User's Guide

for

LibHuAirProp

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

FluidEXL for Excel®

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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ISBN 978-1-933742-74-8

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?

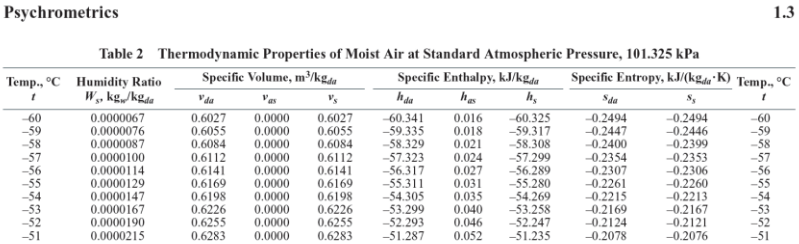
► thermodynamic properties psychrometric functions ◄
► transport properties backward functions ◄

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

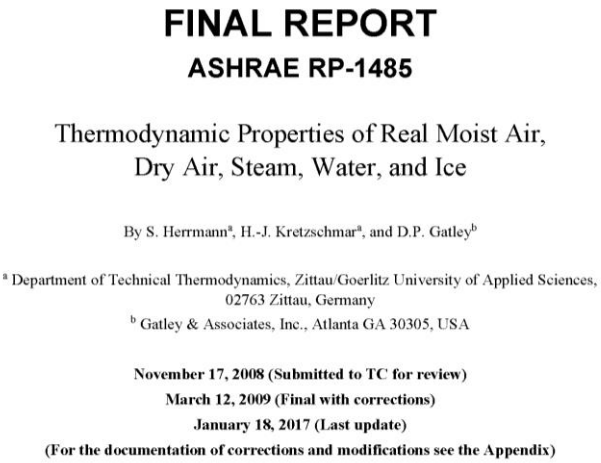


Psychrometrics 1.3

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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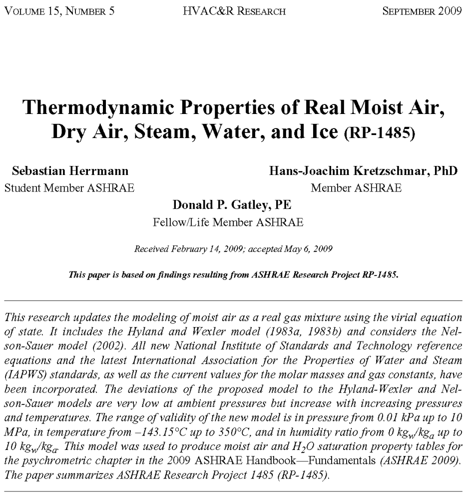
November 17, 2008 (Submitted to TC for review)
March 12, 2009 (Final with corrections)
January 18, 2017 (Last update)
(For the documentation of corrections and modifications see the Appendix)



VOLUME 15, NUMBER 5 HVAC&R RESEARCH SEPTEMBER 2009

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

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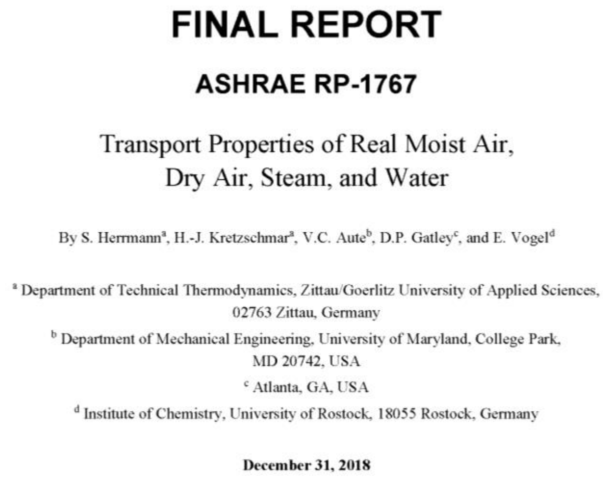
Received February 14, 2009; accepted May 6, 2009

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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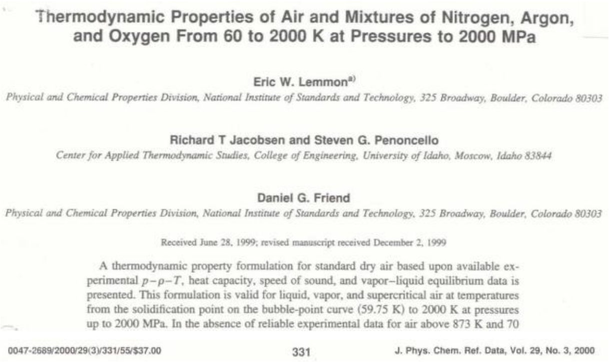
December 31, 2018

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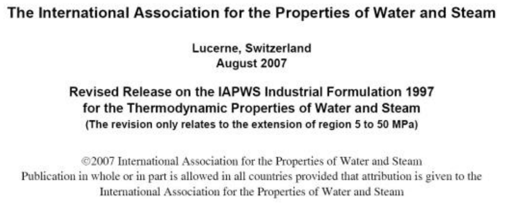
Received June 28, 1999; revised manuscript received December 2, 1999

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)

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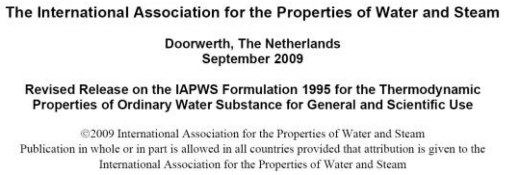

The International Association for the Properties of Water and Steam

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

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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 Microsoft Office®

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

ZIP file "CD_FluidEXL_ASHRAE_LibHuAirProp.zip" for Excel®

The ZIP file contains the following files:

FluidEXL_ASHRAE_LibHuAirProp_Setup.exe	Installation program for the FluidEXL^{Graphics} Add-In for use in Excel®
FluidEXL_ASHRAE_LibHuAirProp_ Users_Guide.pdf	User's Guide

0.2 Add-Ins for 64-bit version of Microsoft Office®

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ZIP file "CD_FluidEXL_ASHRAE_LibHuAirProp_x64.zip" for Excel®

The ZIP file contains the following files and folders:

FluidEXL_ASHRAE_LibHuAirProp_Users_Guide.pdf	User's Guide
FluidEXL_ASHRAE_LibHuAirProp_64_Setup.msi	Self-extracting and self-installing program
setup.exe	Installation program for the FluidEXL^{Graphics} Add-In for use in Excel®
vcredist_x64	Folder containing the "Microsoft Visual C++ 2010 x64 Redistributable Pack"
WindowsInstaller3_1	Folder containing the "Microsoft Windows Installer"

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	ft^2/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/ft^3	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	Btu/lb$_\mathrm{a}$	3/9
$\eta = \mathrm{f}(p,t,W)$	Eta_ptW_HAP_IP	Dynamic viscosity	lb·s/ft^2	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	ft^2/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	Btu/(lb·°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	$\mathrm{lb_w/lb_a}$	3/37
$W_{\mathrm{s}} = \mathrm{f}(p,t)$	Ws_pt_HAP_IP	Saturation humidity ratio	$\mathrm{lb_w/lb_a}$	3/38
$\xi_{\mathrm{Air}} = \mathrm{f}(W)$	XiAir_W_HAP_IP	Mass fraction of dry air in moist air	$\mathrm{lb_a/lb}$	3/39
$\xi_{\mathrm{H2O}} = \mathrm{f}(W)$	XiH2O_W_HAP_IP	Mass fraction of water vapor in moist air	$\mathrm{lb_w/lb}$	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**
$h_{\mathrm{liq}} = \mathrm{f}(p,t)$	hliq_pt_97_IP	Specific enthalpy of liquid water	Btu/lb	3/43
$h_{\mathrm{liq,s}} = \mathrm{f}(t)$	hliqs_t_97_IP	Specific enthalpy of saturated liquid water	Btu/lb	3/44
$h_{\mathrm{vap,s}} = \mathrm{f}(t)$	hvaps_t_97_IP	Specific enthalpy of saturated water vapor	Btu/lb	3/45
$p_{\mathrm{s}} = \mathrm{f}(t)$	ps_t_97_IP	Saturation pressure of water	psi	3/46
$s_{\mathrm{liq}} = \mathrm{f}(p,t)$	sliq_pt_97_IP	Specific entropy of liquid water	Btu/(lb·°R)	3/47
$s_{\mathrm{liq,s}} = \mathrm{f}(t)$	sliqs_t_97_IP	Specific entropy of saturated liquid water	Btu/(lb·°R)	3/48
$s_{\mathrm{vap,s}} = \mathrm{f}(t)$	svaps_t_97_IP	Specific entropy of saturated water vapor	Btu/(lb·°R)	3/49
$t_{\mathrm{s}} = \mathrm{f}(p)$	ts_p_97_IP	Saturation temperature of water	°F	3/50
$v_{\mathrm{liq}} = \mathrm{f}(p,t)$	vliq_pt_97_IP	Specific volume of liquid water	ft³/lb	3/51
$v_{\mathrm{liq,s}} = \mathrm{f}(t)$	vliqs_t_97_IP	Specific volume of saturated liquid water	ft³/lb	3/52
$v_{\mathrm{vap,s}} = \mathrm{f}(t)$	vvaps_t_97_IP	Specific volume of saturated water vapor	ft³/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 $t \le 32°\mathrm{F}$

Functional Dependence	Function Name	Property	Unit of the Result	Page
$h_{\mathrm{ice,sub}} = \mathrm{f}(t)$	hicesub_t_06_IP	Specific enthalpy of saturated ice	Btu/lb	3/55
$h_{\mathrm{vap,sub}} = \mathrm{f}(t)$	hvapsub_t_95_IP	Specific enthalpy of saturated water vapor	Btu/lb	3/56
$p_{\mathrm{mel}} = \mathrm{f}(t)$	pmel_t_08_IP	Melting pressure of ice	psi	3/57
$p_{\mathrm{sub}} = \mathrm{f}(t)$	psub_t_08_IP	Sublimation pressure of ice	psi	3/58
$s_{\mathrm{ice,sub}} = \mathrm{f}(t)$	sicesub_t_06_IP	Specific entropy of saturated ice	Btu/(lb·°R)	3/59
$s_{\mathrm{vap,sub}} = \mathrm{f}(t)$	svapsub_t_95_IP	Specific entropy of saturated water vapor	Btu/(lb·°R)	3/60
$t_{\mathrm{mel}} = \mathrm{f}(p)$	tmel_p_08_IP	Melting temperature of ice	°F	3/61
$t_{\mathrm{sub}} = \mathrm{f}(p)$	tsub_p_08_IP	Sublimation temperature of ice	°F	3/62
$v_{\mathrm{ice,sub}} = \mathrm{f}(t)$	vicesub_t_06_IP	Specific volume of saturated ice	ft³/lb	3/63
$v_{\mathrm{vap,sub}} = \mathrm{f}(t)$	vvapsub_t_95_IP	Specific volume of saturated water vapor	ft³/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	$\frac{a_{\mathrm{IP}}}{\frac{\mathrm{ft^2}}{\mathrm{s}}} = \frac{a_{\mathrm{SI}}}{\frac{\mathrm{m^2}}{\mathrm{s}}} \times 10.76391042$	$\frac{a_{\mathrm{SI}}}{\frac{\mathrm{m^2}}{\mathrm{s}}} = \frac{a_{\mathrm{IP}}}{\frac{\mathrm{ft^2}}{\mathrm{s}}} \times 0.0929304$	m²/s	ft²/s
Relative pressure coefficient	α_p	$\frac{\alpha_{p,\mathrm{IP}}}{\frac{1}{\mathrm{°R}}} = \frac{\alpha_{p,\mathrm{SI}}}{\frac{1}{\mathrm{K}}} \times \frac{9}{5}$	$\frac{\alpha_{p,\mathrm{SI}}}{\frac{1}{\mathrm{K}}} = \frac{\alpha_{p,\mathrm{IP}}}{\frac{1}{\mathrm{°R}}} \times \frac{5}{9}$	1/K	1/°R
Isothermal stress coefficient	β_p	$\frac{\beta_{p,\mathrm{IP}}}{\frac{\mathrm{lb}}{\mathrm{ft^3}}} = \frac{\beta_{p,\mathrm{SI}}}{\frac{\mathrm{kg}}{\mathrm{m^3}}} \times 0.062428$	$\frac{\beta_{p,\mathrm{SI}}}{\frac{\mathrm{kg}}{\mathrm{m^3}}} = \frac{\beta_{p,\mathrm{IP}}}{\frac{\mathrm{lb}}{\mathrm{ft^3}}} \times 16.018463$	kg/m³	lb/ft³
Speed of sound	c	$\frac{c_{\mathrm{IP}}}{\frac{\mathrm{ft}}{\mathrm{s}}} = \frac{c_{\mathrm{SI}}}{\frac{\mathrm{m}}{\mathrm{s}}} \times 3.2808399$	$\frac{c_{\mathrm{SI}}}{\frac{\mathrm{m}}{\mathrm{s}}} = \frac{c_{\mathrm{IP}}}{\frac{\mathrm{ft}}{\mathrm{s}}} \times 0.3048$	m/s	ft/s
Specific isobaric heat capacity	c_p	$\frac{c_{p,\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb\ °R}}} = \frac{c_{p,\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg\ K}}} \times 0.2388459$	$\frac{c_{p,\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg\ K}}} = \frac{c_{p,\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb\ °R}}} \times 4.1868$	kJ/(kg·K)	Btu/(lb·°R)
Specific isochoric heat capacity	c_v	$\frac{c_{v,\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb\ °R}}} = \frac{c_{v,\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg\ K}}} \times 0.2388459$	$\frac{c_{v,\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg\ K}}} = \frac{c_{v,\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb\ °R}}} \times 4.1868$	kJ/(kg·K)	Btu/(lb·°R)
Dynamic viscosity	η	$\frac{\eta_{\mathrm{IP}}}{\frac{\mathrm{lb\ s}}{\mathrm{ft^2}}} = \frac{\eta_{\mathrm{SI}}}{\frac{\mathrm{Pa}}{\mathrm{s}}} \times 0.02088543$	$\frac{\eta_{\mathrm{SI}}}{\frac{\mathrm{Pa}}{\mathrm{s}}} = \frac{\eta_{\mathrm{IP}}}{\frac{\mathrm{lb\ s}}{\mathrm{ft^2}}} \times 47.880259$	Pa·s	lb·s/ft²
Enhancement factor	f	$f_{\mathrm{IP}} = f_{\mathrm{SI}}$	$f_{\mathrm{SI}} = f_{\mathrm{IP}}$	-	-

Property		Conversion: SI Units → I-P Units	Conversion: I-P Units → SI Units	Units SI	Units I-P
Air-specific enthalpy (moist air)	h	$\frac{h_{\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb_a}}} = \frac{h_{\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg_a}}} \times 0.4299226 + 7.68565365666$	$\frac{h_{\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg_a}}} = \left(\frac{h_{\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb_a}}} - 7.68565365666 \right) \times 2.326$	kJ/kg$_a$	Btu/lb$_a$
Specific enthalpy (water, water vapor, ice)	h_w	$\frac{h_{\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb}}} = \frac{h_{\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg}}} \times 0.4299226$	$\frac{h_{\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg}}} = \frac{h_{\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb}}} \times 2.326$	kJ/kg	Btu/lb
Isentropic exponent	κ	$\kappa_{\mathrm{IP}} = \kappa_{\mathrm{SI}}$	$\kappa_{\mathrm{SI}} = \kappa_{\mathrm{IP}}$	-	-
Thermal conductivity	λ	$\frac{\lambda_{\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{h\ ft\ °R}}} = \frac{\lambda_{\mathrm{SI}}}{\frac{\mathrm{W}}{\mathrm{m\ K}}} \times 0.57778932$	$\frac{\lambda_{\mathrm{SI}}}{\frac{\mathrm{W}}{\mathrm{m\ K}}} = \frac{\lambda_{\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{h\ ft\ °R}}} \times 1.73073467$	W/(m·K)	Btu/(h·ft·°R)
Kinematic viscosity	ν	$\frac{\nu_{\mathrm{IP}}}{\frac{\mathrm{ft^2}}{\mathrm{s}}} = \frac{\nu_{\mathrm{SI}}}{\frac{\mathrm{m^2}}{\mathrm{s}}} \times 10.763910417$	$\frac{\nu_{\mathrm{SI}}}{\frac{\mathrm{m^2}}{\mathrm{s}}} = \frac{\nu_{\mathrm{IP}}}{\frac{\mathrm{ft^2}}{\mathrm{s}}} \times 0.092903040$	m²/s	ft²/s
Pressure	p	$\frac{p_{\mathrm{IP}}}{\mathrm{psi}} = \frac{p_{\mathrm{SI}}}{\mathrm{kPa}} \times 0.14503774$	$\frac{p_{\mathrm{SI}}}{\mathrm{kPa}} = \frac{p_{\mathrm{IP}}}{\mathrm{psi}} \times 6.894757$	kPa	psi
Relative humidity	φ	$\varphi_{\mathrm{IP}} = \varphi_{\mathrm{SI}}$	$\varphi_{\mathrm{SI}} = \varphi_{\mathrm{IP}}$	-	-
Prandtl number	Pr	$Pr_{\mathrm{IP}} = Pr_{\mathrm{IP}}$	$Pr_{\mathrm{SI}} = Pr_{\mathrm{IP}}$	-	-
Mole fraction	ψ	$\psi_{\mathrm{IP}} = \psi_{\mathrm{SI}}$	$\psi_{\mathrm{SI}} = \psi_{\mathrm{IP}}$	mol/mol	mol/mol
Density	ρ	$\frac{\rho_{\mathrm{IP}}}{\frac{\mathrm{lb}}{\mathrm{ft^3}}} = \frac{\rho_{\mathrm{SI}}}{\frac{\mathrm{kg}}{\mathrm{m^3}}} \times 0.062428$	$\frac{\rho_{\mathrm{SI}}}{\frac{\mathrm{kg}}{\mathrm{m^3}}} = \frac{\rho_{\mathrm{IP}}}{\frac{\mathrm{lb}}{\mathrm{ft^3}}} \times 16.018463$	kg/m³	lb/ft³
Air-specific entropy (moist air)	s	$\frac{s_{\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb_a\ °R}}} = \frac{s_{\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg_a\ K}}} \times 0.2388459 + 0.01616365106$	$\frac{s_{\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg_a\ K}}} = \left(\frac{s_{\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb_a\ °R}}} - 0.01616365106 \right) \times 4.1868$	kJ/(kg$_a$·K)	Btu/(lb$_a$·°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	$\frac{s_\mathrm{IP}}{\frac{\mathrm{Btu}}{\mathrm{lb_a\ °R}}} = \frac{s_\mathrm{SI}}{\frac{\mathrm{kJ}}{\mathrm{kg_a\ K}}} \times 0.23884589$	$\frac{s_\mathrm{SI}}{\frac{\mathrm{kJ}}{\mathrm{kg_a\ K}}} = \frac{s_\mathrm{IP}}{\frac{\mathrm{Btu}}{\mathrm{lb_a\ °R}}} \times 4.1868$	$\mathrm{kJ/(kg_a{\cdot}K)}$	$\mathrm{Btu/(lb_a{\cdot}°R)}$
Temperature t	$\frac{t_\mathrm{IP}}{\mathrm{°F}} = \frac{t_\mathrm{SI}}{\mathrm{°C}} \times \frac{9}{5} + 32$	$\frac{t_\mathrm{SI}}{\mathrm{°C}} = \left(\frac{t_\mathrm{IP}}{\mathrm{°F}} - 32\right) \times \frac{5}{9}$	°C	°F
Air-specific internal energy (moist air) u	$(u = h - pv)$ $\frac{u_\mathrm{IP}}{\frac{\mathrm{Btu}}{\mathrm{lb_a}}} = \frac{h_\mathrm{SI}}{\frac{\mathrm{kJ}}{\mathrm{kg_a}}} \times 0.4299226 + 7.68565365666 - \frac{p_\mathrm{SI}}{\mathrm{kPa}} \times 0.145037738 \cdot \frac{v_\mathrm{SI}}{\frac{\mathrm{m^3}}{\mathrm{kg_a}}} \times 16.018453$	$(u = h - pv)$ $\frac{u_\mathrm{SI}}{\frac{\mathrm{kJ}}{\mathrm{kg_a}}} = \left(\frac{h_\mathrm{IP}}{\frac{\mathrm{Btu}}{\mathrm{lb_a}}} - 7.68565365666\right) \times 2.236 - \frac{p_\mathrm{IP}}{\mathrm{psi}} \times 6.894757293 \cdot \frac{v_\mathrm{SIP}}{\frac{\mathrm{ft^3}}{\mathrm{lb_a}}} \times 0.062428$	$\mathrm{kJ/kg_a}$	Btu/lb
Air-specific volume (moist air) v	$\frac{v_\mathrm{IP}}{\frac{\mathrm{ft^3}}{\mathrm{lb_a}}} = \frac{v_\mathrm{SI}}{\frac{\mathrm{m^3}}{\mathrm{kg_a}}} \times 16.018453$	$\frac{v_\mathrm{SI}}{\frac{\mathrm{m^3}}{\mathrm{kg_a}}} = \frac{v_\mathrm{IP}}{\frac{\mathrm{ft^3}}{\mathrm{lb_a}}} \times 0.062428$	$\mathrm{m^3/kg_a}$	$\mathrm{ft^3/lb_a}$
Specific volume (water, water vapor, ice) v_w	$\frac{v_\mathrm{IP}}{\frac{\mathrm{ft^3}}{\mathrm{lb}}} = \frac{v_\mathrm{SI}}{\frac{\mathrm{m^3}}{\mathrm{kg}}} \times 16.018453$	$\frac{v_\mathrm{SI}}{\frac{\mathrm{m^3}}{\mathrm{kg}}} = \frac{v_\mathrm{IP}}{\frac{\mathrm{ft^3}}{\mathrm{lb}}} \times 0.062428$	$\mathrm{m^3/kg}$	$\mathrm{ft^3/lb}$
Humidity ratio W	$W_\mathrm{IP} = W_\mathrm{SI}$	$W_\mathrm{SI} = W_\mathrm{IP}$	$\mathrm{kg_w/kg_a}$	$\mathrm{lb_w/lb_a}$
Mass fraction ξ	$\xi_\mathrm{IP} = \xi_\mathrm{SI}$	$\xi_\mathrm{SI} = \xi_\mathrm{IP}$	$\mathrm{kg_w/kg}$	$\mathrm{lb_w/lb}$
Compression factor Z	$Z_\mathrm{IP} = Z_\mathrm{SI}$	$Z_\mathrm{SI} = Z_\mathrm{IP}$	-	-

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, Kretzschmar, Aute, Gatley, and Vogel [3], [4].

1.3.2 Algorithms for Steam and Water for Temperatures *t* ≥ 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* ≤ 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.

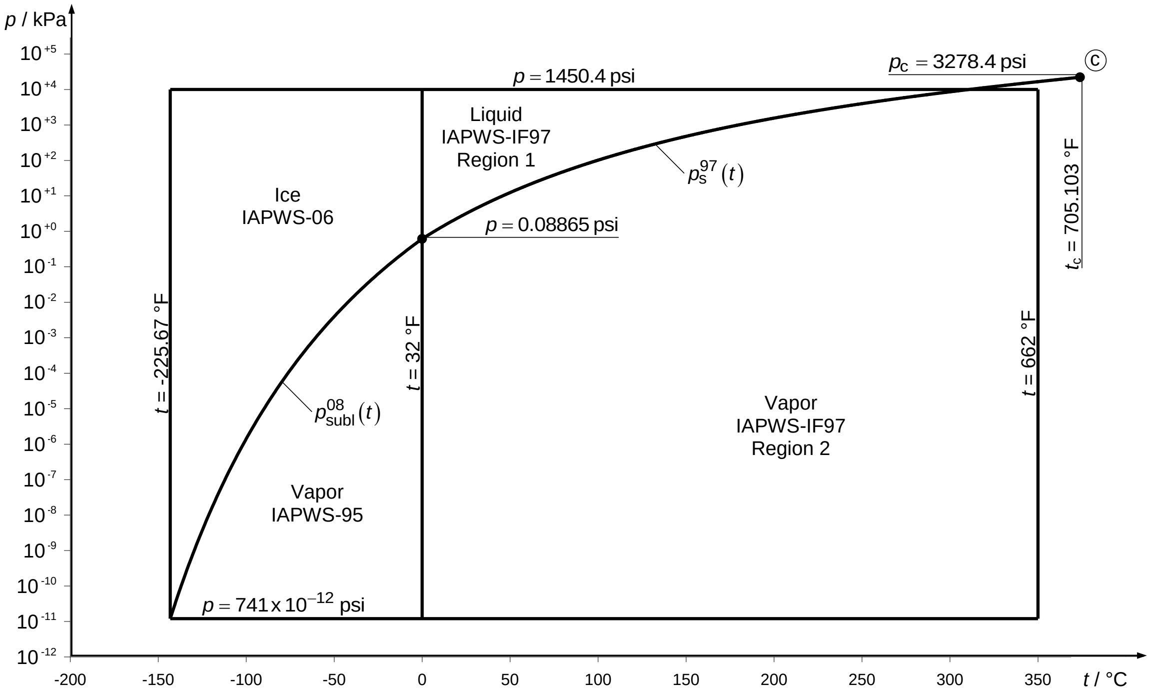


Figure 1: *p*-*T* diagram with used IAPWS formulations for steam, water, and ice.

2 Add-In FluidEXL^{Graphics} for Excel® for ASHRAE-LibHuAirProp-IP

2.1 Installing FluidEXL^{Graphics} for Excel®

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

2.1.1 Installing FluidEXL^{Graphics} including LibHuAirProp

In this section, the installation of FluidEXL^{Graphics} and both LibHuAirProp_IP and LibHuAirProp_SI is described.

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

The installation routine for **32-bit** and **64-bit** versions of **MS Excel** is similar. The following instructions are valid for both versions.

After you have downloaded and extracted the zip-file

for 64-bit version of Excel:

"CD_FluidEXL_ASHRAE_LibHuAirProp_x64.zip"

for 32-bit version of Excel:

" CD_FluidEXL_ASHRAE_LibHuAirProp.zip"

you will see the folder

for 64-bit version of Excel:

\ CD_FluidEXL_ASHRAE_LibHuAirProp_x64

for 32-bit version of Excel:

\CD_FluidEXL_ASHRAE_LibHuAirProp

in your Windows Explorer, Norton Commander or any other similar program you may be using.

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

Within this folder you will see the following files:

FluidEXL_ASHRAE_LibHuAirProp_Users_Guide.pdf	
FluidEXL_ASHRAE_LibHuAirProp_64_Setup.msi	(for 64-bit version of Excel)
FluidEXL_ASHRAE_LibHuAirProp_Setup.msi	(for 32-bit version of Excel)
setup.exe	

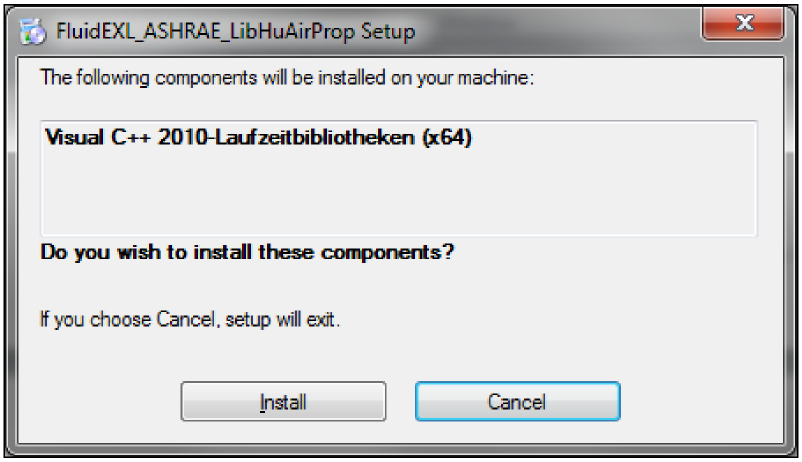
and the folders

vcredist_x64
WindowsInstaller3_1.

In order to run the installation of FluidEXL^{Graphics} including the ASHRAE-LibHuAirProp-IP and ASHRAE-LibHuAirProp-SI property library, double-click on the file

setup.exe.

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



The following components will be installed on your machine:

Visual C++ 2010-Laufzeitbibliotheken (x64)

Do you wish to install these components?

If you choose Cancel, setup will exit.

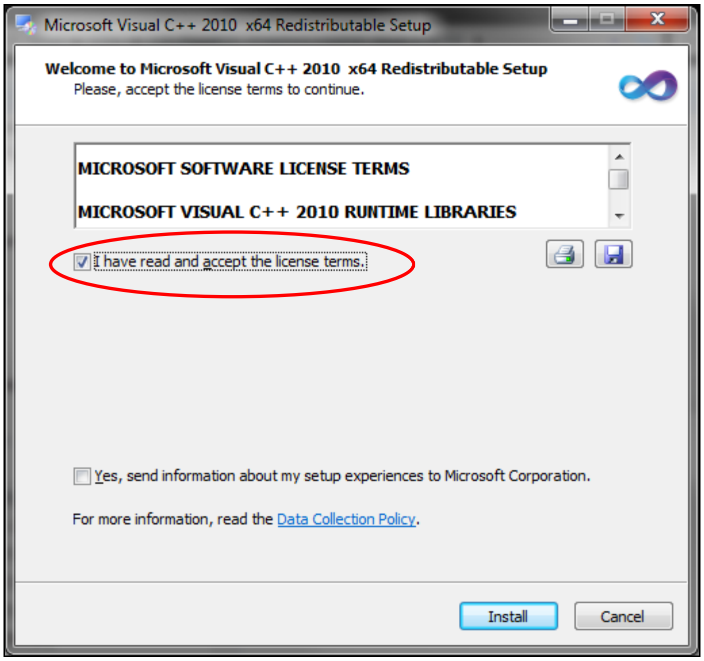
Figure 2.1.1: Installing the "Visual C++ 2010 runtime library"

Click on "Install" to continue.

The installer will now automatically download the required files from the Internet. Should this not happen, you can use the following link to download the relevant file:

for 64-bit version of Windows
https://www.microsoft.com/en-us/download/details.aspx?id=14632
for 32-bit version of Windows
https://www.microsoft.com/en-us/download/details.aspx?id=5555

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



Welcome to Microsoft Visual C++ 2010 x64 Redistributable Setup
Please, accept the license terms to continue.

MICROSOFT SOFTWARE LICENSE TERMS

MICROSOFT VISUAL C++ 2010 RUNTIME LIBRARIES

☑ I have read and accept the license terms.

☐ Yes, send information about my setup experiences to Microsoft Corporation.

For more information, read the Data Collection Policy.

Figure 2.1.2: Accepting the license terms

Now click on "Install" to continue installation.

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

Note.
If there is a newer version Visual C++ runtime library, setup.exe will stop and is followed by an error message. In this case please start the installation again by double-clicking the file

FluidEXL_ASHRAE_LibHuAirProp_64_Setup.msi	(for 64-bit version of Excel)
FluidEXL_ASHRAE_LibHuAirProp_Setup.msi	(for 32-bit version of Excel)

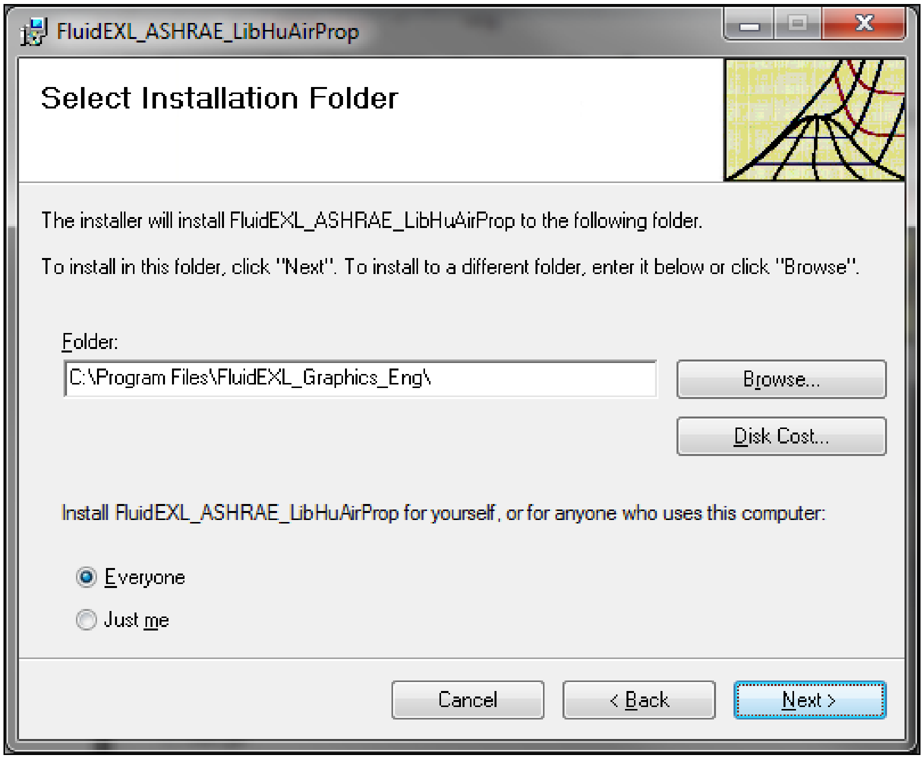
to install FluidEXL_ASHRAE_LibHuAirProp.

Now the installation of FluidEXL_ASHRAE_LibHuAirProp starts with a window noting that the installer will guide you through the installation. Click the "Next >" button to continue.

In the following dialog box, "Select Installation Folder," the default path offered automatically for the installation of FluidEXL^{Graphics} is

C:\Program Files\FluidEXL_Graphics_Eng	(for 64-bit version of Excel)
C:\Program Files (x86)\FluidEXL_Graphics_Eng	(for 32-bit version of Excel)

By clicking the "Browse…" button, you can change the installation directory before installation (see Figure 2.1.3).



Select Installation Folder

The installer will install FluidEXL_ASHRAE_LibHuAirProp to the following folder.

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

Folder: C:\Program Files\FluidEXL_Graphics_Eng\

Install FluidEXL_ASHRAE_LibHuAirProp for yourself, or for anyone who uses this computer:

● Everyone
○ Just me

Figure 2.1.3: Choosing the installation folder

Finally, click on "Next >" to continue installation; click "Next >" again in the "Confirm Installation" window which follows in order to start the installation of FluidEXL^{Graphics}.

After FluidEXL$^{\mathit{Graphics}}$ has been installed, you will see the sentence "FluidEXL_ASHRAE_LibHuAirProp has been successfully installed." Confirm this by clicking the "Close" button.

The installation of FluidEXL$^{\mathit{Graphics}}$ has been completed.

During the installation process the following files will have been copied into the chosen destination folder, the standard being

"C:\Program Files\FluidEXL_Graphics_Eng" for 64-bit version of Excel:

capt_ico_big.ico
FluidEXL_Graphics_Eng.xla
LCKCE.dll
LibHuAirProp_IP.dll
LibHuAirProp_IP.chm
LibHuAirProp_SI.dll
LibHuAirProp_SI.chm
libifcoremd.dll
libiomp5md.dll
libmmd.dll.

"C:\Program Files (x86)\FluidEXL_Graphics_Eng" for 32-bit version of Excel:

capt_ico_big.ico
FluidEXL_Graphics_Eng.xla
LCKCE.dll
LibHuAirProp_IP.dll
LibHuAirProp_IP.chm
advapi32.dll
Dformd.dll
Dforrt.dll
LibHuAirProp_SI.dll
LibHuAirProp_SI.chm
libifcoremd.dll
libiomp5md.dll
libmmd.dll.
msvcp60.dll
msvcrt.dll

2.1.2 Registering FluidEXL^{Graphics} as Add-In in Excel®

Registering FluidEXL^{Graphics} as an Add-In in versions of Excel® from 2007 onwards

(If you are running a version of Excel® from 2003 or earlier, please go straight to the instructions **Registering FluidEXL^{Graphics} as Add-In in Excel® versions 2003 or earlier).**

After installation in Windows®, FluidEXL^{Graphics} must be registered in Excel® versions 2007 and later as an Add-In. To do this, start Excel® and carry out the following steps:

- Click the "File" button in the upper left hand corner of Excel® (see Figure 2.1.4)

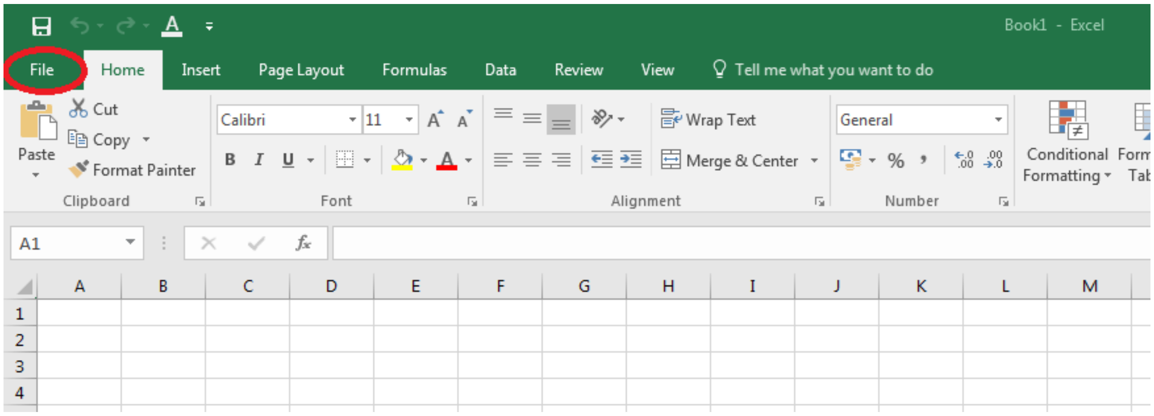


Figure 2.1.4: Registering FluidEXL^{Graphics} as Add-In in Excel® 2016

- Click on the "Options" button in the menu which appears (see Figure 2.1.5)

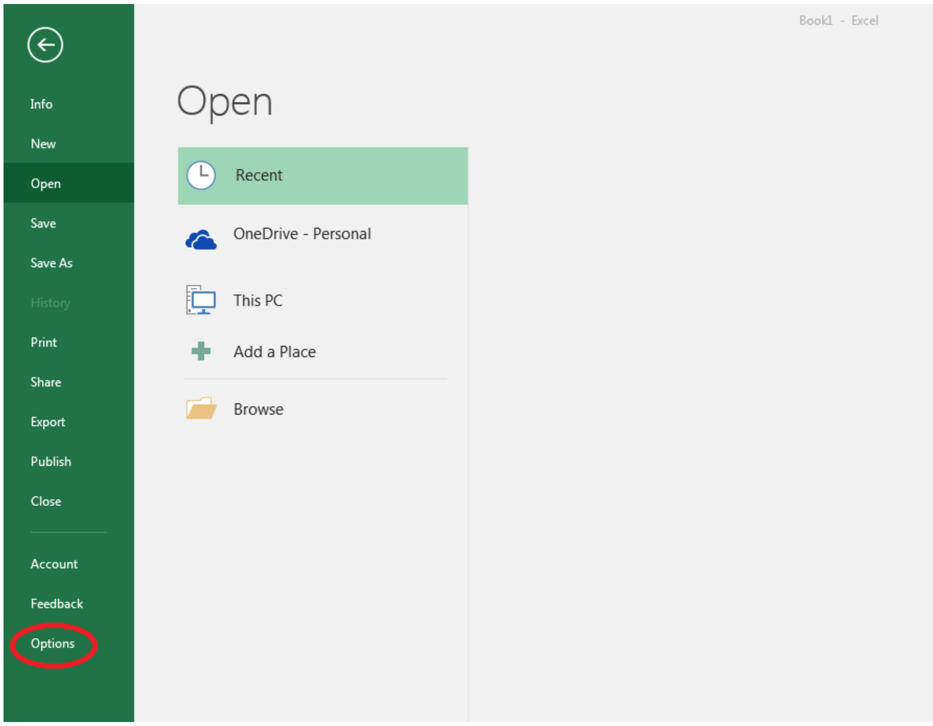
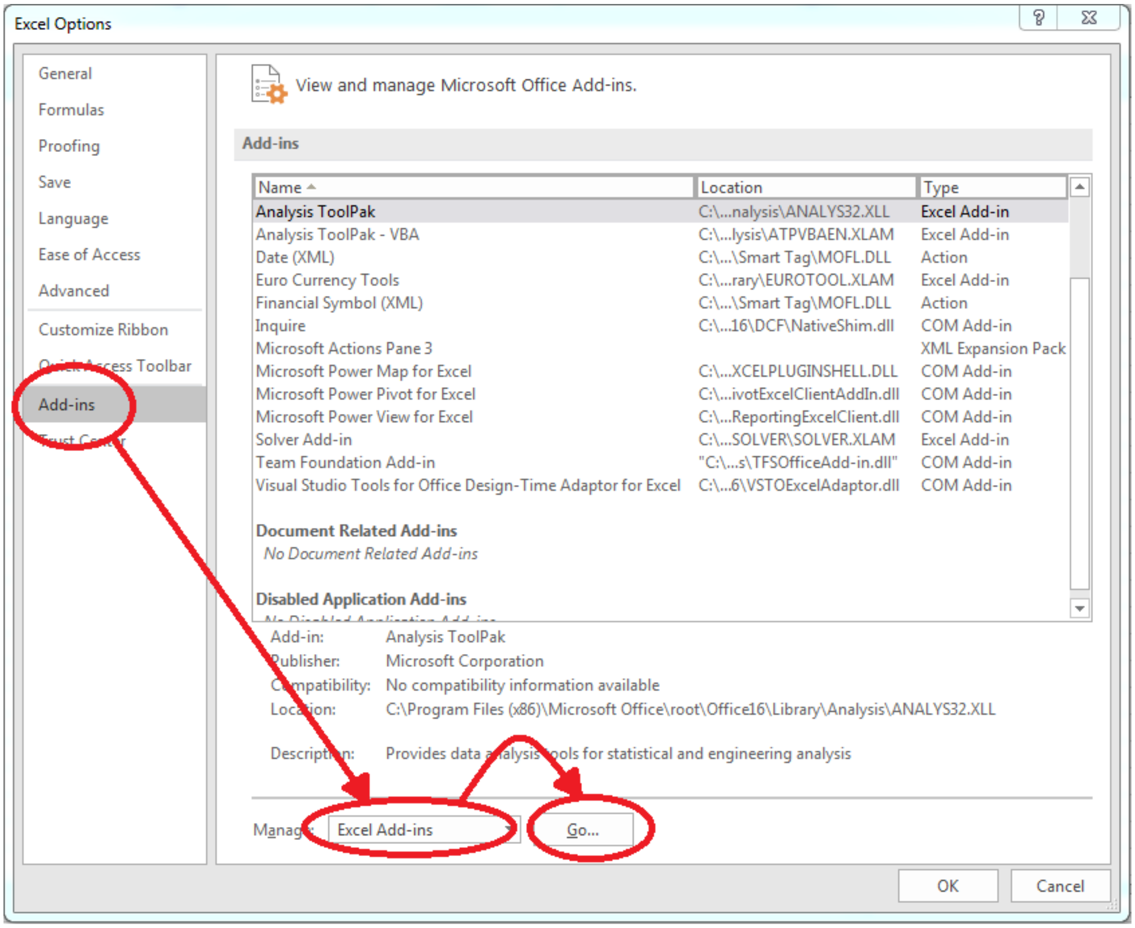


Figure 2.1.5: Registering FluidEXL^{Graphics} as Add-In in Excel® 2016

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



Name	Location	Type
Analysis ToolPak	C:\...nalysis\ANALYS32.XLL	Excel Add-in
Analysis ToolPak - VBA	C:\...lysis\ATPVBAEN.XLAM	Excel Add-in
Date (XML)	C:\...\Smart Tag\MOFL.DLL	Action
Euro Currency Tools	C:\...rary\EUROTOOL.XLAM	Excel Add-in
Financial Symbol (XML)	C:\...\Smart Tag\MOFL.DLL	Action
Inquire	C:\...16\DCF\NativeShim.dll	COM Add-in
Microsoft Actions Pane 3		XML Expansion Pack
Microsoft Power Map for Excel	C:\...XCELPLUGINSHELL.DLL	COM Add-in
Microsoft Power Pivot for Excel	C:\...ivotExcelClientAddIn.dll	COM Add-in
Microsoft Power View for Excel	C:\...ReportingExcelClient.dll	COM Add-in
Solver Add-in	C:\...SOLVER\SOLVER.XLAM	Excel Add-in
Team Foundation Add-in	"C:\...s\TFSOfficeAdd-in.dll"	COM Add-in
Visual Studio Tools for Office Design-Time Adaptor for Excel	C:\...6\VSTOExcelAdaptor.dll	COM Add-in

Document Related Add-ins

No Document Related Add-ins

Disabled Application Add-ins

Add-in: Analysis ToolPak
Publisher: Microsoft Corporation
Compatibility: No compatibility information available
Location: C:\Program Files (x86)\Microsoft Office\root\Office16\Library\Analysis\ANALYS32.XLL

Description: Provides data analysis tools for statistical and engineering analysis

Figure 2.1.6: Dialog window "Add-Ins"

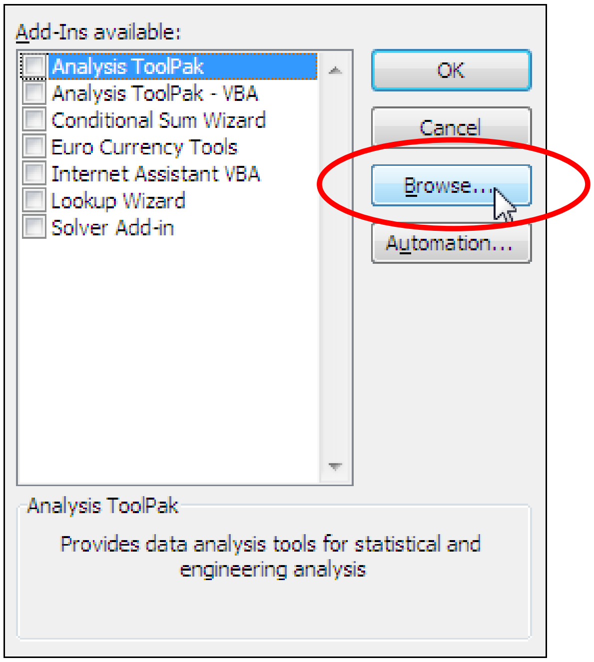
- Should it not be shown in the list automatically, select "Excel Add-ins" (found next to "Manage:" in the lower area of the menu)
- Then click the "Go…" button
- Click "Browse" in the following window and locate the destination folder, generally

C:\Program Files\FluidEXL_Graphics_Eng	(for Excel 64 bit) or
C:\Program Files (x86)\FluidEXL_Graphics_Eng	(for Excel 32 bit)

within that folder click on the file named

"FluidEXL_Graphics_Eng.xla"

and then click "OK."



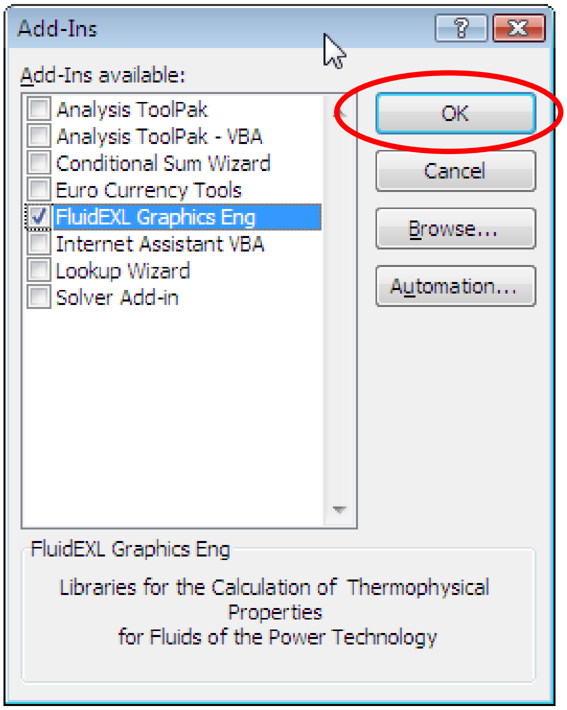
☐ Analysis ToolPak
☐ Analysis ToolPak - VBA
☐ Conditional Sum Wizard
☐ Euro Currency Tools
☐ Internet Assistant VBA
☐ Lookup Wizard
☐ Solver Add-in

Analysis ToolPak

Provides data analysis tools for statistical and engineering analysis

Figure 2.1.7: Dialog window "Add-Ins available"

- Now, "FluidEXL Graphics Eng" will be shown in your list of Add-Ins. (If a check-mark is situated in the box next to the name "FluidEXL Graphics Eng", this Add-In will automatically be loaded whenever Excel starts. This will continue to occur unless the check-mark is removed from the box by clicking on it.)



☐ Analysis ToolPak
☐ Analysis ToolPak - VBA
☐ Conditional Sum Wizard
☐ Euro Currency Tools
☑ FluidEXL Graphics Eng
☐ Internet Assistant VBA
☐ Lookup Wizard
☐ Solver Add-in

FluidEXL Graphics Eng

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Figure 2.1.8: Dialog window "Add-Ins"

- In order to register the Add-In, click the "OK" button in the "Add-Ins" window.

In order to use FluidEXL$^{\mathit{Graphics}}$ in the following example, click on the menu item "Add-Ins," shown in the next figure.

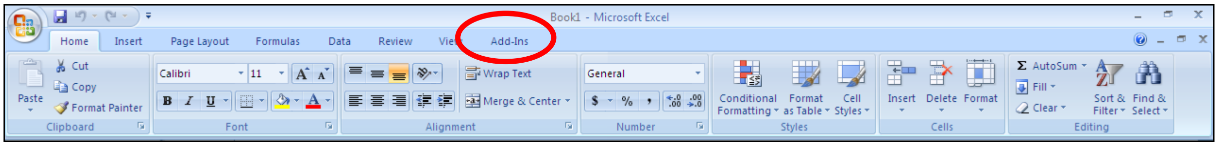


Figure 2.1.9: Menu item "Add-Ins"

In the upper menu region of Excel®, the FluidEXL$^{\mathit{Graphics}}$ menu bar will appear as indicated by the red circle in the next figure.

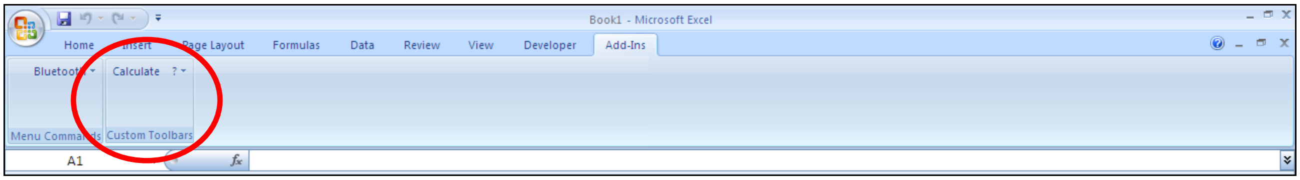


Figure 2.1.10: FluidEXL$^{\mathit{Graphics}}$ menu bar

Installation of FluidEXL$^{\mathit{Graphics}}$ in Excel (versions 2007 and later) is now finished.

An example calculation of LibHuAirProp_IP.DLL library property functions can be found in Section 2.3 of this part of the User's Guide and of LibHuAirProp_SI.DLL library property functions in the SI Units part in Chapter 2.

Registering FluidEXL$^{\mathit{Graphics}}$ as Add-In in Excel® versions 2003 or earlier

After the installation of FluidEXL$^{\mathit{Graphics}}$, the program must be registered as an Add-In in Excel®. In order to do so, start Excel® and carry out the following steps:

- Click "Tools" in the upper menu bar of Excel.
- Here, click on "Add-Ins..." in the menu.

After a short delay the "Add-Ins" dialog box will appear.

- Click "Browse..."
- In the following dialog box, choose your chosen destination folder (the standard being

  C:\Program Files\FluidEXL_Graphics_Eng)

  here select "FluidEXL_Graphics_Eng.xla" and afterwards click "OK".
- Now, the entry "FluidEXL Graphics Eng" will appear in the Add-Ins list.

Note:

As long as the check box next to the file name

"FluidEXL Graphics Eng"

is checked, this Add-In will be loaded automatically every time you start Excel until you unmark the box by clicking on it again.

- In order to register FluidEXL$^{\mathit{Graphics}}$ as an Add-In, click "OK" in the "Add-Ins" dialog box.

Now, the new FluidEXL$^{\mathit{Graphics}}$ menu bar will appear in the upper menu area of your Excel screen, marked with a red circle in Figure 2.1.11:

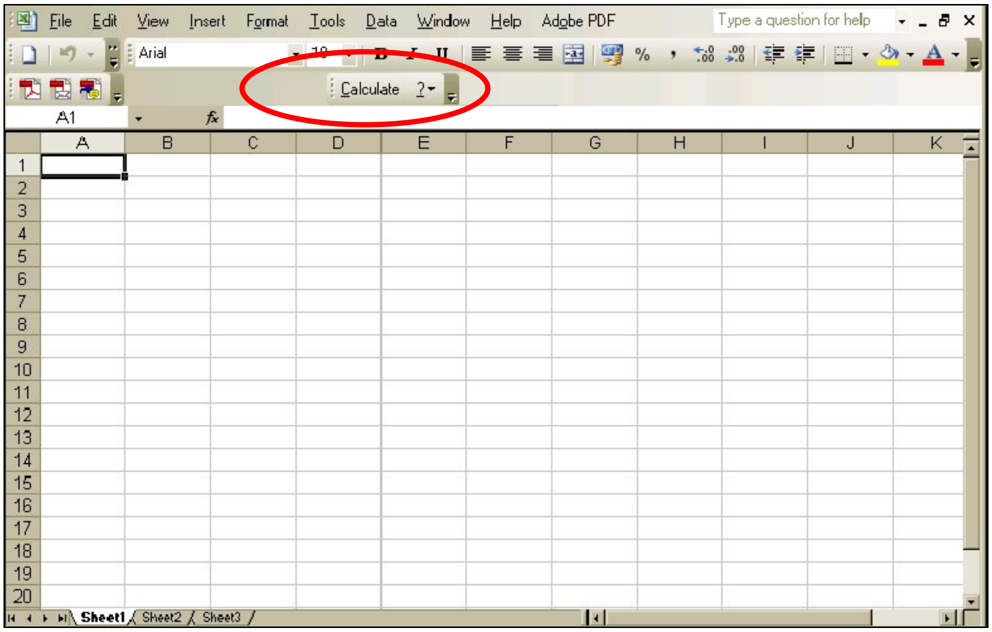


Figure 2.1.11: Menu bar of FluidEXL*Graphics*

From within Excel® you can now select the "ASHRAE-LibHuAirProp-IP" DLL library property functions for moist air via this menu bar.

2.1.3 The FluidEXL*Graphics* Help System

As mentioned earlier, FluidEXL*Graphics* also provides detailed online help functions.

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

- Click "Calculate" in the FluidEXL*Graphics* menu bar.
- Click on the “ASHRAE-LibHuAirProp-IP” library under "Or select a category:" in the "Insert Function" window which will appear.
- Click the "Help on this function" button in the lower left-hand edge of the "Insert Function" window.

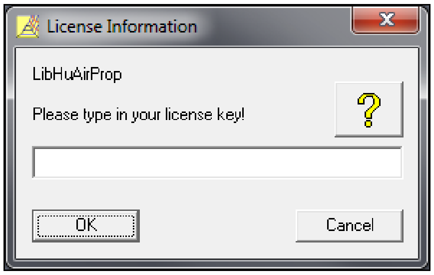
If the LibHuAirProp_IP.chm function help cannot be found, you will be redirected to a Microsoft® help website by your standard browser. In this case, the LibHuAirProp_IP.chm file has to be copied into the folder of FluidEXL*Graphics*, in the standard case

C:\Program Files\FluidEXL_Graphics_Eng (for 64-bit version of Excel)
C:\Program Files (x86)\FluidEXL_Graphics_Eng (for 32-bit version of Excel)

to use the help system.

2.2 Licensing the LibHuAirProp Property Library

The licensing procedure must be carried out when Excel® starts up and a FluidEXL*Graphics* prompt message appears. In this case, you will see the "License Information" window for LibHuAirProp (see figure below).

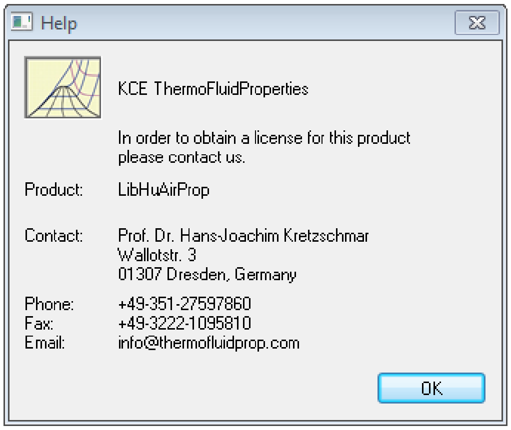


LibHuAirProp

Please type in your license key!

Figure 2.2.1: "License Information" window

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



KCE ThermoFluidProperties

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

Product: LibHuAirProp

Contact: Prof. Dr. Hans-Joachim Kretzschmar
Wallotstr. 3
01307 Dresden, Germany

Phone: +49-351-27597860
Fax: +49-3222-1095810
Email: info@thermofluidprop.com

Figure 2.2.2: "Help" window

If you do not enter a valid license it is still possible to start Excel® by clicking "Cancel" twice. In this case, the LibHuAirProp property library will display the result "–11111111" for every calculation you ask it to make.
The "License Information" window will appear every time you start Excel® unless you uninstall FluidEXL*Graphics* according to the description in section 2.4 of this User's Guide.

Should you not wish to license the LibHuAirProp property library, you have to delete the files

LibHuAirProp_IP.dll	LibHuAirProp_SI.dll
LibHuAirProp_IP.chm	LibHuAirProp_SI.chm

in the installation folder of FluidEXL*Graphics* (the standard being

C:\Program Files\FluidEXL_Graphics_Eng	(for 64-bit version of Excel)
C:\Program Files (x86)\FluidEXL_Graphics_Eng	(for 32-bit version of Excel)

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

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

We will now calculate, step by step, the air-specific enthalpy h of real moist air as a function of total pressure p, temperature t and humidity ratio W, using FluidEXL^{Graphics}. The following description relates to Excel® 2003. The use of FluidEXL^{Graphics} here is analogous to the description for using it with earlier or later Excel® versions.

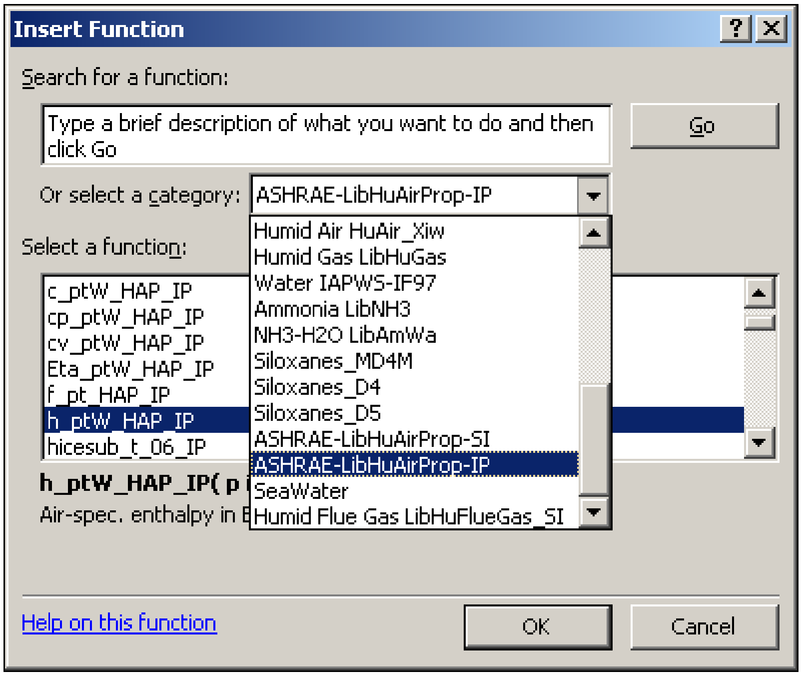
Please carry out the following steps:

- Start Excel®
- Enter the value for p in psi into a cell
  (Range of validity: p = 0.00145 … 1450.4 psi

  ⇒ e.g.: Enter the value 14.6959 into cell A2
- Enter the value for t in °F into a cell
  (Range of validity: t = –226.67 ... 662 °F)

  ⇒ e.g.: Enter the value 68 into cell B2
- Enter the value for W in lb_w/lb_a (*lb water* per *lb dry air*) into a cell
  (Range of validity: W = 0 … 10 lb_w/lb_a)

  ⇒ e.g.: Enter the value 0.01 into cell C2
- Click the cell in which the air-specific enthalpy h in Btu/lb_a is to be displayed
  ⇒ e.g.: Click cell D2
- Click "Calculate" in the FluidEXL^{Graphics} menu bar
  The "Insert Function" window appears (see Figure 2.3.1)



Search for a function:

Type a brief description of what you want to do and then click Go

Or select a category: ASHRAE-LibHuAirProp-IP

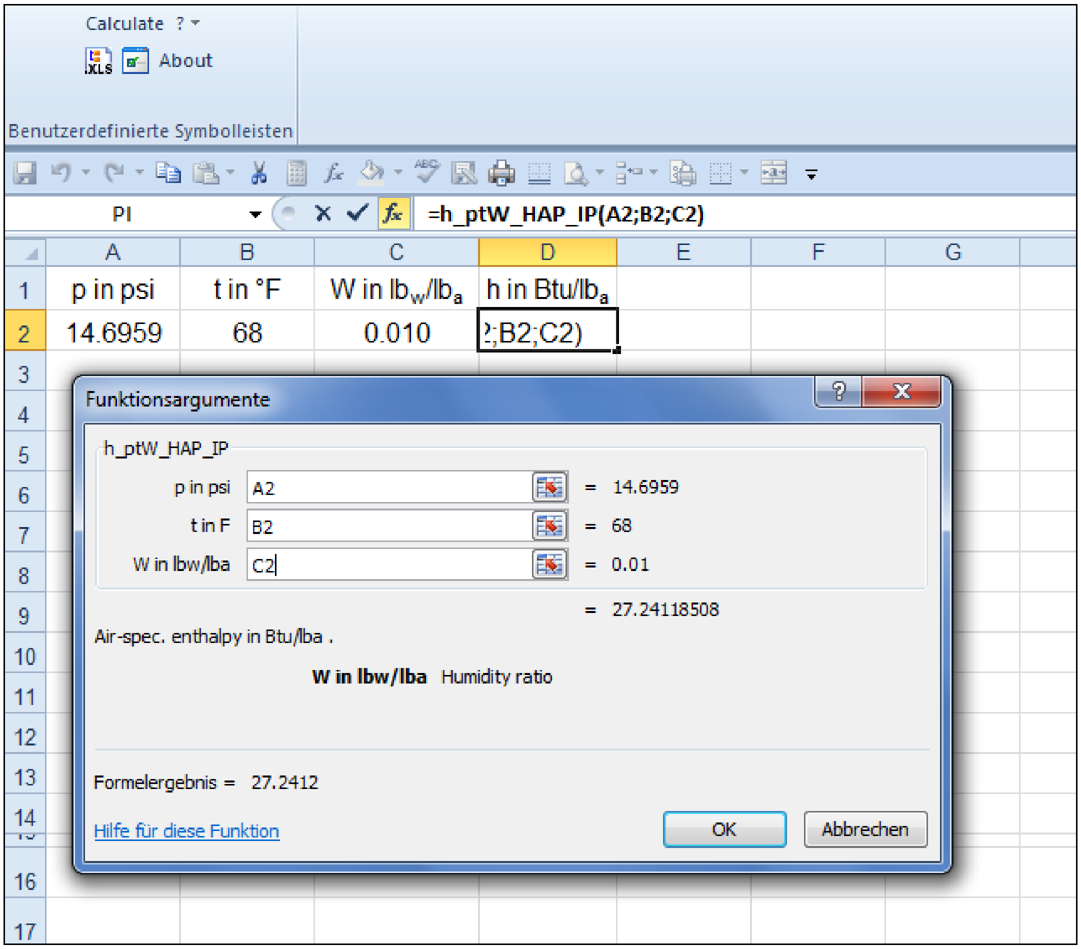
Select a function: h_ptW_HAP_IP

h_ptW_HAP_IP(p

Air-spec. enthalpy in B

Figure 2.3.1: Choosing the library and function name

- Click on the "ASHRAE-LibHuAirProp-IP" library under "Or select a category:" in the upper part of the window
- Choose the function "h_ptW_HAP_IP" under "Select a function:" directly below that
- Click the "OK" button
  The "Function Arguments" menu for the function "h_ptW_HAP_IP" in the next figure will now appear.



=h_ptW_HAP_IP(A2;B2;C2)

	A	B	C	D
1	p in psi	t in °F	W in lb$_w$/lb$_a$	h in Btu/lb$_a$
2	14.6959	68	0.010	?;B2;C2)

h_ptW_HAP_IP

p in psi A2 = 14.6959

t in F B2 = 68

W in lbw/lba C2 = 0.01

= 27.24118508

Air-spec. enthalpy in Btu/lba .

W in lbw/lba Humidity ratio

Formelergebnis = 27.2412

Figure 2.3.2: Input menu for the function

- The cursor is now situated on the line next to "p in psi." You can now enter the value for the mixture pressure *p* either by clicking the cell with the value for *p*, by entering the name of the cell, or by entering the value for *p* directly into the line next to "p in psi."

  ⇒ e. g.: Click on cell A2

- Situate the cursor on the line next to "*t* in °F" and enter the value for *t* either by clicking the cell with the value for *t*, by entering the name of the cell, or by entering the value for *t* directly into the line next to "*t* in °F."

  ⇒ e. g.: Type B2 into the line next to "t in °F"

- Situate the cursor on the line next to "*W* in lb$_w$/lb$_a$" and enter the value for the humidity ratio *W* either by clicking the cell with the value for *W*, by entering the name of the cell, or by entering the value for *W* directly into the line next to "*W* in lb_w/lb_a.

⇒ e. g.: Click on cell C2

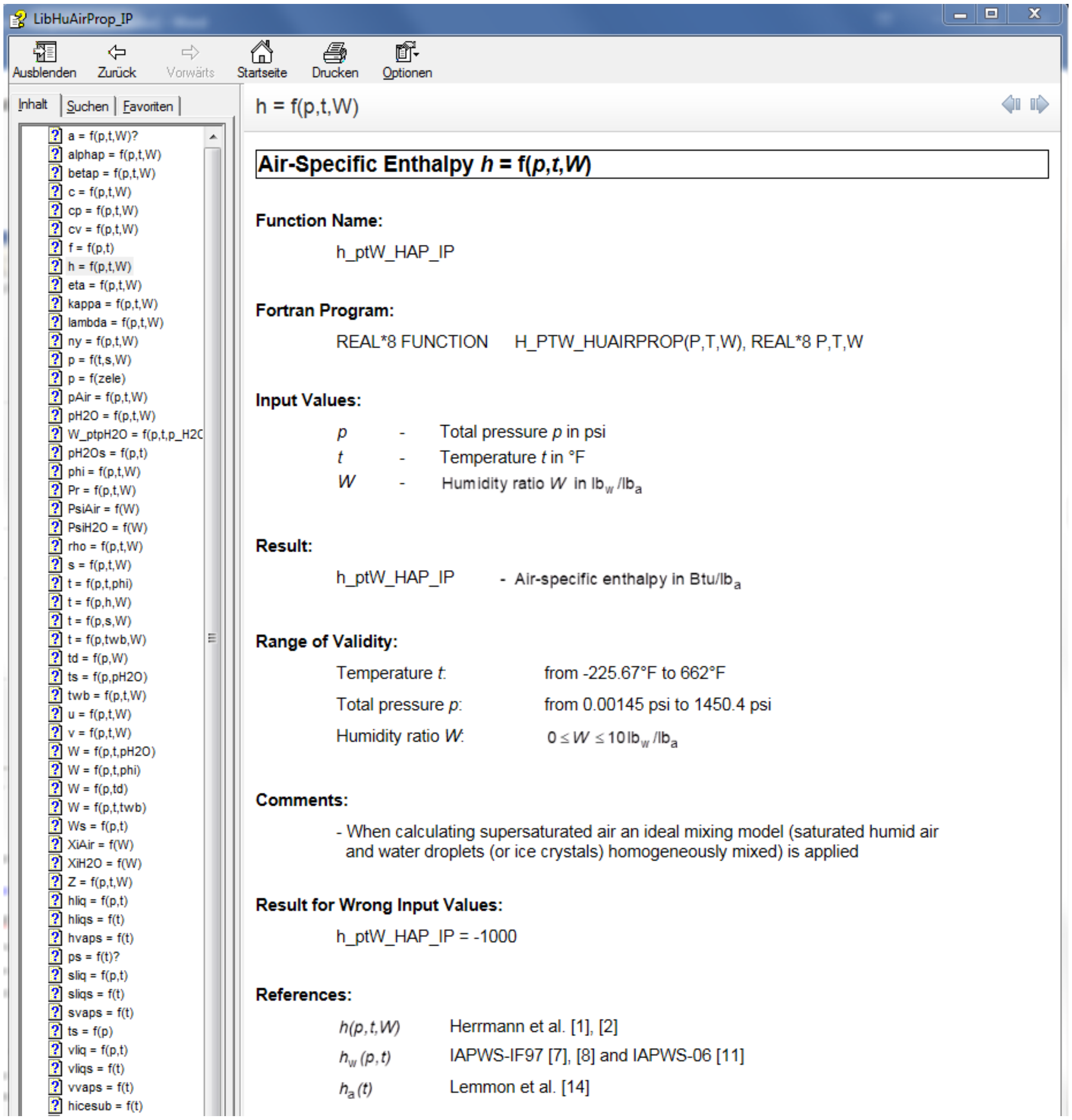
- It is possible to get detailed information on the "h_ptW_HAP_IP" property function.
- Click the blue "Help on this function" link in the lower left-hand edge of the "Function Arguments" window.

You may be informed that the "LibHuAirProp_IP.chm" function help cannot be found. In this case, confirm the question whether you want to look for it yourself with "Yes." Select the "LibHuAirProp_IP.chm" file in the installation menu of FluidEXL*Graphics* in the window which is opened, the standard being

C:\Program Files\FluidEXL_Graphics_Eng	(for 64-bit version of Excel)
C:\Program Files (x86)\FluidEXL_Graphics_Eng	(for 32-bit version of Excel)

and click "Yes" in order to complete the search.

- Now you should see the help page of the "h_ptW_HAP_IP" property function (see Figure 2.3.3).



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]

Figure 2.3.3: Help page for the "h_ptW_HAP_IP" function

- Click the "OK" button

The result for *h* in $\mathrm{Btu/lb_a}$ appears in the cell selected above.

⇒ The cell D2 now contains the value 27.24118508.

The calculation of *h* = f(*p*,*t*,*W*) has thus been completed.

You can now arbitrarily change the values for *p*, *t* or *W* in the appropriate cells. The specific enthalpy *h* is recalculated and updated every time you change the data. This shows that the Excel® data flow and the DLL calculations are working together successfully

Note:

If the calculation result is –1000, this indicates that the values entered are located outside the range of validity of real moist air. More detailed information on each function and its range of validity is available in Chapter 3.

For further property functions calculable in FluidEXL$^{\mathit{Graphics}}$ see the function table in Chapter 1.

2.4 Removing FluidEXL^{Graphics} including LibHuAirProp

Should you wish to remove only the LibHuAirProp-IP library, delete the files

LibHuAirProp_IP.dll and LibHuAirProp_IP.chm

in the directory selected for the installation of FluidEXL^{Graphics}, the standard being

C:\Program Files\FluidEXL_Graphics_Eng (for 64-bit version of Excel)
C:\Program Files (x86)\FluidEXL_Graphics_Eng (for 32-bit version of Excel)

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

Should you wish to remove only the LibHuAirProp-SI library, delete the files

LibHuAirProp_SI.dll and LibHuAirProp_SI.chm

in the directory selected for the installation of FluidEXL^{Graphics}, the standard being

C:\Program Files\FluidEXL_Graphics_Eng (for 64-bit version of Excel)
C:\Program Files (x86)\FluidEXL_Graphics_Eng (for 32-bit version of Excel)

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

Unregistering FluidEXL^{Graphics} as Add-In in versions of Excel® from 2007 onwards

In order to unregister the FluidEXL^{Graphics} Add-In in versions of Excel® from 2007 onwards, start Excel® and carry out the following commands:

(If you are running a version of Excel® from 2003 or earlier, please go straight to the instructions **Unregistering FluidEXL^{Graphics} as Add-In in Excel® versions 2003 or earlier).**

- Click the “File” button in the upper left corner of Excel®
- Click on the "Options" button in the menu which appears (see Figure 2.4.1)

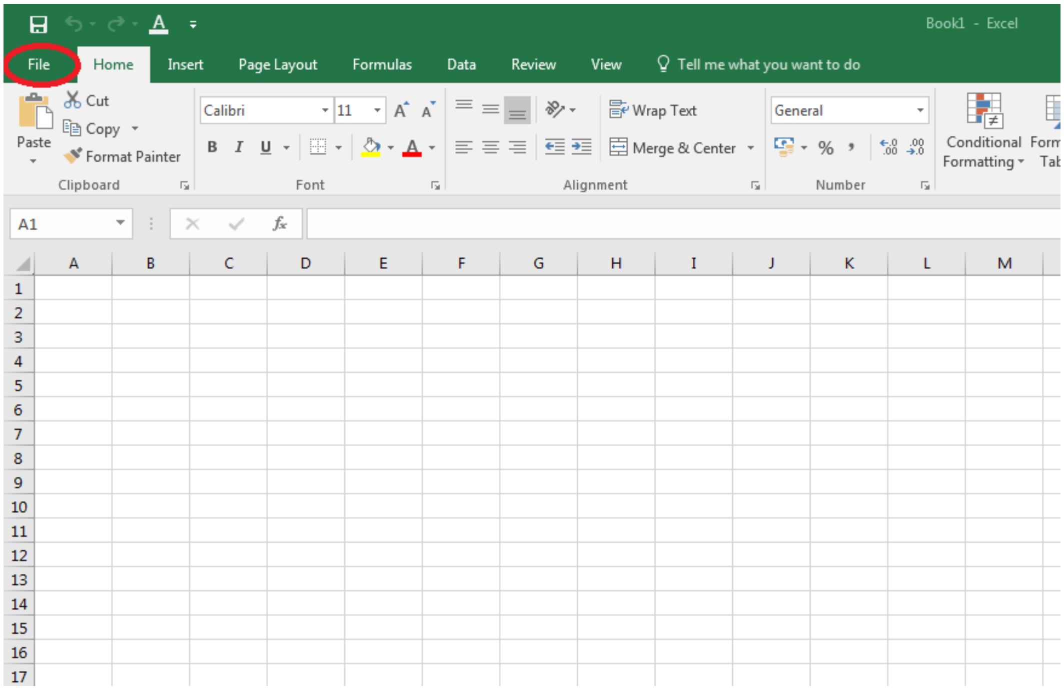


Figure 2.4.1: Unregistering FluidEXL^{Graphics} as Add-In in Excel® 2016

- Click on "Add-Ins" in the next menu (see Figure 2.4.2)

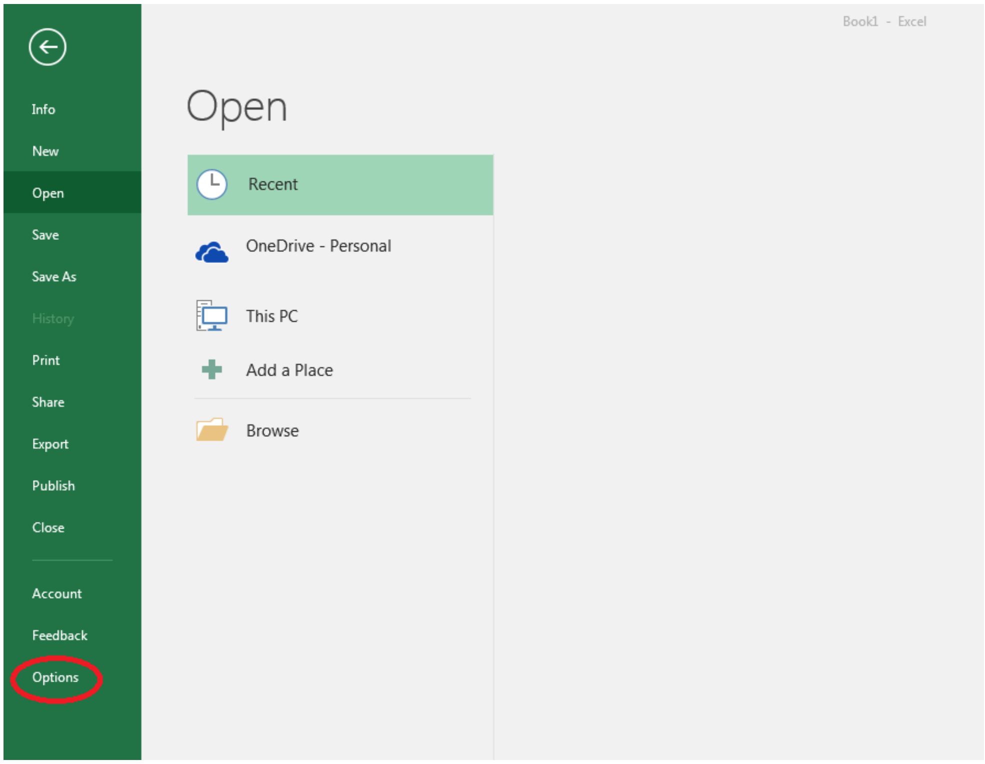
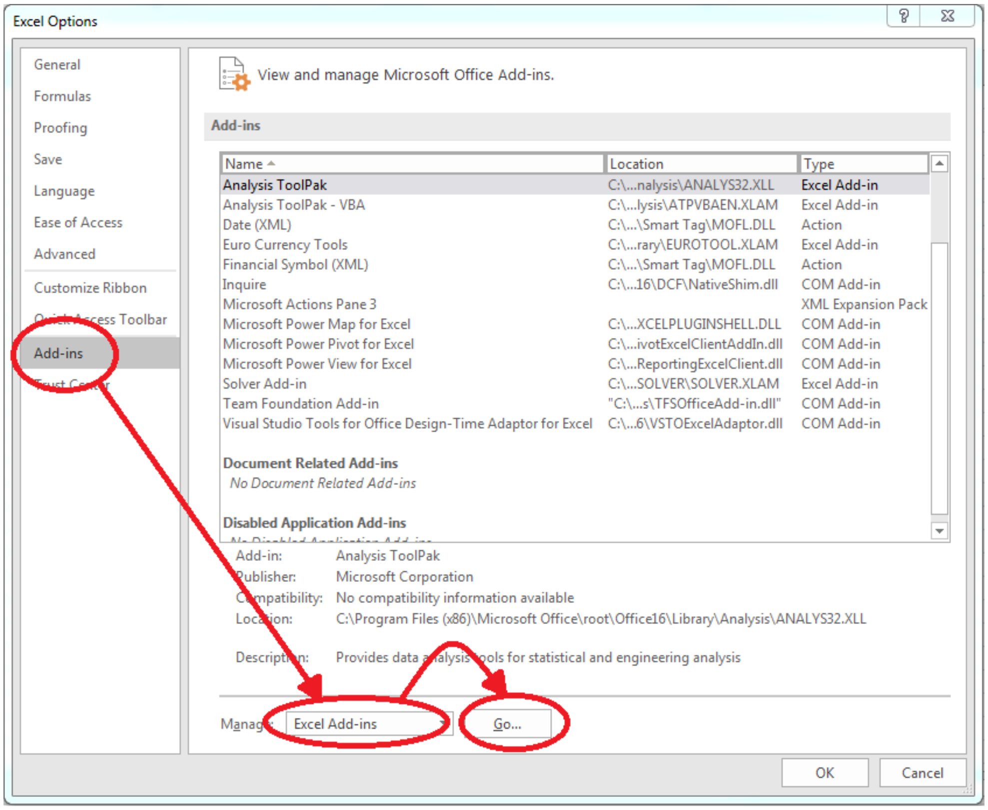


Figure 2.4.2: Unregistering FluidEXL^{Graphics} as Add-In in Excel® 2016



Name	Location	Type
Analysis ToolPak	C:\...nalysis\ANALYS32.XLL	Excel Add-in
Analysis ToolPak - VBA	C:\...lysis\ATPVBAEN.XLAM	Excel Add-in
Date (XML)	C:\...\Smart Tag\MOFL.DLL	Action
Euro Currency Tools	C:\...rary\EUROTOOL.XLAM	Excel Add-in
Financial Symbol (XML)	C:\...\Smart Tag\MOFL.DLL	Action
Inquire	C:\...16\DCF\NativeShim.dll	COM Add-in
Microsoft Actions Pane 3		XML Expansion Pack
Microsoft Power Map for Excel	C:\...XCELPLUGINSHELL.DLL	COM Add-in
Microsoft Power Pivot for Excel	C:\...ivotExcelClientAddIn.dll	COM Add-in
Microsoft Power View for Excel	C:\...ReportingExcelClient.dll	COM Add-in
Solver Add-in	C:\...SOLVER\SOLVER.XLAM	Excel Add-in
Team Foundation Add-in	"C:\...s\TFSOfficeAdd-in.dll"	COM Add-in
Visual Studio Tools for Office Design-Time Adaptor for Excel	C:\...6\VSTOExcelAdaptor.dll	COM Add-in

Document Related Add-ins

No Document Related Add-ins

Disabled Application Add-ins

Add-in: Analysis ToolPak
Publisher: Microsoft Corporation
Compatibility: No compatibility information available
Location: C:\Program Files (x86)\Microsoft Office\root\Office16\Library\Analysis\ANALYS32.XLL

Description: Provides data analysis tools for statistical and engineering analysis

Figure 2.4.3: Dialog window "Add-Ins"

- If it is not shown in the list automatically, chose and select "Excel Add-ins" next to "Manage:" in the lower area of the menu
- Then click the "Go…" button
- Remove the checkmark in front of
  FluidEXL Graphics Eng
  in the window which now appears. Click the "OK" button to confirm your entry (see Figure 2.4.4).

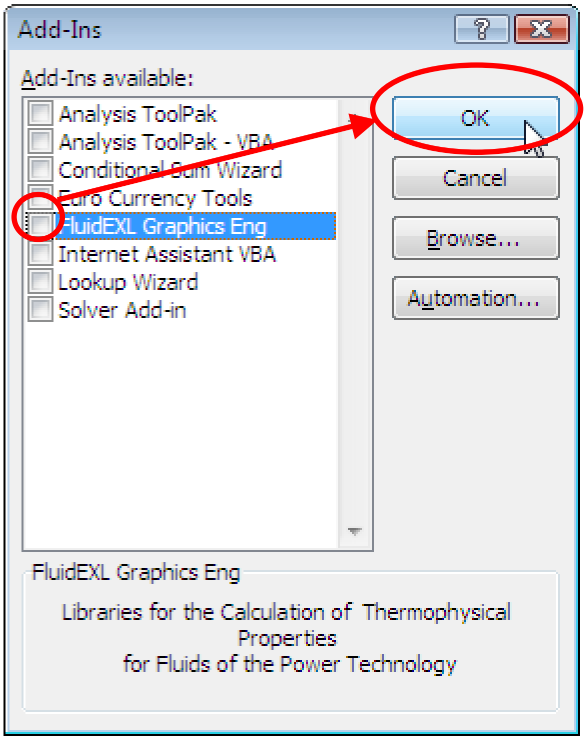


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Figure 2.4.4: Dialog window "Excel Add-Ins"

In order to remove FluidEXL*Graphics* from Windows and the hard drive, click "Start" in the Windows task bar, select "Settings" and click "Control Panel."

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

In the list box of the "Add or Remove Programs" window that appears, select "FluidEXL Graphics Eng" by clicking on it and then clicking the "Add/Remove…" button.

Click "Automatic" in the following dialog box and then the "Next >" button.

Click "Finish" in the "Perform Uninstall" window.

Answer the question of whether all shared components should be removed with "Yes to All."
Finally, close the "Add or Remove Programs" and "Control Panel" windows.

Now FluidEXL*Graphics* has been completely removed from your computer.

Unregistering FluidEXL*Graphics* as Add-In in Excel® versions 2003 or earlier

To remove FluidEXL*Graphics* and both LibHuAirProp_IP and LibHuAirProp_SI completely, proceed as follows: First cancel the registration of "FluidEXL_Graphics_Eng.xla" has to be deleted in Excel®.

In order to do that, click "Tools" in the upper menu bar of Excel® and here "Add-Ins…" Unmark the box on the left-hand side of

"FluidEXL Graphics Eng"

in the window that appears and click the "OK" button. The additional FluidEXL*Graphics* menu bar will disappear from the upper menu of the Excel® window. Afterwards, we recommend closing Excel®.

As the next step, delete the files

LibHuAirProp_IP.dll, LibHuAirProp_IP.chm
LibHuAirProp_SI.dll, LibHuAirProp_SI.chm

in the directory selected for the installation of FluidEXL*Graphics*, the standard being

C:\Program Files\FluidEXL_Graphics_Eng,

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

In order to remove FluidEXL*Graphics* from Windows® and the hard drive, click "Start" in the Windows® task bar, select "Settings" and click "Control Panel."

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

In the list box of the "Add or Remove Programs" window that appears, select "FluidEXL Graphics LibHuAirProp" by clicking on it and click the "Add/Remove…" button.

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

Click "Finish" in the "Perform Uninstall" window.

Answer the question whether all shared components shall be removed with "Yes to All." Finally, close the "Add or Remove Programs" and "Control Panel" windows®.

Now FluidEXL*Graphics* has been removed.

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 $\mathrm{lb_w/lb_a}$

Result:

a_ptW_HAP_IP - Thermal diffusivity of humid air in $\mathrm{ft^2/s}$

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:	$0 \le W \le W_\mathrm{s}$

Comments:

- Thermal diffusivity $a = \dfrac{\lambda}{\rho \cdot c_p}$
- Calculation for supersaturated humid air ($W > W_\mathrm{s}$) 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 $\mathrm{lb_w/lb_a}$

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:	$0 \leq W \leq W_\mathrm{s}$

Comments:

- Relative pressure coefficient $\alpha_p = \frac{1}{p}\left(\frac{\partial p}{\partial T}\right)_\mathrm{v}$
- Calculation for supersaturated humid air ($W > W_\mathrm{s}$) 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 $\mathrm{lb_w/lb_a}$

Result:

betap_ptW_HAP_IP - Isothermal stress coefficient of humid air in $\mathrm{lb/ft^3}$

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:	$0 \le W \le W_\mathrm{s}$

Comments:

- Isothermal stress coefficient $\beta_p = -\frac{1}{p}\left(\frac{\partial p}{\partial v}\right)_\mathrm{T}$
- Calculation for supersaturated humid air ($W > W_\mathrm{s}$) 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 $\mathrm{lb_w/lb_a}$

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

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 $\mathrm{lb_w/lb_a}$

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 $f = \dfrac{p_{\mathrm{H2O,s}}}{p_{\mathrm{s}}(t)}$

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

  for $t < 32$°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 $\mathrm{lb_w/lb_a}$

Result:

h_ptW_HAP_IP - Air-specific enthalpy in $\mathrm{Btu/lb_a}$

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

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 $\eta = \mathrm{f}(p,t,W)$

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 $\mathrm{lb_w/lb_a}$

Result:

Eta_ptW_HAP_IP - Dynamic viscosity of humid air in $(\mathrm{lb\,s/ft^2})$

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

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]
$\eta_{\mathrm{w}}(p,t)$	IAPWS-IF97 [7], [8] and IAPWS-06 [19]
$\eta_{\mathrm{a}}(t)$	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 $\mathrm{lb_w/lb_a}$

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

Comments:

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

- When calculating supersaturated air an ideal mixing model (saturated humid air and water droplets homogeneously mixed) is applied for $t \geq 32$°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 $\lambda = \mathrm{f}(p,t,W)$

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 $\mathrm{lb_w/lb_a}$

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

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]
$\lambda_\mathrm{w}(p,t)$	IAPWS-IF97 [7], [8] and IAPWS-08 [20]
$\lambda_\mathrm{a}(t)$	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 $\nu = \frac{\eta}{\rho}$

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

Result for Wrong Input Values:

p_zele_HAP_IP = -1000

References:

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

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

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 $\mathrm{lb_w/lb_a}$

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

Comments:

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

Result for Wrong Input Values:

pAir_ptW_HAP_IP = -1000

References:

$p_{\mathrm{H2O}}(p,W)$ 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 $\mathrm{lb_w/lb_a}$

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

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 $\mathrm{lb_w/lb_a}$

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

Comments:

- Relative humidity $\varphi = \dfrac{p_{\mathrm{H2O}}}{p_{\mathrm{H2O,s}}}$
- This equation is valid for $p_{\mathrm{H2O}} \le p_{\mathrm{H2O,s}}$ 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 $\mathrm{lb_w/lb_a}$

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

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_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 $\psi_{\mathrm{Air}} = \mathrm{f}(W)$

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 ψ_{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 $\mathrm{lb_w/lb_a}$

Result:

PsiH2O_W_HAP_IP - Mole fraction of water in humid air in $\mathrm{mol_w/mol}$

Range of Validity:

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

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 $\mathrm{lb_w/lb_a}$

Result:

Rho_ptW_HAP_IP - Density of humid air in $\mathrm{lb/ft^3}$

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

Comments:

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

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 $\mathrm{lb_w/lb_a}$

Result:

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

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

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 $\mathrm{Btu/lb_a}$
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 $\mathrm{Btu/lb_a}$ to 12772.088 $\mathrm{Btu/lb_a}$
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 $\mathrm{Btu/lb_a}$

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

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 $\mathrm{Btu/lb_a}$ to 12772.088 $\mathrm{Btu/lb_a}$

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

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/($\mathrm{lb_a} \cdot$ °R)

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

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/($\mathrm{lb_a}$ °R) to 9.32877 Btu/($\mathrm{lb_a}$ °R)
Humidity ratio W:	$0 \le W \le 10\,\mathrm{lb_w/lb_a}$

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 $t = \mathrm{f}(p,t_{\mathrm{wb}},W)$

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 $\mathrm{lb_w/lb_a}$

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

Comments:

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

Result for Wrong Input Values:

t_ptwbW_HAP_IP = -1000

References:

$t_{\mathrm{wb}}(p,t,W)$ 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 $\mathrm{lb_w/lb_a}$

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

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 $\mathrm{lb_w/lb_a}$

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

Comments:

- Iteration of wet-bulb temperature t_{wb} from $h^{\text{unsaturated}}(p,t,W) = h^{\text{fog}}(p,t_{wb},W)$
- 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 $\mathrm{lb_w/lb_a}$

Result:

u_ptW_HAP_IP - Air-specific internal energy in $\mathrm{Btu/lb_a}$

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

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 $\mathrm{lb_w/lb_a}$

Result:

v_ptW_HAP_IP - Air-specific volume in $\mathrm{ft^3/lb_a}$

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*:	$0 \le W \le 10\ \mathrm{lb_w/lb_a}$

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 $W = f(p,t,\varphi)$

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 $\mathrm{lb_w/lb_a}$

Result:

XiAir_W_HAP_IP - Mass fraction of (dry) air in humid air in $\mathrm{lb_a/lb}$

Range of Validity:

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

Comments:

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

Result for Wrong Input Values:

XiAir_W_HAP_IP = -1000

References:

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

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

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 $\mathrm{lb_w/lb_a}$

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:	$0 \le W \le W_\mathrm{s}$

Comments:

- Compression factor $Z = 1 + \dfrac{B_\mathrm{m}}{\bar{v}} + \dfrac{C_\mathrm{m}}{\bar{v}^2}$

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

  and M is the molar mass of humid air

- Calculation for supersaturated humid air ($W > W_\mathrm{s}$) is not possible

Result for Wrong Input Values:

Z_ptW_HAP_IP = -1000

References:

$B_\mathrm{m}(t,W), C_\mathrm{m}(t,W)$	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 $t \geq 32°\mathrm{F}$

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

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 $p_{\mathrm{s}}(32°\mathrm{F}) = 0.08865$ psi to 1450.4 psi

Temperature t: from 32°F to 662°F

Comments:

- Specific enthalpy of liquid water $h_{\mathrm{liq}} = h^{97}(p,t)$ (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 $h_{\text{liq,s}} = \text{f}(t)$

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 $h_{\text{liq,s}} = h^{97}(p_{\text{s}}, t)$ (Region 1)
  with $p_{\text{s}} = p_{\text{s}}^{97}(t)$

Result for Wrong Input Values:

hliqs_t_97_IP = -1000

References:

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

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

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 $h_{\mathrm{vap,s}} = h^{97}(p_{\mathrm{s}}, t)$ (Region 2)
  with $p_{\mathrm{s}} = p_{\mathrm{s}}^{97}(t)$

Result for Wrong Input Values:

hvaps_t_97_IP = -1000

References:

$h^{97}(p, t)$, $p_{\mathrm{s}}^{97}(t)$ 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 $s_{\text{liq}} = \text{f}(p,t)$

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 $p_{\text{s}}(32°\text{F}) = 0.08865$ psi to 1450.4 psi
Temperature t:	from 32°F to 662°F

Comments:

- Specific entropy of liquid water $s_{\text{liq}} = s^{97}(p,t)$ (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 $s_{\mathrm{liq,s}} = \mathrm{f}(t)$

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 $s_{\mathrm{liq,s}} = s^{97}(p_{\mathrm{s}}, t)$ (Region 1)
  with $p_{\mathrm{s}} = p_{\mathrm{s}}^{97}(t)$

Result for Wrong Input Values:

sliqs_t_97_IP = -1000

References:

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

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

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 $v_{\text{liq}} = \text{f}(p,t)$

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 $p_{\text{s}}(32°\text{F}) = 0.08865$ psi to 1450.4 psi

Temperature *t*: from 32°F to 662°F

Comments:

- Specific volume of liquid water $v_{\text{liq}} = v^{97}(p,t)$ (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 $v_{\mathrm{liq,s}} = \mathrm{f}(t)$

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 $\mathrm{ft}^3/\mathrm{lb}$

Range of Validity:

Temperature t: from 32°F to 662°F

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_IP = -1000

References:

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

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

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 $\mathrm{ft}^3/\mathrm{lb}$

Range of Validity:

Temperature t: from 32°F to 662°F

Comments:

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

Result for Wrong Input Values:

vvaps_t_97_IP = -1000

References:

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

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

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

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 $h_{\text{ice,sub}} = h^{06}(p_{\text{sub}}, t)$
  with $p_{\text{sub}} = p_{\text{sub}}^{08}(t)$

Result for Wrong Input Values:

hicesub_t_06_IP = -1000

References:

$h^{06}(p,t)$	IAPWS-06 [10]
$p_{\text{sub}}^{08}(t)$	IAPWS-08 [11]

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

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 $h_{\mathrm{vap,sub}} = h^{95}(p_{\mathrm{sub}}, t)$

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

Result for Wrong Input Values:

hvapsub_t_95_IP = -1000

References:

$h^{95}(p,t)$	IAPWS-95 [5], [6]
$p_{\mathrm{sub}}^{08}(t)$	IAPWS-08 [11]

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

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:

$p_{\mathrm{mel}}^{08}(t)$ 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 $s_{\mathrm{ice,sub}} = \mathrm{f}(t)$

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 $s_{\mathrm{ice,sub}} = s^{06}(p_{\mathrm{sub}}, t)$
  with $p_{\mathrm{sub}} = p_{\mathrm{sub}}^{08}(t)$

Result for Wrong Input Values:

sicesub_t_06_IP = -1000

References:

$s^{06}(p,t)$	IAPWS-06 [10]
$p_{\mathrm{sub}}^{08}(t)$	IAPWS-08 [11]

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

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 $s_{\mathrm{vap,sub}} = s^{95}(p_{\mathrm{sub}}, t)$
  with $p_{\mathrm{sub}} = p_{\mathrm{sub}}^{08}(t)$

Result for Wrong Input Values:

svapsub_t_95_IP = -1000

References:

$s^{95}(p,t)$	IAPWS-95 [7], [8]
$p_{\mathrm{sub}}^{08}(t)$	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 $p_{\mathrm{s}}\,(32°\mathrm{F}) = 0.08865$ psi to 1450.4 psi

Result for Wrong Input Values:

tmel_p_08_IP = -1000

References:

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

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

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

Result for Wrong Input Values:

tsub_p_08_IP = -1000

References:

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

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

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 $\mathrm{ft}^3/\mathrm{lb}$

Range of Validity:

Temperature t:	from -225.67°F to 32°F

Comments:

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

Result for Wrong Input Values:

vicesub_t_06_IP = -1000

References:

$v^{06}(p,t)$	IAPWS-06 [10]
$p_{\mathrm{sub}}^{08}(t)$	IAPWS-08 [11]

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

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 $v_{\mathrm{vap,sub}} = v^{95}(p_{\mathrm{sub}}, t)$
  with $p_{\mathrm{sub}} = p_{\mathrm{sub}}^{08}(t)$

Result for Wrong Input Values:

vvapsub_t_95_IP = -1000

References:

$v^{95}(p,t)$	IAPWS-95 [7], [8]
$p_{\mathrm{sub}}^{08}(t)$	IAPWS-08 [11]

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 Thermodynamic 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
Ne
N_2
O_2
CO
CO_2
Air

NO
H_2O
SO_2
H_2
H_2S
OH

He
F_2
NH_3
Methane
Ethane
Ethylene

Propylene
Propane
Iso-Butane
n-Butane
Benzene
Methanol

Consideration of:

- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

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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01307 Dresden, Germany

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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.

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www.thermofluidprop.com

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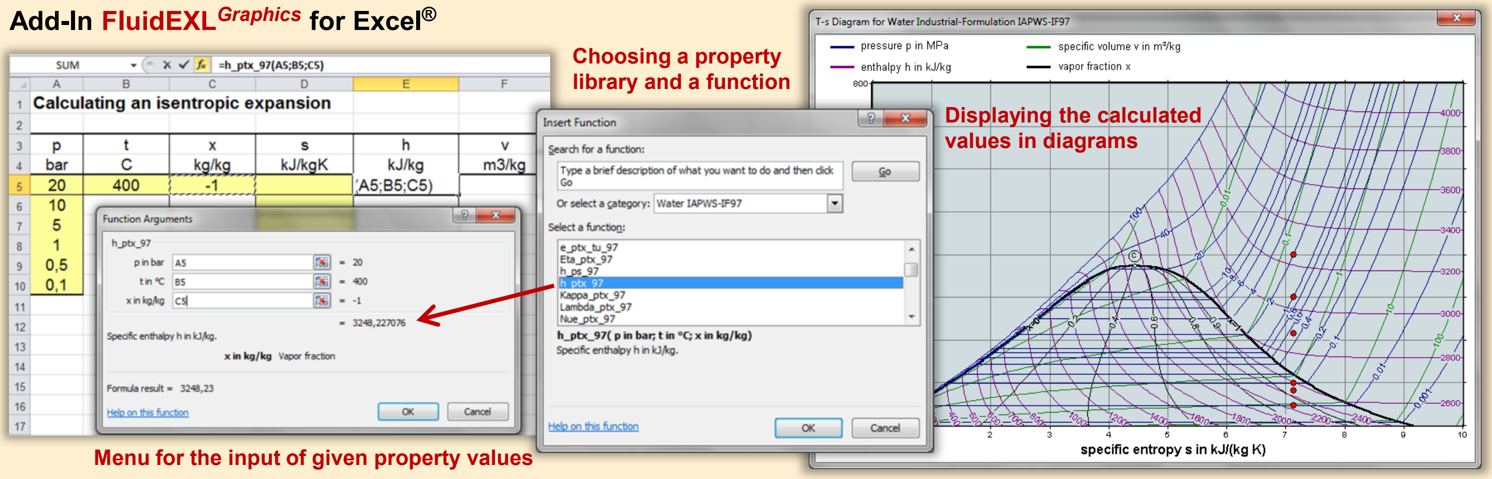
UNIVERSITY OF APPLIED SCIENCES

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

Add-In FluidEXL^{Graphics} for Excel®



SUM =h_ptx_97(A5;B5;C5)

Calculating an isentropic expansion

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

Function Arguments

h_ptx_97
p in bar A5 = 20
t in °C B5 = 400
x in kg/kg C5 = -1
= 3248,227076

Specific enthalpy h in kJ/kg.

x in kg/kg Vapor fraction

Formula result = 3248,23

Insert Function

Or select a category: Water IAPWS-IF97

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

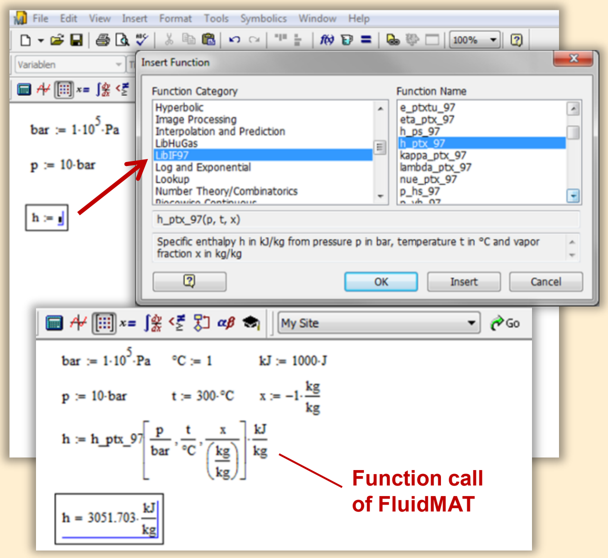
Choosing a property library and a function

Displaying the calculated values in diagrams

Menu for the input of given property values

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

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



Insert Function

Function Category: LibIF97
Function Name: h_ptx_97

h_ptx_97(p, t, x)

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

$bar := 1 \cdot 10^5 \cdot Pa \qquad °C := 1 \qquad kJ := 1000 \cdot J$

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

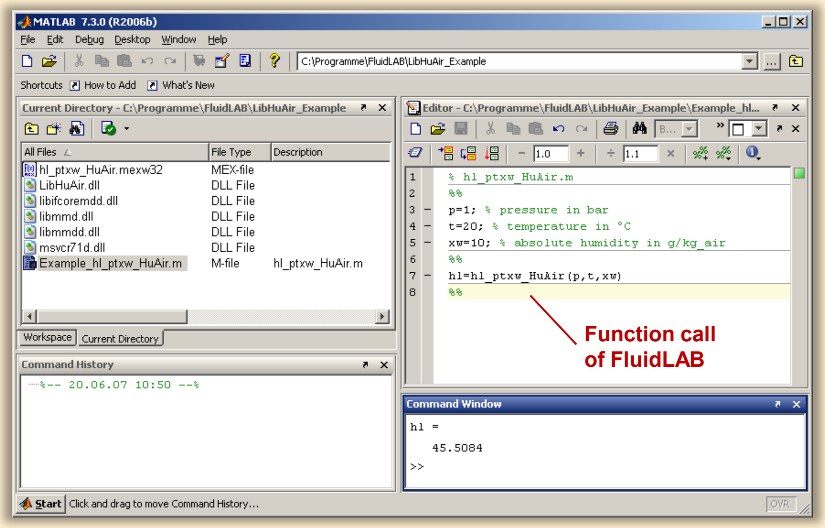
$h := h\_ptx\_97\left(\frac{p}{bar}, \frac{t}{°C}, \frac{x}{\left(\frac{kg}{kg}\right)}\right) \cdot \frac{kJ}{kg}$

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

Function call of FluidMAT

Add-On FluidLAB for MATLAB® and SIMULINK®

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



MATLAB 7.3.0 (R2006b)

Current Directory - C:\Programme\FluidLAB\LibHuAir_Example

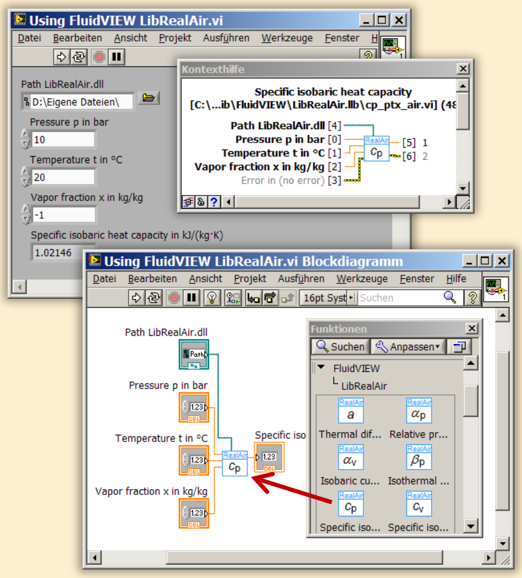
```
% hl_ptxw_HuAir.m
%%
p=1; % pressure in bar
t=20; % temperature in °C
xw=10; % absolute humidity in g/kg_air
%%
hl=hl_ptxw_HuAir(p,t,xw)
%%
```

```
hl =

   45.5084

>>
```

Function call of FluidLAB

Add-On FluidVIEW for LabVIEW™

The property functions can be calculated in LabVIEW™.



Using FluidVIEW LibRealAir.vi

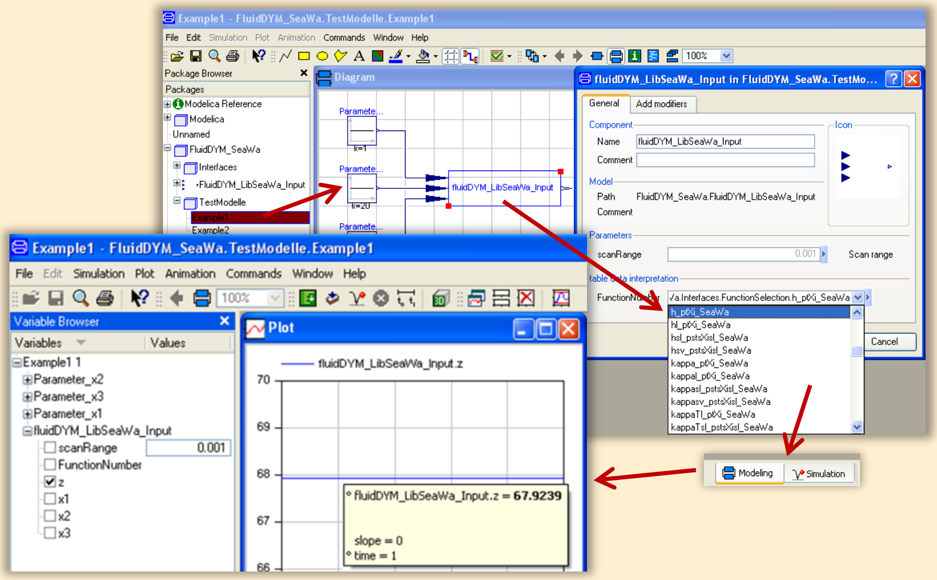
Path LibRealAir.dll: D:\Eigene Dateien\
Pressure p in bar: 10
Temperature t in °C: 20
Vapor fraction x in kg/kg: -1
Specific isobaric heat capacity in kJ/(kg·K): 1.02146

Kontexthilfe

Specific isobaric heat capacity
[C:\...ib\FluidVIEW\LibRealAir.llb\cp_ptx_air.vi]

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

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



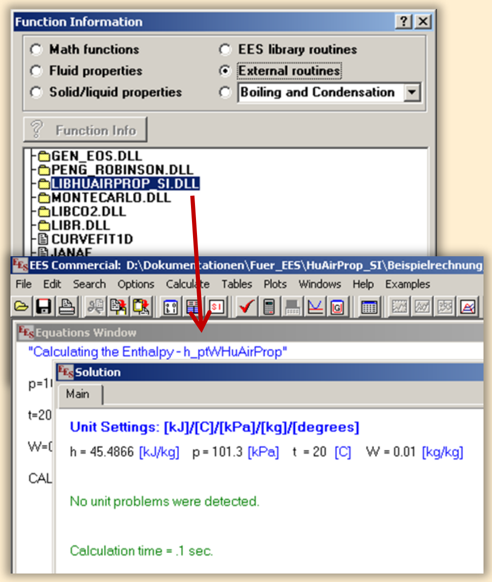
Example1 - FluidDYM_SeaWa.TestModelle.Example1

fluidDYM_LibSeaWa_Input in FluidDYM_SeaWa.TestModelle

Name: fluidDYM_LibSeaWa_Input
Path: FluidDYM_SeaWa.FluidDYM_LibSeaWa_Input
scanRange: 0.001
FunctionNumber: .Interfaces.FunctionSelection.h_pXi_SeaWa

fluidDYM_LibSeaWa_Input.z = 67.9239
slope = 0
time = 1

Add-On FluidEES for Engineering Equation Solver®



"Calculating the Enthalpy - h_ptWHuAirProp"

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

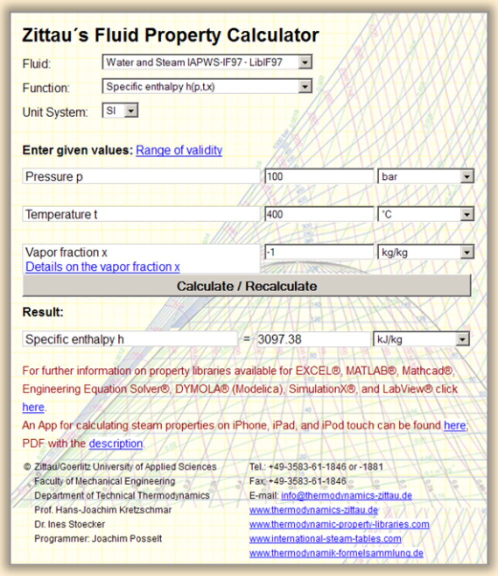
h = 45.4866 [kJ/kg] p = 101.3 [kPa] t = 20 [C] W = 0.01 [kg/kg]

No unit problems were detected.

Calculation time = .1 sec.

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

Online Property Calculator at www.thermofluidprop.com



Fluid: Water and Steam IAPWS-IF97 - LibIF97

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

Unit System: SI

Enter given values: Range of validity

Pressure p 100 bar

Temperature t 400 °C

Vapor fraction x -1 kg/kg

Details on the vapor fraction x

Result:

Specific enthalpy h = 3097.38 kJ/kg

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

An App for calculating steam properties on iPhone, iPad, and iPod touch can be found here; PDF with the description.

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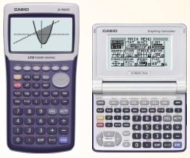
www.thermodynamics-zittau.de
www.thermodynamic-property-libraries.com
www.international-steam-tables.com
www.thermodynamik-formelsammlung.de

Property Software for Pocket Calculators

FluidCasio


fx 9750 G II


CFX 9850
fx-GG20


CFX 9860 G
Graph 85


ALGEBRA
FX 2.0

FluidHP

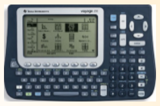

HP 48


HP 49

FluidTI


TI Nspire CX CAS
TI Nspire CAS


TI 83
TI 84
TI 89


TI Voyage 200


TI 92

For more information please contact:

KCE ThermoFluidProperties

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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

[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).

[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).

[3] Herrmann, S.; Kretzschmar, H.-J.; Aute, V.C.; Gatley, D.P.; Vogel, E.: Transport Properties of Real Moist Air, Dry Air, Steam, and Water. ASHRAE RP-1767, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA (2018).

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[18] Lemmon, E.W.; Jacobsen, R.T.: Viscosity and Thermal Conductivity Equations for Nitrogen, Oxygen, Argon, and Air. Int. J. Thermophys. 25, 21-69 (2004).

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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
Hannover University of Applied Sciences	08/2010
ERGION, Mannheim	07/2010
Fichtner IT Consulting, Stuttgart	07/2010
TF Design, Matieland, South Africa	07/2010
MCE, Berlin	07/2010, 12/2010
IPM, Zittau/Goerlitz University of Applied Sciences	06/2010
TUEV Sued, Dresden	06/2010
RWE IT, Essen	06/2010
Glen Dimplex, Kulmbach	05/2010, 07/2010 10/2010
Hot Rock, Karlsruhe	05/2010
Darmstadt University of Applied Sciences	05/2010
Voith, Heidenheim	04/2010
CombTec, Zittau	04/2010
University of Glasgow, Great Britain	04/2010
Universitaet der Bundeswehr, Munich	04/2010
Technical University of Hamburg-Harburg	04/2010
Vattenfall Europe, Berlin	04/2010
HUBER Consulting Engineers, Berching	04/2010
VER, Dresden	04/2010
CCP, Marburg	03/2010
Offenburg University of Applied Sciences	03/2010
Technical University of Berlin	03/2010
NIST Boulder CO, USA	03/2010
Technical University of Dresden	02/2010
Siemens Energy, Nuremberg	02/2010
Augsburg University of Applied Sciences	02/2010

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

2009

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

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

2008

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

2007

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

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

2006

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

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

Freudenberg Service, Weinheim	12/2004

2003

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
CompAir, Simmern	03/2002
GKS Gemeinschaftskraftwerk, Schweinfurt	04/2002
ALSTOM Power Baden, Switzerland (group licenses)	05/2002
InfraServ, Gendorf	05/2002
SoftSolutions, Muehlhausen (company license)	05/2002
DREWAG, Dresden (company license)	05/2002
SOFBID, Zwingenberg (general EBSILON program license)	06/2002
Kleemann Engineering, Dresden	06/2002
Caliqua, Basel, Switzerland (company license)	07/2002
PCK Raffinerie, Schwedt (group license)	07/2002
Fischer-Uhrig Engineering, Berlin	08/2002
Fichtner Consulting & IT, Stuttgart (company licenses and distribution)	08/2002
Stadtwerke Duisburg	08/2002
Stadtwerke Hannover	09/2002
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 (general license and training test benches)	12/2002
VEAG, Berlin (group license)	12/2002

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ALSTOM Power, Baden, Switzerland	01/2001, 06/2001 12/2001
KW2 B. V., Amersfoot, Netherlands	01/2001, 11/2001
Eco Design, Saitamaken, Japan	01/2001
M&M Turbine Technology, Bielefeld	01/2001, 09/2001
MVV Energie, Mannheim	02/2001
Technical University of Dresden, Department of Power Machinery and Plants	02/2001
PREUSSAG NOELL, Wuerzburg	03/2001
Fichtner Consulting & IT Stuttgart (company licenses and distribution)	04/2001
Muenstermann GmbH, Telgte-Westbevern	05/2001
SaarEnergie, Saarbruecken	05/2001
Siemens, Karlsruhe (general license for the WinIS information system)	08/2001
Neusiedler AG, Ulmerfeld, Austria	09/2001
h s energieanlagen, Freising	09/2001
Electrowatt-EKONO, Zurich, Switzerland	09/2001
IPM Zittau/Goerlitz University of Applied Sciences (general license)	10/2001
eta Energieberatung, Pfaffenhofen	11/2001
ALSTOM Power Baden, Switzerland	12/2001

VEAG, Berlin (group license)	12/2001

2000

SOFBID, Zwingenberg (general EBSILON program license)	01/2000
AG KKK - PGW Turbo, Leipzig	01/2000
PREUSSAG NOELL, Wuerzburg	01/2000
M&M Turbine Technology, Bielefeld	01/2000
IBR Engineering Reis, Nittendorf-Undorf	02/2000
GK, Hannover	03/2000
KRUPP-UHDE, Dortmund (company license)	03/2000
UMAG W. UDE, Husum	03/2000
VEAG, Berlin (group license)	03/2000
Thinius Engineering, Erkrath	04/2000
SaarEnergie, Saarbruecken	05/2000, 08/2000
DVO Data Processing Service, Oberhausen	05/2000
RWTH Aachen University	06/2000
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
Steinhaus Informationssysteme, Datteln (general license for process data software)	12/2000

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Bayernwerk, Munich	01/1999
DREWAG, Dresden (company license)	02/1999
KEMA IEV, Dresden	03/1999
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
M&M Turbine Technology Bielefeld	06/1998
B+H Software Engineering Stuttgart	08/1998
Alfa Engineering, Switzerland	09/1998
VEAG Berlin (group license)	09/1998
NUTEC Engineering, Bisikon, Switzerland	10/1998
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	kJ/$\mathrm{kg_a}$	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	$\mathrm{mol_a/mol}$	3/21
$\psi_{\mathrm{H2O}} = \mathrm{f}(W)$	PsiH2O_W_HAP_SI	Mole fraction of water vapor in moist air	$\mathrm{mol_w/mol}$	3/22
$\rho = \mathrm{f}(p,t,W)$	Rho_ptW_HAP_SI	Density	$\mathrm{kg/m^3}$	3/23
$s = \mathrm{f}(p,t,W)$	s_ptW_HAP_SI	Air-specific entropy	$\mathrm{kJ/(kg_a \cdot K)}$	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	$\mathrm{kJ/kg_a}$	3/32
$v = \mathrm{f}(p,t,W)$	v_ptW_HAP_SI	Air-specific volume	$\mathrm{m^3/kg_a}$	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	$\mathrm{kg_w/kg_a}$	3/34
$W = \mathrm{f}(p,t,\varphi)$	W_ptphi_HAP_SI	Humidity ratio from total pressure, temperature, and relative humidity	$\mathrm{kg_w/kg_a}$	3/35
$W = \mathrm{f}(p,t_{\mathrm{d}})$	W_ptd_HAP_SI	Humidity ratio from total pressure and dew-point temperature	$\mathrm{kg_w/kg_a}$	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	$\mathrm{kg_w/kg_a}$	3/37
$W_{\mathrm{s}} = \mathrm{f}(p,t)$	Ws_pt_HAP_SI	Saturation humidity ratio	$\mathrm{kg_w/kg_a}$	3/38
$\xi_{\mathrm{Air}} = \mathrm{f}(W)$	XiAir_W_HAP_SI	Mass fraction of dry air in moist air	$\mathrm{kg_a/kg}$	3/39
$\xi_{\mathrm{H2O}} = \mathrm{f}(W)$	XiH2O_W_HAP_SI	Mass fraction of water vapor in moist air	$\mathrm{kg_w/kg}$	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:	$0.01 \leq p \leq 10\,000$ kPa
Temperature:	$-143.15 \leq t \leq 350$ °C
Humidity ratio:	$0 \leq W \leq 10$ kg_w/kg_a
Relative humidity:	$0 \leq \varphi \leq 1$ (decimal ratio)
Dew-point temperature:	$-143.15 \leq t_d \leq 350$ °C
Wet-bulb temperature:	$-143.15 \leq t_{wb} \leq 350$ °C

Range of Validity of Transport Properties

Property	Range of Validity
Pressure:	$0.01 \leq p \leq 10\,000$ kPa
Temperature:	$-73.15 \leq t \leq 350$ °C
Humidity ratio:	$0 \leq W \leq 10$ kg_w/kg_a
Relative humidity:	$0 \leq \varphi \leq 1$ (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
$h_{\mathrm{liq}} = \mathrm{f}(p,t)$	hliq_pt_97_SI	Specific enthalpy of liquid water	kJ/kg	3/43
$h_{\mathrm{liq,s}} = \mathrm{f}(t)$	hliqs_t_97_SI	Specific enthalpy of saturated liquid water	kJ/kg	3/44
$h_{\mathrm{vap,s}} = \mathrm{f}(t)$	hvaps_t_97_SI	Specific enthalpy of saturated water vapor	kJ/kg	3/45
$p_{\mathrm{s}} = \mathrm{f}(t)$	ps_t_97_SI	Saturation pressure of water	kPa	3/46
$s_{\mathrm{liq}} = \mathrm{f}(p,t)$	sliq_pt_97_SI	Specific entropy of liquid water	kJ/(kg·K)	3/47
$s_{\mathrm{liq,s}} = \mathrm{f}(t)$	sliqs_t_97_SI	Specific entropy of saturated liquid water	kJ/(kg·K)	3/48
$s_{\mathrm{vap,s}} = \mathrm{f}(t)$	svaps_t_97_SI	Specific entropy of saturated water vapor	kJ/(kg·K)	3/49
$t_{\mathrm{s}} = \mathrm{f}(p)$	ts_p_97_SI	Saturation temperature of water	°C	3/50
$v_{\mathrm{liq}} = \mathrm{f}(p,t)$	vliq_pt_97_SI	Specific volume of liquid water	m³/kg	3/51
$v_{\mathrm{liq,s}} = \mathrm{f}(t)$	vliqs_t_97_SI	Specific volume of saturated liquid water	m³/kg	3/52
$v_{\mathrm{vap,s}} = \mathrm{f}(t)$	vvaps_t_97_SI	Specific volume of saturated water vapor	m³/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

Units

Symbol	Quantity	Unit
p	Pressure	kPa
t	Temperature	°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)

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**
$h_{\mathrm{ice,sub}} = \mathrm{f}(t)$	hicesub_t_06_SI	Specific enthalpy of saturated ice	kJ/kg	3/55
$h_{\mathrm{vap,sub}} = \mathrm{f}(t)$	hvapsub_t_95_SI	Specific enthalpy of saturated water vapor	kJ/kg	3/56
$p_{\mathrm{mel}} = \mathrm{f}(t)$	pmel_t_08_SI	Melting pressure of ice	kPa	3/57
$p_{\mathrm{sub}} = \mathrm{f}(t)$	psub_t_08_SI	Sublimation pressure of ice	kPa	3/58
$s_{\mathrm{ice,sub}} = \mathrm{f}(t)$	sicesub_t_06_SI	Specific entropy of saturated ice	kJ/(kg·K)	3/59
$s_{\mathrm{vap,sub}} = \mathrm{f}(t)$	svapsub_t_95_SI	Specific entropy of saturated water vapor	kJ/(kg·K)	3/60
$t_{\mathrm{mel}} = \mathrm{f}(p)$	tmel_p_08_SI	Melting temperature of ice	°C	3/61
$t_{\mathrm{sub}} = \mathrm{f}(p)$	tsub_p_08_SI	Sublimation temperature of ice	°C	3/62
$v_{\mathrm{ice,sub}} = \mathrm{f}(t)$	vicesub_t_06_SI	Specific volume of saturated ice	m³/kg	3/63
$v_{\mathrm{vap,sub}} = \mathrm{f}(t)$	vvapsub_t_95_SI	Specific volume of saturated water vapor	m³/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	$\frac{a_{\mathrm{IP}}}{\frac{\mathrm{ft}^2}{\mathrm{s}}} = \frac{a_{\mathrm{SI}}}{\frac{\mathrm{m}^2}{\mathrm{s}}} \times 10.76391042$	$\frac{a_{\mathrm{SI}}}{\frac{\mathrm{m}^2}{\mathrm{s}}} = \frac{a_{\mathrm{IP}}}{\frac{\mathrm{ft}^2}{\mathrm{s}}} \times 0.0929304$	m²/s	ft²/s
Relative pressure coefficient	α_p	$\frac{\alpha_{p,\mathrm{IP}}}{\frac{1}{°\mathrm{R}}} = \frac{\alpha_{p,\mathrm{SI}}}{\frac{1}{\mathrm{K}}} \times \frac{9}{5}$	$\frac{\alpha_{p,\mathrm{SI}}}{\frac{1}{\mathrm{K}}} = \frac{\alpha_{p,\mathrm{IP}}}{\frac{1}{°\mathrm{R}}} \times \frac{5}{9}$	1/K	1/°R
Isothermal stress coefficient	β_p	$\frac{\beta_{p,\mathrm{IP}}}{\frac{\mathrm{lb}}{\mathrm{ft}^3}} = \frac{\beta_{p,\mathrm{SI}}}{\frac{\mathrm{kg}}{\mathrm{m}^3}} \times 0.062428$	$\frac{\beta_{p,\mathrm{SI}}}{\frac{\mathrm{kg}}{\mathrm{m}^3}} = \frac{\beta_{p,\mathrm{IP}}}{\frac{\mathrm{lb}}{\mathrm{ft}^3}} \times 16.018463$	kg/m³	lb/ft³
Speed of sound	c	$\frac{c_{\mathrm{IP}}}{\frac{\mathrm{ft}}{\mathrm{s}}} = \frac{c_{\mathrm{SI}}}{\frac{\mathrm{m}}{\mathrm{s}}} \times 3.2808399$	$\frac{c_{\mathrm{SI}}}{\frac{\mathrm{m}}{\mathrm{s}}} = \frac{c_{\mathrm{IP}}}{\frac{\mathrm{ft}}{\mathrm{s}}} \times 0.3048$	m/s	ft/s
Specific isobaric heat capacity	c_p	$\frac{c_{p,\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb}\ °\mathrm{R}}} = \frac{c_{p,\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg\ K}}} \times 0.2388459$	$\frac{c_{p,\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg\ K}}} = \frac{c_{p,\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb}\ °\mathrm{R}}} \times 4.1868$	kJ/(kg·K)	Btu/(lb·°R)
Specific isochoric heat capacity	c_v	$\frac{c_{v,\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb}\ °\mathrm{R}}} = \frac{c_{v,\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg\ K}}} \times 0.2388459$	$\frac{c_{v,\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg\ K}}} = \frac{c_{v,\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb}\ °\mathrm{R}}} \times 4.1868$	kJ/(kg·K)	Btu/(lb·°R)
Dynamic viscosity	η	$\frac{\eta_{\mathrm{IP}}}{\frac{\mathrm{lb\ s}}{\mathrm{ft}^2}} = \frac{\eta_{\mathrm{SI}}}{\frac{\mathrm{Pa}}{\mathrm{s}}} \times 0.02088543$	$\frac{\eta_{\mathrm{SI}}}{\frac{\mathrm{Pa}}{\mathrm{s}}} = \frac{\eta_{\mathrm{IP}}}{\frac{\mathrm{lb\ s}}{\mathrm{ft}^2}} \times 47.880259$	Pa·s	lb·s/ft²
Enhancement factor	f	$f_{\mathrm{IP}} = f_{\mathrm{SI}}$	$f_{\mathrm{SI}} = f_{\mathrm{IP}}$	-	-

Property		Conversion: SI Units → I-P Units	Conversion: I-P Units → SI Units	Units SI	Units I-P
Air-specific enthalpy (moist air)	h	$\frac{h_{\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb_a}}} = \frac{h_{\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg_a}}} \times 0.4299226 + 7.68565365666$	$\frac{h_{\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg_a}}} = \left(\frac{h_{\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb_a}}} - 7.68565365666 \right) \times 2.326$	kJ/kg$_a$	Btu/lb$_a$
Specific enthalpy (water, water vapor, ice)	h_w	$\frac{h_{\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb}}} = \frac{h_{\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg}}} \times 0.4299226$	$\frac{h_{\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg}}} = \frac{h_{\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb}}} \times 2.326$	kJ/kg	Btu/lb
Isentropic exponent	κ	$\kappa_{\mathrm{IP}} = \kappa_{\mathrm{SI}}$	$\kappa_{\mathrm{SI}} = \kappa_{\mathrm{IP}}$	-	-
Thermal conductivity	λ	$\frac{\lambda_{\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{h\ ft\ °R}}} = \frac{\lambda_{\mathrm{SI}}}{\frac{\mathrm{W}}{\mathrm{m\ K}}} \times 0.57778932$	$\frac{\lambda_{\mathrm{SI}}}{\frac{\mathrm{W}}{\mathrm{m\ K}}} = \frac{\lambda_{\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{h\ ft\ °R}}} \times 1.73073467$	W/(m·K)	Btu/(h·ft·°R)
Kinematic viscosity	ν	$\frac{\nu_{\mathrm{IP}}}{\frac{\mathrm{ft^2}}{\mathrm{s}}} = \frac{\nu_{\mathrm{SI}}}{\frac{\mathrm{m^2}}{\mathrm{s}}} \times 10.763910417$	$\frac{\nu_{\mathrm{SI}}}{\frac{\mathrm{m^2}}{\mathrm{s}}} = \frac{\nu_{\mathrm{IP}}}{\frac{\mathrm{ft^2}}{\mathrm{s}}} \times 0.092903040$	m^2/s	ft^2/s
Pressure	p	$\frac{p_{\mathrm{IP}}}{\mathrm{psi}} = \frac{p_{\mathrm{SI}}}{\mathrm{kPa}} \times 0.14503774$	$\frac{p_{\mathrm{SI}}}{\mathrm{kPa}} = \frac{p_{\mathrm{IP}}}{\mathrm{psi}} \times 6.894757$	kPa	psi
Relative humidity	φ	$\varphi_{\mathrm{IP}} = \varphi_{\mathrm{SI}}$	$\varphi_{\mathrm{SI}} = \varphi_{\mathrm{IP}}$	-	-
Prandtl number	Pr	$Pr_{\mathrm{IP}} = Pr_{\mathrm{IP}}$	$Pr_{\mathrm{SI}} = Pr_{\mathrm{IP}}$	-	-
Mole fraction	ψ	$\psi_{\mathrm{IP}} = \psi_{\mathrm{SI}}$	$\psi_{\mathrm{SI}} = \psi_{\mathrm{IP}}$	mol/mol	mol/mol
Density	ρ	$\frac{\rho_{\mathrm{IP}}}{\frac{\mathrm{lb}}{\mathrm{ft^3}}} = \frac{\rho_{\mathrm{SI}}}{\frac{\mathrm{kg}}{\mathrm{m^3}}} \times 0.062428$	$\frac{\rho_{\mathrm{SI}}}{\frac{\mathrm{kg}}{\mathrm{m^3}}} = \frac{\rho_{\mathrm{IP}}}{\frac{\mathrm{lb}}{\mathrm{ft^3}}} \times 16.018463$	kg/m^3	lb/ft^3
Air-specific entropy (moist air)	s	$\frac{s_{\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb_a\ °R}}} = \frac{s_{\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg_a\ K}}} \times 0.2388459 + 0.01616365106$	$\frac{s_{\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg_a\ K}}} = \left(\frac{s_{\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb_a\ °R}}} - 0.01616365106 \right) \times 4.1868$	kJ/(kg$_a$·K)	Btu/(lb$_a$·°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	$\frac{s_{IP}}{\frac{\mathrm{Btu}}{\mathrm{lb_a\ °R}}} = \frac{s_{SI}}{\frac{\mathrm{kJ}}{\mathrm{kg_a\ K}}} \times 0.23884589$	$\frac{s_{SI}}{\frac{\mathrm{kJ}}{\mathrm{kg_a\ K}}} = \frac{s_{IP}}{\frac{\mathrm{Btu}}{\mathrm{lb_a\ °R}}} \times 4.1868$	$\mathrm{kJ/(kg_a{\cdot}K)}$	$\mathrm{Btu/(lb_a{\cdot}°R)}$
Temperature	t	$\frac{t_{IP}}{\mathrm{°F}} = \frac{t_{SI}}{\mathrm{°C}} \times \frac{9}{5} + 32$	$\frac{t_{SI}}{\mathrm{°C}} = \left(\frac{t_{IP}}{\mathrm{°F}} - 32\right) \times \frac{5}{9}$	°C	°F
Air-specific internal energy (moist air)	u	$(u = h - pv)$ $\frac{u_{IP}}{\frac{\mathrm{Btu}}{\mathrm{lb_a}}} = \frac{h_{SI}}{\frac{\mathrm{kJ}}{\mathrm{kg_a}}} \times 0.4299226 + 7.68565365666$ $- \frac{p_{SI}}{\mathrm{kPa}} \times 0.145037738 \cdot \frac{v_{SI}}{\frac{\mathrm{m^3}}{\mathrm{kg_a}}} \times 16.018453$	$(u = h - pv)$ $\frac{u_{SI}}{\frac{\mathrm{kJ}}{\mathrm{kg_a}}} = \left(\frac{h_{IP}}{\frac{\mathrm{Btu}}{\mathrm{lb_a}}} - 7.68565365666\right) \times 2.236$ $- \frac{p_{IP}}{\mathrm{psi}} \times 6.894757293 \cdot \frac{v_{SIP}}{\frac{\mathrm{ft^3}}{\mathrm{lb_a}}} \times 0.062428$	$\mathrm{kJ/kg_a}$	Btu/lb
Air-specific volume (moist air)	v	$\frac{v_{IP}}{\frac{\mathrm{ft^3}}{\mathrm{lb_a}}} = \frac{v_{SI}}{\frac{\mathrm{m^3}}{\mathrm{kg_a}}} \times 16.018453$	$\frac{v_{SI}}{\frac{\mathrm{m^3}}{\mathrm{kg_a}}} = \frac{v_{IP}}{\frac{\mathrm{ft^3}}{\mathrm{lb_a}}} \times 0.062428$	$\mathrm{m^3/kg_a}$	$\mathrm{ft^3/lb_a}$
Specific volume (water, water vapor, ice)	v_w	$\frac{v_{IP}}{\frac{\mathrm{ft^3}}{\mathrm{lb}}} = \frac{v_{SI}}{\frac{\mathrm{m^3}}{\mathrm{kg}}} \times 16.018453$	$\frac{v_{SI}}{\frac{\mathrm{m^3}}{\mathrm{kg}}} = \frac{v_{IP}}{\frac{\mathrm{ft^3}}{\mathrm{lb}}} \times 0.062428$	$\mathrm{m^3/kg}$	$\mathrm{ft^3/lb}$
Humidity ratio	W	$W_{IP} = W_{SI}$	$W_{SI} = W_{IP}$	$\mathrm{kg_w/kg_a}$	$\mathrm{lb_w/lb_a}$
Mass fraction	ξ	$\xi_{IP} = \xi_{SI}$	$\xi_{SI} = \xi_{IP}$	$\mathrm{kg_w/kg}$	$\mathrm{lb_w/lb}$
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, Kretzschmar, Aute, Gatley, and Vogel [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 $p_\mathrm{s}^{97}(t)$ and saturation temperature equation $t_\mathrm{s}^{97}(p)$.
- 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 $p_\mathrm{subl}^{08}(t)$ [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.

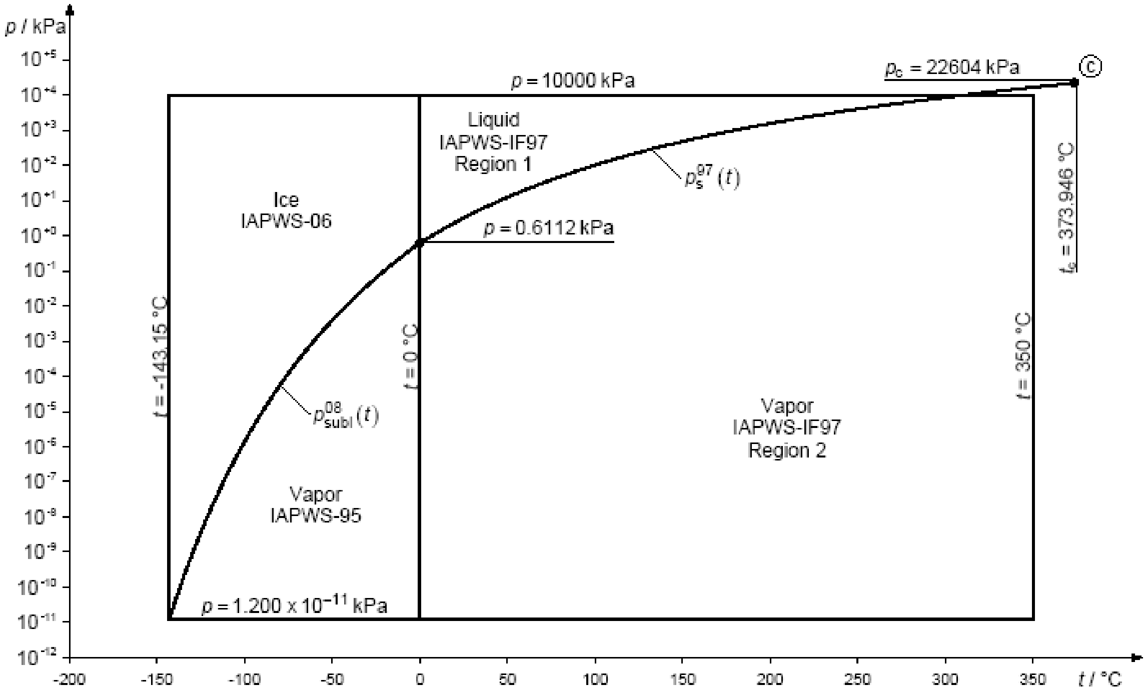


Figure 1: *p*-*T* diagram with used IAPWS formulations for steam, water, and ice.

2 Add-In FluidEXL^{Graphics} for Excel® for ASHRAE-LibHuAirProp-SI

2.1 Installing FluidEXL^{Graphics}

The FluidEXL^{Graphics} Add-In has been developed to calculate thermophysical properties in Excel® more conveniently. Within Excel®, it enables the direct call of functions relating to real moist air, steam, water, and ice from the ASHRAE-LibHuAirProp-SI property library.

The installation of FluidEXL^{Graphics} and ASHRAE-LibHuAirProp_SI is described in Section 2.1 in "Part I-P Units" of this User's Guide.

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

We will now calculate, step by step, the air-specific enthalpy h of real moist air as a function of total pressure p, temperature t and humidity ratio W, using FluidEXL^{Graphics}. The following description relates to Excel® 2003. The procedure is analogous for Excel® 97, 2000, XP, and 2007.

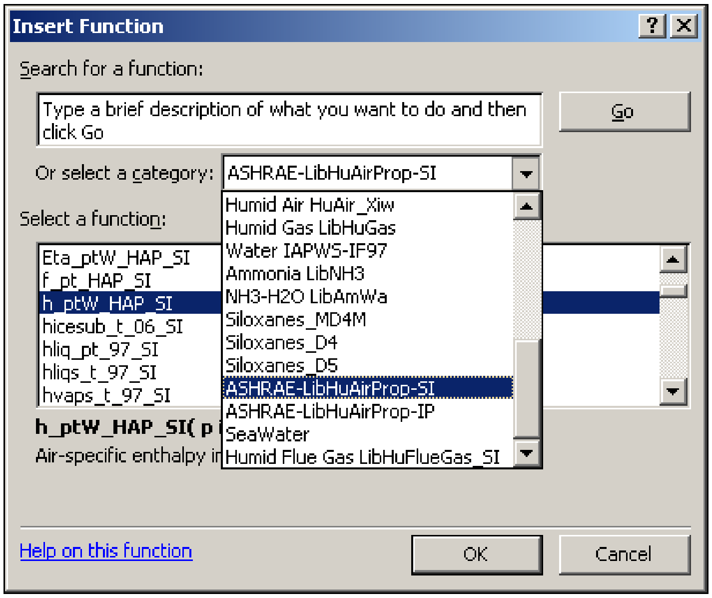
Please carry out the following steps:

- Start Excel®
- Enter the value for p in kPa into a cell
  (Range of validity: p = 0.01 … 10 000 kPa

  ⇒ e.g.: Enter the value 101.325 into cell A2
- Enter the value for t in °C into a cell
  (Range of validity: t = –143.15 ... 350°C)

  ⇒ e.g.: Enter the value 20 into cell B2
- Enter the value for W in kg_w/kg_a (*kg water* per *kg air*) into a cell
  (Range of validity: W = 0 … 10 kg_w/kg_a)

  ⇒ e.g.: Enter the value 0.01 into cell C2
- Click the cell in which the air-specific enthalpy h in kJ/kg_a is to be displayed
  ⇒ e.g.: Click the cell D2
- Click "Calculate" in the FluidEXL^{Graphics} menu bar
  The "Insert Function" window appears (see Figure 2.1.1.)



Search for a function:

Type a brief description of what you want to do and then click Go

Or select a category: ASHRAE-LibHuAirProp-SI

Humid Air HuAir_Xiw
Humid Gas LibHuGas
Water IAPWS-IF97
Ammonia LibNH3
NH3-H2O LibAmWa
Siloxanes_MD4M
Siloxanes_D4
Siloxanes_D5
ASHRAE-LibHuAirProp-SI
ASHRAE-LibHuAirProp-IP
SeaWater
Humid Flue Gas LibHuFlueGas_SI

Select a function:

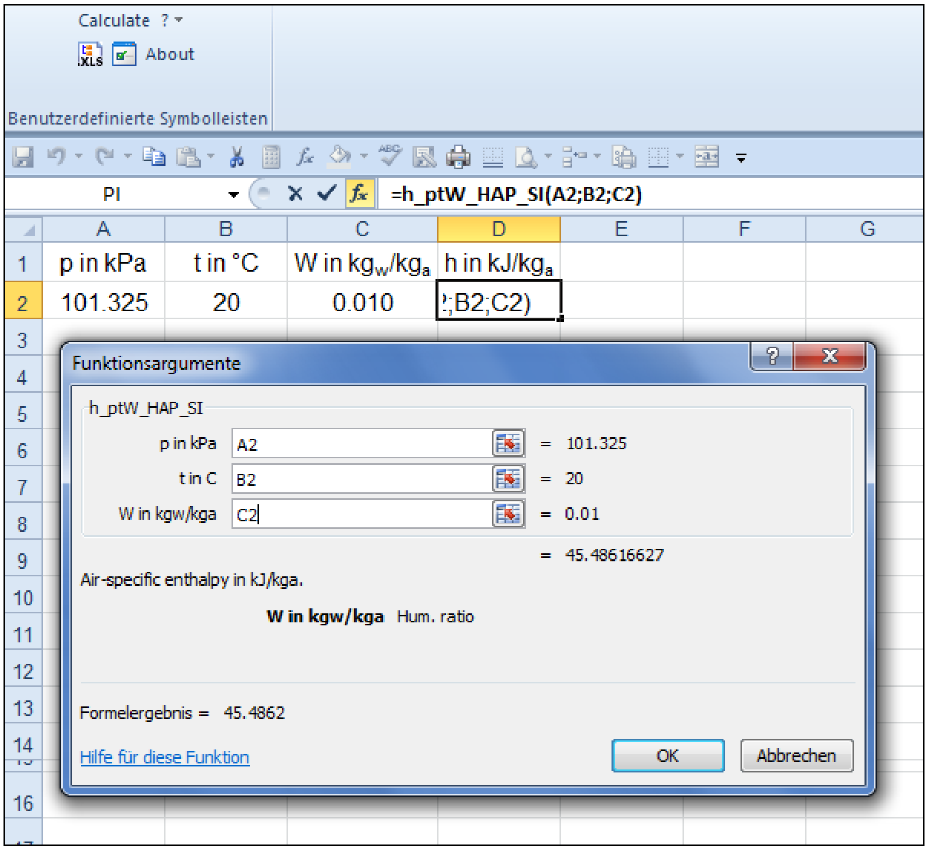
Eta_ptW_HAP_SI
f_pt_HAP_SI
h_ptW_HAP_SI
hicesub_t_06_SI
hliq_pt_97_SI
hliqs_t_97_SI
hvaps_t_97_SI

h_ptW_HAP_SI(p i

Air-specific enthalpy i

Figure 2.1.1: Choosing the library and function name

- Search and click the "ASHRAE-LibHuAirProp-SI" library under "Or select a category:" in the upper part of the window
- Search and click the "h_ptW_HAP_SI" function under "Select a function:" right below
- Click the "OK" button
  The "Function Arguments" menu for the function "h_ptW_HAP_SI" in the next figure will now appear.



=h_ptW_HAP_SI(A2;B2;C2)

	A	B	C	D
1	p in kPa	t in °C	W in kg_w/kg_a	h in kJ/kg_a
2	101.325	20	0.010	;B2;C2)

h_ptW_HAP_SI

p in kPa A2 = 101.325
t in C B2 = 20
W in kgw/kga C2 = 0.01
= 45.48616627

Air-specific enthalpy in kJ/kga.

W in kgw/kga Hum. ratio

Formelergebnis = 45.4862

Figure 2.1.2: Input menu for the function

- The cursor is now situated on the line next to "p in kPa". You can now enter the value for the mixture pressure p either by clicking the cell with the value for p, by entering the name of the cell, or by entering the value for p directly into the line next to "p in kPa".

  ⇒ e. g.: Click the cell A2

- Situate the cursor on the line next to "t in °C" and enter the value for t either by clicking the cell with the value for t, by entering the name of the cell, or by entering the value for t directly into the line next to "t in °C".

  ⇒ e. g.: Type B2 into the line next to "t in °C"

- Situate the cursor on the line next to "W in kg_w/kg_a" and enter the value for the humidity ratio W either by clicking the cell with the value for W, by entering the name of the cell, or by entering the value for W directly into the line next to "W in kg_w/kg_a.

  ⇒ e. g.: Click the cell C2

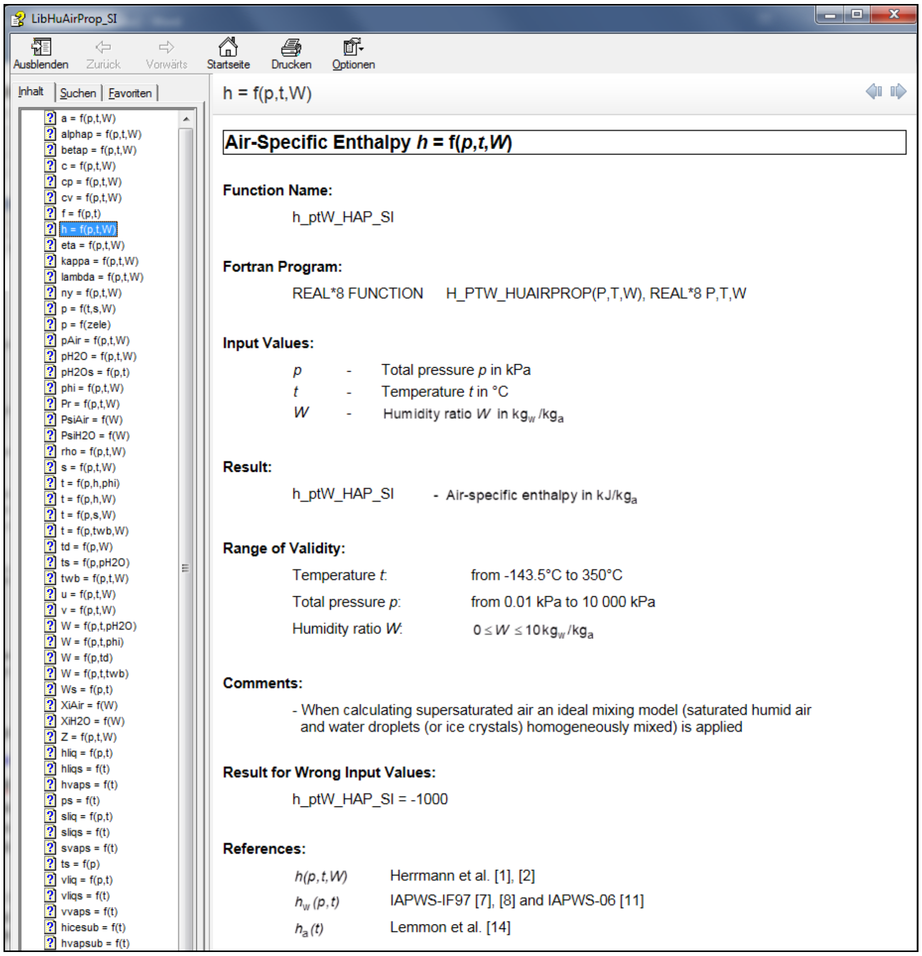
- Here it is possible to get detailed information on the "h_ptW_HAP_SI" property function.
- Click the blue "Help on this function" link in the lower left-hand edge of the "Function Arguments" window.

You may be informed that the "LibHuAirProp_SI.chm" function help cannot be found. In this case, confirm the question whether you want to look for it yourself with "Yes". Search and click on the "LibHuAirProp_SI.chm" file in the installation menu of FluidEXL*Graphics* in the window which is opened, in the standard case

C:\Program Files\FluidEXL_Graphics_Eng

and click "Yes" in order to complete the search.

- Now you should see the help page of the "h_ptW_HAP_SI" property function (see Figure 2.1.3).



h = f(p,t,W)

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]

Figure 2.1.3: Help page for the "h_ptW_HAP_SI" function

- Click the "OK" button

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

⇒ The cell D2 now contains the value 45.48616627.

The calculation of $h = f(p,t,W)$ has thus been completed.

You can now arbitrarily change the values for p, t or W in the appropriate cells. The specific enthalpy h is recalculated and updated every time you change the data. This shows that the Excel® data flow and the DLL calculations are working together successfully

Note:

If the calculation results in −1000, this indicates that the values entered are located outside the range of validity of real moist air. More detailed information on each function and its range of validity is available in Chapter 3.

For further property functions calculable in FluidEXL*Graphics* see the function table in Chapter 1.

2.3 Removing FluidEXL*Graphics* including LibHuAirProp

The de-installation of FluidEXL*Graphics* 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 $\mathrm{kg_w/kg_a}$

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:	$0 \le W \le W_\mathrm{s}$

Comments:

- Thermal diffusivity $a = \dfrac{\lambda}{\rho \cdot c_p}$
- Calculation for supersaturated humid air ($W > W_\mathrm{s}$) 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 $\mathrm{kg_w/kg_a}$

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 $\mathrm{kg_w/kg_a}$

Result:

betap_ptW_HAP_SI - Isothermal stress coefficient of humid air in $\mathrm{kg/m^3}$

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 $\mathrm{kg_w/kg_a}$

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

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 $\mathrm{kg_w/kg_a}$

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:	$0 \leq W \leq W_\mathrm{s}$

Comments:

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

- Calculation for supersaturated humid air ($W > W_\mathrm{s}$) 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 $f = \dfrac{p_{\mathrm{H2O,s}}}{p_{\mathrm{s}}(t)}$

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 $\mathrm{kg_w/kg_a}$

Result:

h_ptW_HAP_SI - Air-specific enthalpy in $\mathrm{kJ/kg_a}$

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

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 $\mathrm{kg_w/kg_a}$

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

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]
$\eta_\mathrm{a}(t)$	Lemmon et al. [18]
$\eta_\mathrm{w}(p,t)$	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 $t \geq 0.01$°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 $\lambda = \mathrm{f}(p,t,W)$

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 $\mathrm{kg_w/kg_a}$

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

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 $\mathrm{kg_w/kg_a}$

Result:

Ny_ptW_HAP_SI - Kinematic viscosity in $\mathrm{m^2/s}$

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 $p = \mathrm{f}(z_{\mathrm{ele}})$

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

Result for Wrong Input Values:

p_zele_HAP_SI = -1000

References:

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

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

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 $\mathrm{kg_w/kg_a}$

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

Comments:

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

Result for Wrong Input Values:

pAir_ptW_HAP_SI = -1000

References:

$p_{\mathrm{H2O}}(p,W)$ 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 $\mathrm{kg_w/kg_a}$

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

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 $p_{\mathrm{H2O,s}}$ = 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 $p_{\mathrm{H2O,s}} = f \cdot p_{\mathrm{s}}(t)$

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

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

Result for Wrong Input Values:

pH2Os_pt_HAP_SI = -1000

References:

$f(p,t)$		Herrmann et al. [1], [2]
$p_{\mathrm{s}}(t)$	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 $\mathrm{kg_w/kg_a}$

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

Comments:

- Relative humidity $\varphi = \dfrac{p_{\mathrm{H2O}}}{p_{\mathrm{H2O,s}}}$
- This equation is valid for $p_{\mathrm{H2O}} \le p_{\mathrm{H2O,s}}$ 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 $\mathrm{kg_w/kg_a}$

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

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 $\mathrm{kg_w/kg_a}$

Result:

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

Range of Validity:

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

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 $\mathrm{kg_w/kg_a}$

Result:

Rho_ptW_HAP_SI - Density of humid air in $\mathrm{kg/m^3}$

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

Comments:

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

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 $\mathrm{kg_w/kg_a}$

Result:

s_ptW_HAP_SI - Air-specific entropy in kJ/($\mathrm{kg_a}$ 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:	$0 \le W \le 10\,\mathrm{kg_w/kg_a}$

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 $\mathrm{kJ/kg_a}$
W	-	Humidity ratio W in $\mathrm{kg_w/kg_a}$

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 $\mathrm{kJ/kg_a}$ to 29690 $\mathrm{kJ/kg_a}$
Humidity ratio W:	$0 \leq W \leq 10\,\mathrm{kg_w/kg_a}$

Comments:

- Iteration of temperature t from $h = \mathrm{f}(p,t,W)$

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

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 $\mathrm{kg_w/kg_a}$

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

Comments:

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

Result for Wrong Input Values:

t_ptwbW_HAP_SI = -1000

References:

$t_{\mathrm{wb}}(p,t,W)$ 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 $\mathrm{kg_w/kg_a}$

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

Comments:

Dew-point temperature $t_d = t_s(p_{H2O})$ for $t \ge 0.01°\mathrm{C}$ (saturation temperature of water in humid air)

$t_d = t_{sub}(p_{H2O})$ for $t \le 0.01°\mathrm{C}$ (sublimation temperature of water in humid air)

Result for Wrong Input Values:

td_pW_HAP_SI = -1000

References:

$t_s(p_{H2O})$	for $t_d \ge 0.01°\mathrm{C}$	IAPWS-IF97 [7], [8]
$t_{sub}(p_{H2O})$	for $t_d \le 0.01°\mathrm{C}$	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 $h^{\text{unsaturated}}(p,t,W) = h^{\text{fog}}(p,t_{wb},W)$
- 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 $\mathrm{kg_w/kg_a}$

Result:

u_ptW_HAP_SI - Air-specific internal energy in $\mathrm{kJ/kg_a}$

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

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 $\mathrm{kg_w/kg_a}$

Result:

v_ptW_HAP_SI - Air-specific volume in $\mathrm{m^3/kg_a}$

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

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 $W = f(p, t, \varphi)$

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 $\mathrm{kg_w/kg_a}$

Result:

XiAir_W_HAP_SI - Mass fraction of (dry) air in humid air in $\mathrm{kg_a/kg}$

Range of Validity:

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

Comments:

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

Result for Wrong Input Values:

XiAir_W_HAP_SI = -1000

References:

$\xi_{\mathrm{Air}}(W)$ 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 $\mathrm{kg_w/kg_a}$

Result:

XiH2O_W_HAP_SI	- Mass fraction of water vapor in humid air in $\mathrm{kg_w/kg}$

Range of Validity:

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

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 $\mathrm{kg_w/kg_a}$

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:	$0 \le W \le W_\mathrm{s}$

Comments:

- Compression factor $Z = 1 + \frac{B_\mathrm{m}}{\bar{v}} + \frac{C_\mathrm{m}}{\bar{v}^2}$

  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 ($W > W_\mathrm{s}$) is not possible

Result for Wrong Input Values:

Z_ptW_HAP_SI = -1000

References:

$B_\mathrm{m}(t,W), C_\mathrm{m}(t,W)$	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 $h_{\text{liq}} = \text{f}(p,t)$

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 $p_{\text{s}}(0°\text{C}) = 0.6112$ kPa to 10000 kPa

Temperature t: from 0°C to 350°C

Comments:

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

Result for Wrong Input Values:

hliqs_t_97_SI = -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_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 $s_{\text{liq}} = f(p,t)$

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 $p_s(0°\text{C}) = 0.6112$ kPa to 10 000 kPa

Temperature t: from 0°C to 350°C

Comments:

- Specific entropy of liquid water $s_{\text{liq}} = s^{97}(p,t)$ (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 $s_{\mathrm{liq,s}} = \mathrm{f}(t)$

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 $s_{\mathrm{liq,s}} = s^{97}(p_{\mathrm{s}}, t)$ (Region 1)
  with $p_{\mathrm{s}} = p_{\mathrm{s}}^{97}(t)$

Result for Wrong Input Values:

sliqs_t_97_SI = -1000

References:

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

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

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 $v_{\text{liq}} = \text{f}(p,t)$

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 $p_\text{s}(0°\text{C}) = 0.6112$ kPa to 10 000 kPa
Temperature t:	from 0°C to 350°C

Comments:

- Specific volume of liquid water $v_{\text{liq}} = v^{97}(p,t)$ (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 $v_{\mathrm{liq,s}}$ = 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 $v_{\mathrm{vap,s}} = \mathrm{f}(t)$

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 $v_{\mathrm{vap,s}} = v^{97}(p_{\mathrm{s}}, t)$ (Region 2) with $p_{\mathrm{s}} = p_{\mathrm{s}}^{97}(t)$

Result for Wrong Input Values:

vvaps_t_97_SI = -1000

References:

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

3.3 Functions for Steam and Ice for Temperatures *t* ≤ 0°C

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

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 $h_{\mathrm{ice,sub}} = h^{06}(p_{\mathrm{sub}}, t)$
  with $p_{\mathrm{sub}} = p_{\mathrm{sub}}^{08}(t)$

Result for Wrong Input Values:

hicesub_t_06_SI = -1000

References:

$h^{06}(p,t)$	IAPWS-06 [10]
$p_{\mathrm{sub}}^{08}(t)$	IAPWS-08 [11]

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

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 $h_{\mathrm{vap,sub}} = h^{95}(p_{\mathrm{sub}}, t)$
  with $p_{\mathrm{sub}} = p_{\mathrm{sub}}^{08}(t)$

Result for Wrong Input Values:

hvapsub_t_95_SI = -1000

References:

$h^{95}(p,t)$	IAPWS-95 [5], [6]
$p_{\mathrm{sub}}^{08}(t)$	IAPWS-08 [11]

Melting Pressure $p_{\mathrm{mel}} = \mathrm{f}(t)$

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:

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

Sublimation Pressure $p_{\text{sub}} = \text{f}(t)$

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:

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

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

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 $s_{\mathrm{ice,sub}} = s^{06}(p_{\mathrm{sub}}, t)$
  with $p_{\mathrm{sub}} = p_{\mathrm{sub}}^{08}(t)$

Result for Wrong Input Values:

sicesub_t_06_SI = -1000

References:

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

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

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

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 $s_{\mathrm{vap,sub}} = s^{95}(p_{\mathrm{sub}}, t)$

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

Result for Wrong Input Values:

svapsub_t_95_SI = -1000

References:

$s^{95}(p,t)$	IAPWS-95 [7], [8]
$p_{\mathrm{sub}}^{08}(t)$	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 $p_{\mathrm{s}}(0°\mathrm{C}) = 0.6112$ kPa to 10 000 kPa

Result for Wrong Input Values:

tmel_p_08_SI = -1000

References:

$t_{\mathrm{mel}}^{08}(p)$ 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 $v_{\text{ice,sub}} = \mathrm{f}(t)$

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 $v_{\text{ice,sub}} = v^{06}(p_{\text{sub}}, t)$
  with $p_{\text{sub}} = p_{\text{sub}}^{08}(t)$

Result for Wrong Input Values:

vicesub_t_06_SI = -1000

References:

$v^{06}(p,t)$	IAPWS-06 [10]
$p_{\text{sub}}^{08}(t)$	IAPWS-08 [11]

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

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 $v_{\mathrm{vap,sub}} = v^{95}(p_{\mathrm{sub}}, t)$ with $p_{\mathrm{sub}} = p_{\mathrm{sub}}^{08}(t)$

Result for Wrong Input Values:

vvapsub_t_95_SI = -1000

References:

$v^{95}(p,t)$	IAPWS-95 [7], [8]
$p_{\mathrm{sub}}^{08}(t)$	IAPWS-08 [11]

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 Thermodynamic 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
Ne
N_2
O_2
CO
CO_2
Air

NO
H_2O
SO_2
H_2
H_2S
OH

He
F_2
NH_3
Methane
Ethane
Ethylene

Propylene
Propane
Iso-Butane
n-Butane
Benzene
Methanol

Consideration of:

- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

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

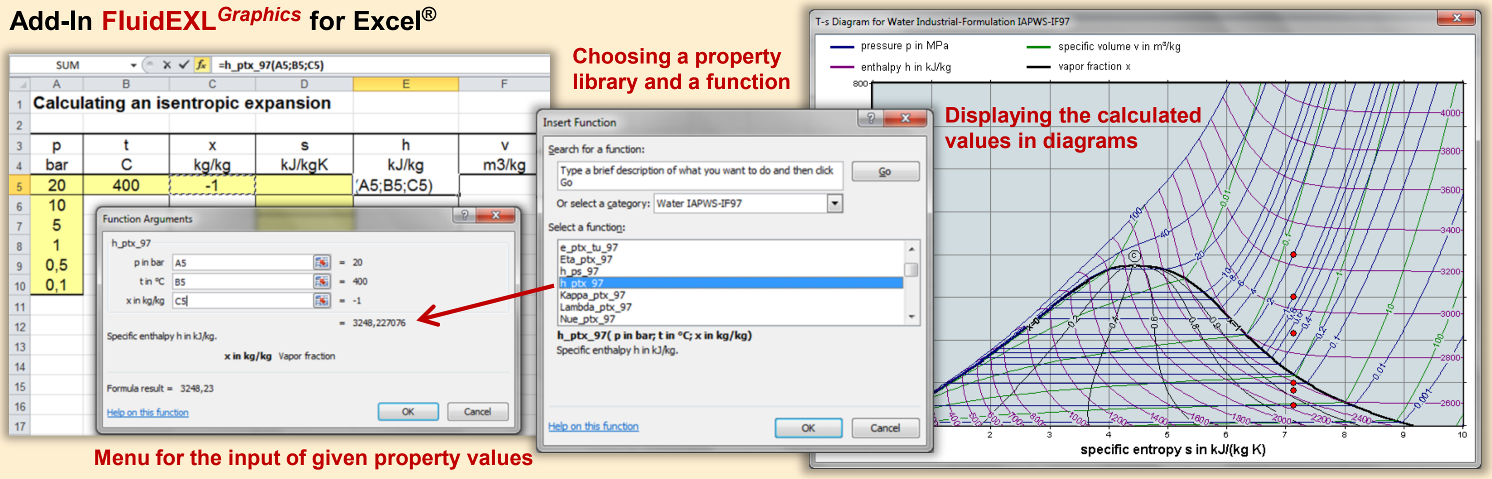
KCE ThermoFluidProperties

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®



Choosing a property library and a function

Displaying the calculated values in diagrams

Menu for the input of given property values

SUM =h_ptx_97(A5;B5;C5)

	A	B	C	D	E	F
1	Calculating an isentropic expansion					
2						
3	p	t	x	s	h	v
4	bar	C	kg/kg	kJ/kgK	kJ/kg	m3/kg
5	20	400	-1		(A5;B5;C5)	
6	10					
7	5					
8	1					
9	0,5					
10	0,1					

Function Arguments

h_ptx_97

p in bar: A5 = 20

t in °C: B5 = 400

x in kg/kg: C5 = -1

= 3248,227076

Specific enthalpy h in kJ/kg.

x in kg/kg Vapor fraction

Formula result = 3248,23

Insert Function

Search for a function: Type a brief description of what you want to do and then click Go

Or select a category: Water IAPWS-IF97

Select a function:

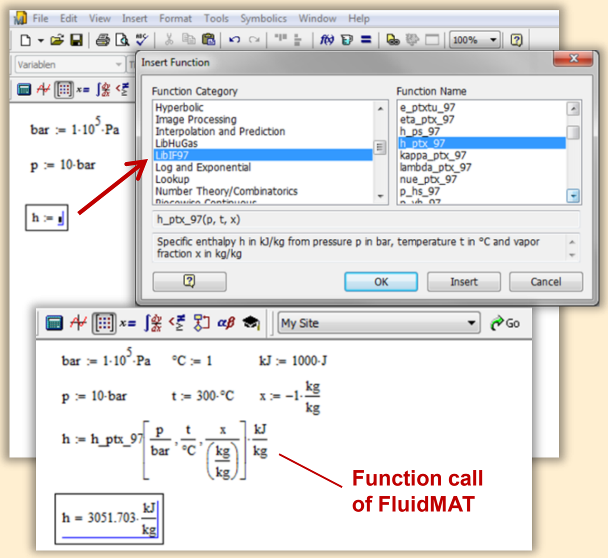
- e_ptx_tu_97
- Eta_ptx_97
- h_ps_97
- h_ptx_97
- Kappa_ptx_97
- Lambda_ptx_97
- Nue_ptx_97

h_ptx_97(p in bar; t in °C; x in kg/kg)

Specific enthalpy h in kJ/kg.

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

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



Function call of FluidMAT

$bar := 1 \cdot 10^5 \cdot Pa$

$p := 10 \cdot bar$

$h :=$

Insert Function

Function Category:

- Hyperbolic
- Image Processing
- Interpolation and Prediction
- LibHuGas
- LibIF97
- Log and Exponential
- Lookup
- Number Theory/Combinatorics

Function Name:

- e_ptxtu_97
- eta_ptx_97
- h_ps_97
- h_ptx_97
- kappa_ptx_97
- lambda_ptx_97
- nue_ptx_97
- p_hs_97

h_ptx_97(p, t, x)

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

$bar := 1 \cdot 10^5 \cdot Pa \qquad °C := 1 \qquad kJ := 1000 \cdot J$

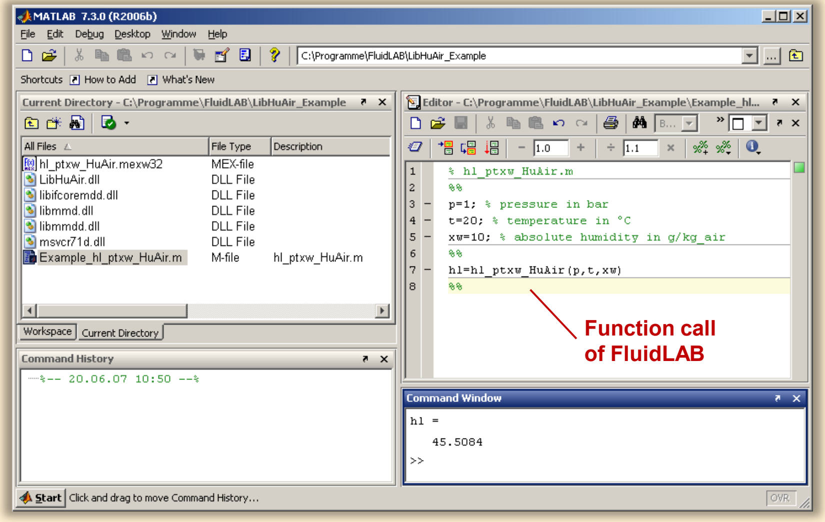
$p := 10 \cdot bar \qquad t := 300 \cdot °C \qquad x := -1 \cdot \frac{kg}{kg}$

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

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

Add-On FluidLAB for MATLAB® and SIMULINK®

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



Function call of FluidLAB

MATLAB 7.3.0 (R2006b)

Current Directory - C:\Programme\FluidLAB\LibHuAir_Example

All Files	File Type	Description
hl_ptxw_HuAir.mexw32	MEX-file	
LibHuAir.dll	DLL File	
libifcoremdd.dll	DLL File	
libmmd.dll	DLL File	
libmmdd.dll	DLL File	
msvcr71d.dll	DLL File	
Example_hl_ptxw_HuAir.m	M-file	hl_ptxw_HuAir.m

Editor - C:\Programme\FluidLAB\LibHuAir_Example\Example_hl...

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

Command History

```
%-- 20.06.07 10:50 --%
```

Command Window

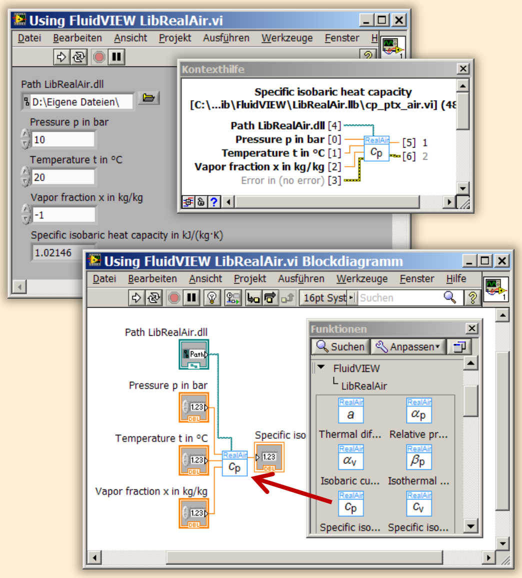
```
hl =

   45.5084

>>
```

Add-On FluidVIEW for LabVIEW™

The property functions can be calculated in LabVIEW™.



Using FluidVIEW LibRealAir.vi

Path LibRealAir.dll: D:\Eigene Dateien\

Pressure p in bar: 10

Temperature t in °C: 20

Vapor fraction x in kg/kg: -1

Specific isobaric heat capacity in kJ/(kg·K): 1.02146

Kontexthilfe

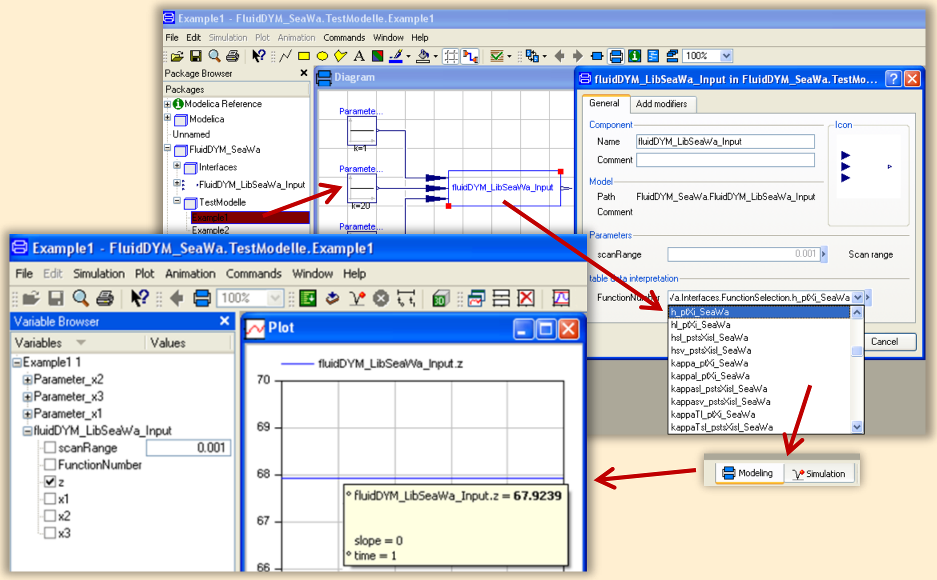
Specific isobaric heat capacity
[C:\...ib\FluidVIEW\LibRealAir.llb\cp_ptx_air.vi] (48

Path LibRealAir.dll [4]
Pressure p in bar [0]
Temperature t in °C [1]
Vapor fraction x in kg/kg [2]
Error in (no error) [3]
[5] 1
[6] 2

Using FluidVIEW LibRealAir.vi Blockdiagramm

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

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



Example1 - FluidDYM_SeaWa.TestModelle.Example1

Package Browser

- Modelica Reference
- Modelica
- Unnamed
- FluidDYM_SeaWa
  - Interfaces
  - FluidDYM_LibSeaWa_Input
  - TestModelle
    - Example1
    - Example2

fluidDYM_LibSeaWa_Input in FluidDYM_SeaWa.TestMo...

Component
Name: fluidDYM_LibSeaWa_Input
Comment:

Model
Path: FluidDYM_SeaWa.FluidDYM_LibSeaWa_Input
Comment:

Parameters
scanRange: 0.001 Scan range

table data interpretation
FunctionNumber: /a.Interfaces.FunctionSelection.h_pXi_SeaWa

- h_pXi_SeaWa
- hl_pXi_SeaWa
- hsl_pstsXisl_SeaWa
- hsv_pstsXisl_SeaWa
- kappa_pXi_SeaWa
- kappal_pXi_SeaWa
- kappasl_pstsXisl_SeaWa
- kappasv_pstsXisl_SeaWa
- kappaTl_pXi_SeaWa
- kappaTsl_pstsXisl_SeaWa

Variable Browser

Variables	Values
Example1 1	
Parameter_x2	
Parameter_x3	
Parameter_x1	
fluidDYM_LibSeaWa_Input	
☐ scanRange	0.001
☐ FunctionNumber	
☑ z	
☐ x1	
☐ x2	
☐ x3	

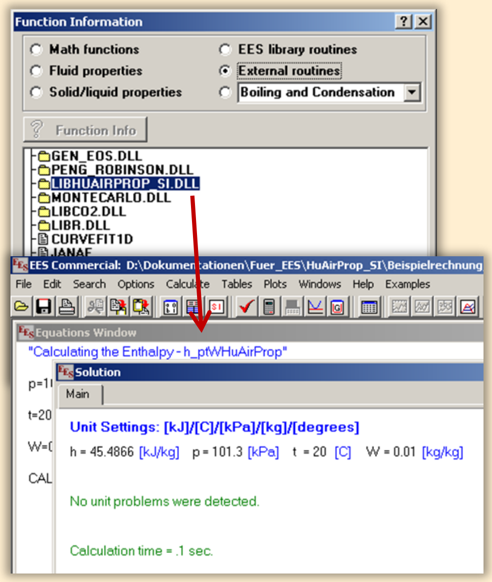
Plot

fluidDYM_LibSeaWa_Input.z = 67.9239

slope = 0

time = 1

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



Function Information

○ Math functions
○ Fluid properties
○ Solid/liquid properties
○ EES library routines
● External routines
○ Boiling and Condensation

EES Commercial: D:\Dokumentationen\Fuer_EES\HuAirProp_SI\Beispielrechnung

"Calculating the Enthalpy - h_ptWHuAirProp"

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

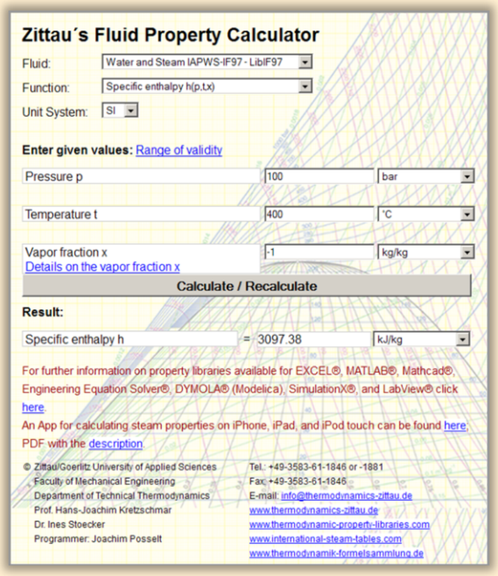
h = 45.4866 [kJ/kg]   p = 101.3 [kPa]   t = 20 [C]   W = 0.01 [kg/kg]

No unit problems were detected.

Calculation time = .1 sec.

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

Online Property Calculator at www.thermofluidprop.com



Zittau´s Fluid Property Calculator

Fluid: Water and Steam IAPWS-IF97 - LibIF97
Function: Specific enthalpy h(p,t,x)
Unit System: SI

Enter given values: Range of validity

Pressure p 100 bar
Temperature t 400 °C
Vapor fraction x -1 kg/kg
Details on the vapor fraction x

Result:

Specific enthalpy h = 3097.38 kJ/kg

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

An App for calculating steam properties on iPhone, iPad, and iPod touch can be found here; PDF with the description.

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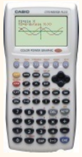
www.thermodynamics-zittau.de
www.thermodynamic-property-libraries.com
www.international-steam-tables.com
www.thermodynamik-formelsammlung.de

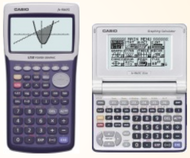
Property Software for Pocket Calculators

FluidCasio

fx 9750 G II



CFX 9850
fx-GG20



CFX 9860 G
Graph 85

ALGEBRA
FX 2.0

FluidHP

HP 48

HP 49

FluidTI

TI Nspire CX CAS
TI Nspire CAS

TI 83
TI 84
TI 89

TI Voyage 200

TI 92

For more information please contact:

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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

[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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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
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GMVA Oberhausen	07/2019
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Midiplan, Bietigheim-Bissingen	06/2019
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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)	05/2012
via Fichtner IT Consult	
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
Hannover University of Applied Sciences	08/2010
ERGION, Mannheim	07/2010
Fichtner IT Consulting, Stuttgart	07/2010
TF Design, Matieland, South Africa	07/2010
MCE, Berlin	07/2010, 12/2010
IPM, Zittau/Goerlitz University of Applied Sciences	06/2010
TUEV Sued, Dresden	06/2010
RWE IT, Essen	06/2010
Glen Dimplex, Kulmbach	05/2010, 07/2010 10/2010
Hot Rock, Karlsruhe	05/2010
Darmstadt University of Applied Sciences	05/2010
Voith, Heidenheim	04/2010
CombTec, Zittau	04/2010
University of Glasgow, Great Britain	04/2010
Universitaet der Bundeswehr, Munich	04/2010
Technical University of Hamburg-Harburg	04/2010
Vattenfall Europe, Berlin	04/2010
HUBER Consulting Engineers, Berching	04/2010
VER, Dresden	04/2010
CCP, Marburg	03/2010
Offenburg University of Applied Sciences	03/2010
Technical University of Berlin	03/2010
NIST Boulder CO, USA	03/2010
Technical University of Dresden	02/2010
Siemens Energy, Nuremberg	02/2010
Augsburg University of Applied Sciences	02/2010

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

2009

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

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

2008

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

2007

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

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

2006

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

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
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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
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KEMA IEV, Dresden	12/2005

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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

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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

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Hamilton Medical AG, Rhaezuens, Switzerland	01/2002
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G.U.N.T. Geraetebau, Barsbuettel (general license and training test benches)	12/2002
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ALSTOM Power, Baden, Switzerland	01/2001, 06/2001 12/2001
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Eco Design, Saitamaken, Japan	01/2001
M&M Turbine Technology, Bielefeld	01/2001, 09/2001
MVV Energie, Mannheim	02/2001
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SaarEnergie, Saarbruecken	05/2001
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Neusiedler AG, Ulmerfeld, Austria	09/2001
h s energieanlagen, Freising	09/2001
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VEAG, Berlin (group license)	12/2001

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Thinius Engineering, Erkrath	04/2000
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DVO Data Processing Service, Oberhausen	05/2000
RWTH Aachen University	06/2000
VAUP Process Automation, Landau	08/2000
Knuerr-Lommatec, Lommatzsch	09/2000
AVACON, Helmstedt	10/2000
Compania Electrica, Bogota, Colombia	10/2000
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Steinhaus Informationssysteme, Datteln (general license for process data software)	12/2000

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Bayernwerk, Munich	01/1999
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KEMA IEV, Dresden	03/1999
Regensburg University of Applied Sciences	04/1999
Fichtner Consulting & IT, Stuttgart (company licenses and distribution)	07/1999
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Technical University of Graz, Department of Thermal Engineering, Austria	11/1999
Ostendorf Engineering, Gummersbach	12/1999

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Technical University of Cottbus, Chair in Power Plant Engineering	05/1998
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B+H Software Engineering Stuttgart	08/1998
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SCA Hygiene Products, Munich	10/1998

RWE Energie, Neurath	10/1998
Wilhelmshaven University of Applied Sciences	10/1998
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Energieversorgung, Offenbach	11/1998

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