User’s Guide

for

LibHuAirProp

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

FluidDYM for DYMOLA®

Version 6.0

Based on ASHRAE Research Project RP-1485
and PTB-CP-3 Report

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Prepared by

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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®, EES®, LabVIEW™, DYMOLA®, or SimulationX®?

► Use the add-ins FluidEXL, FluidLAB, FluidMAT, 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 *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)
December 11, 2009 (revised Table C.2)

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 properties of moist air from the PTB Report PTB-CP-3 and the related paper in the Journal of Engineering for Gas Turbines and Power

PTB Report

Determination of Thermodynamic and Transport Properties of Humid Air for Power-Cycle Calculations

By S. Herrmann[1,2,3], H.-J. Kretzschmar[1,4], V. Teske[2,5], E. Vogel[2], P. Ulbig[6], R. Span[7], D.P. Gatley[8]

January 2009

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Properties of Humid Air for Calculating Power Cycles

Accurate calculation algorithms for the thermodynamic and transport properties of humid air are required for modeling compressed air energy-storage power cycles and designing their individual components. The development of such algorithms was part of the Advanced Adiabatic Compressed Air Energy Storage (AA-CAES) project, which had been supported by the European Commission. To obtain the statements of this paper, all available experimental data and new experimental data generated within the AA-CAES project were used as basis for comparisons between the different models for thermodynamic and transport properties. As a result, one model for calculating thermodynamic and one model for transport properties of humid air in AA-CAES cycle design and operation is recommended. Their application is possible for wide ranges of temperature from 243 K up to 2000 K, total pressure from 0.611 kPa up to 100 MPa, and water content up to 10% mass fraction with some restrictions concerning the calculation of viscosity η and thermal conductivity λ (up to 1000 K for both and up to 40 MPa for λ). These models have been implemented into a property library, which meets the requirements of programs for calculating compressed air energy-storage cycles. The developed property library can be used for the daily work of an engineer who calculates such cycles. The results summarized in this paper have been used for preparing Section 6, "Real Gas" of the ASME Report No. STP-TS-012, "Thermophysical Properties of Gases used in Working Gas Turbine Applications." [DOI: 10.1115/1.4000611]

Journal of Engineering for Gas Turbines and Power SEPTEMBER 2010, Vol. 132 / **093001-1**

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

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

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

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

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

The International Association for the Properties of Water and Steam

Lucerne, Switzerland
August 2007

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

The International Association for the Properties of Water and Steam

Doorwerth, The Netherlands
September 2009

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

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

ASHRAE-LibHuAirProp

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0 Package Contents

Add-In for 32-bit version of DYMOLA®

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

ZIP file "CD_FluidDYM_ASHRAE_LibHuAirProp.zip" for DYMOLA®

The ZIP file contains the following files:

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

Add-In for 64-bit version of DYMOLA®

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

ZIP file "CD_FluidDYM_ASHRAE_LibHuAirProp_64.zip" for DYMOLA®

The ZIP file contains the following files:

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

Part I-P Units

1 Property Library ASHRAE-LibHuAirProp-IP

1.1 Function Overview

1.1.1 Function Overview for Real Moist Air

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

Functional Dependence	Function Name	Property or Function	Unit of the Result	Page
$\varphi = \mathrm{f}(p,t,W)$	phi_ptW_HAP_IP	Relative humidity (decimal ratio)	-	3/19
$Pr = \mathrm{f}(p,t,W)$	Pr_ptW_HAP_IP	PRANDTL number	-	3/20
$\psi_{\mathrm{Air}} = \mathrm{f}(W)$	PsiAir_W_HAP_IP	Mole fraction of dry air in moist air	$\mathrm{mol_a/mol}$	3/21
$\psi_{\mathrm{H2O}} = \mathrm{f}(W)$	PsiH2O_W_HAP_IP	Mole fraction of water vapor in moist air	$\mathrm{mol_w/mol}$	3/22
$\rho = \mathrm{f}(p,t,W)$	Rho_ptW_HAP_IP	Density	$\mathrm{lb/ft^3}$	3/23
$s = \mathrm{f}(p,t,W)$	s_ptW_HAP_IP	Air-specific entropy	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	lb_w/lb_a	3/37
$W_{\mathrm{s}} = \mathrm{f}(p,t)$	Ws_pt_HAP_IP	Saturation humidity ratio	lb_w/lb_a	3/38
$\xi_{\mathrm{Air}} = \mathrm{f}(W)$	XiAir_W_HAP_IP	Mass fraction of dry air in moist air	lb_a/lb	3/39
$\xi_{\mathrm{H2O}} = \mathrm{f}(W)$	XiH2O_W_HAP_IP	Mass fraction of water vapor in moist air	lb_w/lb	3/40
$Z = \mathrm{f}(p,t,W)$	Z_ptW_HAP_IP	Compression factor (decimal ratio)	-	3/41

Range of Validity of Thermodynamic Properties

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

Units

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

Range of Validity of Transport Properties

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

Molar Masses

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

Reference States

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

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

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

Range of Validity

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

Units

Symbol	Quantity	Unit
p	Pressure	psi
t	Temperature	°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)

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

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

Property		Conversion: SI Units → I-P Units	Conversion: I-P Units → SI Units	Units SI	Units I-P
Air-specific enthalpy (moist air)	h	$\frac{h_{IP}}{\frac{Btu}{lb_a}} = \frac{h_{SI}}{\frac{kJ}{kg_a}} \times 0.4299226 + 7.68565365666$	$\frac{h_{SI}}{\frac{kJ}{kg_a}} = \left(\frac{h_{IP}}{\frac{Btu}{lb_a}} - 7.68565365666 \right) \times 2.326$	kJ/kg_a	Btu/lb_a
Specific enthalpy (water, water vapor, ice)	h_w	$\frac{h_{IP}}{\frac{Btu}{lb}} = \frac{h_{SI}}{\frac{kJ}{kg}} \times 0.4299226$	$\frac{h_{SI}}{\frac{kJ}{kg}} = \frac{h_{IP}}{\frac{Btu}{lb}} \times 2.326$	kJ/kg	Btu/lb
Isentropic exponent	κ	$\kappa_{IP} = \kappa_{SI}$	$\kappa_{SI} = \kappa_{IP}$	-	-
Thermal conductivity	λ	$\frac{\lambda_{IP}}{\frac{Btu}{h\ ft\ °R}} = \frac{\lambda_{SI}}{\frac{W}{m\ K}} \times 0.57778932$	$\frac{\lambda_{SI}}{\frac{W}{m\ K}} = \frac{\lambda_{IP}}{\frac{Btu}{h\ ft\ °R}} \times 1.73073467$	W/(m·K)	Btu/(h·ft·°R)
Kinematic viscosity	ν	$\frac{\nu_{IP}}{\frac{ft^2}{s}} = \frac{\nu_{SI}}{\frac{m^2}{s}} \times 10.763910417$	$\frac{\nu_{SI}}{\frac{m^2}{s}} = \frac{\nu_{IP}}{\frac{ft^2}{s}} \times 0.092903040$	m^2/s	ft^2/s
Pressure	p	$\frac{p_{IP}}{psi} = \frac{p_{SI}}{kPa} \times 0.14503774$	$\frac{p_{SI}}{kPa} = \frac{p_{IP}}{psi} \times 6.894757$	kPa	psi
Relative humidity	φ	$\varphi_{IP} = \varphi_{SI}$	$\varphi_{SI} = \varphi_{IP}$	-	-
Prandtl number	Pr	$Pr_{IP} = Pr_{IP}$	$Pr_{SI} = Pr_{IP}$	-	-
Mole fraction	ψ	$\psi_{IP} = \psi_{SI}$	$\psi_{SI} = \psi_{IP}$	mol/mol	mol/mol
Density	ρ	$\frac{\rho_{IP}}{\frac{lb}{ft^3}} = \frac{\rho_{SI}}{\frac{kg}{m^3}} \times 0.062428$	$\frac{\rho_{SI}}{\frac{kg}{m^3}} = \frac{\rho_{IP}}{\frac{lb}{ft^3}} \times 16.018463$	kg/m^3	lb/ft^3
Air-specific entropy (moist air)	s	$\frac{s_{IP}}{\frac{Btu}{lb_a\ °R}} = \frac{s_{SI}}{\frac{kJ}{kg_a\ K}} \times 0.2388459 + 0.01616365106$	$\frac{s_{SI}}{\frac{kJ}{kg_a\ K}} = \left(\frac{s_{IP}}{\frac{Btu}{lb_a\ °R}} - 0.01616365106 \right) \times 4.1868$	kJ/(kg_a·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}	$\dfrac{s_{\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb_a\ °R}}} = \dfrac{s_{\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg_a\ K}}} \times 0.23884589$	$\dfrac{s_{\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg_a\ K}}} = \dfrac{s_{\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb_a\ °R}}} \times 4.1868$	kJ/(kg$_a$·K)	Btu/(lb$_a$·°R)
Temperature	t	$\dfrac{t_{\mathrm{IP}}}{°\mathrm{F}} = \dfrac{t_{\mathrm{SI}}}{°\mathrm{C}} \times \dfrac{9}{5} + 32$	$\dfrac{t_{\mathrm{SI}}}{°\mathrm{C}} = \left(\dfrac{t_{\mathrm{IP}}}{°\mathrm{F}} - 32\right) \times \dfrac{5}{9}$	°C	°F
Air-specific internal energy (moist air)	u	$(u = h - pv)$ $\dfrac{u_{\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb_a}}} = \dfrac{h_{\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg_a}}} \times 0.4299226 + 7.68565365666 - \dfrac{p_{\mathrm{SI}}}{\mathrm{kPa}} \times 0.145037738 \cdot \dfrac{v_{\mathrm{SI}}}{\frac{\mathrm{m^3}}{\mathrm{kg_a}}} \times 16.018453$	$(u = h - pv)$ $\dfrac{u_{\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg_a}}} = \left(\dfrac{h_{\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb_a}}} - 7.68565365666\right) \times 2.236 - \dfrac{p_{\mathrm{IP}}}{\mathrm{psi}} \times 6.894757293 \cdot \dfrac{v_{\mathrm{SIP}}}{\frac{\mathrm{ft^3}}{\mathrm{lb_a}}} \times 0.062428$	kJ/kg$_a$	Btu/lb
Air-specific volume (moist air)	v	$\dfrac{v_{\mathrm{IP}}}{\frac{\mathrm{ft^3}}{\mathrm{lb_a}}} = \dfrac{v_{\mathrm{SI}}}{\frac{\mathrm{m^3}}{\mathrm{kg_a}}} \times 16.018453$	$\dfrac{v_{\mathrm{SI}}}{\frac{\mathrm{m^3}}{\mathrm{kg_a}}} = \dfrac{v_{\mathrm{IP}}}{\frac{\mathrm{ft^3}}{\mathrm{lb_a}}} \times 0.062428$	m³/kg$_a$	ft³/lb$_a$
Specific volume (water, water vapor, ice)	v_{w}	$\dfrac{v_{\mathrm{IP}}}{\frac{\mathrm{ft^3}}{\mathrm{lb}}} = \dfrac{v_{\mathrm{SI}}}{\frac{\mathrm{m^3}}{\mathrm{kg}}} \times 16.018453$	$\dfrac{v_{\mathrm{SI}}}{\frac{\mathrm{m^3}}{\mathrm{kg}}} = \dfrac{v_{\mathrm{IP}}}{\frac{\mathrm{ft^3}}{\mathrm{lb}}} \times 0.062428$	m³/kg	ft³/lb
Humidity ratio	W	$W_{\mathrm{IP}} = W_{\mathrm{SI}}$	$W_{\mathrm{SI}} = W_{\mathrm{IP}}$	kg$_w$/kg$_a$	lb$_w$/lb$_a$
Mass fraction	ξ	$\xi_{\mathrm{IP}} = \xi_{\mathrm{SI}}$	$\xi_{\mathrm{SI}} = \xi_{\mathrm{IP}}$	kg$_w$/kg	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]
- the calculation of the second and third molar virial coefficients B_{ww} and C_{www} for water and steam from IAPWS-95 [5], [6]
- 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.

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

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

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

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

- The sublimation curve is covered by the IAPWS-08 sublimation pressure equation $p_{\mathrm{subl}}^{08}(t)$ [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.

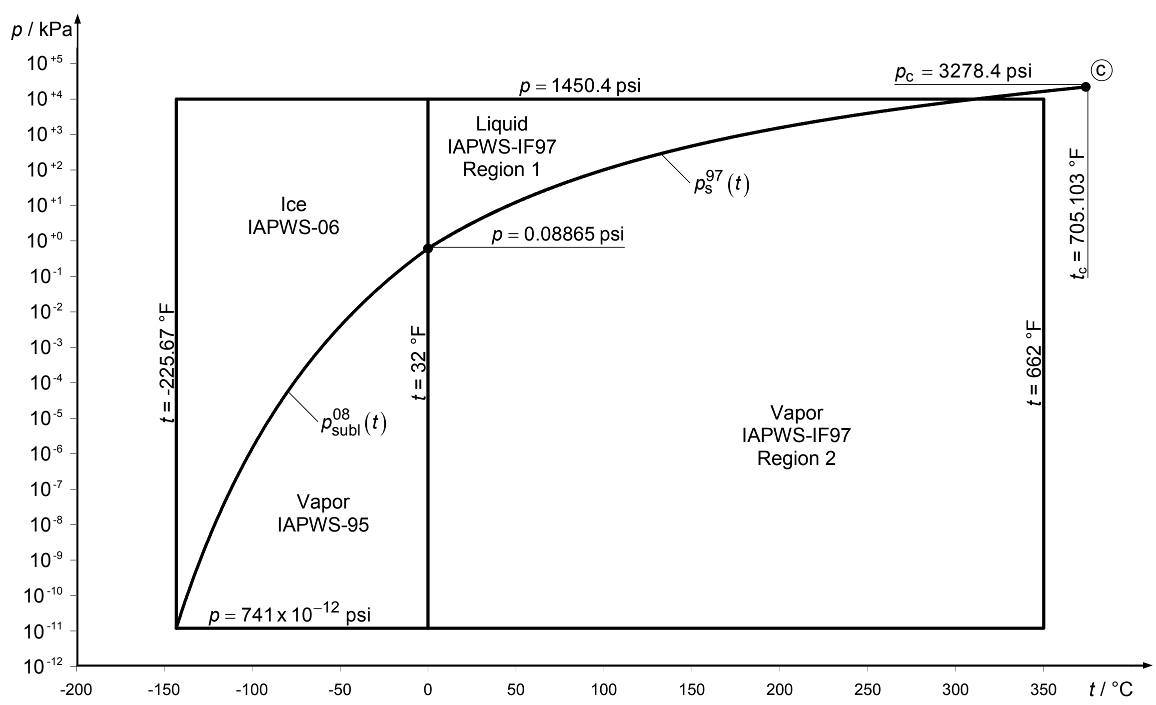


Figure 1: *p*-*T* diagram with used IAPWS formulations for steam, water, and ice.

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

2.1 Installing FluidDYM

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

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

2.1.1 Installing FluidDYM including LibHuAirProp

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

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

After you have downloaded and extracted the zip-file

"CD_FluidDYM_ASHRE_LibHuAirProp.zip," (32-bit version)

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

you will see the folder

CD_FluidDYM_ASHRAE_LibHuAirProp (32-bit version)

CD_FluidDYM_ASHRAE_LibHuAirProp_64 (64-bit version)

in your Windows Explorer®, Norton Commander® etc.

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

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

FluidDYM_ASHRAE_LibHuAirProp_Users_Guide.pdf

FluidDYM_LibHuAirProp_Setup.exe (32-bit version)

and the folder

"Users_Guide."

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

FluidDYM_ASHRAE_LibHuAirProp_Users_Guide.pdf

FluidDYM_ASHRAE_LibHuAirProp_64_Setup.msi

Setup.exe

and the folder

"Users_Guide."

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

FluidDYM_LibHuAirProp_Setup.exe.

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

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

C:\Program Files\FluidDYM\LibHuAirProp.

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

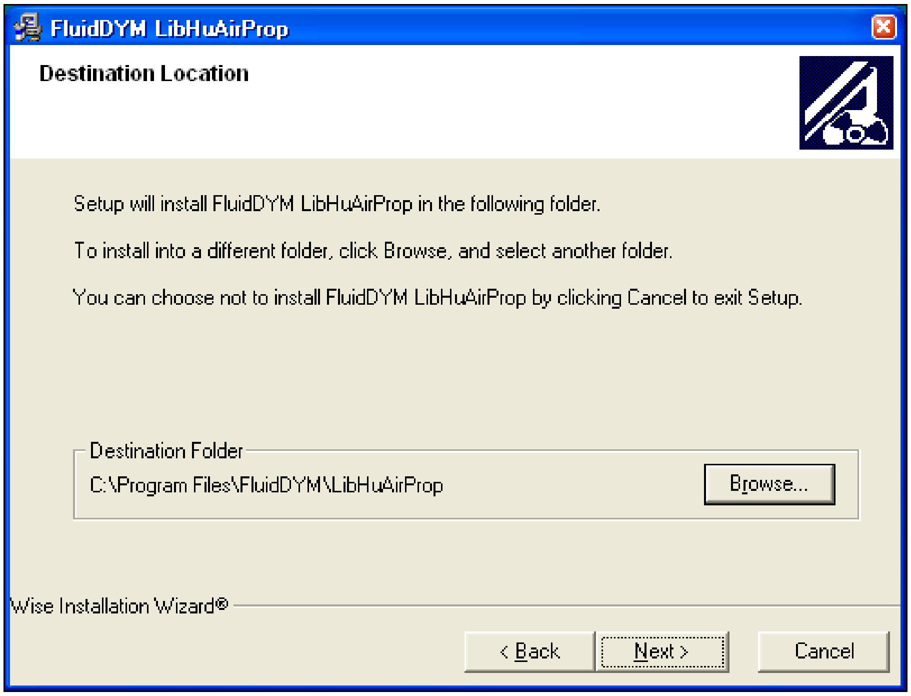


Figure 2.1.1: "Choose Destination Location"

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

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

The installation of FluidDYM 32-bit has been completed.

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

Setup.exe.

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

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

C:\Users\...\Documents\FluidDYM_64\LibHuAirProp.

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

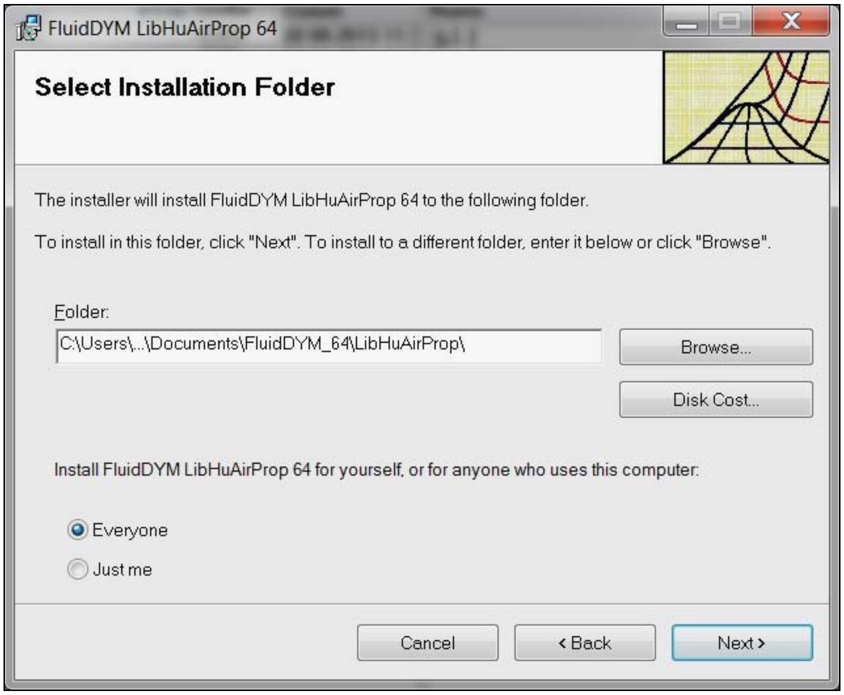


Figure 2.1.2: "Choose Destination Location"

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

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

The installation of FluidDYM 64-bit has been completed.

The installation program has copied the following files for both the I-P and the SI version into the directory "C:\Program Files\FluidDYM\LibHuAirProp":

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

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

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

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

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

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

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

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

2.1.2 The FluidDYM Help System

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

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

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

- Make sure Dymola is set to the "Modeling-Mode".
- Now click the button in the Dymola menu bar to choose the "Documentation Mode".
- Double-click on the "FluidDYM_HuAirProp_IP" block on the left and then click on "Users_Guide" (see Figure 2.1.3).

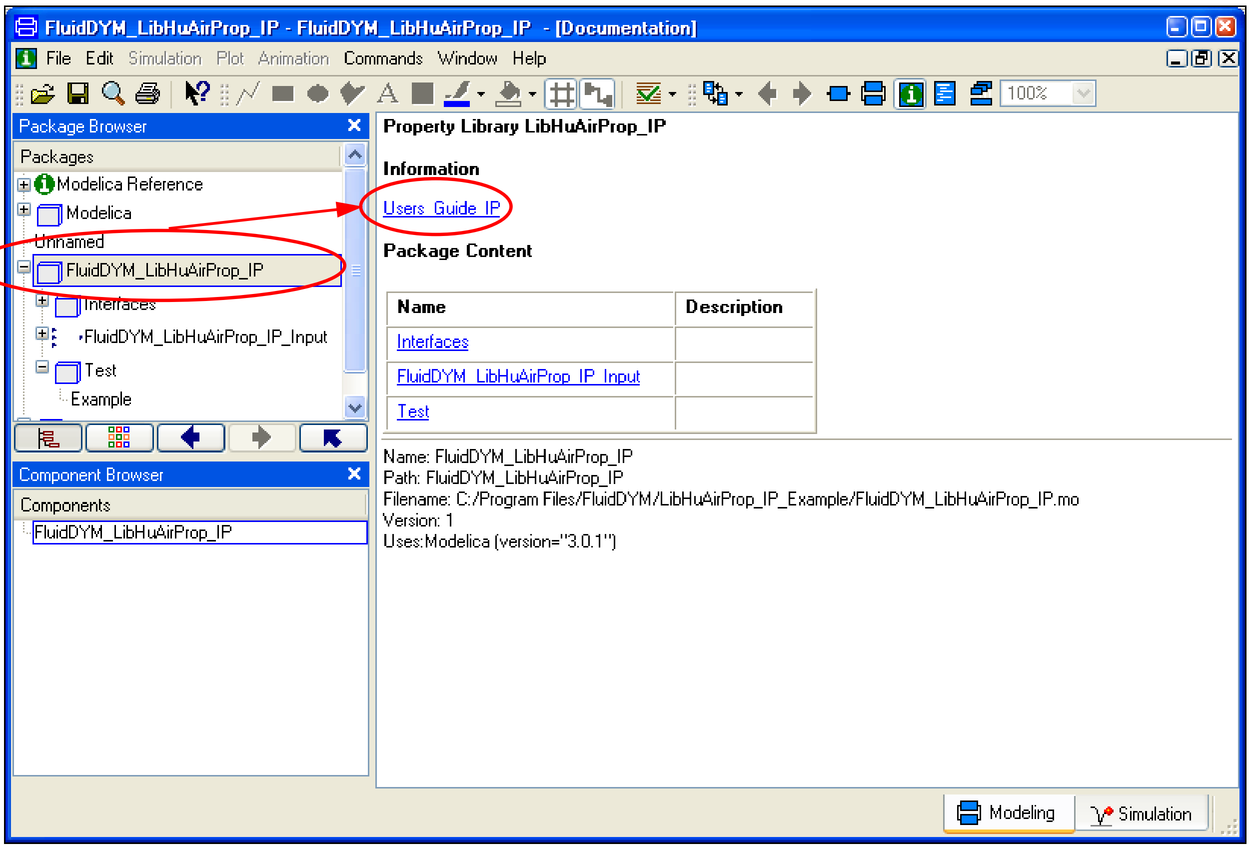


Figure 2.1.3: Selecting the "Users_Guide"

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

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

- Make sure Dymola is set to the "Modeling-Mode".
- Now click the button in the Dymola menu bar to choose the "Documentation Mode".
- Double-click on the "FluidDYM_LibHuAirProp_IP_Input" block on the left (see Figure 2.1.4).

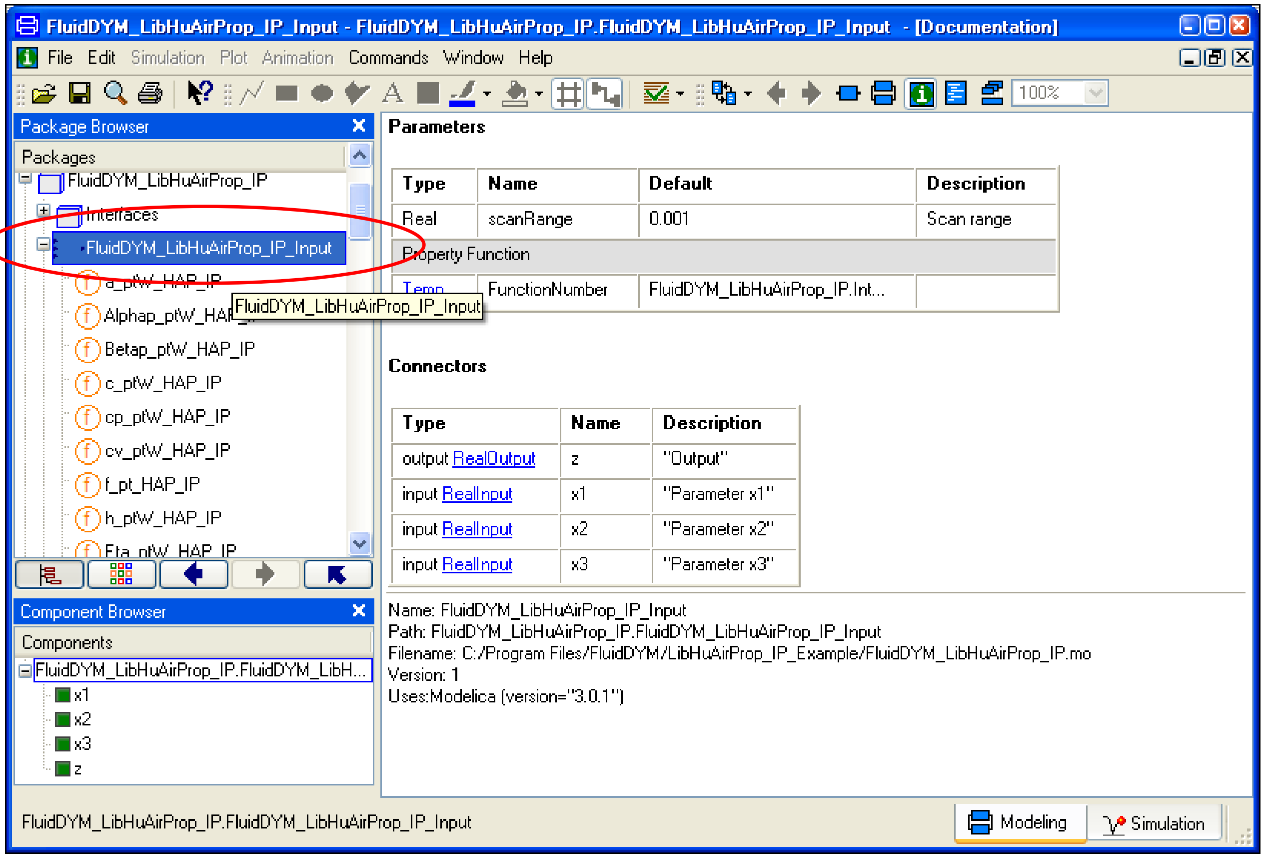


Figure 2.1.4: Selected "FluidDYM_LibHuAirProp_IP_Input" Block

- Below "FluidDYM_LibHuAirProp_IP_Input" you will see all functions of the LibHuAirProp_IP property function.
- Now select a function, e.g. "h_ptW_HAP_IP", and then click on "Users_Guide" (see Figure 2.1.5).

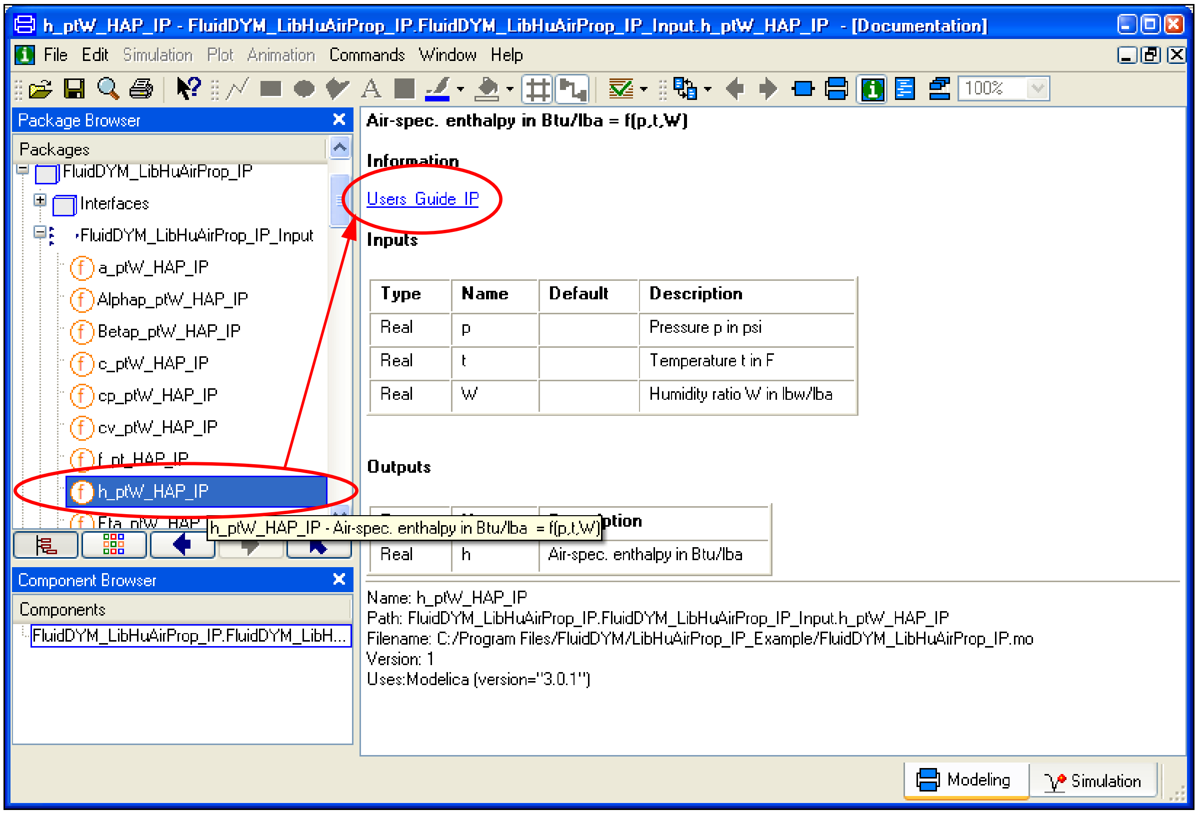


Figure 2.1.5: Marking the "h_ptW_HAP_IP" function and selecting the "Users_Guide"

- You will now see the help page of the selected function, here "h_ptW_HAP_IP", in your default web browser (see Figure 2.1.6).

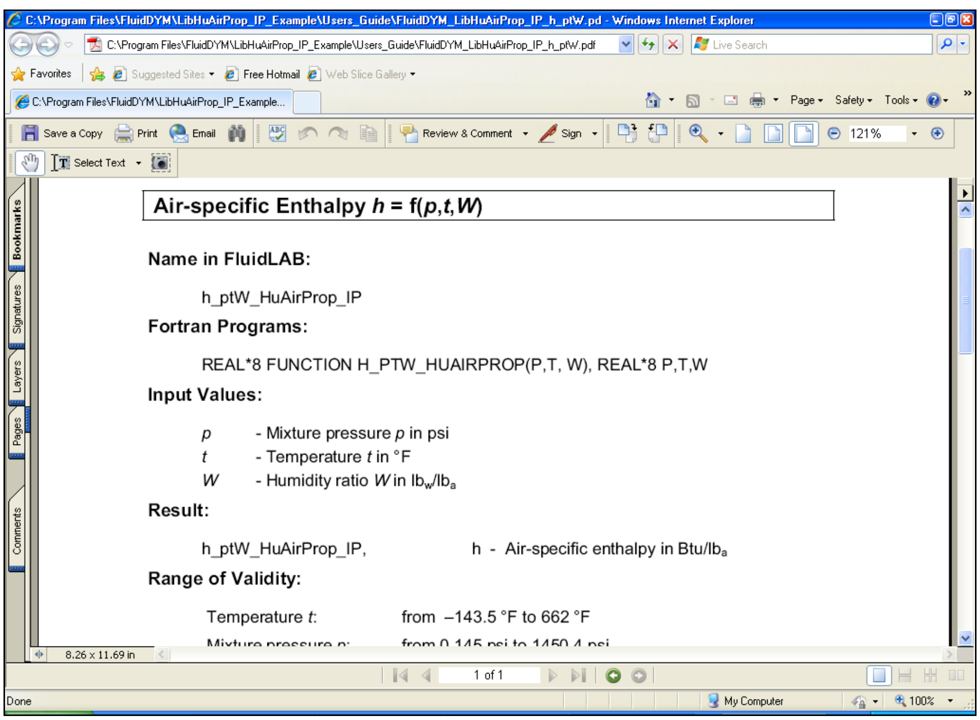


Figure 2.1.6: Help page of the function "h_ptW_HAP_IP" in the web browser

2.2 Licensing the LibHuAirProp Property Library

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

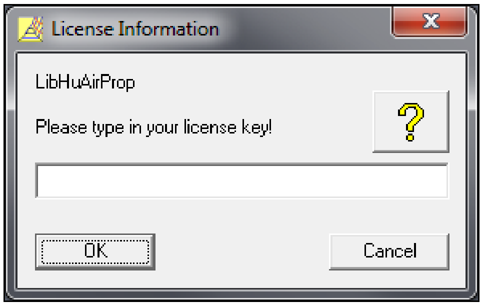


Figure 2.2.1: "License Information" window

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

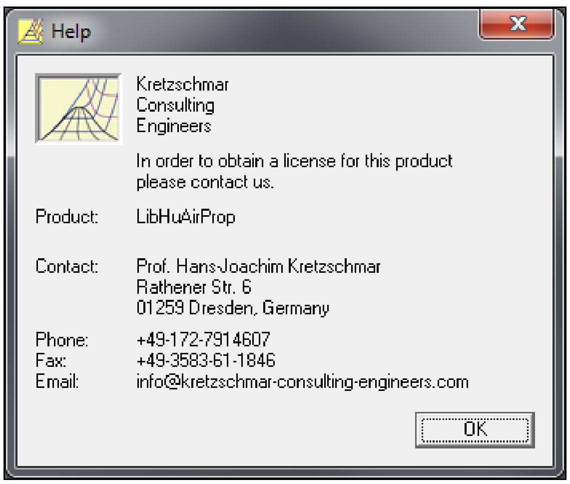


Figure 2.2.2: "Help" window

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

The "License Information" window will appear every time you use FluidDYM LibHuAirProp until you enter a license code to complete registration. If you decide not to use FluidDYM LibHuAirProp, you can uninstall the program following the instructions given in section 2.1.5 of this User's Guide.

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

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

Now we will calculate, step by step, the specific enthalpy *h* of moist air as a function of pressure *p*, temperature *t* and humidity ratio *W*, using Dymola®.

Please carry out the following instructions:

- Start Windows Explorer®, Total Commander®, My Computer or another file manager program. The description here refers to Windows Explorer
- Your Windows Explorer should be set to Details for a better view. Click the "View" button and select "Details".
- Switch into the program directory of FluidDYM in which you will find the folder "\LibHuAirProp;" the standard location is:
  "C:\Program Files\FluidDYM\LibHuAirProp"
- Create the folder "\LibHuAirProp_IP_Example" by clicking on "File" in the Explorer menu, then "New" in the menu which appears, and then selecting "Folder". Name the new folder "\LibHuAirProp_IP_Example".
- You will see the following window:

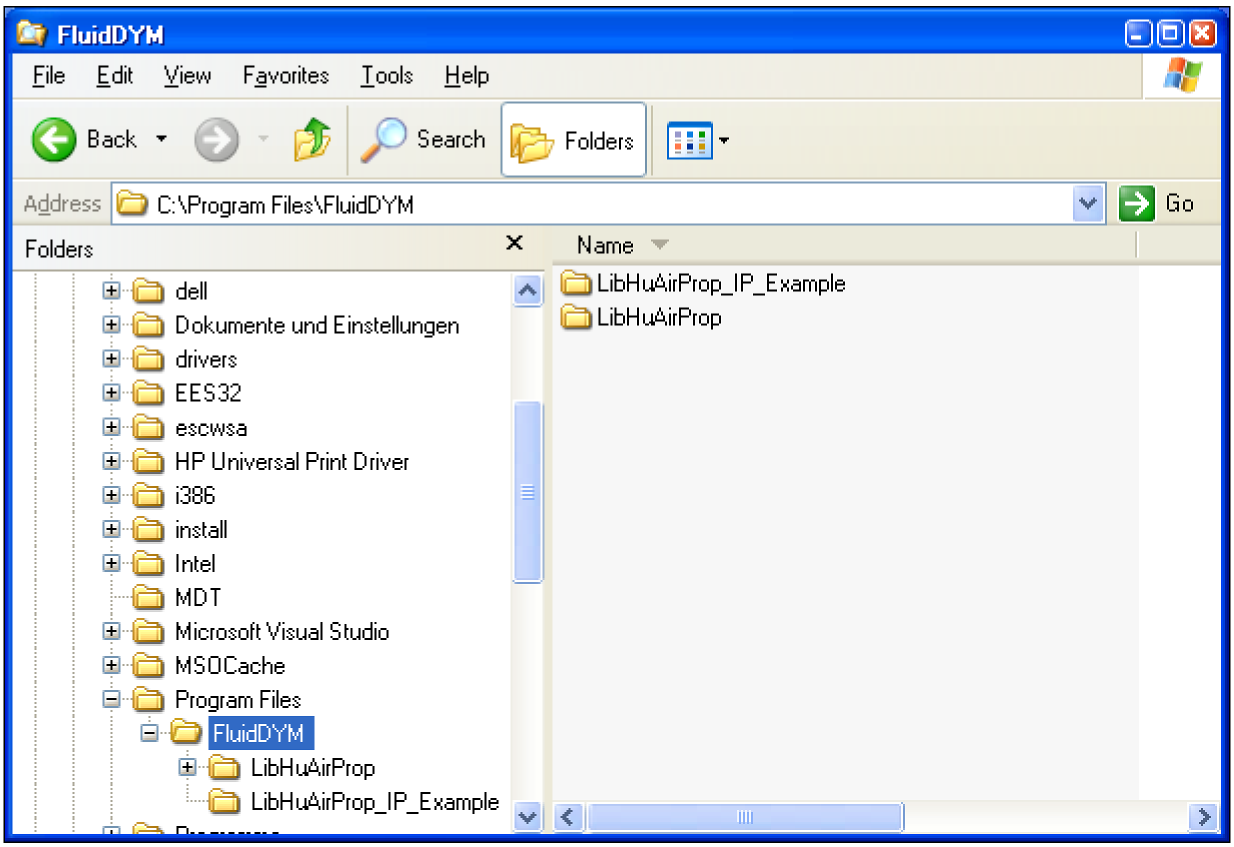


Figure 2.3.1: Highlighted *LibHuAirProp_IP_Example* directory in Program Files

- Switch into the directory "\LibHuAirProp" within "\FluidDYM", the standard being:
  "C:\Program Files\FluidDYM\LibHuAirProp".

- You will see the following window:

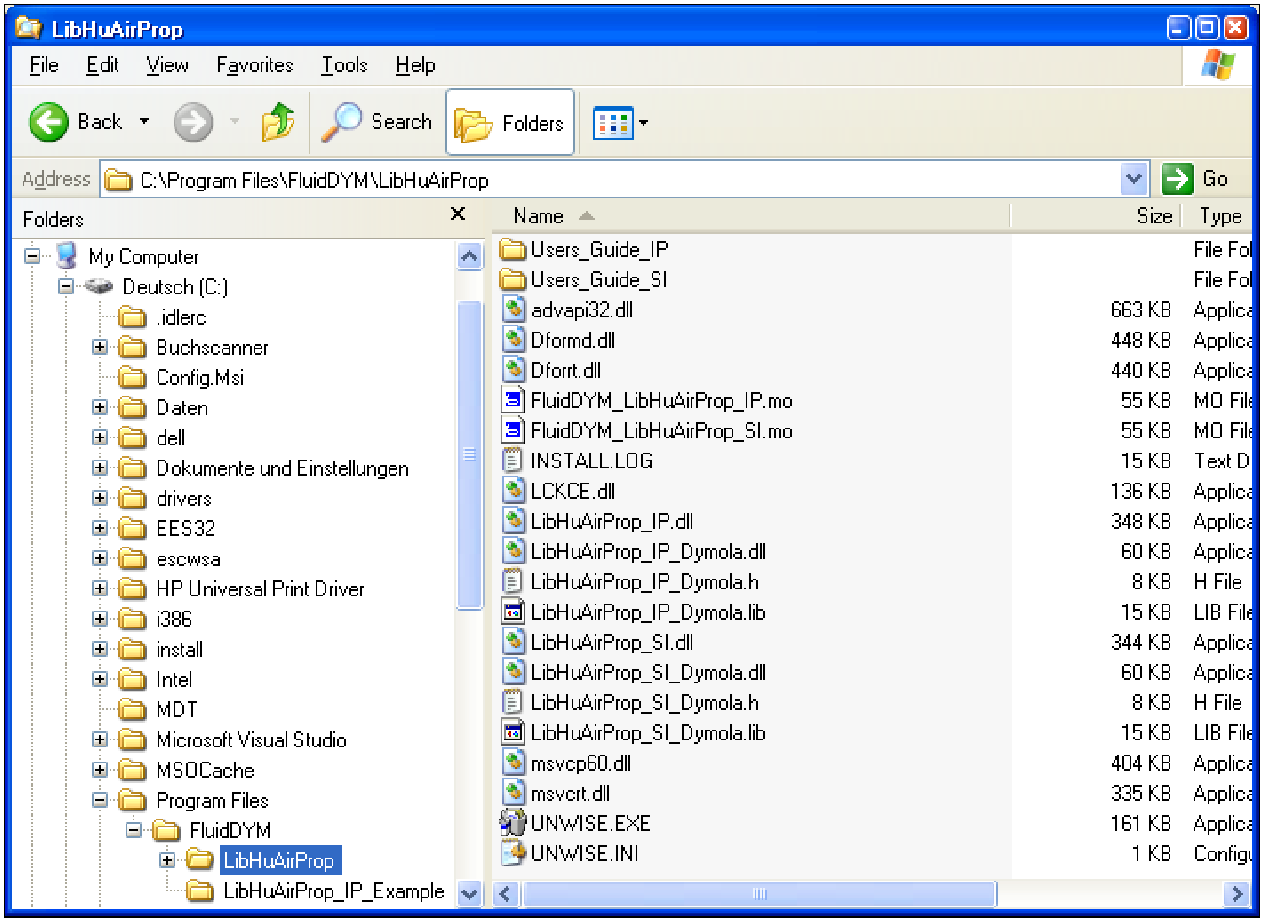


Figure 2.3.2: *LibHuAirProp_IP* directory including installed files

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

- "advapi32.dll"
- "Dforrt.dll"
- "Dformd.dll"
- "FluidDYM_HuAirProp_IP.mo"
- "LCKCE.dll"
- "LibHuAirProp_IP.dll"
- "LibHuAirProp_IP_Dymola.dll"
- "LibHuAirProp_IP_Dymola.h"
- "LibHuAirProp_IP_Dymola.lib"
- "msvcp60.dll"
- "msvcrt.dll"
- the folder "Users_Guide"

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

and then "Paste".

- You will see the following window:

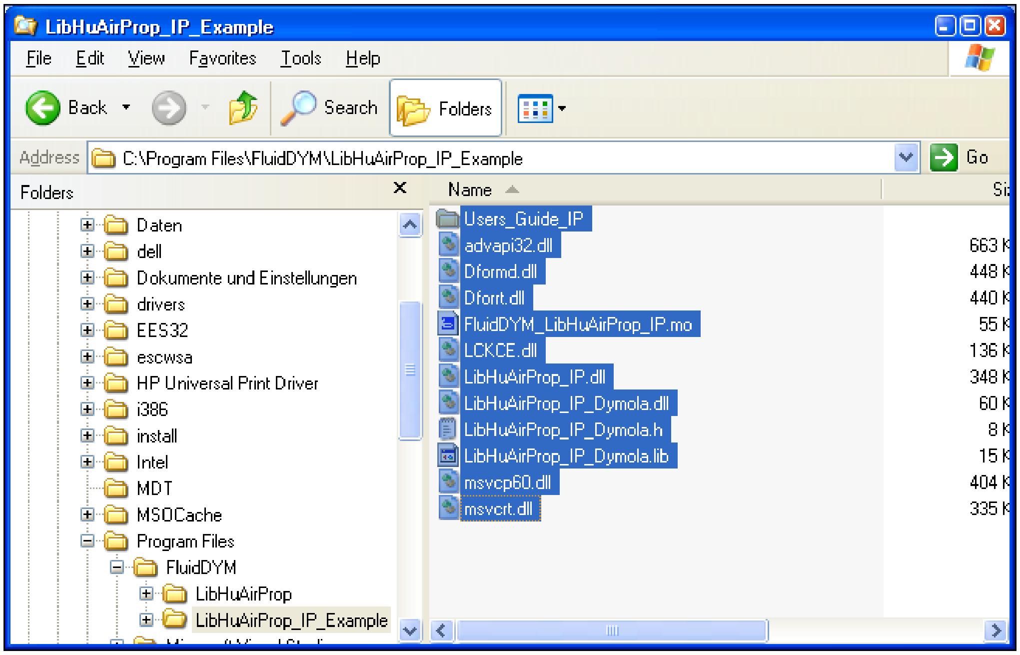


Figure 2.3.3: *LibHuAirProp_IP_Example* directory including the newly-copied files

- Start Dymola®.
- Now click on "File" in the Dymola menu bar and select "Open" (see Figure 2.3.4).

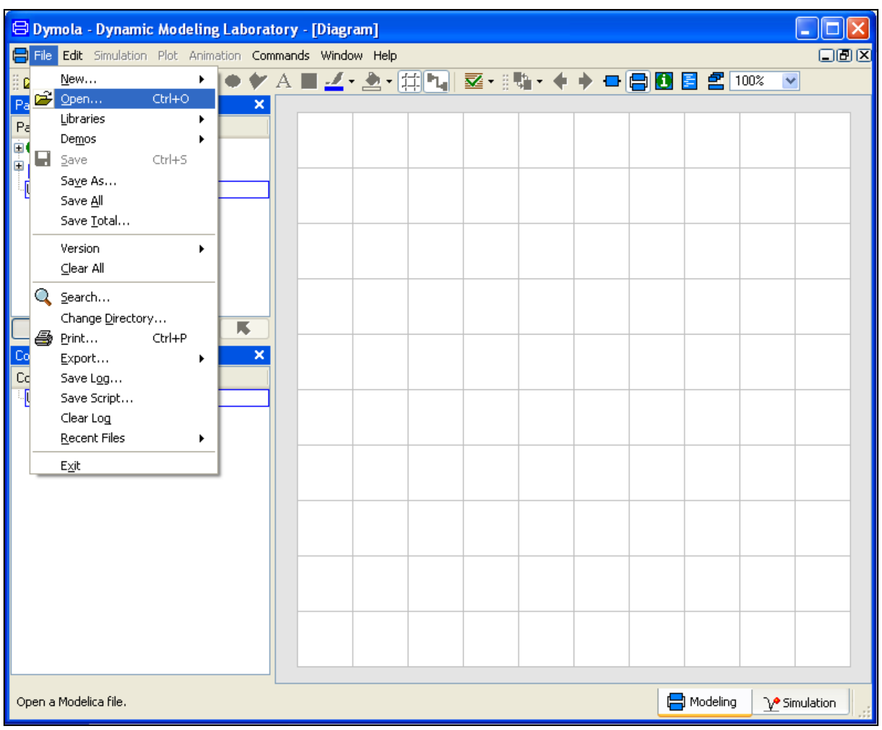


Figure 2.3.4: Selecting the menu entry "Open"

- Search and click on the directory "C:\Program Files\FluidDYM\LibHuAirProp_IP_Example" in the menu that appears.

- Select the "FluidDYM_LibHuAirProp_IP.mo" file and click on the "Open" button (see Figure 2.3.5)

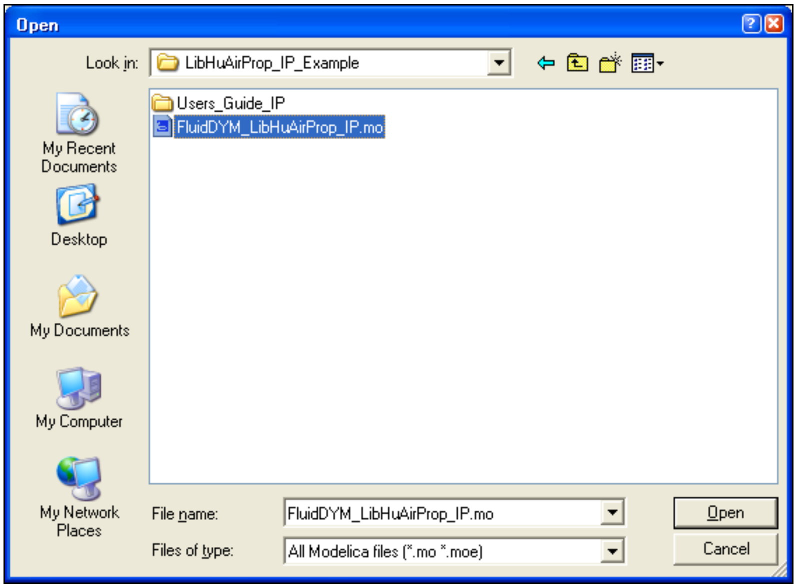


Figure 2.3.5: Selecting the *FluidDYM_HuAirProp_IP.mo* file

- The library will be loaded by Dymola which may take a few seconds.
- After Dymola has finished loading the LibHuAirProp_IP library, you will see the window shown in Figure 2.3.6.

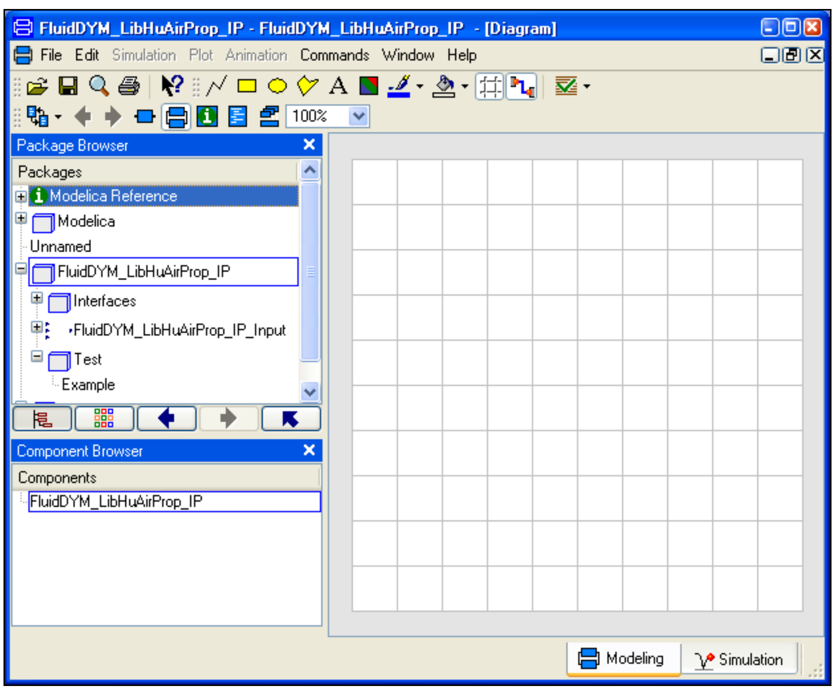


Figure 2.3.6: Dymola window after loading the *LibHuAirProp_IP* library

- Now, click on "File" in the Dymola menu bar and select "Change Directory…" in order to open the folder "\LibHuAirProp_IP_Example" (see Figure 2.3.7).

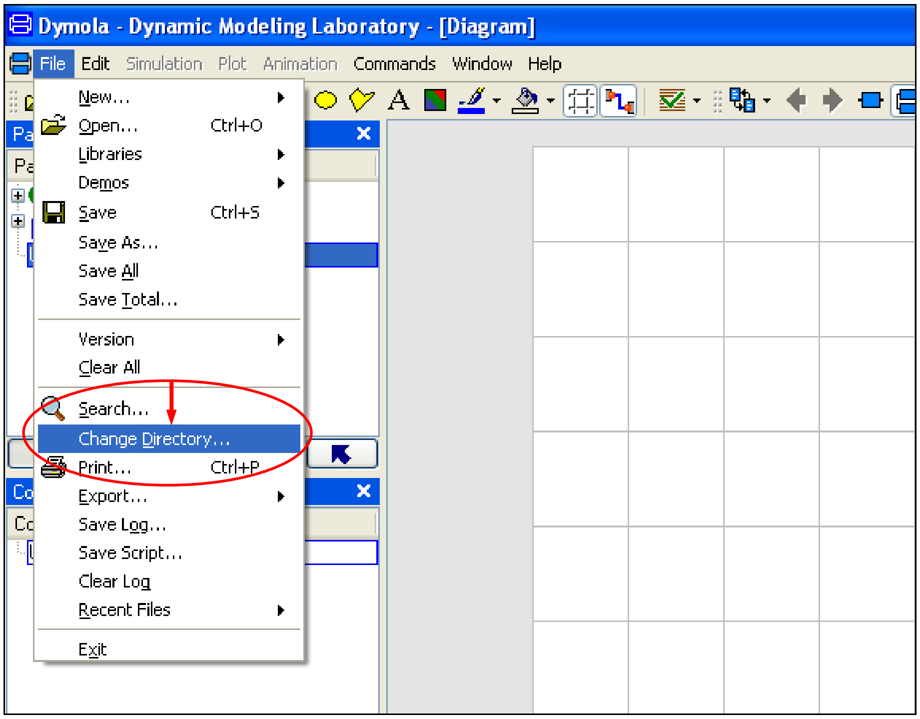


Figure 2.3.7: Selecting the menu entry "Change Directory…"

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

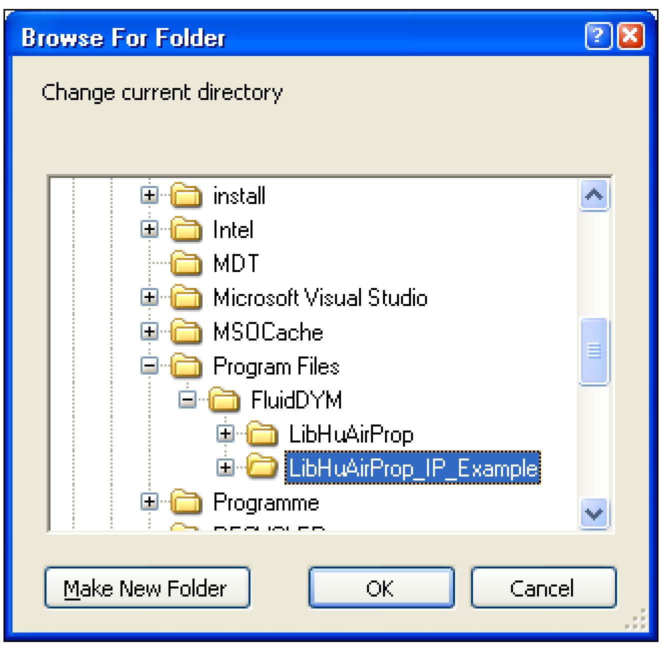
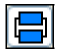


Figure 2.3.8: Selecting the *LibHuAirProp_IP_Example* directory

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

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

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

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

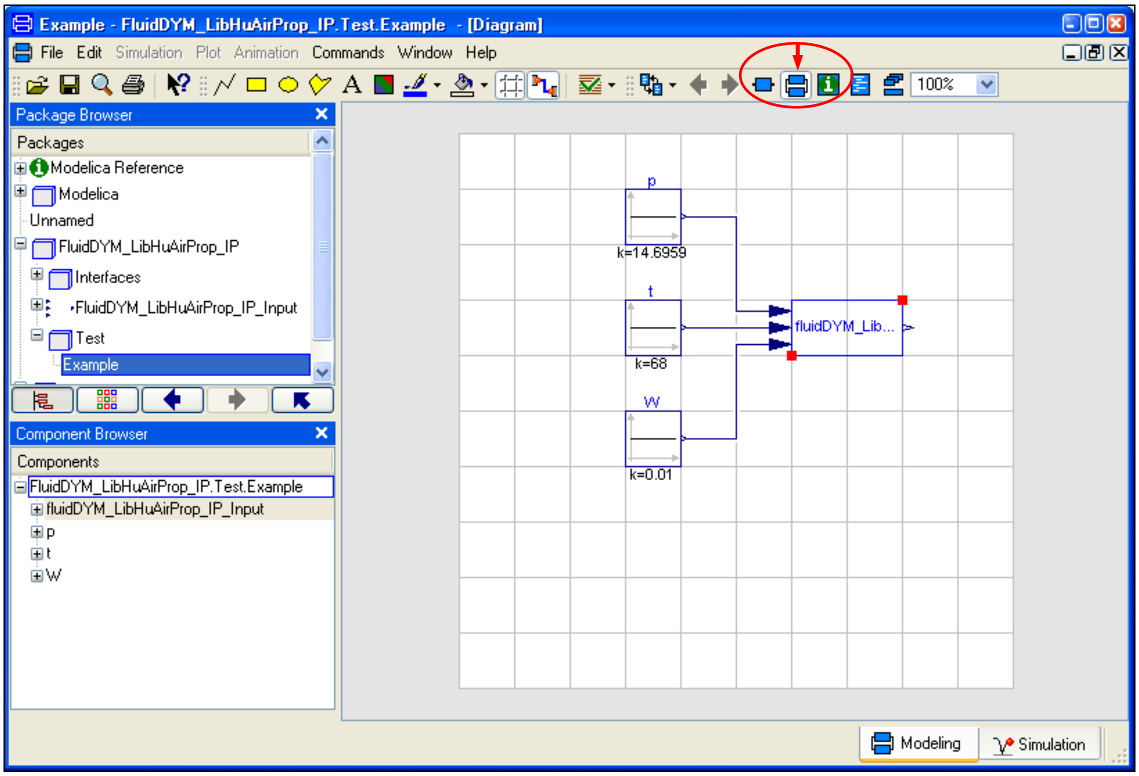


Figure 2.3.9: Dymola in Diagram Mode

- Now double-click on the "fluidDYM_LibHuAirProp_IP_Input" block on the right hand side of the Dymola window.

- Search and click the "h_ptW_HAP_IP" function next to "Function Number" in the menu that appears (see figure below).

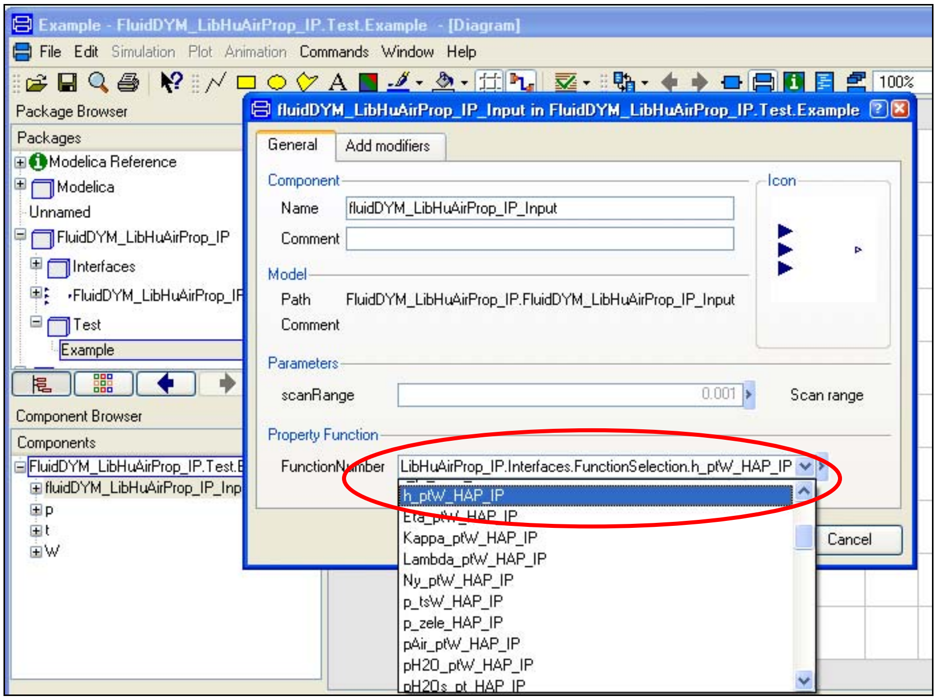


Figure 2.3.10: Choosing the function *h_ptW_HAP_IP*

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

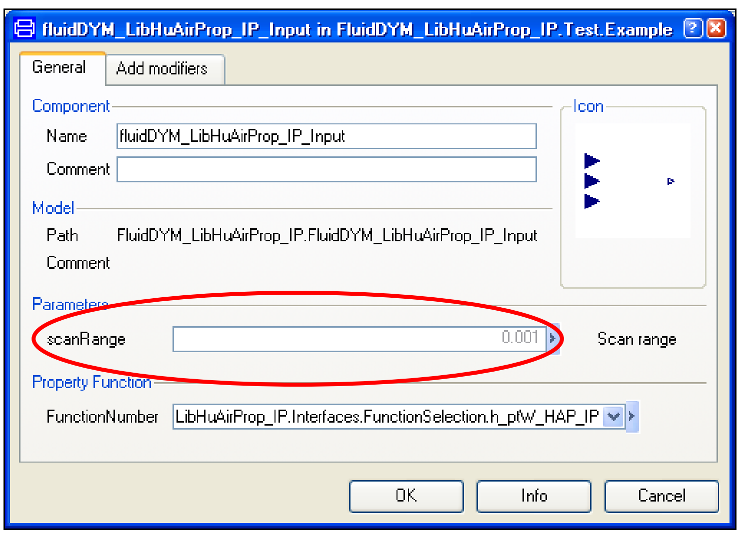


Figure 2.3.11: Setting the scan range

- Now we will configure the input parameters *p*, *t*, and *W*. When calculating a function with only two input parameters, the third input parameter will not be defined.
- First, double click on the "p" block which represents the first input parameter, here the pressure *p* in psi (see Figure 2.3.12).

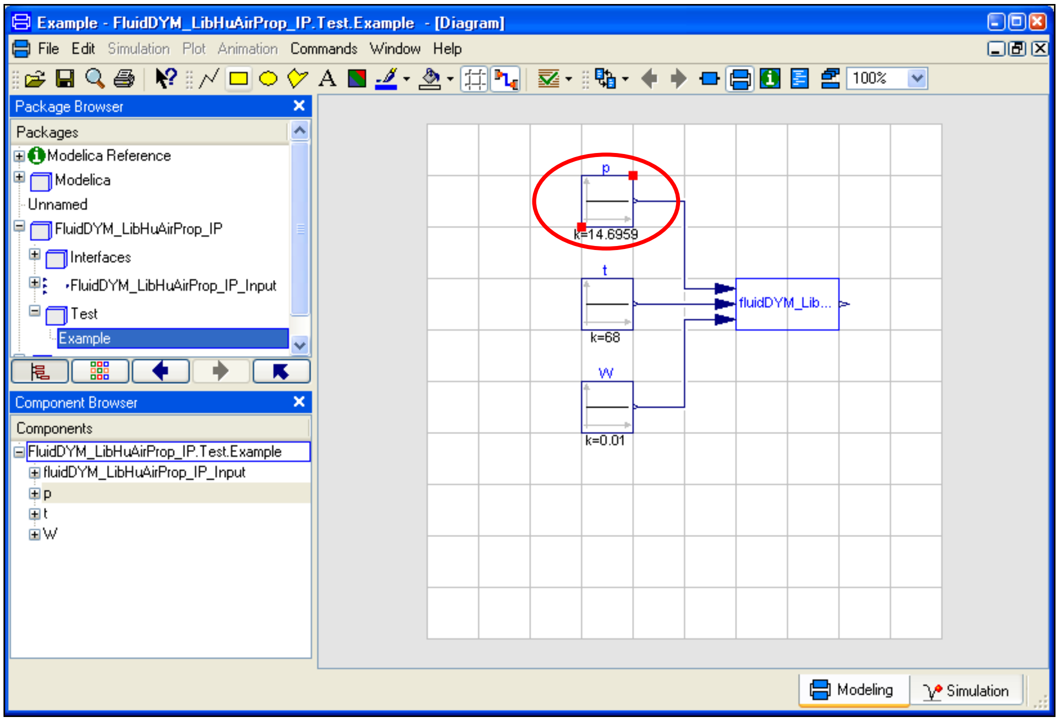


Figure 2.3.12: "Parameter *p* in psi" block in Dymola

- Enter the value 14.6959 on the line next to "k" in the dialog window which appears and then click the "OK" button (see Figure 2.3.13).

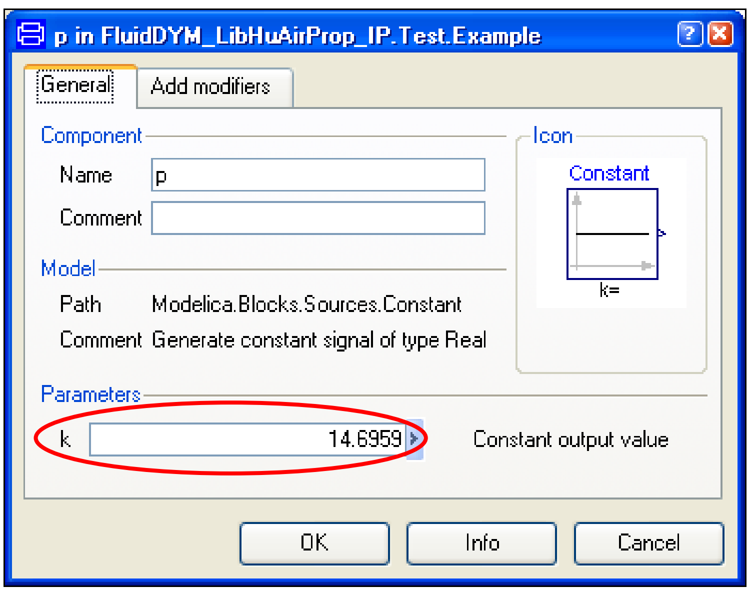


Figure 2.3.13: Entering the value for the pressure *p*

- Now, double click on the "t" block which represents the second input parameter, here the temperature *t* in °F.
- Enter the value 68 on the line next to "k" in the dialog window which appears and then click the "OK" button (see Figure 2.3.14).

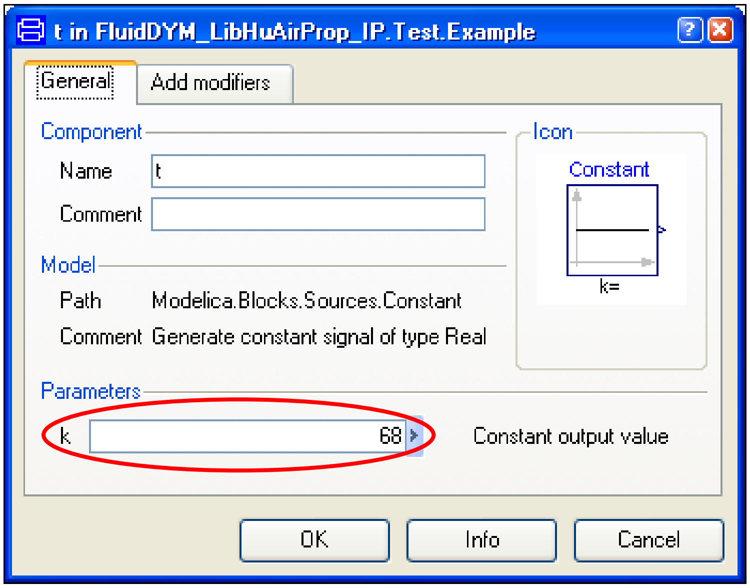


Figure 2.3.14: Entering the value for the temperature *t*

- Now, double click on the "W" block which represents the third input parameter, here the humidity ratio *W* in lb_w/lb_a.
- Enter the value 0.01 on the line next to "k" in the dialog window which appears and then click the "OK" button (see Figure 2.3.15).

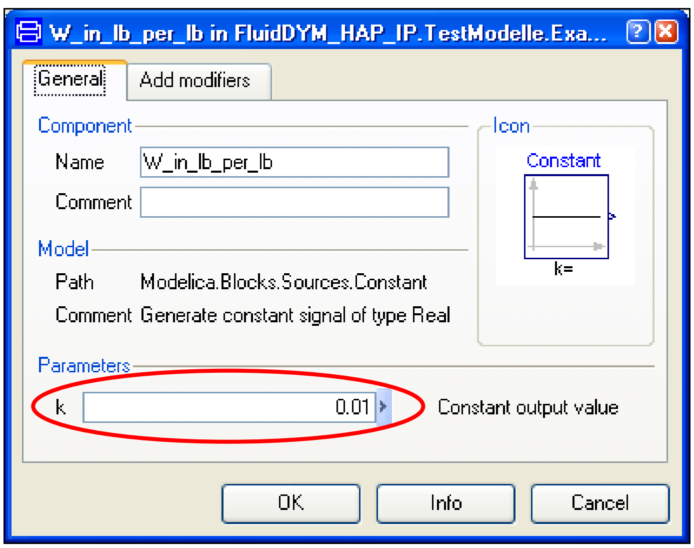
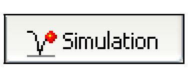


Figure 2.3.15: Entering the value for the humidity ratio *W*

All parameters have now been defined.

- Click on the 

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

In Figure 2.3.16 you can see what the Dymola "Simulation Mode" looks like.

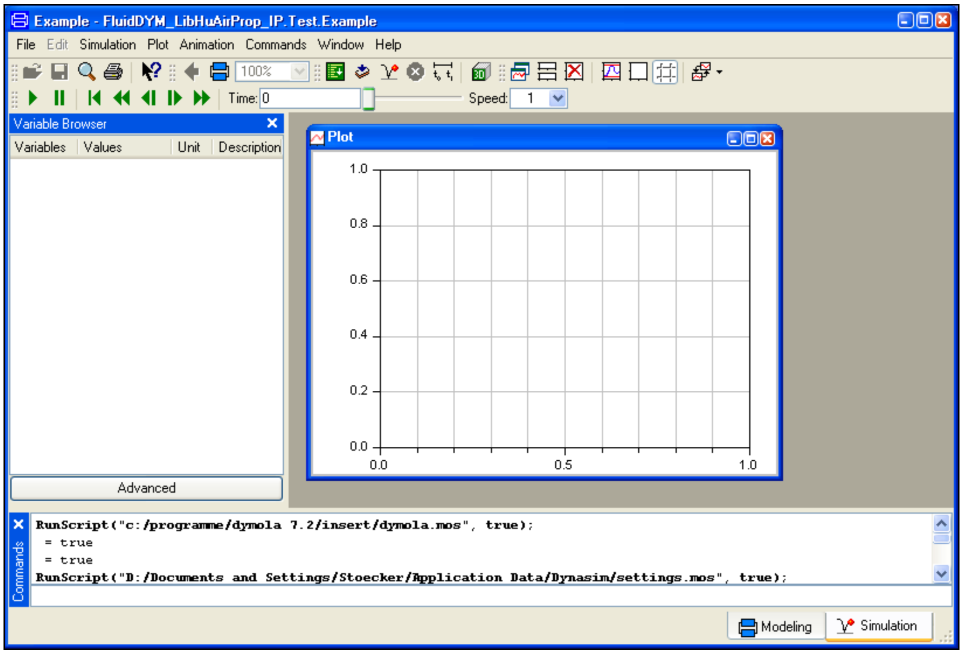


Figure 2.3.16: "Simulation Mode" window

IMPORTANT NOTICE:

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

"Advanced.CompileWith64=2"

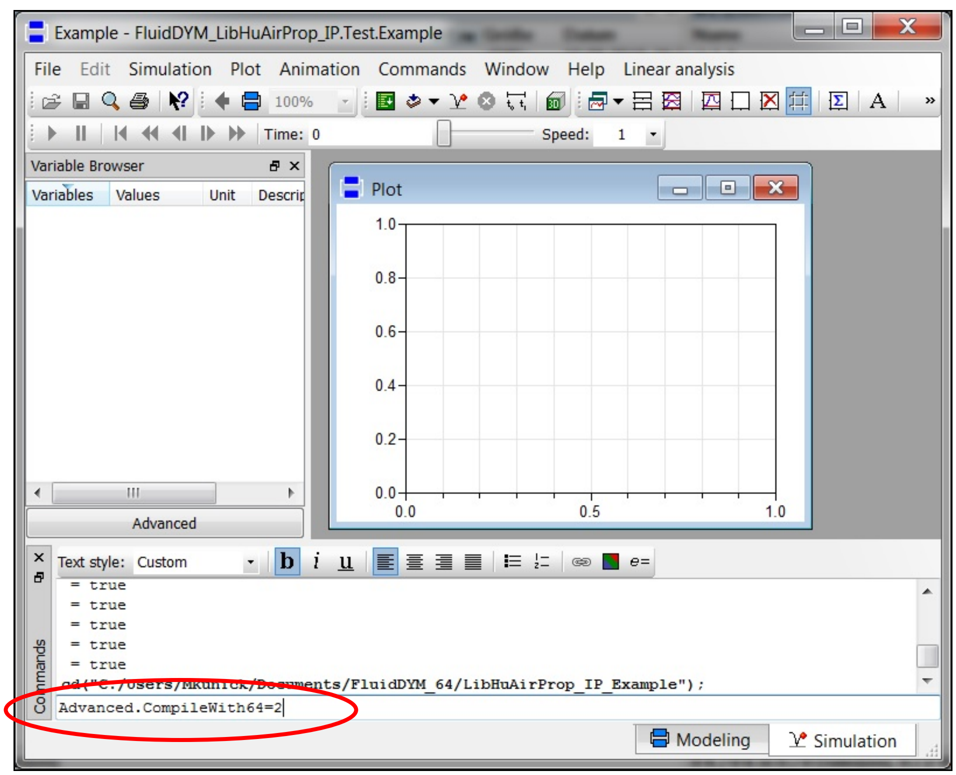
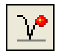


Figure 2.3.17: "Simulation Mode" window with 64-bit command

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

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

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

- Click on the "Simulate" Button  in the Dymola menu bar to start the calculation. Now the model will be compiled and the simulation started.
- Afterwards you will see the following entries within the "Variable Browser" window in Dymola (see Figure 2.3.18):

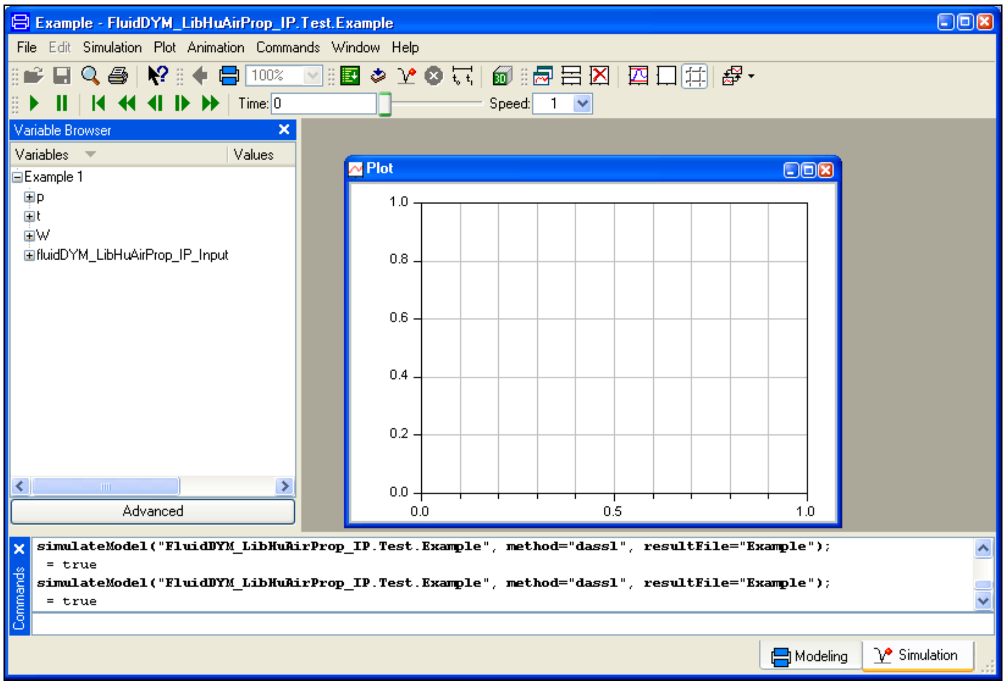


Figure 2.3.18: "Variable Browser" with new entries

- By clicking on the "NewPlotWindow" button , a new diagram window will be opened.
- Click on "fluidDYM_LibHuAirProp_IP_Input" within the "Variable Browser"; then you will see the input and output parameters "scanRange", "FunctionNumber", "z", "x1", "x2", and "x3" (see Figure 2.3.19).

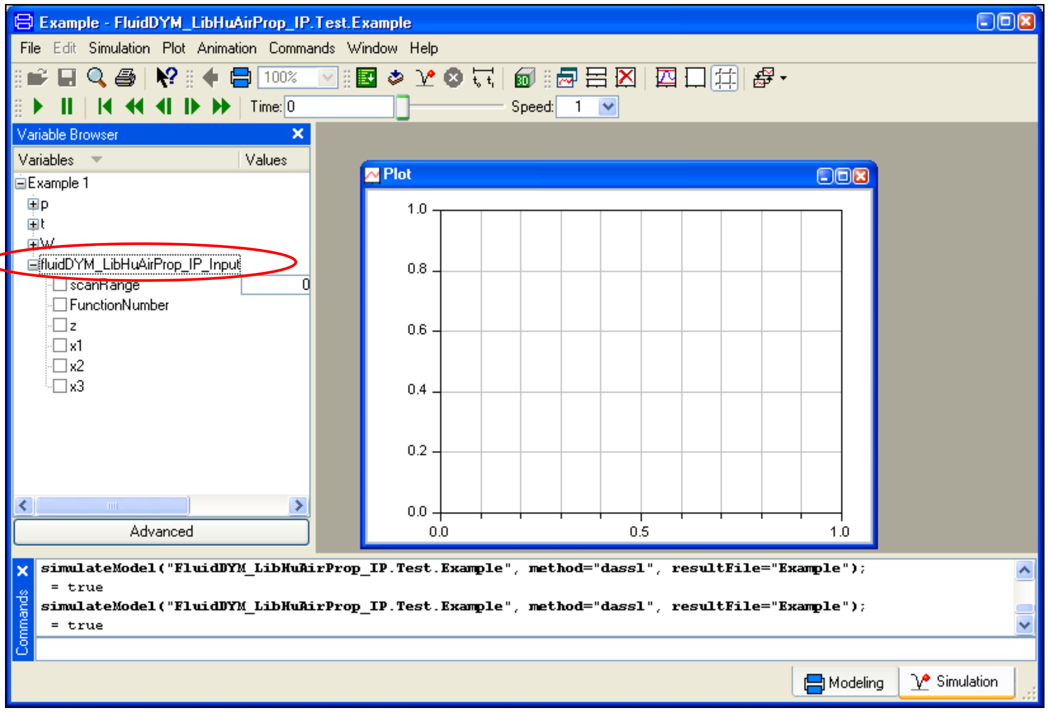


Figure 2.3.19: Parameters of *fluidDYM_LibHuAirProp_IP_Input*

- After clicking on the output parameter "z", the calculated property will be represented graphically in the "PlotWindow".
- Move the mouse over the curve to see the result of the Simulation at a specific point in time (see Figure 2.3.20).

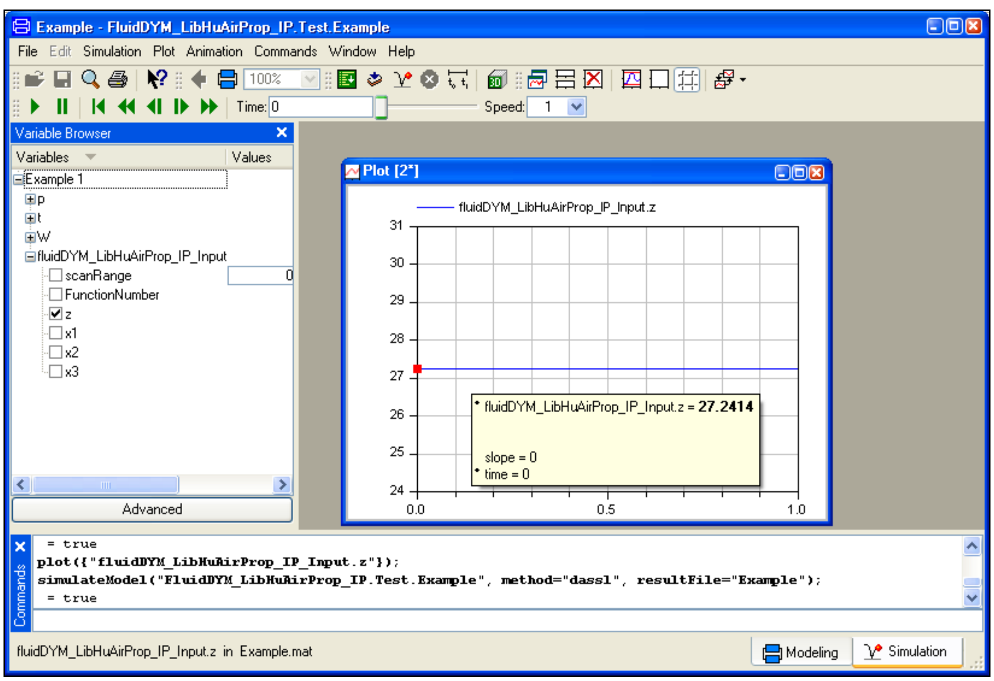
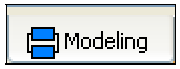


Figure 2.3.20: "DiagramWindow" showing the result

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

⇒ The result in our sample calculation here is: "h = 27.2414". The corresponding unit is Btu/lb_a (see table of the property functions in Chapter 1).

- Now click on the Modeling button 

in the lower right area of Dymola in order to switch into the "Modeling Mode". Here you can arbitrarily change the values for *p*, *t*, or *W* in the appropriate blocks.

2.4 Removing FluidDYM including LibHuAirProp

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

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

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

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

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

Finally, close the "Add or Remove Programs" and "Control Panel" windows. "FluidDYM LibHuAirProp" has now been removed.

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

3 Property Functions of ASHRAE-LibHuAirProp-IP

3.1 Functions for Real Moist Air

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

Function Name:

a_ptW_HAP_IP

Fortran Program:

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

Input Values:

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

Result:

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

Range of Validity:

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

Comments:

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

Result for Wrong Input Values:

a_ptW_HAP_IP = -1000

References:

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

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

Function Name:

alphap_ptW_HAP_IP

Fortran Program:

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

Input Values:

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

Result:

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

Range of Validity:

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

Comments:

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

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

Result for Wrong Input Values:

alphap_ptW_HAP_IP = -1000

References:

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

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

Function Name:

betap_ptW_HAP_IP

Fortran Program:

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

Input Values:

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

Result:

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

Range of Validity:

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

Comments:

- Isothermal stress coefficient $\beta_p = -\frac{1}{p}\left(\frac{\partial p}{\partial v}\right)_T$
- Calculation for supersaturated humid air ($W > W_s$) is not possible

Result for Wrong Input Values:

betap_ptW_HAP_IP = -1000

References:

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

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

Function Name:

c_ptW_HAP_IP

Fortran Program:

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

Input Values:

p - Total pressure *p* in psi

t - Temperature *t* in °F

W - Humidity ratio *W* in lb_w/lb_a

Result:

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

Range of Validity:

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

Comments:

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

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

Result for Wrong Input Values:

c_ptW_HAP_IP = -1000

References:

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

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

Function Name:

cp_ptW_HAP_IP

Fortran Program:

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

Input Values:

p - Total pressure p in psi

t - Temperature t in °F

W - Humidity ratio W in lb_w/lb_a

Result:

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

Range of Validity:

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

Total pressure p: from 0.00145 psi to 1450.4 psi

Humidity ratio W: $0 \le W \le W_s$

Comments:

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

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

Result for Wrong Input Values:

cp_ptW_HAP_IP = -1000

References:

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

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

Function Name:

cv_ptW_HAP_IP

Fortran Program:

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

Input Values:

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

Result:

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

Range of Validity:

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

Comments:

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

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

Result for Wrong Input Values:

cv_ptW_HAP_IP = -1000

References:

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

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

Function Name:

f_pt_HAP_IP

Fortran Program:

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

Input Values:

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

Result:

f_pt_HAP_IP - Enhancement factor of water (decimal ratio)

Range of Validity:

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

Comments:

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

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

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

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

Result for Wrong Input Values:

f_pt_HAP_IP = -1000

References:

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

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

Function Name:

h_ptW_HAP_IP

Fortran Program:

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

Input Values:

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

Result:

h_ptW_HAP_IP - Air-specific enthalpy in Btu/lb_a

Range of Validity:

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

Comments:

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

Result for Wrong Input Values:

h_ptW_HAP_IP = -1000

References:

$h(p,t,W)$	Herrmann et al. [1], [2]
$h_w(p,t)$	IAPWS-IF97 [7], [8] and IAPWS-06 [11]
$h_a(t)$	Lemmon et al. [14]

Dynamic Viscosity η = f(p,t,W)

Function Name:

Eta_ptW_HAP_IP

Fortran Program:

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

Input Values:

p - Total pressure p in psi

t - Temperature t in °F

W - Humidity ratio W in lb_w/lb_a

Result:

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

Range of Validity:

Temperature t: from -99.67°F to 662°F

Total pressure p: from 0.00145 psi to 1450.4 psi

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

Comments:

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

Result for Wrong Input Values:

Eta_ptW_HAP_IP = -1000

References:

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

$\eta_w(p,t)$ IAPWS-IF97 [7], [8] and IAPWS-06 [19]

$\eta_a(t)$ Lemmon et al. [18]

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

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 $\kappa = -\frac{v}{p}\left(\frac{\partial p}{\partial v}\right)_s$
- When calculating supersaturated air an ideal mixing model (saturated humid air and water droplets homogeneously mixed) is applied for $t \ge 32$°F. For temperatures below (ice fog) the value of the saturated state is applied.

Result for Wrong Input Values:

Kappa_ptW_HAP_IP = -1000

References:

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

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

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 $\mathrm{lb_w/lb_a}$

Result:

Ny_ptW_HAP_IP - Kinematic viscosity 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:	$0 \le W \le W_s$

Comments:

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

Result for Wrong Input Values:

Ny_ptW_HAP_IP = -1000

References:

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

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

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

Function Name:

p_tsW_HAP_IP

Fortran Program:

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

Input Values:

t - Temperature t in °F

s - Air-specific entropy s in Btu/(lb$_a$ °R)

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

Result:

p_tsW_HAP_IP - Total pressure of humid air in psi

Range of Validity:

Temperature t:	from -225.67°F to 662°F
Air-specific entropy s:	from -6.32 Btu/(lb$_a$ °R) to 9.32877 Btu/(lb$_a$ °R)
Humidity ratio W:	$0 \le W \le 10$ lb$_w$/lb$_a$

Comments:

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

Result for Wrong Input Values:

p_tsW_HAP_IP = -1000

References:

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

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

Function Name:

p_zele_HAP_IP

Fortran Program:

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

Input Values:

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

Result:

p_zele_HAP_IP - Pressure of humid air in psi

Range of Validity:

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

Comments:

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

Result for Wrong Input Values:

p_zele_HAP_IP = -1000

References:

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

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

Function Name:

pAir_ptW_HAP_IP

Fortran Program:

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

Input Values:

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

Result:

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

Range of Validity:

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

Comments:

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

Result for Wrong Input Values:

pAir_ptW_HAP_IP = -1000

References:

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

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

Function Name:

pH2O_ptW_HAP_IP

Fortran Program:

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

Input Values:

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

Result:

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

Range of Validity:

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

Comments:

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

Result for Wrong Input Values:

pH2O_ptW_HAP_IP = -1000

References:

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

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

Function Name:

pH2Os_pt_HAP_IP

Fortran Program:

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

Input Values:

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

Result:

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

Range of Validity:

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

Total pressure p: from 0.00145 psi to 1450.4 psi

Comments:

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

Result for Wrong Input Values:

pH2Os_pt_HAP_IP = -1000

References:

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

Relative Humidity φ = f(p,t,W)

Function Name:

phi_ptW_HAP_IP

Fortran Program:

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

Input Values:

p	-	Total pressure p in psi
t	-	Temperature t in °F
W	-	Humidity ratio W in $\mathrm{lb_w/lb_a}$

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 lb_w/lb_a

Result:

Pr_ptW_HAP_IP - Prandtl number

Range of Validity:

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

Comments:

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

Result for Wrong Input Values:

Pr_ptW_HAP_IP = -1000

References:

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

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

$\lambda(p,t,W)$ Lemmon et al. [20]

Mole Fraction of Air ψ_{Air} = f(W)

Function Name:

PsiAir_W_HAP_IP

Fortran Program:

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

Input Values:

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

Result:

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

Range of Validity:

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

Comments:

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

Result for Wrong Input Values:

PsiAir_W_HAP_IP = -1000

References:

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

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

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 $\psi_{\mathrm{H2O}} = \dfrac{W}{\dfrac{R_\mathrm{a}}{\mathrm{R_{H2O}}} + W}$

Result for Wrong Input Values:

PsiH2O_W_HAP_IP = -1000

References:

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

Density ρ = f(p,t,W)

Function Name:

Rho_ptW_HAP_IP

Fortran Program:

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

Input Values:

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

Result:

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

Range of Validity:

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

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 lb_w/lb_a

Result:

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

Range of Validity:

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

Comments:

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

Result for Wrong Input Values:

s_ptW_HAP_IP = -1000

References:

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

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

Function Name:

t_phphi_HAP_IP

Fortran Program:

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

Input Values:

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

Result:

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

Range of Validity:

Total pressure p:	from 0.00145 psi to 1450.4 psi
Air-specific enthalpy h:	from -2469.22 Btu/lb_a to 12772.088 Btu/lb_a
Relative humidity φ:	$0 \le \varphi \le 1$

Comments:

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

Result for Wrong Input Values:

t_phphi_HAP_IP = -1000

References:

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

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

Function Name:

t_phW_HAP_IP

Fortran Program:

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

Input Values:

p - Total pressure p in psi

h - Air-specific enthalpy h in Btu/lb_a

W - Humidity ratio W in lb_w/lb_a

Result:

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

Range of Validity:

Total pressure p: from 0.00145 psi to 1450.4 psi

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

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

Comments:

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

Result for Wrong Input Values:

t_phW_HAP_IP = -1000

References:

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

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

Function Name:

t_psW_HAP_IP

Fortran Program:

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

Input Values:

p - Total pressure *p* in psi

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

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 $\mathrm{Btu/(lb_a\ °R)}$ to 9.32877 $\mathrm{Btu/(lb_a\ °R)}$

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 = f(p,t_{wb},W)

Function Name:

t_ptwbW_HAP_IP

Fortran Program:

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

Input Values:

p	-	Total pressure p in psi
t_{wb}	-	Wet-bulb temperature in °F
W	-	Humidity ratio W in lb_w/lb_a

Result:

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

Range of Validity:

Total pressure p:	from 0.00145 psi to 1450.4 psi
Wet bulb temperature t_{wb}:	from -225.67°F to 662°F
Humidity ratio W:	$0 \le W \le 10\,lb_w/lb_a$

Comments:

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

Result for Wrong Input Values:

t_ptwbW_HAP_IP = -1000

References:

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

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

Function Name:

td_pW_HAP_IP

Fortran Program:

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

Input Values:

p - Total pressure p in psi

W - Humidity ratio W in lb_w/lb_a

Result:

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

Range of Validity:

Total pressure p: from 0.00145 psi to 1450.4 psi

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

Comments:

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

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

Result for Wrong Input Values:

td_pW_HAP_IP = -1000

References:

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

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

Function Name:

ts_ppH2O_HAP_IP

Fortran Program:

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

Input Values:

p - Total pressure p in psi

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

Result:

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

Range of Validity:

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

Comments:

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

Result for Wrong Input Values:

ts_ppH2O_HAP_IP = -1000

References:

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

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

Function Name:

twb_ptW_HAP_IP

Fortran Program:

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

Input Values:

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

Result:

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

Range of Validity:

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

Comments:

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

Result for Wrong Input Values:

twb_ptW_HAP_IP = -1000

References:

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

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

Function Name:

u_ptW_HAP_IP

Fortran Program:

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

Input Values:

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

Result:

u_ptW_HAP_IP - Air-specific internal energy in Btu/lb_a

Range of Validity:

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

Comments:

- Internal energy $u = h - pv$

Result for Wrong Input Values:

u_ptW_HAP_IP = -1000

References:

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

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

Function Name:

v_ptW_HAP_IP

Fortran Program:

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

Input Values:

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

Result:

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

Range of Validity:

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

Comments:

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

Result for Wrong Input Values:

v_ptW_HAP_IP = -1000

References:

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

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

Function Name:

W_ptpH2O_HAP_IP

Fortran Program:

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

Input Values:

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

Result:

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

Range of Validity:

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

Comments:

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

Result for Wrong Input Values:

W_ptpH2O_HAP_IP = -1000

References:

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

Humidity Ratio from Relative Humidity $W = f(p,t,\varphi)$

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 lb_w/lb_a

Result:

Z_ptW_HAP_IP - Compression factor (decimal ratio)

Range of Validity:

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

Comments:

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

  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 ($W > W_s$) is not possible

Result for Wrong Input Values:

Z_ptW_HAP_IP = -1000

References:

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

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

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

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 $h_{liq,s} = f(t)$

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

Result for Wrong Input Values:

hliqs_t_97_IP = -1000

References:

$h^{97}(p,t)$, $p_s^{97}(t)$ 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 $s_{liq} = f(p,t)$

Function Name:

sliq_pt_97_IP

Fortran Program:

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

Input Values:

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

Result:

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

Range of Validity:

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

Temperature t: from 32°F to 662°F

Comments:

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

Result for Wrong Input Values:

sliq_pt_97_IP = -1000

References:

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

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

Function Name:

sliqs_t_97_IP

Fortran Program:

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

Input Values:

t   -   Temperature *t* in °F

Result:

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

Range of Validity:

Temperature *t*:   from 32°F to 662°F

Comments:

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

Function Name:

svaps_t_97_IP

Fortran Program:

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

Input Values:

t - Temperature *t* in °F

Result:

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

Range of Validity:

Temperature *t*: from 32°F to 662°F

Comments:

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

Result for Wrong Input Values:

svaps_t_97_IP = -1000

References:

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

Saturation Temperature of Water t_s = f(p)

Function Name:

ts_p_97_IP

Fortran Program:

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

Input Values:

p - Pressure *p* in psi

Result:

ts_p_97_IP - Saturation temperature of water in °F

Range of Validity:

Pressure *p*: from 0.08865 psi to 1450.4 psi

Comments:

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

Result for Wrong Input Values:

ts_p_97_IP = -1000

References:

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

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

Function Name:

vliq_pt_97_IP

Fortran Program:

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

Input Values:

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

Result:

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

Range of Validity:

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

Temperature *t*: from 32°F to 662°F

Comments:

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

Result for Wrong Input Values:

vliq_pt_97_IP = -1000

References:

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

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

Function Name:

vliqs_t_97_IP

Fortran Program:

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

Input Values:

t - Temperature t in °F

Result:

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

Range of Validity:

Temperature t: from 32°F to 662°F

Comments:

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

Result for Wrong Input Values:

vliqs_t_97_IP = -1000

References:

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

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

Function Name:

vvaps_t_97_IP

Fortran Program:

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

Input Values:

t - Temperature t in °F

Result:

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

Range of Validity:

Temperature t: from 32°F to 662°F

Comments:

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

Result for Wrong Input Values:

vvaps_t_97_IP = -1000

References:

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

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

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

Function Name:

hicesub_t_06_IP

Fortran Program:

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

Input Values:

t - Temperature t in °F

Result:

hicesub_t_06_IP - Specific enthalpy of saturated ice in Btu/lb

Range of Validity:

Temperature t: from -225.67°F to 32°F

Comments:

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

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

Result for Wrong Input Values:

hicesub_t_06_IP = -1000

References:

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

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

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

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 $p_{mel} = f(t)$

Function Name:

pmel_t_08_IP

Fortran Program:

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

Input Values:

t - Temperature *t* in °F

Result:

pmel_t_08_IP - Melting pressure of ice in psi

Range of Validity:

Temperature *t*: from -7.573°F to 32°F

Result for Wrong Input Values:

pmel_t_08_IP = -1000

References:

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

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

Function Name:

psub_t_08_IP

Fortran Program:

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

Input Values:

t - Temperature t in °F

Result:

psub_t_08_IP - Sublimation pressure of ice in psi

Range of Validity:

Temperature t: from -225.67°F to 32°F

Result for Wrong Input Values:

psub_t_08_IP = -1000

References:

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

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

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

Result for Wrong Input Values:

sicesub_t_06_IP = -1000

References:

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

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

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

Function Name:

svapsub_t_95_IP

Fortran Program:

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

Input Values:

t - Temperature t in °F

Result:

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

Range of Validity:

Temperature t: from -225.67°F to 32°F

Comments:

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

  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_s (32°F) = 0.08865 psi to 1450.4 psi

Result for Wrong Input Values:

tmel_p_08_IP = -1000

References:

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

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

Function Name:

tsub_p_08_IP

Fortran Program:

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

Input Values:

p - Pressure *p* in psi

Result:

tsub_p_08_IP - Sublimation temperature of ice in °F

Range of Validity:

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

Result for Wrong Input Values:

tsub_p_08_IP = -1000

References:

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

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

Function Name:

vicesub_t_06_IP

Fortran Program:

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

Input Values:

t - Temperature *t* in °F

Result:

vicesub_t_06_IP - Specific volume of saturated ice in $\mathrm{ft}^3/\mathrm{lb}$

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 $v_{\text{vap,sub}} = f(t)$

Function Name:

vvapsub_t_95_IP

Fortran Program:

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

Input Values:

t - Temperature *t* in °F

Result:

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

Range of Validity:

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

Comments:

- Specific volume of saturated water vapor $v_{\text{vap,sub}} = v^{95}(p_{\text{sub}}, t)$
  with $p_{\text{sub}} = p_{\text{sub}}^{08}(t)$

Result for Wrong Input Values:

vvapsub_t_95_IP = -1000

References:

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

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

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www.thermodynamics-zittau.de

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
  - IAPWS-IF97-S03rev
  - IAPWS-IF97-S04
  - IAPWS-IF97-S05
- IAPWS Revised Advisory Note No. 3 on Thermodynamic Derivatives (2008)

Humid Combustion Gas Mixtures

Library LibHuGas

Model: Ideal mixture of the real fluids:

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

and of the ideal gases:

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

Consideration of:

Dissociation from VDI 4670 and Poynting effect

Humid Air

Library LibHuAir

Model: Ideal mixture of the real fluids:

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

Consideration of:

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

Carbon Dioxide Including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1996)

Seawater

Library LibSeaWa

IAPWS Industrial Formulation 2013

Ice

Library LibICE

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

Ideal Gas Mixtures

Library LibIdGasMix

Model: Ideal mixture of the ideal gases:

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

Consideration of:

- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

Humid Air

Library ASHRAE LibHuAirProp

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

Consideration of:

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

www.ashrae.org/bookstore

Dry Air Including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth et al. (1993)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of Bücker and Wagner (2006)

n-Butane

Library LibButane_n

Formulation of Bücker and Wagner (2006)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

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

Helmholtz energy equation for the mixing term

(also useable for calculating Kalina Cycle)

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

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

Formulation of the International Institute of Refrigeration (1997)

Ethanol
Library LibC2H5OH
Formulation of Schroeder (2012)

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

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

Siloxanes as ORC Working Fluids

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

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

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

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

Formulation of Colonna et al. (2006)

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

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

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

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

Formulation of Colonna et al. (2008)

Nitrogen
Library LibN2
Formulation of Span et al. (2000)

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**
Dinitrogen monooxide N_2O **Library LibN2O**
Sulfur dioxide SO_2 **Library LibSO2**
Acetone C_3H_6O **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

For more information please contact:

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Fax.: +49-3583-61-1846

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

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

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

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

Thermodynamic Derivatives
- Partial derivatives can be calculated.

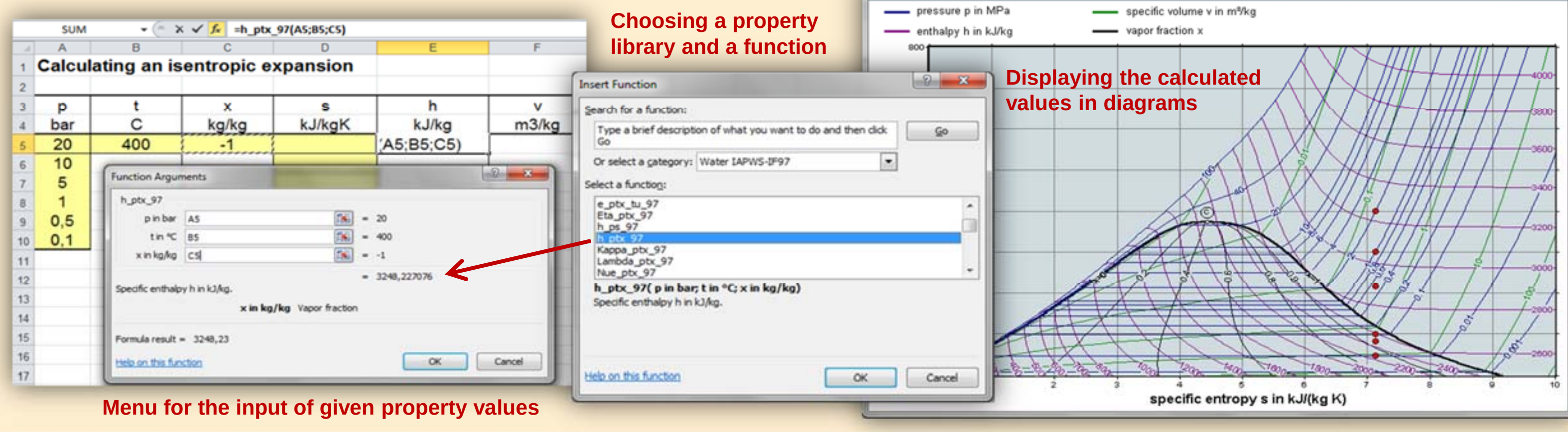
[a] Not all of these property functions are available in all property libraries.

www.thermodynamic-property-libraries.com

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

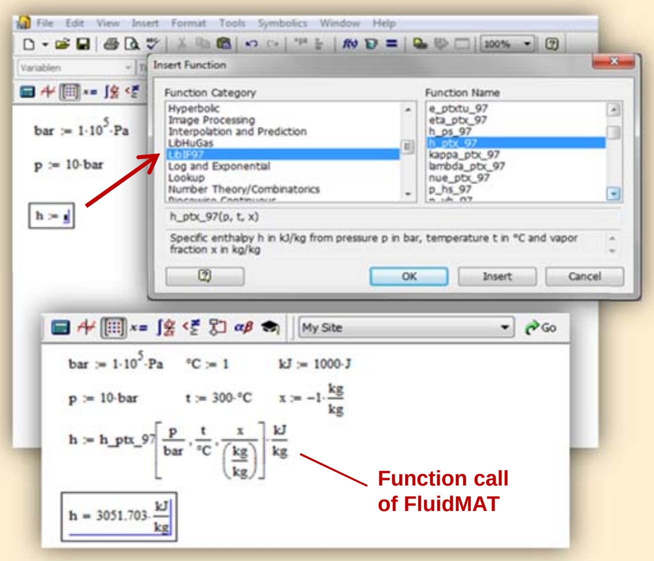
Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

Add-In FluidEXL^Graphics for Excel®



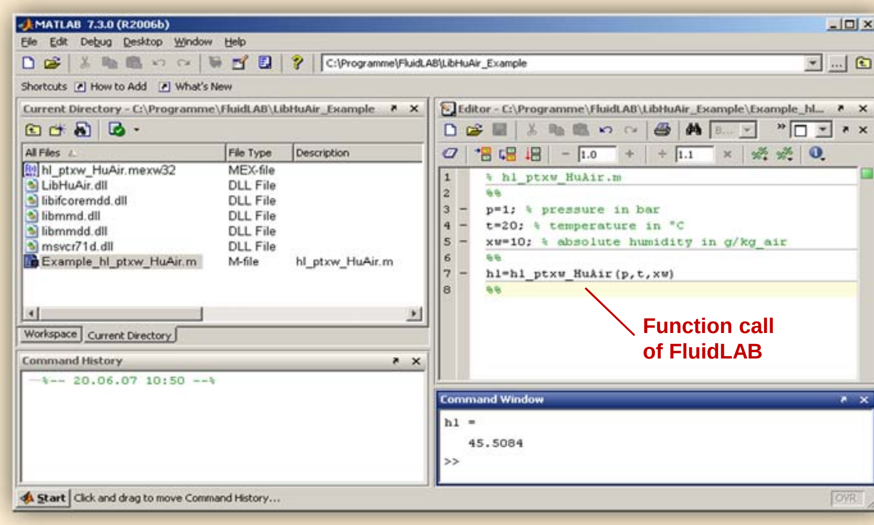
Add-In FluidMAT for Mathcad®

The property libraries can be used in Mathcad®.



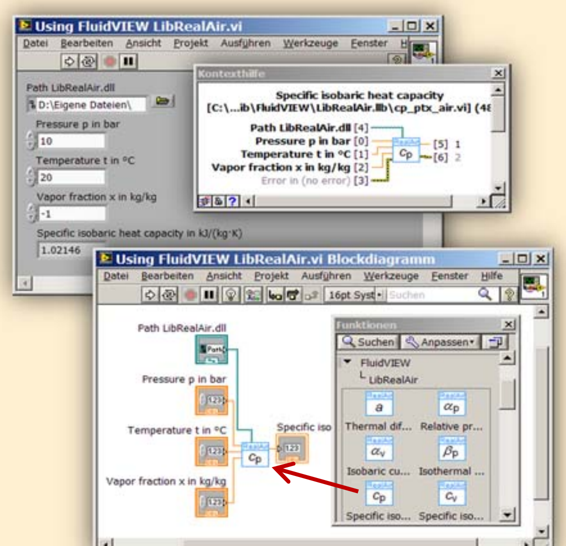
Add-In FluidLAB for MATLAB®

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



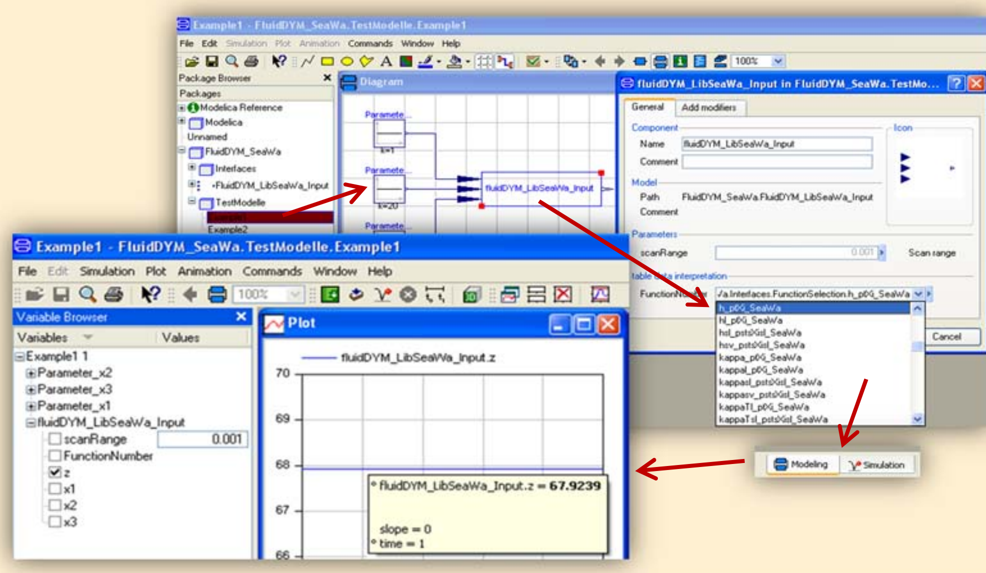
Add-On FluidVIEW for LabVIEW®

The property functions can be calculated in LabVIEW®.

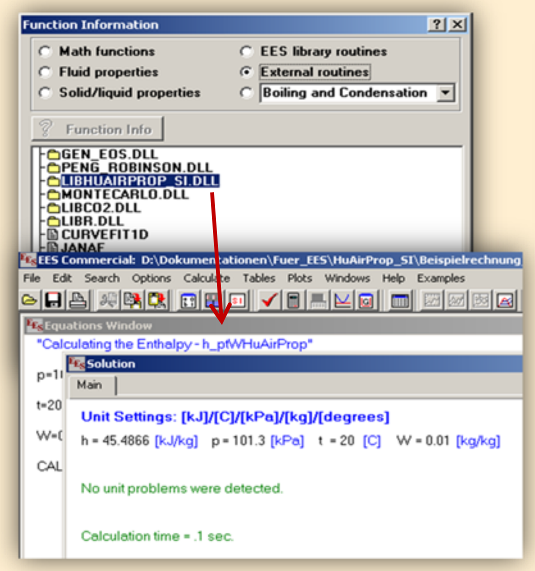


Add-In FluidDYM for DYMOLA® (Modelica) and SimulationX®

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

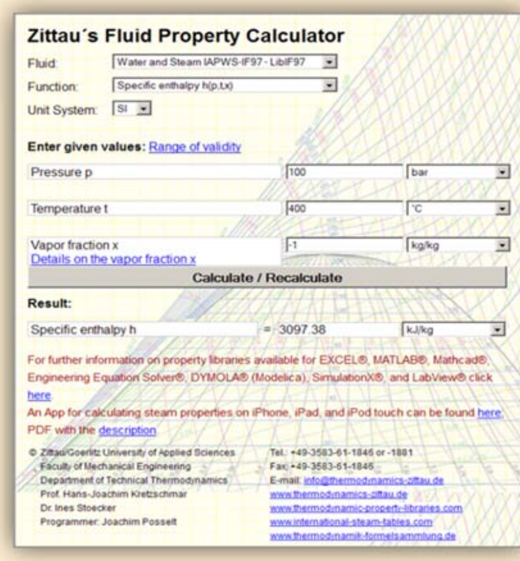


Add-In FluidEES for Engineering Equation Solver®



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

Online Property Calculator at www.thermodynamics-zittau.de



Property Software for Pocket Calculators

FluidCasio

fx 9750 G II

CFX 9850
fx-GG20

CFX 9860 G
Graph 85

ALGEBRA
FX 2.0

FluidHP

HP 48

HP 49

FluidTI

TI Nspire CX CAS
TI Nspire CAS

TI 83
TI 84
TI 89

TI Voyage 200

TI 92

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives can be calculated.

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

www.thermodynamic-property-libraries.com

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Part SI Units

1 Property Library ASHRAE-LibHuAirProp-SI

1.1 Function Overview

1.1.1 Function Overview for Real Moist Air

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

Functional Dependence	Function Name	Property or Function	Unit of the Result	Page
$\varphi = \mathrm{f}(p,t,W)$	phi_ptW_HAP_SI	Relative humidity (decimal ratio)	-	3/19
$Pr = \mathrm{f}(p,t,W)$	Pr_ptW_HAP_SI	PRANDTL number	-	3/20
$\psi_{Air} = \mathrm{f}(W)$	PsiAir_W_HAP_SI	Mole fraction of dry air in moist air	$\mathrm{mol_a/mol}$	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	kg_w/kg_a	3/37
$W_{\mathrm{s}} = \mathrm{f}(p,t)$	Ws_pt_HAP_SI	Saturation humidity ratio	kg_w/kg_a	3/38
$\xi_{\mathrm{Air}} = \mathrm{f}(W)$	XiAir_W_HAP_SI	Mass fraction of dry air in moist air	kg_a/kg	3/39
$\xi_{\mathrm{H2O}} = \mathrm{f}(W)$	XiH2O_W_HAP_SI	Mass fraction of water vapor in moist air	kg_w/kg	3/40
$Z = \mathrm{f}(p,t,W)$	Z_ptW_HAP_SI	Compression factor (decimal ratio)	-	3/41

Range of Validity of Thermodynamic Properties

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

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

Range of Validity of Transport Properties

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

Molar Masses

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

Reference States

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

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

Functional Dependence	Function Name	Property	Unit of the Result	Page
$h_{liq} = f(p,t)$	hliq_pt_97_SI	Specific enthalpy of liquid water	kJ/kg	3/43
$h_{liq,s} = f(t)$	hliqs_t_97_SI	Specific enthalpy of saturated liquid water	kJ/kg	3/44
$h_{vap,s} = f(t)$	hvaps_t_97_SI	Specific enthalpy of saturated water vapor	kJ/kg	3/45
$p_s = f(t)$	ps_t_97_SI	Saturation pressure of water	kPa	3/46
$s_{liq} = f(p,t)$	sliq_pt_97_SI	Specific entropy of liquid water	kJ/(kg·K)	3/47
$s_{liq,s} = f(t)$	sliqs_t_97_SI	Specific entropy of saturated liquid water	kJ/(kg·K)	3/48
$s_{vap,s} = f(t)$	svaps_t_97_SI	Specific entropy of saturated water vapor	kJ/(kg·K)	3/49
$t_s = f(p)$	ts_p_97_SI	Saturation temperature of water	°C	3/50
$v_{liq} = f(p,t)$	vliq_pt_9_SI	Specific volume of liquid water	m³/kg	3/51
$v_{liq,s} = f(t)$	vliqs_t_97_SI	Specific volume of saturated liquid water	m³/kg	3/52
$v_{vap,s} = f(t)$	vvaps_t_97_SI	Specific volume of saturated water vapor	m³/kg	3/53

Range of Validity

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

Reference State

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

Units

Symbol	Quantity	Unit
p	Pressure	kPa
t	Temperature	°C

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

Functional Dependence	Function Name	Property	Unit of the Result	Page
$h_{ice,sub} = f(t)$	hicesub_t_06_SI	Specific enthalpy of saturated ice	kJ/kg	3/55
$h_{vap,sub} = f(t)$	hvapsub_t_95_SI	Specific enthalpy of saturated water vapor	kJ/kg	3/56
$p_{mel} = f(t)$	pmel_t_08_SI	Melting pressure of ice	kPa	3/57
$p_{sub} = f(t)$	psub_t_08_SI	Sublimation pressure of ice	kPa	3/58
$s_{ice,sub} = f(t)$	sicesub_t_06_SI	Specific entropy of saturated ice	kJ/(kg·K)	3/59
$s_{vap,sub} = f(t)$	svapsub_t_95_SI	Specific entropy of saturated water vapor	kJ/(kg·K)	3/60
$t_{mel} = f(p)$	tmel_p_08_SI	Melting temperature of ice	°C	3/61
$t_{sub} = f(p)$	tsub_p_08_SI	Sublimation temperature of ice	°C	3/62
$v_{ice,sub} = f(t)$	vicesub_t_06_SI	Specific volume of saturated ice	m³/kg	3/63
$v_{vap,sub} = f(t)$	vvapsub_t_95_SI	Specific volume of saturated water vapor	m³/kg	3/64

Range of Validity

Property	Range of Validity
Pressure:	$p_{sub}(-143.15°C) = 1.2002 \times 10^{-11} \le p \le 10\,000$ kPa
Temperature:	$-143.15 \le t \le 0$ °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	$\dfrac{a_{\mathrm{IP}}}{\frac{\mathrm{ft^2}}{\mathrm{s}}} = \dfrac{a_{\mathrm{SI}}}{\frac{\mathrm{m^2}}{\mathrm{s}}} \times 10.76391042$	$\dfrac{a_{\mathrm{SI}}}{\frac{\mathrm{m^2}}{\mathrm{s}}} = \dfrac{a_{\mathrm{IP}}}{\frac{\mathrm{ft^2}}{\mathrm{s}}} \times 0.0929304$	m²/s	ft²/s
Relative pressure coefficient	α_p	$\dfrac{\alpha_{p,\mathrm{IP}}}{\frac{1}{\mathrm{°R}}} = \dfrac{\alpha_{p,\mathrm{SI}}}{\frac{1}{\mathrm{K}}} \times \dfrac{9}{5}$	$\dfrac{\alpha_{p,\mathrm{SI}}}{\frac{1}{\mathrm{K}}} = \dfrac{\alpha_{p,\mathrm{IP}}}{\frac{1}{\mathrm{°R}}} \times \dfrac{5}{9}$	1/K	1/°R
Isothermal stress coefficient	β_p	$\dfrac{\beta_{p,\mathrm{IP}}}{\frac{\mathrm{lb}}{\mathrm{ft^3}}} = \dfrac{\beta_{p,\mathrm{SI}}}{\frac{\mathrm{kg}}{\mathrm{m^3}}} \times 0.062428$	$\dfrac{\beta_{p,\mathrm{SI}}}{\frac{\mathrm{kg}}{\mathrm{m^3}}} = \dfrac{\beta_{p,\mathrm{IP}}}{\frac{\mathrm{lb}}{\mathrm{ft^3}}} \times 16.018463$	kg/m³	lb/ft³
Speed of sound	c	$\dfrac{c_{\mathrm{IP}}}{\frac{\mathrm{ft}}{\mathrm{s}}} = \dfrac{c_{\mathrm{SI}}}{\frac{\mathrm{m}}{\mathrm{s}}} \times 3.2808399$	$\dfrac{c_{\mathrm{SI}}}{\frac{\mathrm{m}}{\mathrm{s}}} = \dfrac{c_{\mathrm{IP}}}{\frac{\mathrm{ft}}{\mathrm{s}}} \times 0.3048$	m/s	ft/s
Specific isobaric heat capacity	c_p	$\dfrac{c_{p,\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb\ °R}}} = \dfrac{c_{p,\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg\ K}}} \times 0.2388459$	$\dfrac{c_{p,\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg\ K}}} = \dfrac{c_{p,\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb\ °R}}} \times 4.1868$	kJ/(kg·K)	Btu/(lb·°R)
Specific isochoric heat capacity	c_v	$\dfrac{c_{v,\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb\ °R}}} = \dfrac{c_{v,\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg\ K}}} \times 0.2388459$	$\dfrac{c_{v,\mathrm{SI}}}{\frac{\mathrm{kJ}}{\mathrm{kg\ K}}} = \dfrac{c_{v,\mathrm{IP}}}{\frac{\mathrm{Btu}}{\mathrm{lb\ °R}}} \times 4.1868$	kJ/(kg·K)	Btu/(lb·°R)
Dynamic viscosity	η	$\dfrac{\eta_{\mathrm{IP}}}{\frac{\mathrm{lb\ s}}{\mathrm{ft^2}}} = \dfrac{\eta_{\mathrm{SI}}}{\frac{\mathrm{Pa}}{\mathrm{s}}} \times 0.02088543$	$\dfrac{\eta_{\mathrm{SI}}}{\frac{\mathrm{Pa}}{\mathrm{s}}} = \dfrac{\eta_{\mathrm{IP}}}{\frac{\mathrm{lb\ s}}{\mathrm{ft^2}}} \times 47.880259$	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	$\dfrac{h_{IP}}{\frac{\text{Btu}}{\text{lb}_a}} = \dfrac{h_{SI}}{\frac{\text{kJ}}{\text{kg}_a}} \times 0.4299226 + 7.68565365666$	$\dfrac{h_{SI}}{\frac{\text{kJ}}{\text{kg}_a}} = \left(\dfrac{h_{IP}}{\frac{\text{Btu}}{\text{lb}_a}} - 7.68565365666 \right) \times 2.326$	kJ/kg_a	Btu/lb_a
Specific enthalpy (water, water vapor, ice)	h_w	$\dfrac{h_{IP}}{\frac{\text{Btu}}{\text{lb}}} = \dfrac{h_{SI}}{\frac{\text{kJ}}{\text{kg}}} \times 0.4299226$	$\dfrac{h_{SI}}{\frac{\text{kJ}}{\text{kg}}} = \dfrac{h_{IP}}{\frac{\text{Btu}}{\text{lb}}} \times 2.326$	kJ/kg	Btu/lb
Isentropic exponent	κ	$\kappa_{IP} = \kappa_{SI}$	$\kappa_{SI} = \kappa_{IP}$	-	-
Thermal conductivity	λ	$\dfrac{\lambda_{IP}}{\frac{\text{Btu}}{\text{h ft °R}}} = \dfrac{\lambda_{SI}}{\frac{\text{W}}{\text{m K}}} \times 0.57778932$	$\dfrac{\lambda_{SI}}{\frac{\text{W}}{\text{m K}}} = \dfrac{\lambda_{IP}}{\frac{\text{Btu}}{\text{h ft °R}}} \times 1.73073467$	W/(m·K)	Btu/(h·ft·°R)
Kinematic viscosity	ν	$\dfrac{\nu_{IP}}{\frac{\text{ft}^2}{\text{s}}} = \dfrac{\nu_{SI}}{\frac{\text{m}^2}{\text{s}}} \times 10.763910417$	$\dfrac{\nu_{SI}}{\frac{\text{m}^2}{\text{s}}} = \dfrac{\nu_{IP}}{\frac{\text{ft}^2}{\text{s}}} \times 0.092903040$	m^2/s	ft^2/s
Pressure	p	$\dfrac{p_{IP}}{\text{psi}} = \dfrac{p_{SI}}{\text{kPa}} \times 0.14503774$	$\dfrac{p_{SI}}{\text{kPa}} = \dfrac{p_{IP}}{\text{psi}} \times 6.894757$	kPa	psi
Relative humidity	φ	$\varphi_{IP} = \varphi_{SI}$	$\varphi_{SI} = \varphi_{IP}$	-	-
Prandtl number	Pr	$Pr_{IP} = Pr_{IP}$	$Pr_{SI} = Pr_{IP}$	-	-
Mole fraction	ψ	$\psi_{IP} = \psi_{SI}$	$\psi_{SI} = \psi_{IP}$	mol/mol	mol/mol
Density	ρ	$\dfrac{\rho_{IP}}{\frac{\text{lb}}{\text{ft}^3}} = \dfrac{\rho_{SI}}{\frac{\text{kg}}{\text{m}^3}} \times 0.062428$	$\dfrac{\rho_{SI}}{\frac{\text{kg}}{\text{m}^3}} = \dfrac{\rho_{IP}}{\frac{\text{lb}}{\text{ft}^3}} \times 16.018463$	kg/m^3	lb/ft^3
Air-specific entropy (moist air)	s	$\dfrac{s_{IP}}{\frac{\text{Btu}}{\text{lb}_a\ \text{°R}}} = \dfrac{s_{SI}}{\frac{\text{kJ}}{\text{kg}_a\ \text{K}}} \times 0.2388459 + 0.01616365106$	$\dfrac{s_{SI}}{\frac{\text{kJ}}{\text{kg}_a\ \text{K}}} = \left(\dfrac{s_{IP}}{\frac{\text{Btu}}{\text{lb}_a\ \text{°R}}} - 0.01616365106 \right) \times 4.1868$	$\text{kJ/(kg}_a\text{·K)}$	$\text{Btu/(lb}_a\text{·°R)}$

Property		Conversion: SI Units → I-P Units	Conversion: I-P Units → SI Units	Units SI	Units I-P
Specific entropy (water, water vapor, ice)	s_w	$\frac{s_{IP}}{\frac{Btu}{lb_a\ °R}} = \frac{s_{SI}}{\frac{kJ}{kg_a\ K}} \times 0.23884589$	$\frac{s_{SI}}{\frac{kJ}{kg_a\ K}} = \frac{s_{IP}}{\frac{Btu}{lb_a\ °R}} \times 4.1868$	kJ/(kg$_a$·K)	Btu/(lb$_a$·°R)
Temperature	t	$\frac{t_{IP}}{°F} = \frac{t_{SI}}{°C} \times \frac{9}{5} + 32$	$\frac{t_{SI}}{°C} = \left(\frac{t_{IP}}{°F} - 32\right) \times \frac{5}{9}$	°C	°F
Air-specific internal energy (moist air)	u	$(u = h - pv)$ $\frac{u_{IP}}{\frac{Btu}{lb_a}} = \frac{h_{SI}}{\frac{kJ}{kg_a}} \times 0.4299226 + 7.68565365666 - \frac{p_{SI}}{kPa} \times 0.145037738 \cdot \frac{v_{SI}}{\frac{m^3}{kg_a}} \times 16.018453$	$(u = h - pv)$ $\frac{u_{SI}}{\frac{kJ}{kg_a}} = \left(\frac{h_{IP}}{\frac{Btu}{lb_a}} - 7.68565365666\right) \times 2.236 - \frac{p_{IP}}{psi} \times 6.894757293 \cdot \frac{v_{SIP}}{\frac{ft^3}{lb_a}} \times 0.062428$	kJ/kg$_a$	Btu/lb
Air-specific volume (moist air)	v	$\frac{v_{IP}}{\frac{ft^3}{lb_a}} = \frac{v_{SI}}{\frac{m^3}{kg_a}} \times 16.018453$	$\frac{v_{SI}}{\frac{m^3}{kg_a}} = \frac{v_{IP}}{\frac{ft^3}{lb_a}} \times 0.062428$	m³/kg$_a$	ft³/lb$_a$
Specific volume (water, water vapor, ice)	v_w	$\frac{v_{IP}}{\frac{ft^3}{lb}} = \frac{v_{SI}}{\frac{m^3}{kg}} \times 16.018453$	$\frac{v_{SI}}{\frac{m^3}{kg}} = \frac{v_{IP}}{\frac{ft^3}{lb}} \times 0.062428$	m³/kg	ft³/lb
Humidity ratio	W	$W_{IP} = W_{SI}$	$W_{SI} = W_{IP}$	kg$_w$/kg$_a$	lb$_w$/lb$_a$
Mass fraction	ξ	$\xi_{IP} = \xi_{SI}$	$\xi_{SI} = \xi_{IP}$	kg$_w$/kg	lb$_w$/lb
Compression factor	Z	$Z_{IP} = Z_{SI}$	$Z_{SI} = Z_{IP}$	-	-

1.3 Calculation Algorithms

1.3.1 Algorithms for Real Moist Air

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

- the value for the universal molar gas constant from the CODATA standard by Mohr and Taylor [22]
- the value for the molar mass of dry air from Gatley et al. [17] and that of water from IAPWS-95 [5], [6]
- the calculation of the ideal-gas parts of the heat capacity, enthalpy, and entropy for dry air from the fundamental equation of Lemmon et al. [14]
- the calculation of the ideal-gas parts of the heat capacity, enthalpy, and entropy for water vapor from IAPWS-IF97 [7], [8], [9] for $t \geq 0°\mathrm{C}$ and from IAPWS-95 [5], [6] for $t \leq 0°\mathrm{C}$
- the calculation of the vapor-pressure enhancement factor from the equation given by the models of Hyland and Wexler [21]
- the calculation of the second and third molar virial coefficients B_{aa} and C_{aaa} for dry air from the fundamental equation of Lemmon et al. [14]
- the calculation of the second and third molar virial coefficients B_{ww} and C_{www} for water and steam from IAPWS-95 [5], [6]
- 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.

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

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

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

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

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

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

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

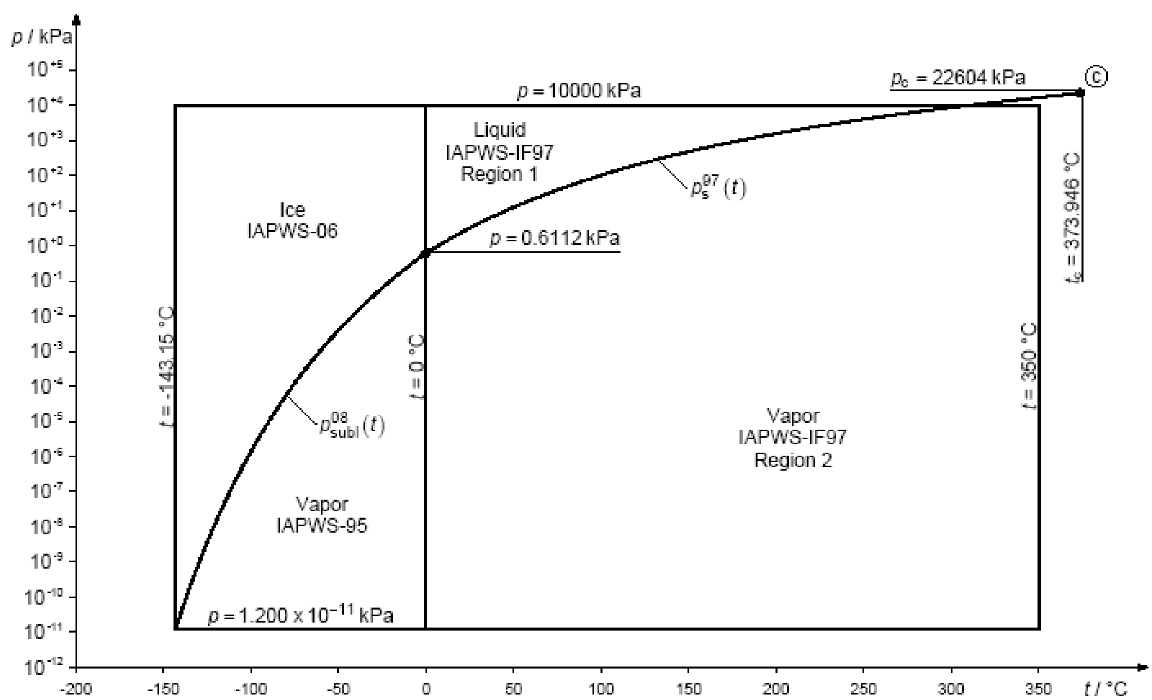


Figure 1: *p*-*T* diagram with used IAPWS formulations for steam, water, and ice.

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

2.1 Installing FluidDYM

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

2.1.1 Installing FluidDYM including LibHuAirProp

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

2.1.2 The FluidDYM Help System

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

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

Now we will calculate, step by step, the specific enthalpy *h* of moist air as a function of pressure *p*, temperature *t* and humidity ratio *W*, using Dymola®.
Please carry out the following instructions:

- Start Windows Explorer®, Total Commander®, My Computer or another file manager program. The description here refers to Windows Explorer
- Your Windows Explorer should be set to Details for a better view. Click the "View" (Ansicht) button and select "Details".
- Switch into the program directory of FluidDYM in which you will find the folder "\LibHuAirProp_SI"; the standard location is: "C:\Program Files\FluidDYM\LibHuAirProp_SI"
- Create the folder "\LibHuAirProp_SI_Example" by clicking on "File" in the Explorer menu, then "New" in the menu which appears, and then selecting "Folder". Name the new folder "\LibHuAirProp_SI_Example".
- You will see the following window:

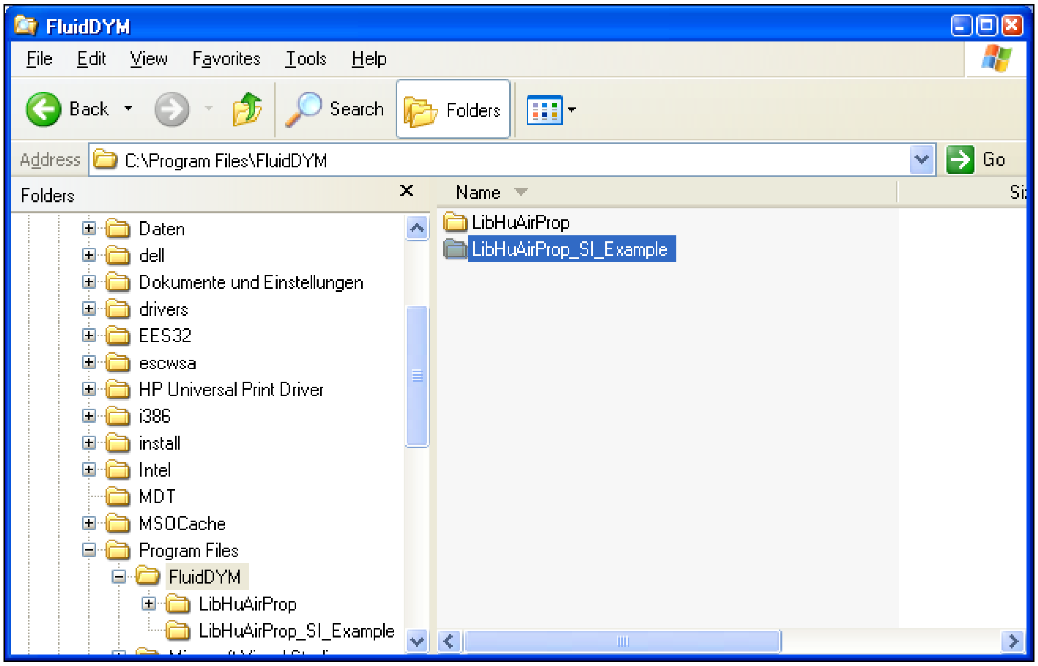


Figure 2.2.1: Highlighted *LibHuAirProp_SI_Example* directory in Program Files

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

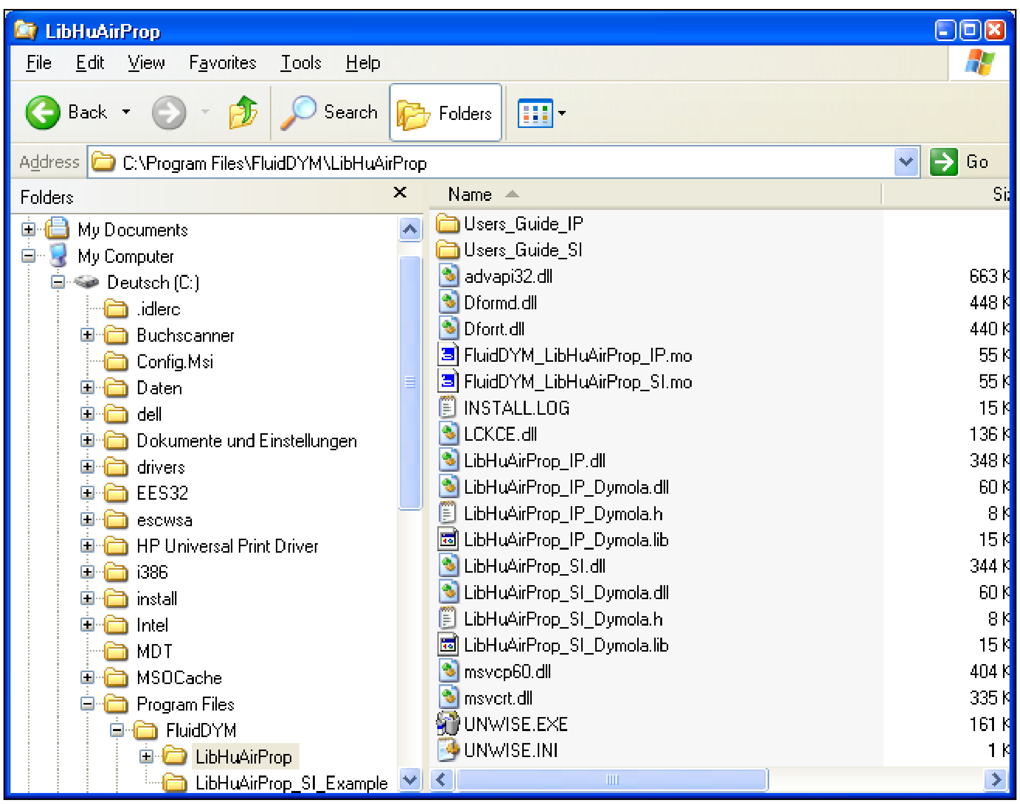


Figure 2.2.2: *LibHuAirProp_SI* directory including installed files

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

- "advapi32.dll"
- "Dforrt.dll"
- "Dformd.dll"
- "FluidDYM_HuAirProp_SI.mo"
- "LCKCE.dll"
- "LibHuAirProp_SI.dll"
- "LibHuAirProp_SI_Dymola.dll"
- "LibHuAirProp_SI_Dymola.h"
- "LibHuAirProp_SI_Dymola.lib"
- "msvcp60.dll"
- "msvcrt.dll"
- the folder "Users_Guide"

- Mark up these files, then click "Edit" in the upper menu bar and select "Copy".
- Switch into the directory "C:\Program Files\FluidDYM\LibHuAirProp_SI_Example", click "Edit" and then "Paste".
- You will see the following window:

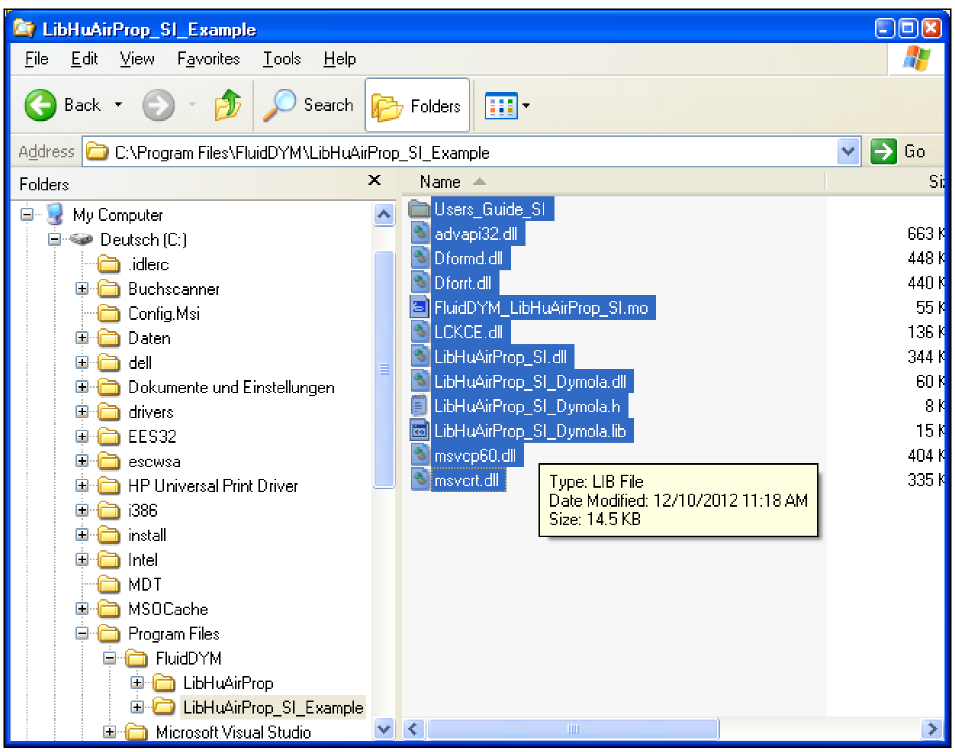


Figure 2.2.3: *LibHuAirProp_SI_Example* directory including the newly-copied files

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

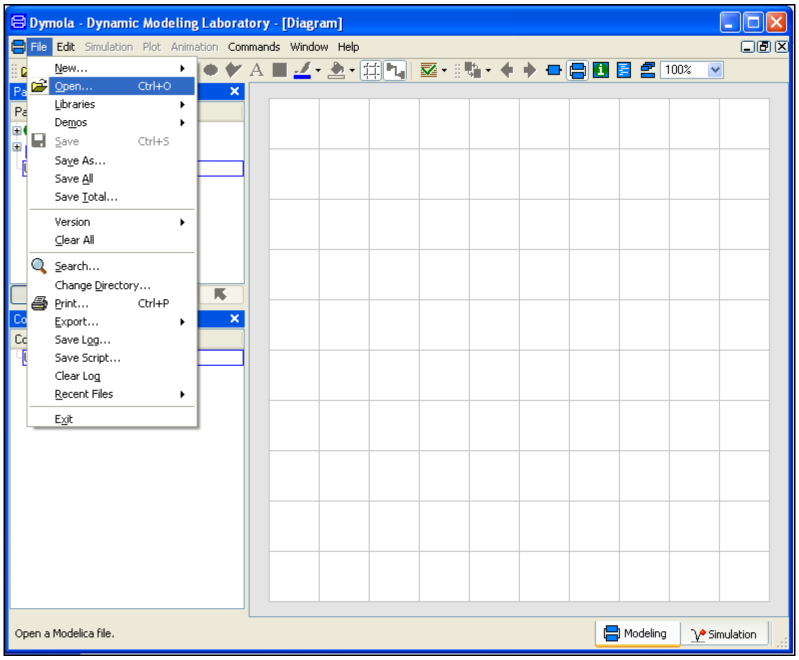


Figure 2.2.4: Selecting the menu entry "Open"

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

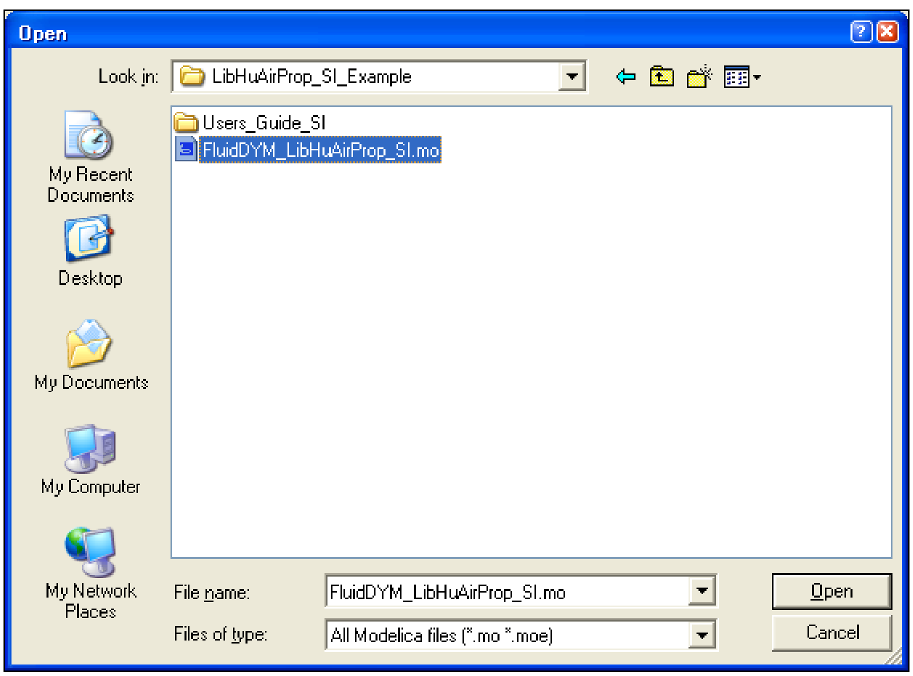


Figure 2.2.5: Selecting the *FluidDYM_LibHuAirProp_SI.mo* file

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

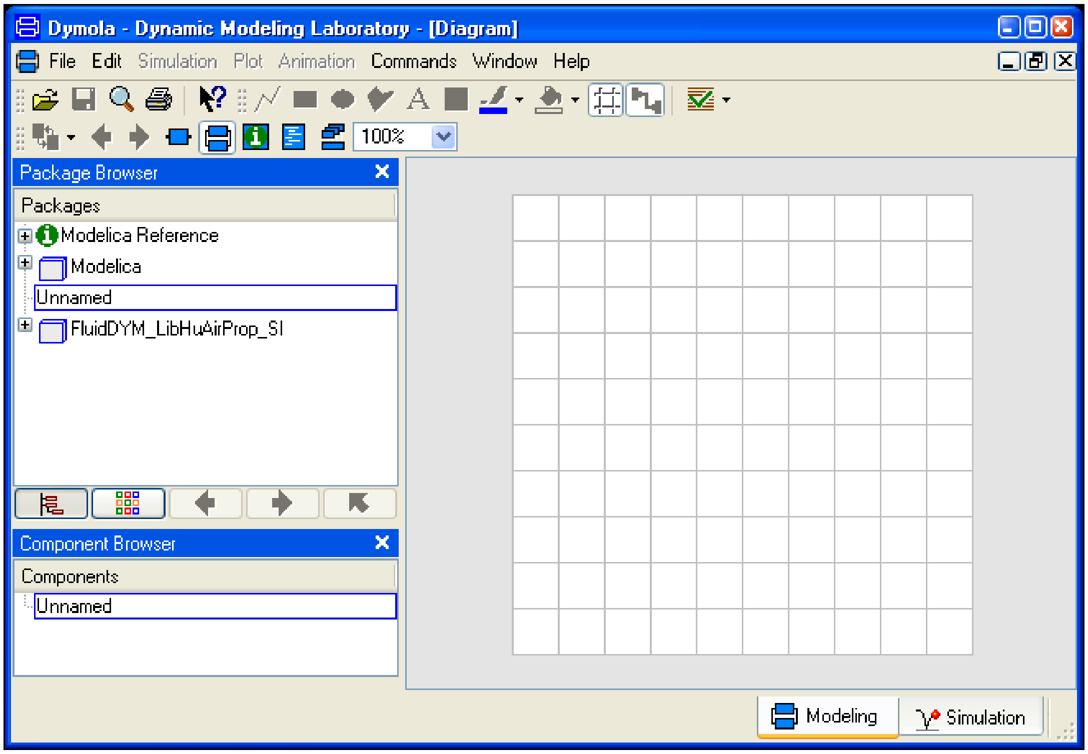


Figure 2.2.6: Dymola window after loading the *LibHuAirProp_SI* library

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

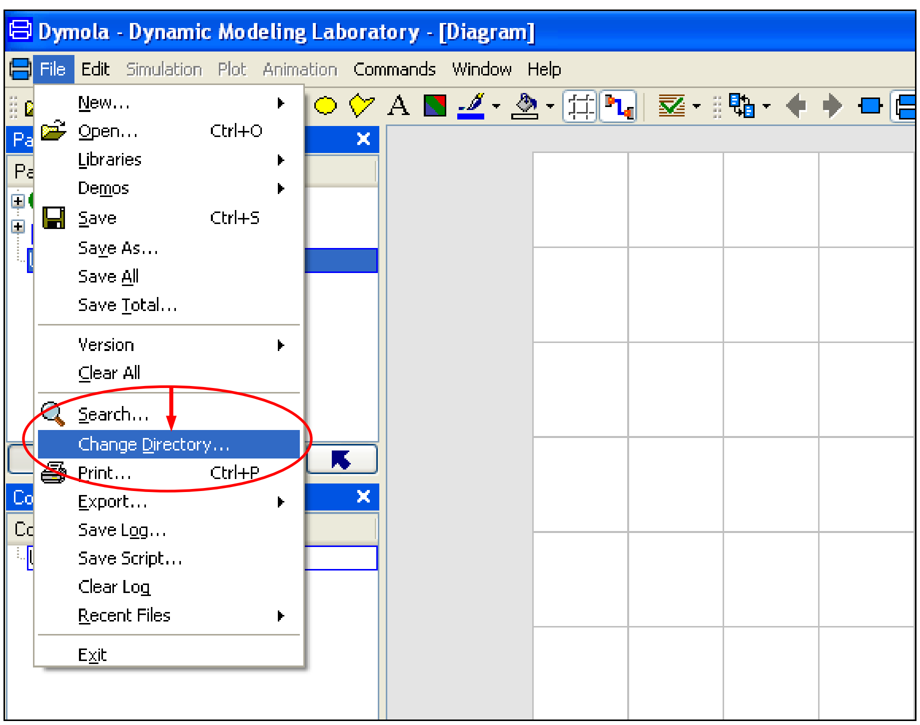


Figure 2.2.7: Selecting the menu entry "Change Directory…"

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

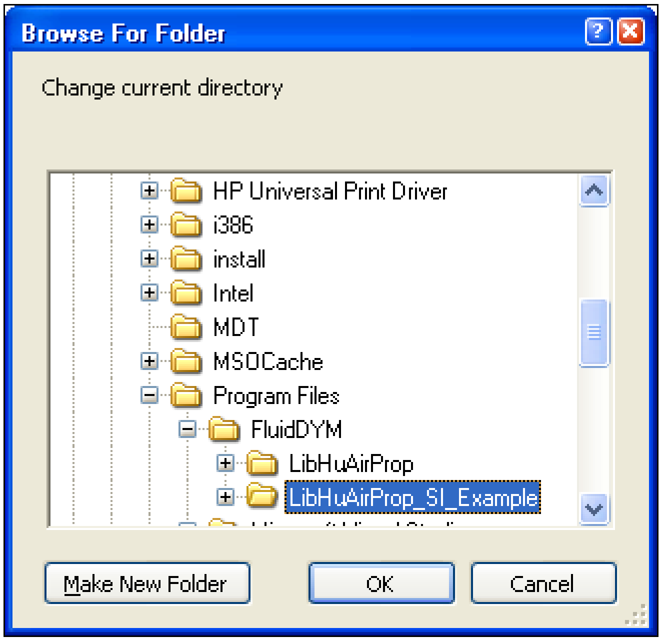
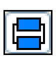


Figure 2.2.8: Selecting the *LibHuAirProp_SI_Example* directory

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

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

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

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

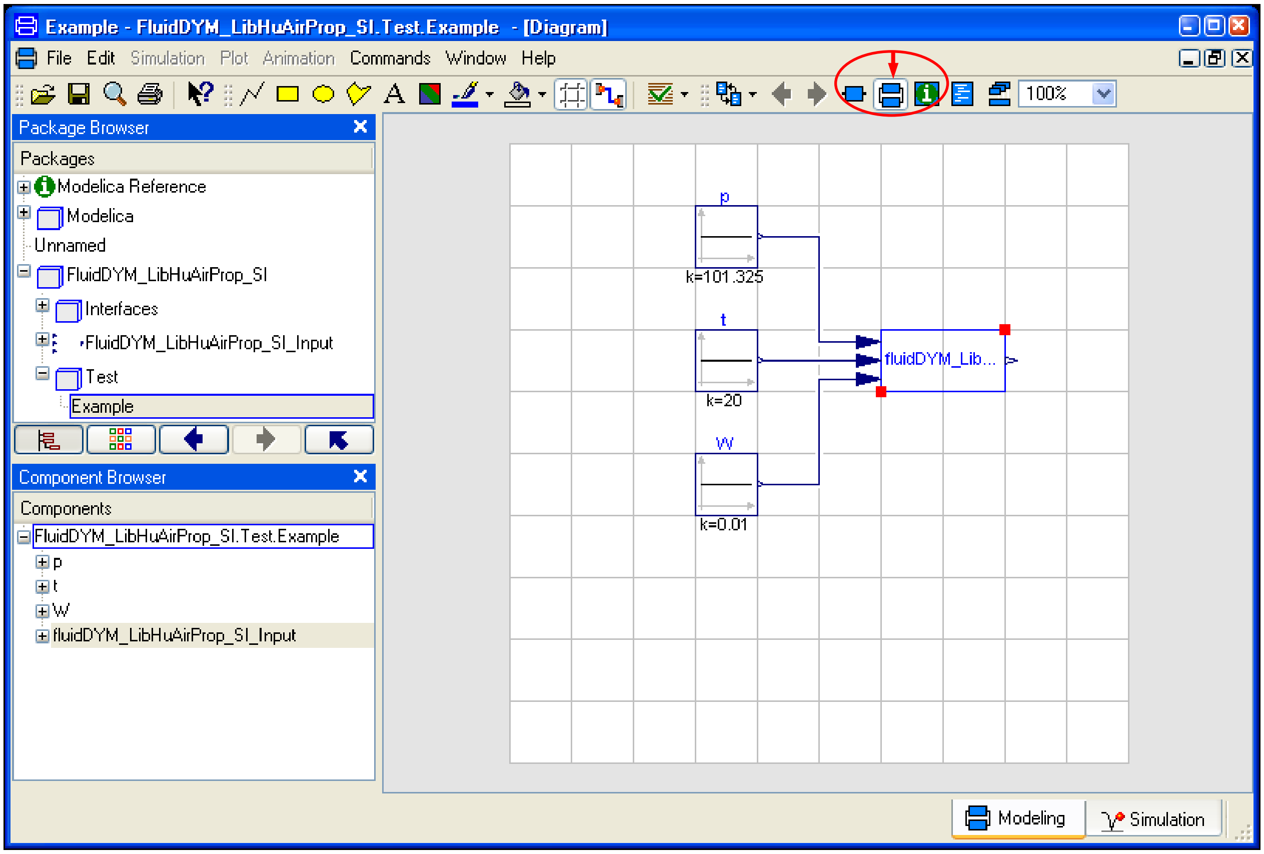


Figure 2.2.9: Dymola in Diagram Mode

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

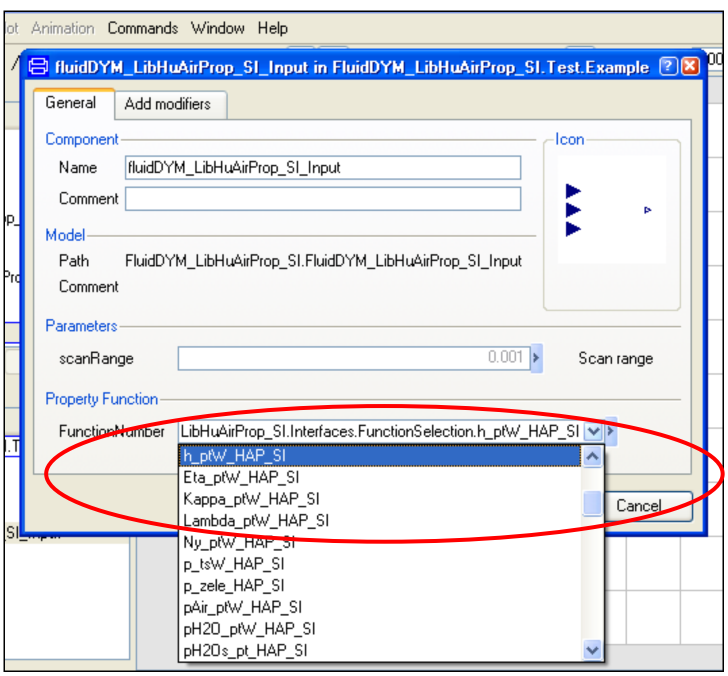


Figure 2.2.10: Choosing the function *h_ptW_HAP_SI*

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

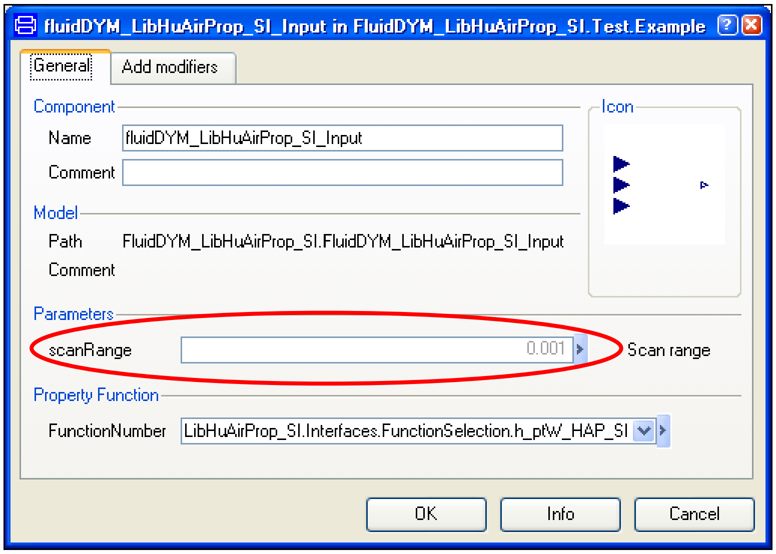


Figure 2.2.11: Setting the scan range

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

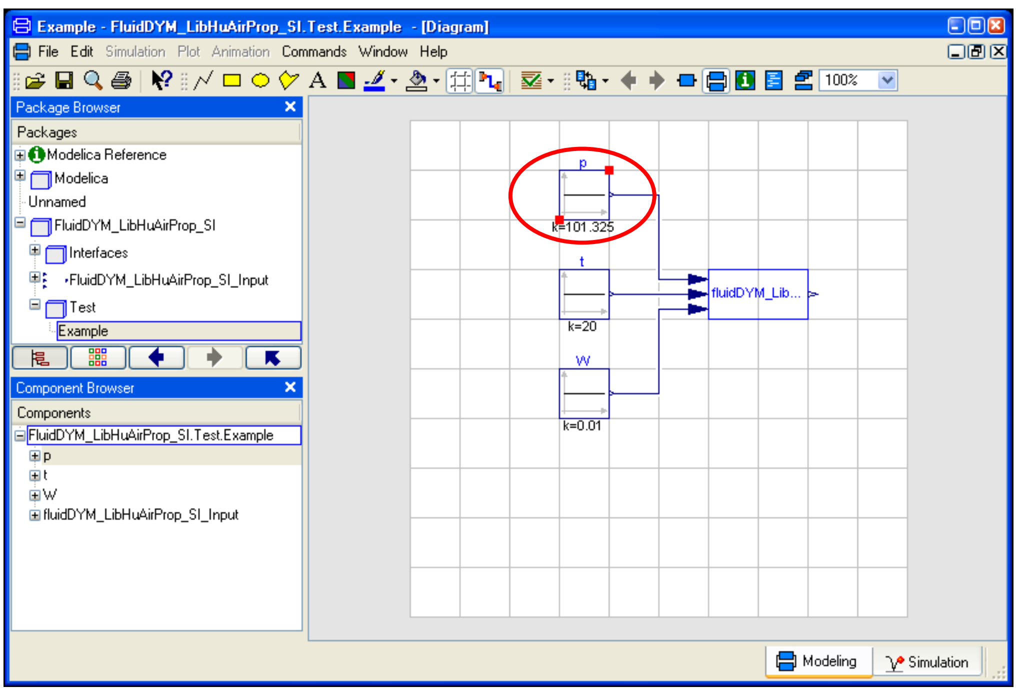


Figure 2.2.12: "Parameter p" block in Dymola

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

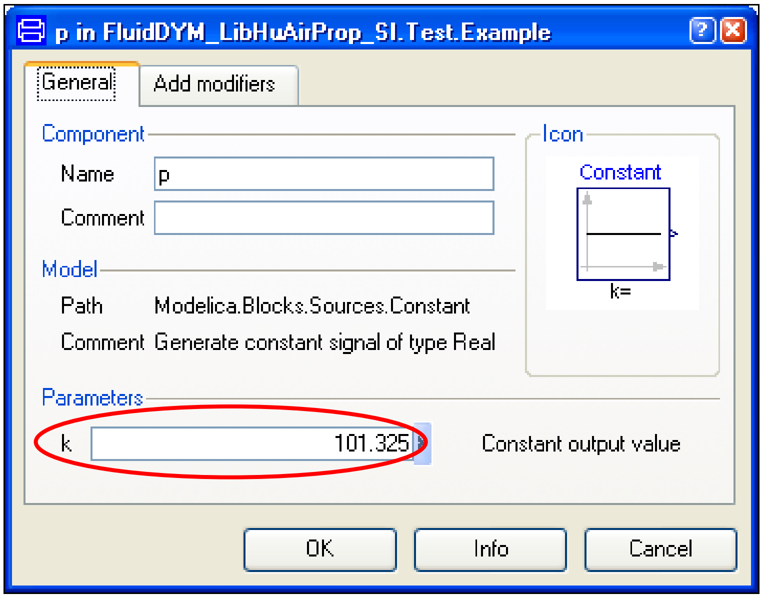


Figure 2.2.13: Entering the value for the pressure *p*

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

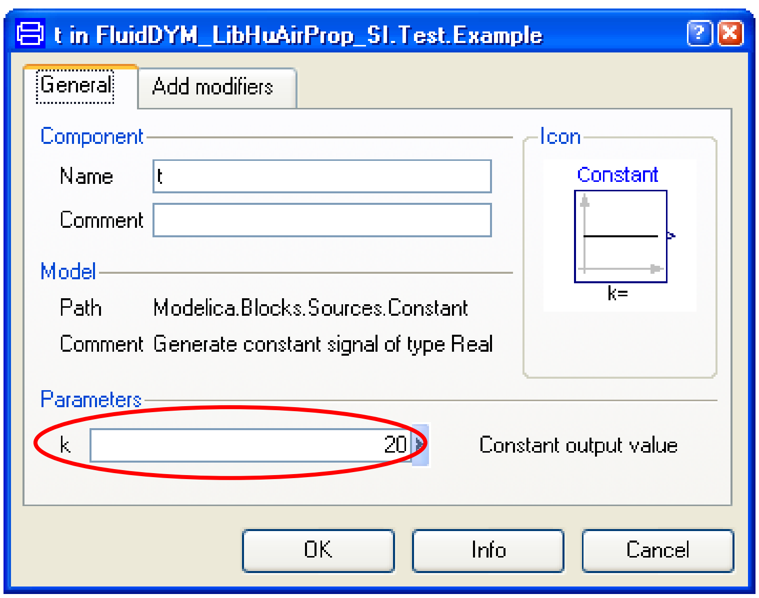


Figure 2.2.14: Entering the value for the temperature *t*

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

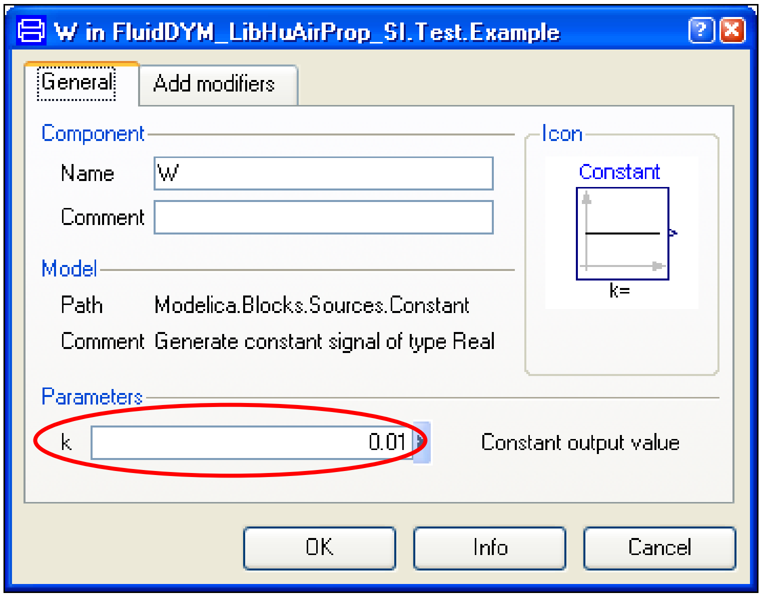
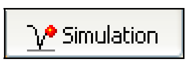


Figure 2.2.15: Entering the value for the humidity ratio *W*

All parameters have now been defined.

- Click on the 

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

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

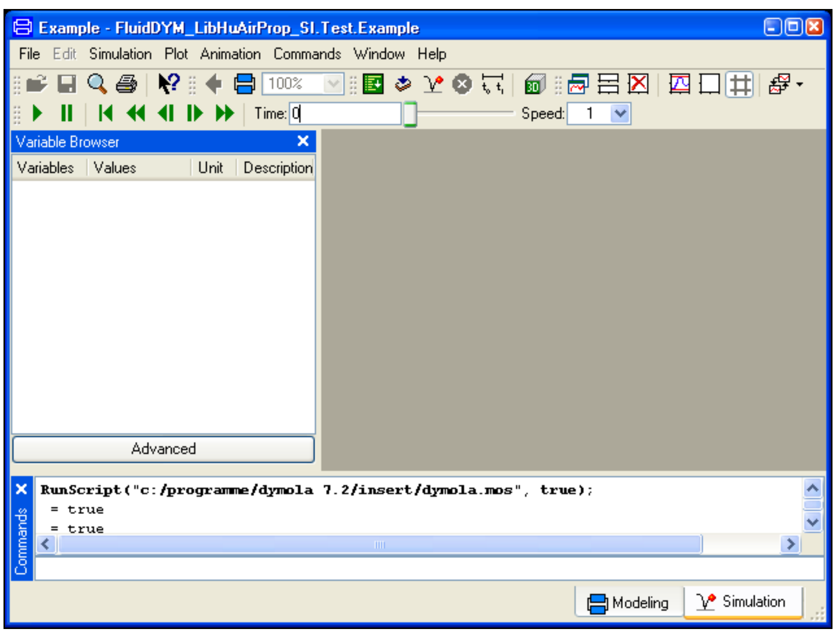


Figure 2.2.16: "Simulation Mode" window

IMPORTANT NOTICE:

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

"Advanced.CompileWith64=2"

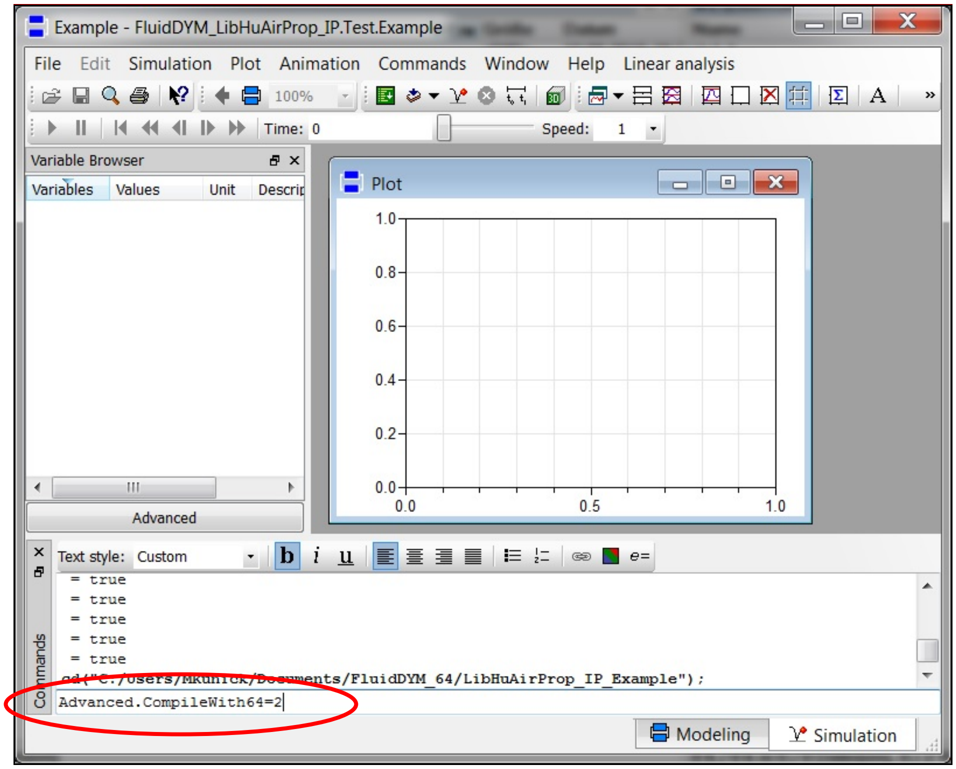
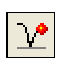


Figure 2.2.17: "Simulation Mode" window with 64-bit command

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

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

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

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

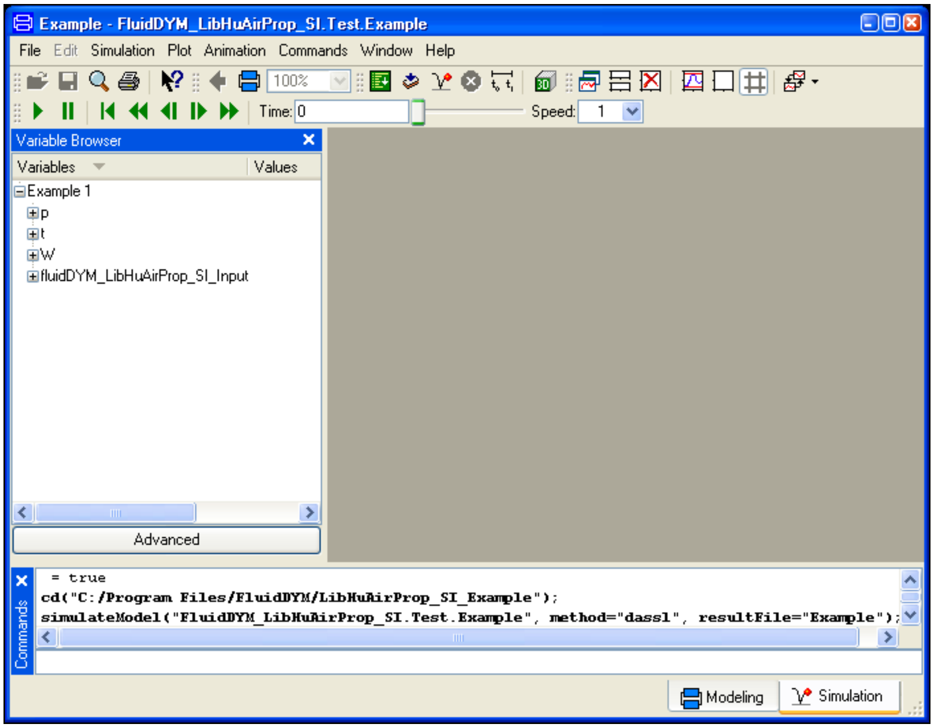


Figure 2.2.18: "Variable Browser" with new entries

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

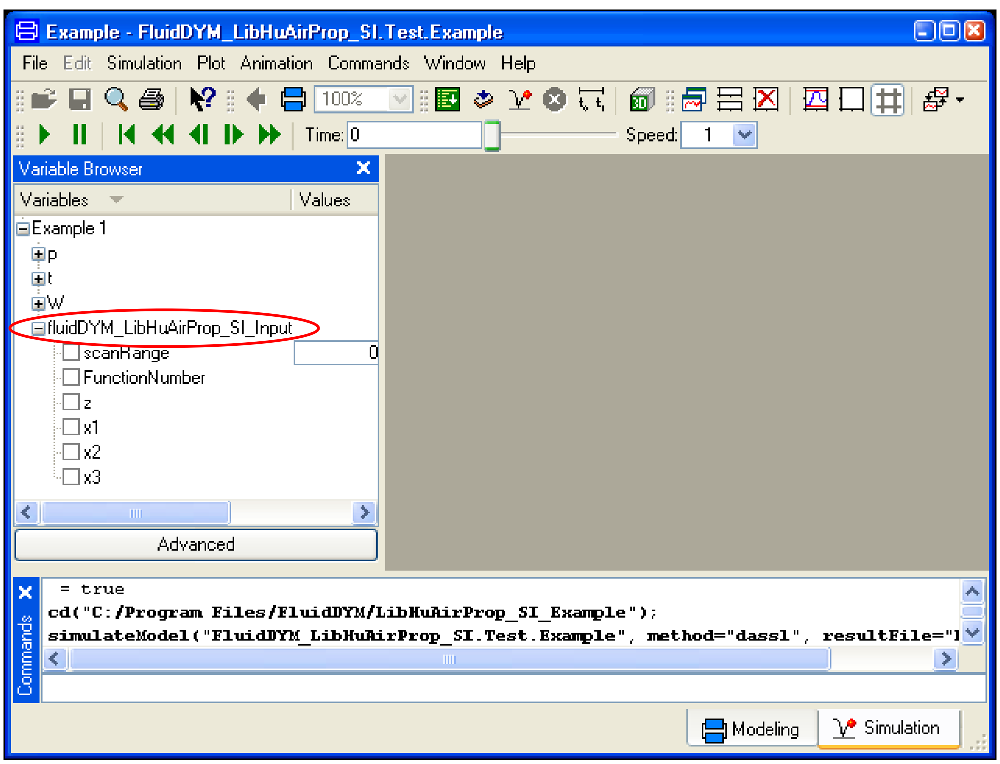


Figure 2.2.19: Parameters of *fluidDYM_LibHuAirProp_SI_Input*

- After clicking on the output parameter "z", the calculated property will be represented graphically in the "PlotWindow".
- Move the mouse over the curve to see the result of the simulation at a specific point in time (see Figure 2.2.20).

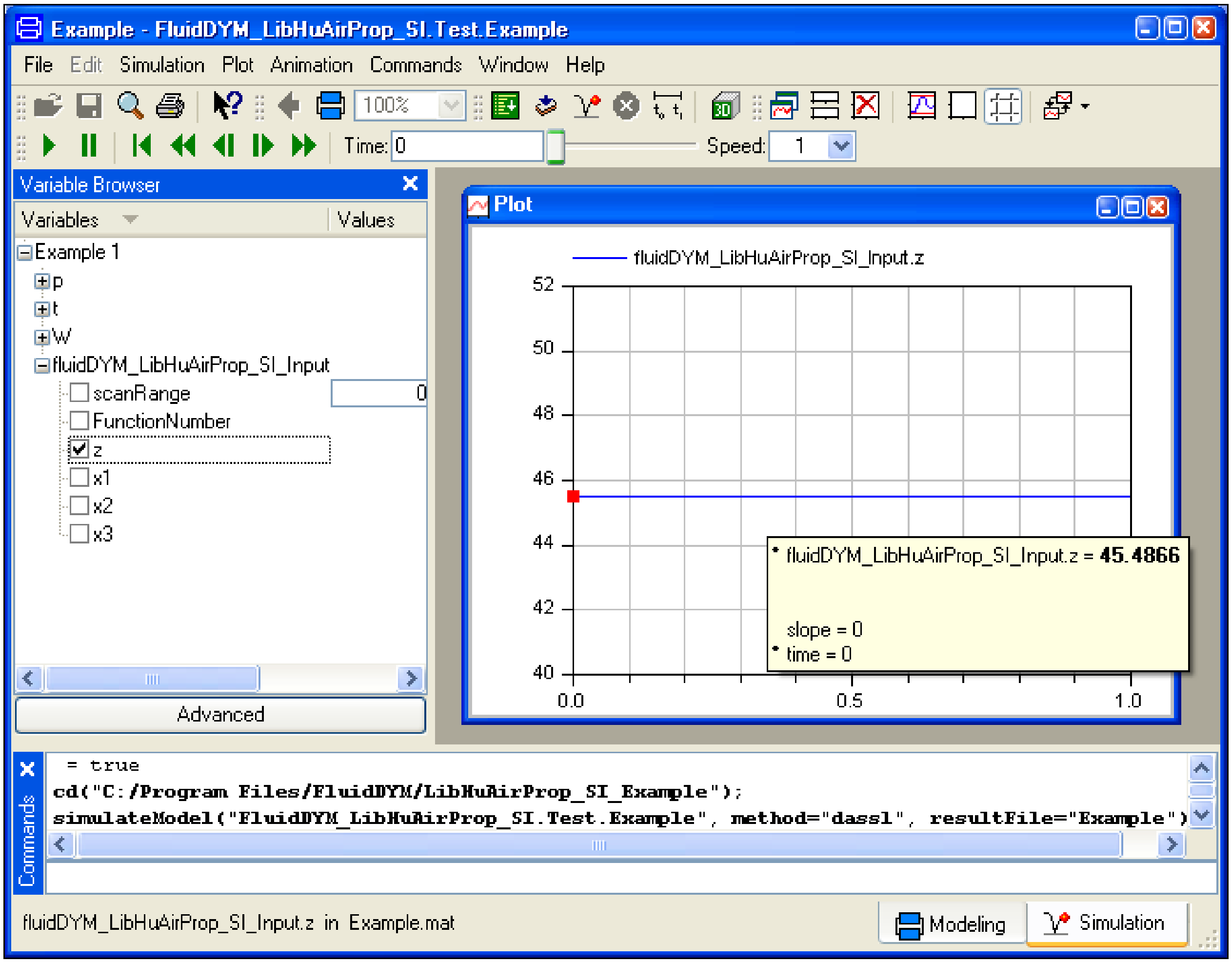
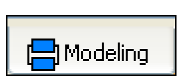


Figure 2.2.20: "DiagramWindow" showing the result

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

⇒ The result in our sample calculation here is: "h = 45.4866". The corresponding unit is kJ/kg (see table of the property functions in Chapter 1).

- Now click on the Modeling button 

in the lower right area of Dymola in order to switch into the "Modeling Mode". Here you can arbitrarily change the values for *p*, *t*, or *W* in the appropriate blocks.

2.3 Removing FluidDYM including LibHuAirProp

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

3 Property Functions of ASHRAE-LibHuAirProp-SI

3.1 Functions for Real Moist Air

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

Function Name:

a_ptW_HAP_SI

Fortran Program:

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

Input Values:

p - Total pressure p in kPa

t - Temperature t in °C

W - Humidity ratio W in kg_w/kg_a

Result:

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

Range of Validity:

Temperature t: from -73.15°C to 350°C

Total pressure p: from 0.01 kPa to 10 000 kPa

Humidity ratio W: $0 \le W \le W_s$

Comments:

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

Result for Wrong Input Values:

a_ptW_HAP_SI = -1000

References:

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

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

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

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

Function Name:

alphap_ptW_HAP_SI

Fortran Program:

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

Input Values:

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

Result:

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

Range of Validity:

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

Comments:

- Relative pressure coefficient $\alpha_p = \frac{1}{p}\left(\frac{\partial p}{\partial T}\right)_v$
- Calculation for supersaturated humid air ($W > W_s$) is not possible

Result for Wrong Input Values:

alphap_ptW_HAP_SI = -1000

References:

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

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

Function Name:

betap_ptW_HAP_SI

Fortran Program:

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

Input Values:

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

Result:

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

Range of Validity:

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

Comments:

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

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

Result for Wrong Input Values:

betap_ptW_HAP_SI = -1000

References:

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

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

Function Name:

c_ptW_HAP_SI

Fortran Program:

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

Input Values:

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

Result:

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

Range of Validity:

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

Comments:

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

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

Result for Wrong Input Values:

c_ptW_HAP_SI = -1000

References:

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

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

Function Name:

cp_ptW_HAP_SI

Fortran Program:

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

Input Values:

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

Result:

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

Range of Validity:

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

Comments:

- Specific isobaric heat capacity $c_p = \left(\frac{\partial h}{\partial T}\right)_p$
- Calculation for supersaturated humid air ($W > W_s$) is not possible

Result for Wrong Input Values:

cp_ptW_HAP_SI = -1000

References:

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

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

Function Name:

cv_ptW_HAP_SI

Fortran Program:

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

Input Values:

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

Result:

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

Range of Validity:

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

Comments:

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

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

Result for Wrong Input Values:

cv_ptW_HAP_SI = -1000

References:

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

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

Function Name:

f_pt_HAP_SI

Fortran Program:

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

Input Values:

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

Result:

f_pt_HAP_SI - Enhancement factor of water (decimal ratio)

Range of Validity:

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

Comments:

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

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

  for $t < 0.01°\mathrm{C}$ - Sublimation pressure of water

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

Result for Wrong Input Values:

f_pt_HAP_SI = -1000

References:

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

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

Function Name:

h_ptW_HAP_SI

Fortran Program:

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

Input Values:

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

Result:

h_ptW_HAP_SI - Air-specific enthalpy in kJ/kg_a

Range of Validity:

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

Comments:

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

Result for Wrong Input Values:

h_ptW_HAP_SI = -1000

References:

h(p,t,W) Herrmann et al. [1], [2]
$h_w(p,t)$ IAPWS-IF97 [7], [8] and IAPWS-06 [11]
$h_a(t)$ Lemmon et al. [14]

Dynamic Viscosity η = f(p,t,W)

Function Name:

Eta_ptW_HAP_SI

Fortran Program:

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

Input Values:

p - Total pressure p in kPa

t - Temperature t in °C

W - Humidity ratio W in kg_w/kg_a

Result:

Eta_ptW_HAP_SI - Dynamic viscosity of humid air in Pa s

Range of Validity:

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

Comments:

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

Result for Wrong Input Values:

Eta_ptW_HAP_SI = -1000

References:

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

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

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 $\mathrm{kg_w/kg_a}$

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

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 $t \ge 0.01$°C. For temperatures below (ice fog) the value of the saturated state is applied.

Result for Wrong Input Values:

Kappa_ptW_HAP_SI = -1000

References:

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

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

Function Name:

Lambda_ptW_HAP_SI

Fortran Program:

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

Input Values:

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

Result:

Lambda_ptW_HAP_SI - Thermal conductivity in W/(m K)

Range of Validity:

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

Comments:

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

Result for Wrong Input Values:

Lambda_ptW_HAP_SI = -1000

References:

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

Kinematic Viscosity ν = f(p,t,W)

Function Name:

Ny_ptW_HAP_SI

Fortran Program:

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

Input Values:

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

Result:

Ny_ptW_HAP_SI - Kinematic viscosity in m^2/s

Range of Validity:

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

Comments:

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

Result for Wrong Input Values:

Ny_ptW_HAP_SI = -1000

References:

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

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

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

Function Name:

p_tsW_HAP_SI

Fortran Program:

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

Input Values:

t - Temperature *t* in °C
s - Air-specific entropy *s* in kJ/(kg$_a$ K)
W - Humidity ratio *W* in kg$_w$/kg$_a$

Result:

p_tsW_HAP_SI - Total pressure in kPa

Range of Validity:

Temperature *t*:	from -143.5°C to 350°C
Air-specific entropy *s*:	from -26.53 kJ/(kg$_a$ K) to 38.990 kJ/(kg$_a$ K)
Humidity ratio *W*:	$0 \le W \le 10\,\mathrm{kg_w/kg_a}$

Comments:

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

Result for Wrong Input Values:

p_tsW_HAP_SI = -1000

References:

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

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

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_{Air} = f(p,t,W)

Function Name:

pAir_ptW_HAP_SI

Fortran Program:

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

Input Values:

p - Total pressure p in kPa

t - Temperature t in °C

W - Humidity ratio W in kg_w/kg_a

Result:

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

Range of Validity:

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

Comments:

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

Result for Wrong Input Values:

pAir_ptW_HAP_SI = -1000

References:

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

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

Function Name:

pH2O_ptW_HAP_SI

Fortran Program:

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

Input Values:

p - Total pressure p in kPa

t - Temperature t in °C

W - Humidity ratio W in kg_w/kg_a

Result:

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

Range of Validity:

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

Total pressure p: from 0.01 kPa to 10 000 kPa

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

Comments:

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

Result for Wrong Input Values:

pH2O_ptW_HAP_SI = -1000

References:

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

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

Function Name:

pH2Os_pt_HAP_SI

Fortran Program:

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

Input Values:

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

Result:

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

Range of Validity:

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

Comments:

- Partial pressure of steam at saturation $p_{\mathrm{H2O,s}} = f \cdot p_{\mathrm{s}}(t)$

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]
$p_s(t)$	for $t \geq 0.01$°C	IAPWS-IF97 [7], [8]
	for $t < 0.01$°C	IAPWS-08 [11]

Relative Humidity φ = f(p,t,W)

Function Name:

phi_ptW_HAP_SI

Fortran Program:

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

Input Values:

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

Result:

phi_ptW_HAP_SI - Relative humidity (decimal ratio)

Range of Validity:

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

Comments:

- Relative humidity $\varphi = \dfrac{p_{H2O}}{p_{H2O,s}}$

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

Result for Wrong Input Values:

phi_ptW_HAP_SI = -1000

References:

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

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

Function Name:

Pr_ptW_HAP_SI

Fortran Program:

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

Input Values:

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

Result:

Pr_ptW_HAP_SI - Prandtl number

Range of Validity:

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

Comments:

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

Result for Wrong Input Values:

Pr_ptW_HAP_SI = -1000

References:

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

Mole Fraction of Dry Air ψ_{Air} = f(W)

Function Name:

PsiAir_W_HAP_SI

Fortran Program:

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

Input Values:

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

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 kg_w/kg_a

Result:

Rho_ptW_HAP_SI - Density of humid air in kg/m^3

Range of Validity:

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

Comments:

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

Result for Wrong Input Values:

Rho_ptW_HAP_SI = -1000

References:

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

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

Function Name:

s_ptW_HAP_SI

Fortran Program:

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

Input Values:

p - Total pressure p in kPa

t - Temperature t in °C

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

Result:

s_ptW_HAP_SI - Air-specific entropy in $\mathrm{kJ/(kg_a\ K)}$

Range of Validity:

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

Total pressure p: from 0.01 kPa to 10 000 kPa

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

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

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

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

Comments:

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

Result for Wrong Input Values:

t_phW_HAP_SI = -1000

References:

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

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

Function Name:

t_psW_HAP_SI

Fortran Program:

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

Input Values:

p	-	Total pressure p in kPa
s	-	Air-specific entropy s in kJ/(kg_a K)
W	-	Humidity ratio W in kg_w/kg_a

Result:

t_psW_HAP_SI - Temperature from pressure, entropy, and humidity ratio in °C

Range of Validity:

Total pressure p:	from 0.01 kPa to 10 000 kPa
Air-specific entropy s:	from -26.53 kJ/(kg_a K) to 38.990 kJ/(kg_a K)
Humidity ratio W:	$0 \le W \le 10\,kg_w/kg_a$

Comments:

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

Result for Wrong Input Values:

t_psW_HAP_SI = -1000

References:

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

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

Function Name:

t_ptwbW_HAP_SI

Fortran Program:

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

Input Values:

p - Total pressure p in kPa

t_{wb} - Wet-bulb temperature in °C

W - Humidity ratio W in kg_w/kg_a

Result:

t_ptwbW_HAP_SI - Temperature from pressure, wet bulb temperature and humidity ratio in °C

Range of Validity:

Total pressure p:	from 0.01 kPa to 10 000 kPa
Wet bulb temperature t_{wb}:	from -143.15°C to 350°C
Humidity ratio W:	$0 \le W \le 10\,\mathrm{kg_w/kg_a}$

Comments:

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

Result for Wrong Input Values:

t_ptwbW_HAP_SI = -1000

References:

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

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

Function Name:

td_pW_HAP_SI

Fortran Program:

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

Input Values:

p - Total pressure p in kPa

W - Humidity ratio W in kg_w/kg_a

Result:

td_pW_HAP_SI - Dew-point/frost-point temperature in °C

Range of Validity:

Total pressure p:	from 0.01 kPa to 10 000 kPa
Humidity ratio W:	$0 \le W \le 10\,kg_w/kg_a$

Comments:

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

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

Result for Wrong Input Values:

td_pW_HAP_SI = -1000

References:

$t_s(p_{H2O})$	for $t_d \ge 0.01°C$	IAPWS-IF97 [7], [8]
$t_{sub}(p_{H2O})$	for $t_d \le 0.01°C$	IAPWS-08 [11]
p_{H2O}		Herrmann et. al. [1], [2]

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

Function Name:

ts_ppH2O_HAP_SI

Fortran Program:

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

Input Values:

p - Total pressure p in kPa

p_{H2O} - Partial pressure of water vapor p_{H2O} in kPa

Result:

ts_ppH2O_HAP_SI - Saturation temperature in °C

Range of Validity:

Total pressure p:	from 0.01 kPa to 10 000 kPa
Partial Pressure p_{H2O} :	from 0.01 kPa to 10 000 kPa

Comments:

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

Result for Wrong Input Values:

ts_ppH2O_HAP_SI = -1000

References:

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

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

Function Name:

twb_ptW_HAP_SI

Fortran Program:

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

Input Values:

p - Total pressure p in kPa

t - Temperature t in °C

W - Humidity ratio W in kg_w/kg_a

Result:

twb_ptW_HAP_SI - Wet-bulb/ice-bulb temperature in °C

Range of Validity:

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

Comments:

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

Result for Wrong Input Values:

twb_ptW_HAP_SI = -1000

References:

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

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

Function Name:

u_ptW_HAP_SI

Fortran Program:

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

Input Values:

p - Total pressure p in kPa

t - Temperature t in °C

W - Humidity ratio W in kg_w/kg_a

Result:

u_ptW_HAP_SI - Air-specific internal energy in kJ/kg_a

Range of Validity:

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

Comments:

- Internal energy $u = h - pv$

Result for Wrong Input Values:

u_ptW_HAP_SI = -1000

References:

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

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

Function Name:

v_ptW_HAP_SI

Fortran Program:

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

Input Values:

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

Result:

v_ptW_HAP_SI - Air-specific volume in m^3/kg_a

Range of Validity:

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

Comments:

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

Result for Wrong Input Values:

v_ptW_HAP_SI = -1000

References:

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

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

Function Name:

W_ptpH2O_HAP_SI

Fortran Program:

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

Input Values:

p	-	Total pressure p in kPa
t	-	Temperature t in °C
p_{H2O}	-	Partial pressure of water p_{H2O} in kPa

Result:

W_ptpH2O_HAP_SI - Humidity ratio from temperature and partial pressure of water vapor in kg_w/kg_a

Range of Validity:

Total pressure p:	from 0.01 kPa to 10 000 kPa
Temperature t :	from -143.15°C to 350°C
Partial pressure p_{H2O} :	from 0.01 kPa to 10 000 kPa

Comments:

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

Result for Wrong Input Values:

W_ptpH2O_HAP_SI = -1000

References:

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

Humidity Ratio from Relative Humidity $W = f(p, t, \varphi)$

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 kg_w/kg_a

Result:

XiH2O_W_HAP_SI - Mass fraction of water vapor in humid air in kg_w/kg

Range of Validity:

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

Comments:

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

Result for Wrong Input Values:

XiH2O_W_HAP_SI = -1000

References:

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

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

Function Name:

Z_ptW_HAP_SI

Fortran Program:

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

Input Values:

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

Result:

Z_ptW_HAP_SI - Compression factor (decimal ratio)

Range of Validity:

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

Comments:

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

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

  and M is the molar mass of humid air

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

Result for Wrong Input Values:

Z_ptW_HAP_SI = -1000

References:

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

3.2 Functions for Steam and Water for Temperatures $t \geq 0°C$

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

Function Name:

hliq_pt_97_SI

Fortran Program:

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

Input Values:

p - Pressure *p* in kPa
t - Temperature *t* in °C

Result:

hliq_pt_97_SI - Specific enthalpy of liquid water in kJ/kg

Range of Validity:

Pressure *p*: from $p_s(0°C) = 0.6112$ kPa to 10 000 kPa

Temperature *t*: from 0°C to 350°C

Comments:

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

Result for Wrong Input Values:

hliq_pt_97_SI = -1000

References:

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

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

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 $h_{\mathrm{vap,s}} = \mathrm{f}(t)$

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

Result for Wrong Input Values:

hvaps_t_97_SI = -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_SI

Fortran Program:

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

Input Values:

t - Temperature t in °C

Result:

ps_t_97_SI - Saturation pressure of water in kPa

Range of Validity:

Temperature t: from 0°C to 350°C

Comments:

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

Result for Wrong Input Values:

ps_t_97_SI -1000

References:

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

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

Function Name:

sliq_pt_97_SI

Fortran Program:

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

Input Values:

p - Pressure p in kPa

t - Temperature t in °C

Result:

sliq_pt_97_SI - Specific entropy of liquid water in kJ/(kg K)

Range of Validity:

Pressure p: from $p_s(0°C) = 0.6112$ kPa to 10 000 kPa

Temperature t: from 0°C to 350°C

Comments:

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

Result for Wrong Input Values:

sliq_pt_97_SI = -1000

References:

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

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

Function Name:

sliqs_t_97_SI

Fortran Program:

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

Input Values:

t - Temperature t in °C

Result:

sliqs_t_97_SI - Specific entropy of saturated liquid water in kJ/(kg K)

Range of Validity:

Temperature t: from 0°C to 350°C

Comments:

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

Result for Wrong Input Values:

sliqs_t_97_SI = -1000

References:

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

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

Function Name:

svaps_t_97_SI

Fortran Program:

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

Input Values:

t - Temperature *t* in °C

Result:

svaps_t_97_SI - Specific entropy of saturated water vapor in kJ/(kg K)

Range of Validity:

Temperature *t*: from 0°C to 350°C

Comments:

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

Result for Wrong Input Values:

svaps_t_97_SI = -1000

References:

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

Saturation Temperature of Water $t_s = f(p)$

Function Name:

ts_p_97_SI

Fortran Program:

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

Input Values:

p - Pressure *p* in kPa

Result:

ts_p_97_SI - Saturation temperature of water in °C

Range of Validity:

Pressure *p*: from 0.6112 kPa to 10 000 kPa

Comments:

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

Result for Wrong Input Values:

ts_p_97_SI = -1000

References:

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

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

Function Name:

vliq_pt_97_SI

Fortran Program:

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

Input Values:

p   -   Pressure *p* in kPa
t   -   Temperature *t* in °C

Result:

vliq_pt_97_SI - Specific volume of liquid water in m^3/kg

Range of Validity:

Pressure *p*: from $p_s(0°C) = 0.6112$ kPa to 10 000 kPa

Temperature *t*: from 0°C to 350°C

Comments:

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

Result for Wrong Input Values:

vliq_pt_97_SI = -1000

References:

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

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

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 Water for Temperatures $t \leq 0°C$

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 $p_{mel} = f(t)$

Function Name:

pmel_t_08_SI

Fortran Program:

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

Input Values:

t - Temperature t in °C

Result:

pmel_t_08_SI - Melting pressure of ice in kPa

Range of Validity:

Temperature t: from -21.985°C to 0°C

Result for Wrong Input Values:

pmel_t_08_SI = -1000

References:

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

Sublimation Pressure p_{sub} = f(t)

Function Name:

psub_t_08_SI

Fortran Program:

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

Input Values:

t - Temperature *t* in °C

Result:

psub_t_08_SI - Sublimation pressure of ice in kPa

Range of Validity:

Temperature *t*: from -143.15°C to 0°C

Result for Wrong Input Values:

psub_t_08_SI = -1000

References:

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

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

Function Name:

sicesub_t_06_SI

Fortran Program:

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

Input Values:

t - Temperature t in °C

Result:

sicesub_t_06_SI - Specific entropy of saturated ice in kJ/(kg K)

Range of Validity:

Temperature t: from -143.15°C to 0°C

Comments:

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

Result for Wrong Input Values:

sicesub_t_06_SI = -1000

References:

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

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

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

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

Result for Wrong Input Values:

svapsub_t_95_SI = -1000

References:

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

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

Melting Temperature t_{mel} = f(p)

Function Name:

tmel_p_08_SI

Fortran Program:

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

Input Values:

p - Pressure *p* in kPa

Result:

tmel_p_08_SI - Melting temperature of ice in °C

Range of Validity:

Pressure *p*: from $p_s(0°C) = 0.6112$ kPa to 10 000 kPa

Result for Wrong Input Values:

tmel_p_08_SI = -1000

References:

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

Sublimation Temperature t_{sub} = f(p)

Function Name:

tsub_p_08_SI

Fortran Program:

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

Input Values:

p - Pressure p in kPa

Result:

tsub_p_08_SI - Sublimation temperature of ice in °C

Range of Validity:

Pressure p: from p_{subl}(-143.15°C) = 1.2002 x 10^{-11} kPa to p_{subl}(0°C) = 0.6112 kPa

Result for Wrong Input Values:

tsub_p_08_SI = -1000

References:

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

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

Function Name:

vicesub_t_06_SI

Fortran Program:

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

Input Values:

t - Temperature *t* in °C

Result:

vicesub_t_06_SI - Specific volume of saturated ice in m^3/kg

Range of Validity:

Temperature *t*: from -143.15°C to 0°C

Comments:

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

Result for Wrong Input Values:

vicesub_t_06_SI = -1000

References:

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

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

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

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]

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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
  - IAPWS-IF97-S03rev
  - IAPWS-IF97-S04
  - IAPWS-IF97-S05
- IAPWS Revised Advisory Note No. 3 on Thermodynamic Derivatives (2008)

Humid Combustion Gas Mixtures

Library LibHuGas

Model: Ideal mixture of the real fluids:

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

and of the ideal gases:

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

Consideration of:

Dissociation from VDI 4670 and Poynting effect

Humid Air

Library LibHuAir

Model: Ideal mixture of the real fluids:

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

Consideration of:

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

Carbon Dioxide Including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1996)

Seawater

Library LibSeaWa

IAPWS Industrial Formulation 2013

Ice

Library LibICE

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

Ideal Gas Mixtures

Library LibIdGasMix

Model: Ideal mixture of the ideal gases:

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

Consideration of:

- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

Humid Air

Library ASHRAE LibHuAirProp

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

Consideration of:

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

www.ashrae.org/bookstore

Dry Air Including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth et al. (1993)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of Bücker and Wagner (2006)

n-Butane

Library LibButane_n

Formulation of Bücker and Wagner (2006)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

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

Helmholtz energy equation for the mixing term

(also useable for calculating Kalina Cycle)

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

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

Formulation of the International Institute of Refrigeration (1997)

Ethanol
Library LibC2H5OH
Formulation of Schroeder (2012)

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

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

Siloxanes as ORC Working Fluids

Octamethylcyclotetrasiloxane $C_8H_{24}O_4Si_4$ **Library LibD4**
Decamethylcyclopentasiloxane $C_{10}H_{30}O_5Si_5$ **Library LibD5**
Tetradecamethylhexasiloxane $C_{14}H_{42}O_5Si_6$ **Library LibMD4M**
Hexamethyldisiloxane $C_6H_{18}OSi_2$ **Library LibMM**
Formulation of Colonna et al. (2006)

Dodecamethylcyclohexasiloxane $C_{12}H_{36}O_6Si_6$ **Library LibD6**
Decamethyltetrasiloxane $C_{10}H_{30}O_3Si_4$ **Library LibMD2M**
Dodecamethylpentasiloxane $C_{12}H_{36}O_4Si_5$ **Library LibMD3M**
Octamethyltrisiloxane $C_8H_{24}O_2Si_3$ **Library LibMDM**
Formulation of Colonna et al. (2008)

Nitrogen
Library LibN2
Formulation of Span et al. (2000)

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**
Dinitrogen monooxide N_2O **Library LibN2O**
Sulfur dioxide SO_2 **Library LibSO2**
Acetone C_3H_6O **Library LibC3H6O**
Formulation of Lemmon and Span (2006)

For more information please contact:

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Fax.: +49-3583-61-1846

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives can be calculated.

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

www.thermodynamic-property-libraries.com

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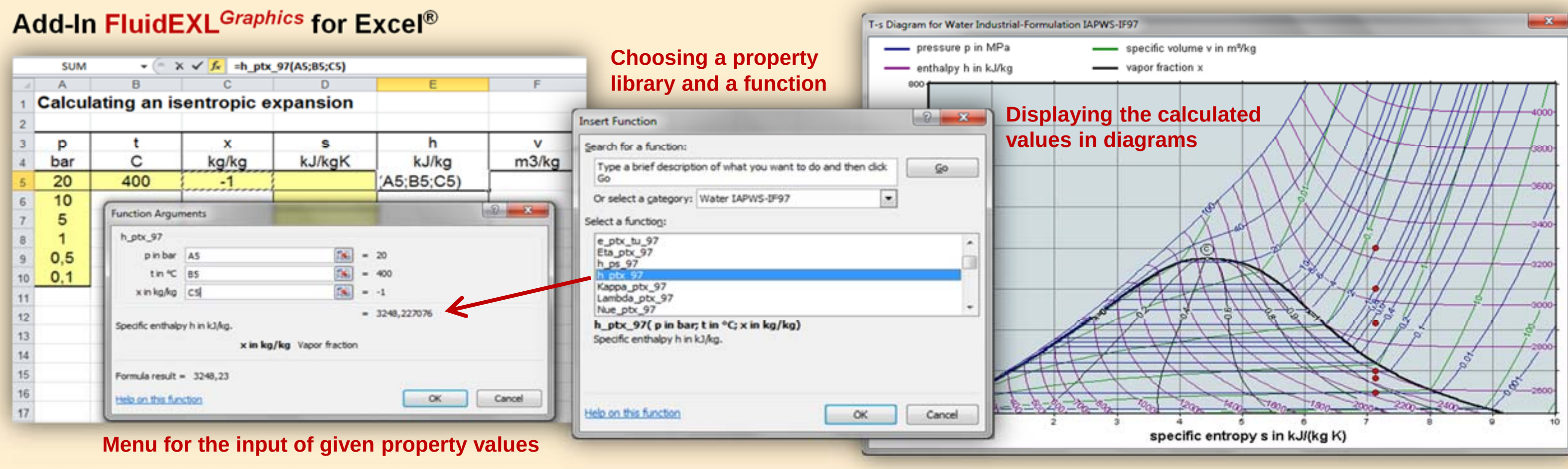
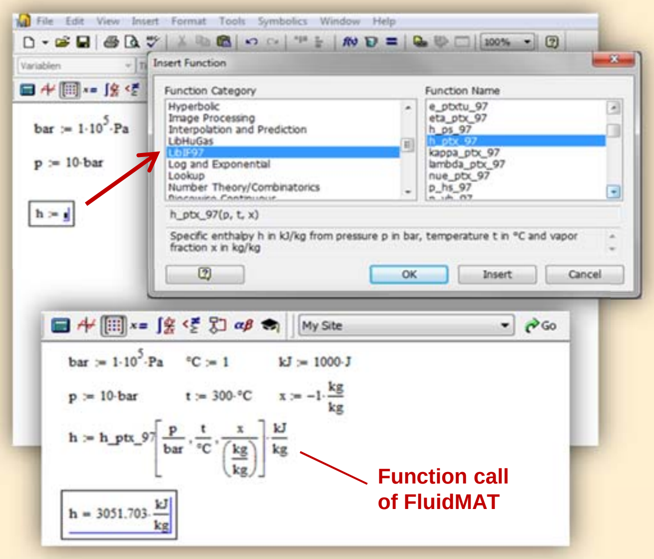
Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

Add-In FluidEXL*Graphics* for Excel®



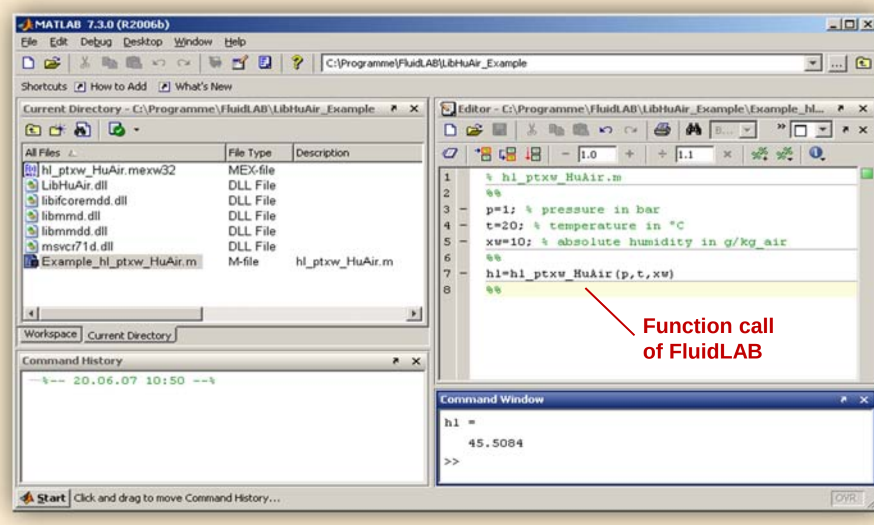
Add-In FluidMAT for Mathcad®

The property libraries can be used in Mathcad®.



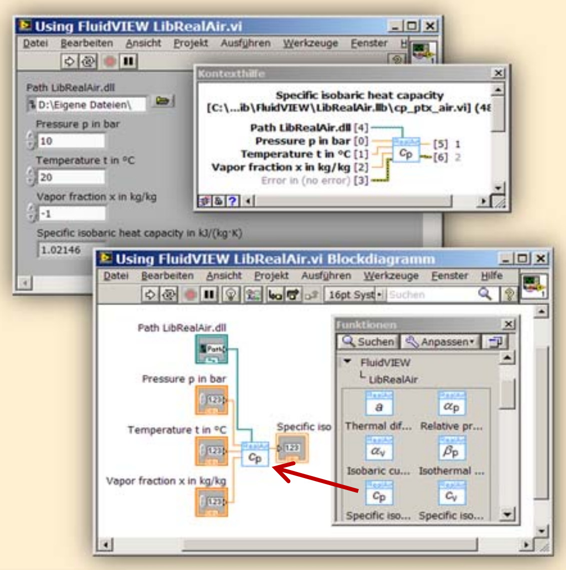
Add-In FluidLAB for MATLAB®

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



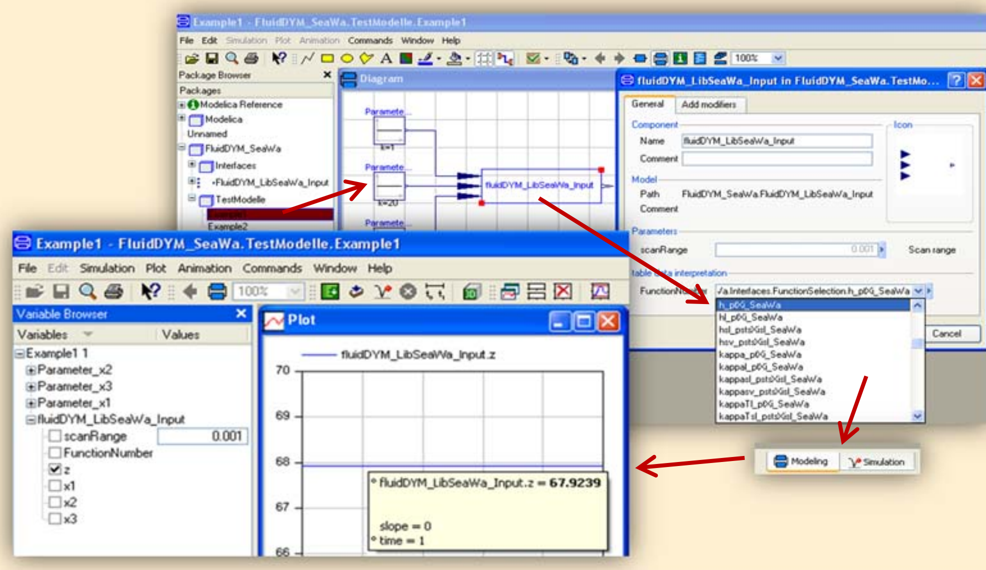
Add-On FluidVIEW for LabVIEW®

The property functions can be calculated in LabVIEW®.

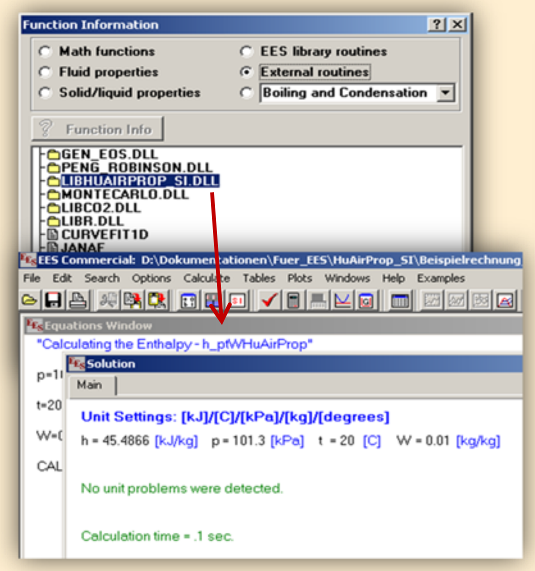


Add-In FluidDYM for DYMOLA® (Modelica) and SimulationX®

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

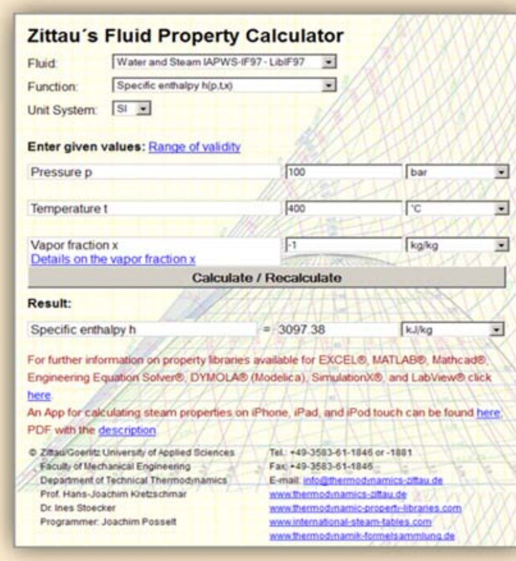


Add-In FluidEES for Engineering Equation Solver®



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

Online Property Calculator at www.thermodynamics-zittau.de



Property Software for Pocket Calculators

FluidCasio


fx 9750 G II


CFX 9850
fx-GG20



CFX 9860 G
Graph 85


ALGEBRA
FX 2.0

FluidHP


HP 48


HP 49

FluidTI


TI Nspire CX CAS
TI Nspire CAS


TI 83
TI 84
TI 89


TI Voyage 200


TI 92

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives can be calculated.

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

www.thermodynamic-property-libraries.com

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