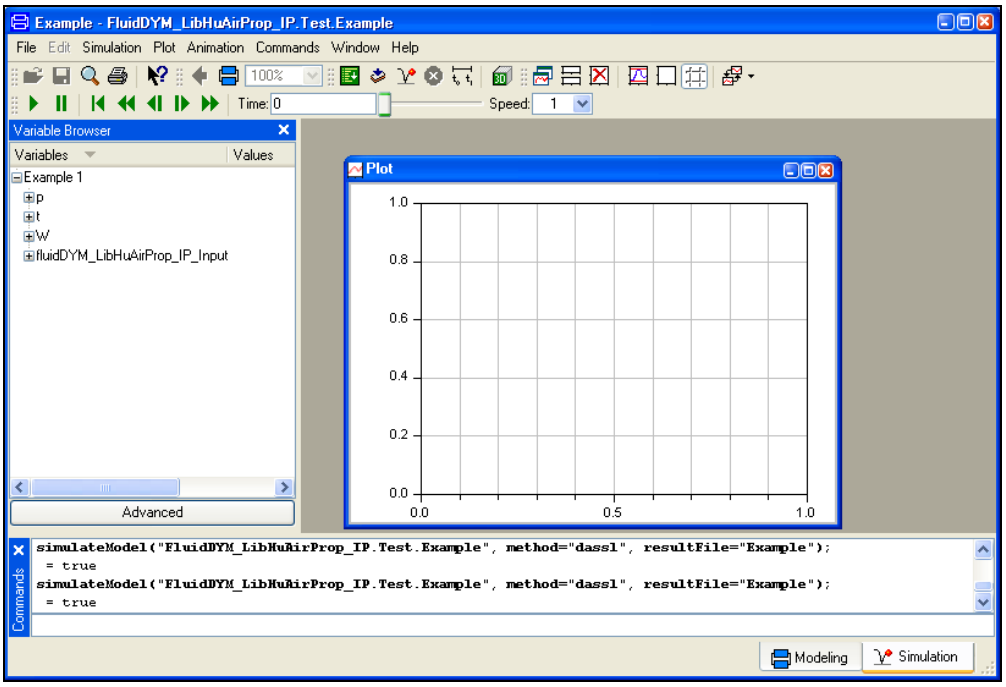


Figure 2.3.15: "Variable Browser" with new entries

- By clicking on the "NewPlotWindow" button , a new diagram window will be opened.
- Click on "fluidDYM_LibHuAirProp_IP_Input" within the "Variable Browser"; then you will see the input and output parameters "scanRange", "FunctionNumber", "z", "x1", "x2", and "x3" (see Figure 2.3.16).

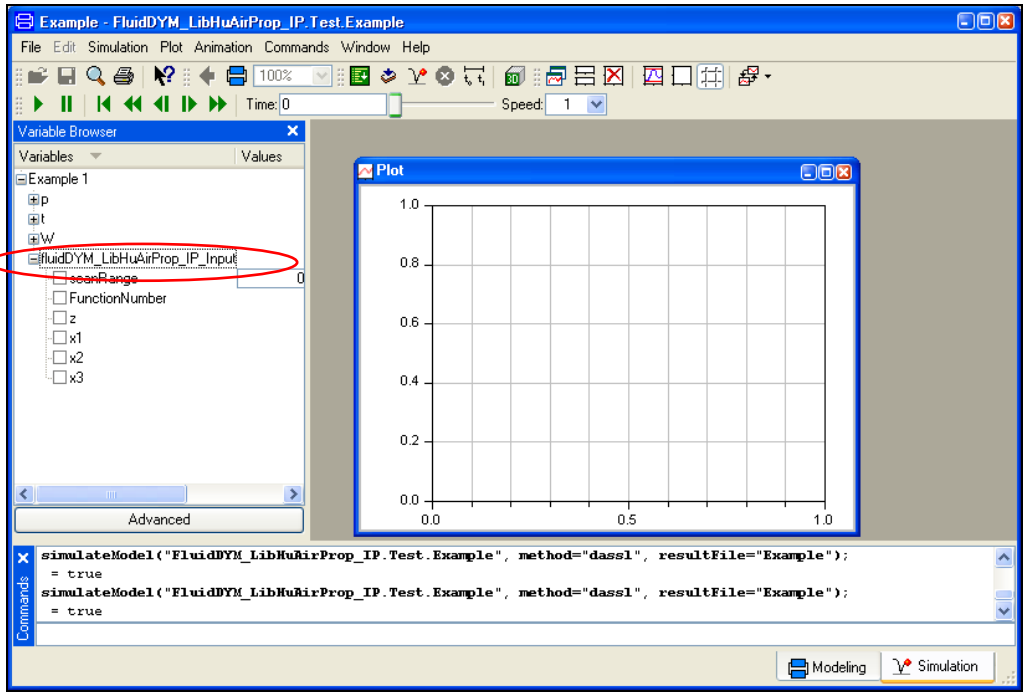


Figure 2.3.16: Parameters of *fluidDYM_LibHuAirProp_IP_Input*

- 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 2.3.17).

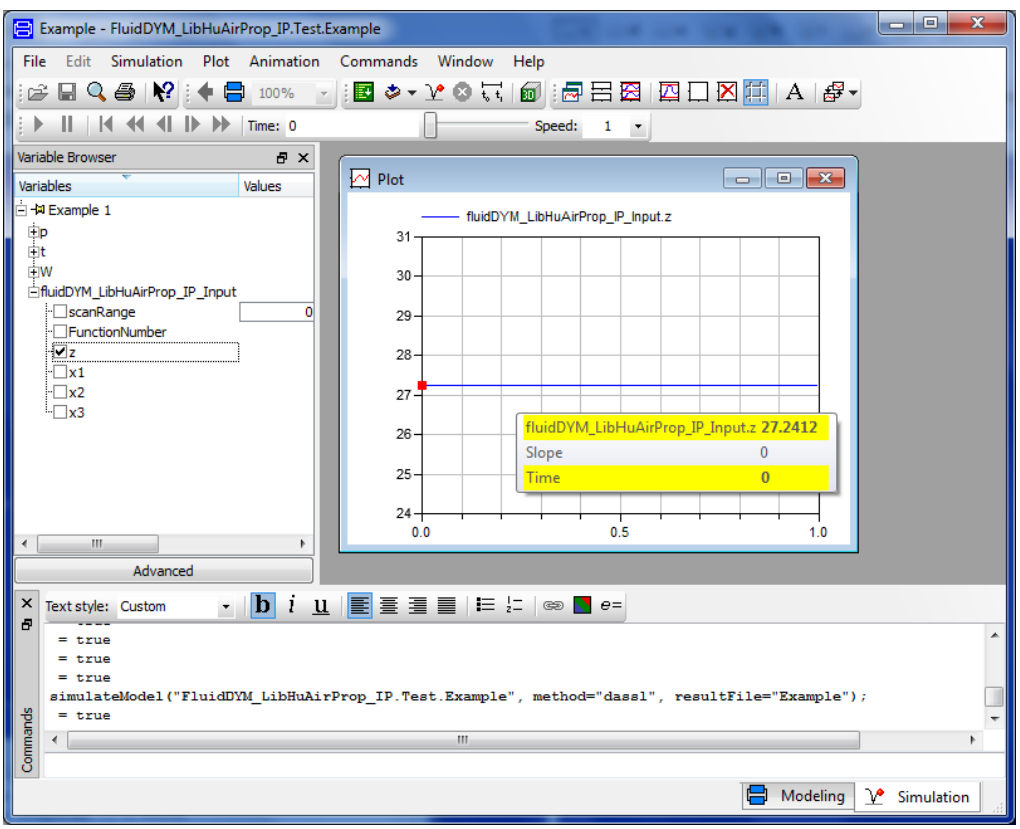
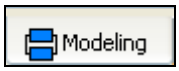


Figure 2.3.17: "DiagramWindow" showing the result

The result for *h* appears in the "DiagramWindow"

⇒ The result in our sample calculation here is: "h = 27.2412". The corresponding unit is Btu/lb_a (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*, or *W* in the appropriate blocks.

2.4 Removing FluidDYM including LibHuAirProp

In order to remove the property library LibHuAirProp 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 LibHuAirProp" 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 LibHuAirProp" has now been removed.

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

3 Property Functions of ASHRAE-LibHuAirProp-IP

3.1 Functions for Real Moist Air

Thermal Diffusivity a = f(p,t,W)

Function Name:

a_ptW_HAP_IP

Fortran Program:

REAL*8 FUNCTION A_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p	-	Total pressure p in psi
t	-	Temperature t in °F
W	-	Humidity ratio W in lb_w/lb_a

Result:

a_ptW_HAP_IP - Thermal diffusivity of humid air in ft^2/s

Range of Validity:

Temperature t:	from -99.67°F to 662°F
Total pressure p:	from 0.00145 psi to 1450.4 psi
Humidity ratio W:	$0 \le W \le W_s$

Comments:

- Thermal diffusivity $a = \dfrac{\lambda}{\rho \cdot c_p}$
- Calculation for supersaturated humid air ($W > W_s$) is not possible

Result for Wrong Input Values:

a_ptW_HAP_IP = -1000

References:

$\lambda(p,t,W)$	Herrmann et al. [3], [4]
$\rho(p,t,W)$	Herrmann et al. [1], [2]
$c_p(p,t,W)$	Herrmann et al. [1], [2]

Relative Pressure Coefficient α_p = f(p,t,W)

Function Name:

alphap_ptW_HAP_IP

Fortran Program:

REAL*8 FUNCTION ALPHAP_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p	-	Total pressure p in psi
t	-	Temperature t in °F
W	-	Humidity ratio W in lb_w/lb_a

Result:

alphap_ptW_HAP_IP - Relative pressure coefficient of humid air in 1/°R

Range of Validity:

Temperature t:	from -225.67°F to 662°F
Total pressure p:	from 0.00145 psi to 1450.4 psi
Humidity ratio W:	$0 \le W \le W_s$

Comments:

- Relative pressure coefficient $\alpha_p = \frac{1}{p}\left(\frac{\partial p}{\partial T}\right)_v$

- Calculation for supersaturated humid air ($W > W_s$) is not possible

Result for Wrong Input Values:

alphap_ptW_HAP_IP = -1000

References:

$\alpha_p(p,t,W)$ Herrmann et al. [1], [2]

Isothermal Stress Coefficient β_p = f(p,t,W)

Function Name:

betap_ptW_HAP_IP

Fortran Program:

REAL*8 FUNCTION BETAP_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p	-	Total pressure p in psi
t	-	Temperature t in °F
W	-	Humidity ratio W in lb_w/lb_a

Result:

betap_ptW_HAP_IP - Isothermal stress coefficient of humid air in lb/ft^3

Range of Validity:

Temperature t:	from -225.67°F to 662°F
Total pressure p:	from 0.00145 psi to 1450.4 psi
Humidity ratio W:	$0 \le W \le W_s$

Comments:

- Isothermal stress coefficient $\beta_p = -\frac{1}{p}\left(\frac{\partial p}{\partial v}\right)_T$

- Calculation for supersaturated humid air ($W > W_s$) is not possible

Result for Wrong Input Values:

betap_ptW_HAP_IP = -1000

References:

$\beta_p(p,t,W)$ Herrmann et al. [1], [2]

Speed of Sound c = f(p,t,W)

Function Name:

c_ptW_HAP_IP

Fortran Program:

REAL*8 FUNCTION C_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in psi

t - Temperature t in °F

W - Humidity ratio W in lb_w/lb_a

Result:

c_ptW_HAP_IP - Speed of sound of humid air in ft/s

Range of Validity:

Temperature t:	from -225.67°F to 662°F
Total pressure p:	from 0.00145 psi to 1450.4 psi
Humidity ratio W:	$0 \le W \le 10\,lb_w/lb_a$

Comments:

- Speed of sound $c = v\sqrt{-\left(\frac{\partial p}{\partial v}\right)_s}$

- When calculating supersaturated air an ideal mixing model (saturated humid air and water droplets (or ice crystals) homogeneously mixed) is applied

Result for Wrong Input Values:

c_ptW_HAP_IP = -1000

References:

$c(p,t,W)$ Herrmann et al. [1], [2]

Isobaric Heat Capacity c_p = f(p,t,W)

Function Name:

cp_ptW_HAP_IP

Fortran Program:

REAL*8 FUNCTION CP_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in psi
t - Temperature t in °F
W - Humidity ratio W in lb_w/lb_a

Result:

cp_ptW_HAP_IP - Isobaric heat capacity of humid air in Btu/(lb °R)

Range of Validity:

Temperature t:	from -225.67°F to 662°F
Total pressure p:	from 0.00145 psi to 1450.4 psi
Humidity ratio W:	$0 \le W \le W_s$

Comments:

- Isobaric heat capacity $c_p = \left(\frac{\partial h}{\partial T}\right)_p$

- Calculation for supersaturated humid air ($W > W_s$) is not possible

Result for Wrong Input Values:

cp_ptW_HAP_IP = -1000

References:

$c_p(p,t,W)$ Herrmann et al. [1], [2]

Isochoric Heat Capacity c_v = f(p,t,W)

Function Name:

cv_ptW_HAP_IP

Fortran Program:

REAL*8 FUNCTION CV_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in psi
t - Temperature t in °F
W - Humidity ratio W in lb_w/lb_a

Result:

cv_ptW_HAP_IP - Isochoric heat capacity of humid air in Btu/(lb °R)

Range of Validity:

Temperature t: from -225.67°F to 662°F
Total pressure p: from 0.00145 psi to 1450.4 psi
Humidity ratio W: $0 \le W \le W_s$

Comments:

- Isochoric heat capacity $c_v = \left(\frac{\partial u}{\partial T}\right)_v$

- Calculation for supersaturated humid air ($W > W_s$) is not possible

Result for Wrong Input Values:

cv_ptW_HAP_IP = -1000

References:

$c_v(p,t,W)$ Herrmann et al. [3], [4]

Enhancement Factor *f* = f(*p*,*t*)

Function Name:

f_pt_HAP_IP

Fortran Program:

REAL*8 FUNCTION F_PT_HUAIRPROP(P,T), REAL*8 P,T

Input Values:

p - Total pressure *p* in psi
t - Temperature *t* in °F

Result:

f_pt_HAP_IP - Enhancement factor of water (decimal ratio)

Range of Validity:

Temperature *t*: from -225.67°F to 662°F

Total pressure *p*: from 0.00145 psi to 1450.4 psi

Comments:

- Enhancement factor $f = \frac{p_{\mathrm{H2O,s}}}{p_{\mathrm{s}}(t)}$

  with $p_{\mathrm{s}}(t)$ for $t \geq 32°\mathrm{F}$ - Steam pressure of water

  for $t < 32°\mathrm{F}$ - Sublimation pressure of water

- Describes the enhancement of the saturation pressure of water in the air atmosphere under elevated pressure
- Derived iteratively from the isothermal compressibility of liquid water, from Henry's constant [15], [16] and from the virial coefficients of air, water, and the air-water mixture

Result for Wrong Input Values:

f_pt_HAP_IP = -1000

References:

$f(p,t)$ Herrmann et al. [1], [2]

Air-Specific Enthalpy $h = f(p,t,W)$

Function Name:

h_ptW_HAP_IP

Fortran Program:

REAL*8 FUNCTION H_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in psi

t - Temperature t in °F

W - Humidity ratio W in lb_w/lb_a

Result:

h_ptW_HAP_IP - Air-specific enthalpy in Btu/lb_a

Range of Validity:

Temperature t: from -225.67°F to 662°F

Total pressure p: from 0.00145 psi to 1450.4 psi

Humidity ratio W: $0 \le W \le 10\,lb_w/lb_a$

Comments:

- When calculating supersaturated air an ideal mixing model (saturated humid air and water droplets (or ice crystals) homogeneously mixed) is applied

Result for Wrong Input Values:

h_ptW_HAP_IP = -1000

References:

$h(p,t,W)$ Herrmann et al. [1], [2]

$h_w(p,t)$ IAPWS-IF97 [7], [8] and IAPWS-06 [11]

$h_a(t)$ Lemmon et al. [14]

Dynamic Viscosity η = f(p,t,W)

Function Name:

Eta_ptW_HAP_IP

Fortran Program:

REAL*8 FUNCTION ETA_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p	-	Total pressure p in psi
t	-	Temperature t in °F
W	-	Humidity ratio W in lb_w/lb_a

Result:

Eta_ptW_HAP_IP - Dynamic viscosity of humid air in (lb s/ft²)

Range of Validity:

Temperature t:	from -99.67°F to 662°F
Total pressure p:	from 0.00145 psi to 1450.4 psi
Humidity ratio W:	$0 \le W \le 10\,lb_w/lb_a$

Comments:

- A new very accurate algorithm is implemented between 32°F and 662°F
- When calculating supersaturated air an ideal mixing model (saturated humid air and water droplets (or ice crystals) homogeneously mixed) is applied

Result for Wrong Input Values:

Eta_ptW_HAP_IP = -1000

References:

$\eta(p,t,W)$	Herrmann et al. [3], [4]
$\eta_w(p,t)$	IAPWS-IF97 [7], [8] and IAPWS-06 [19]
$\eta_a(t)$	Lemmon et al. [18]

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

Function Name:

Kappa_ptW_HAP_IP

Fortran Program:

REAL*8 FUNCTION KAPPA_PTW_HUAIRPROP(P,T, W), REAL*8 P,T,W

Input Values:

p - Total pressure p in psi

t - Temperature t in °F

W - Humidity ratio W in lb_w/lb_a

Result:

Kappa_ptW_HAP_IP - Isentropic exponent

Range of Validity:

Temperature t: from -225.67°F to 662°F

Total pressure p: from 0.00145 psi to 1450.4 psi

Humidity ratio W: $0 \le W \le 10\,lb_w/lb_a$

Comments:

- Isentropic exponent $\kappa = -\frac{v}{p}\left(\frac{\partial p}{\partial v}\right)_s$

- When calculating supersaturated air an ideal mixing model (saturated humid air and water droplets homogeneously mixed) is applied for $t \ge 32$°F. For temperatures below (ice fog) the value of the saturated state is applied.

Result for Wrong Input Values:

Kappa_ptW_HAP_IP = -1000

References:

$v(p,t,W)$ Herrmann et al. [1], [2]

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

Function Name:

Lambda_ptW_HAP_IP

Fortran Program:

REAL*8 FUNCTION LAMBDA_PTW_HUAIRPROP(P,T, W), REAL*8 P,T,W

Input Values:

p	-	Total pressure p in psi
t	-	Temperature t in °F
W	-	Humidity ratio W in lb_w/lb_a

Result:

Lambda_ptW_HAP_IP - Thermal conductivity in Btu/(h ft °R)

Range of Validity:

Temperature t:	from -99.67°F to 662°F
Total pressure p:	from 0.00145 psi to 1450.4 psi
Humidity ratio W:	$0 \le W \le 10\,lb_w/lb_a$

Comments:

- A new very accurate algorithm is implemented between 32°F and 662°F
- When calculating supersaturated air an ideal mixing model (saturated humid air and water droplets (or ice crystals) homogeneously mixed) is applied

Result for Wrong Input Values:

Lambda_ptW_HAP_IP = -1000

References:

$\lambda(p,t,W)$	Herrmann et al. [3], [4]
$\lambda_w(p,t)$	IAPWS-IF97 [7], [8] and IAPWS-08 [20]
$\lambda_a(t)$	Lemmon et al. [18]

Kinematic Viscosity ν = f(p,t,W)

Function Name:

Ny_ptW_HAP_IP

Fortran Program:

REAL*8 FUNCTION NY_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in psi
t - Temperature t in °F
W - Humidity ratio W in lb_w/lb_a

Result:

Ny_ptW_HAP_IP - Kinematic viscosity in ft^2/s

Range of Validity:

Temperature t:	from -99.67°F to 662°F
Total pressure p:	from 0.00145 psi to 1450.4 psi
Humidity ratio W:	$0 \le W \le W_s$

Comments:

- Kinematic Viscosity $\nu = \dfrac{\eta}{\rho}$

Result for Wrong Input Values:

Ny_ptW_HAP_IP = -1000

References:

$\eta(p,t,W)$ Herrmann et al. [3], [4]
$\rho(p,t,W)$ Herrmann et al. [1], [2]

Backward Function: Pressure p = f(t,s,W)

Function Name:

p_tsW_HAP_IP

Fortran Program:

REAL*8 FUNCTION P_TSW_HUAIRPROP(T,S,W), REAL*8 T,S,W

Input Values:

t - Temperature t in °F

s - Air-specific entropy s in Btu/(lb_a °R)

W - Humidity ratio W in lb_w/lb_a

Result:

p_tsW_HAP_IP - Total pressure of humid air in psi

Range of Validity:

Temperature t: from -225.67°F to 662°F

Air-specific entropy s: from -6.32 Btu/(lb_a °R) to 9.32877 Btu/(lb_a °R)

Humidity ratio W: $0 \le W \le 10\ lb_w/lb_a$

Comments:

- Iteration of total pressure p from s = f(p,t,W)

Result for Wrong Input Values:

p_tsW_HAP_IP = -1000

References:

$s(p,t,W)$ Herrmann et al. [1], [2]

Pressure $p = f(z_{ele})$

Function Name:

p_zele_HAP_IP

Fortran Program:

REAL*8 FUNCTION P_ZELE_HUAIRPROP(ZELE), REAL*8 ZELE

Input Values:

z_{ele} - Elevation z_{ele} in ft

Result:

p_zele_HAP_IP - Pressure of humid air in psi

Range of Validity:

Elevation z_{ele} from -16,404 ft to 36,089 ft

Comments:

- Pressure of humid air from elevation

- $p(z_{ele}) = 14.696\,\text{psi} \cdot \left(1 - 6.8754 \cdot 10^{-6} \cdot \frac{z_{ele}}{\text{ft}}\right)^{5.256}$

Result for Wrong Input Values:

p_zele_HAP_IP = -1000

References:

$p(z_{ele})$ ASHRAE [23]

Partial Pressure of Air p_{Air} = f(p,t,W)

Function Name:

pAir_ptW_HAP_IP

Fortran Program:

REAL*8 FUNCTION PAIR_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in psi
t - Temperature t in °F
W - Humidity ratio W in lb_w/lb_a

Result:

pAir_ptW_HAP_IP - Partial pressure of (dry) air in humid air in psi

Range of Validity:

Temperature t:	from -225.67°F to 662°F
Total pressure p:	from 0.00145 psi to 1450.4 psi
Humidity ratio W:	$0 \le W \le 10\,lb_w/lb_a$

Comments:

- Partial pressure of (dry) air in humid air $p_{Air} = 1 - p_{H2O}$
- Partial pressure of water vapor at saturation is calculated in case of supersaturated humid air ($W > W_s(p,t)$)
- The temperature value is used to calculate the saturation state

Result for Wrong Input Values:

pAir_ptW_HAP_IP = -1000

References:

$p_{H2O}(p,W)$ Herrmann et al. [1], [2]

Partial Pressure of Water Vapor p_{H2O} = f(p,t,W)

Function Name:

pH2O_ptW_HAP_IP

Fortran Program:

REAL*8 FUNCTION PH2O_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in psi
t - Temperature t in °F
W - Humidity ratio W in lb_w/lb_a

Result:

pH2O_ptW_HAP_IP - Partial pressure of water vapor in humid air in psi

Range of Validity:

Temperature t: from -225.67°F to 662°F
Total pressure p: from 0.00145 psi to 1450.4 psi
Humidity ratio W: $0 \le W \le 10\,lb_w/lb_a$

Comments:

- Partial pressure of water vapor in humid air $p_{H2O} = \dfrac{W \cdot p}{\left(\dfrac{R_a}{R_w} + W\right)}$
- Partial pressure of water vapor at saturation is calculated in case of supersaturated humid air ($W > W_s(p,t)$)
- The temperature value is used to calculate the saturation state

Result for Wrong Input Values:

pH2O_ptW_HAP_IP = -1000

References:

$p_{H2O}(p,W)$ Herrmann et al. [1], [2]

Partial Sat. Pressure of Water Vapor in Humid Air $p_{H2O,s}$ = f(p,t)

Function Name:

pH2Os_pt_HAP_IP

Fortran Program:

REAL*8 FUNCTION PH2OS_PT_HUAIRPROP(P,T), REAL*8 P,T

Input Values:

p - Total pressure p in psi
t - Temperature t in °F

Result:

pH2Os_pt_HAP_IP - Partial saturation pressure of water vapor in humid air in psi

Range of Validity:

Temperature t: from -225.67°F to 662°F
Total pressure p: from 0.00145 psi to 1450.4 psi

Comments:

- Partial pressure of water vapor at saturation $p_{H2O,s} = f \cdot p_s(t)$
with $p_s(t)$ for $t \geq 32$°F - Steam pressure of water
for $t < 32$°F - Sublimation pressure of water

Result for Wrong Input Values:

pH2Os_pt_HAP_IP = -1000

References:

$f(p,t)$		Herrmann et al. [1], [2]
$p_s(t)$	for $t \geq 32$°F	IAPWS-IF97 [7], [8]
	for t < 32°F	IAPWS-08 [11]

Relative Humidity φ = f(p,t,W)

Function Name:

phi_ptW_HAP_IP

Fortran Program:

REAL*8 FUNCTION PHI_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p	-	Total pressure p in psi
t	-	Temperature t in °F
W	-	Humidity ratio W in lb_w/lb_a

Result:

phi_ptW_HAP_IP - Relative humidity (decimal ratio)

Range of Validity:

Temperature t:	from -225.67°F to 662°F
Total pressure p:	from 0.00145 psi to 1450.4 psi
Humidity ratio W:	$0 \le W \le 10\ lb_w/lb_a$

Comments:

- Relative humidity $\varphi = \dfrac{p_{H2O}}{p_{H2O,s}}$
- This equation is valid for $p_{H2O} \le p_{H2O,s}$ and for $0 \le \varphi \le 1$

Result for Wrong Input Values:

phi_ptW_HAP_IP = -1000

References:

$\varphi(p,t,W)$ Herrmann et al. [1], [2]

Prandtl Number *Pr* = f(*p*,*t*,*W*)

Function Name:

Pr_ptW_HAP_IP

Fortran Program:

REAL*8 FUNCTION PR_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p	-	Total pressure p in psi
t	-	Temperature t in °F
W	-	Humidity ratio W in lb_w/lb_a

Result:

Pr_ptW_HAP_IP - Prandtl number

Range of Validity:

Temperature t:	from -99.67°F to 662°F
Total pressure p:	from 0.00145 psi to 1450.4 psi
Humidity ratio W:	$0 \le W \le 10 lb_w/lb_a$

Comments:

- Prandtl number $Pr = \frac{\eta \cdot c_p}{\lambda}$
- Calculation for supersaturated humid air ($W > W_s$) is not possible

Result for Wrong Input Values:

Pr_ptW_HAP_IP = -1000

References:

$\eta(p,t,W)$	Herrmann et al. [3], [4]
$c_p(p,t,W)$	Herrmann et al. [3], [4]
$\lambda(p,t,W)$	Lemmon et al. [20]

Mole Fraction of Air ψ_{Air} = f(W)

Function Name:

PsiAir_W_HAP_IP

Fortran Program:

REAL*8 FUNCTION PSIAIR_W_HUAIRPROP(W), REAL*8 W

Input Values:

W - Humidity ratio W in $\mathrm{lb_w/lb_a}$

Result:

PsiAir_W_HAP_IP - Mole fraction of (dry) air in humid air in $\mathrm{mol_a/mol}$

Range of Validity:

Humidity ratio W: $0 \le W \le 10\,\mathrm{lb_w/lb_a}$

Comments:

- Mole fraction of air $\psi_{\mathrm{Air}} = 1 - \psi_{\mathrm{H2O}} = 1 - \left(\dfrac{W}{\dfrac{R_{\mathrm{a}}}{R_{\mathrm{H2O}}} + W} \right)$

Result for Wrong Input Values:

PsiAir_W_HAP_IP = -1000

References:

$\psi_{\mathrm{Air}}(W)$ Herrmann et al. [1], [2]

Mole Fraction of Water $\psi_{H2O} = f(W)$

Function Name:

PsiH2O_W_HAP_IP

Fortran Program:

REAL*8 FUNCTION PSIH2O_W_HUAIRPROP(W), REAL*8 W

Input Values:

W - Humidity ratio W in lb_w/lb_a

Result:

PsiH2O_W_HAP_IP - Mole fraction of water in humid air in mol_w/mol

Range of Validity:

Humidity ratio W: $0 \le W \le 10\,lb_w/lb_a$

Comments:

- Mole fraction of water $\psi_{H2O} = \dfrac{W}{\dfrac{R_a}{R_{H2O}} + W}$

Result for Wrong Input Values:

PsiH2O_W_HAP_IP = -1000

References:

$\psi_{H2O}(W)$ Herrmann et al. [1], [2]

Density ρ = f(p,t,W)

Function Name:

Rho_ptW_HAP_IP

Fortran Program:

REAL*8 FUNCTION RHO_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in psi
t - Temperature t in °F
W - Humidity ratio W in lb_w/lb_a

Result:

Rho_ptW_HAP_IP - Density of humid air in lb/ft^3

Range of Validity:

Temperature t:	from -225.67°F to 662°F
Total pressure p:	from 0.00145 psi to 1450.4 psi
Humidity ratio W:	$0 \le W \le 10\, lb_w/lb_a$

Comments:

- Density of humid air obtained from air-specific volume: $\rho = \frac{1+W}{v}$

Result for Wrong Input Values:

Rho_ptW_HAP_IP = -1000

References:

$\rho(p,t,W)$ Herrmann et al. [1], [2]

Air-Specific Entropy $s = f(p,t,W)$

Function Name:

s_ptW_HAP_IP

Fortran Program:

REAL*8 FUNCTION S_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in psi
t - Temperature t in °F
W - Humidity ratio W in lb_w/lb_a

Result:

s_ptW_HAP_IP - Air-specific entropy in $Btu/(lb_a \cdot °R)$

Range of Validity:

Temperature t:	from -225.67°F to 662°F
Total pressure p:	from 0.00145 psi to 1450.4 psi
Humidity ratio W:	$0 \le W \le 10\, lb_w/lb_a$

Comments:

- When calculating supersaturated air an ideal mixing model (saturated humid air and water droplets (or ice crystals) homogeneously mixed) is applied

Result for Wrong Input Values:

s_ptW_HAP_IP = -1000

References:

$s(p,t,W)$ Herrmann et al. [1], [2]

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

Function Name:

t_phphi_HAP_IP

Fortran Program:

REAL*8 FUNCTION T_PHPHI_HUAIRPROP(P,H,PHI), REAL*8 P,H,PHI

Input Values:

p - Total pressure p in psi
h - Air-specific enthalpy h in Btu/lb$_a$
φ - Relative humidity φ (decimal ratio)

Result:

t_phphi_HAP_IP - Temperature from pressure, enthalpy, and relative humidity in °F

Range of Validity:

Total pressure p: from 0.00145 psi to 1450.4 psi

Air-specific enthalpy h: from -2469.22 Btu/lb$_a$ to 12772.088 Btu/lb$_a$

Relative humidity φ: $0 \le \varphi \le 1$

Comments:

- Iteration of temperature t from h = f(p,t,W) using W = f(p,t,φ)

Result for Wrong Input Values:

t_phphi_HAP_IP = -1000

References:

$h(p,t,W)$ Herrmann et al. [1], [2]

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

Function Name:

t_phW_HAP_IP

Fortran Program:

REAL*8 FUNCTION T_PHW_HUAIRPROP(P,H,W), REAL*8 P,H,W

Input Values:

p - Total pressure *p* in psi

h - Air-specific enthalpy *h* in Btu/lb_a

W - Humidity ratio *W* in lb_w/lb_a

Result:

t_phW_HAP_IP - Temperature from pressure, enthalpy, and humidity ratio in °F

Range of Validity:

Total pressure *p*: from 0.00145 psi to 1450.4 psi

Air-specific enthalpy *h*: from -2469.22 Btu/lb_a to 12772.088 Btu/lb_a

Humidity ratio *W*: $0 \le W \le 10\,lb_w/lb_a$

Comments:

- Iteration of temperature *t* from *h* = f(*p*,*t*,*W*)

Result for Wrong Input Values:

t_phW_HAP_IP = -1000

References:

$h(p,t,W)$ Herrmann et al. [1], [2]

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

Function Name:

t_psW_HAP_IP

Fortran Program:

REAL*8 FUNCTION T_PSW_HUAIRPROP(P,S,W), REAL*8 P,S,W

Input Values:

p - Total pressure p in psi

s - Air-specific entropy in Btu/($lb_a \cdot$°R)

W - Humidity ratio W in lb_w/lb_a

Result:

t_psW_HAP_IP - Temperature from pressure, entropy, and humidity ratio in °F

Range of Validity:

Total pressure p: from 0.00145 psi to 1450.4 psi

Air-specific entropy s: from -6.32 Btu/(lb_a °R) to 9.32877 Btu/(lb_a °R)

Humidity ratio W: $0 \le W \le 10\,lb_w/lb_a$

Comments:

- Iteration of temperature t from s = f(p,t,W)

Result for Wrong Input Values:

t_psW_HAP_IP = -1000

References:

$s(p,t,W)$ Herrmann et al. [1], [2]

Backward Function: Temperature $t = f(p, t_{wb}, W)$

Function Name:

t_ptwbW_HAP_IP

Fortran Program:

REAL*8 FUNCTION T_PTWBW_HUAIRPROP(P,TWB,W), REAL*8 P,TWB,W

Input Values:

p - Total pressure p in psi

t_{wb} - Wet-bulb temperature in °F

W - Humidity ratio W in lb_w/lb_a

Result:

t_ptwbW_HAP_IP - Temperature from pressure, wet bulb temperature and humidity ratio in °F

Range of Validity:

Total pressure p: from 0.00145 psi to 1450.4 psi

Wet bulb temperature t_{wb}: from -225.67°F to 662°F

Humidity ratio W: $0 \le W \le 10 lb_w/lb_a$

Comments:

- Iterationof temperature t from $t_{wb} = f(p, t, W)$

Result for Wrong Input Values:

t_ptwbW_HAP_IP = -1000

References:

$t_{wb}(p, t, W)$ Herrmann et al. [1], [2]

Dew-Point/Frost-Point Temperature t_d = f(p,W)

Function Name:

td_pW_HAP_IP

Fortran Program:

REAL*8 FUNCTION TD_PW_HUAIRPROP(P,W), REAL*8 P,W

Input Values:

p - Total pressure p in psi

W - Humidity ratio W in lb_w/lb_a

Result:

td_pW_HAP_IP - Dew-point/frost-point temperature in °F

Range of Validity:

Total pressure p: from 0.00145 psi to 1450.4 psi

Humidity ratio W: $0 \le W \le 10\,lb_w/lb_a$

Comments:

Dew-point temperature $t_d = t_s(p_{H2O})$ for $t \ge 32°F$ (saturation temperature of water in humid air)

$t_d = t_{sub}(p_{H2O})$ for $t \le 32°F$ (sublimation temperature of water in humid air)

Result for Wrong Input Values:

td_pW_HAP_IP = -1000

References:

$t_s(p_{H2O})$	for $t_d \ge 32°F$	IAPWS-IF97 [7], [8]
$t_{sub}(p_{H2O})$	for $t_d \le 32°F$	IAPWS-08 [11]
p_{H2O}		Herrmann et. al. [1], [2]

Saturation Temperature $t_s = f(p, p_{H2O})$

Function Name:

ts_ppH2O_HAP_IP

Fortran Program:

REAL*8 FUNCTION TS_PPH2O_HUAIRPROP(P,PH2O), REAL*8 P,PH2O

Input Values:

p - Total pressure p in psi

p_{H2O} - Partial saturation pressure of water p_{H2O} in psi

Result:

ts_ppH2O_HAP_IP - Saturation temperature of water in humid air in °F

Range of Validity:

Total pressure p: from 0.00145 psi to 1450.4 psi

Partial pressure p_{H2O} : from 0.00145 psi to 1450.4 psi

Comments:

- Iteration of saturation temperature t_s from $p_{H2O,s} = f(p,t)$

Result for Wrong Input Values:

ts_ppH2O_HAP_IP = -1000

References:

$p_{H2O,s}$ Herrmann et. al. [1], [2]

Wet-Bulb/Ice-Bulb Temperature t_{wb} = f(p,t,W)

Function Name:

twb_ptW_HAP_IP

Fortran Program:

REAL*8 FUNCTION TWB_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in psi
t - Temperature t in °F
W - Humidity ratio W in lb_w/lb_a

Result:

twb_ptW_HAP_IP - Wet-bulb/ice-bulb temperature in °F

Range of Validity:

Temperature t:	from -225.67°F to 662°F
Total pressure p:	from 0.00145 psi to 1450.4 psi
Humidity ratio W:	$0 \le W \le 10\,lb_w/lb_a$

Comments:

- Iteration of wet-bulb temperature t_{wb} from $h^{unsaturated}(p,t,W) = h^{fog}(p,t_{wb},W)$
- Calculation for supersaturated humid air ($W > W_s$) is not possible

Result for Wrong Input Values:

twb_ptW_HAP_IP = -1000

References:

$t_{wb}(p,t,W)$ Herrmann et al. [1], [2]

Air-Specific Internal Energy u = f(p,t,W)

Function Name:

u_ptW_HAP_IP

Fortran Program:

REAL*8 FUNCTION U_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in psi
t - Temperature t in °F
W - Humidity ratio W in lb_w/lb_a

Result:

u_ptW_HAP_IP - Air-specific internal energy in Btu/lb_a

Range of Validity:

Temperature t: from -225.67°F to 662°F
Total pressure p: from 0.00145 psi to 1450.4 psi
Humidity ratio W: $0 \le W \le 10\,lb_w/lb_a$

Comments:

- Internal energy $u = h - pv$

Result for Wrong Input Values:

u_ptW_HAP_IP = -1000

References:

$u(p,t,W)$ Herrmann et al. [1], [2]

Air-Specific Volume $v = f(p,t,W)$

Function Name:

v_ptW_HAP_IP

Fortran Program:

REAL*8 FUNCTION V_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in psi
t - Temperature t in °F
W - Humidity ratio W in lb_w/lb_a

Result:

v_ptW_HAP_IP - Air-specific volume in ft^3/lb_a

Range of Validity:

Temperature t: from -225.67°F to 662°F
Total pressure p: from 0.00145 psi to 1450.4 psi
Humidity ratio W: $0 \le W \le 10\ lb_w/lb_a$

Comments:

- When calculating supersaturated air an ideal mixing model (saturated humid air and water droplets (or ice crystals) homogeneously mixed) is applied

Result for Wrong Input Values:

v_ptW_HAP_IP = -1000

References:

$v(p,t,W)$ Herrmann et al. [1], [2]

Humidity Ratio from Partial Pressure of Water Vapor $W = f(p,t,p_{H2O})$

Function Name:

W_ptpH2O_HAP_IP

Fortran Program:

REAL*8 FUNCTION W_PTPH2O_HUAIRPROP(P,T,PH2O), REAL*8 P,T,PH2O

Input Values:

p - Total pressure p in psi
t - Temperature t in °F
p_{H2O} - Partial pressure of water p_{H2O} in psi

Result:

W_ptpH2O_HAP_IP - Humidity ratio from pressure, temperature and partial pressure of water vapor in lb_w/lb_a

Range of Validity:

Total pressure p:	from 0.00145 psi to 1450.4 psi
Temperature t :	from -225.67°F to 662°F
Partial pressure p_{H2O} :	from 0.00145 psi to 1450.4 psi

Comments:

- Iteration of humidity ratio W from $p_{H2O} = f(p,t,W)$
- Result for supersaturated humid air is W_s

Result for Wrong Input Values:

W_ptpH2O_HAP_IP = -1000

References:

$p_{H2O}(p,t,W)$ Herrmann et al. [1], [2]

Humidity Ratio from Relative Humidity W = f(p,t,φ)

Function Name:

W_ptphi_HAP_IP

Fortran Program:

REAL*8 FUNCTION W_PTPHI_HUAIRPROP(P,T,PHI), REAL*8 P,T,PHI

Input Values:

p - Total pressure p in psi
t - Temperature t in °F
φ - Relative humidity (decimal ratio)

Result:

W_ptphi_HAP_IP - Humidity ratio from pressure, temperature and relative humidity in lb_w/lb_a

Range of Validity:

Temperature t: from -225.67°F to 662°F
Total pressure p: from 0.00145 psi to 1450.4 psi
Relative humidity φ: $0 \le \varphi \le 1$

Comments:

- Iteration of humidity ratio W from $\varphi = f(p,t,W)$

Result for Wrong Input Values:

W_ptphi_HAP_IP = -1000

References:

$\varphi(p,t,W)$ Herrmann et al. [1], [2]

Humidity Ratio from Dew-Point Temperature $W = f(p,t_d)$

Function Name:

W_ptd_HAP_IP

Fortran Program:

REAL*8 FUNCTION W_PTD_HUAIRPROP(P,TD), REAL*8 P,TD

Input Values:

p - Total pressure p in psi

t_d - Dew-point temperature t_d in °F

Result:

W_ptd_HAP_IP - Humidity ratio from pressure and dew-point temperature in lb_w/lb_a

Range of Validity:

Dew point temperature t_d: from -225.67°F to 662°F

Total pressure p: from 0.00145 psi to 1450.4 psi

Comments:

- Iteration of humidity ratio W from $t_d = f(p,W)$

Result for Wrong Input Values:

W_ptd_HAP_IP = -1000

References:

$t_d(p,W)$ Herrmann et al. [1], [2]

Humidity Ratio from Wet-Bulb Temperature $W = f(p,t,t_{wb})$

Function Name:

W_pttwb_HAP_IP

Fortran Program:

REAL*8 FUNCTION W_PTTWB_HUAIRPROP(P,T,TWB), REAL*8 P,T,TWB

Input Values:

p - Total pressure p in psi
t - Temperature t in °F
t_{wb} - Wet-bulb temperature in °F

Result:

W_pttwb_HAP_IP - Humidity ratio from pressure, temperature and wet-bulb temperature in lb_w/lb_a

Range of Validity:

Total pressure p:	from 0.00145 psi to 1450.4 psi
Temperature t:	from -225.67°F to 662°F
Wet-bulb temperature t_{wb}:	from -225.67°F to 662°F

Comments:

- Iteration of humidity ratio W from $t_{wb} = f(p,t,W)$
- Calculation for supersaturated humid air ($W > W_s$) is not possible

Result for Wrong Input Values:

W_pttwb_HAP_IP = -1000

References:

$t_{wb}(p,t,W)$ Herrmann et al. [1], [2]

Saturation Humidity Ratio W_s = f(p,t)

Function Name:

Ws_pt_HAP_IP

Fortran Program:

REAL*8 FUNCTION WS_PT_HUAIRPROP(P,T), REAL*8 P,T

Input Values:

p - Total pressure p in psi
t - Temperature t in °F

Result:

Ws_pt_HAP_IP - Saturation humidity ratio in lb_w/lb_a

Range of Validity:

Total pressure p: from 0.00145 psi to 1450.4 psi
Temperature t: from -225.67°F to 662°F

Comments:

- Calculation of saturation humidity ratio W_s from $W_s = \frac{M_{H2O}}{M_a} \frac{p_{H2O,s}}{\left(p - p_{H2O,s}\right)}$

Result for Wrong Input Values:

Ws_pt_HAP_IP = -1000

References:

$p_{H2O,s}$ Herrmann et al. [1], [2]

Mass Fraction of Air ξ_{Air} = f(W)

Function Name:

XiAir_W_HAP_IP

Fortran Program:

REAL*8 FUNCTION XIAIR_W_HUAIRPROP(W), REAL*8 W

Input Values:

W - Humidity ratio W in lb_w/lb_a

Result:

XiAir_W_HAP_IP - Mass fraction of (dry) air in humid air in lb_a/lb

Range of Validity:

Humidity ratio W: $0 \le W \le 10\,lb_w/lb_a$

Comments:

- Mass fraction of (dry) air $\xi_{Air} = 1 - \xi_{H2O} = 1 - \dfrac{W}{1+W}$

Result for Wrong Input Values:

XiAir_W_HAP_IP = -1000

References:

$\xi_{Air}(W)$ Herrmann et al. [1], [2]

Mass Fraction of Water Vapor in Humid Air ξ_{H2O} = f(W)

Function Name:

XiH2O_W_HAP_IP

Fortran Program:

REAL*8 FUNCTION XIH2O_W_HUAIRPROP(W), REAL*8 W

Input Values:

W - Humidity ratio W in lb_w/lb_a

Result:

XiH2O_W_HAP_IP - Mass fraction of water vapor in humid air in lb_w/lb

Range of Validity:

Humidity ratio W: $0 \le W \le 10\,lb_w/lb_a$

Comments:

- Mass fraction of water $\xi_{H2O} = \dfrac{W}{1+W}$

Result for Wrong Input Values:

XiH2O_W_HAP_IP = -1000

References:

$\xi_{H2O}(W)$ Herrmann et al. [1], [2]

Compression Factor Z = f(p,t,W)

Function Name:

Z_ptW_HAP_IP

Fortran Program:

REAL*8 FUNCTION Z_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in psi
t - Temperature t in °F
W - Humidity ratio W in lb_w/lb_a

Result:

Z_ptW_HAP_IP - Compression factor (decimal ratio)

Range of Validity:

Total pressure p: from 0.00145 psi to 1450.4 psi
Temperature t: from -225.67°F to 662°F
Humidity ratio W: $0 \le W \le W_s$

Comments:

- Compression factor $Z = 1 + \frac{B_m}{\bar{v}} + \frac{C_m}{\bar{v}^2}$

  with $\bar{v} = \frac{M}{\rho} = \frac{M v}{1+W}$

  and M is the molar mass of humid air

- Calculation for supersaturated humid air ($W > W_s$) is not possible

Result for Wrong Input Values:

Z_ptW_HAP_IP = -1000

References:

$B_m(t,W), C_m(t,W)$ Herrmann et al. [1], [2]
$\rho(p,t,W), v(p,t,W)$ Herrmann et al. [1], [2]

3.2 Functions for Steam and Water for Temperatures $t \geq 32°F$

Specific Enthalpy of Liquid Water $h_{liq} = f(p,t)$

Function Name:

hliq_pt_97_IP

Fortran Program:

REAL*8 FUNCTION HLIQ_PT_97(P,T), REAL*8 P,T

Input Values:

p - Pressure *p* in psi
t - Temperature *t* in °F

Result:

hliq_pt_97_IP - Specific enthalpy of liquid water in Btu/lb

Range of Validity:

Pressure *p*: from $p_s(32°F) = 0.08865$ psi to 1450.4 psi

Temperature *t*: from 32°F to 662°F

Comments:

- Specific enthalpy of liquid water $h_{liq} = h^{97}(p,t)$ (Region 1)

Result for Wrong Input Values:

hliq_pt_97_IP = -1000

References:

$h^{97}(p,t)$ IAPWS-IF97 [7], [8]

Specific Enthalpy of Saturated Liquid Water $h_{\mathrm{liq,s}} = \mathrm{f}(t)$

Function Name:

hliqs_t_97_IP

Fortran Program:

REAL*8 FUNCTION HLIQS_T_97(T), REAL*8 T

Input Values:

t - Temperature *t* in °F

Result:

hliqs_t_97_IP - Specific enthalpy of saturated liquid water in Btu/lb

Range of Validity:

Temperature *t*: from 32°F to 662°F

Comments:

- Specific enthalpy of liquid water $h_{\mathrm{liq,s}} = h^{97}(p_{\mathrm{s}}, t)$ (Region 1)

  with $p_{\mathrm{s}} = p_{\mathrm{s}}^{97}(t)$

Result for Wrong Input Values:

hliqs_t_97_IP = -1000

References:

$h^{97}(p,t)$, $p_{\mathrm{s}}^{97}(t)$ IAPWS-IF97 [7], [8]

Specific Enthalpy of Saturated Water Vapor $h_{vap,s} = f(t)$

Function Name:

hvaps_t_97_IP

Fortran Program:

REAL*8 FUNCTION HVAPS_T_97(T), REAL*8 T

Input Values:

t - Temperature *t* in °F

Result:

hvaps_t_97_IP - Specific enthalpy of saturated water vapor in Btu/lb

Range of Validity:

Temperature *t*: from 32°F to 662°F

Comments:

- Specific enthalpy of saturated water vapor $h_{vap,s} = h^{97}(p_s, t)$ (Region 2)

  with $p_s = p_s^{97}(t)$

Result for Wrong Input Values:

hvaps_t_97_IP = -1000

References:

$h^{97}(p,t)$, $p_s^{97}(t)$ IAPWS-IF97 [7], [8]

Saturation Pressure of Water p_s = f(t)

Function Name:

ps_t_97_IP

Fortran Program:

REAL*8 FUNCTION PS_T_97(T), REAL*8 T

Input Values:

t - Temperature t in °F

Result:

ps_t_97_IP - Saturation pressure of water in psi

Range of Validity:

Temperature t: from 32°F to 662°F

Comments:

- Saturation pressure of water $p_s = p_s^{97}(t)$ (Region 4)

Result for Wrong Input Values:

ps_t_97_IP -1000

References:

$p_s^{97}(t)$ IAPWS-IF97 [7], [8]

Specific Entropy of Liquid Water $s_{liq} = f(p,t)$

Function Name:

sliq_pt_97_IP

Fortran Program:

REAL*8 FUNCTION SLIQ_PT_97(P,T), REAL*8 P,T

Input Values:

p - Pressure *p* in psi
t - Temperature *t* in °F

Result:

sliq_pt_97_IP - Specific entropy of liquid water in Btu/(lb °R)

Range of Validity:

Pressure *p*: from $p_s(32°F) = 0.08865$ psi to 1450.4 psi

Temperature *t*: from 32°F to 662°F

Comments:

- Specific entropy of liquid water $s_{liq} = s^{97}(p,t)$ (Region 1)

Result for Wrong Input Values:

sliq_pt_97_IP = -1000

References:

$s^{97}(p,t)$ IAPWS-IF97 [7], [8]

Specific Entropy of Saturated Liquid Water $s_{liq,s} = f(t)$

Function Name:

sliqs_t_97_IP

Fortran Program:

REAL*8 FUNCTION SLIQS_T_97(T), REAL*8 T

Input Values:

t - Temperature *t* in °F

Result:

sliqs_t_97_IP - Specific entropy of saturated liquid water in Btu/(lb °R)

Range of Validity:

Temperature *t*: from 32°F to 662°F

Comments:

- Specific entropy of liquid water $s_{liq,s} = s^{97}(p_s, t)$ (Region 1)

  with $p_s = p_s^{97}(t)$

Result for Wrong Input Values:

sliqs_t_97_IP = -1000

References:

$s^{97}(p,t), p_s^{97}(t)$ IAPWS-IF97 [7], [8]

Specific Entropy of Saturated Water Vapor $s_{vap,s} = f(t)$

Function Name:

svaps_t_97_IP

Fortran Program:

REAL*8 FUNCTION SVAPS_T_97(T), REAL*8 T

Input Values:

t - Temperature *t* in °F

Result:

svaps_t_97_IP - Specific entropy of saturated water vapor in Btu/(lb °R)

Range of Validity:

Temperature *t*: from 32°F to 662°F

Comments:

- Specific entropy of saturated water vapor $s_{\mathrm{vap,s}} = s^{97}(p_{\mathrm{s}}, t)$ (Region 2)

  with $p_{\mathrm{s}} = p_{\mathrm{s}}^{97}(t)$

Result for Wrong Input Values:

svaps_t_97_IP = -1000

References:

$s^{97}(p,t), p_{\mathrm{s}}^{97}(t)$ IAPWS-IF97 [7], [8]

Saturation Temperature of Water t_s = f(p)

Function Name:

ts_p_97_IP

Fortran Program:

REAL*8 FUNCTION TS_P_97(P), REAL*8 P

Input Values:

p - Pressure p in psi

Result:

ts_p_97_IP - Saturation temperature of water in °F

Range of Validity:

Pressure p: from 0.08865 psi to 1450.4 psi

Comments:

- Saturation temperature of water $t_s = t_s^{97}(p)$ (Region 4)

Result for Wrong Input Values:

ts_p_97_IP = -1000

References:

$t_s^{97}(p)$ IAPWS-IF97 [7], [8]

Specific Volume of Liquid Water $v_{liq} = f(p,t)$

Function Name:

vliq_pt_97_IP

Fortran Program:

REAL*8 FUNCTION VLIQ_PT_97(P,T), REAL*8 P,T

Input Values:

p - Pressure *p* in psi
t - Temperature *t* in °F

Result:

vliq_pt_97_IP - Specific volume of liquid water in ft^3/lb

Range of Validity:

Pressure *p*: from $p_s(32°F) = 0.08865$ psi to 1450.4 psi

Temperature *t*: from 32°F to 662°F

Comments:

- Specific volume of liquid water $v_{liq} = v^{97}(p,t)$ (Region 1)

Result for Wrong Input Values:

vliq_pt_97_IP = -1000

References:

$v^{97}(p,t)$ IAPWS-IF97 [7], [8]

Specific Volume of Saturated Liquid Water $v_{liq,s} = f(t)$

Function Name:

vliqs_t_97_IP

Fortran Program:

REAL*8 FUNCTION VLIQS_T_97(T), REAL*8 T

Input Values:

t - Temperature t in °F

Result:

vliqs_t_97_IP - Specific volume of saturated liquid water in ft^3/lb

Range of Validity:

Temperature t: from 32°F to 662°F

Comments:

- Specific volume of liquid water $v_{liq,s} = v^{97}(p_s, t)$ (Region 1)

  with $p_s = p_s^{97}(t)$

Result for Wrong Input Values:

vliqs_t_97_IP = -1000

References:

$v^{97}(p,t), p_s^{97}(t)$ IAPWS-IF97 [7], [8]

Specific Volume of Saturated Water Vapor $v_{vap,s} = f(t)$

Function Name:

vvaps_t_97_IP

Fortran Program:

REAL*8 FUNCTION VVAPS_T_97(T), REAL*8 T

Input Values:

t - Temperature *t* in °F

Result:

vvaps_t_97_IP - Specific volume of saturated water vapor in ft^3/lb

Range of Validity:

Temperature *t*: from 32°F to 662°F

Comments:

- Specific volume of saturated water vapor $v_{vap,s} = v^{97}(p_s, t)$ (Region 2)

  with $p_s = p_s^{97}(t)$

Result for Wrong Input Values:

vvaps_t_97_IP = -1000

References:

$v^{97}(p,t), p_s^{97}(t)$ IAPWS-IF97 [7], [8]

3.3 Functions for Steam and Ice for Temperatures $t \leq 32°F$

Specific Enthalpy of Saturated Ice $h_{ice,sub}$ = f(t)

Function Name:

hicesub_t_06_IP

Fortran Program:

REAL*8 FUNCTION HICESUB_T_06(T), REAL*8 T

Input Values:

t - Temperature t in °F

Result:

hicesub_t_06_IP - Specific enthalpy of saturated ice in Btu/lb

Range of Validity:

Temperature t: from -225.67°F to 32°F

Comments:

- Specific enthalpy of saturated ice $h_{ice,sub} = h^{06}(p_{sub}, t)$

  with $p_{sub} = p_{sub}^{08}(t)$

Result for Wrong Input Values:

hicesub_t_06_IP = -1000

References:

$h^{06}(p,t)$ IAPWS-06 [10]

$p_{sub}^{08}(t)$ IAPWS-08 [11]

Specific Enthalpy of Saturated Water Vapor $h_{vap,sub} = f(t)$

Function Name:

hvapsub_t_95_IP

Fortran Program:

REAL*8 FUNCTION HVAPSUB_T_95(T), REAL*8 T

Input Values:

t - Temperature *t* in °F

Result:

hvapsub_t_95_IP - Specific enthalpy of saturated water vapor in Btu/lb

Range of Validity:

Temperature *t*: from -225.67°F to 32°F

Comments:

- Specific enthalpy of saturated water vapor $h_{vap,sub} = h^{95}(p_{sub}, t)$

  with $p_{sub} = p_{sub}^{08}(t)$

Result for Wrong Input Values:

hvapsub_t_95_IP = -1000

References:

$h^{95}(p,t)$ IAPWS-95 [5], [6]

$p_{sub}^{08}(t)$ IAPWS-08 [11]

Melting Pressure of Ice $p_{mel} = f(t)$

Function Name:

pmel_t_08_IP

Fortran Program:

REAL*8 FUNCTION PMEL_T_08 (T), REAL*8 T

Input Values:

t - Temperature t in °F

Result:

pmel_t_08_IP - Melting pressure of ice in psi

Range of Validity:

Temperature t: from -7.573°F to 32°F

Result for Wrong Input Values:

pmel_t_08_IP = -1000

References:

$p_{mel}^{08}(t)$ IAPWS-08 [11]

Sublimation Pressure of Ice $p_{sub} = f(t)$

Function Name:

psub_t_08_IP

Fortran Program:

REAL*8 FUNCTION PSUB_T_08 (T), REAL*8 T

Input Values:

t - Temperature t in °F

Result:

psub_t_08_IP - Sublimation pressure of ice in psi

Range of Validity:

Temperature t: from -225.67°F to 32°F

Result for Wrong Input Values:

psub_t_08_IP = -1000

References:

$p_{sub}^{08}(t)$ IAPWS-08 [11]

Specific Entropy of Saturated Ice $s_{ice,sub} = f(t)$

Function Name:

sicesub_t_06_IP

Fortran Program:

REAL*8 FUNCTION SICESUB_T_06(T), REAL*8 T

Input Values:

t - Temperature *t* in °F

Result:

sicesub_t_06_IP - Specific entropy of saturated ice in Btu/(lb °R)

Range of Validity:

Temperature *t*: from -225.67°F to 32°F

Comments:

- Specific entropy of saturated ice $s_{ice,sub} = s^{06}(p_{sub}, t)$
  with $p_{sub} = p_{sub}^{08}(t)$

Result for Wrong Input Values:

sicesub_t_06_IP = -1000

References:

$s^{06}(p,t)$ IAPWS-06 [10]

$p_{sub}^{08}(t)$ IAPWS-08 [11]

Specific Entropy of Saturated Water Vapor $s_{vap,sub}$ = f(t)

Function Name:

svapsub_t_95_IP

Fortran Program:

REAL*8 FUNCTION SVAPSUB_T_95(T), REAL*8 T

Input Values:

t - Temperature t in °F

Result:

svapsub_t_95_IP - Specific entropy of saturated water vapor in Btu/(lb °R)

Range of Validity:

Temperature t: from -225.67°F to 32°F

Comments:

- Specific entropy of saturated water vapor $s_{vap,sub} = s^{95}(p_{sub}, t)$

  with $p_{sub} = p_{sub}^{08}(t)$

Result for Wrong Input Values:

svapsub_t_95_IP = -1000

References:

$s^{95}(p,t)$ IAPWS-95 [7], [8]

$p_{sub}^{08}(t)$ IAPWS-08 [11]

Melting Temperature of Ice t_{mel} = f(p)

Function Name:

tmel_p_08_IP

Fortran Program:

REAL*8 FUNCTION TMEL_P_08(P), REAL*8 P

Input Values:

p - Pressure p in psi

Result:

tmel_p_08_IP - Melting temperature of ice in °F

Range of Validity:

Pressure p: from p_s (32°F) = 0.08865 psi to 1450.4 psi

Result for Wrong Input Values:

tmel_p_08_IP = -1000

References:

$t_{mel}^{08}(p)$ IAPWS-08 [11]

Sublimation Temperature of Ice t_{sub} = f(p)

Function Name:

tsub_p_08_IP

Fortran Program:

REAL*8 FUNCTION TSUB_P_08(P), REAL*8 P

Input Values:

p - Pressure p in psi

Result:

tsub_p_08_IP - Sublimation temperature of ice in °F

Range of Validity:

Pressure p: from $p_{subl}(-225.67°F) = 1.7407 \times 10^{-12}$ psi to $p_{subl}(32°F) = 0.08865$ psi

Result for Wrong Input Values:

tsub_p_08_IP = -1000

References:

$t_{sub}^{08}(p)$ IAPWS-08 [11]

Specific Volume of Saturated Ice $v_{ice,sub}$ = f(t)

Function Name:

vicesub_t_06_IP

Fortran Program:

REAL*8 FUNCTION VICESUB_T_06(T), REAL*8 T

Input Values:

t - Temperature t in °F

Result:

vicesub_t_06_IP - Specific volume of saturated ice in ft^3 /lb

Range of Validity:

Temperature t: from -225.67°F to 32°F

Comments:

- Specific volume of saturated ice $v_{ice,sub} = v^{06}(p_{sub}, t)$
  with $p_{sub} = p_{sub}^{08}(t)$

Result for Wrong Input Values:

vicesub_t_06_IP = -1000

References:

$v^{06}(p,t)$ IAPWS-06 [10]

$p_{sub}^{08}(t)$ IAPWS-08 [11]

Specific Volume of Saturated Water Vapor $v_{vap,sub} = f(t)$

Function Name:

vvapsub_t_95_IP

Fortran Program:

REAL*8 FUNCTION VVAPSUB_T_95(T), REAL*8 T

Input Values:

t - Temperature t in °F

Result:

vvapsub_t_95_IP - Specific volume of saturated water vapor in ft^3/lb

Range of Validity:

Temperature t: from -225.67°F to 32°F

Comments:

- Specific volume of saturated water vapor $v_{vap,sub} = v^{95}(p_{sub}, t)$

  with $p_{sub} = p_{sub}^{08}(t)$

Result for Wrong Input Values:

vvapsub_t_95_IP = -1000

References:

$v^{95}(p,t)$ IAPWS-95 [7], [8]

$p_{sub}^{08}(t)$ IAPWS-08 [11]

KCE ThermoFluidProperties

KCE-ThermoFluidProperties
www.thermofluidprop.com

Hochschule Zittau/Görlitz
UNIVERSITY OF APPLIED SCIENCES

4. 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, -S03rev, -S04, and -S05
- IAPWS Revised Advisory Note No. 3 on Thermo-dynamic Derivatives (2008)

Library LibIF97_META

- Industrial Formulation IAPWS-IF97 (Revision 2007) for metastable steam

Humid Combustion Gas Mixtures

Library LibHuGas

Model: Ideal mixture of the real fluids:

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

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

Consideration of:

- Dissociation from VDI 4670
- Poynting effect

Humid Air

Library LibHuAir

Model: Ideal mixture of the real fluids:

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

Consideration of:

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

Extremely Fast Property Calculations

Spline-Based Table Look-up Method (SBTL)

Library LibSBTL_IF97
Library LibSBTL_95
Library LibSBTL_HuAir

For steam, water, humid air, carbon dioxide and other fluids and mixtures according IAPWS Guideline 2015 for Computational Fluid Dynamics (CFD), real-time and non-stationary simulations

Carbon Dioxide Including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1996)

Seawater

Library LibSeaWa

IAPWS Industrial Formulation 2013

Ice

Library LibICE

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

Ideal Gas Mixtures

Library LibIdGasMix

Model: Ideal mixture of the ideal gases:

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

Consideration of:

- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

Humid Air

Library ASHRAE LibHuAirProp

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

Consideration of:

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

www.ashrae.org/bookstore

Dry Air Including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth et al. (1993)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of Bücker and Wagner (2006)

n-Butane

Library LibButane_n

Formulation of Bücker and Wagner (2006)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

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

Helmholtz energy equation for the mixing term

(also useable for calculating the Kalina Cycle)

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

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

Formulation of the International Institute of Refrigeration (IIR 2010)

Ethanol

Library LibC2H5OH

Formulation of
Schroeder et al. (2014)

Methanol

Library LibCH3OH

Formulation of
de Reuck and Craven (1993)

Propane

Library LibPropane

Formulation of
Lemmon et al. (2009)

Siloxanes as ORC Working Fluids

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

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

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

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

Formulation of Colonna et al. (2006)

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

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

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

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

Formulation of Colonna et al. (2008)

Nitrogen and Oxygen

Libraries LibN2 and LibO2

Formulations of Span et al. (2000)
and Schmidt and Wagner (1985)

Hydrogen

Library LibH2

Formulation of
Leachman et al. (2009)

Helium

Library LibHe

Formulation of
Arp et al. (1998)

Hydrocarbons

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

Isopentane C_5H_{12} **Library LibC5H12_Iso**

Neopentane C_5H_{12} **Library LibC5H12_Neo**

Isohexane C_6H_{14} **Library LibC6H14**

Toluene C_7H_8 **Library LibC7H8**

Formulation of Lemmon and Span (2006)

Further Fluids

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

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

Hydrogen sulfide H_2S **Library LibH2S**

Nitrous oxide N_2O **Library LibN2O**

Sulfur dioxide SO_2 **Library LibSO2**

Acetone C_3H_6O **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

KCE ThermoFluidProperties

For more information please contact:

KCE-ThermoFluidProperties UG & Co. KG
Prof. Dr. Hans-Joachim Kretzschmar
Wallotstr. 3
01307 Dresden, Germany

Internet: www.thermofluidprop.com
Email: info@thermofluidprop.com
Phone: +49-351-27597860
Mobile: +49-172-7914607
Fax: +49-3222-1095810

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
- Thermal diffusivity a

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 used in process modeling can be calculated.

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

www.thermofluidprop.com

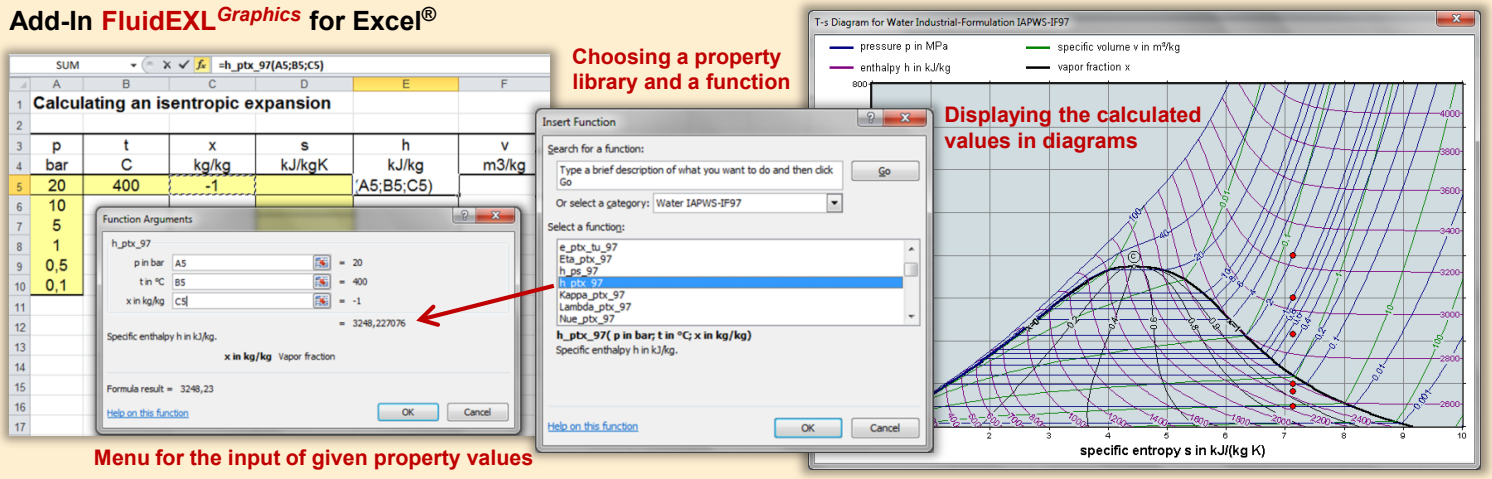
KCE ThermoFluidProperties

KCE-ThermoFluidProperties
www.thermofluidprop.com

Hochschule Zittau/Görlitz
UNIVERSITY OF APPLIED SCIENCES

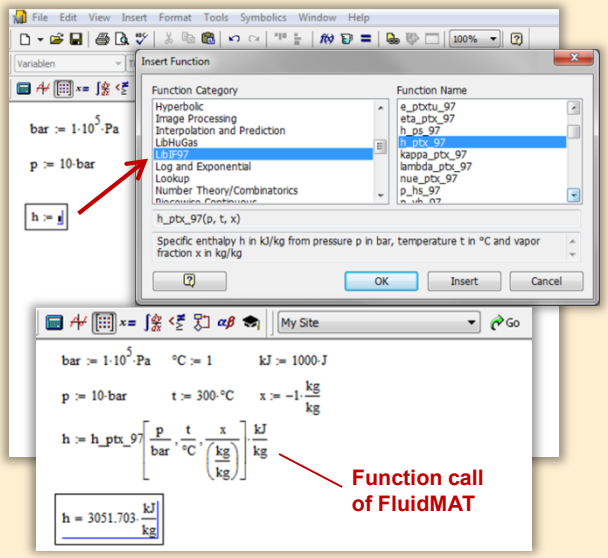
Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

Add-In FluidEXL*Graphics* for Excel®



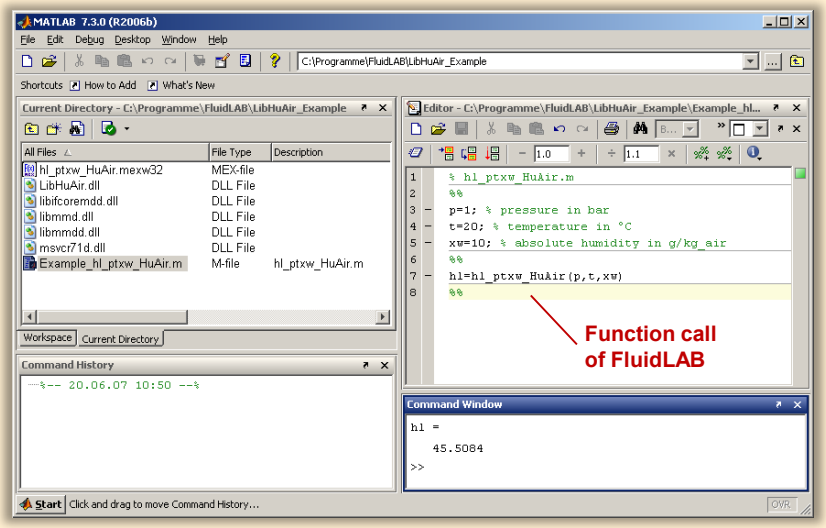
Add-On FluidMAT for Mathcad®
Add-On FluidPRIME for Mathcad Prime®

The property libraries can be used in Mathcad® and Mathcad Prime®.



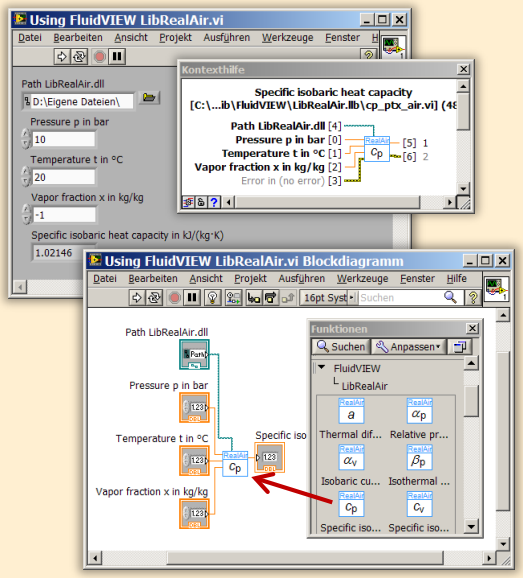
Add-On FluidLAB for MATLAB® and SIMULINK®

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



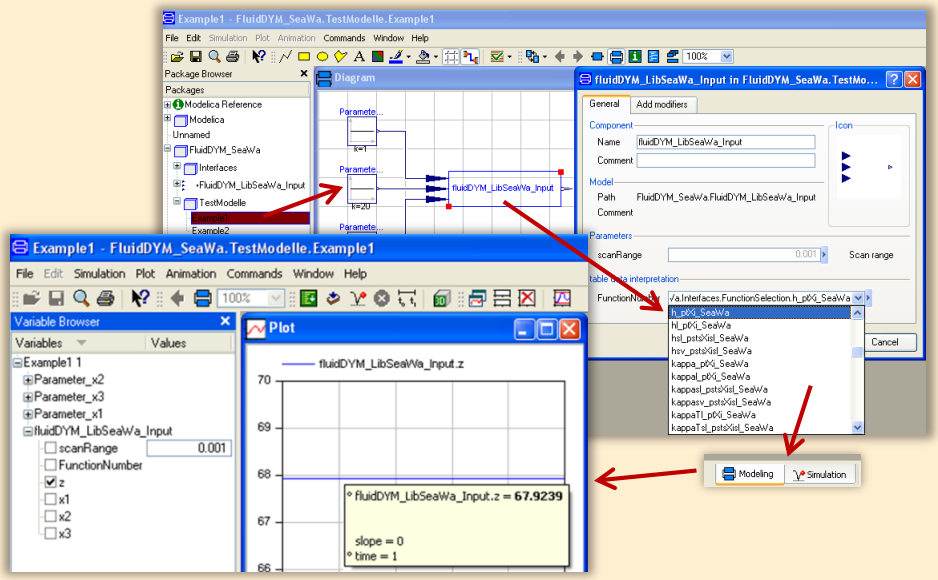
Add-On FluidVIEW for LabVIEW™

The property functions can be calculated in LabVIEW™.

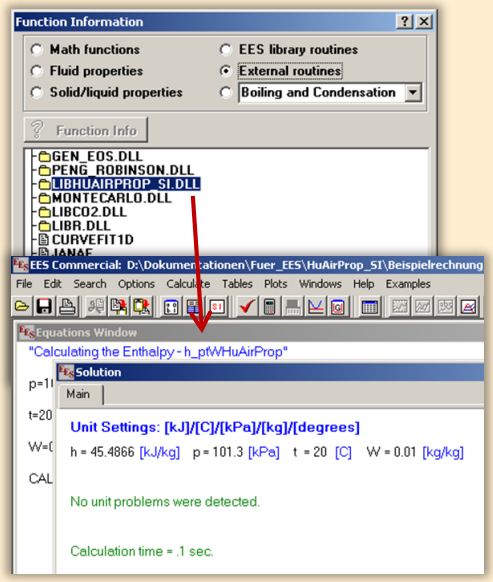


Add-On FluidDYM for DYMOLA® (Modelica) and SimulationX®

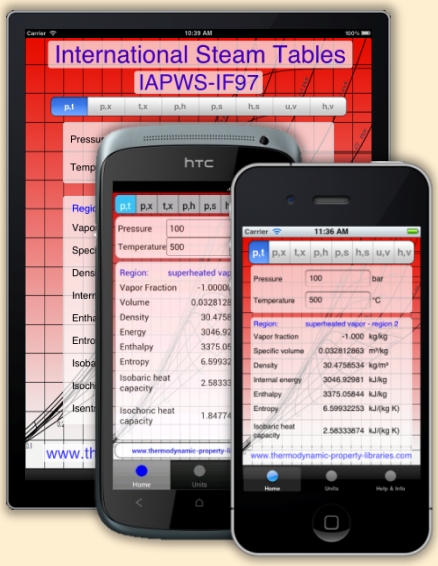
The property functions can be called in DYMOLA® and SimulationX®.



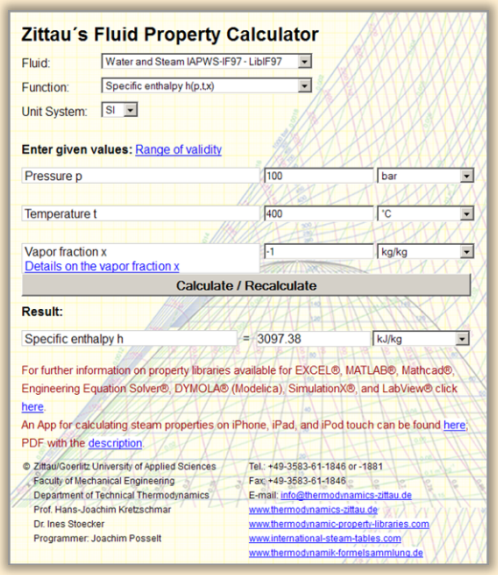
Add-On FluidEES for Engineering Equation Solver®



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



Online Property Calculator at www.thermofluidprop.com



Property Software for Pocket Calculators

FluidCasio

fx 9750 G II | CFX 9850 fx-GG20 | CFX 9860 G Graph 85 | ALGEBRA FX 2.0

FluidHP

HP 48 | HP 49

FluidTI

TI Nspire CX CAS
TI Nspire CAS

TI 83
TI 84
TI 89

TI Voyage 200

TI 92

For more information please contact:

KCE ThermoFluidProperties

KCE-ThermoFluidProperties UG & Co. KG
Prof. Dr. Hans-Joachim Kretzschmar
Wallotstr. 3
01307 Dresden, Germany

Internet: www.thermofluidprop.com
Email: info@thermofluidprop.com
Phone: +49-351-27597860
Mobile: +49-172-7914607
Fax: +49-3222-1095810

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
- Thermal diffusivity a

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

Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

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

www.thermofluidprop.com

5 References

[1] Herrmann, S.; Kretzschmar, H.-J.; Gatley, D.P.: Thermodynamic Properties of Real Moist Air, Dry Air, Steam, Water, and Ice. HVAC&R Research 5, 961-986 (2009).

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[14] Lemmon, E.W.; Jacobsen, R.T.; Penoncello, S.G.; Friend, D.G.: Thermodynamic Properties of Air and Mixture of Nitrogen, Argon, and Oxygen from 60 to 2000 K at Pressures to 2000 MPa. J. Phys. Chem. Ref. Data 29, 331-385 (2000).

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6 Satisfied Customers

Date: 12/2019

The following companies and institutions use the property libraries:

- FluidEXL*Graphics* for Excel®
- FluidLAB for MATLAB® and Simulink
- FluidMAT for Mathcad®
- FluidPRIME for Mathcad Prime®
- FluidEES for Engineering Equation Solver® EES
- FluidDYM for Dymola® (Modelica) and SimulationX®
- FluidVIEW for LabVIEW™
- DLLs for Windows™
- Shared Objects for Linux®.

2019

PEU Leipzig, Rötha	12/2019
MB-Holding, Vestenbergsgreuth	12/2019
COMPAREX, Leipzig for RWE Supply & Trading GmbH, Essen	12/2019
Georg-Büchner-Hochschule, Darmstadt	11/2019
EEB ENERKO, Aldenhoven	11/2019
Robert Benoufa Energietechnik, Wiesloch	11/2019
Kehrein & Kubanek Klimatechnik, Moers	10/2019
Hanon Systems Autopal Services, Hluk, Czech Republic	10/2019
CEA Saclay, Gif Sur Yvette cedex, France	10/2019
Saudi Energy Efficiency Center SEEC, Riyadh, Saudi Arabia	10/2019
VPC, Vetschau	09/2019
jGanser PM + Engineering, Forchheim	09/2019
Ruchti IB, Uster, Switzerland	09/2019
ZWILAG Zwischenlager Würenlingen, Switzerland	08/2019
Hochschule Zittau/Görlitz, Faculty Maschinenwesen	08/2019
Stadtwerke Neubrandenburg	08/2019
Physikalisch Technische Bundesanstalt PTB, Braunschweig	08/2019
GMVA Oberhausen	07/2019
Endress+Hauser Flowtec AG, Reinach, Switzerland	07/2019, 09/2019
WARNICA, Waterloo, Canada	07/2019
MIBRAG, Zeitz	06/2019
Pöyry, Zürich, Switzerland	06/2019
RWTH Aachen, Institut für Strahlantriebe und Turbomaschinen	06/2019
Midiplan, Bietigheim-Bissingen	06/2019
GKS Schweinfurt	06/2019
HS Zittau/Görlitz, Wirtschaftswissenschaften und Wirtschaftsingenieurwesen	06/2019
ILK Dresden	06/2019
HZDR Helmholtz Zentrum Dresden-Rossendorf	06/2019

TH Köln, Technische Gebäudeausrüstung	05/2019
IB Knittel, Braunschweig	05/2019
Norsk Energi, Oslo, Norway	05/2019
STEAG, Essen	05/2019
Stora Enso, Eilenburg	05/2019
IB Lücke, Paderborn	05/2019
Haarslev, Sonderso, Denmark	05/2019
MAN Augsburg	05/2019
Wieland Werke, Ulm	04/2019
Fels-Werke, Elbingerode	04/2019
Univ. Luxembourg, Luxembourg	04/2019
BTU Cottbus, Power Engineering	03/2009
Eins-Energie Sachsen, Schwarzenberg	03/2019
TU Dresden, Kälte- und Kryotechnik	03/2019
ITER, St. Paul Lez Durance Cedex, France	03/2019
Fraunhofer UMSICHT, Oberhausen	03/2019
Comparex Leipzig for Spedition Thiele HEMMERSBACH	03/2019
Rückert NaturGas, Lauf/Pegnitz	03/2019
BASF, Basel, Switzerland	02/2019
Stadtwerke Leipzig	02/2019
Maerz Ofenbau Zürich, Switzerland	02/2019
Hanon Systems Germany, Kerpen	02/2019
Thermofin, Heinsdorfergrund	01/2019
BSH Berlin	01/2019

2018

Jaguar Energy, Guatemala	12/2018
WEBASTO, Gilching	12/2018
Smurfit Kappa, Oosterhout, Netherlands	12/2018
Univ. BW München	12/2018
RAIV, Liberec for VALEO, Prague, Czech Republic	11/2018
VPC Group Vetschau	11/2018
SEITZ, Wetzikon, Switzerland	11/2018
MVV, Mannheim	10/2018
IB Troche	10/2018
KANIS Turbinen, Nürnberg	10/2018
TH Ingolstadt, Institut für neue Energiesysteme	10/2018
IB Kristl & Seibt, Graz, Austria	09/2018
INEOS, Köln	09/2018
IB Lücke, Paderborn	09/2018
Südzucker, Ochsenfurt	08/2018
K&K Turbinenservice, Bielefeld	07/2018
OTH Regensburg, Elektrotechnik	07/2018
Comparex Leipzig for LEAG, Berlin	06/2018
Münstermann, Telgte	05/2018
TH Nürnberg, Verfahrenstechnik	05/2018

Universität Madrid, Madrid, Spanien	05/2018
HS Zittau/Görlitz, Wirtschaftswissenschaften und Wirtschaftsingenieurwesen	05/2018
HS Niederrhein, Krefeld	05/2018
Wilhelm-Büchner HS, Pfungstadt	03/2018
GRS, Köln	03/2018
WIB, Dennheritz	03/2018
RONAL AG, Härklingen, Schweiz	02/2018
Ingenieurbüro Leipert, Riegelsberg	02/2018
AIXPROCESS, Aachen	02/2018
KRONES, Neutraubling	02/2018
Doosan Lentjes, Ratingen	01/2018

2017

Compact Kältetechnik, Dresden	12/2017
Endress + Hauser Messtechnik GmbH +Co. KG, Hannover	12/2017
TH Mittelhessen, Gießen	11/2017
Haarslev Industries, Søndersø, Denmark	11/2017
Hochschule Zittau/Görlitz, Fachgebiet Energiesystemtechnik	11/2017
ATESTEO, Alsdorf	10/2017
Wijbenga, PC Geldermalsen, Netherlands	10/2017
Fels-Werke GmbH, Elbingerode	10/2017
KIT Karlsruhe, Institute für Neutronenphysik und Reaktortechnik	09/2017
Air-Consult, Jena	09/2017
Papierfabrik Koehler, Oberkirch	09/2017
ZWILAG, Würenlingen, Switzerland	09/2017
TLK-Thermo Universität Braunschweig, Braunschweig	08/2017
Fichtner IT Consulting AG, Stuttgart	07/2017
Hochschule Ansbach, Ansbach	06/2017
RONAL, Härkingen, Switzerland	06/2017
BORSIG Service, Berlin	06/2017
BOGE Kompressoren, Bielefeld	06/2017
STEAG Energy Services, Zwingenberg	06/2017
CES clean energy solutions, Wien, Austria	04/2017
Princeton University, Princeton, USA	04/2017
B2P Bio-to-Power, Wadersloh	04/2017
TU Dresden, Institute for Energy Engineering, Dresden	04/2017
SAINT-GOBAIN, Vaujours, France	03/2017
TU Bergakademie Freiberg, Chair of Thermodynamics, Freiberg	03/2017
SCHMIDT + PARTNER, Therwil, Switzerland	03/2017
KAESER Kompressoren, Gera	03/2017
F&R, Praha, Czech Republic	03/2017
ULT Umwelt-Lufttechnik, Löbau	02/2017
JS Energie & Beratung, Erding	02/2017
Kelvion Brazed PHE, Nobitz-Wilchwitz	02/2017
MTU Aero Engines, München	02/2017
Hochschule Zittau/Görlitz, IPM	01/2017

CombTec ProCE, Zittau	01/2017
SHELL Deutschland Oil, Wesseling	01/2017
MARTEC Education Center, Frederikshaven, Denmark	01/2017
SynErgy Thermal Management, Krefeld	01/2017

2016

BOGE Druckluftsysteme, Bielefeld	12/2016
BFT Planung, Aachen	11/2016
Midiplan, Bietigheim-Bissingen	11/2016
BBE Barnich IB	11/2016
Wenisch IB,	11/2016
INL, Idaho Falls	11/2016
TU Kältetechnik, Dresden	11/2016
Kopf SynGas, Sulz	11/2016
INTVEN, Bellevne (USA)	11/2016
DREWAG Dresden, Dresden	10/2016
AGO AG Energie+Anlagen, Kulmbach	10/2016
Universität Stuttgart, ITW, Stuttgart	09/2016
Pöyry Deutschland GmbH, Dresden	09/2016
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
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
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
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

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 Dresen + 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
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
Pöyry 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	05/2012

via Fichtner IT Consult	
Endress & Hauser	05/2012
PEU, Espenheim	05/2012
Luzern University of Applied Sciences, Switzerland	05/2012
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 Destilation, Sprendlingen	02/2012
Lopez, Munguia, Spain	02/2012
Endress & Hauser, Hannover	02/2012
Palo Alto Research Center, USA	02/2012
WIPAK, Walsrode	02/2012
Freudenberg, Weinheim	01/2012
Fichtner, Stuttgart	01/2012
airinotec, Bayreuth	01/2012, 07/2012
University Auckland, New Zealand	01/2012
VPC, Vetschau	01/2012
Franken Guss, Kitzingen	01/2012

2011

XRG-Simulation, Hamburg	12/2011
Smurfit Kappa PPT, AX Roermond, Netherlands	12/2011
AWTEC, Zurich, Switzerland	12/2011
eins-energie, Bad Elster	12/2011
BeNow, Rodenbach	11/2011
Luzern University of Applied Sciences, Switzerland	11/2011
GMVA, Oberhausen	11/2011
CCI, Karlsruhe	10/2011
W.-Büchner University of Applied Sciences, Pfungstadt	10/2011
PLANAIR, La Sagne, Switzerland	10/2011
LAWI, Dresden	10/2011
Lopez, Munguia, Spain	10/2011
University of KwaZulu-Natal, Westville, South Africa	10/2011
Voith, Heidenheim	09/2011

SpgBe Montreal, Canada	09/2011
SPG TECH, Montreuil Cedex, France	09/2011
Voith, Heidenheim-Mergelstetten	09/2011
MTU Aero Engines, Munich	08/2011
MIBRAG, Zeitz	08/2011
RWE, Essen	07/2011
Fels, Elingerode	07/2011
Weihenstephan University of Applied Sciences	07/2011, 09/2011 10/2011
Forschungszentrum Juelich	07/2011
RWTH Aachen University	07/2011, 08/2011
INNEO Solutions, Ellwangen	06/2011
Caliqua, Basel, Switzerland	06/2011
Technical University of Freiberg	06/2011
Fichtner IT Consulting, Stuttgart	05/2011, 06/2011, 08/2011
Salzgitter Flachstahl, Salzgitter	05/2011
Helbling Beratung & Bauplanung, Zurich, Switzerland	05/2011
INEOS, Cologne	04/2011
Enseleit Consulting Engineers, Siebigerode	04/2011
Witt Consulting Engineers, Stade	03/2011
Helbling, Zurich, Switzerland	03/2011
MAN Diesel, Copenhagen, Denmark	03/2011
AGO, Kulmbach	03/2011
University of Duisburg	03/2011, 06/2011
CCP, Marburg	03/2011
BASF, Ludwigshafen	02/2011
ALSTOM Power, Baden, Switzerland	02/2011
Universität der Bundeswehr, Munich	02/2011
Calorifer, Elgg, Switzerland	01/2011
STRABAG, Vienna, Austria	01/2011
TUEV Sued, Munich	01/2011
ILK Dresden	01/2011
Technical University of Dresden	01/2011, 05/2011 06/2011, 08/2011

2010

Umweltinstitut Neumarkt	12/2010
YIT Austria, Vienna, Austria	12/2010
MCI Innsbruck, Austria	12/2010
University of Stuttgart	12/2010
HS Cooler, Wittenburg	12/2010
Visteon, Novi Jicin, Czech Republic	12/2010
CompuWave, Brunntal	12/2010
Stadtwerke Leipzig	12/2010
MCI Innsbruck, Austria	12/2010

EVONIK Energy Services, Zwingenberg	12/2010
Caliqua, Basel, Switzerland	11/2010
Shanghai New Energy Resources Science & Technology, China	11/2010
Energieversorgung Halle	11/2010
Hochschule für Technik Stuttgart, University of Applied Sciences	11/2010
Steinmueller, Berlin	11/2010
Amberg-Weiden University of Applied Sciences	11/2010
AREVA NP, Erlangen	10/2010
MAN Diesel, Augsburg	10/2010
KRONES, Neutraubling	10/2010
Vaillant, Remscheid	10/2010
PC Ware, Leipzig	10/2010
Schubert Consulting Engineers, Weißenberg	10/2010
Fraunhofer Institut UMSICHT, Oberhausen	10/2010
Behringer Consulting Engineers, Tagmersheim	09/2010
Saacke, Bremen	09/2010
WEBASTO, Neubrandenburg	09/2010
Concordia University, Montreal, Canada	09/2010
Compañía Eléctrica de Sochagota, Bogota, Colombia	08/2010
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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
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Hot Rock, Karlsruhe	05/2010
Darmstadt University of Applied Sciences	05/2010
Voith, Heidenheim	04/2010
CombTec, Zittau	04/2010
University of Glasgow, Great Britain	04/2010
Universitaet der Bundeswehr, Munich	04/2010
Technical University of Hamburg-Harburg	04/2010
Vattenfall Europe, Berlin	04/2010
HUBER Consulting Engineers, Berching	04/2010
VER, Dresden	04/2010
CCP, Marburg	03/2010
Offenburg University of Applied Sciences	03/2010
Technical University of Berlin	03/2010
NIST Boulder CO, USA	03/2010
Technical University of Dresden	02/2010
Siemens Energy, Nuremberg	02/2010
Augsburg University of Applied Sciences	02/2010

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

2009

ALSTOM Power, Baden, Schweiz	01/2009, 03/2009
	05/2009
Nordostschweizerische Kraftwerke AG, Doettingen, Switzerland	02/2009
RWE, Neurath	02/2009
Brandenburg University of Technology, Cottbus	02/2009
Hamburg University of Applied Sciences	02/2009
Kehrein, Moers	03/2009
EPP Software, Marburg	03/2009
Bernd Münstermann, Telgte	03/2009
Suedzucker, Zeitz	03/2009
CPP, Marburg	03/2009
Gelsenkirchen University of Applied Sciences	04/2009
Regensburg University of Applied Sciences	05/2009
Gatley & Associates, Atlanta, USA	05/2009
BOSCH, Stuttgart	06/2009, 07/2009
Dr. Nickolay, Consulting Engineers, Gommersheim	06/2009
Ferrostal Power, Saarlouis	06/2009
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Intraserv, Wiesbaden	06/2009
Lausitz University of Applied Sciences, Senftenberg	06/2009
Nuernberg University of Applied Sciences	06/2009
Technical University of Berlin	06/2009
Fraunhofer Institut UMSICHT, Oberhausen	07/2009
Bischoff, Aurich	07/2009
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Techsoft, Linz, Austria	08/2009
DLR, Stuttgart	08/2009
Wienstrom, Vienna, Austria	08/2009
RWTH Aachen University	09/2009
Vattenfall, Hamburg	10/2009
AIC, Chemnitz	10/2009
Midiplan, Bietigheim-Bissingen	11/2009
Institute of Air Handling and Refrigeration ILK, Dresden	11/2009
FZD, Rossendorf	11/2009
Techgroup, Ratingen	11/2009
Robert Sack, Heidelberg	11/2009
EC, Heidelberg	11/2009

MCI, Innsbruck, Austria	12/2009
Saacke, Bremen	12/2009
ENERKO, Aldenhoven	12/2009

2008

Pink, Langenwang	01/2008
Fischer-Uhrig, Berlin	01/2008
University of Karlsruhe	01/2008
MAAG, Kuesnacht, Switzerland	02/2008
M&M Turbine Technology, Bielefeld	02/2008
Lentjes, Ratingen	03/2008
Siemens Power Generation, Goerlitz	04/2008
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CFC Solutions, Munich	04/2008
RWE IT, Essen	04/2008
Rerum Cognitio, Zwickau	04/2008, 05/2008
ARUP, Berlin	05/2008
Research Center, Karlsruhe	07/2008
AWECO, Neukirch	07/2008
Technical University of Dresden, Professorship of Building Services	07/2008
Technical University of Cottbus, Chair in Power Plant Engineering	07/2008, 10/2008
Ingersoll-Rand, Unicov, Czech Republic	08/2008
Technip Benelux BV, Zoetermeer, Netherlands	08/2008
Fennovoima Oy, Helsinki, Finland	08/2008
Fichtner Consulting & IT, Stuttgart	09/2008
PEU, Espenhain	09/2008
Poyry, Dresden	09/2008
WINGAS, Kassel	09/2008
TUEV Sued, Dresden	10/2008
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	10/2008, 11/2008
AWTEC, Zurich, Switzerland	11/2008
Siemens Power Generation, Erlangen	12/2008

2007

Audi, Ingolstadt	02/2007
ANO Abfallbehandlung Nord, Bremen	02/2007
TUEV NORD SysTec, Hamburg	02/2007
VER, Dresden	02/2007
Technical University of Dresden, Chair in Jet Propulsion Systems	02/2007
Redacom, Nidau, Switzerland	02/2007
Universität der Bundeswehr, Munich	02/2007
Maxxtec, Sinsheim	03/2007
University of Rostock, Chair in Technical Thermodynamics	03/2007

AGO, Kulmbach	03/2007
University of Stuttgart, Chair in Aviation Propulsions	03/2007
Siemens Power Generation, Duisburg	03/2007
ENTHAL Haustechnik, Rees	05/2007
AWECO, Neukirch	05/2007
ALSTOM, Rugby, Great Britain	06/2007
SAAS, Possendorf	06/2007
Grenzebach BSH, Bad Hersfeld	06/2007
Reichel Engineering, Haan	06/2007
Technical University of Cottbus, Chair in Power Plant Engineering	06/2007
Voith Paper Air Systems, Bayreuth	06/2007
Egger Holzwerkstoffe, Wismar	06/2007
Tissue Europe Technologie, Mannheim	06/2007
Dometic, Siegen	07/2007
RWTH Aachen University, Institute for Electrophysics	09/2007
National Energy Technology Laboratory, Pittsburg, USA	10/2007
Energieversorgung Halle	10/2007
AL-KO, Jettingen	10/2007
Grenzebach BSH, Bad Hersfeld	10/2007
Wiesbaden University of Applied Sciences, Department of Engineering Sciences	10/2007
Endress+Hauser Messtechnik, Hannover	11/2007
Munich University of Applied Sciences, Department of Mechanical Engineering	11/2007
Rerum Cognitio, Zwickau	12/2007
Siemens Power Generation, Erlangen	11/2007
University of Rostock, Chair in Technical Thermodynamics	11/2007, 12/2007

2006

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

Siemens Power Generation, Goerlitz	04/2006
Technical University of Braunschweig, Department of Thermodynamics	04/2006
EnviCon & Plant Engineering, Nuremberg	04/2006
Brassel Engineering, Dresden	05/2006
University of Halle-Merseburg, Department of USET Merseburg incorporated society	05/2006
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	05/2006
Fichtner Consulting & IT Stuttgart (company licenses and distribution)	05/2006
Suedzucker, Ochsenfurt	06/2006
M&M Turbine Technology, Bielefeld	06/2006
Feistel Engineering, Volkach	07/2006
ThyssenKrupp Marine Systems, Kiel	07/2006
Caliqua, Basel, Switzerland (company license)	09/2006
Atlas-Stord, Rodovre, Denmark	09/2006
Konstanz University of Applied Sciences, Course of Studies Construction and Development	10/2006
Siemens Power Generation, Duisburg	10/2006
Hannover University of Applied Sciences, Department of Mechanical Engineering	10/2006
Siemens Power Generation, Berlin	11/2006
Zikesch Armaturentechnik, Essen	11/2006
Wismar University of Applied Sciences, Seafaring Department	11/2006
BASF, Schwarzheide	12/2006
Enertech Energie und Technik, Radebeul	12/2006

2005

TUEV Nord, Hannover	01/2005
J.H.K Plant Engineering and Service, Bremerhaven	01/2005
Electrowatt-EKONO, Zurich, Switzerland	01/2005
FCIT, Stuttgart	01/2005
Energietechnik Leipzig (company license)	02/2005, 04/2005 07/2005
eta Energieberatung, Pfaffenhofen	02/2005
FZR Forschungszentrum, Rossendorf/Dresden	04/2005
University of Saarbruecken	04/2005
Technical University of Dresden Professorship of Thermic Energy Machines and Plants	04/2005
Grenzebach BSH, Bad Hersfeld	04/2005
TUEV Nord, Hamburg	04/2005
Technical University of Dresden, Waste Management	05/2005
Siemens Power Generation, Goerlitz	05/2005
Duesseldorf University of Applied Sciences, Department of Mechanical Engineering and Process Engineering	05/2005
Redacom, Nidau, Switzerland	06/2005

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

2004

Vattenfall Europe (group license)	01/2004
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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
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STORA ENSO Sachsen, Eilenburg	12/2004
Technical University of Cottbus, Chair in Power Plant Engineering	12/2004

Freudenberg Service, Weinheim	12/2004

2003

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

2002

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

FZR Forschungszentrum, Rossendorf/Dresden	03/2002
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Stadtwerke Duisburg	08/2002
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Siemens Power Generation, Goerlitz	10/2002
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Dillinger Huette, Dillingen	11/2002
G.U.N.T. Geraetebau, Barsbuettel	12/2002
(general license and training test benches)	
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2001

ALSTOM Power, Baden, Switzerland	01/2001, 06/2001
	12/2001
KW2 B. V., Amersfoot, Netherlands	01/2001, 11/2001
Eco Design, Saitamaken, Japan	01/2001
M&M Turbine Technology, Bielefeld	01/2001, 09/2001
MVV Energie, Mannheim	02/2001
Technical University of Dresden, Department of	02/2001
Power Machinery and Plants	
PREUSSAG NOELL, Wuerzburg	03/2001
Fichtner Consulting & IT Stuttgart	04/2001
(company licenses and distribution)	
Muenstermann GmbH, Telgte-Westbevern	05/2001
SaarEnergie, Saarbruecken	05/2001
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Neusiedler AG, Ulmerfeld, Austria	09/2001
h s energieanlagen, Freising	09/2001
Electrowatt-EKONO, Zurich, Switzerland	09/2001
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ALSTOM Power Baden, Switzerland	12/2001

VEAG, Berlin (group license)	12/2001

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PREUSSAG NOELL, Wuerzburg	01/2000
M&M Turbine Technology, Bielefeld	01/2000
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GK, Hannover	03/2000
KRUPP-UHDE, Dortmund (company license)	03/2000
UMAG W. UDE, Husum	03/2000
VEAG, Berlin (group license)	03/2000
Thinius Engineering, Erkrath	04/2000
SaarEnergie, Saarbruecken	05/2000, 08/2000
DVO Data Processing Service, Oberhausen	05/2000
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VAUP Process Automation, Landau	08/2000
Knuerr-Lommatec, Lommatzsch	09/2000
AVACON, Helmstedt	10/2000
Compania Electrica, Bogota, Colombia	10/2000
G.U.N.T. Geraetebau, Barsbuettel (general license for training test benches)	11/2000
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1999

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

1998

Technical University of Cottbus, Chair in Power Plant Engineering	05/1998
Fichtner Consulting & IT (CADIS information systems) Stuttgart (general KPRO program license)	05/1998
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B+H Software Engineering Stuttgart	08/1998
Alfa Engineering, Switzerland	09/1998
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SCA Hygiene Products, Munich	10/1998

RWE Energie, Neurath	10/1998
Wilhelmshaven University of Applied Sciences	10/1998
BASF, Ludwigshafen (group license)	11/1998
Energieversorgung, Offenbach	11/1998

1997

Gerb, Dresden	06/1997
Siemens Power Generation, Goerlitz	07/1997

Part SI Units

1 Property Library ASHRAE-LibHuAirProp-SI

1.1 Function Overview

1.1.1 Function Overview for Real Moist Air

Functional Dependence	Function Name	Property or Function	Unit of the Result	Page
$a = \mathrm{f}(p,t,W)$	a_ptW_HAP_SI	Thermal diffusivity	m²/s	3/2
$\alpha_p = \mathrm{f}(p,t,W)$	alphap_ptW_HAP_SI	Relative pressure coefficient	1/K	3/3
$\beta_p = \mathrm{f}(p,t,W)$	betap_ptW_HAP_SI	Isothermal stress coefficient	kg/m³	3/4
$c = \mathrm{f}(p,t,W)$	c_ptW_HAP_SI	Speed of sound	m/s	3/5
$c_p = \mathrm{f}(p,t,W)$	cp_ptW_HAP_SI	Specific isobaric heat capacity	kJ/(kg·K)	3/6
$c_v = \mathrm{f}(p,t,W)$	cv_ptW_HAP_SI	Specific isochoric heat capacity	kJ/(kg·K)	3/7
$f = \mathrm{f}(p,t)$	f_pt_HAP_SI	Enhancement factor (decimal ratio)	-	3/8
$h = \mathrm{f}(p,t,W)$	h_ptW_HAP_SI	Air-specific enthalpy	$\mathrm{kJ/kg_a}$	3/9
$\eta = \mathrm{f}(p,t,W)$	Eta_ptW_HAP_SI	Dynamic viscosity	Pa·s	3/10
$\kappa = \mathrm{f}(p,t,W)$	Kappa_ptW_HAP_SI	Isentropic exponent	-	3/11
$\lambda = \mathrm{f}(p,t,W)$	Lambda_ptW_HAP_SI	Thermal conductivity	W/(m·K)	3/12
$\nu = \mathrm{f}(p,t,W)$	Ny_ptW_HAP_SI	Kinematic viscosity	m²/s	3/13
$p = \mathrm{f}(t,s,W)$	p_tsW_HAP_SI	Pressure of humid air	kPa	3/14
$p = \mathrm{f}(z_{\mathrm{ele}})$	p_zele_HAP_SI	Pressure of humid air from elevation	kPa	3/15
$p_{\mathrm{Air}} = \mathrm{f}(p,t,W)$	pAIR_ptW_HAP_SI	Partial pressure of dry air in moist air	kPa	3/16
$p_{\mathrm{H2O}} = \mathrm{f}(p,t,W)$	pH2O_ptW_HAP_SI	Partial pressure of water vapor in moist air	kPa	3/17
$p_{\mathrm{H2Os}} = \mathrm{f}(p,t)$	pH2Os_pt_HAP_SI	Partial saturation pressure of water vapor	kPa	3/18

Functional Dependence	Function Name	Property or Function	Unit of the Result	Page
$\varphi = \mathrm{f}(p,t,W)$	phi_ptW_HAP_SI	Relative humidity (decimal ratio)	-	3/19
$Pr = \mathrm{f}(p,t,W)$	Pr_ptW_HAP_SI	PRANDTL number	-	3/20
$\psi_{Air} = \mathrm{f}(W)$	PsiAir_W_HAP_SI	Mole fraction of dry air in moist air	mol_a/mol	3/21
$\psi_{\mathrm{H2O}} = \mathrm{f}(W)$	PsiH2O_W_HAP_SI	Mole fraction of water vapor in moist air	mol_w/mol	3/22
$\rho = \mathrm{f}(p,t,W)$	Rho_ptW_HAP_SI	Density	kg/m^3	3/23
$s = \mathrm{f}(p,t,W)$	s_ptW_HAP_SI	Air-specific entropy	$kJ/(kg_a \cdot K)$	3/24
$t = \mathrm{f}(p,h,\varphi)$	t_phphi_HAP_SI	Backward function: temperature from total pressure, air-specific enthalpy and relative humidity	°C	3/25
$t = \mathrm{f}(p,h,W)$	t_phW_HAP_SI	Backward function: temperature from total pressure, air-specific enthalpy and humidity ratio	°C	3/26
$t = \mathrm{f}(p,s,W)$	t_psW_HAP_SI	Backward function: temperature from total pressure, air-specific entropy and humidity ratio	°C	3/27
$t = \mathrm{f}(p,t_{\mathrm{wb}},W)$	t_ptwbW_HAP_SI	Backward function: temperature from total pressure, wet-bulb temperature and humidity ratio	°C	3/28
$t_{\mathrm{d}} = \mathrm{f}(p,W)$	td_pW_HAP_SI	Dew-point/frost-point temperature	°C	3/29
$t_{\mathrm{s}} = \mathrm{f}(p,p_{\mathrm{H2O}})$	ts_ppH2O_HAP_SI	Backward function: saturation temperature of water from total pressure and partial pressure of water vapor	°C	3/30
$t_{\mathrm{wb}} = \mathrm{f}(p,t,W)$	twb_ptW_HAP_SI	Wet-bulb/ice-bulb temperature	°C	3/31
$u = \mathrm{f}(p,t,W)$	u_ptW_HAP_SI	Air-specific internal energy	kJ/kg_a	3/32
$v = \mathrm{f}(p,t,W)$	v_ptW_HAP_SI	Air-specific volume	m^3/kg_a	3/33
$W = \mathrm{f}(p,t,p_{\mathrm{H2O}})$	W_ptpH2O_HAP_SI	Humidity ratio from total pressure, temperature, and partial pressure of water vapor	kg_w/kg_a	3/34
$W = \mathrm{f}(p,t,\varphi)$	W_ptphi_HAP_SI	Humidity ratio from total pressure, temperature, and relative humidity	kg_w/kg_a	3/35
$W = \mathrm{f}(p,t_{\mathrm{d}})$	W_ptd_HAP_SI	Humidity ratio from total pressure and dew-point temperature	kg_w/kg_a	3/36

Functional Dependence	Function Name	Property or Function	Unit of the Result	Page
$W = \mathrm{f}(p,t,t_{\mathrm{wb}})$	W_pttwb_HAP_SI	Humidity ratio from total pressure, (dry bulb) temperature, and wet-bulb temperature	kg_w/kg_a	3/37
$W_{\mathrm{s}} = \mathrm{f}(p,t)$	Ws_pt_HAP_SI	Saturation humidity ratio	kg_w/kg_a	3/38
$\xi_{\mathrm{Air}} = \mathrm{f}(W)$	XiAir_W_HAP_SI	Mass fraction of dry air in moist air	kg_a/kg	3/39
$\xi_{\mathrm{H2O}} = \mathrm{f}(W)$	XiH2O_W_HAP_SI	Mass fraction of water vapor in moist air	kg_w/kg	3/40
$Z = \mathrm{f}(p,t,W)$	Z_ptW_HAP_SI	Compression factor (decimal ratio)	-	3/41

Range of Validity of Thermodynamic Properties

Property	Range of Validity					
Pressure:	0.01	≤	p	≤	10 000	kPa
Temperature:	–143.15	≤	t	≤	350	°C
Humidity ratio:	0	≤	W	≤	10	kg_w/kg_a
Relative humidity:	0	≤	φ	≤	1	(decimal ratio)
Dew-point temperature:	–143.15	≤	t_d	≤	350	°C
Wet-bulb temperature:	–143.15	≤	t_{wb}	≤	350	°C

Range of Validity of Transport Properties

Property	Range of Validity					
Pressure:	0.01	≤	p	≤	10 000	kPa
Temperature:	–73.15	≤	t	≤	350	°C
Humidity ratio:	0	≤	W	≤	10	kg_w/kg_a
Relative humidity:	0	≤	φ	≤	1	(decimal ratio)

Molar Masses

Component	Molar Mass	Reference
Dry Air	28.966 kg/kmol	[17]
Water	18.015268 kg/kmol	[5], [6]

Reference States

Property	Dry Air	Steam, Water, and Ice
Pressure	101.325 kPa	p_s(0.01°C) = 0.611657 kPa
Temperature	0°C	0.01°C
Enthalpy	0 kJ/kg	0.000611782 kJ/kg
Entropy	0 kJ/(kg K)	0 kJ/(kg K)

Units

Symbol	Quantity	Unit
p	Pressure	kPa
t	Temperature	°C
W	Humidity ratio	kg_w/kg_a (kg water / kg dry air)
φ	Relative humidity	(decimal ratio)
t_d	Dew point temperature	°C
t_{wb}	Wet bulb temperature	°C

1.1.2 Function Overview for Steam and Water for Temperatures $t \geq 0°C$

Functional Dependence	Function Name	Property	Unit of the Result	Page
$h_{liq} = f(p,t)$	hliq_pt_97_SI	Specific enthalpy of liquid water	kJ/kg	3/43
$h_{liq,s} = f(t)$	hliqs_t_97_SI	Specific enthalpy of saturated liquid water	kJ/kg	3/44
$h_{vap,s} = f(t)$	hvaps_t_97_SI	Specific enthalpy of saturated water vapor	kJ/kg	3/45
$p_s = f(t)$	ps_t_97_SI	Saturation pressure of water	kPa	3/46
$s_{liq} = f(p,t)$	sliq_pt_97_SI	Specific entropy of liquid water	kJ/(kg·K)	3/47
$s_{liq,s} = f(t)$	sliqs_t_97_SI	Specific entropy of saturated liquid water	kJ/(kg·K)	3/48
$s_{vap,s} = f(t)$	svaps_t_97_SI	Specific entropy of saturated water vapor	kJ/(kg·K)	3/49
$t_s = f(p)$	ts_p_97_SI	Saturation temperature of water	°C	3/50
$v_{liq} = f(p,t)$	vliq_pt_97_SI	Specific volume of liquid water	m^3/kg	3/51
$v_{liq,s} = f(t)$	vliqs_t_97_SI	Specific volume of saturated liquid water	m^3/kg	3/52
$v_{vap,s} = f(t)$	vvaps_t_97_SI	Specific volume of saturated water vapor	m^3/kg	3/53

Range of Validity

Property	Range of Validity
Pressure:	$0.01 \leq p \leq 10\,000$ kPa
Temperature:	$0 \leq t \leq 350$ °C

Reference State

Property	Water Vapor and Liquid Water
Pressure	p_s(0.01°C) = 0.611657 kPa
Temperature	0.01°C
Enthalpy	0.000611782 kJ/kg
Entropy	0 kJ/(kg K)

Units

Symbol	Quantity	Unit
p	Pressure	kPa
t	Temperature	°C

1.1.3 Function Overview for Steam and Ice for Temperatures $t \leq 0°C$

Functional Dependence	Function Name	Property	Unit of the Result	Page
$h_{ice,sub} = f(t)$	hicesub_t_06_SI	Specific enthalpy of saturated ice	kJ/kg	3/55
$h_{vap,sub} = f(t)$	hvapsub_t_95_SI	Specific enthalpy of saturated water vapor	kJ/kg	3/56
$p_{mel} = f(t)$	pmel_t_08_SI	Melting pressure of ice	kPa	3/57
$p_{sub} = f(t)$	psub_t_08_SI	Sublimation pressure of ice	kPa	3/58
$s_{ice,sub} = f(t)$	sicesub_t_06_SI	Specific entropy of saturated ice	kJ/(kg·K)	3/59
$s_{vap,sub} = f(t)$	svapsub_t_95_SI	Specific entropy of saturated water vapor	kJ/(kg·K)	3/60
$t_{mel} = f(p)$	tmel_p_08_SI	Melting temperature of ice	°C	3/61
$t_{sub} = f(p)$	tsub_p_08_SI	Sublimation temperature of ice	°C	3/62
$v_{ice,sub} = f(t)$	vicesub_t_06_SI	Specific volume of saturated ice	m^3/kg	3/63
$v_{vap,sub} = f(t)$	vvapsub_t_95_SI	Specific volume of saturated water vapor	m^3/kg	3/64

Range of Validity

Property	Range of Validity
Pressure:	$p_{sub}(-143.15°C) = 1.2002 \times 10^{-11} \leq p \leq 10\,000$ kPa
Temperature:	$-143.15 \leq t \leq 0$ °C

Units

Symbol	Quantity	Unit
p	Pressure	kPa
t	Temperature	°C

Reference State

Property	Water Vapor and Ice
Pressure	$p_s(0.01°C) = 0.611657$ kPa
Temperature	0.01°C
Enthalpy	0.000611782 kJ/kg
Entropy	0 kJ/(kg K)

1.2 Conversion of SI and I-P Units

Property		Conversion: SI Units → I-P Units	Conversion: I-P Units → SI Units	Units SI	Units I-P
Thermal diffusivity	a	$\frac{a_{IP}}{\frac{ft^2}{s}} = \frac{a_{SI}}{\frac{m^2}{s}} \times 10.76391042$	$\frac{a_{SI}}{\frac{m^2}{s}} = \frac{a_{IP}}{\frac{ft^2}{s}} \times 0.0929304$	m²/s	ft²/s
Relative pressure coefficient	α_p	$\frac{\alpha_{p,IP}}{\frac{1}{°R}} = \frac{\alpha_{p,SI}}{\frac{1}{K}} \times \frac{9}{5}$	$\frac{\alpha_{p,SI}}{\frac{1}{K}} = \frac{\alpha_{p,IP}}{\frac{1}{°R}} \times \frac{5}{9}$	1/K	1/°R
Isothermal stress coefficient	β_p	$\frac{\beta_{p,IP}}{\frac{lb}{ft^3}} = \frac{\beta_{p,SI}}{\frac{kg}{m^3}} \times 0.062428$	$\frac{\beta_{p,SI}}{\frac{kg}{m^3}} = \frac{\beta_{p,IP}}{\frac{lb}{ft^3}} \times 16.018463$	kg/m³	lb/ft³
Speed of sound	c	$\frac{c_{IP}}{\frac{ft}{s}} = \frac{c_{SI}}{\frac{m}{s}} \times 3.2808399$	$\frac{c_{SI}}{\frac{m}{s}} = \frac{c_{IP}}{\frac{ft}{s}} \times 0.3048$	m/s	ft/s
Specific isobaric heat capacity	c_p	$\frac{c_{p,IP}}{\frac{Btu}{lb\ °R}} = \frac{c_{p,SI}}{\frac{kJ}{kg\ K}} \times 0.2388459$	$\frac{c_{p,SI}}{\frac{kJ}{kg\ K}} = \frac{c_{p,IP}}{\frac{Btu}{lb\ °R}} \times 4.1868$	kJ/(kg·K)	Btu/(lb·°R)
Specific isochoric heat capacity	c_v	$\frac{c_{v,IP}}{\frac{Btu}{lb\ °R}} = \frac{c_{v,SI}}{\frac{kJ}{kg\ K}} \times 0.2388459$	$\frac{c_{v,SI}}{\frac{kJ}{kg\ K}} = \frac{c_{v,IP}}{\frac{Btu}{lb\ °R}} \times 4.1868$	kJ/(kg·K)	Btu/(lb·°R)
Dynamic viscosity	η	$\frac{\eta_{IP}}{\frac{lb\ s}{ft^2}} = \frac{\eta_{SI}}{\frac{Pa}{s}} \times 0.02088543$	$\frac{\eta_{SI}}{\frac{Pa}{s}} = \frac{\eta_{IP}}{\frac{lb\ s}{ft^2}} \times 47.880259$	Pa·s	lb·s/ft²
Enhancement factor	f	$f_{IP} = f_{SI}$	$f_{SI} = f_{IP}$	-	-

Property		Conversion: SI Units → I-P Units	Conversion: I-P Units → SI Units	Units SI	Units I-P
Air-specific enthalpy (moist air)	h	$\frac{h_{IP}}{\frac{Btu}{lb_a}} = \frac{h_{SI}}{\frac{kJ}{kg_a}} \times 0.4299226 + 7.68565365666$	$\frac{h_{SI}}{\frac{kJ}{kg_a}} = \left(\frac{h_{IP}}{\frac{Btu}{lb_a}} - 7.68565365666\right) \times 2.326$	kJ/kg_a	Btu/lb_a
Specific enthalpy (water, water vapor, ice)	h_w	$\frac{h_{IP}}{\frac{Btu}{lb}} = \frac{h_{SI}}{\frac{kJ}{kg}} \times 0.4299226$	$\frac{h_{SI}}{\frac{kJ}{kg}} = \frac{h_{IP}}{\frac{Btu}{lb}} \times 2.326$	kJ/kg	Btu/lb
Isentropic exponent	κ	$\kappa_{IP} = \kappa_{SI}$	$\kappa_{SI} = \kappa_{IP}$	-	-
Thermal conductivity	λ	$\frac{\lambda_{IP}}{\frac{Btu}{h\ ft\ °R}} = \frac{\lambda_{SI}}{\frac{W}{m\ K}} \times 0.57778932$	$\frac{\lambda_{SI}}{\frac{W}{m\ K}} = \frac{\lambda_{IP}}{\frac{Btu}{h\ ft\ °R}} \times 1.73073467$	W/(m·K)	Btu/(h·ft·°R)
Kinematic viscosity	ν	$\frac{\nu_{IP}}{\frac{ft^2}{s}} = \frac{\nu_{SI}}{\frac{m^2}{s}} \times 10.763910417$	$\frac{\nu_{SI}}{\frac{m^2}{s}} = \frac{\nu_{IP}}{\frac{ft^2}{s}} \times 0.092903040$	m^2/s	ft^2/s
Pressure	p	$\frac{p_{IP}}{psi} = \frac{p_{SI}}{kPa} \times 0.14503774$	$\frac{p_{SI}}{kPa} = \frac{p_{IP}}{psi} \times 6.894757$	kPa	psi
Relative humidity	φ	$\varphi_{IP} = \varphi_{SI}$	$\varphi_{SI} = \varphi_{IP}$	-	-
Prandtl number	Pr	$Pr_{IP} = Pr_{IP}$	$Pr_{SI} = Pr_{IP}$	-	-
Mole fraction	ψ	$\psi_{IP} = \psi_{SI}$	$\psi_{SI} = \psi_{IP}$	mol/mol	mol/mol
Density	ρ	$\frac{\rho_{IP}}{\frac{lb}{ft^3}} = \frac{\rho_{SI}}{\frac{kg}{m^3}} \times 0.062428$	$\frac{\rho_{SI}}{\frac{kg}{m^3}} = \frac{\rho_{IP}}{\frac{lb}{ft^3}} \times 16.018463$	kg/m^3	lb/ft^3
Air-specific entropy (moist air)	s	$\frac{s_{IP}}{\frac{Btu}{lb_a\ °R}} = \frac{s_{SI}}{\frac{kJ}{kg_a\ K}} \times 0.2388459 + 0.01616365106$	$\frac{s_{SI}}{\frac{kJ}{kg_a\ K}} = \left(\frac{s_{IP}}{\frac{Btu}{lb_a\ °R}} - 0.01616365106\right) \times 4.1868$	$kJ/(kg_a \cdot K)$	$Btu/(lb_a \cdot °R)$

Property	Conversion: SI Units → I-P Units	Conversion: I-P Units → SI Units	Units SI	Units I-P
Specific entropy (water, water vapor, ice) s_w	$\frac{s_{IP}}{\frac{Btu}{lb_a\ °R}} = \frac{s_{SI}}{\frac{kJ}{kg_a\ K}} \times 0.23884589$	$\frac{s_{SI}}{\frac{kJ}{kg_a\ K}} = \frac{s_{IP}}{\frac{Btu}{lb_a\ °R}} \times 4.1868$	kJ/(kg$_a$·K)	Btu/(lb$_a$·°R)
Temperature t	$\frac{t_{IP}}{°F} = \frac{t_{SI}}{°C} \times \frac{9}{5} + 32$	$\frac{t_{SI}}{°C} = \left(\frac{t_{IP}}{°F} - 32\right) \times \frac{5}{9}$	°C	°F
Air-specific internal energy (moist air) u	$(u = h - pv)$ $\frac{u_{IP}}{\frac{Btu}{lb_a}} = \frac{h_{SI}}{\frac{kJ}{kg_a}} \times 0.4299226 + 7.68565365666 - \frac{p_{SI}}{kPa} \times 0.145037738 \cdot \frac{v_{SI}}{\frac{m^3}{kg_a}} \times 16.018453$	$(u = h - pv)$ $\frac{u_{SI}}{\frac{kJ}{kg_a}} = \left(\frac{h_{IP}}{\frac{Btu}{lb_a}} - 7.68565365666\right) \times 2.236 - \frac{p_{IP}}{psi} \times 6.894757293 \cdot \frac{v_{SIP}}{\frac{ft^3}{lb_a}} \times 0.062428$	kJ/kg$_a$	Btu/lb$_a$
Air-specific volume (moist air) v	$\frac{v_{IP}}{\frac{ft^3}{lb_a}} = \frac{v_{SI}}{\frac{m^3}{kg_a}} \times 16.018453$	$\frac{v_{SI}}{\frac{m^3}{kg_a}} = \frac{v_{IP}}{\frac{ft^3}{lb_a}} \times 0.062428$	m^3/kg$_a$	ft^3/lb$_a$
Specific volume (water, water vapor, ice) v_w	$\frac{v_{IP}}{\frac{ft^3}{lb}} = \frac{v_{SI}}{\frac{m^3}{kg}} \times 16.018453$	$\frac{v_{SI}}{\frac{m^3}{kg}} = \frac{v_{IP}}{\frac{ft^3}{lb}} \times 0.062428$	m^3/kg	ft^3/lb
Humidity ratio W	$W_{IP} = W_{SI}$	$W_{SI} = W_{IP}$	kg$_w$/kg$_a$	lb$_w$/lb$_a$
Mass fraction ξ	$\xi_{IP} = \xi_{SI}$	$\xi_{SI} = \xi_{IP}$	kg$_w$/kg	lb$_w$/lb
Compression factor Z	$Z_{IP} = Z_{SI}$	$Z_{SI} = Z_{IP}$	-	-

1.3 Calculation Algorithms

1.3.1 Algorithms for Real Moist Air

The properties of moist air are calculated from the modified Hyland-Wexler model given in Herrmann, Kretzschmar, and Gatley (HKG) [1], [2]. The modifications incorporate:

- the value for the universal molar gas constant from the CODATA standard by Mohr and Taylor [22]
- the value for the molar mass of dry air from Gatley et al. [17] and that of water from IAPWS-95 [5], [6]
- the calculation of the ideal-gas parts of the heat capacity, enthalpy, and entropy for dry air from the fundamental equation of Lemmon et al. [14]
- the calculation of the ideal-gas parts of the heat capacity, enthalpy, and entropy for water vapor from IAPWS-IF97 [7], [8], [9] for $t \geq 0°\mathrm{C}$ and from IAPWS-95 [5], [6] for $t \leq 0°\mathrm{C}$
- the calculation of the vapor-pressure enhancement factor from the equation given by the models of Hyland and Wexler [21]
- the calculation of the second and third molar virial coefficients B_{aa} and C_{aaa} for dry air from the fundamental equation of Lemmon et al. [14] according to Feistel et al. [24]
- the calculation of the second and third molar virial coefficients B_{ww} and C_{www} for water and steam from IAPWS-95 [5], [6] according to Feistel et al. [24]
- the calculation of the air-water second molar cross-virial coefficient B_{aw} from Harvey and Huang [15]
- the calculation of the air-water third molar cross-virial coefficients C_{aaw} and C_{aww} from Nelson and Sauer [12], [13]
- the calculation of the saturation pressure of water from IAPWS-IF97 [7], [8], [9] for $t \geq 0°\mathrm{C}$ and of the sublimation pressure of water from IAPWS-08 [11] for $t \leq 0°\mathrm{C}$
- the calculation of the isothermal compressibility of saturated liquid water from IAPWS-IF97 [7], [8], [9] for $t \geq 0°\mathrm{C}$ and that of ice from IAPWS-06 [10] for $t \leq 0°\mathrm{C}$ in the determination of the vapor-pressure enhancement factor
- the calculation of Henry's constant from the IAPWS Guideline 2004 [16] in the determination of the enhancement factor. The mole fractions for the three main components of dry air were taken from Lemmon et al. [14]. Argon was not considered in the calculation of Henry’s constant in the former research projects, but it is now the third component of dry air.

The transport properties of moist air are calculated from the model given in Herrmann et al. [3], [4].

1.3.2 Algorithms for Steam and Water for Temperatures $t \geq 0°C$

The *p-T* diagram in Fig. 1 shows the formulations used for water and water vapor. The temperature range above 0°C is covered by IAPWS-IF97 [7], [8], [9]:

- The saturation line is calculated from the IAPWS-IF97 saturation pressure equation $p_s^{97}(t)$ and saturation temperature equation $t_s^{97}(p)$.
- The properties in the liquid region including saturated-liquid line are calculated from the fundamental equation of the IAPWS-IF97 region 1.
- The properties in the vapor region including saturated-vapor line are calculated from the fundamental equation of the IAPWS-IF97 region 2.

1.3.3 Algorithms for Steam and Ice for Temperatures $t \leq 0°C$

- The sublimation curve is covered by the IAPWS-08 sublimation pressure equation $p_{subl}^{08}(t)$ [11] (see Fig. 1).
- The properties of ice including saturated ice are determined by the fundamental equation of the IAPWS-06 [10].
- The properties of vapor including saturated vapor are calculated from the fundamental equation of IAPWS-95 [5], [6].

1.3.4 Overview of the Applied Formulations for Steam, Water, and Ice

The following *p-T* diagram shows the used IAPWS Formulations and the ranges where they are applied.

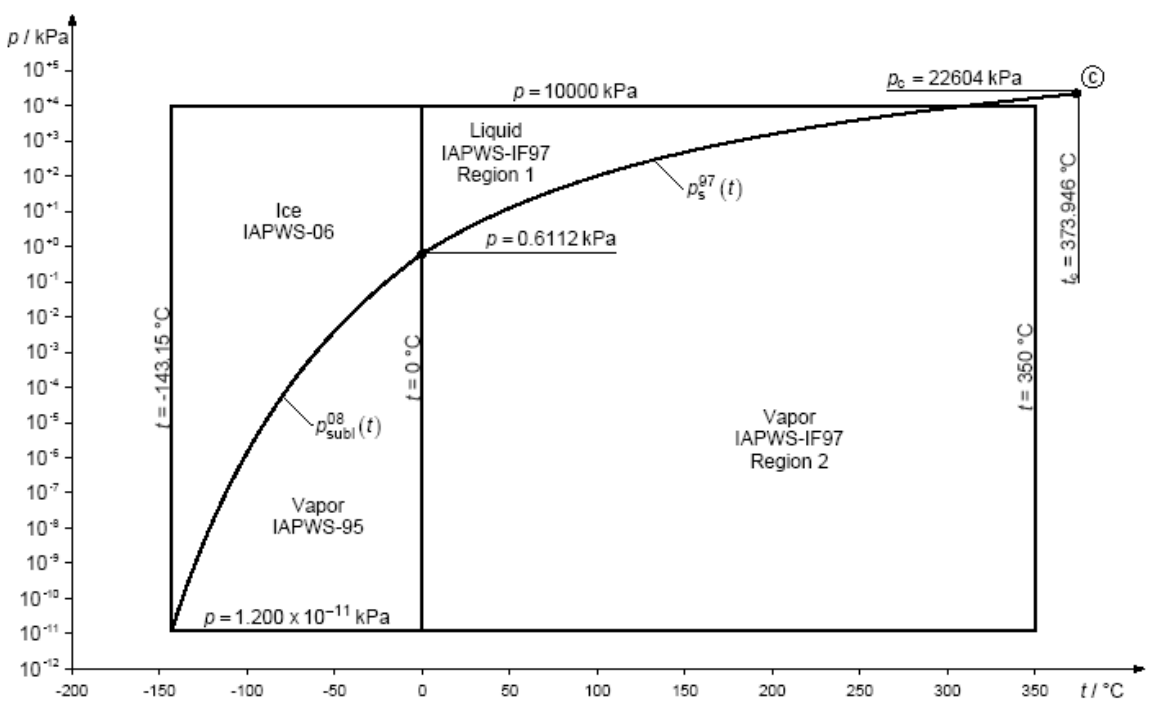


Figure 1: *p-T* diagram with used IAPWS formulations for steam, water, and ice.

2 Add-In FluidDYM for DYMOLA® for ASHRAE-LibHuAirProp-SI

2.1 Installing FluidDYM

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 moist air from the ASHRAE-LibHuAirProp-SI property library. The 32-bit version of FluidDYM LibHuAirProp runs on both the 32-bit and 64-bit version of Dymola®.

2.1.1 Installing FluidDYM including LibHuAirProp

The installation of FluidDYM and ASHRAE-LibHuAirProp_SI is described in section 2.1.1 in "Part IP Units" of this User's Guide.

2.1.2 The FluidDYM Help System

Dymola® provides detailed help functions which are described in in section 2.1.2 in "Part I-P Units" of this User's Guide.

2.2 Example: Calculation of $h = f(p,t,W)$

Now we will calculate, step by step, the specific enthalpy h of moist air as a function of pressure p, temperature t and humidity ratio W, 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 "\LibHuAirProp_SI"; the standard location is:
  "C:\Program Files\FluidDYM\LibHuAirProp_SI"
- Create the folder "\LibHuAirProp_SI_Example" by clicking on "File" in the Explorer menu, then "New" in the menu which appears, and then selecting "Folder". Name the new folder "\LibHuAirProp_SI_Example".
- You will see the following window:

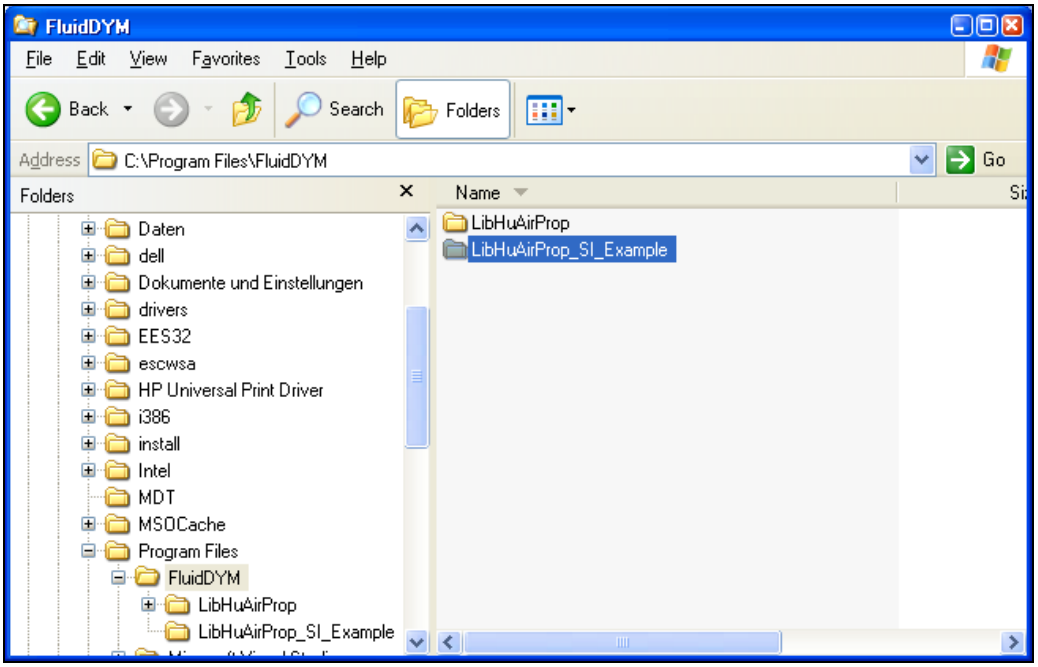


Figure 2.2.1: Highlighted *LibHuAirProp_SI_Example* directory in Program Files

- Switch into the directory "\LibHuAirProp" within "\FluidDYM", the standard being: "C:\Program Files\FluidDYM\LibHuAirProp".
- You will see the following window:

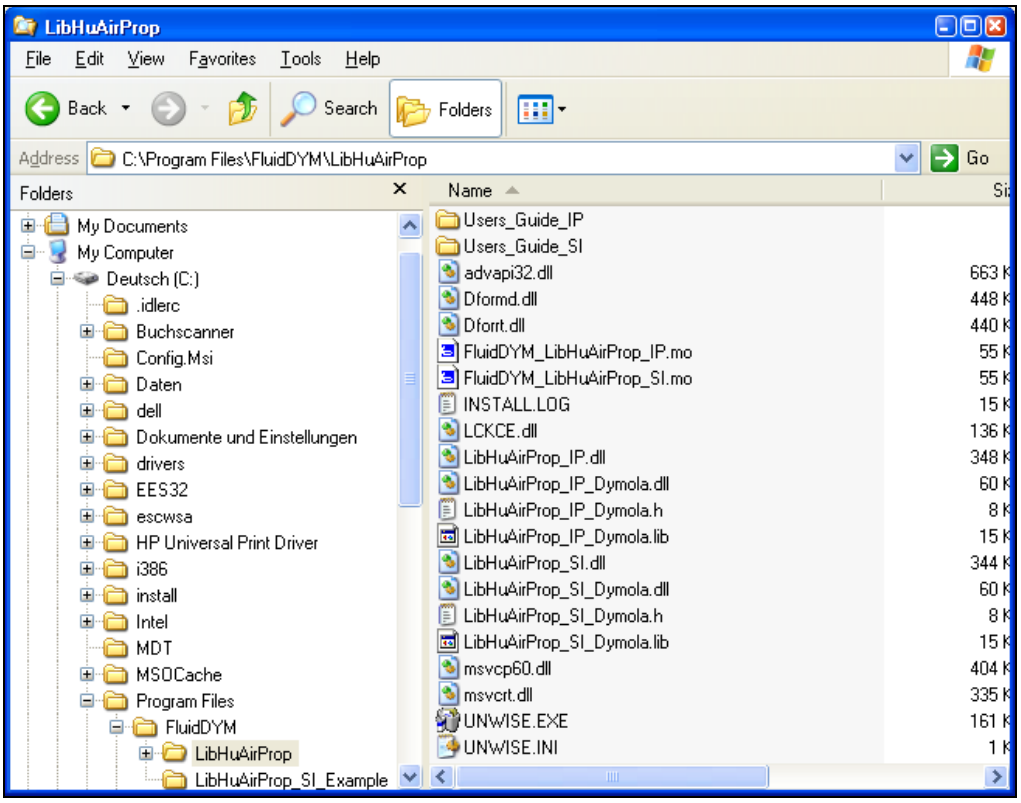


Figure 2.2.2: *LibHuAirProp_SI* directory including installed files

In order to calculate the function $h = f(p,t,W)$, the following files are necessary. Copy these into the directory "C:\Program Files\FluidDYM\LibHuAirProp_SI_Example":

- "advapi32.dll"
- "Dforrt.dll"
- "Dformd.dll"
- "FluidDYM_HuAirProp_SI.mo"
- "LCKCE.dll"
- "LibHuAirProp_SI.dll"
- "LibHuAirProp_SI_Dymola.dll"
- "LibHuAirProp_SI_Dymola.h"
- "LibHuAirProp_SI_Dymola.lib"
- "msvcp60.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\LibHuAirProp_SI_Example", click "Edit" and then "Paste".
- You will see the following window:

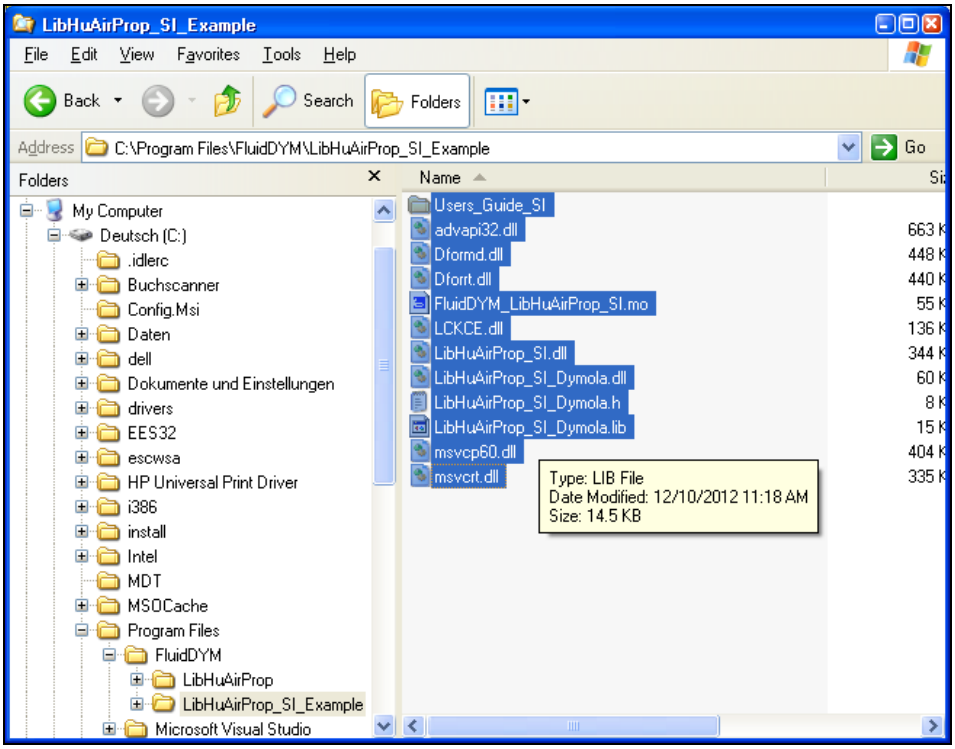


Figure 2.2.3: *LibHuAirProp_SI_Example* directory including the newly-copied files

- Start Dymola®.
- Now click on "File" in the Dymola® menu bar and select "Open" (see Figure 2.2.4).

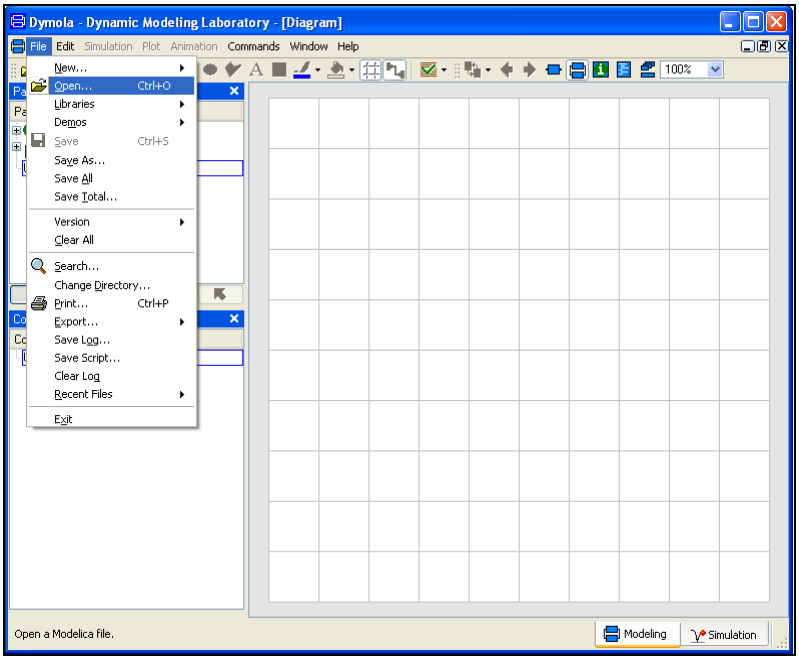


Figure 2.2.4: Selecting the menu entry "Open"

- Search and click on the directory "C:\Program Files\FluidDYM\LibHuAirProp_SI_Example" in the menu that appears.
- Select the "FluidDYM_LibHuAirProp_SI.mo" file and click on the "Open" button (see Figure 2.2.5)

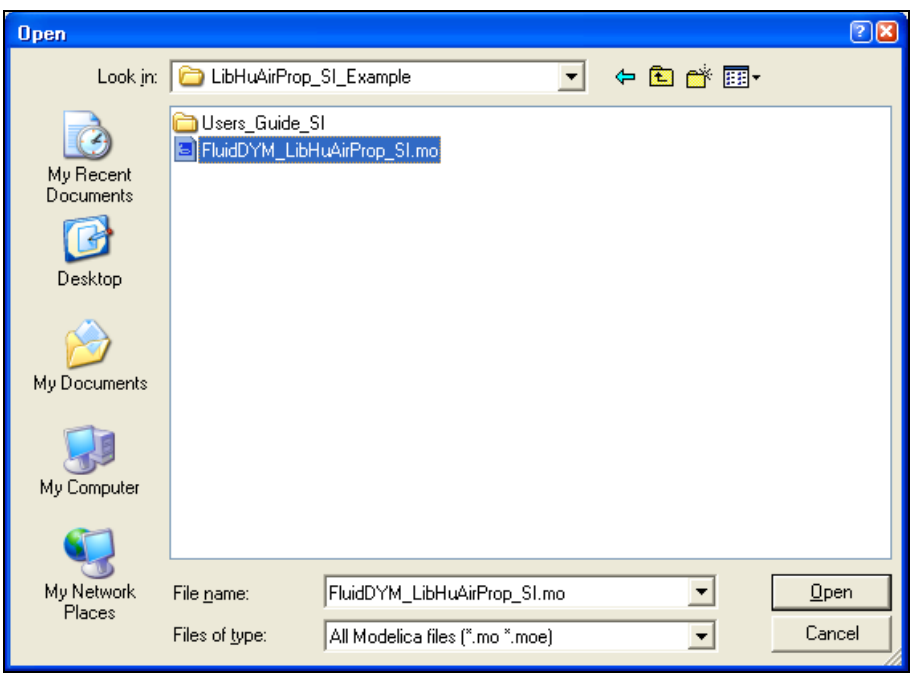


Figure 2.2.5: Selecting the *FluidDYM_LibHuAirProp_SI.mo* file

- The library will be loaded by Dymola® which may take a few seconds.
- After Dymola® has finished loading the LibHuAirProp_SI library, you will see the window shown in Figure 2.2.6.

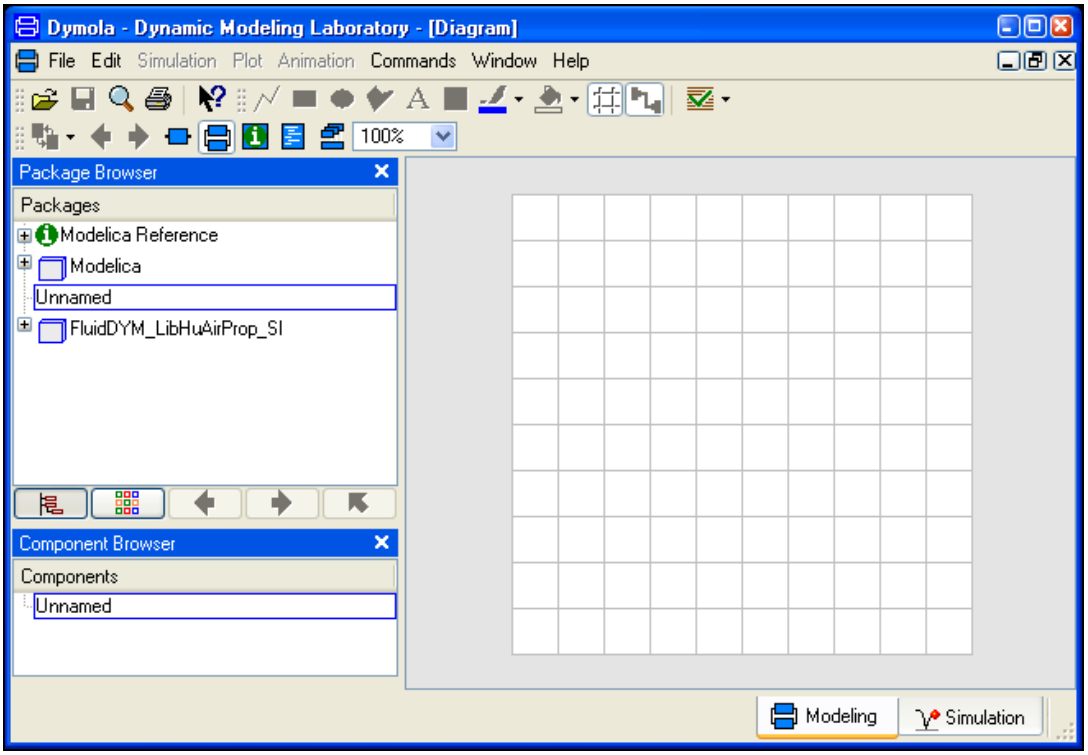


Figure 2.2.6: Dymola® window after loading the *LibHuAirProp_SI* library

- Now, click on "File" in the Dymola® menu bar and select "Change Directory…" in order to open the folder "\LibHuAirProp_SI_Example" (see Figure 2.2.7).

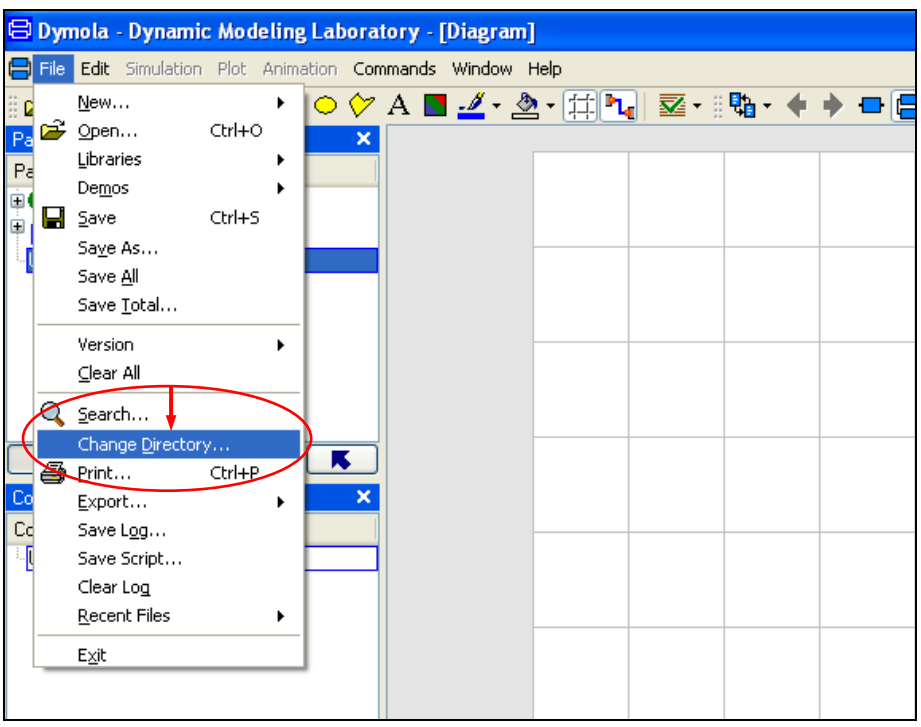


Figure 2.2.7: Selecting the menu entry "Change Directory…"

- Search and click on the directory "C:\Program Files\FluidDYM\LibHuAirProp_SI_Example" in the menu that appears (see figure below).

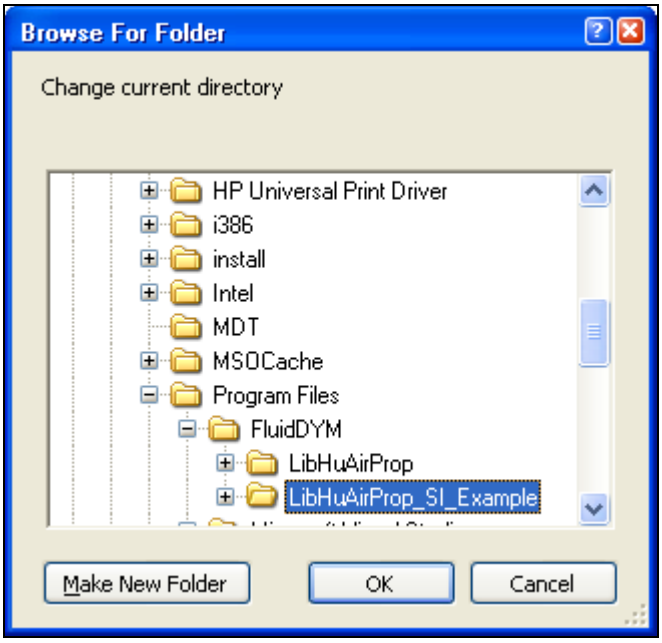


Figure 2.2.8: Selecting the *LibHuAirProp_SI_Example* directory

- 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_ptW_HAP_SI" as follows for calculating $h = f(p,t,W)$.

- Click on the Dymola® block "Test," which can be found in the FluidDYM_HuAirProp_SI package in the "Package Browser" on the left hand side of the Dymola® window. Here choose Example 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:

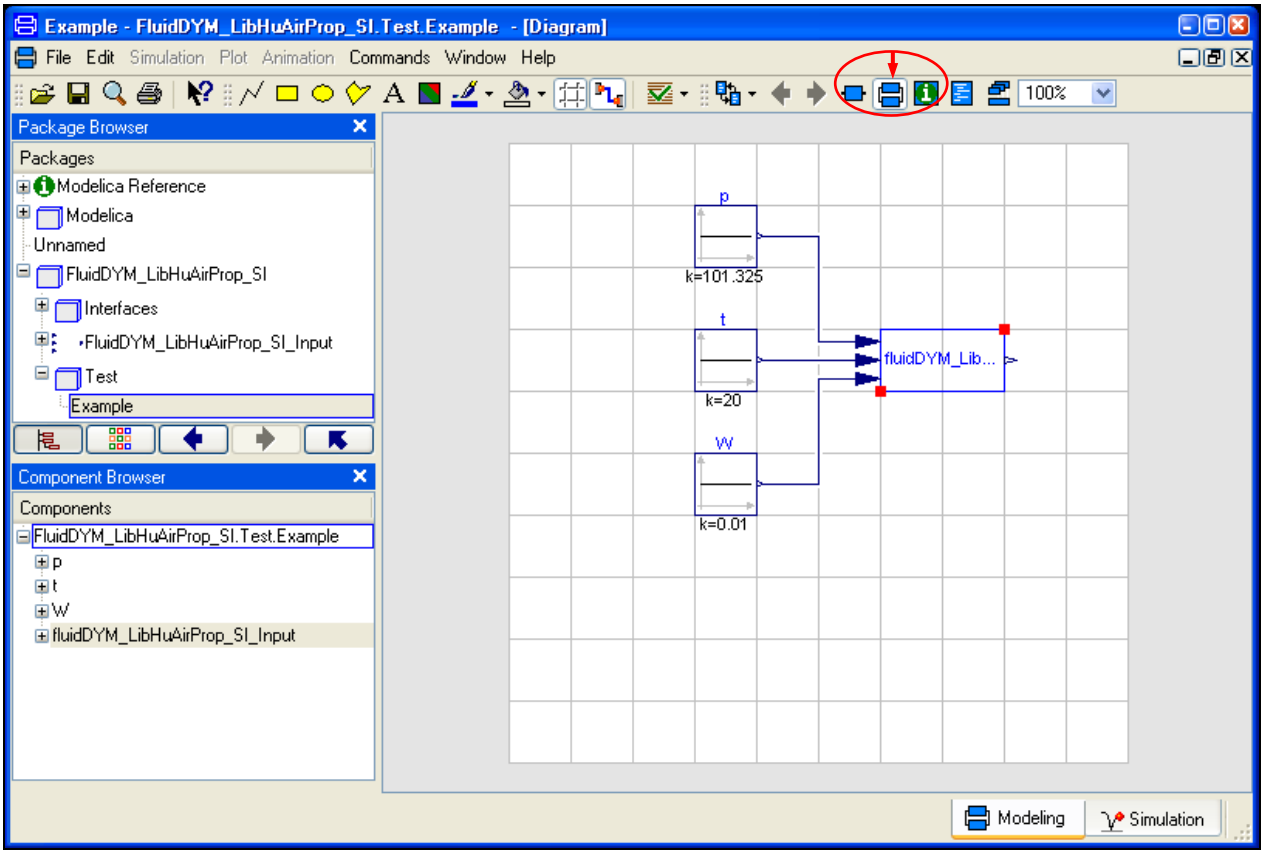


Figure 2.2.9: Dymola® in Diagram Mode

- Now double-click on the "FluidDYM_LibHuAirProp_SI_Input" block on the right hand side of the Dymola® window.
- Search and click the "h_ptW_HAP_SI" function next to "Function Number" in the menu that appears (see figure below).

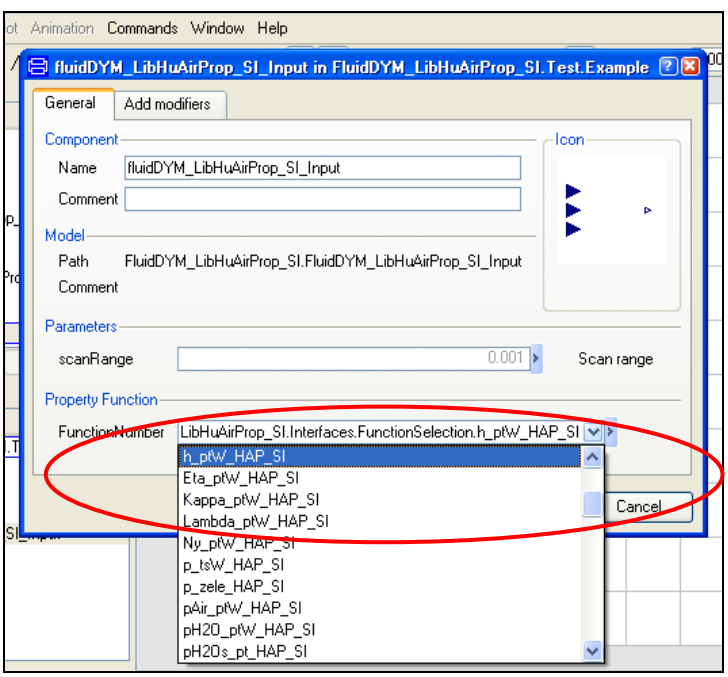


Figure 2.2.10: Choosing the function *h_ptW_HAP_SI*

- 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. If you enter the value 1, for example, the property will be calculated once per second. Do not change the preset value of 0.001 for our example calculation.

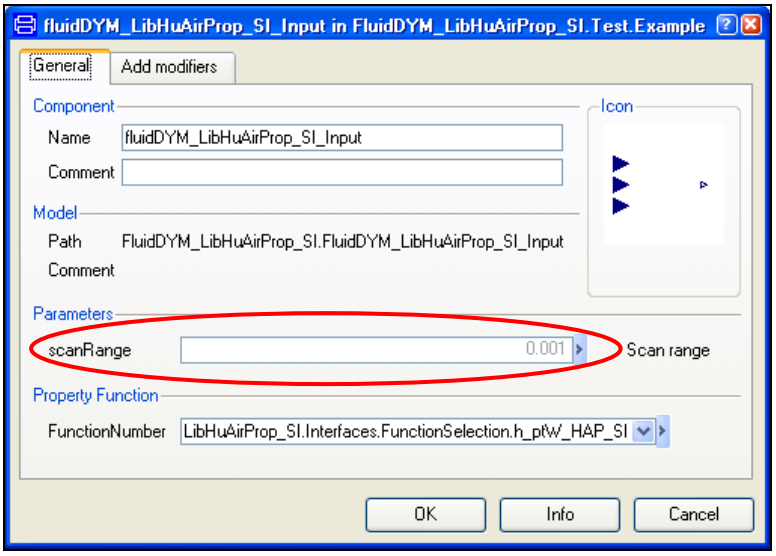


Figure 2.2.11: Setting the scan range

- Now we will configure the input parameters *p*, *t*, and *W*. When calculating a function with only two input parameters, the third input parameter will not be defined.
- First, double click on the "p" block which represents the first input parameter, here the pressure *p* in kPa (see Figure 2.2.12).

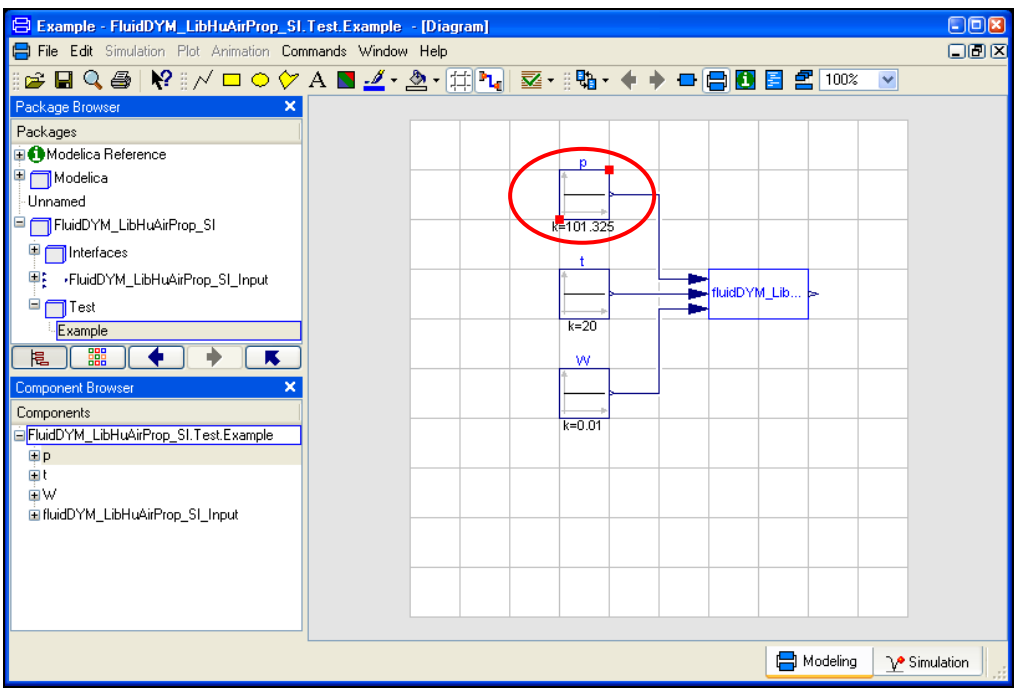


Figure 2.2.12: "Parameter p" block in Dymola®

- Enter the value 101.325 on the line next to "k" in the dialog window which appears and then click the "OK" button (see Figure 2.2.13).

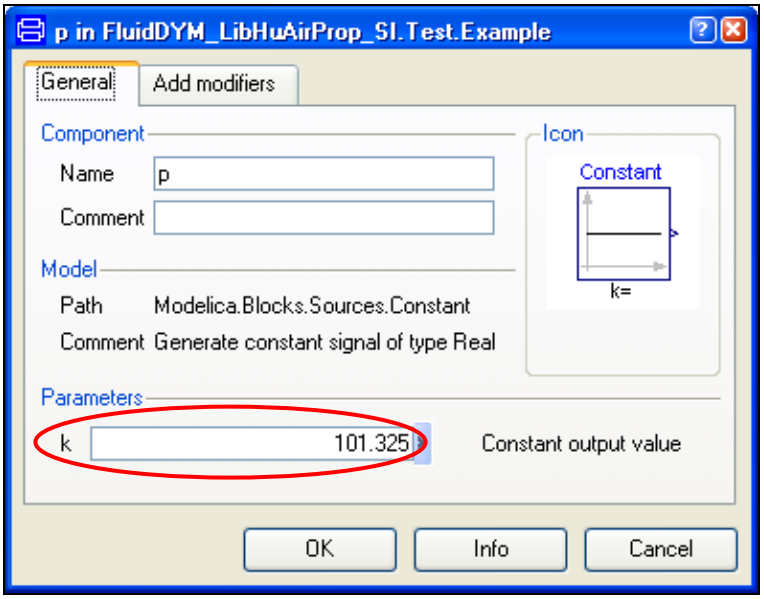


Figure 2.2.13: Entering the value for the pressure *p*

- Now, double click on the "t" block which represents the second input parameter, here the temperature *t* in °C.
- Enter the value 20 on the line next to "k" in the dialog window which appears and then click the "OK" button (see Figure 2.2.14).

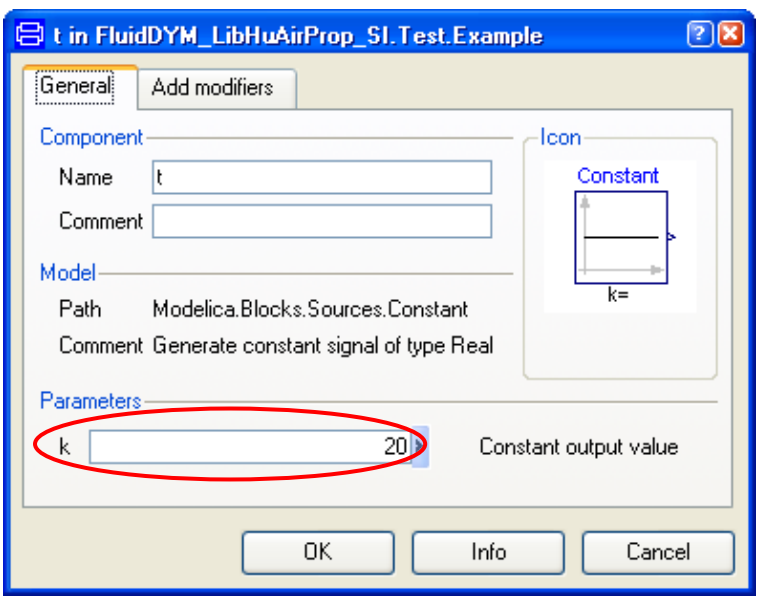


Figure 2.2.14: Entering the value for the temperature *t*

- Now, double click on the "W" block which represents the third input parameter, here the humidity ratio *W* in kg_w/kg_a.
- Enter the value 0.01 on the line next to "k" in the dialog window which appears and then click the "OK" button (see Figure 2.2.15).

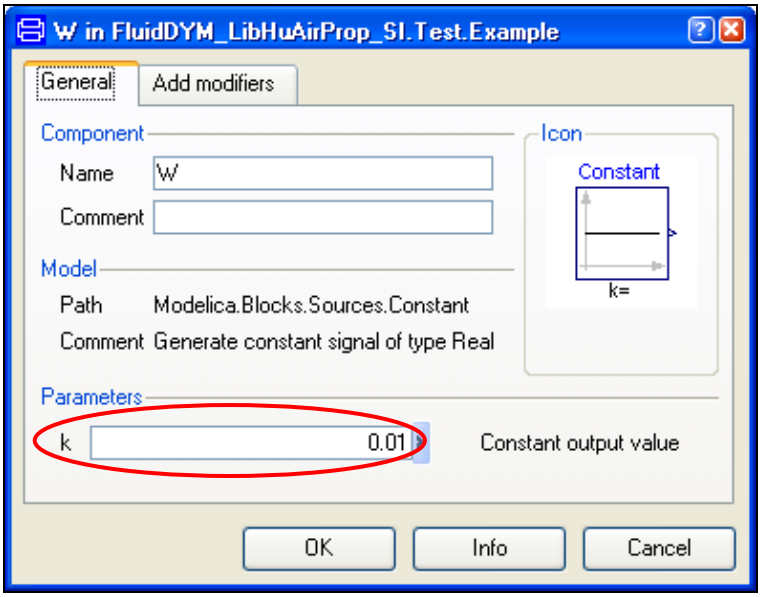
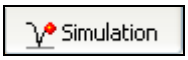


Figure 2.2.15: Entering the value for the humidity ratio *W*

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 2.2.16 you can see what the Dymola® "Simulation Mode" looks like.

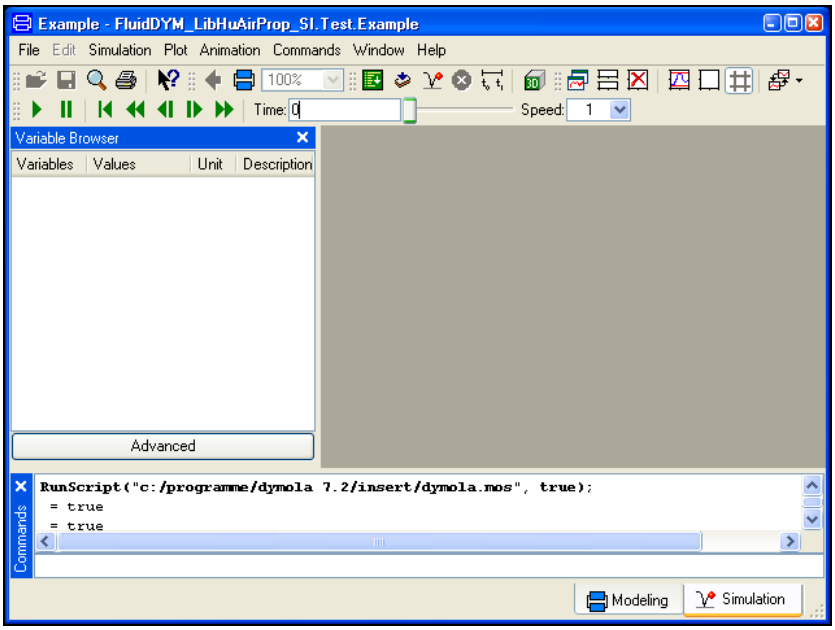


Figure 2.2.16: "Simulation Mode" window

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 LibHuAirProp 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"

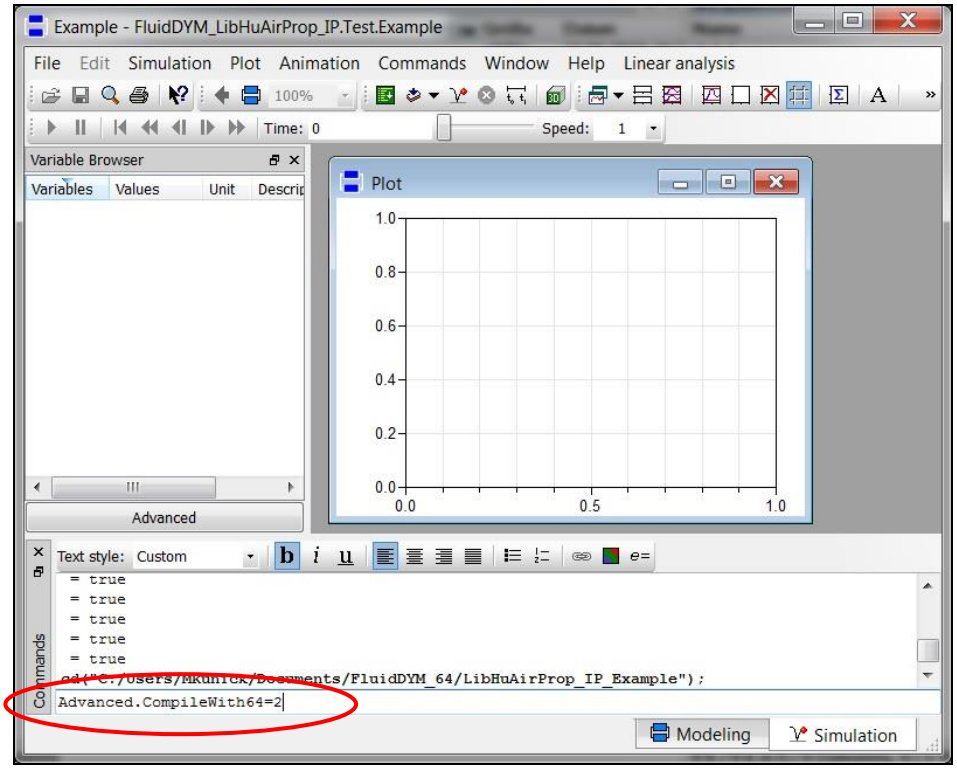


Figure 2.2.17: "Simulation Mode" window with 64-bit command

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

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.

- Click on the "Simulate" Button in the Dymola® menu bar to start the calculation. Now the model will be compiled and the simulation starts.
- Afterwards you will see the following entries within the "Variable Browser" window in Dymola® (see Figure 2.2.18):

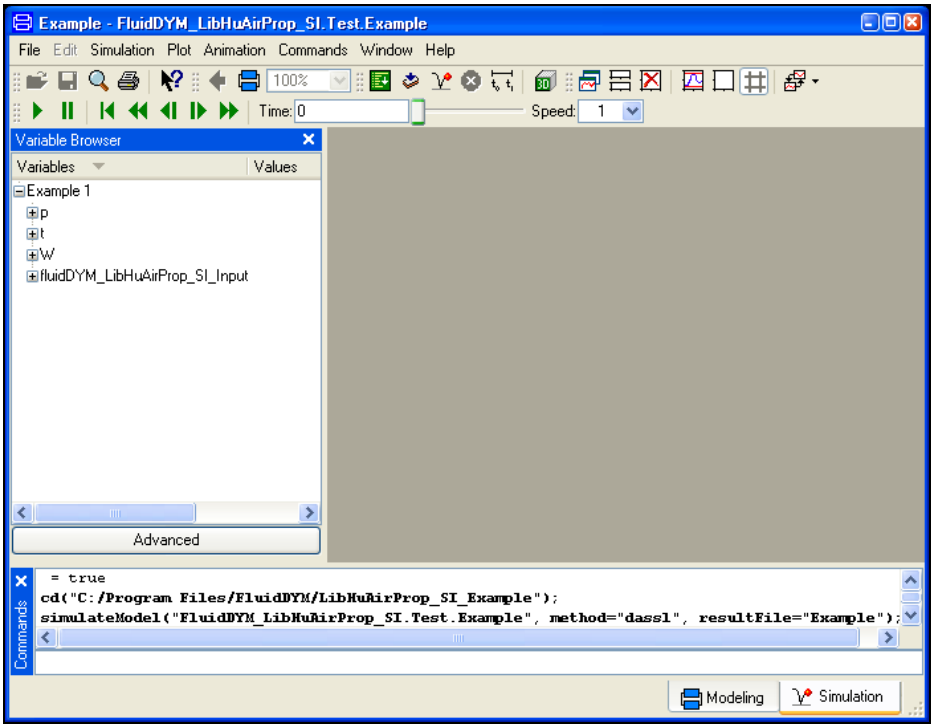


Figure 2.2.18: "Variable Browser" with new entries

- By clicking on the "NewPlotWindow" button  , a new diagram window will be opened.
- Click on "FluidDYM_LibHuAirProp_SI_Input" within the "Variable Browser"; then you will see the input and output parameters "scanRange", "FunctionNumber", "z", "x1", "x2", and "x3" (see Figure 2.2.19).

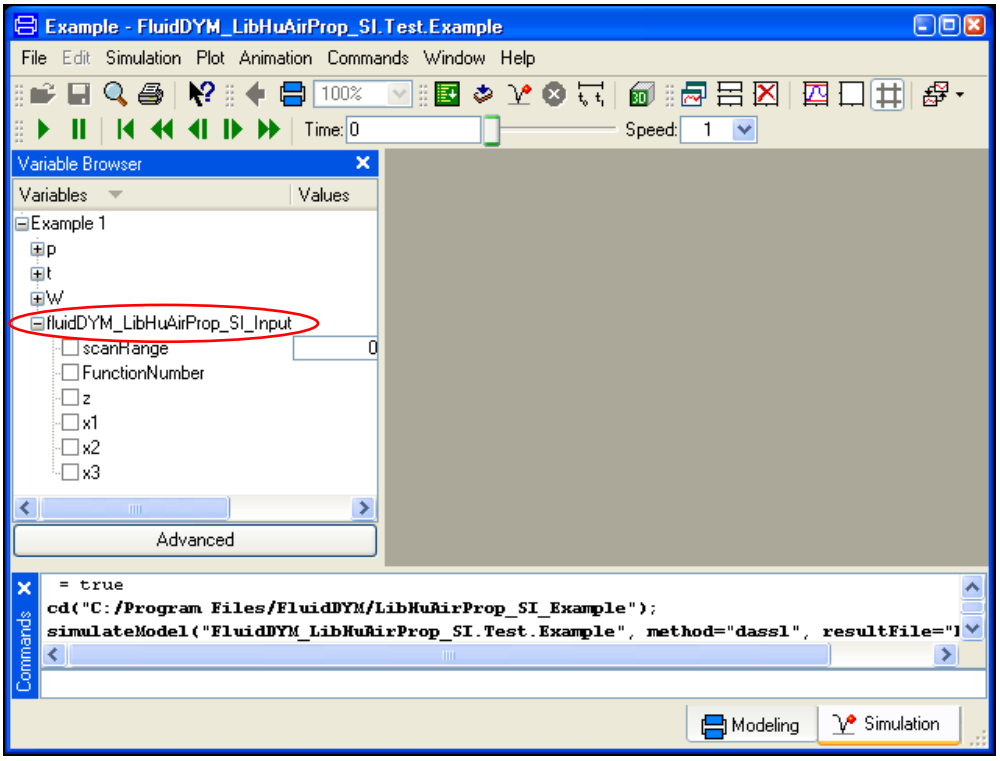


Figure 2.2.19: Parameters of *fluidDYM_LibHuAirProp_SI_Input*

- 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 2.2.20).

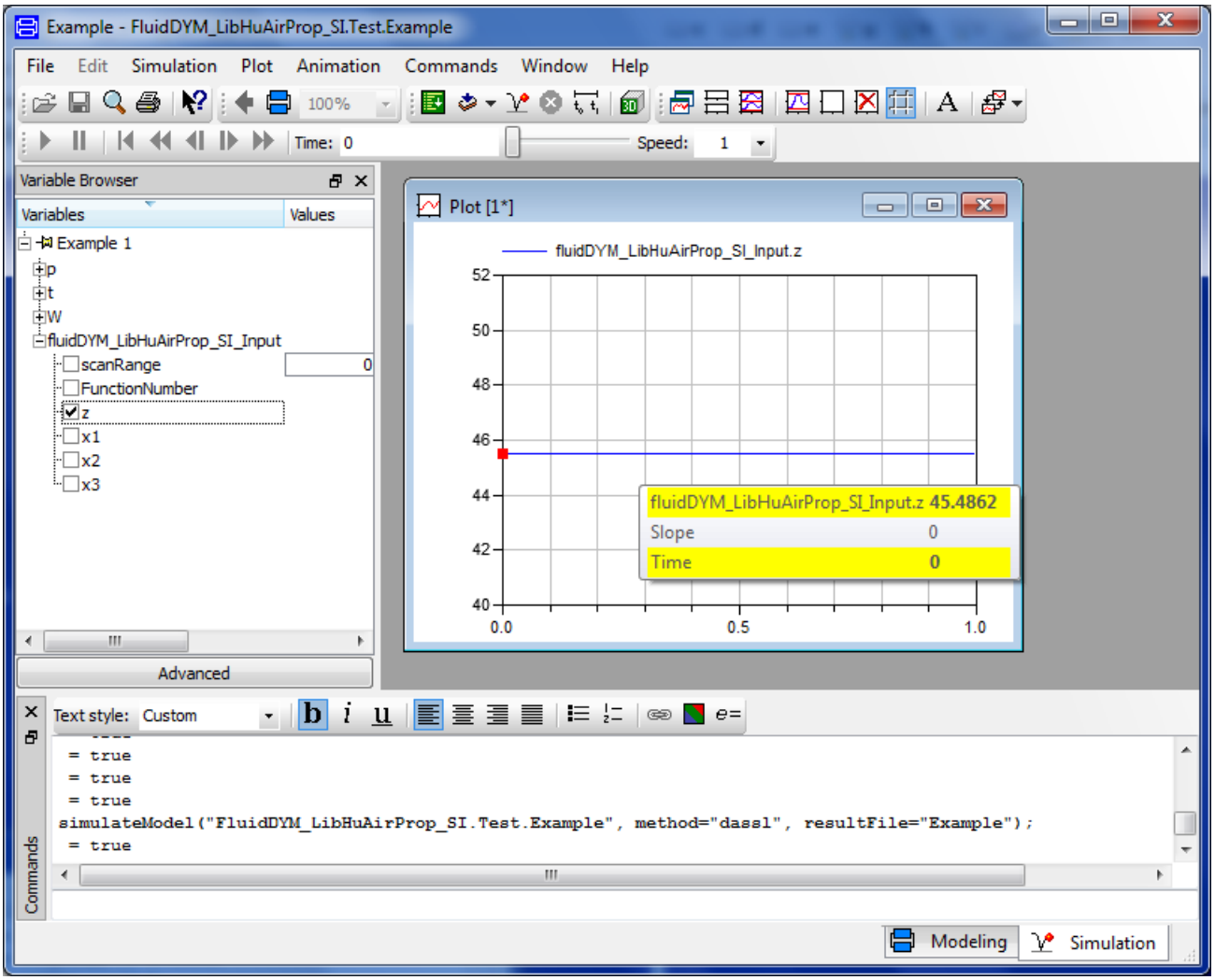


Figure 2.2.20: "DiagramWindow" showing the result

The result for *h* appears in the "DiagramWindow"

⇒ The result in our sample calculation here is: "h = 45.4862". 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*, or *W* in the appropriate blocks.

2.3 Removing FluidDYM including LibHuAirProp

The de-installation of FluidDYM and ASHRAE-LibHuAirProp_SI is described in section 2.4 in "Part I-P Units" of this User's Guide.

3 Property Functions of ASHRAE-LibHuAirProp-SI

3.1 Functions for Real Moist Air

Thermal Diffusivity a = f(p,t,W)

Function Name:

a_ptW_HAP_SI

Fortran Program:

REAL*8 FUNCTION A_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p	-	Total pressure p in kPa
t	-	Temperature t in °C
W	-	Humidity ratio W in kg_w/kg_a

Result:

a_ptW_HAP_SI - Thermal diffusivity of humid air in m^2/s

Range of Validity:

Temperature t:	from -73.15°C to 350°C
Total pressure p:	from 0.01 kPa to 10 000 kPa
Humidity ratio W:	$0 \le W \le W_s$

Comments:

- Thermal diffusivity $a = \dfrac{\lambda}{\rho \cdot c_p}$
- Calculation for supersaturated humid air ($W > W_s$) is not possible

Result for Wrong Input Values:

a_ptW_HAP_SI = -1000

References:

$\lambda(p,t,W)$	Herrmann et al. [3], [4]
$\rho(p,t,W)$	Herrmann et al. [1], [2]
$c_p(p,t,W)$	Herrmann et al. [1], [2]

Relative Pressure Coefficient α_p = f(p,t,W)

Function Name:

alphap_ptW_HAP_SI

Fortran Program:

REAL*8 FUNCTION ALPHAP_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p	-	Total pressure p in kPa
t	-	Temperature t in °C
W	-	Humidity ratio W in kg_w/kg_a

Result:

alphap_ptW_HAP_SI - Relative pressure coefficient of humid air in 1/K

Range of Validity:

Temperature t:	from -143.15°C to 350°C
Total pressure p:	from 0.01 kPa to 10 000 kPa
Humidity ratio W:	$0 \le W \le W_s$

Comments:

- Relative pressure coefficient $\alpha_p = \frac{1}{p}\left(\frac{\partial p}{\partial T}\right)_v$

- Calculation for supersaturated humid air ($W > W_s$) is not possible

Result for Wrong Input Values:

alphap_ptW_HAP_SI = -1000

References:

$\rho(p,t,W)$ Herrmann et al. [1], [2]

Isothermal Stress Coefficient β_p = f(p,t,W)

Function Name:

betap_ptW_HAP_SI

Fortran Program:

REAL*8 FUNCTION BETAP_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in kPa
t - Temperature t in °C
W - Humidity ratio W in kg_w/kg_a

Result:

betap_ptW_HAP_SI - Isothermal stress coefficient of humid air in kg/m^3

Range of Validity:

Temperature t: from -143.15°C to 350°C
Total pressure p: from 0.01 kPa to 10 000 kPa
Humidity ratio W: $0 \le W \le W_s$

Comments:

- Isothermal stress coefficient $\beta_p = -\frac{1}{p}\left(\frac{\partial p}{\partial v}\right)_T$

- Calculation for supersaturated humid air ($W > W_s$) is not possible

Result for Wrong Input Values:

betap_ptW_HAP_SI = -1000

References:

$v(p,t,W)$ Herrmann et al. [1], [2]

Speed of Sound c = f(p,t,W)

Function Name:

c_ptW_HAP_SI

Fortran Program:

REAL*8 FUNCTION C_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p	-	Total pressure p in kPa
t	-	Temperature t in °C
W	-	Humidity ratio W in kg_w/kg_a

Result:

c_ptW_HAP_SI - Speed of sound of humid air in m/s

Range of Validity:

Temperature t:	from -143.15°C to 350°C
Total pressure p:	from 0.01 kPa to 10 000 kPa
Humidity ratio W:	$0 \le W \le 10\,kg_w/kg_a$

Comments:

- Speed of sound $c = v\sqrt{-\left(\frac{\partial p}{\partial v}\right)_s}$

- When calculating supersaturated air an ideal mixing model (saturated humid air and water droplets (or ice crystals) homogeneously mixed) is applied

Result for Wrong Input Values:

c_ptW_HAP_SI = -1000

References:

$v(p,t,W)$	Herrmann et al. [1], [2]

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

Function Name:

cp_ptW_HAP_SI

Fortran Program:

REAL*8 FUNCTION CP_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in kPa
t - Temperature t in °C
W - Humidity ratio W in kg_w/kg_a

Result:

cp_ptW_HAP_SI - Specific isobaric heat capacity of humid air in kJ/(kg K)

Range of Validity:

Temperature t: from -143.15°C to 350°C
Total pressure p: from 0.01 kPa to 10 000 kPa
Humidity ratio W: $0 \le W \le W_s$

Comments:

- Specific isobaric heat capacity $c_p = \left(\frac{\partial h}{\partial T}\right)_p$

- Calculation for supersaturated humid air ($W > W_s$) is not possible

Result for Wrong Input Values:

cp_ptW_HAP_SI = -1000

References:

$h(p,t,W)$ Herrmann et al. [1], [2]

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

Function Name:

cv_ptW_HAP_SI

Fortran Program:

REAL*8 FUNCTION CV_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in kPa
t - Temperature t in °C
W - Humidity ratio W in kg_w/kg_a

Result:

cv_ptW_HAP_SI - Specific isochoric heat capacity of humid air in kJ/(kg K)

Range of Validity:

Temperature t: from -143.15°C to 350°C
Total pressure p: from 0.01 kPa to 10 000 kPa
Humidity ratio W: $0 \le W \le W_s$

Comments:

- Specific isochoric heat capacity $c_v = \left(\frac{\partial u}{\partial T}\right)_v$

- Calculation for supersaturated humid air ($W > W_s$) is not possible

Result for Wrong Input Values:

cv_ptW_HAP_SI = -1000

References:

$c_v(p,t,W)$ Herrmann et al. [3], [4]

Enhancement Factor *f* = f(*p*,*t*)

Function Name:

f_pt_HAP_SI

Fortran Program:

REAL*8 FUNCTION F_PT_HUAIRPROP(P,T), REAL*8 P,T

Input Values:

p - Total pressure *p* in kPa
t - Temperature *t* in °C

Result:

f_pt_HAP_SI - Enhancement factor of water (decimal ratio)

Range of Validity:

Temperature *t*: from -143.15°C to 350°C

Total pressure *p*: from 0.01 kPa to 10 000 kPa

Comments:

- Enhancement factor $f = \frac{p_{\mathrm{H2O,s}}}{p_{\mathrm{s}}(t)}$

  with $p_{\mathrm{s}}(t)$ for $t \geq 0.01$°C - Steam pressure of water

  for $t < 0.01$°C - Sublimation pressure of water

- Describes the enhancement of the saturation pressure of water in the air atmosphere under elevated pressure
- Derived iteratively from the isothermal compressibility of liquid water, from Henry's constant [15], [16] and from the virial coefficients of air, water, and the air-water mixture

Result for Wrong Input Values:

f_pt_HAP_SI = -1000

References:

$f(p,t)$ Herrmann et al. [1], [2]

Air-Specific Enthalpy $h = f(p,t,W)$

Function Name:

h_ptW_HAP_SI

Fortran Program:

REAL*8 FUNCTION H_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in kPa
t - Temperature t in °C
W - Humidity ratio W in kg_w/kg_a

Result:

h_ptW_HAP_SI - Air-specific enthalpy in kJ/kg_a

Range of Validity:

Temperature t: from -143.5°C to 350°C

Total pressure p: from 0.01 kPa to 10 000 kPa

Humidity ratio W: $0 \le W \le 10\,kg_w/kg_a$

Comments:

- When calculating supersaturated air an ideal mixing model (saturated humid air and water droplets (or ice crystals) homogeneously mixed) is applied

Result for Wrong Input Values:

h_ptW_HAP_SI = -1000

References:

$h(p,t,W)$ Herrmann et al. [1], [2]

$h_w(p,t)$ IAPWS-IF97 [7], [8] and IAPWS-06 [11]

$h_a(t)$ Lemmon et al. [14]

Dynamic Viscosity η = f(p,t,W)

Function Name:

Eta_ptW_HAP_SI

Fortran Program:

REAL*8 FUNCTION ETA_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p	-	Total pressure p in kPa
t	-	Temperature t in °C
W	-	Humidity ratio W in kg_w/kg_a

Result:

Eta_ptW_HAP_SI - Dynamic viscosity of humid air in Pa s

Range of Validity:

Temperature t:	from -73.15°C to 350°C
Total pressure p:	from 0.01 kPa to 10 000 kPa
Humidity ratio W:	$0 \le W \le 10\,kg_w/kg_a$

Comments:

- A new very accurate algorithm is implemented between 0°C and 350°C
- When calculating supersaturated air an ideal mixing model (saturated humid air and water droplets (or ice crystals) homogeneously mixed) is applied

Result for Wrong Input Values:

Eta_ptW_HAP_SI = -1000

References:

$\eta(p,t,W)$	Herrmann et al. [3], [4]
$\eta_a(t)$	Lemmon et al. [18]
$\eta_w(p,t)$	IAPWS-IF97 [7], [8] and IAPWS-08 [19]

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

Function Name:

Kappa_ptW_HAP_SI

Fortran Program:

REAL*8 FUNCTION KAPPA_PTW_HUAIRPROP(P,T, W), REAL*8 P,T,W

Input Values:

p - Total pressure p in kPa
t - Temperature t in °C
W - Humidity ratio W in kg_w/kg_a

Result:

Kappa_ptW_HAP_SI - Isentropic exponent

Range of Validity:

Temperature t: from -143.5°C to 350°C
Total pressure p: from 0.01 kPa to 10 000 kPa
Humidity ratio W: $0 \le W \le 10\,kg_w/kg_a$

Comments:

- Isentropic exponent $\kappa = -\frac{v}{p}\left(\frac{\partial p}{\partial v}\right)_s$
- When calculating supersaturated air an ideal mixing model (saturated humid air and water droplets homogeneously mixed) is applied for $t \ge 0.01$°C. For temperatures below (ice fog) the value of the saturated state is applied.

Result for Wrong Input Values:

Kappa_ptW_HAP_SI = -1000

References:

$v(p,t,W)$ Herrmann et al. [1], [2]

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

Function Name:

Lambda_ptW_HAP_SI

Fortran Program:

REAL*8 FUNCTION LAMBDA_PTW_HUAIRPROP(P,T, W), REAL*8 P,T,W

Input Values:

p	-	Total pressure p in kPa
t	-	Temperature t in °C
W	-	Humidity ratio W in kg_w/kg_a

Result:

Lambda_ptW_HAP_SI - Thermal conductivity in W/(m K)

Range of Validity:

Temperature t:	from -73.5°C to 350°C
Total pressure p:	from 0.01 kPa to 10 000 kPa
Humidity ratio W:	$0 \le W \le 10\,kg_w/kg_a$

Comments:

- A new very accurate algorithm is implemented between 0°C and 350°C
- When calculating supersaturated air an ideal mixing model (saturated humid air and water droplets (or ice crystals) homogeneously mixed) is applied

Result for Wrong Input Values:

Lambda_ptW_HAP_SI = -1000

References:

$\lambda(p,t,W)$	Herrmann et al. [3], [4]
$\lambda_a(t)$	Lemmon et al. [18]
$\lambda_w(p,t)$	IAPWS-IF97 [7], [8] and IAPWS-08 [20]

Kinematic Viscosity ν = f(p,t,W)

Function Name:

Ny_ptW_HAP_SI

Fortran Program:

REAL*8 FUNCTION NY_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in kPa
t - Temperature t in °C
W - Humidity ratio W in kg_w/kg_a

Result:

Ny_ptW_HAP_SI - Kinematic viscosity in m^2/s

Range of Validity:

Temperature t:	from -73.5°C to 350°C
Total pressure p:	from 0.01 kPa to 10 000 kPa
Humidity ratio W:	$0 \le W \le W_s$

Comments:

- Kinematic Viscosity $\nu = \dfrac{\eta}{\rho}$

Result for Wrong Input Values:

Ny_ptW_HAP_SI = -1000

References:

$\eta(p,t,W)$	Herrmann et al. [3], [4]
$\rho(p,t,W)$	Herrmann et al. [1], [2]

Backward Function: Total Pressure p = f(t,s,W)

Function Name:

p_tsW_HAP_SI

Fortran Program:

REAL*8 FUNCTION P_TSW_HUAIRPROP(T,S,W), REAL*8 T,S,W

Input Values:

t - Temperature t in °C

s - Air-specific entropy s in kJ/(kg$_a$ K)

W - Humidity ratio W in kg$_w$/kg$_a$

Result:

p_tsW_HAP_SI - Total pressure in kPa

Range of Validity:

Temperature t: from -143.5°C to 350°C

Air-specific entropy s: from -26.53 kJ/(kg$_a$ K) to 38.990 kJ/(kg$_a$ K)

Humidity ratio W: $0 \le W \le 10\,\mathrm{kg_w/kg_a}$

Comments:

- Iteration of total pressure p from s = f(p,t,W)

Result for Wrong Input Values:

p_tsW_HAP_SI = -1000

References:

$s(p,t,W)$ Herrmann et al. [1], [2]

Pressure $p = f(z_{ele})$

Function Name:

p_zele_HAP_SI

Fortran Program:

REAL*8 FUNCTION P_ZELE_HUAIRPROP(ZELE), REAL*8 ZELE

Input Values:

z_{ele} - Elevation z_{ele} in m

Result:

p_zele_HAP_SI - Pressure of humid air in kPa

Range of Validity:

Elevation z_{ele} from -5,000 m to 11,000 m

Comments:

- Pressure of humid air from elevation

- $p(z_{ele}) = 101.325\,\text{kPa} \cdot \left(1 - 2.25577 \cdot 10^{-5} \cdot \frac{z_{ele}}{\text{m}}\right)^{5.256}$

Result for Wrong Input Values:

p_zele_HAP_SI = -1000

References:

$p(z_{ele})$ ASHRAE [23]

Partial Pressure of Dry Air p_{Air} = f(p,t,W)

Function Name:

pAir_ptW_HAP_SI

Fortran Program:

REAL*8 FUNCTION PAIR_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p	-	Total pressure p in kPa
t	-	Temperature t in °C
W	-	Humidity ratio W in kg_w/kg_a

Result:

pAir_ptW_HAP_SI - Partial pressure of (dry) air in humid air in kPa

Range of Validity:

Temperature t:	from -143.15°C to 350°C
Total pressure p:	from 0.01 kPa to 10 000 kPa
Humidity ratio W:	$0 \le W \le 10\,kg_w/kg_a$

Comments:

- Partial pressure of (dry) air in humid air $p_{Air} = 1 - p_{H2O}$
- Partial pressure of water vapor at saturation is calculated in case of supersaturated humid air ($W > W_s(p,t)$)
- The temperature value is used to calculate the saturation state

Result for Wrong Input Values:

pAir_ptW_HAP_SI = -1000

References:

$p_{H2O}(p,W)$ Herrmann et al. [1], [2]

Partial Pressure of Water Vapor p_{H2O} = f(p,t,W)

Function Name:

pH2O_ptW_HAP_SI

Fortran Program:

REAL*8 FUNCTION PH2O_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in kPa
t - Temperature t in °C
W - Humidity ratio W in kg_w/kg_a

Result:

pH2O_ptW_HAP_SI - Partial pressure of water vapor in humid air in kPa

Range of Validity:

Temperature t: from -143.15°C to 350°C
Total pressure p: from 0.01 kPa to 10 000 kPa
Humidity ratio W: $0 \le W \le 10\,kg_w/kg_a$

Comments:

- Partial pressure of water vapor in humid air $p_{H2O} = \dfrac{W \cdot p}{\left(\dfrac{R_a}{R_w} + W\right)}$
- Partial pressure of water vapor at saturation is calculated in case of supersaturated humid air ($W > W_s(p,t)$)
- The temperature value is used to calculate the saturation state

Result for Wrong Input Values:

pH2O_ptW_HAP_SI = -1000

References:

$p_{H2O}(p,W)$ Herrmann et al. [1], [2]

Partial Saturation Pressure of Water Vapor $p_{H2O,s}$ = f(p,t)

Function Name:

pH2Os_pt_HAP_SI

Fortran Program:

REAL*8 FUNCTION PH2OS_PT_HUAIRPROP(P,T), REAL*8 P,T

Input Values:

p - Total pressure p in kPa
t - Temperature t in °C

Result:

pH2Os_pt_HAP_SI - Partial saturation pressure of water vapor in humid air in kPa

Range of Validity:

Temperature t: from -143.15°C to 350°C
Total pressure p: from 0.01 kPa to 10 000 kPa

Comments:

- Partial pressure of steam at saturation $p_{H2O,s} = f \cdot p_s(t)$
with $p_s(t)$ for $t \geq 0.01$°C - Steam pressure of water
for $t < 0.01$°C - Sublimation pressure of water

Result for Wrong Input Values:

pH2Os_pt_HAP_SI = -1000

References:

$f(p,t)$		Herrmann et al. [1], [2]
$p_s(t)$	for $t \geq 0.01$°C	IAPWS-IF97 [7], [8]
	for t < 0.01°C	IAPWS-08 [11]

Relative Humidity φ = f(p,t,W)

Function Name:

phi_ptW_HAP_SI

Fortran Program:

REAL*8 FUNCTION PHI_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p	-	Total pressure p in kPa
t	-	Temperature t in °C
W	-	Humidity ratio W in kg_w/kg_a

Result:

phi_ptW_HAP_SI - Relative humidity (decimal ratio)

Range of Validity:

Temperature t:	from -143.15°C to 350°C
Total pressure p:	from 0.01 kPa to 10 000 kPa
Humidity ratio W:	$0 \le W \le 10\,kg_w/kg_a$

Comments:

- Relative humidity $\varphi = \dfrac{p_{H2O}}{p_{H2O,s}}$
- This equation is valid for $p_{H2O} \le p_{H2O,s}$ and for $0 \le \varphi \le 1$

Result for Wrong Input Values:

phi_ptW_HAP_SI = -1000

References:

$\varphi(p,t,W)$ Herrmann et al. [1], [2]

Prandtl Number *Pr* = f(*p*,*t*,*W*)

Function Name:

Pr_ptW_HAP_SI

Fortran Program:

REAL*8 FUNCTION PR_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p	-	Total pressure p in kPa
t	-	Temperature t in °C
W	-	Humidity ratio W in kg_w/kg_a

Result:

Pr_ptW_HAP_SI - Prandtl number

Range of Validity:

Temperature t:	from -73.5°C to 350°C
Total pressure p:	from 0.01 kPa to 10 000 kPa
Humidity ratio W:	$0 \le W \le 10\,kg_w/kg_a$

Comments:

- Prandtl number $Pr = \dfrac{\eta \cdot c_p}{\lambda}$

- Calculation for supersaturated humid air ($W > W_s$) is not possible

Result for Wrong Input Values:

Pr_ptW_HAP_SI = -1000

References:

$\eta(p,t,W)$	Herrmann et al. [3], [4]
$c_p(p,t,W)$	Herrmann et al. [3], [4]
$\lambda(p,t,W)$	Lemmon et al. [20]

Mole Fraction of Dry Air ψ_{Air} = f(W)

Function Name:

PsiAir_W_HAP_SI

Fortran Program:

REAL*8 FUNCTION PSIAIR_W_HUAIRPROP(W), REAL*8 W

Input Values:

W - Humidity ratio W in kg_w/kg_a

Result:

PsiAir_W_HAP_SI - Mole fraction of (dry) air in humid air in mol_a/mol

Range of Validity:

Humidity ratio W: $0 \le W \le 10\,kg_w/kg_a$

Comments:

- Mole fraction of air $\psi_{\mathrm{Air}} = 1 - \psi_{\mathrm{H2O}} = 1 - \left(\dfrac{W}{\dfrac{R_{\mathrm{a}}}{R_{\mathrm{H2O}}} + W} \right)$

Result for Wrong Input Values:

PsiAir_W_HAP_SI = -1000

References:

$\psi_{\mathrm{Air}}(W)$ Herrmann et al. [1], [2]

Mole Fraction of Water ψ_{H2O} = f(W)

Function Name:

PsiH2O_W_HAP_SI

Fortran Program:

REAL*8 FUNCTION PSIH2O_W_HUAIRPROP(W), REAL*8 W

Input Values:

W - Humidity ratio W in kg_w/kg_a

Result:

PsiH2O_W_HAP_SI - Mole fraction of water in humid air in mol_w/mol

Range of Validity:

Humidity ratio W: $0 \le W \le 10\,kg_w/kg_a$

Comments:

- Mole fraction of water $\psi_{H2O} = \dfrac{W}{\dfrac{R_a}{R_{H2O}} + W}$

Result for Wrong Input Values:

PsiH2O_W_HAP_SI = -1000

References:

$\psi_{H2O}(W)$ Herrmann et al. [1], [2]

Density ρ = f(p,t,W)

Function Name:

Rho_ptW_HAP_SI

Fortran Program:

REAL*8 FUNCTION RHO_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in kPa
t - Temperature t in °C
W - Humidity ratio W in kg_w/kg_a

Result:

Rho_ptW_HAP_SI - Density of humid air in kg/m^3

Range of Validity:

Temperature t:	from -143.15°C to 350°C
Total pressure p:	from 0.01 kPa to 10 000 kPa
Humidity ratio W:	$0 \le W \le 10\,kg_w/kg_a$

Comments:

- Density of humid air obtained from air-specific volume: $\rho = \frac{1+W}{v}$

Result for Wrong Input Values:

Rho_ptW_HAP_SI = -1000

References:

$\rho(p,t,W)$ Herrmann et al. [1], [2]

Air-Specific Entropy $s = f(p,t,W)$

Function Name:

s_ptW_HAP_SI

Fortran Program:

REAL*8 FUNCTION S_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in kPa
t - Temperature t in °C
W - Humidity ratio W in kg_w/kg_a

Result:

s_ptW_HAP_SI - Air-specific entropy in $kJ/(kg_a\,K)$

Range of Validity:

Temperature t:	from -143.15°C to 350°C
Total pressure p:	from 0.01 kPa to 10 000 kPa
Humidity ratio W:	$0 \le W \le 10\,kg_w/kg_a$

Comments:

- When calculating supersaturated air an ideal mixing model (saturated humid air and water droplets (or ice crystals) homogeneously mixed) is applied

Result for Wrong Input Values:

s_ptW_HAP_SI = -1000

References:

$s(p,t,W)$ Herrmann et al. [1], [2]

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

Function Name:

t_phphi_HAP_SI

Fortran Program:

REAL*8 FUNCTION T_PHPHI_HUAIRPROP(P,H,PHI), REAL*8 P,H,PHI

Input Values:

p - Total pressure p in kPa
h - Air-specific enthalpy h in kJ/kg$_a$
φ - Relative humidity φ (decimal ratio)

Result:

t_phphi_HAP_SI - Temperature from pressure, enthalpy, and relative humidity in °C

Range of Validity:

Total pressure p: from 0.01 kPa to 10 000 kPa

Air-specific enthalpy h: from -5745 kJ/kg$_a$ to 29690 kJ/kg$_a$

Relative humidity φ: $0 \le \varphi \le 1$

Comments:

- Iteration of temperature t from h = f(p,t,W) using W = f(p,t,φ)

Result for Wrong Input Values:

t_phphi_HAP_SI = -1000

References:

$h(p,t,W)$ Herrmann et al. [1], [2]

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

Function Name:

t_phW_HAP_SI

Fortran Program:

REAL*8 FUNCTION T_PHW_HUAIRPROP(P,H,W), REAL*8 P,H,W

Input Values:

p - Total pressure *p* in kPa
h - Air-specific enthalpy *h* in kJ/kg_a
W - Humidity ratio *W* in kg_w/kg_a

Result:

t_phW_HAP_SI - Temperature from pressure, enthalpy, and humidity ratio in °C

Range of Validity:

Total pressure *p*: from 0.01 kPa to 10 000 kPa

Air-specific enthalpy *h*: from -5745 kJ/kg_a to 29690 kJ/kg_a

Humidity ratio *W*: $0 \le W \le 10\,kg_w/kg_a$

Comments:

- Iteration of temperature *t* from *h* = f(*p*,*t*,*W*)

Result for Wrong Input Values:

t_phW_HAP_SI = -1000

References:

$h(p,t,W)$ Herrmann et al. [1], [2]

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

Function Name:

t_psW_HAP_SI

Fortran Program:

REAL*8 FUNCTION T_PSW_HUAIRPROP(P,S,W), REAL*8 P,S,W

Input Values:

p - Total pressure *p* in kPa

s - Air-specific entropy *s* in kJ/(kg_a K)

W - Humidity ratio *W* in kg_w/kg_a

Result:

t_psW_HAP_SI - Temperature from pressure, entropy, and humidity ratio in °C

Range of Validity:

Total pressure *p*: from 0.01 kPa to 10 000 kPa

Air-specific entropy *s*: from -26.53 kJ/(kg_a K) to 38.990 kJ/(kg_a K)

Humidity ratio *W*: $0 \le W \le 10\,kg_w/kg_a$

Comments:

- Iteration of temperature *t* from *s* = f(*p*,*t*,*W*)

Result for Wrong Input Values:

t_psW_HAP_SI = -1000

References:

$s(p,t,W)$ Herrmann et al. [1], [2]

Backward Function: Temperature $t = f(p, t_{wb}, W)$

Function Name:

t_ptwbW_HAP_SI

Fortran Program:

REAL*8 FUNCTION T_PTWBW_HUAIRPROP(P,TWB,W), REAL*8 P,TWB,W

Input Values:

p - Total pressure p in kPa

t_{wb} - Wet-bulb temperature in °C

W - Humidity ratio W in kg_w/kg_a

Result:

t_ptwbW_HAP_SI - Temperature from pressure, wet bulb temperature and humidity ratio in °C

Range of Validity:

Total pressure p: from 0.01 kPa to 10 000 kPa

Wet bulb temperature t_{wb}: from -143.15°C to 350°C

Humidity ratio W: $0 \le W \le 10 kg_w/kg_a$

Comments:

- Iterationof temperature t from $t_{wb} = f(p, t, W)$

Result for Wrong Input Values:

t_ptwbW_HAP_SI = -1000

References:

$t_{wb}(p, t, W)$ Herrmann et al. [1], [2]

Dew-Point/Frost-Point Temperature t_d = f(p,W)

Function Name:

td_pW_HAP_SI

Fortran Program:

REAL*8 FUNCTION TD_PW_HUAIRPROP(P,W), REAL*8 P,W

Input Values:

p - Total pressure p in kPa

W - Humidity ratio W in kg_w/kg_a

Result:

td_pW_HAP_SI - Dew-point/frost-point temperature in °C

Range of Validity:

Total pressure p: from 0.01 kPa to 10 000 kPa

Humidity ratio W: $0 \le W \le 10\,kg_w/kg_a$

Comments:

Dew-point temperature $t_d = t_s(p_{H2O})$ for $t \ge 0.01°C$ (saturation temperature of water in humid air)

$t_d = t_{sub}(p_{H2O})$ for $t \le 0.01°C$ (sublimation temperature of water in humid air)

Result for Wrong Input Values:

td_pW_HAP_SI = -1000

References:

$t_s(p_{H2O})$	for $t_d \ge 0.01°C$	IAPWS-IF97 [7], [8]
$t_{sub}(p_{H2O})$	for $t_d \le 0.01°C$	IAPWS-08 [11]
p_{H2O}		Herrmann et. al. [1], [2]

Saturation Temperature $t_s = f(p, p_{H2O})$

Function Name:

ts_ppH2O_HAP_SI

Fortran Program:

REAL*8 FUNCTION TS_PPH2O_HUAIRPROP(P,PH2O), REAL*8 P,PH2O

Input Values:

p - Total pressure p in kPa

p_{H2O} - Partial pressure of water vapor p_{H2O} in kPa

Result:

ts_ppH2O_HAP_SI - Saturation temperature in °C

Range of Validity:

Total pressure p: from 0.01 kPa to 10 000 kPa

Partial Pressure p_{H2O}: from 0.01 kPa to 10 000 kPa

Comments:

- Iteration of saturation temperature t_s from $p_{H2O,s} = f(p,t)$

Result for Wrong Input Values:

ts_ppH2O_HAP_SI = -1000

References:

$p_{H2O,s}$ Herrmann et. al. [1], [2]

Wet-Bulb/Ice-Bulb Temperature t_{wb} = f(p,t,W)

Function Name:

twb_ptW_HAP_SI

Fortran Program:

REAL*8 FUNCTION TWB_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in kPa
t - Temperature t in °C
W - Humidity ratio W in kg_w/kg_a

Result:

twb_ptW_HAP_SI - Wet-bulb/ice-bulb temperature in °C

Range of Validity:

Temperature t:	from -143.15°C to 350°C
Total pressure p:	from 0.01 kPa to 10 000 kPa
Humidity ratio W:	$0 \le W \le 10\,kg_w/kg_a$

Comments:

- Iteration of wet-bulb/ice-bulb temperature t_{wb}
  from $h^{unsaturated}(p,t,W) = h^{fog}(p,t_{wb},W)$
- Calculation for supersaturated humid air ($W > W_s$) is not possible

Result for Wrong Input Values:

twb_ptW_HAP_SI = -1000

References:

$t_{wb}(p,t,W)$ Herrmann et al. [1], [2]

Air-Specific Internal Energy u = f(p,t,W)

Function Name:

u_ptW_HAP_SI

Fortran Program:

REAL*8 FUNCTION U_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in kPa
t - Temperature t in °C
W - Humidity ratio W in kg_w/kg_a

Result:

u_ptW_HAP_SI - Air-specific internal energy in kJ/kg_a

Range of Validity:

Temperature t: from -143.15°C to 350°C
Total pressure p: from 0.01 kPa to 10 000 kPa
Humidity ratio W: $0 \le W \le 10\,kg_w/kg_a$

Comments:

- Internal energy $u = h - pv$

Result for Wrong Input Values:

u_ptW_HAP_SI = -1000

References:

$u(p,t,W)$ Herrmann et al. [1], [2]

Air-Specific Volume $v = f(p,t,W)$

Function Name:

v_ptW_HAP_SI

Fortran Program:

REAL*8 FUNCTION V_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in kPa
t - Temperature t in °C
W - Humidity ratio W in kg_w/kg_a

Result:

v_ptW_HAP_SI - Air-specific volume in m^3/kg_a

Range of Validity:

Temperature t: from -143.15°C to 350°C
Total pressure p: from 0.01 kPa to 10 000 kPa
Humidity ratio W: $0 \le W \le 10\,kg_w/kg_a$

Comments:

- When calculating supersaturated air an ideal mixing model (saturated humid air and water droplets (or ice crystals) homogeneously mixed) is applied

Result for Wrong Input Values:

v_ptW_HAP_SI = -1000

References:

$v(p,t,W)$ Herrmann et al. [1], [2]

Humidity Ratio from Partial Pressure of Steam $W = f(p,t,p_{H2O})$

Function Name:

W_ptpH2O_HAP_SI

Fortran Program:

REAL*8 FUNCTION W_PTPH2O_HUAIRPROP(P,T,PH2O), REAL*8 P,T,PH2O

Input Values:

p - Total pressure p in kPa
t - Temperature t in °C
p_{H2O} - Partial pressure of water p_{H2O} in kPa

Result:

W_ptpH2O_HAP_SI - Humidity ratio from temperature and partial pressure of water vapor in kg_w/kg_a

Range of Validity:

Total pressure p:	from 0.01 kPa to 10 000 kPa
Temperature t :	from -143.15°C to 350°C
Partial pressure p_{H2O} :	from 0.01 kPa to 10 000 kPa

Comments:

- Iteration of humidity ratio W from $p_{H2O} = f(p,t,W)$
- Result for supersaturated humid air is W_s

Result for Wrong Input Values:

W_ptpH2O_HAP_SI = -1000

References:

$p_{H2O}(p,t,W)$ Herrmann et al. [1], [2]

Humidity Ratio from Relative Humidity W = f(p,t,φ)

Function Name:

W_ptphi_HAP_SI

Fortran Program:

REAL*8 FUNCTION W_PTPHI_HUAIRPROP(P,T,PHI), REAL*8 P,T,PHI

Input Values:

p - Total pressure p in kPa
t - Temperature t in °C
φ - Relative humidity (decimal ratio)

Result:

W_ptphi_HAP_SI - Humidity ratio from temperature and relative humidity in kg_w/kg_a

Range of Validity:

Temperature t: from -143.15°C to 350°C

Total pressure p: from 0.01 kPa to 10 000 kPa

Relative humidity φ: $0 \le \varphi \le 1$

Comments:

- Iteration of humidity ratio W from $\varphi = f(p,t,W)$

Result for Wrong Input Values:

W_ptphi_HAP_SI = -1000

References:

$\varphi(p,t,W)$ Herrmann et al. [1], [2]

Humidity Ratio from Dew-Point Temperature $W = f(p,t_d)$

Function Name:

W_ptd_HAP_SI

Fortran Program:

REAL*8 FUNCTION W_PTD_HUAIRPROP(P,TD), REAL*8 P,TD

Input Values:

p - Total pressure p in kPa

t_d - Dew-point temperature t_d in °C

Result:

W_ptd_HAP_SI - Humidity ratio from temperature and dew-point temperature in kg_w/kg_a

Range of Validity:

Dew point temperature t_d: from -143.15°C to 350°C

Total pressure p: from 0.01 kPa to 10 000 kPa

Comments:

- Iteration of humidity ratio W from $t_d = f(p,W)$

Result for Wrong Input Values:

W_ptd_HAP_SI = -1000

References:

$t_d(p,W)$ Herrmann et al. [1], [2]

Humidity Ratio from Wet-Bulb Temperature $W = f(p,t,t_{wb})$

Function Name:

W_pttwb_HAP_SI

Fortran Program:

REAL*8 FUNCTION W_PTTWB_HUAIRPROP(P,T,TWB), REAL*8 P,T,TWB

Input Values:

p - Total pressure p in kPa
t - Temperature t in °C
t_{wb} - Wet-bulb temperature in °C

Result:

W_pttwb_HAP_SI - Humidity ratio from temperature and wet-bulb temperature in kg_w/kg_a

Range of Validity:

Total pressure p:	from 0.01 kPa to 10 000 kPa
Temperature t:	from -143.15°C to 350°C
Wet-bulb temperature t_{wb}:	from -143.15°C to 350°C

Comments:

- Iteration of humidity ratio W from $t_{wb} = f(p,t,W)$
- Calculation for supersaturated humid air ($W > W_s$) is not possible

Result for Wrong Input Values:

W_pttwb_HAP_SI = -1000

References:

$t_{wb}(p,t,W)$ Herrmann et al. [1], [2]

Saturation Humidity Ratio W_s = f(p,t)

Function Name:

Ws_pt_HAP_SI

Fortran Program:

REAL*8 FUNCTION WS_PT_HUAIRPROP(P,T), REAL*8 P,T

Input Values:

p - Total pressure p in kPa
t - Temperature t in °C

Result:

Ws_pt_HAP_SI - Saturation humidity ratio (mass fraction) in kg_w/kg_a

Range of Validity:

Total pressure p: from 0.01 kPa to 10 000 kPa
Temperature t: from -143.15°C to 350°C

Comments:

- Calculation of saturation humidity ratio W_s from $W_s = \frac{M_{H2O}}{M_a} \frac{p_{H2O,s}}{\left(p - p_{H2O,s}\right)}$

Result for Wrong Input Values:

Ws_pt_HAP_SI = -1000

References:

$p_{H2O,s}$ Herrmann et al. [1], [2]

Mass Fraction of Dry Air ξ_{Air} = f(W)

Function Name:

XiAir_W_HAP_SI

Fortran Program:

REAL*8 FUNCTION XIAIR_W_HUAIRPROP(W), REAL*8 W

Input Values:

W - Humidity ratio W in kg_w/kg_a

Result:

XiAir_W_HAP_SI - Mass fraction of (dry) air in humid air in kg_a/kg

Range of Validity:

Humidity ratio W: $0 \le W \le 10\,kg_w/kg_a$

Comments:

- Mass fraction of (dry) air $\xi_{Air} = 1 - \xi_{H2O} = 1 - \dfrac{W}{1+W}$

Result for Wrong Input Values:

XiAir_W_HAP_SI = -1000

References:

$\xi_{Air}(W)$ Herrmann et al. [1], [2]

Mass Fraction of Water Vapor ξ_{H2O} = f(W)

Function Name:

XiH2O_W_HAP_SI

Fortran Program:

REAL*8 FUNCTION XIH2O_W_HUAIRPROP(W), REAL*8 W

Input Values:

W - Humidity ratio W in kg_w/kg_a

Result:

XiH2O_W_HAP_SI - Mass fraction of water vapor in humid air in kg_w/kg

Range of Validity:

Humidity ratio W: $0 \le W \le 10\,kg_w/kg_a$

Comments:

- Mass fraction of water vapor $\xi_{H2O} = \dfrac{W}{1+W}$

Result for Wrong Input Values:

XiH2O_W_HAP_SI = -1000

References:

$\xi_{H2O}(W)$ Herrmann et al. [1], [2]

Compression Factor Z = f(p,t,W)

Function Name:

Z_ptW_HAP_SI

Fortran Program:

REAL*8 FUNCTION Z_PTW_HUAIRPROP(P,T,W), REAL*8 P,T,W

Input Values:

p - Total pressure p in kPa
t - Temperature t in °C
W - Humidity ratio W in kg_w/kg_a

Result:

Z_ptW_HAP_SI - Compression factor (decimal ratio)

Range of Validity:

Total pressure p: from 0.01 kPa to 10 000 kPa
Temperature t: from -143.15°C to 350°C
Humidity ratio W: $0 \le W \le W_s$

Comments:

- Compression factor $Z = 1 + \frac{B_m}{\bar{v}} + \frac{C_m}{\bar{v}^2}$

  with $\bar{v} = \frac{M}{\rho} = \frac{M v}{1+W}$

  and M is the molar mass of humid air

- Calculation for supersaturated humid air ($W > W_s$) is not possible

Result for Wrong Input Values:

Z_ptW_HAP_SI = -1000

References:

$B_m(t,W), C_m(t,W)$ Herrmann et al. [1], [2]
$\rho(p,t,W), v(p,t,W)$ Herrmann et al. [1], [2]

3.2 Functions for Steam and Water for Temperatures $t \geq 0°C$

Specific Enthalpy of Liquid Water h_{liq} = f(p,t)

Function Name:

hliq_pt_97_SI

Fortran Program:

REAL*8 FUNCTION HLIQ_PT_97(P,T), REAL*8 P,T

Input Values:

p - Pressure p in kPa
t - Temperature t in °C

Result:

hliq_pt_97_SI - Specific enthalpy of liquid water in kJ/kg

Range of Validity:

Pressure p: from $p_s(0°C) = 0.6112$ kPa to 10000 kPa

Temperature t: from 0°C to 350°C

Comments:

- Specific enthalpy of liquid water $h_{liq} = h^{97}(p,t)$ (Region 1)

Result for Wrong Input Values:

hliq_pt_97_SI = -1000

References:

$h^{97}(p,t)$ IAPWS-IF97 [7], [8]

Specific Enthalpy of Saturated Liquid Water $h_{liq,s} = f(t)$

Function Name:

hliqs_t_97_SI

Fortran Program:

REAL*8 FUNCTION HLIQS_T_97(T), REAL*8 T

Input Values:

t - Temperature *t* in °C

Result:

hliqs_t_97_SI - Specific enthalpy of saturated liquid water in kJ/kg

Range of Validity:

Temperature *t*: from 0°C to 350°C

Comments:

- Specific enthalpy of liquid water $h_{liq,s} = h^{97}(p_s, t)$ (Region 1)

  with $p_s = p_s^{97}(t)$

Result for Wrong Input Values:

hliqs_t_97_SI = -1000

References:

$h^{97}(p,t)$, $p_s^{97}(t)$ IAPWS-IF97 [7], [8]

Specific Enthalpy of Saturated Water Vapor $h_{vap,s} = f(t)$

Function Name:

hvaps_t_97_SI

Fortran Program:

REAL*8 FUNCTION HVAPS_T_97(T), REAL*8 T

Input Values:

t - Temperature t in °C

Result:

hvaps_t_97_SI - Specific enthalpy of saturated water vapor in kJ/kg

Range of Validity:

Temperature t: from 0°C to 350°C

Comments:

- Specific enthalpy of saturated water vapor $h_{vap,s} = h^{97}(p_s, t)$ (Region 2)

  with $p_s = p_s^{97}(t)$

Result for Wrong Input Values:

hvaps_t_97_SI = -1000

References:

$h^{97}(p,t)$, $p_s^{97}(t)$ IAPWS-IF97 [7], [8]

Saturation Pressure of Water p_s = f(t)

Function Name:

ps_t_97_SI

Fortran Program:

REAL*8 FUNCTION PS_T_97(T), REAL*8 T

Input Values:

t - Temperature t in °C

Result:

ps_t_97_SI - Saturation pressure of water in kPa

Range of Validity:

Temperature t: from 0°C to 350°C

Comments:

- Saturation pressure of water $p_s = p_s^{97}(t)$ (Region 4)

Result for Wrong Input Values:

ps_t_97_SI -1000

References:

$p_s^{97}(t)$ IAPWS-IF97 [7], [8]

Specific Entropy of Liquid Water $s_{liq} = f(p,t)$

Function Name:

sliq_pt_97_SI

Fortran Program:

REAL*8 FUNCTION SLIQ_PT_97(P,T), REAL*8 P,T

Input Values:

p - Pressure *p* in kPa
t - Temperature *t* in °C

Result:

sliq_pt_97_SI - Specific entropy of liquid water in kJ/(kg K)

Range of Validity:

Pressure *p*: from $p_s(0°C) = 0.6112$ kPa to 10000 kPa

Temperature *t*: from 0°C to 350°C

Comments:

- Specific entropy of liquid water $s_{liq} = s^{97}(p,t)$ (Region 1)

Result for Wrong Input Values:

sliq_pt_97_SI = -1000

References:

$s^{97}(p,t)$ IAPWS-IF97 [7], [8]

Specific Entropy of Saturated Liquid Water $s_{liq,s} = f(t)$

Function Name:

sliqs_t_97_SI

Fortran Program:

REAL*8 FUNCTION SLIQS_T_97(T), REAL*8 T

Input Values:

t - Temperature *t* in °C

Result:

sliqs_t_97_SI - Specific entropy of saturated liquid water in kJ/(kg K)

Range of Validity:

Temperature *t*: from 0°C to 350°C

Comments:

- Specific entropy of liquid water $s_{liq,s} = s^{97}(p_s, t)$ (Region 1)

  with $p_s = p_s^{97}(t)$

Result for Wrong Input Values:

sliqs_t_97_SI = -1000

References:

$s^{97}(p,t), p_s^{97}(t)$ IAPWS-IF97 [7], [8]

Specific Entropy of Saturated Water Vapor $s_{vap,s} = f(t)$

Function Name:

svaps_t_97_SI

Fortran Program:

REAL*8 FUNCTION SVAPS_T_97(T), REAL*8 T

Input Values:

t - Temperature *t* in °C

Result:

svaps_t_97_SI - Specific entropy of saturated water vapor in kJ/(kg K)

Range of Validity:

Temperature *t*: from 0°C to 350°C

Comments:

- Specific entropy of saturated water vapor $s_{\mathrm{vap,s}} = s^{97}(p_{\mathrm{s}}, t)$ (Region 2)

  with $p_{\mathrm{s}} = p_{\mathrm{s}}^{97}(t)$

Result for Wrong Input Values:

svaps_t_97_SI = -1000

References:

$s^{97}(p,t), p_{\mathrm{s}}^{97}(t)$ IAPWS-IF97 [7], [8]

Saturation Temperature of Water $t_s = f(p)$

Function Name:

ts_p_97_SI

Fortran Program:

REAL*8 FUNCTION TS_P_97(P), REAL*8 P

Input Values:

p - Pressure p in kPa

Result:

ts_p_97_SI - Saturation temperature of water in °C

Range of Validity:

Pressure p: from 0.6112 kPa to 10 000 kPa

Comments:

- Saturation temperature of water $t_s = t_s^{97}(p)$ (Region 4)

Result for Wrong Input Values:

ts_p_97_SI = -1000

References:

$t_s^{97}(p)$ IAPWS-IF97 [7], [8]

Specific Volume of Liquid Water v_{liq} = f(p,t)

Function Name:

vliq_pt_97_SI

Fortran Program:

REAL*8 FUNCTION VLIQ_PT_97(P,T), REAL*8 P,T

Input Values:

p - Pressure p in kPa
t - Temperature t in °C

Result:

vliq_pt_97_SI - Specific volume of liquid water in m^3/kg

Range of Validity:

Pressure p: from $p_s(0°C) = 0.6112$ kPa to 10 000 kPa

Temperature t: from 0°C to 350°C

Comments:

- Specific volume of liquid water $v_{liq} = v^{97}(p,t)$ (Region 1)

Result for Wrong Input Values:

vliq_pt_97_SI = -1000

References:

$v^{97}(p,t)$ IAPWS-IF97 [7], [8]

Specific Volume of Saturated Liquid Water $v_{\mathrm{liq,s}} = \mathrm{f}(t)$

Function Name:

vliqs_t_97_SI

Fortran Program:

REAL*8 FUNCTION VLIQS_T_97(T), REAL*8 T

Input Values:

t - Temperature t in °C

Result:

vliqs_t_97_SI - Specific volume of saturated liquid water in m^3/kg

Range of Validity:

Temperature t: from 0°C to 350°C

Comments:

- Specific volume of liquid water $v_{\mathrm{liq,s}} = v^{97}(p_{\mathrm{s}}, t)$ (Region 1)

  with $p_{\mathrm{s}} = p_{\mathrm{s}}^{97}(t)$

Result for Wrong Input Values:

vliqs_t_97_SI = -1000

References:

$v^{97}(p,t)$, $p_{\mathrm{s}}^{97}(t)$ IAPWS-IF97 [7], [8]

Specific Volume of Saturated Water Vapor $v_{vap,s} = f(t)$

Function Name:

vvaps_t_97_SI

Fortran Program:

REAL*8 FUNCTION VVAPS_T_97(T), REAL*8 T

Input Values:

t - Temperature *t* in °C

Result:

vvaps_t_97_SI - Specific volume of saturated water vapor in m^3/kg

Range of Validity:

Temperature *t*: from 0°C to 350°C

Comments:

- Specific volume of saturated water vapor $v_{vap,s} = v^{97}(p_s, t)$ (Region 2)

  with $p_s = p_s^{97}(t)$

Result for Wrong Input Values:

vvaps_t_97_SI = -1000

References:

$v^{97}(p,t), p_s^{97}(t)$ IAPWS-IF97 [7], [8]

3.3 Functions for Steam and Ice for Temperatures $t \leq 0°C$

Specific Enthalpy of Saturated Ice $h_{ice,sub}$ = f(t)

Function Name:

hicesub_t_06_SI

Fortran Program:

REAL*8 FUNCTION HICESUB_T_06(T), REAL*8 T

Input Values:

t - Temperature t in °C

Result:

hicesub_t_06_SI - Specific enthalpy of saturated ice in kJ/kg

Range of Validity:

Temperature t: from -143.15°C to 0°C

Comments:

- Specific enthalpy of saturated ice $h_{ice,sub} = h^{06}(p_{sub}, t)$

  with $p_{sub} = p_{sub}^{08}(t)$

Result for Wrong Input Values:

hicesub_t_06_SI = -1000

References:

$h^{06}(p,t)$ IAPWS-06 [10]

$p_{sub}^{08}(t)$ IAPWS-08 [11]

Specific Enthalpy of Saturated Water Vapor $h_{vap,sub}$ = f(t)

Function Name:

hvapsub_t_95_SI

Fortran Program:

REAL*8 FUNCTION HVAPSUB_T_95(T), REAL*8 T

Input Values:

t - Temperature t in °C

Result:

hvapsub_t_95_SI - Specific enthalpy of saturated water vapor in kJ/kg

Range of Validity:

Temperature t: from -143.15°C to 0°C

Comments:

- Specific enthalpy of saturated water vapor $h_{vap,sub} = h^{95}(p_{sub}, t)$

  with $p_{sub} = p_{sub}^{08}(t)$

Result for Wrong Input Values:

hvapsub_t_95_SI = -1000

References:

$h^{95}(p,t)$ IAPWS-95 [5], [6]

$p_{sub}^{08}(t)$ IAPWS-08 [11]

Melting Pressure p_{mel} = f(t)

Function Name:

pmel_t_08_SI

Fortran Program:

REAL*8 FUNCTION PMEL_T_08 (T), REAL*8 T

Input Values:

t - Temperature t in °C

Result:

pmel_t_08_SI - Melting pressure of ice in kPa

Range of Validity:

Temperature t: from -21.985°C to 0°C

Result for Wrong Input Values:

pmel_t_08_SI = -1000

References:

$p_{mel}^{08}(t)$ IAPWS-08 [11]

Sublimation Pressure p_{sub} = f(t)

Function Name:

psub_t_08_SI

Fortran Program:

REAL*8 FUNCTION PSUB_T_08 (T), REAL*8 T

Input Values:

t - Temperature t in °C

Result:

psub_t_08_SI - Sublimation pressure of ice in kPa

Range of Validity:

Temperature t: from -143.15°C to 0°C

Result for Wrong Input Values:

psub_t_08_SI = -1000

References:

$p_{sub}^{08}(t)$ IAPWS-08 [11]

Specific Entropy of Saturated Ice $s_{ice,sub} = f(t)$

Function Name:

sicesub_t_06_SI

Fortran Program:

REAL*8 FUNCTION SICESUB_T_06(T), REAL*8 T

Input Values:

t - Temperature *t* in °C

Result:

sicesub_t_06_SI - Specific entropy of saturated ice in kJ/(kg K)

Range of Validity:

Temperature *t*: from -143.15°C to 0°C

Comments:

- Specific entropy of saturated ice $s_{ice,sub} = s^{06}(p_{sub}, t)$

  with $p_{sub} = p_{sub}^{08}(t)$

Result for Wrong Input Values:

sicesub_t_06_SI = -1000

References:

$s^{06}(p,t)$ IAPWS-06 [10]

$p_{sub}^{08}(t)$ IAPWS-08 [11]

Specific Entropy of Saturated Water Vapor $s_{vap,sub}$ = f(t)

Function Name:

svapsub_t_95_SI

Fortran Program:

REAL*8 FUNCTION SVAPSUB_T_95(T), REAL*8 T

Input Values:

t - Temperature t in °C

Result:

svapsub_t_95_SI - Specific entropy of saturated water vapor in kJ/(kg K)

Range of Validity:

Temperature t: from -143.15°C to 0°C

Comments:

- Specific entropy of saturated water vapor $s_{vap,sub} = s^{95}(p_{sub}, t)$

  with $p_{sub} = p_{sub}^{08}(t)$

Result for Wrong Input Values:

svapsub_t_95_SI = -1000

References:

$s^{95}(p,t)$ IAPWS-95 [7], [8]

$p_{sub}^{08}(t)$ IAPWS-08 [11]

Melting Temperature t_{mel} = f(p)

Function Name:

tmel_p_08_SI

Fortran Program:

REAL*8 FUNCTION TMEL_P_08(P), REAL*8 P

Input Values:

p - Pressure p in kPa

Result:

tmel_p_08_SI - Melting temperature of ice in °C

Range of Validity:

Pressure p: from $p_s(0°C) = 0.6112$ kPa to 10 000 kPa

Result for Wrong Input Values:

tmel_p_08_SI = -1000

References:

$t_{mel}^{08}(p)$ IAPWS-08 [11]

Sublimation Temperature t_{sub} = f(p)

Function Name:

tsub_p_08_SI

Fortran Program:

REAL*8 FUNCTION TSUB_P_08(P), REAL*8 P

Input Values:

p - Pressure p in kPa

Result:

tsub_p_08_SI - Sublimation temperature of ice in °C

Range of Validity:

Pressure p: from $p_{subl}(-143.15°C) = 1.2002 \times 10^{-11}$ kPa to $p_{subl}(0°C) = 0.6112$ kPa

Result for Wrong Input Values:

tsub_p_08_SI = -1000

References:

$t_{sub}^{08}(p)$ IAPWS-08 [11]

Specific Volume of Saturated Ice $v_{ice,sub}$ = f(t)

Function Name:

vicesub_t_06_SI

Fortran Program:

REAL*8 FUNCTION VICESUB_T_06(T), REAL*8 T

Input Values:

t - Temperature t in °C

Result:

vicesub_t_06_SI - Specific volume of saturated ice in m^3/kg

Range of Validity:

Temperature t: from -143.15°C to 0°C

Comments:

- Specific volume of saturated ice $v_{ice,sub} = v^{06}(p_{sub}, t)$
  with $p_{sub} = p_{sub}^{08}(t)$

Result for Wrong Input Values:

vicesub_t_06_SI = -1000

References:

$v^{06}(p,t)$ IAPWS-06 [10]

$p_{sub}^{08}(t)$ IAPWS-08 [11]

Specific Volume of Saturated Water Vapor $v_{vap,sub}$ = f(t)

Function Name:

vvapsub_t_95_SI

Fortran Program:

REAL*8 FUNCTION VVAPSUB_T_95(T), REAL*8 T

Input Values:

t - Temperature t in °C

Result:

vvapsub_t_95_SI - Specific volume of saturated water vapor in m^3/kg

Range of Validity:

Temperature t: from -143.15°C to 0°C

Comments:

- Specific volume of saturated water vapor $v_{vap,sub} = v^{95}(p_{sub}, t)$

  with $p_{sub} = p_{sub}^{08}(t)$

Result for Wrong Input Values:

vvapsub_t_95_SI = -1000

References:

$v^{95}(p,t)$ IAPWS-95 [7], [8]

$p_{sub}^{08}(t)$ IAPWS-08 [11]

KCE ThermoFluidProperties

KCE-ThermoFluidProperties
www.thermofluidprop.com

Hochschule Zittau/Görlitz
UNIVERSITY OF APPLIED SCIENCES

4. 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, -S03rev, -S04, and -S05
- IAPWS Revised Advisory Note No. 3 on Thermo-dynamic Derivatives (2008)

Library LibIF97_META

- Industrial Formulation IAPWS-IF97 (Revision 2007) for metastable steam

Humid Combustion Gas Mixtures

Library LibHuGas

Model: Ideal mixture of the real fluids:

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

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

Consideration of:

- Dissociation from VDI 4670
- Poynting effect

Humid Air

Library LibHuAir

Model: Ideal mixture of the real fluids:

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

Consideration of:

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

Extremely Fast Property Calculations

Spline-Based Table Look-up Method (SBTL)

Library LibSBTL_IF97
Library LibSBTL_95
Library LibSBTL_HuAir

For steam, water, humid air, carbon dioxide and other fluids and mixtures according IAPWS Guideline 2015 for Computational Fluid Dynamics (CFD), real-time and non-stationary simulations

Carbon Dioxide Including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1996)

Seawater

Library LibSeaWa

IAPWS Industrial Formulation 2013

Ice

Library LibICE

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

Ideal Gas Mixtures

Library LibIdGasMix

Model: Ideal mixture of the ideal gases:

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

Consideration of:

- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

Humid Air

Library ASHRAE LibHuAirProp

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

Consideration of:

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

www.ashrae.org/bookstore

Dry Air Including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth et al. (1993)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of Bücker and Wagner (2006)

n-Butane

Library LibButane_n

Formulation of Bücker and Wagner (2006)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

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

Helmholtz energy equation for the mixing term

(also useable for calculating the Kalina Cycle)

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

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

Formulation of the International Institute of Refrigeration (IIR 2010)

Ethanol

Library LibC2H5OH

Formulation of
Schroeder et al. (2014)

Methanol

Library LibCH3OH

Formulation of
de Reuck and Craven (1993)

Propane

Library LibPropane

Formulation of
Lemmon et al. (2009)

Siloxanes as ORC Working Fluids

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

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

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

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

Formulation of Colonna et al. (2006)

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

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

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

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

Formulation of Colonna et al. (2008)

Nitrogen and Oxygen

**Libraries
LibN2 and LibO2**

Formulations of Span et al. (2000)
and Schmidt and Wagner (1985)

Hydrogen

Library LibH2

Formulation of
Leachman et al. (2009)

Helium

Library LibHe

Formulation of
Arp et al. (1998)

Hydrocarbons

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

Isopentane C_5H_{12} **Library LibC5H12_Iso**

Neopentane C_5H_{12} **Library LibC5H12_Neo**

Isohexane C_6H_{14} **Library LibC6H14**

Toluene C_7H_8 **Library LibC7H8**

Formulation of Lemmon and Span (2006)

Further Fluids

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

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

Hydrogen sulfide H_2S **Library LibH2S**

Nitrous oxide N_2O **Library LibN2O**

Sulfur dioxide SO_2 **Library LibSO2**

Acetone C_3H_6O **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

KCE
ThermoFluidProperties

For more information please contact:

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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
- Thermal diffusivity a

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 used in process modeling can be calculated.

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

www.thermofluidprop.com

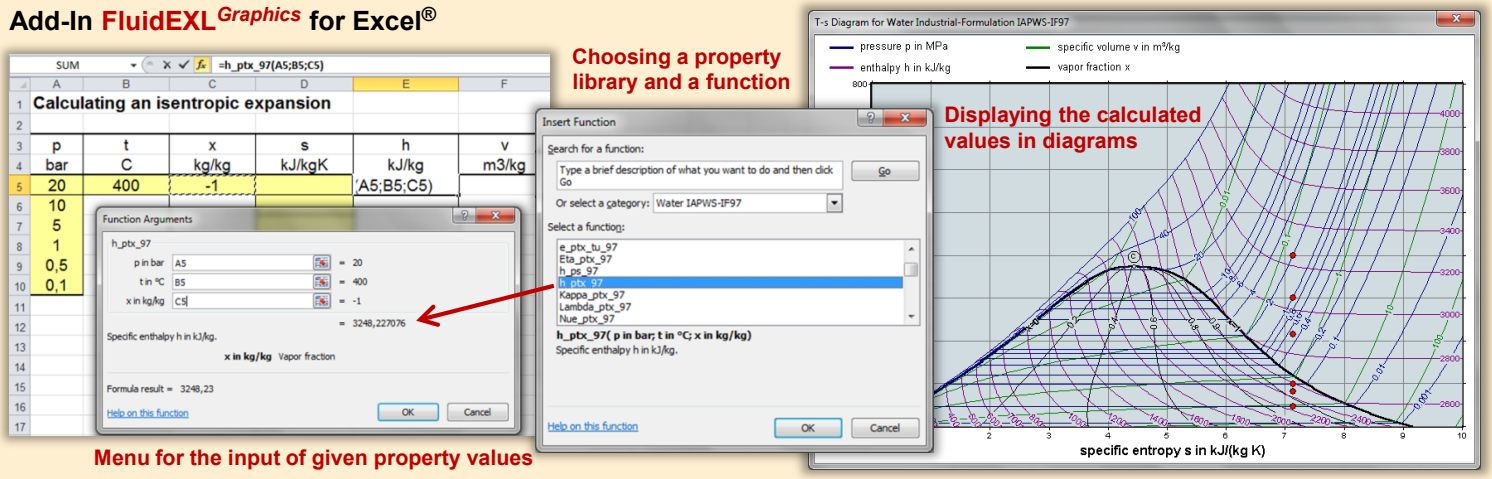
KCE ThermoFluidProperties

KCE-ThermoFluidProperties
www.thermofluidprop.com

Hochschule Zittau/Görlitz
UNIVERSITY OF APPLIED SCIENCES

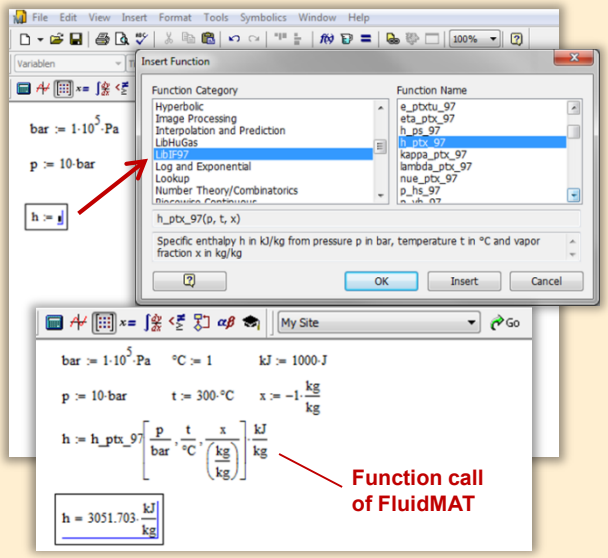
Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

Add-In FluidEXL*Graphics* for Excel®



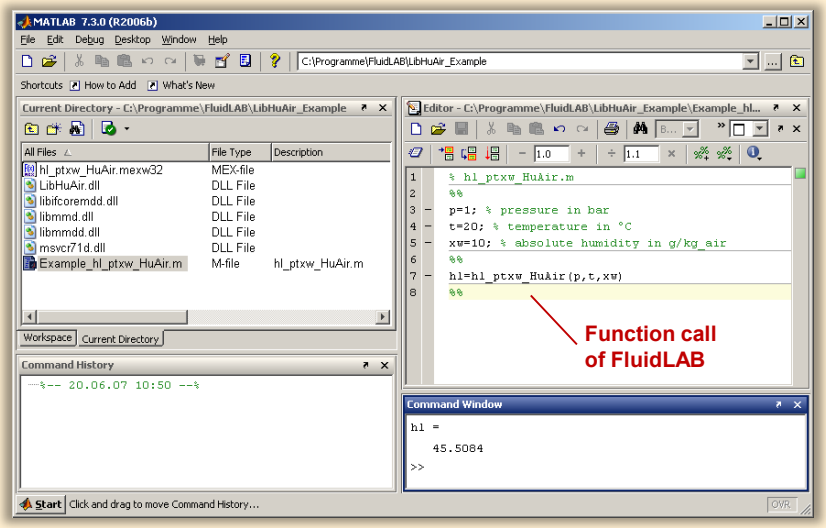
Add-On FluidMAT for Mathcad®
Add-On FluidPRIME for Mathcad Prime®

The property libraries can be used in Mathcad® and Mathcad Prime®.



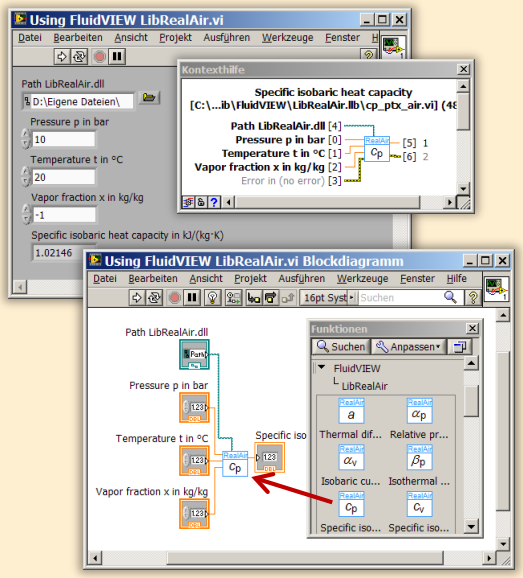
Add-On FluidLAB for MATLAB® and SIMULINK®

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



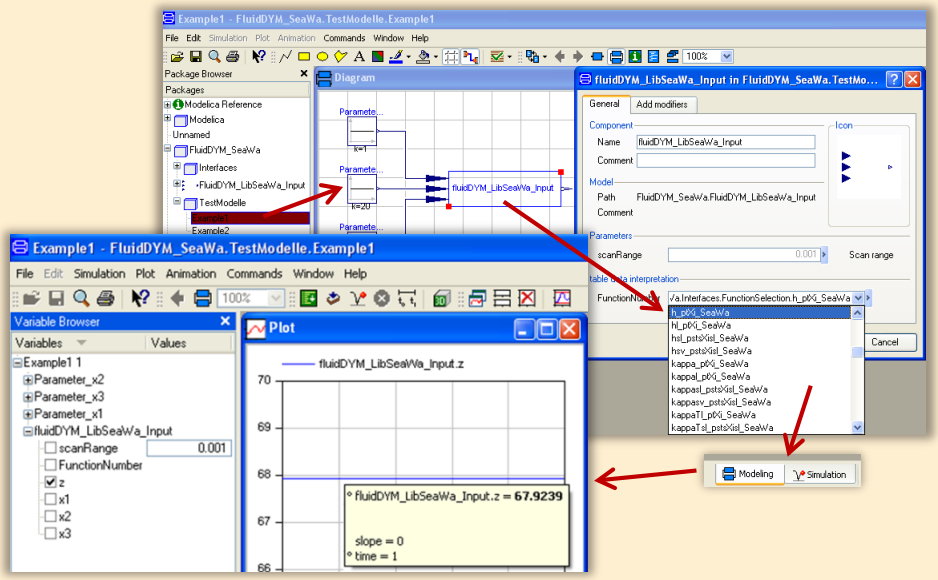
Add-On FluidVIEW for LabVIEW™

The property functions can be calculated in LabVIEW™.

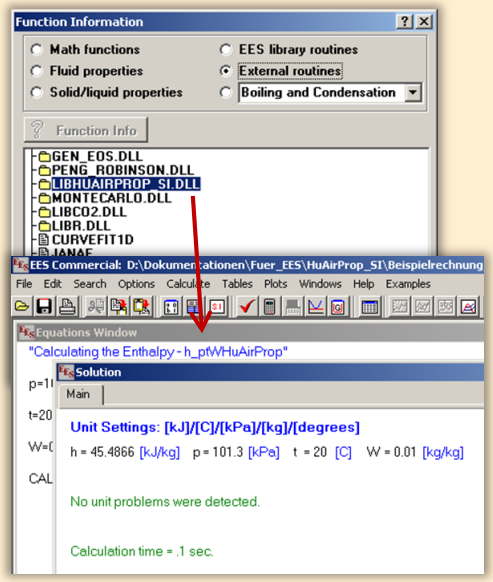


Add-On FluidDYM for DYMOLA® (Modelica) and SimulationX®

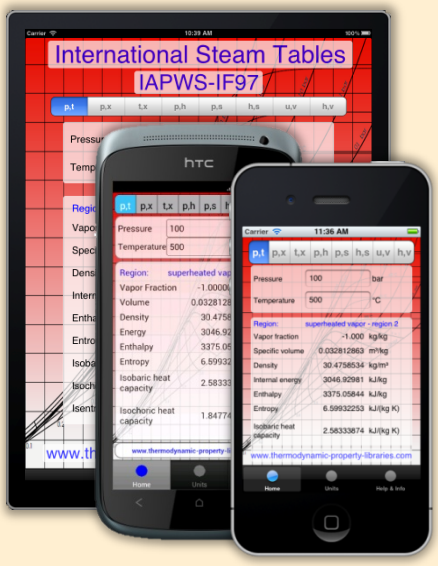
The property functions can be called in DYMOLA® and SimulationX®.



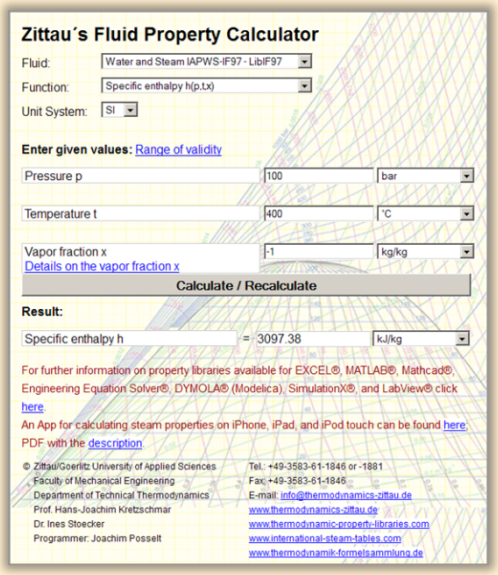
Add-On FluidEES for Engineering Equation Solver®



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



Online Property Calculator at www.thermofluidprop.com



Property Software for Pocket Calculators

FluidCasio

fx 9750 G II | CFX 9850 fx-GG20 | CFX 9860 G Graph 85 | ALGEBRA FX 2.0

FluidHP

HP 48 | HP 49

FluidTI

TI Nspire CX CAS
TI Nspire CAS

TI 83
TI 84
TI 89

TI Voyage 200

TI 92

For more information please contact:

KCE ThermoFluidProperties

KCE-ThermoFluidProperties UG & Co. KG
Prof. Dr. Hans-Joachim Kretzschmar
Wallotstr. 3
01307 Dresden, Germany

Internet: www.thermofluidprop.com
Email: info@thermofluidprop.com
Phone: +49-351-27597860
Mobile: +49-172-7914607
Fax: +49-3222-1095810

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
- Thermal diffusivity a

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 used in process modeling can be calculated.

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

www.thermofluidprop.com

5 References

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[2] Herrmann, S.; Kretzschmar, H.-J.; Gatley, D.P.: Thermodynamic Properties of Real Moist Air, Dry Air, Steam, Water, and Ice. ASHRAE RP-1485, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA (2009).

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6 Satisfied Customers

Date: 12/2019

The following companies and institutions use the property libraries:

- FluidEXL*Graphics* for Excel®
- FluidLAB for MATLAB® and Simulink
- FluidMAT for Mathcad®
- FluidPRIME for Mathcad Prime®
- FluidEES for Engineering Equation Solver® EES
- FluidDYM for Dymola® (Modelica) and SimulationX®
- FluidVIEW for LabVIEW™
- DLLs for Windows™
- Shared Objects for Linux®.

2019

PEU Leipzig, Rötha	12/2019
MB-Holding, Vestenbergsgreuth	12/2019
COMPAREX, Leipzig for RWE Supply & Trading GmbH, Essen	12/2019
Georg-Büchner-Hochschule, Darmstadt	11/2019
EEB ENERKO, Aldenhoven	11/2019
Robert Benoufa Energietechnik, Wiesloch	11/2019
Kehrein & Kubanek Klimatechnik, Moers	10/2019
Hanon Systems Autopal Services, Hluk, Czech Republic	10/2019
CEA Saclay, Gif Sur Yvette cedex, France	10/2019
Saudi Energy Efficiency Center SEEC, Riyadh, Saudi Arabia	10/2019
VPC, Vetschau	09/2019
jGanser PM + Engineering, Forchheim	09/2019
Ruchti IB, Uster, Switzerland	09/2019
ZWILAG Zwischenlager Würenlingen, Switzerland	08/2019
Hochschule Zittau/Görlitz, Faculty Maschinenwesen	08/2019
Stadtwerke Neubrandenburg	08/2019
Physikalisch Technische Bundesanstalt PTB, Braunschweig	08/2019
GMVA Oberhausen	07/2019
Endress+Hauser Flowtec AG, Reinach, Switzerland	07/2019, 09/2019
WARNICA, Waterloo, Canada	07/2019
MIBRAG, Zeitz	06/2019
Pöyry, Zürich, Switzerland	06/2019
RWTH Aachen, Institut für Strahlantriebe und Turbomaschinen	06/2019
Midiplan, Bietigheim-Bissingen	06/2019
GKS Schweinfurt	06/2019
HS Zittau/Görlitz, Wirtschaftswissenschaften und Wirtschaftsingenieurwesen	06/2019
ILK Dresden	06/2019
HZDR Helmholtz Zentrum Dresden-Rossendorf	06/2019

TH Köln, Technische Gebäudeausrüstung	05/2019
IB Knittel, Braunschweig	05/2019
Norsk Energi, Oslo, Norway	05/2019
STEAG, Essen	05/2019
Stora Enso, Eilenburg	05/2019
IB Lücke, Paderborn	05/2019
Haarslev, Sonderso, Denmark	05/2019
MAN Augsburg	05/2019
Wieland Werke, Ulm	04/2019
Fels-Werke, Elbingerode	04/2019
Univ. Luxembourg, Luxembourg	04/2019
BTU Cottbus, Power Engineering	03/2009
Eins-Energie Sachsen, Schwarzenberg	03/2019
TU Dresden, Kälte- und Kryotechnik	03/2019
ITER, St. Paul Lez Durance Cedex, France	03/2019
Fraunhofer UMSICHT, Oberhausen	03/2019
Comparex Leipzig for Spedition Thiele HEMMERSBACH	03/2019
Rückert NaturGas, Lauf/Pegnitz	03/2019
BASF, Basel, Switzerland	02/2019
Stadtwerke Leipzig	02/2019
Maerz Ofenbau Zürich, Switzerland	02/2019
Hanon Systems Germany, Kerpen	02/2019
Thermofin, Heinsdorfergrund	01/2019
BSH Berlin	01/2019

2018

Jaguar Energy, Guatemala	12/2018
WEBASTO, Gilching	12/2018
Smurfit Kappa, Oosterhout, Netherlands	12/2018
Univ. BW München	12/2018
RAIV, Liberec for VALEO, Prague, Czech Republic	11/2018
VPC Group Vetschau	11/2018
SEITZ, Wetzikon, Switzerland	11/2018
MVV, Mannheim	10/2018
IB Troche	10/2018
KANIS Turbinen, Nürnberg	10/2018
TH Ingolstadt, Institut für neue Energiesysteme	10/2018
IB Kristl & Seibt, Graz, Austria	09/2018
INEOS, Köln	09/2018
IB Lücke, Paderborn	09/2018
Südzucker, Ochsenfurt	08/2018
K&K Turbinenservice, Bielefeld	07/2018
OTH Regensburg, Elektrotechnik	07/2018
Comparex Leipzig for LEAG, Berlin	06/2018
Münstermann, Telgte	05/2018
TH Nürnberg, Verfahrenstechnik	05/2018

Universität Madrid, Madrid, Spanien	05/2018
HS Zittau/Görlitz, Wirtschaftswissenschaften und Wirtschaftsingenieurwesen	05/2018
HS Niederrhein, Krefeld	05/2018
Wilhelm-Büchner HS, Pfungstadt	03/2018
GRS, Köln	03/2018
WIB, Dennheritz	03/2018
RONAL AG, Härklingen, Schweiz	02/2018
Ingenieurbüro Leipert, Riegelsberg	02/2018
AIXPROCESS, Aachen	02/2018
KRONES, Neutraubling	02/2018
Doosan Lentjes, Ratingen	01/2018

2017

Compact Kältetechnik, Dresden	12/2017
Endress + Hauser Messtechnik GmbH +Co. KG, Hannover	12/2017
TH Mittelhessen, Gießen	11/2017
Haarslev Industries, Søndersø, Denmark	11/2017
Hochschule Zittau/Görlitz, Fachgebiet Energiesystemtechnik	11/2017
ATESTEO, Alsdorf	10/2017
Wijbenga, PC Geldermalsen, Netherlands	10/2017
Fels-Werke GmbH, Elbingerode	10/2017
KIT Karlsruhe, Institute für Neutronenphysik und Reaktortechnik	09/2017
Air-Consult, Jena	09/2017
Papierfabrik Koehler, Oberkirch	09/2017
ZWILAG, Würenlingen, Switzerland	09/2017
TLK-Thermo Universität Braunschweig, Braunschweig	08/2017
Fichtner IT Consulting AG, Stuttgart	07/2017
Hochschule Ansbach, Ansbach	06/2017
RONAL, Härkingen, Switzerland	06/2017
BORSIG Service, Berlin	06/2017
BOGE Kompressoren, Bielefeld	06/2017
STEAG Energy Services, Zwingenberg	06/2017
CES clean energy solutions, Wien, Austria	04/2017
Princeton University, Princeton, USA	04/2017
B2P Bio-to-Power, Wadersloh	04/2017
TU Dresden, Institute for Energy Engineering, Dresden	04/2017
SAINT-GOBAIN, Vaujours, France	03/2017
TU Bergakademie Freiberg, Chair of Thermodynamics, Freiberg	03/2017
SCHMIDT + PARTNER, Therwil, Switzerland	03/2017
KAESER Kompressoren, Gera	03/2017
F&R, Praha, Czech Republic	03/2017
ULT Umwelt-Lufttechnik, Löbau	02/2017
JS Energie & Beratung, Erding	02/2017
Kelvion Brazed PHE, Nobitz-Wilchwitz	02/2017
MTU Aero Engines, München	02/2017
Hochschule Zittau/Görlitz, IPM	01/2017

CombTec ProCE, Zittau	01/2017
SHELL Deutschland Oil, Wesseling	01/2017
MARTEC Education Center, Frederikshaven, Denmark	01/2017
SynErgy Thermal Management, Krefeld	01/2017

2016

BOGE Druckluftsysteme, Bielefeld	12/2016
BFT Planung, Aachen	11/2016
Midiplan, Bietigheim-Bissingen	11/2016
BBE Barnich IB	11/2016
Wenisch IB,	11/2016
INL, Idaho Falls	11/2016
TU Kältetechnik, Dresden	11/2016
Kopf SynGas, Sulz	11/2016
INTVEN, Bellevne (USA)	11/2016
DREWAG Dresden, Dresden	10/2016
AGO AG Energie+Anlagen, Kulmbach	10/2016
Universität Stuttgart, ITW, Stuttgart	09/2016
Pöyry Deutschland GmbH, Dresden	09/2016
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
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
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
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

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 Dresen + 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
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
Pöyry 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	05/2012

via Fichtner IT Consult	
Endress & Hauser	05/2012
PEU, Espenheim	05/2012
Luzern University of Applied Sciences, Switzerland	05/2012
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 Destilation, Sprendlingen	02/2012
Lopez, Munguia, Spain	02/2012
Endress & Hauser, Hannover	02/2012
Palo Alto Research Center, USA	02/2012
WIPAK, Walsrode	02/2012
Freudenberg, Weinheim	01/2012
Fichtner, Stuttgart	01/2012
airinotec, Bayreuth	01/2012, 07/2012
University Auckland, New Zealand	01/2012
VPC, Vetschau	01/2012
Franken Guss, Kitzingen	01/2012

2011

XRG-Simulation, Hamburg	12/2011
Smurfit Kappa PPT, AX Roermond, Netherlands	12/2011
AWTEC, Zurich, Switzerland	12/2011
eins-energie, Bad Elster	12/2011
BeNow, Rodenbach	11/2011
Luzern University of Applied Sciences, Switzerland	11/2011
GMVA, Oberhausen	11/2011
CCI, Karlsruhe	10/2011
W.-Büchner University of Applied Sciences, Pfungstadt	10/2011
PLANAIR, La Sagne, Switzerland	10/2011
LAWI, Dresden	10/2011
Lopez, Munguia, Spain	10/2011
University of KwaZulu-Natal, Westville, South Africa	10/2011
Voith, Heidenheim	09/2011

SpgBe Montreal, Canada	09/2011
SPG TECH, Montreuil Cedex, France	09/2011
Voith, Heidenheim-Mergelstetten	09/2011
MTU Aero Engines, Munich	08/2011
MIBRAG, Zeitz	08/2011
RWE, Essen	07/2011
Fels, Elingerode	07/2011
Weihenstephan University of Applied Sciences	07/2011, 09/2011 10/2011
Forschungszentrum Juelich	07/2011
RWTH Aachen University	07/2011, 08/2011
INNEO Solutions, Ellwangen	06/2011
Caliqua, Basel, Switzerland	06/2011
Technical University of Freiberg	06/2011
Fichtner IT Consulting, Stuttgart	05/2011, 06/2011, 08/2011
Salzgitter Flachstahl, Salzgitter	05/2011
Helbling Beratung & Bauplanung, Zurich, Switzerland	05/2011
INEOS, Cologne	04/2011
Enseleit Consulting Engineers, Siebigerode	04/2011
Witt Consulting Engineers, Stade	03/2011
Helbling, Zurich, Switzerland	03/2011
MAN Diesel, Copenhagen, Denmark	03/2011
AGO, Kulmbach	03/2011
University of Duisburg	03/2011, 06/2011
CCP, Marburg	03/2011
BASF, Ludwigshafen	02/2011
ALSTOM Power, Baden, Switzerland	02/2011
Universität der Bundeswehr, Munich	02/2011
Calorifer, Elgg, Switzerland	01/2011
STRABAG, Vienna, Austria	01/2011
TUEV Sued, Munich	01/2011
ILK Dresden	01/2011
Technical University of Dresden	01/2011, 05/2011 06/2011, 08/2011

2010

Umweltinstitut Neumarkt	12/2010
YIT Austria, Vienna, Austria	12/2010
MCI Innsbruck, Austria	12/2010
University of Stuttgart	12/2010
HS Cooler, Wittenburg	12/2010
Visteon, Novi Jicin, Czech Republic	12/2010
CompuWave, Brunntal	12/2010
Stadtwerke Leipzig	12/2010
MCI Innsbruck, Austria	12/2010

EVONIK Energy Services, Zwingenberg	12/2010
Caliqua, Basel, Switzerland	11/2010
Shanghai New Energy Resources Science & Technology, China	11/2010
Energieversorgung Halle	11/2010
Hochschule für Technik Stuttgart, University of Applied Sciences	11/2010
Steinmueller, Berlin	11/2010
Amberg-Weiden University of Applied Sciences	11/2010
AREVA NP, Erlangen	10/2010
MAN Diesel, Augsburg	10/2010
KRONES, Neutraubling	10/2010
Vaillant, Remscheid	10/2010
PC Ware, Leipzig	10/2010
Schubert Consulting Engineers, Weißenberg	10/2010
Fraunhofer Institut UMSICHT, Oberhausen	10/2010
Behringer Consulting Engineers, Tagmersheim	09/2010
Saacke, Bremen	09/2010
WEBASTO, Neubrandenburg	09/2010
Concordia University, Montreal, Canada	09/2010
Compañía Eléctrica de Sochagota, Bogota, Colombia	08/2010
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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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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
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Siemens Energy, Nuremberg	02/2010
Augsburg University of Applied Sciences	02/2010

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

2009

ALSTOM Power, Baden, Schweiz	01/2009, 03/2009
	05/2009
Nordostschweizerische Kraftwerke AG, Doettingen, Switzerland	02/2009
RWE, Neurath	02/2009
Brandenburg University of Technology, Cottbus	02/2009
Hamburg University of Applied Sciences	02/2009
Kehrein, Moers	03/2009
EPP Software, Marburg	03/2009
Bernd Münstermann, Telgte	03/2009
Suedzucker, Zeitz	03/2009
CPP, Marburg	03/2009
Gelsenkirchen University of Applied Sciences	04/2009
Regensburg University of Applied Sciences	05/2009
Gatley & Associates, Atlanta, USA	05/2009
BOSCH, Stuttgart	06/2009, 07/2009
Dr. Nickolay, Consulting Engineers, Gommersheim	06/2009
Ferrostal Power, Saarlouis	06/2009
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Intraserv, Wiesbaden	06/2009
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Nuernberg University of Applied Sciences	06/2009
Technical University of Berlin	06/2009
Fraunhofer Institut UMSICHT, Oberhausen	07/2009
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Techsoft, Linz, Austria	08/2009
DLR, Stuttgart	08/2009
Wienstrom, Vienna, Austria	08/2009
RWTH Aachen University	09/2009
Vattenfall, Hamburg	10/2009
AIC, Chemnitz	10/2009
Midiplan, Bietigheim-Bissingen	11/2009
Institute of Air Handling and Refrigeration ILK, Dresden	11/2009
FZD, Rossendorf	11/2009
Techgroup, Ratingen	11/2009
Robert Sack, Heidelberg	11/2009
EC, Heidelberg	11/2009

MCI, Innsbruck, Austria	12/2009
Saacke, Bremen	12/2009
ENERKO, Aldenhoven	12/2009

2008

Pink, Langenwang	01/2008
Fischer-Uhrig, Berlin	01/2008
University of Karlsruhe	01/2008
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Lentjes, Ratingen	03/2008
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CFC Solutions, Munich	04/2008
RWE IT, Essen	04/2008
Rerum Cognitio, Zwickau	04/2008, 05/2008
ARUP, Berlin	05/2008
Research Center, Karlsruhe	07/2008
AWECO, Neukirch	07/2008
Technical University of Dresden, Professorship of Building Services	07/2008
Technical University of Cottbus, Chair in Power Plant Engineering	07/2008, 10/2008
Ingersoll-Rand, Unicov, Czech Republic	08/2008
Technip Benelux BV, Zoetermeer, Netherlands	08/2008
Fennovoima Oy, Helsinki, Finland	08/2008
Fichtner Consulting & IT, Stuttgart	09/2008
PEU, Espenhain	09/2008
Poyry, Dresden	09/2008
WINGAS, Kassel	09/2008
TUEV Sued, Dresden	10/2008
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	10/2008, 11/2008
AWTEC, Zurich, Switzerland	11/2008
Siemens Power Generation, Erlangen	12/2008

2007

Audi, Ingolstadt	02/2007
ANO Abfallbehandlung Nord, Bremen	02/2007
TUEV NORD SysTec, Hamburg	02/2007
VER, Dresden	02/2007
Technical University of Dresden, Chair in Jet Propulsion Systems	02/2007
Redacom, Nidau, Switzerland	02/2007
Universität der Bundeswehr, Munich	02/2007
Maxxtec, Sinsheim	03/2007
University of Rostock, Chair in Technical Thermodynamics	03/2007

AGO, Kulmbach	03/2007
University of Stuttgart, Chair in Aviation Propulsions	03/2007
Siemens Power Generation, Duisburg	03/2007
ENTHAL Haustechnik, Rees	05/2007
AWECO, Neukirch	05/2007
ALSTOM, Rugby, Great Britain	06/2007
SAAS, Possendorf	06/2007
Grenzebach BSH, Bad Hersfeld	06/2007
Reichel Engineering, Haan	06/2007
Technical University of Cottbus, Chair in Power Plant Engineering	06/2007
Voith Paper Air Systems, Bayreuth	06/2007
Egger Holzwerkstoffe, Wismar	06/2007
Tissue Europe Technologie, Mannheim	06/2007
Dometic, Siegen	07/2007
RWTH Aachen University, Institute for Electrophysics	09/2007
National Energy Technology Laboratory, Pittsburg, USA	10/2007
Energieversorgung Halle	10/2007
AL-KO, Jettingen	10/2007
Grenzebach BSH, Bad Hersfeld	10/2007
Wiesbaden University of Applied Sciences, Department of Engineering Sciences	10/2007
Endress+Hauser Messtechnik, Hannover	11/2007
Munich University of Applied Sciences, Department of Mechanical Engineering	11/2007
Rerum Cognitio, Zwickau	12/2007
Siemens Power Generation, Erlangen	11/2007
University of Rostock, Chair in Technical Thermodynamics	11/2007, 12/2007

2006

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

Siemens Power Generation, Goerlitz	04/2006
Technical University of Braunschweig, Department of Thermodynamics	04/2006
EnviCon & Plant Engineering, Nuremberg	04/2006
Brassel Engineering, Dresden	05/2006
University of Halle-Merseburg, Department of USET Merseburg incorporated society	05/2006
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	05/2006
Fichtner Consulting & IT Stuttgart (company licenses and distribution)	05/2006
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ThyssenKrupp Marine Systems, Kiel	07/2006
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Konstanz University of Applied Sciences, Course of Studies Construction and Development	10/2006
Siemens Power Generation, Duisburg	10/2006
Hannover University of Applied Sciences, Department of Mechanical Engineering	10/2006
Siemens Power Generation, Berlin	11/2006
Zikesch Armaturentechnik, Essen	11/2006
Wismar University of Applied Sciences, Seafaring Department	11/2006
BASF, Schwarzheide	12/2006
Enertech Energie und Technik, Radebeul	12/2006

2005

TUEV Nord, Hannover	01/2005
J.H.K Plant Engineering and Service, Bremerhaven	01/2005
Electrowatt-EKONO, Zurich, Switzerland	01/2005
FCIT, Stuttgart	01/2005
Energietechnik Leipzig (company license)	02/2005, 04/2005 07/2005
eta Energieberatung, Pfaffenhofen	02/2005
FZR Forschungszentrum, Rossendorf/Dresden	04/2005
University of Saarbruecken	04/2005
Technical University of Dresden Professorship of Thermic Energy Machines and Plants	04/2005
Grenzebach BSH, Bad Hersfeld	04/2005
TUEV Nord, Hamburg	04/2005
Technical University of Dresden, Waste Management	05/2005
Siemens Power Generation, Goerlitz	05/2005
Duesseldorf University of Applied Sciences, Department of Mechanical Engineering and Process Engineering	05/2005
Redacom, Nidau, Switzerland	06/2005

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

2004

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

Freudenberg Service, Weinheim	12/2004

2003

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

2002

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

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Stadtwerke Duisburg	08/2002
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Siemens Power Generation, Goerlitz	10/2002
Energieversorgung Halle (company license)	10/2002
Bayer, Leverkusen	11/2002
Dillinger Huette, Dillingen	11/2002
G.U.N.T. Geraetebau, Barsbuettel	12/2002
(general license and training test benches)	
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2001

ALSTOM Power, Baden, Switzerland	01/2001, 06/2001
	12/2001
KW2 B. V., Amersfoot, Netherlands	01/2001, 11/2001
Eco Design, Saitamaken, Japan	01/2001
M&M Turbine Technology, Bielefeld	01/2001, 09/2001
MVV Energie, Mannheim	02/2001
Technical University of Dresden, Department of	02/2001
Power Machinery and Plants	
PREUSSAG NOELL, Wuerzburg	03/2001
Fichtner Consulting & IT Stuttgart	04/2001
(company licenses and distribution)	
Muenstermann GmbH, Telgte-Westbevern	05/2001
SaarEnergie, Saarbruecken	05/2001
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Neusiedler AG, Ulmerfeld, Austria	09/2001
h s energieanlagen, Freising	09/2001
Electrowatt-EKONO, Zurich, Switzerland	09/2001
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ALSTOM Power Baden, Switzerland	12/2001

VEAG, Berlin (group license)	12/2001

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PREUSSAG NOELL, Wuerzburg	01/2000
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GK, Hannover	03/2000
KRUPP-UHDE, Dortmund (company license)	03/2000
UMAG W. UDE, Husum	03/2000
VEAG, Berlin (group license)	03/2000
Thinius Engineering, Erkrath	04/2000
SaarEnergie, Saarbruecken	05/2000, 08/2000
DVO Data Processing Service, Oberhausen	05/2000
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VAUP Process Automation, Landau	08/2000
Knuerr-Lommatec, Lommatzsch	09/2000
AVACON, Helmstedt	10/2000
Compania Electrica, Bogota, Colombia	10/2000
G.U.N.T. Geraetebau, Barsbuettel (general license for training test benches)	11/2000
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1999

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

1998

Technical University of Cottbus, Chair in Power Plant Engineering	05/1998
Fichtner Consulting & IT (CADIS information systems) Stuttgart (general KPRO program license)	05/1998
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B+H Software Engineering Stuttgart	08/1998
Alfa Engineering, Switzerland	09/1998
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SCA Hygiene Products, Munich	10/1998

RWE Energie, Neurath	10/1998
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BASF, Ludwigshafen (group license)	11/1998
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1997

Gerb, Dresden	06/1997
Siemens Power Generation, Goerlitz	07/1997