

@AIR USER'S MANUAL

VERSION 4.0

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1. INTRODUCTION

1.1 OVERVIEW

@Air is a software product that provides accurate thermodynamic, psychrometric and transport properties of moist air through functions contained in a Dynamic Link Library (DLL). The **@Air** package includes **DeskTop Air**, an interactive air property calculator and various add-ins, which allow the functions to be used as if they were built into 1-2-3 for Windows, Microsoft Excel and Mathcad. In 1-2-3 and Excel, you can access the functions directly from within cell formulas. Programmers can call the functions in the DLL directly from many Windows programming languages such as Microsoft's Visual Basic, Visual C++ and Access.

The DLL provides a library of accurate functions, which are based on data published by the *National Bureau of Standards* (NBS) in 1955 (1). The NBS data is also the basis of the formulations used to develop the tables published in the *American Society of Heating, Refrigeration and Air-Conditioning (ASHRAE) Fundamentals, 1993*. All of the properties calculated by **@Air** are based on real gas properties, not perfect gas approximations. As such, they include the effects of pressure and interactions caused by the mixing of water vapor and dry air components. For details on the theory and accuracy of the functions, check the html version of the user's manual.

The psychrometric functions facilitate conversion among various moist air parameters such as absolute humidity, relative humidity, wet bulb temperature and degree of saturation. The thermodynamic property functions provide forward and inverse relationships using specific volume, specific enthalpy and specific entropy. The transport property functions provide specific heat, dynamic viscosity and thermal conductivity from pressure, temperature and humidity ratio. Also included are several functions, which provide thermodynamic properties of water which are useful in calculations involving addition or removal of moisture from air streams.

The **@Air** functions are valid over a temperature range from 180 °K, (-136 °F) to 2000 °K, (3140 °F) and at pressures up to 5.0 MPa, (725 psia). The functions detect requests for calculations outside that range and return an error value.

The Setup program and the installation instructions contained in the **@Air** package guide you through installing the files you'll need for the applications you expect to use. Example files to help you get started will also be installed.

The name, **@Air**, was created to signify that it contains @ functions that were compatible with Lotus 1-2-3, the dominant spreadsheet program several years ago. Today, the @ symbol is most recognized as part of an internet e-mail address. However, for continuity, we have retained the name **@Air** even though the current product supports a variety of Windows applications.

1.2 32-BIT AND 64-BIT VERSIONS

The **@Air** package includes both 32-bit and 64-bit installation files. The installation instructions you received with the **@Air** package will guide you through installing the files you'll need for the applications you expect to use. Example files to help you get started will also be installed.

1.3 WHAT'S NEW

@Air 4.0 adds 64-bit versions of the TAir DLL, the DeskTop Air calculator and the Excel add-in. It also has converted all help files to compiled HTML format for compatibility with newer operating systems.

@Air 3.2 does not install the help shortcut on the toolbar when using Excel 2007 or later in order to operate more reliably.

@Air 3.1 adds a seventh unit set, METF, which is similar to the MET unit set but uses kg/cm^2 for pressure. This version also improves the accuracy of the transport properties.

@Air 3.0 adds many new features over the previous version, **@Air 2.0**. These include the following:

- Extends the temperature range upwards from 200 °C, (392 °F) to 2000 °K, (3140 °F).
- Adds transport property functions:
 - AirPTWC, which calculates specific heat given pressure, temperature and humidity ratio.
 - AirPTWM, which calculates dynamic viscosity given pressure, temperature and humidity ratio.
 - AirPTWK, which calculates thermal conductivity given pressure, temperature and humidity ratio.
- Includes **DeskTop Air**, an advanced air property calculator with many improved features over the previous air property calculator.
- Adds four new unit sets, EngG using psig for pressure instead of psia, SIF, which uses the formal SI units, MPa for pressure instead of bar and °K for temperature, instead of °C, SIK using kPa instead of bar for pressure and MET using the calorie instead of the joule for energy.
- Allows specific properties to be expressed on either a dry or wet basis.
- Allows the humidity ratio parameter to be input alternately, as mole fraction or mass fraction.
- Added new thermodynamic functions:
 - AirPTHs, which calculates saturated enthalpy given pressure and temperature.

-
- AirPHTs, which calculates saturation temperature for a given pressure and enthalpy.
 - AirWX, which calculates either the mole or mass fraction given the humidity ratio,
 - AirXW, which calculates the humidity ratio given either the mole or mass fraction.
 - Improved installation program that allows distribution over the web.

2. USING THE @AIR PROPERTY FUNCTIONS

2.1 GENERAL INFORMATION

All applications using the air property functions use the same set of functions. In most applications, the functions are called by name. In the **DeskTop Air** calculator, the appropriate functions are called automatically according to your on-screen selections.

Each user of spreadsheets or programs you write using the air property functions, must have their own copy of @Air. Spreadsheets and programs calling the functions must access the dynamic link libraries at run time. Since these files will be called by many applications, they must be installed on the computer in either the Windows directory or preferably, in the Windows System directory. Normally, the installation program will set this up for you automatically.

In Excel, 1-2-3, Mathcad, Visual BASIC and your own Windows programs, the functions provided by @Air can be used within equations just like each application's built-in math functions. The functions can even be nested. Each function returns a single, floating point result. The functions require up to three inputs and a unit set parameter to identify the state point. Subsequent sections of this chapter describe the calling syntax and other considerations in using the functions within supported applications.

2.2 DESCRIPTION OF @AIR FUNCTIONS

All of the @Air functions, which are accessible to the user, are summarized in the table below.

Function	Input(s)	Output
Equations of State		
AirPTWV()	Pressure, Temperature, H2O Content	Specific Volume
AirPVWT()	Pressure, Volume, H2O Content	Dry Bulb Temperature
AirTVWP()	Temperature, Volume, H2O Content	Pressure
Thermodynamic and Psychrometric Functions		
AirPTW()	Pressure, Temperature	Saturated Humidity Ratio
AirPWD()	Pressure, H2O Content	Dew Point Temperature
AirPTF()	Pressure, Temperature	Enhancement Factor
AirPTRW()	Pressure, Temperature, Relative Humidity	H2O Content
AirPTWR()	Pressure, Temperature, H2O Content	Relative Humidity
AirPTWB()	Pressure, Temperature, H2O Content	Wet Bulb Temperature
AirPTBW()	Pressure, Temperature, Wet Bulb	H2O Content
AirPBWT()	Pressure, Wet Bulb, H2O Content	Temperature
AirPBRT()	Pressure, Wet Bulb, Relative Humidity	Temperature
AirPTWU()	Pressure, Temperature, H2O Content	Degree of Saturation
AirPTUW()	Pressure, Temperature, Degree of	Humidity Ratio

	Saturation	
AirPTWH()	Pressure, Temperature, H2O Content	Specific Enthalpy
AirPHWT()	Pressure, Enthalpy, H2O Content	Temperature
AirPWHT()	Pressure, H2O Content, Enthalpy	Temperature
AirPTHs()	Pressure, Temperature	Saturated Enthalpy
AirPHTs	Pressure, Enthalpy	Saturated Temp
AirPTWS()	Pressure, Temperature, H2O Content	Specific Entropy
AirPSWT()	Pressure, Entropy, H2O Content	Temperature
AirPWST()	Pressure, H2O Content, Entropy	Temperature
Transport Property Functions		
AirPTWC()	Pressure, Temperature, H2O Content	Specific Heat
AirPTWM()	Pressure, Temperature, H2O Content	Dynamic Viscosity
AirPTWK()	Pressure, Temperature, H2O Content	Thermal Conduct
Vapor and Liquid Water Property Function		
AirVapTP()	Water Vapor Temperature	Sat Pressure
AirVapPT()	Water Vapor Pressure	Sat Temperature.
AirCondPTH()	Pressure, Water Temperature	Specific Enthalpy
AirCondPTS()	Pressure, Water Temperature	Specific Entropy
Miscellaneous Functions		
AirWX()	Humidity Ratio	Mass or Mole Fraction
AirXW()	Mass or Mole Fraction	Humidity Ratio
AirVer()	None	Version/serial no.

Theoretically, an air property state point can be uniquely identified by specifying any two thermodynamic properties and a measure of the ratio of water vapor to dry air. In most practical applications, pressure is one of the known variables. Therefore, most of the functions described above assume that pressure is one of the known variables. If this is not the case, one of the equations of state may be used to obtain the pressure.

You may be familiar with psychrometric charts or air property tables in which pressure is not one of the variables. There are a couple of reasons for this. Typically, psychrometric charts and ASHRAE tables are valid only at atmospheric pressure. In these cases, the pressure variable is implied as standard atmospheric pressure. In other references, air is sometimes treated as a perfect gas in which properties such as enthalpy, entropy and specific heat are not dependent upon pressure. Treating air as a perfect gas produces only rough approximations to the actual properties. The perfect gas approximations are reasonable at low pressures but increase in error as the pressure is increased. The formulations used in @Air are based on real gas properties and include the effects of pressure and the mixing of air and water vapor. Refer to section 4 for more information about the model used and its accuracy.

The property “Moisture Content” refers to the humidity ratio by default. You can change it to refer to mole fraction of water vapor by adding a “C” to the unit set argument or mass fraction by adding an “M”. If some other measure of moisture is known such as Relative Humidity, Wet Bulb Temperature, Degree of Saturation or Dew Point Temperature, use one of the functions provided to obtain the Moisture Content. As long as the state point is defined, you should be able to find the property you need in most cases, by using various combinations of the functions.

A function, AirPTW is provided to obtain the saturated moisture content for a known pressure and temperature. The Dry Bulb Temperature at saturation is synonymous with the Dew Point Temperature. Therefore, this function can be used with a pressure and the Dew Point Temperature to obtain the moisture content. The inverse of this function is AirPWD, which returns the Dew Point or Dry Bulb Temperature at which the air becomes saturated based on the level of water vapor specified.

The function AirPTHs calculates the enthalpy of moist air saturated with water at a given pressure and temperature. It is equivalent to calling the AirPTW function to get the saturated moisture content and then calling the AirPTWH function with the calculated moisture content.

The function AirPHTs is used to analyze a process of simultaneous heating and humidification or cooling and evaporation when the output stream is in a saturated state.

2.2.1 Valid Operating Range

The @Air functions are valid over a temperature range from 180 °K, (-136 °F) to 2000 °K, (3140 °F) and at pressures up to 5.0 MPa, (725 psia). The functions detect requests for calculations outside that range and return an error value.

2.2.2 Basic Unit Sets

Input to all the functions and all results can be in any of the available unit sets.

The table below summarizes the units used for each unit set.

	English	SI	English Gauge	SI Formal	SI kPa	Metric	Metric Formal
Unit Set Number	0	1	2	3	4	5	6
Unit Set Name	"ENG"	"SI"	"ENGG"	"SIF"	"SIK"	"MET"	"METF"
Temperature	°F	°C	°F	°K	°C	°C	°C
Pressure	psia	Bar	psig	MPa	kPa	bar	kg/cm ²
Entropy	Btu/lbm/ °F	kJ/kg/°C	Btu/lbm/°F	kJ/kg/°C	kJ/kg/°C	kcal/kg/°C	kcal/kg/°C
Enthalpy	Btu/lbm	kJ/kg	Btu/lbm	kJ/kg	kJ/kg	kcal/kg	kcal/kg
Specific Volume	ft ³ /lbm	m ³ /kg	ft ³ /lbm	m ³ /kg	m ³ /kg	m ³ /kg	m ³ /kg
Specific Heat	Btu/lbm/°F	kJ/kg/°C	Btu/lbm/°F	kJ/kg/ °K	kJ/kg/°C	kcal/kg/°C	kcal/kg/°C
Viscosity	lbm/ft-hr	Centipoise	lbm/ft-hr	Pa-sec	Centipoise	Centipoise	Centipoise
Conductivity	Btu/hr/Ft/°F	watt/m/°C	Btu/hr/Ft/°F	watt/m/°K	watt/m/°C	watt/m/°C	watt/m/°K
Humidity Ratio	Non-Dim	Non-Dim	Non-Dim	Non-Dim	Non-Dim	Non-Dim	Non-Dim
Relative Humidity	Non-Dim	Non-Dim	Non-Dim	Non-Dim	Non-Dim	Non-Dim	Non-Dim
Degree of Sat.	Non-Dim	Non-Dim	Non-Dim	Non-Dim	Non-Dim	Non-Dim	Non-Dim

@Air lets the user select the desired unit set with each function call by the use of an extra function argument, the unit set parameter. The unit set parameter selects basic units, Eng, SI, etc. and optional unit set modifiers. The air property functions within the function library contain the conversion factors for the basic unit sets and the set modifiers.

When calling air property functions from Visual Basic or any other Windows programming language, the unit set parameter is required and must be an integer value.

Additional flexibility in entering the unit set parameter is available when using the air property

add-in functions from Excel or 1-2-3. The spreadsheet add-ins allow the unit set parameter to be entered either as a character string or an integer value. For most users, the character string method is preferable because the characters representing the unit sets and their options are mnemonic. For Mathcad, the unit set can only be entered as a number, however, you can achieve the same effect by defining mnemonics for the base unit sets and the options right on your Mathcad worksheet

2.2.3 Wet or Dry Basis

All mass-dependent properties (specific volume, enthalpy, entropy, specific heat, viscosity and conductivity) can be based on either a dry or wet basis. The default for all basic unit sets expresses the properties per mass of dry air. This is consistent with ASHRAE conventions and is quite useful when dealing with processes that involve evaporation or condensation of water vapor.

In some cases, you may wish to express these properties on a wet basis, that is, per mass of wet air (dry air plus water vapor). You can accomplish this by adding the letter "W" to the unit set name or adding 16 to the unit set number. Remember that the choice of wet or dry basis affects both input and output properties.

For example in Excel, you can calculate the enthalpy of moist air on a wet basis at a pressure of 15 psia, a temperature of 150 °F and a humidity ratio of 0.015 as follows:

```
=AirPTWH(15,150,0.015,"EngW")
```

2.2.4 Alternate Moisture Parameters

The amount of moisture in the air can be expressed in several ways, including humidity ratio, mole fraction and mass fraction. Humidity ratio is defined as the ratio of the mass of water vapor to the mass of dry air. This method of expressing moisture is particularly useful when dealing with evaporation or condensation because the flow of dry air remains constant with either of these processes. Mole fraction, which is equivalent to volume fraction, is the ratio of the moles of water vapor to the total moles of water vapor plus dry air. Mass fraction is the ratio of the mass of water vapor to the mass of water vapor plus the mass of dry air.

The moisture content parameter W, refers to humidity ratio by default. This is a natural choice if properties are expressed on a dry basis. If you choose to express properties on a wet basis, you may find it more convenient to express the moisture parameter as a mole or mass fraction. You can substitute mole fraction wherever humidity ratio is used, by adding a "C" to the unit set name or 32 to the unit set number. Similarly, you may substitute mass fraction of water vapor wherever Humidity Ratio is used, by adding an "M" to the unit set name or 64 to the unit set number. If "CM" is added to the unit set name or 96 is added to the unit set number, the mass fraction alternative is selected.

For example in Excel, you can calculate the enthalpy of moist air at a pressure of 5 psig, a temperature of 180 °F and a moisture content of 1.5% by volume as follows:

```
=AirPTWH(5,180,0.015,"EngGC")
```

2.2.5 Reference Conditions

Enthalpy and entropy values are always expressed relative to particular reference conditions. Many people forget that the values of enthalpy and entropy that are found in published tables are not absolute values but instead, are relative to particular reference conditions. Engineering calculations always deal with enthalpy or entropy differences, typically between in-flowing and out-flowing streams. For this reason, it does not matter what you select as the reference conditions, as long as you use them consistently. @Air allows you to select reference conditions consistent with ASHRAE or an alternate set of conditions based on absolute zero temperature.

In SI units, ASHRAE uses a reference condition of 0 °C and one atmosphere of pressure for dry air. For water vapor, ASHRAE used a reference condition of liquid water at the triple point temperature of 0.01 °C. In English units, however, ASHRAE uses a reference condition of 0 °F at one atmosphere of pressure for dry air properties while maintaining the convention of using the triple point as a reference temperature for water properties. The @Air functions will use a reference temperature of 0 °F if an English unit set is selected or 0 °C if an SI unit set is selected.

If you try to convert enthalpy (or entropy) values from English to SI units using standard conversion factors, you will find a difference equal to the difference in dry air enthalpy (or entropy) between 0 °F and 32.018 °F. You can avoid this problem by converting the input parameters (e.g. pressure and temperature) to either English or SI units before calling the desired @Air function.

As an alternative, you can set the reference temperature for the dry air portion to absolute zero, (0 °K) by adding an "A" to the unit set name or adding 8 to the unit set number. In this case the 0 °K reference temperature will be used for any of the English or SI unit sets.

For example in Excel, you can calculate the enthalpy of moist air with 0 °K reference temperature at a pressure of 15 psia, a temperature of 150 °F and a humidity ratio of 0.015 as follows:

```
=AirPTWH(15,150,0.015,"EngA")
```

Please note that in all cases, the enthalpy and entropy of the water portion are set to zero for liquid water at the triple point temperature. Some publications, which are based on perfect gas assumptions, assign the zero point for enthalpy and entropy to water in the vapor state at the triple point or some other specified temperature. We believe that setting the zero point for enthalpy and entropy to water in the liquid state rather than in the vapor state has two major advantages. First, the values are numerically equivalent to standard international steam tables (and Techware's WinSteam product). This facilitates the handling of processes that include both moist air and liquid water streams without worrying about reference temperatures. Second, It greatly simplifies analysis of processes in which water is either condensed from or evaporated to the air stream.

All reference conditions use the International Temperature Scale of 1990 (ITS-90) described in reference (5) as the basis of temperature.

2.3 USING @AIR FROM EXCEL

@Air 4.0 supports 32-bit and 64-bit versions of Microsoft Excel. If you followed the guidelines in the *Installation Instructions*, you should have the proper version of the Excel add-in installed. Before you can use the @Air functions in Excel, you have to load the add-in using the Excel Add-in Manager. The procedure for activating the add-in is slightly different for 32-bit and 64-bit versions and so separate instructions are provided.

2.3.1 Loading the @Air Functions into Excel (32-bit)

Once you have started Excel, use the Tools, Add-ins menu to start Excel's Add-In Manager. (In Office 2007, click the Office button, then click the "Excel Options" button, then select the Add-ins tab and click the "Go..." button at the bottom. In Office 2010, you can get to the Add-ins tab by clicking the File menu and then the Options item.) You should see an item "@Air for Excel" in the list box. If you did not find "@Air for Excel" in the Add-in Manager list box, click the 'Browse' button and look for the file XLAir32.xll. It should be in the C:\Program Files\Microsoft Office\OfficeXX\Library directory, where OfficeXX is the latest Office version installed. When you find it, click OK. "@Air for Excel" should now appear in the list box. If you are running Windows 7, look in the C:\Program Files (x86)\Microsoft Office\OfficeXX\Library directory for the file.

Click the check box next to "@Air for Excel" and press 'OK'. The @Air copyright notice should be displayed on the status bar at the bottom of Excel. The @Air add-in is now loaded into Excel and will reload every time you start Excel. If you do not want the Add-in to load each time you start Excel, go back to the Add-in Manager and uncheck the @Air box before closing Excel.

Once selected this way using the Add-in Manager, the functions will be loaded automatically, each time you start Excel. If you wish to unload the functions, use the Add-In Manager and uncheck the box labeled "@Air for Excel". Thereafter, @Air for Excel will not load until you select it again using the Add-In Manager as described above.

2.3.2 Loading the @Air Functions into Excel (64-bit)

Once you have started Excel, click the File Menu, then click the "Options" button, then select the Add-ins tab and click the "Go..." button at the bottom. Click the 'Browse' button and look for the file XLAir64.xll. It should be in the C:\Program Files\TechwareEng\@Air (x64) directory. When you find it, click OK. "@Air for Excel 2010" should now appear in the list box.

Click the check box next to "@Air for Excel 2010" and press 'OK'. The @Air copyright notice should be displayed on the status bar at the bottom of Excel. The @Air add-in is now loaded into Excel and will reload every time you start Excel. If you do not want the Add-in to load each time you start Excel, go back to the Add-in Manager and uncheck the @Air box before closing Excel.

Once selected this way using the Add-in Manager, the functions will be loaded automatically, each time you start Excel. If you wish to unload the functions, use the Add-In Manager and uncheck the box labeled "@Air for Excel 2010". Thereafter, @Air for Excel will not load until you select it again using the Add-In Manager as described above.

2.3.3 Using the @Air Functions

Once the add-in is loaded, the air property functions are available in the same ways as Excel's built-in functions. That is, they can be typed into cell formulas or they can be inserted by pressing the f_x button while creating a cell equation or using the Formula Paste Function menu selection. When using either of the two latter methods, the air property functions will be sorted alphabetically in a function category called "Engineering". Generally, you can use any of the functions listed in section 2.2 in any cell formula. Be sure to prefix the function name with an "=" character if it is the first or only item in a formula. The line below presents an example of a call to an air property function from Excel assuming that the pressure is in cell A1, the temperature is in cell B1, the humidity ratio is in cell C1 and all values are in English units:

```
=AirPTWH(A1,B1,C1,"Eng")
```

The @Air package includes a sample Excel spreadsheet file named EXAMPLE.XLS, which demonstrates the air property functions using various unit set arguments. You can find this file in a "Samples" folder in the @Air program folder.

Since the @Air property functions make many floating-point calculations, they can add to a spreadsheet's recalculation time. You may find it desirable to set the spreadsheet to manual recalculation rather than automatic.

The @Air functions can use any of several unit sets and a variety of options, all of which are accessed using the unit set argument. This allows different unit sets and options to be mixed in the same spreadsheet. Please see section 2.2 for instructions regarding the use of these features.

2.4 USING @AIR FROM 1-2-3

@Air works with 32-bit versions of 1-2-3 including 1-2-3 97 and 1-2-3 Millennium. You must load the add-in file named 123AIR.12A to access the air property functions from 1-2-3. When the add-in is loaded into memory it establishes links between 1-2-3 and the @Air dynamic link library.

Use the File, Add-Ins, Manage Add-ins menu selections to start the Add-In manager. Before you can use the @Air add-in for the first time, you must register the add-in by pressing the 'Register..' push-button. If installed using the default values, the file 123AIR.12A should be in the \LOTUS\123\ADDINS directory and will be shown in the Register Add-Ins window. If you installed the file elsewhere, you will have to use the 'Look in' window to search for the file. When you have located the 123AIR.12A file, select it and press the 'Open' push-button. The add-in is now registered with 1-2-3.

To load the add-in after it is registered, click on the path name that has the 123AIR.12A file. A check mark will appear to the left of the path name indicating that the add-in is selected. Press the 'Done' push-button to complete the task.

Thereafter, each time you start 1-2-3, the functions will be loaded automatically. If you wish to unload the functions, use the Add-In manager to un-check the add-in. Thereafter, the 123AIR.12A add-in will not load until you select it again using the Add-In manager as described above but it should be unnecessary to go through the registration process again.

Once the add-in is loaded, the air property functions can be used in any cell formula by typing the function name in the same ways as 1-2-3's built-in functions. If you need help, use the 1-2-3 Help menu and select the '@Air Help' item. This will launch an interactive help window, which provides information regarding the functions and their usage.

Generally, you can use any of the functions listed in section 2.1 in any cell formula simply by prefixing the function name with an "@" character. The @Air package contains a sample 1-2-3 spreadsheet file named EXAMPLE.123 which makes several typical calls to the air property functions.

The line below presents an example of a call to an air property function from 1-2-3:

```
@AirPTXH(A1,B1,C1,"SI")
```

The argument "A1" is for the air pressure and can be a cell reference or an actual pressure value. In a similar manner, "B1" is for temperature and "C1" is for the humidity ratio. The last argument selects the units set and any options.

This syntax actually calls an add-in function in the 123AIR.12A add-in. These add-in functions perform error checking and return an appropriate 1-2-3 error value when necessary - typically when input arguments are out of range or when too many arguments are supplied to the function. 1-2-3 will not accept a cell formula that contains a function reference with too few input arguments. The 123AIR add-in functions themselves, call functions in TAIR32.DLL to actually perform the calculations.

The @Air functions can use any of several unit sets and a variety of options, all of which are accessed using the unit set argument. This allows different unit sets and options to be mixed in the same spreadsheet. Please see section 2.2 for instructions regarding the use of these features.

2.5 USING @AIR FROM MATHCAD

The @Air add-in for Mathcad is a self-registering DLL. All that is required for Mathcad to access the functions is that the add-in file, MCDAIR32.DLL, be located in the WINMCADUSEREF1 directory. Whenever a @Air function is used, Mathcad will automatically load and register the function.

The @Air add-in for Mathcad allows the use of any of the unit sets. Mathcad, however, allows only pure numbers (without units) to be passed to and from user-defined functions. The last argument in each function call is the unit set designator and can have a value from 0 to 127 depending upon the selection of base unit set and the unit set options. The other arguments to the function must be numbers without units whose values are consistent with the selected unit set.

The @Air package contains a sample Mathcad file named EXAMPLE.MCD, which makes typical calls to the air property functions and illustrates the use of the unit set designator.

Although on-line help for @Air is not directly available from within Mathcad, the Choose function feature does recognize the @Air functions and assists the user with the functions. Use the Math, Choose Function menu selections to open the Choose Function window. Scroll

down the 'Function name is' box to find all of the air functions listed in alphabetical order. The 'Returns' box will describe the input arguments and the return value for the function that is selected. Pressing the 'Insert' push-button will copy the function to your worksheet with placeholders for each function argument.

2.6 USING @AIR FROM VISUAL BASIC

The air property functions can be used directly in your Visual Basic programs just like the built-in functions. Before the functions can be used, however, they must be declared as functions and Visual BASIC must be told where to find them. This can all be accomplished by including a DECLARE statement for each of the air property functions in either the Form code or in the Global code. The DECLARE statement must include the name of the function, the dynamic link library where it can be found (TAIR32.DLL) and the list of arguments (which must all be passed by value, 'ByVal'). A sample DECLARE statement is as follows:

```
Declare Function AirPTW Lib "TAIR32.DLL" (ByVal P As Double, ByVal T As Double, ByVal UnitSet As Integer) As Double
```

If you are using a 64-bit version of Office, the DLL name is "TAir64.dll" instead of "TAir32.dll" and you must include the term "PtrSafe" after the keyword "Declare", for example:

```
Declare PtrSafe Function AirPTW Lib "TAIR64.DLL" (ByVal P As Double, ByVal T As Double, ByVal UnitSet As Integer) As Double
```

A text file, TAIRVBDEC.TXT, which lists declarations for all of the @Air functions is included in the @Air package in the \Programming subdirectory.

If you are using the @Air functions in an Excel Visual Basic module to create additional functions, you should use a different name to declare the functions or else they will conflict with the functions in the XIAir.xll add-in. In this case, you must use the ALIAS keyword in the declaration to identify the true name in the DLL. For example,

```
Declare Function MyAirPTWH Lib "TAIR32.DLL" ALIAS "AirPTWH" (ByVal P As Double, ByVal T As Double, ByVal W As Double, ByVal Unitset As Integer) As Double
```

If you are using a 64-bit version of Office, the DLL name is "TAir64.dll" instead of "TAir32.dll" and you must include the term "PtrSafe" after the keyword "Declare", for example:

```
Declare PtrSafe Function MyAirPTWH Lib "TAIR64.DLL" ALIAS "AirPTWH" (ByVal P As Double, ByVal T As Double, ByVal W As Double, ByVal Unitset As Integer) As Double
```

A text file, TAIRVBADEC.TXT, which lists declarations using the Alias format is included in the @Air package in the \Programming subdirectory.

With each TAIR32 function call, your code should check to ensure that the values returned are greater than -1000. Return values of -1000 or smaller indicate error conditions. See the Appendix for a listing of error codes and their meanings.

2.7 USING @AIR WITH PROGRAMMING LANGUAGES

The air property functions in TAIR32.DLL or TAIR64.DLL can also be called from within C/C++ programs compiled to run under Windows. Prototypes for all functions are provided in the file named TAIRPROTO.H. All files needed to support your programming applications can be found in the \Programming directory if you choose to install programming support during installation. You may also find it convenient to include the file named AIRERR.H. It defines mnemonic constants for the various error values returned by air functions. The compiled code should also be linked with the import library named TAIR32.LIB or TAIR64.LIB as appropriate.

With each air property function call, your code should check to ensure that the values returned are smaller (more negative) than -1000. Return values of -1000 or smaller indicate error conditions. See the Appendix for a listing of error codes and their meanings.

2.8 VERSION AND SERIAL NUMBER

There may be new releases of @Air to add features or to support new applications. Each new release of @Air will have a version number that is printed on the diskette label. The TAIR32.DLL file has its own version number, which may differ from the @Air version number. Every copy of @Air sold is provided with a unique serial number. You can identify the version of the DLL and serial numbers of your copy by using the *AirVer* function, which takes no arguments. In Excel, an empty pair of parentheses is needed. In 1-2-3 no parentheses is needed. The *AirVer* function returns a floating-point number containing the information (e.g., 4.071234). The first two digits indicate the DLL version number. The next five digits make up your copy's serial number.

The serial number also can be found by selecting About on the Help menu of **DeskTop Air**.

3. USING DESKTOP AIR

3.1 OVERVIEW

DeskTop Air is a Windows application, which calculates the thermodynamic and transport properties of moist air. It can be used as an interactive replacement for air property tables and psychrometric charts but does much more than that. It automatically calculates all unknown properties when a state point is defined by known properties. The program is flexible, and designed to minimize keystrokes for common calculations. *DeskTop Air* allows you to enter any number of state points, label them and store the collection of points for later reference. You can print a table of stored points or copy them to the clipboard and paste them into your favorite spreadsheet or word processor.

Major features of this program include:

- validity over **@Air's** full range of pressures and temperatures
- flexible interactive design
- large choice of units for each property
- tools for heating, cooling, expansion and compression processes
- instant response time
- extensive help screens

If installed properly, *DeskTop Air* is started by simply double clicking on its name/icon in the **@Air** subgroup of the *TechwareEng* Group appearing in the Windows Start Menu.

3.2 BASIC OPERATION

The *DeskTop Air* display is arranged in a tabular format that remains constant although the program window can be re-sized. You may sometimes find it convenient to make the program window smaller. Each of the rows is dedicated to one of the air properties (pressure, dry bulb temperature, specific volume, enthalpy, entropy, wet bulb temperature, dew point, relative humidity, humidity ratio, degree of saturation, H₂O mole fraction, H₂O mass fraction, molecular mass, specific heat, dynamic viscosity and thermal conductivity). There is a column that displays the property values for the active point and a column that displays data for one of the stored points.

The key properties that can be used to define the air state point are: pressure, temperature, specific volume, enthalpy, entropy, and one of the moisture indicators. Theoretically, a state point can be uniquely identified by specifying the moisture content and any two of the other five properties. On a Psychrometric chart, the state point is normally determined as the intersection of two lines, which represent two variables. Only two values are required on the Psychrometric chart because the chart is valid for only a single air pressure. In most practical applications, pressure is usually one of the known variables. Most of the calculations require

that the pressure be known. In the rare case when pressure is not known, it can be calculated from the equation of state if the dry bulb temperature, specific volume and humidity ratio is known.

Each of the key properties has a check box associated with it. When checked, it signifies that this property is to be used in calculating the state point. In general, two thermodynamic properties and one other property, which indicates the moisture content, must be selected before *DeskTop Air* will allow a computation. There are some combinations of only two properties that allow computation in the saturated state. In these cases, you will notice that the 'Compute Saturated' button is enabled. Once you select one property, *DeskTop Air* will disable all the other check boxes whose properties are not allowed in combination with the first selected property. You may change your selections by un-checking one or all of the check boxes and selecting a new combination.

To compute an air property state point, begin by selecting the input properties and set the corresponding check boxes as described above. Enter values for those properties in the boxes to the right of the property names. (The next section describes various methods for entering data.) When you enter a value for any of the key properties, a red "X" appears next to the property value to indicate that a new value has been entered. This is a warning that the value being displayed is not consistent with the current state point. After a compute command is completed successfully, all property values are recalculated and the red "X's" are cleared.

Be sure to enter the values in units consistent with the unit displayed to the right of the value box. If you wish to change units, select the desired units before entering the value. If you change units after the value is entered, the value entered will be converted to the new units.

Next, click the 'Compute' button to find all the unknown properties. If the 'Compute' button is grayed, you have not checked enough properties to define the state point. Fields without check boxes are output only. These include molecular mass, specific heat, viscosity and thermal conductivity. After recalculation, all fields contain property values for moist air at a particular state point.

The box labeled "Reference" identifies the reference conditions for the property values. It indicates whether the values are on a wet or dry basis, the reference pressure for entropy and the reference temperature for dry air enthalpy and entropy.

3.3 ENTERING DATA

Numeric data is entered in a specially designed edit box called an IO Box, which behaves like a standard Windows edit box but includes some additional features. To enter new data, double click the IO Box and all the data will be highlighted. As you enter new data, the old data will be replaced. To edit data, hold the left mouse button down and drag the mouse over the characters that you wish to replace, thereby highlighting them. Release the mouse button and type new characters to replace the highlighted ones.

The IO Box has two modes of operation, input and output. When new data is entered, the IO Box is placed in the input mode and a red X appears to the left of the box. After a new state point is computed, all IO Boxes are placed in the output mode and the red X's are removed.

The IO Box accepts either numerical values or arithmetic expressions that can be evaluated to a numeric value. A number can be entered in either decimal or scientific notation. The expression can be any valid arithmetic expression using the following operators:

+	add
-	subtract
*	multiply
/	divide
^	exponent
()	parentheses

Arithmetic calculations can be nested to any level using parentheses. An example of a valid expression is:

$$((1004^2 + 997^2) / 2)^.5$$

which evaluates to 1000.506.

Expressions are evaluated whenever you tab to or click on another control or press the 'Enter' button. Only the resulting value is shown in the box. If you enter an incorrect expression, your computer will beep and the edit cursor will highlight the offending character. You must fix the error before *DeskTop Air* will allow you to continue.

If the expression you are entering is too long to fit in the box, the box will temporarily increase in length so that you may view more of the expression. When you are finished editing, the box returns to its original length.

To recall the last expression used in an input box, use the 'Recall Expression' command on the 'Edit' menu. You'll then have the opportunity to edit the expression and let the IO Box re-evaluate it. Note that the box retains the last number or expression entered even after a compute command is issued. As a result, the value in the box will not reflect the value of the recalled expression if a compute command has altered the value.

You may use the 'Cut', 'Copy' and 'Paste' commands on the 'Edit' menu or the toolbar to exchange numeric data between *DeskTop Air's* IO Boxes and any other application that supports the clipboard. If you start entering data in an IO Box and wish to go back to the original data you may use the 'Undo' command on the 'Edit' menu. However, once the IO Box loses the focus, the 'Undo' command is no longer available.

3.4 UNIT SELECTION

DeskTop Air allows you to use any combination of units for input and output properties. The units for each property can be set independently by using its associated combo box. To change a unit, select its combo box and scroll through the list of available units using either the keyboard cursor arrows or the mouse. Whenever a new unit is selected, the program converts the values displayed for that property to the new units. Therefore, when entering data you should first select the units and then key in the input values. Otherwise, the values will be converted to the new units and you will have to re-enter them.

The first time the program is started, the properties will be displayed in SI units. You can change all of the units to either standard English or SI units by issuing the 'English Units' or 'SI

Units' command from the 'Format' menu or pressing the 'Eng' or 'SI' toolbar button. When you change to English units in this manner, the reference temperature for dry air is changed to 0 °F. Similarly, when changing to SI units, the reference temperature is changed to 0 °C.

You may choose any combination of available units for your default unit set. Simply select the units you desire for each property and issue the 'Use Settings As Default' command from the 'Format' menu. The next time you start *DeskTop Air*, your default unit set will be used.

If you change units and then save a file, those selected units will be restored whenever the file is opened. If you wish to change the units back to your default unit set, issue the command 'Restore Default Settings' from the 'Format' menu.


Unit system changes in *DeskTop Air* do not affect use of @Air from any other applications (e.g., Excel, 1-2-3, etc.).

3.5 CALCULATING STATE POINTS

When you have finished entering values for the selected input variables, click the on-screen button labeled 'Compute' to calculate all of the state point properties. If the 'Compute' button is grayed, you have not checked enough properties to define the state point.

You may also compute the state point by pressing the 'Enter' key on your keyboard. Note that the 'Enter' key serves two purposes in *DeskTop Air*. Pressing the 'Enter' key just after entering data in an IO Box, tells *DeskTop Air* to evaluate the expression in the IO Box. Pressing the 'Enter' key a second time tells *DeskTop Air* to compute the state point. If you move the focus to any other control after entering data in an IO Box, the expression is evaluated automatically and you only have to press the 'Enter' key only once to compute the state point. The 'Enter' key will not compute a state point if the 'Compute' button is grayed.

3.6 FORMATTING PROPERTY VALUES

DeskTop Air normally displays all property values in fixed decimal notation. You may increase or decrease the number of decimal places in a selected property IO Box by selecting 'Add Decimal Places' or 'Decrease Decimal Places' from the 'Format' menu or by clicking either of the  toolbar buttons, respectively.

If you wish to change the selected property to scientific notation, select the 'Scientific Notation' command from the 'Format' menu or press the 'EE' toolbar button. The 'Format' menu may be used to change the number format to 'Fixed Decimal' or 'Percent' as well. Corresponding toolbar buttons are 'Fix' and '%' respectively. Of course, the percent format only makes sense for the non-dimensional properties.

The formatting commands are only enabled when the focus is on an IO Box.

3.7 LABELING AND STORING STATE POINTS

DeskTop Air gives you the option of labeling and storing any number of state points for future reference. After computing the state point, *DeskTop Air* will automatically suggest a unique

name for the new state point such as Point 1 or Point 2, but you will probably want to enter something more descriptive. Just enter a new name in the Point Label box.

To store this point, press the 'Store Point' button. (The Store button will not be enabled if the displayed data is not a correctly calculated state point.) *DeskTop Air* requires all stored points to have a unique label. If you try to store two points with the same label, *DeskTop Air* will query whether you wish to replace the stored point, which has the same label, with the current point. If not, you should rename the point and try to store it again.

After storing the point, the state point values for the active point will be copied into a storage array and given the name you selected. The point will be displayed in the stored points column in same units as the active point. After a state point is stored, its name is added to the point name combo box in the upper right hand corner of the main window. You can view a stored point by pressing the arrow on the point name combo box and selecting a point from the drop down list.

If you wish to use a stored point with any of the special tools or as the basis for calculating a new point, you must recall the stored point to the active point. Begin by selecting the point from the point name combo box's dropdown list. Next, press the 'Recall Point' button to copy the stored point to the active point. You may now use the active point for new calculations. If you change any input data and press 'Compute', the active point will be changed but the stored point from which you copied the values will remain intact.

You can delete a stored point by first selecting it from the Point Name combo box and then select 'Delete Point' from the 'Edit' menu.

This collection of state points can be saved as a *DeskTop Air* file. In addition, you can copy state points to the clipboard, where they can be transferred to another application such as a spreadsheet program or word processor.

3.8 PRINTING

You can print a table consisting of all of the stored points by selecting the Print command from either the file menu or the toolbar. The tables will include a column for each of the stored points with each of its properties listed in a row. A label for each row includes the property name and the current units selected. The printing utility will attempt to fit as many points on a page as possible, based on the paper size and orientation that you specify using the 'Print Setup' command. You can preview the output by selecting the 'Print Preview' command from the 'File' Menu.

3.9 SAVING AND OPENING DATA FILES

When you start *DeskTop Air* or open a new file, it will be untitled. You may save a collection of stored state points along with your selections of units and formats to a *DeskTop Air* file. Select 'Save' from the 'File' menu or click the disk icon on the toolbar, which will open the "Save As" dialog box. You should enter a name for the file; the file extension ".air" will be added automatically. You may choose a folder in which to save the file or accept the default folder.

If you have saved the file at least one time during the session, you can save the work under a

different filename by choosing the 'Save As' command from the 'File' menu.

To open a saved file, select 'Open' from the 'File' menu or click the open file icon on the toolbar. This will open a dialog box that lists all of your *DeskTop Air* data files in the current folder. You may select a different folder to view other files. Select the file you want to open and press the 'Open' button to load the file.

To start a new file, select the 'New' button from the Toolbar. If you have stored any points and have not saved the file, you will be prompted to do so.

3.10 ADVANCED FEATURES

DeskTop Air includes special tools that facilitate the calculation of some common air processes. These tools include an expansion/compression tool and a heating/cooling tool.

3.10.1 Expansion/Compression Tool

The Expansion/Compression tool is used to evaluate performance of an air turbine or an air compressor. If you are predicting the performance and know the efficiency of the turbine or compressor, the tool can be used to calculate the state point conditions at the expansion or compression end point. If you are analyzing the performance of a turbine or compressor and know the conditions at the end point, the tool can be used to calculate the efficiency. The tool also computes the energy converted to shaft work generated by the turbine or used by the compressor.

To use the tool, first select the active state point representing the start of the expansion or compression path. Next, select 'Expand/Compress' from the 'Tools' menu or click the turbine icon on the toolbar, which will open the Expansion/Compression tool dialog box.

In the tool dialog box, select the conditions you will use to compute the end point from the combo box near the top of the screen. Select "Pressure & Efficiency" if you know the pressure and efficiency. If you are checking an actual machine you will need to know the exiting air temperature or enthalpy. Check either the "Pressure, Enthalpy" or "Pressure, Temperature" buttons as required. The two variables you have chosen will have their value fields enabled; all others will be grayed. Enter the appropriate values and click the 'Compute' button.

The "Air Flow In" column displays the state point properties entering the equipment, which were copied from the active point. The "Total Flow Out" box has three columns that display the state point properties at the end of the expansion. The first column identifies the thermodynamic properties for the mixture of moist air and liquid water exiting the equipment. The second column displays the thermodynamic properties for the moist air exiting and the third column shows the properties for the liquid water if any condensation occurs. The units displayed are those currently in use on *DeskTop Air's* main window. If you wish to use different units, you should select those units on the main window before opening the expansion tool.

Below the state point properties, you will find the shaft power based on the entering air flow rate that you entered. The units for these results will be consistent with your input units.

You may change any of the data and repeat the calculation as required. When you are

satisfied with the result, you may copy that state point back to the active point on *DeskTop Air's* main window by pressing the 'OK' button. Note that the values of moist air in the second column will be copied back to the active point. If no condensation has occurred, these values will be the same as in the first column labeled mixture. If condensation has occurred, then the values in the second column will be at saturated conditions.

If you do not wish to replace the current point on the main window with the expansion end point calculated, just press the 'Cancel' button.

3.10.2 Heating/Cooling Tool

The Heating/Cooling tool is used to analyze an air stream in which heat is either added or removed. If you know the quantity of heat that is being added to or removed from the air stream, you can use the tool to calculate the resulting state point temperature and other conditions. If you know the temperature or enthalpy of the air leaving the heating or cooling device, you can use the tool to calculate the quantity of heat exchanged.

To use the tool, first make sure that the active state point represents the conditions of the air entering the heating or cooling device. Next, select 'Heat/Cool Tool' from the 'Tools' menu or click the flame icon on the toolbar, which will open the Heating/Cooling tool dialog box.

In the tool dialog box, select the conditions you will use to compute the end point from the combo box near the top of the screen. Select "Pressure, Heat Flow" if you know the pressure and heat added or removed. If you are measuring performance on an existing device you will need to know the exiting air temperature or enthalpy. Check either the "Pressure, Enthalpy" or "Pressure, Temperature" buttons as required. The two variables you have chosen will have their value fields enabled; all others will be grayed. Enter the appropriate values and click the 'Compute' button.

The "Air Flow In" column displays the state point properties entering the equipment, which were copied from the Active Point in the main screen window. The "Total Flow Out" box has three columns that display the state point properties at the end of the expansion. The first column identifies the thermodynamic properties for the mixture of moist air and liquid water exiting the equipment. The second column displays the thermodynamic properties for the moist air exiting and the third column shows the properties for the liquid water if any condensation occurs. The units displayed are those currently in use on *DeskTop Air's* main window. If you wish to use different units, you should select those units on the main window before opening the Heating/Cooling tool.

Below the state point properties, you will find the heat added based on the entering airflow rate that you entered. The units for these results will be consistent with your input units.

You may change any of the data and repeat the calculation as required. When you are satisfied with the result, you may copy that state point back to the Active Point on *DeskTop Air's* main window by pressing the 'OK' button. Note that the values for moist air in the second column will be copied back to the active point. If no condensation has occurred, these values will be the same as in the first column labeled mixture. If condensation has occurred, then the values in the second column will be at saturated conditions.

If you do not wish to replace the Active Point on the main window with the heating/cooling state point calculated, just press the 'Cancel' button.

3.10.3 Exchanging Data with Other Programs

DeskTop Air includes two ways to share data with other applications running on your PC such as Excel. Both methods use the Windows clipboard.

In the first data sharing method, *DeskTop Air's* 'Edit / Copy' command copies whatever text is highlighted in an IO Box (e.g., a number or part of a number) to the Windows clipboard. From there, that text can be pasted into other applications running on your PC. This is typically done using those applications' 'Edit / Paste' command).

The second data sharing method also places text on the clipboard but uses an extended format that is especially useful for calculations involving air properties. This method is accessed using the 'Copy Point' command on the 'Edit' menu. Regardless of whether any text is selected, this command copies a *table* of text values to the clipboard using either the Active Point or all of the stored points. The table includes one column for each point. You can optionally direct *DeskTop Air* to also include property and unit labels in which case they appear as the first column in the table. The table includes one row for each property in the same order as they are displayed on *DeskTop Air's* main window. All values are copied to the clipboard using the same format displayed on the screen. So, if you need more accuracy in your Excel calculations, set the *DeskTop Air* display accuracy accordingly, before issuing the 'Copy Point' command.

3.11 GETTING HELP

The Help menu offers extensive on-line help for *DeskTop Air*. The 'About' item in the Help menu presents the version and serial numbers of your copy of @Air.

3.12 ERROR MESSAGES

When input values are out of range or any other errors occur, a message box is displayed describing the error. The calculated fields will not be updated until the error condition is resolved.

3.13 EXITING DESKTOP AIR

You may exit *DeskTop Air* by using any of the standard methods for closing Windows applications. These include the following:

- Click the upper left corner of its program window and select close from the menu.
- Select Exit from the File menu.
- Press Alt + F4 keys.
- Click the "X" button in the upper right corner of the program window

4. THEORETICAL BASIS OF @AIR FUNCTIONS

4.1 BASIS OF CALCULATIONS

The formulations used in developing the air property functions treat moist air as a mixture of two real gases, namely, dry atmospheric air and water vapor. Furthermore, dry atmospheric air is assumed to be a homogeneous, single-component gas with an apparent molecular weight of 28.9645 g/mol.

The P-V-T behavior of the mixture is described by a virial equation of state:

$$\frac{P\bar{v}}{RT} = 1 + \frac{B_m}{\bar{v}} + \frac{C_m}{\bar{v}^2} + \dots$$

where,

P = Total pressure

T = Absolute Thermodynamic Temperature

\bar{v} = Total volume of gas

R = Universal Gas Constant

B_m = second order virial coefficient of the mixture

C_m = third order virial coefficient of the mixture

For the ranges of pressure and temperature used in these functions, the higher order coefficients can be ignored. It can be shown for the air-water mixture that

$$B_m = x_a^2 B_{aa} + 2x_a x_w B_{aw} + x_w^2 B_{ww}$$

and

$$C_m = x_a^3 C_{aaa} + 3x_a^2 x_w C_{aaw} + 3x_a x_w^2 C_{aww} + x_w^3 C_{www}$$

where,

x_a = mole fraction of air in the mixture

x_w = mole fraction of water in the mixture

B_{aa}, C_{aaa} = virial coefficients of air

B_{ww}, C_{www} = virial coefficients of water vapor

B_{aw}, C_{aaw}, C_{aww} = virial coefficients of the mixture

ASHRAE uses polynomial equations for estimating the virial coefficients of air and water vapor as presented by Hyland and Wexler [8]. These equations are derived from the data presented by the NBS [1]. While these equations produce reasonable results, they are limited in temperature range from about -100 °C to 200 °C and are clearly inadequate for this application, which supports temperatures up to 2000 °K.

Instead of using polynomial equations, Techware has developed a gas property database from the NBS [1] data. The database includes virial coefficients as well as ideal gas properties for enthalpy, entropy and specific heat that span the range of temperatures from 180 °K to 2000 °K. Coefficients are extracted from the database at any desired temperature using non-linear interpolation.

The molar enthalpy of moist air, h_m can be described by the equation

$$h_m = x_a(h_a^o + h_a') + x_w(h_w^o + h_w') + RT \left[\left(B_m - T \frac{dB_m}{dT} \right) \frac{1}{\bar{v}} + \left(C_m - \frac{1}{2} T \frac{dC_m}{dT} \right) \frac{1}{\bar{v}^2} \right]$$

where,

h_a^o = ideal gas molar enthalpy for air

h_w^o = ideal gas molar enthalpy for water

h_a' = constant to adjust reference state for air

h_w' = constant to adjust reference state for water

The molar entropy of moist air, s_m can be described by the equation

$$s_m = x_a(s_a^o + s_a') + x_w(s_w^o + s_w') - R \ln P + x_a R \ln \left(\frac{P\bar{v}}{x_a RT} \right) + x_w R \ln \left(\frac{P\bar{v}}{x_w RT} \right) - R \left[\left(B_m - T \frac{dB_m}{dT} \right) \frac{1}{\bar{v}} + \frac{1}{2} \left(C_m - T \frac{dC_m}{dT} \right) \frac{1}{\bar{v}^2} \right]$$

where,

s_a^o = ideal gas molar entropy for air

s_w^o = ideal gas molar entropy for water

s_a' = constant to adjust reference state for air

s_w' = constant to adjust reference state for water

The molar specific heat at constant pressure of moist air, c_m , can be described by the equation:

$$c_m = c_a^o x_a + c_w^o x_w - R - \frac{RT}{v} \left(2 \frac{\partial B_m}{\partial T} + T \frac{\partial^2 B_m}{\partial T^2} \right) - \frac{RT}{2v^2} \left(2 \frac{\partial C_m}{\partial T} + T \frac{\partial^2 C_m}{\partial T^2} \right) + \frac{R \left(1 + \frac{B_m}{v} + \frac{C_m}{v^2} + \frac{T}{v} \frac{\partial B_m}{\partial T} + \frac{T}{v} \frac{\partial C_m}{\partial T} \right)}{1 + \frac{2B_m}{v} + \frac{3C_m}{v^2}}$$

where,

c_a^o = ideal gas molar specific heat of dry air at constant pressure

c_w^o = ideal gas molar specific heat of water vapor at constant pressure

For combinations of pressure and temperature below the boiling point of water, there is a maximum quantity of water that can exist at that temperature in the vapor state. In this condition, the air is said to be saturated. For the case where moist air exists in a saturated state, the mole fraction of water vapor, x_{ws} is given by

$$x_{ws} = \frac{fp}{P}$$

and the mole fraction of air, x_{as} is given by

$$x_{as} = \frac{P - fp}{P}$$

where,

p = the pressure of saturated vapor over pure condensed phase ice or water.

f = a dimensionless quantity introduced by Goff (1949) called the enhancement factor or excess solubility, which is equal to $x_{ws} / x_{wsideal}$.

$x_{wsideal}$ = the ratio of the vapor pressure of the pure water, to the total pressure of the mixture.

ASHRAE uses equations for estimating the enhancement factor as well as the virial coefficients of dry air and air/water mixture developed by Hyland and Wexler [8]. While earlier versions of @Air used these same formulations, this current version uses another method for calculating the enhancement factor presented by Rabinovich [3]. We believe that this method produces better correlation with the original experimental data developed by Goff. Even so, the differences between the two methods are generally small.

Assuming that the condensed phase is pure water, the value of x_{ws} can be found by equating the chemical potential of pure condensed water with the chemical potential of its vapor in the gas solution. Since the equations describing chemical potentials are non-linear and difficult to analyze, phase equilibrium is often described in terms of a thermodynamic function called fugacity. The equality of chemical potentials can be replaced by equating the logarithms of the fugacity of pure condensed water with that of its vapor in the gas mixture solution. The equation of solubility based on this concept is derived by Rabinovich [3] and can be expressed as follows:

$$\ln \frac{x_{ws} P}{p_{ws}} = \ln \frac{z(p, T, x_{ws})}{z_w(p_{ws}, T)} + \frac{1}{RT} \int_{p_{ws}}^p v_{wcond} dp + \frac{2B_{ww}}{v_w''} + \frac{3C_{www}}{2(v_w'')^2} - \frac{2}{v} (B_{aw} + (B_{ww} - B_{aw})x_{ws}^2) - \frac{3}{2v^2} (C_{aaw} + 2(C_{aww} - C_{aaw})x_{ws} + (C_{aaw} - 2C_{gww} + C_{www})x_{ws}^2)$$

where,

$$z = 1 + \frac{B}{v} + \frac{C}{v^2} \quad \text{the compressibility of the air mixture or the water vapor as required.}$$

p_{ws} = saturation pressure of water vapor at temperature T.

v_{wcond} = the volume of the condensed water.

The solubility equation can be solved for x_{ws} by iteration. The value of x_{ws} is used to find the dew point temperature of a gas mixture, to determine the amount of condensation that occurs in a cooling process and to verify that the value of x input by the user does not exceed x_{ws} .

4.2 HUMIDITY PARAMETERS

In determining the thermodynamic properties of moist air, it is required to know the relative quantities of water vapor and dry air in the mixture. The formulations described above use the mole fractions of air and water for this purpose. In practice, it is common to use other parameters as well to define the proportions of air and water vapor in the mixture. The most common of these parameters include humidity ratio, relative humidity, degree of saturation, wet bulb temperature and dew point temperature and mass fraction of water vapor. @Air includes a number of functions whose purpose is to relate the various parameters for determining the level of moisture in the air.

The functions use a key character to indicate each humidity parameter. The key characters and the definitions of each parameter are as follows:

$$\text{Humidity Ratio} = \frac{M_w}{M_a}$$

where,

M_w = mass of water vapor in sample

M_a = mass of dry air in sample

As described in section on alternate moisture parameters, mole fraction or mass fraction of water vapor can be substituted for humidity ratio through the unit set argument.

$$\text{Relative Humidity} = \frac{x_w}{x_{ws}}$$

where,

x_w = mole fraction of water vapor

x_{ws} = mole fraction of water vapor saturated at the same temperature and pressure

$$\text{Degree of Saturation} = \frac{W}{W_s}$$

where,

W = humidity ratio

W_s = humidity ratio of saturated air at the same temperature and pressure

Dew Point Temperature (D) is defined as the solution to the equation:

$$W_s(P, D)_s = W$$

It represents the temperature to which a sample of moist air at a given unchanging pressure can be cooled before condensation begins.

Thermodynamic Wet Bulb Temperature (B) is the temperature at which water, by evaporating into moist air at a given dry-bulb temperature and humidity ratio, can bring the air to saturation adiabatically at the same temperature B while the pressure is maintained constant. It is defined as the solution to the equation:

$$h(P, T, W) + [W_s(P, B) - W(P, T)]h_w(B) = h_s(P, B)$$

where,

$h(P, T, W)$ = enthalpy of the moist air sample at given pressure, dry bulb temperature and humidity ratio.

h_w = enthalpy of water added at the wet bulb temperature.

$h_s(P, B)$ = enthalpy of saturated air at the wet bulb temperature.

4.3 TRANSPORT PROPERTIES

Values for viscosity and thermal conductivity of dry air at atmospheric pressure can be found in

many references although there does not appear to be any definitive standard of accepted values as there are for steam and water. We found the most complete coverage by Vasserman, Kazavchinskii, and Rabinovich [2] who have surveyed the available literature and presented tables of values over a range of temperatures and pressures. We have used their tabular values of viscosity and thermal conductivity as the basis of our database for dry air. We have also used their recommended polynomial adjustment factors as a function of density to account for variations associated with pressure.

We have used the equations recommended by ASME (6) to compute the viscosity and thermal conductivity properties for water vapor. These are the same equations used in our WinSteam product.

There is little information available regarding the viscosity and conductivity of moist air. In most practical cases, the relatively small quantity of water vapor in air has a small effect on the overall transport properties, unlike the thermodynamic properties, which are greatly affected by moisture. Nonetheless, we have selected a method to account for the effects of moisture based on kinetic theory as presented by Hirshfelder, Curtis and Bird [4].

The equation for viscosity of a binary mixture is as follows:

$$1/\eta = \frac{X_\eta + Y_\eta}{1 + Z_\eta}$$

where

η = viscosity of the mixture

$$X_\eta = \frac{x_a^2}{\eta_a} + \frac{2x_a x_w}{\eta_{aw}} + \frac{x_w^2}{\eta_w}$$

$$Y_\eta = \frac{3}{5} A_{12}^* \left[\frac{x_a^2 \left(\frac{M_a}{M_w} \right)}{\eta_a \left(\frac{M_w}{M_a} \right)} + \frac{2x_a x_w \left(\frac{(M_a + M_w)^2}{4M_a M_w} \right) \left(\frac{\eta_{aw}^2}{\eta_a \eta_w} \right) + \frac{x_w^2 \left(\frac{M_w}{M_a} \right)}{\eta_w \left(\frac{M_a}{M_w} \right)} \right]$$

$$Z_\eta = \frac{3}{5} A_{12}^* \left[x_a^2 \left(\frac{M_a}{M_w} \right) + 2x_a x_w \left[\left(\frac{(M_a + M_w)^2}{4M_a M_w} \right) \left(\frac{\eta_{aw}}{\eta_a} + \frac{\eta_{aw}}{\eta_w} - 1 \right) \right] + x_w^2 \left(\frac{M_w}{M_a} \right) \right]$$

η_a = viscosity of dry air at the specified pressure and temperature

η_w = viscosity of water vapor at the specified pressure and temperature

$$\eta_{aw} = C_1 \frac{\sqrt{2M_a M_w T / (M_a + M_w)}}{\sigma_{aw}^2 \Omega_{12}^{(2,2)*} (T_{aw}^*)} \text{ and } C_1 = 266.93E-7$$

σ_{aw} = potential function parameter for mixture adjusted for one polar molecule

$\Omega_{12}^{(2,2)*}$ = transport property integral as a function of T^* , the reduced temperature

A_{12}^* = function of reduced temperature

In a similar manner, the equations for thermal conductivity of moist air is as follows:

$$1/\lambda = \frac{X_\lambda + Y_\lambda}{1 + Z_\lambda}$$

where,

λ = thermal conductivity of the mixture

$$X_\lambda = \frac{x_a^2}{\lambda_a} + \frac{2x_a x_w}{\lambda_{aw}} + \frac{x_w^2}{\lambda_w}$$

$$Y_\lambda = \frac{x_a^2}{\lambda_a} U^{(1)} + \frac{2x_a x_w}{\lambda_{aw}} U^{(Y)} + \frac{x_w^2}{\lambda_w} U^{(2)}$$

$$Z_\lambda = x_a^2 U^{(1)} + 2x_a x_w U^{(Y)} + x_w^2 U^{(2)}$$

$$U^{(1)} = \frac{4}{15} A_{12}^* - \frac{1}{12} \left(\frac{12}{5} B_{12}^* + 1 \right) \frac{M_a}{M_w} + \frac{1}{2} \frac{(M_a - M_w)^2}{M_a M_w}$$

$$U^{(2)} = \frac{4}{15} A_{12}^* - \frac{1}{12} \left(\frac{12}{5} B_{12}^* + 1 \right) \frac{M_w}{M_a} + \frac{1}{2} \frac{(M_w - M_a)^2}{M_a M_w}$$

$$U^{(Y)} = \frac{4}{15} A_{12}^* \left(\frac{(M_a + M_w)^2}{4M_a M_w} \right) \frac{\lambda_{aw}^2}{\lambda_a \lambda_w} - \frac{1}{12} \left(\frac{12}{5} B_{12}^* + 1 \right) \frac{5}{32 A_{12}^*} \left(\frac{12}{5} B_{12}^* - 5 \right) \frac{(M_a - M_w)^2}{M_a M_w}$$

$$U^{(Z)} = \frac{4}{15} A_{12}^* \left[\left(\frac{(M_a + M_w)^2}{4M_a M_w} \right) \left(\frac{\lambda_{aw}}{\lambda_a} + \frac{\lambda_{aw}}{\lambda_w} \right) - 1 \right] - \frac{1}{12} \left(\frac{12}{5} B_{12}^* + 1 \right)$$

λ_a = Thermal conductivity of dry air at the specified pressure and temperature

λ_w = Thermal conductivity of water vapor at the specified pressure and temperature

$$\lambda_{aw} = C_2 \frac{\sqrt{T(M_a + M_w) / 2M_a M_w}}{\sigma_{aw}^2 \Omega_{12}^{(2,2)*}(T_{aw}^*)} \text{ and } C_2 = 1989.1E-7$$

B_{12}^* = function of reduced temperature

5. SPEED AND ACCURACY CHARACTERISTICS

5.1 SPEED OF CALCULATIONS

This section addresses the **@Air** calculation speed as measured within Microsoft Excel. Performance within other applications is similar.

The time required to recalculate a spreadsheet is a function of many features of the computer system hardware and the nature of the spreadsheet. Since the supported spreadsheets use double precision math exclusively, calculation time is sensitive to the number and complexity of numerical equations used.

The time required to perform the calculations also varies depending on the specific functions. Some calculations are more complex than others. Some require iterations. The simplest functions run the fastest while those that are more complex and require iterations run slower. The table below lists times required to calculate some typical **@Air** functions from Microsoft Excel.

Function	Calculation Time
AirPTRW	0.00016
AirPTWH	0.00001
AirPWD	0.00070
AirPHWT	0.00045

Typical calculation times in seconds per calculation.
A calculation returns one property at one state point.

These times were measured on a computer using a 233 MHz Pentium II processor. Calculation times will vary depending on your particular computer.

Note that the recalculation options selected will also affect perceived calculation time.

5.2 ACCURACY OF CALCULATIONS

Thermodynamic properties for dry air calculated by **@Air** have been checked against the values published by NBS [1]. As shown on Exhibits 5.1 through 5.4, the calculated values

show excellent agreement with the source data throughout most of the valid range. Some small differences can be observed at low temperatures and high pressures. This is due to the limitations of using a third order virial equation of state. Even so, the maximum error is less than 0.3% for thermodynamic properties and 3.17% for specific heat.

Another smaller difference is shown in the compressibility factor between 1500 °K and 2000 °K. This is due to the dissociation of Nitrogen and Oxygen at these temperatures. This error is less than 0.02%.

The tables show some differences in enthalpy, entropy and specific heat occurring at 850 °K and growing with temperature. This initially, was thought to be attributed to dissociation, but this was dismissed for two reasons. First, dissociation effects were not included below 1500 °K in reference 1. Second, the error is much greater than what can be attributed to dissociation above 1500 °K.

Further examination of the data tables suggests that the tables in reference 1 are in error. One would expect the thermodynamic properties to approach the ideal gas properties as the pressure is reduced to zero. While this is the case for temperatures up to 800 °K, it is not the case above 800 °K. Curiously, at 800 °K, the tables in reference 1 change from a temperature increment of 10 °K to 50 °K at the point where the error begins. Perhaps this change of temperature increment was not handled properly.

Comparison of data from Vasserman et al [2] in the temperature range from 850 °K to 1300 °K supports the conclusion that the tables from NBS [1] are in error. Unfortunately, the tables from Vasserman et al [2] does not contain data for temperatures above 1300 °K.

Moist air properties are compared against values published by ASHRAE [9] in Exhibits 5.5 – 5.7, which show excellent agreement. It should be noted that there are small differences in the saturated humidity ratio between @Air and ASHRAE, which are attributed to the different models used as explained in the section on basis of calculations.

Exhibit 5.8 plots the enhancement factors from @Air and ASHRAE with the original experimental data from Goff. This clearly shows that the model used by @Air provides better agreement with the original experimental data than the model used by ASHRAE. Since the enhancement factor is the basis for calculating saturated humidity ratio, we place a higher confidence on the saturated humidity ratio calculated by @Air.

**COMPARISON OF RESULTS WITH NBS [1] DATA
EXHIBIT 5.1 - COMPRESSIBILITY OF DRY AIR**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	0.001%	0.002%	0.019%	0.028%	0.125%	0.279%
260	300	0.001%	0.001%	0.005%	0.008%	0.009%	0.014%
310	350	0.001%	0.001%	0.003%	0.003%	0.009%	0.013%
360	400	0.000%	0.001%	0.003%	0.004%	0.002%	0.004%
410	500	0.001%	0.001%	0.003%	0.004%	0.010%	0.013%
510	600	0.000%	0.001%	0.002%	0.003%	0.012%	0.013%
610	700	0.001%	0.001%	0.001%	0.002%	0.008%	0.010%
710	800	0.000%	0.001%	0.001%	0.001%	0.004%	0.006%
850	1450	0.000%	0.001%	0.001%	0.002%	0.002%	0.004%
1500	2000	0.004%	0.016%	0.004%	0.006%	0.004%	0.010%

**COMPARISON OF RESULTS WITH NBS [1] DATA
EXHIBIT 5.2 - ENTHALPY OF DRY AIR**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	0.00%	0.01%	0.03%	0.12%	0.13%	0.26%
260	300	0.00%	0.00%	0.00%	0.01%	0.04%	0.07%
310	350	0.00%	0.00%	0.00%	0.01%	0.01%	0.01%
360	400	0.00%	0.00%	0.01%	0.01%	0.01%	0.01%
410	500	0.00%	0.00%	0.00%	0.01%	0.01%	0.01%
510	600	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%
610	700	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%
710	800	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%
810	1450	* 0.03%	* 0.09%	* 0.03%	* 0.09%	* 0.03%	* 0.10%
1500	2000	**	**	**	**	**	**

**COMPARISON OF RESULTS WITH NBS [1] DATA
EXHIBIT 5.3 - ENTROPY OF DRY AIR**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	Deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	0.00%	0.00%	0.01%	0.02%	0.02%	0.05%
260	300	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%
310	350	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%
360	400	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
410	500	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
510	600	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
610	700	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
710	800	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
850	1450	0.00%	0.01%	0.00%	0.00%	0.01%	0.01%
1500	2000	**	**	**	**	**	**

**COMPARISON OF RESULTS WITH NBS [1] DATA
EXHIBIT 5.4 - SPECIFIC HEAT OF DRY AIR**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	0.04%	0.11%	0.35%	1.04%	1.05%	3.17%
260	300	0.00%	0.00%	0.05%	0.06%	0.29%	0.38%
310	350	0.00%	0.01%	0.02%	0.03%	0.10%	0.17%
360	400	0.00%	0.00%	0.00%	0.01%	0.02%	0.03%
410	500	0.00%	0.00%	0.01%	0.01%	0.04%	0.06%
510	600	0.00%	0.00%	0.01%	0.01%	0.03%	0.04%
610	700	0.00%	0.00%	0.00%	0.01%	0.01%	0.02%
710	800	0.00%	0.00%	0.00%	0.02%	0.01%	0.04%
850	1450	* 0.47%	* 0.07%	* 0.47%	* 1.37%	* 0.49%	* 1.40%
1500	2000	**	**	**	**	**	**

Notes: *, ** - Questionable reference data.

**COMPARISON OF RESULTS WITH ASHRAE [9] & NBS [1]
EXHIBIT 5.5 - SPECIFIC VOLUME**

Temp ° F	Dry Air at 1 atm ft ³ /lbm			Saturated Moist Air at 1 atm ft ³ /lbm of Dry Air	
	NBS	@Air	ASHRAE	@Air	ASHRAE
-80	9.556	9.554	9.553	9.554	9.553
-70	9.809	9.807	9.807	9.807	9.807
-60	10.062	10.061	10.060	10.061	10.06
-50	10.316	10.314	10.313	10.314	10.314
-40	10.569	10.567	10.567	10.568	10.568
-30	10.822	10.820	10.820	10.823	10.822
-20	11.075	11.073	11.073	11.078	11.078
-10	11.328	11.326	11.326	11.335	11.335
0	11.581	11.579	11.579	11.594	11.594
10	11.834	11.832	11.832	11.857	11.857
20	12.087	12.085	12.085	12.127	12.127
30	12.340	12.338	12.338	12.406	12.406
40	12.592	12.591	12.591	12.696	12.696
50	12.845	12.844	12.844	13.001	13.001
60	13.098	13.096	13.096	13.329	13.329
70	13.351	13.349	13.349	13.688	13.688
80	13.604	13.602	13.602	14.089	14.089
90	13.856	13.854	13.855	14.547	14.547
100	14.109	14.107	14.107	15.083	15.084
110	14.361	14.360	14.360	15.727	15.727
120	14.614	14.612	14.613	16.519	16.519
130	14.867	14.865	14.865	17.520	17.52
140	15.119	15.118	15.118	18.826	18.825
150	15.372	15.370	15.370	20.589	20.589
160	15.624	15.623	15.623	23.082	23.082
170	15.877	15.875	15.875	26.835	26.834
180	16.130	16.128	16.128	33.037	33.037
190	16.382	16.380	16.381	45.043	45.042
200	16.635	16.633	16.633	77.426	77.426

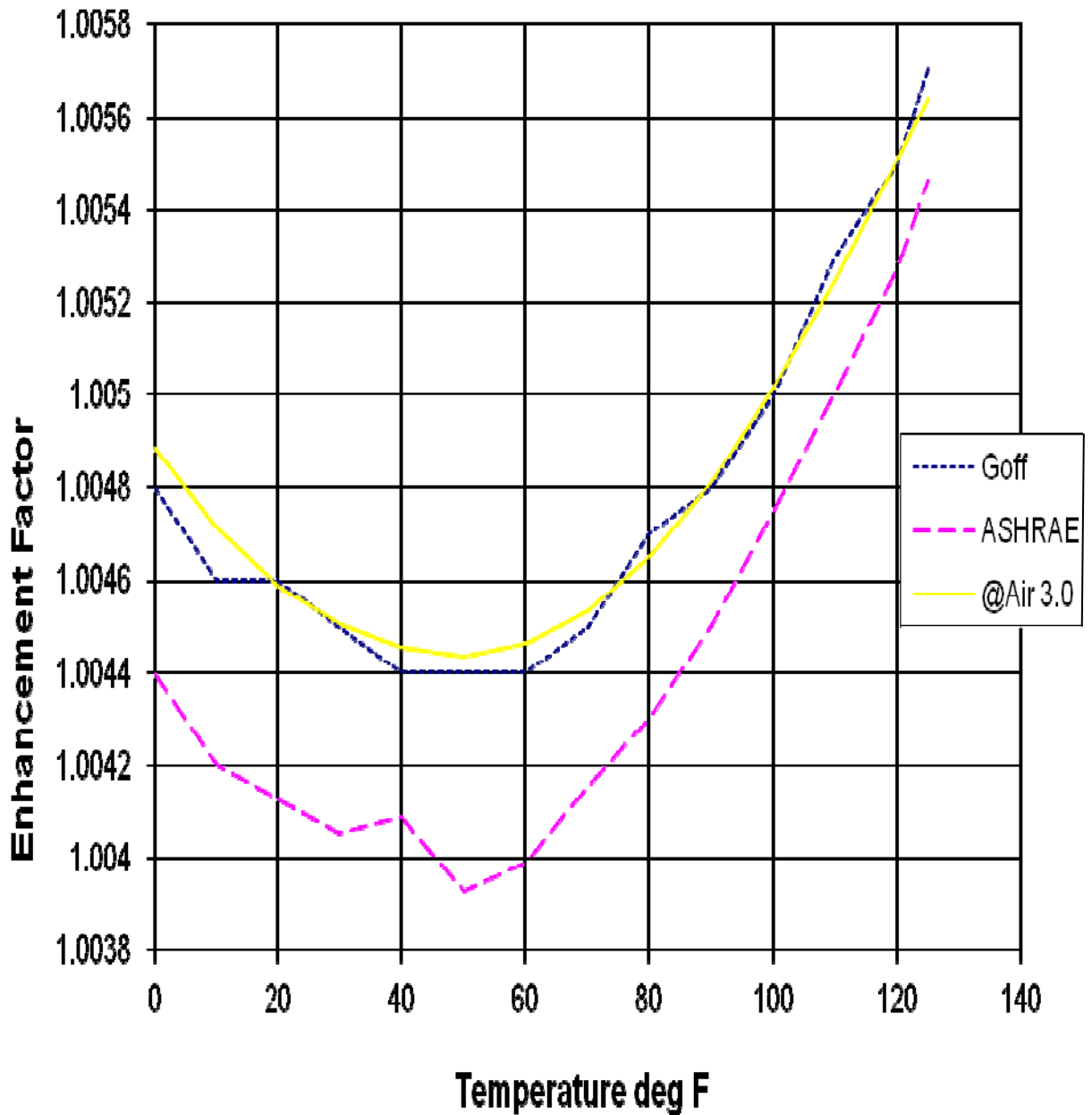
**COMPARISON OF RESULTS WITH ASHRAE [9] & NBS [1]
EXHIBIT 5.6 - ENTHALPY**

Temp ° F	Dry Air at 1 atm Btu/lbm			Saturated Moist Air at 1 atm Btu/lbm of Dry Air	
	NBS	@Air	ASHRAE	@Air	ASHRAE
-80	-19.217	-19.218	-19.221	-19.213	-19.215
-70	-16.815	-16.814	-16.806	-16.803	-16.817
-60	-14.412	-14.410	-14.414	-14.388	-14.392
-50	-12.009	-12.007	-12.011	-11.964	-11.968
-40	-9.606	-9.605	-9.609	-9.522	-9.526
-30	-7.203	-7.203	-7.206	-7.050	-7.053
-20	-4.802	-4.802	-4.804	-4.525	-4.527
-10	-2.401	-2.401	-2.402	-1.914	-1.915
0	0.000	0.000	0.000	0.836	0.835
10	2.401	2.401	2.402	3.803	3.804
20	4.802	4.803	4.804	7.106	7.107
30	7.203	7.205	7.206	10.916	10.917
40	9.606	9.606	9.609	15.233	15.233
50	12.009	12.009	12.012	20.307	20.306
60	14.412	14.412	14.415	26.470	26.467
70	16.815	16.815	16.818	34.101	34.097
80	19.218	19.218	19.222	43.706	43.701
90	21.622	21.622	21.626	55.959	55.951
100	24.027	24.027	24.031	71.770	71.761
110	26.432	26.431	26.436	92.397	92.386
120	28.837	28.836	28.842	119.628	119.612
130	31.244	31.244	31.249	156.095	156.076
140	33.652	33.652	33.656	205.849	205.824
150	36.060	36.059	36.064	275.516	275.49
160	38.469	38.468	38.474	376.760	376.737
170	40.878	40.877	40.884	532.293	532.256
180	43.289	43.288	43.295	793.156	793.166
190	45.703	45.700	45.707	1303.287	1303.321
200	48.120	48.114	48.121	2688.073	2688.205

**COMPARISON OF RESULTS WITH ASHRAE [9] & NBS [1]
EXHIBIT 5.7 – ENTROPY**

Temp ° F	Dry Air at 1 atm Btu/lbm/°F			Saturated Moist Air at 1 atm Btu/lbm/°F of Dry Air	
	NBS	@Air	ASHRAE	@Air	ASHRAE
-80	-0.04589	-0.04593	-0.04594	-0.04592	-0.04592
-70	-0.03964	-0.03968	-0.03969	-0.03965	-0.03966
-60	-0.03357	-0.03359	-0.03360	-0.03354	-0.03354
-50	-0.02766	-0.02766	-0.02766	-0.02754	-0.02755
-40	-0.02189	-0.02186	-0.02187	-0.02165	-0.02166
-30	-0.01623	-0.01621	-0.01621	-0.01583	-0.01583
-20	-0.01071	-0.01068	-0.01069	-0.01001	-0.01002
-10	-0.00531	-0.00528	-0.00528	-0.00414	-0.00414
0	0.00000	0.00000	0.00000	0.00192	0.00192
10	0.00519	0.00517	0.00517	0.00832	0.00832
20	0.01024	0.01023	0.01023	0.01528	0.01528
30	0.01518	0.01518	0.01519	0.02315	0.02315
40	0.02002	0.02004	0.02004	0.03187	0.03187
50	0.02478	0.02480	0.02480	0.04192	0.04192
60	0.02945	0.02946	0.02947	0.05389	0.05389
70	0.03403	0.03405	0.03406	0.06845	0.06844
80	0.03853	0.03854	0.03855	0.08643	0.08642
90	0.04295	0.04296	0.04297	0.10896	0.10895
100	0.04729	0.04729	0.04730	0.13754	0.13752
110	0.05157	0.05155	0.05156	0.17421	0.17418
120	0.05577	0.05573	0.05575	0.22183	0.22180
130	0.05989	0.05985	0.05986	0.28460	0.28457
140	0.06394	0.06390	0.06391	0.36894	0.36890
150	0.06793	0.06788	0.06790	0.48529	0.48524
160	0.07185	0.07180	0.07181	0.65193	0.65188
170	0.07572	0.07566	0.07567	0.90433	0.90425
180	0.07951	0.07946	0.07947	1.32184	1.32183
190	0.08325	0.08320	0.08321	2.12731	2.12733
200	0.08692	0.08689	0.08690	4.28462	4.28477

**COMPARISON OF RESULTS WITH ASHRAE [9]
EXHIBIT 5.8 - ENHANCEMENT FACTORS**



**COMPARISON OF RESULTS WITH ASHRAE [9]
EXHIBIT 5.9 - SATURATED HUMIDITY RATIO**

Temp ° F	Saturated Moist Air at 1 atm			
	ASHRAE	@Air	Difference	% Error
-80	0.0000049	0.0000049	0.0000000	0.00%
-70	0.0000104	0.0000104	0.0000000	0.00%
-60	0.0000212	0.0000212	0.0000000	0.00%
-50	0.0000416	0.0000417	0.0000001	0.24%
-40	0.0000793	0.0000793	0.0000000	0.00%
-30	0.0001465	0.0001466	0.0000001	0.07%
-20	0.0002632	0.0002633	0.0000001	0.04%
-10	0.0004608	0.0004610	0.0000002	0.04%
0	0.0007875	0.0007879	0.0000004	0.05%
10	0.0013158	0.0013165	0.0000007	0.05%
20	0.0021531	0.0021541	0.0000010	0.05%
30	0.0034552	0.0034568	0.0000016	0.05%
40	0.005216	0.005219	0.000003	0.05%
50	0.007661	0.007666	0.000005	0.06%
60	0.011087	0.011094	0.000007	0.06%
70	0.015832	0.015841	0.000009	0.06%
80	0.022340	0.022352	0.000012	0.05%
90	0.031203	0.031218	0.000015	0.05%
100	0.043219	0.043238	0.000019	0.04%
110	0.059486	0.059510	0.000024	0.04%
120	0.081560	0.081592	0.000032	0.04%
130	0.111738	0.111775	0.000037	0.03%
140	0.153538	0.153585	0.000047	0.03%
150	0.21273	0.21279	0.00006	0.03%
160	0.29945	0.29951	0.00006	0.02%
170	0.43343	0.43352	0.00009	0.02%
180	0.65911	0.65917	0.00006	0.01%
190	1.10154	1.10162	0.00008	0.01%
200	2.30454	2.30460	0.00006	0.00%

6. REFERENCES

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APPENDIX @Air ERROR CODES

If an error is encountered by a TAIR32.DLL or TAIR64.DLL function during calculation of an air property, the function returns a negative value (-1000 or lower). This Appendix presents the error numbers together with an explanation of each possible error condition. The header file AIRERR.H defines mnemonic constants for the error codes. The mnemonics are listed below also.

The error codes listed below are accessible only from Windows programming languages such as Visual C, Quick C or Visual BASIC. The interfaces provided for Excel, 1-2-3 and Mathcad intercept these error numbers and return appropriate error values. This is done to avoid inadvertent use of an error value in a cell equation. DeskTop Air also intercepts these codes and displays appropriate messages.

ERR_NOSAT(-1100): No Saturation

Saturated conditions are not defined for the calculated state point.

ERR_THIGH(-2000): Temperature Too High
ERR_TLOW(-2100): Temperature Too Low
ERR_WBHIGH(-2200): Wet Bulb Temperature Too High
ERR_WBLOW(-2300): Wet Bulb Temperature Too Low
ERR_DPHIGH(-2400): Dew Point Temperature Too High
ERR_DPLOW(-2500): Dew Point Temperature Too Low

@AIR will accept a maximum temperature of 2000 deg K and a minimum temperature of 180 deg K. Any attempt to calculate air properties at temperatures outside of this range will return one of these error numbers.

ERR_PHIGH(-3000): Pressure Too High
ERR_PLOW(-3100): Pressure Too Low

@AIR will accept a maximum pressure of 50 bar and a minimum pressure of 0 bar. Any attempt to calculate air properties at pressures outside of this range will return one of these error numbers.

ERR_VOLHIGH(-4000): Volume Too High
ERR_VOLLOW(-4100): Volume Too Low

Any attempt to calculate air properties at volumes that correspond to temperatures and pressures outside of the ranges described above will return one of these error numbers.

```
ERR_RHIGH(-5000): Relative Humidity Too High
ERR_RLOW(-5100):  Relative Humidity Too Low
ERR_UHIGH(-6000): Degree of Saturation Too High
ERR_ULOW(-6100):  Degree of Saturation Too Low
```

Relative Humidity and Degree of Saturation can have values ranging from 0 to 1. Any attempt to calculate air properties at a relative humidity or degree of saturation outside of this range above will return one of these error numbers.

```
ERR_WHIGH(-7000): Humidity Ratio Too High
```

Any attempt to calculate air properties at a humidity ratio that is greater than the saturated humidity ratio for the specified pressure and temperature will return this error number.

```
ERR_WLOW(-7100):  Humidity Ratio Too Low
```

Any attempt to calculate air properties at a humidity ratio that is less than 0 will return this error number.

```
ERR_XHIGH(-7300): Mole or Mass Fraction Too High
```

Mole or Mass fraction of water vapor cannot be greater than 1. Any attempt to calculate an air property with a mole or mass fraction greater than 1.0 will return this error number.

```
ERR_HHIGH(-9000): Enthalpy Too High
ERR_HLOW(-9100):  Enthalpy Too Low
ERR_SHIGH(-9200): Entropy Too High
ERR_SLOW(-9300):  Entropy Too Low
```

Any attempt to calculate air properties at enthalpy or entropy values outside of the program range will return one of these error numbers.