CT-Natural

Windows Application

USER GUIDE

Windows® Operating System
SI and I-P Units
Version 2.0

Table of Contents

www.fluidika.com
support@fluidika.com

Overview

CT-Natural is a computational set of tools to analyze and determine cooling performance curves and thermophysical operational variables in natural draft counterflow wet cooling towers.

All calculations are performed employing accurate numerical techniques implementing some of the most precise mathematical models for the properties of humid air, water and steam developed for industrial purposes.

- **Natural Draft :** Numerical calculation and graphical display of cooling performance curves and thermophysical operational variables in natural draft counterflow wet cooling towers based on a mathematical model of heat and mass transfer between water and humid air in the cooling fill zone.

- **Demand Curves** : Calculation and graphical display of demand curves and approach points.

- **Merkel Number** : Calculation of Merkel number using the Chebyshev numerical method.

- **Psychrometrics Calculator** : A psychrometrics calculator based on the latest mathematical models to numerically evaluate the properties of humid air, water, steam, ice and psychrometrics.

Mathematical Models

Calculation of the properties of humid air, water and steam used for the numerical solution of the equations that describe the energy processes are based on the mathematical formulations of the following thermodynamic and transport properties:

Properties of Water and Steam

- Formulations from the IAPWS (International Association for the Properties of Water and Steam) IAPWS-IF97 Industrial formulation (Revision 2007) and related models.

Properties of Humid Air

- Thermodynamic and psychrometrics property algorithms from the ASHRAE Research Project 1485.
- Scientific Formulation IAPWS-95, IAPWS Formulation 2008 and IAPWS Formulation 2006. Properties of dry air are from the NIST Reference equation of Lemmon et al.

Demand Curves

- Numerical calculation and graphical display of demand curves following the integration of Merkel´s equation.
- Calculation and graphical display of approach data points.
- Complete validation of input variables.
- Creation of projects in a database that describe a particular set of input variables together with the calculated demand curves and approach data points for later retrieval or recalculation.
- Generation of high-quality pdf files of demand curves.
- Generation of excel and pdf files of approach data point calculation results.
- Supports input variables and calculation results in SI (metric) and I-P (english) system of units.

Merkel Number

- Calculation of Merkel number using the Chebyshev numerical method.
- Complete validation of input variables, informing of the correct range of variables for a valid calculation.
- Supports input variables and calculation results in SI (metric) and I-P (english) system of units.

Natural Draft

- Numerical calculation and graphical display of cooling performance curves and thermophysical operational variables in natural draft counterflow wet cooling towers based on a mathematical model of heat and mass transfer between water and humid air in the cooling fill zone.
- Complete validation of input variables, informing the user of the correct range of variables for a valid numerical calculation.
- Creation of calculation projects in a database to save a specific cooling tower geometry, atmospheric and operational conditions together with numerical calculation results for later retrieval or recalculations.
- Generation of high-quality pdf files of cooling performance curve plots and data calculation points for a particular project.
- Generation of excel and pdf files of numerical results of data calculations.
- Supports input variables and calculation results in SI (metric) system of units.

Psychrometrics Calculator

- Calculation of 42 properties of humid air, water, steam, ice and psychrometrics.
- Allows for 17 combinations of two thermodynamic properties to be entered as input parameters.
- Supports input parameters and calculation results in both SI (metric) and I-P (english) system of units.
- For each combination of input thermodynamic properties, calculates and provides the user with information about the appropriate input values in the valid range of computations.
- Calculation results can be saved to a database.
- Calculation results can be exported to excel and pdf file formats.

1.2 System Requirements — Software

The following are the requirements in order to install and utilize **CT-Natural.** Please note that if your operating system does not include any of the components, they will be installed by the installation file.

Operating System (64-bit)	Windows 8 Windows 8.1 Windows 10
C++ Runtime Library	Microsoft Visual C++ 2010 Redistributable (x86) Microsoft Visual C++ 2015-2019 Redistributable (x64)
NET. Framework	4.6
Memory	4 GB RAM or more
Screen Resolution	1152 × 864 (minimum)

Table 1.1 System requirements for CT-Natural.

1.3 Installation — Software

Double-click on the installation file and follow the on-screen instructions. When prompted, introduce the **License Key** that was delivered to you. Contact **support@fluidika.com** if you require assistance.

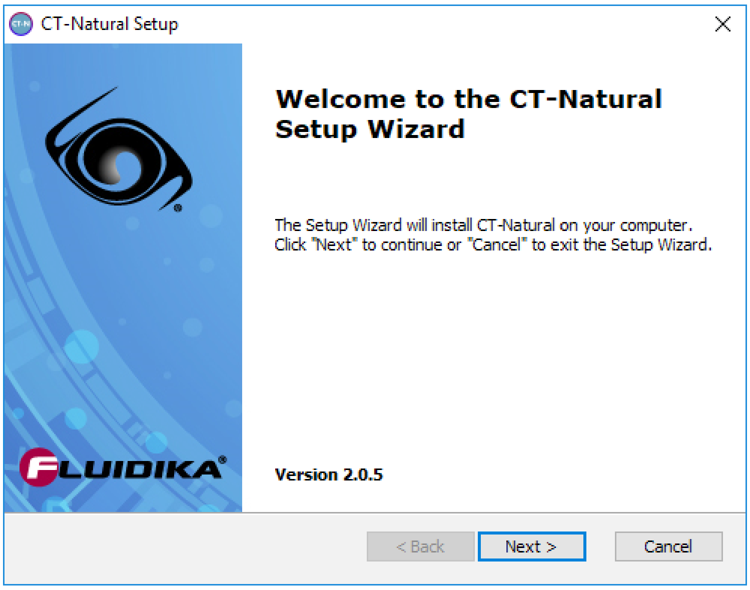


Figure 1.1 Installation screen of CT-Natural.

You need to have **Administrator** privileges on your computer in order to install this software.

1.4 License Activation

Internet activation requires direct access to the Internet. Make sure that you are not connected to a proxy and that your firewall or network is not configured to block access to the Internet. After activation, you can return to your previous network configuration.

Activation via Internet is required in order to unlock and use all the capabilities of **CT-Natural**. Once you have a valid Internet connection, the procedure to activate the license is as follows:

1. Click on the About button located on the upper right hand side of the application. This will bring the about screen of **CT-Natural** (Figure 1.2).
2. Click on the ACTIVATE button to start the activation process. The activation screen of **CT-Natural** appears on the left hand side of the application's window (Figure 1.3).
3. Introduce the **License Key** that was provided to you to install the application. Once all the fields of the license key are validated, click on the ACTIVATE button of the activation screen.
4. If the activation was successful (Figure 1.4), a screen indicating that the applications was activated will be displayed.

Contact **support@fluidika.com** if you require assistance during the activation process.

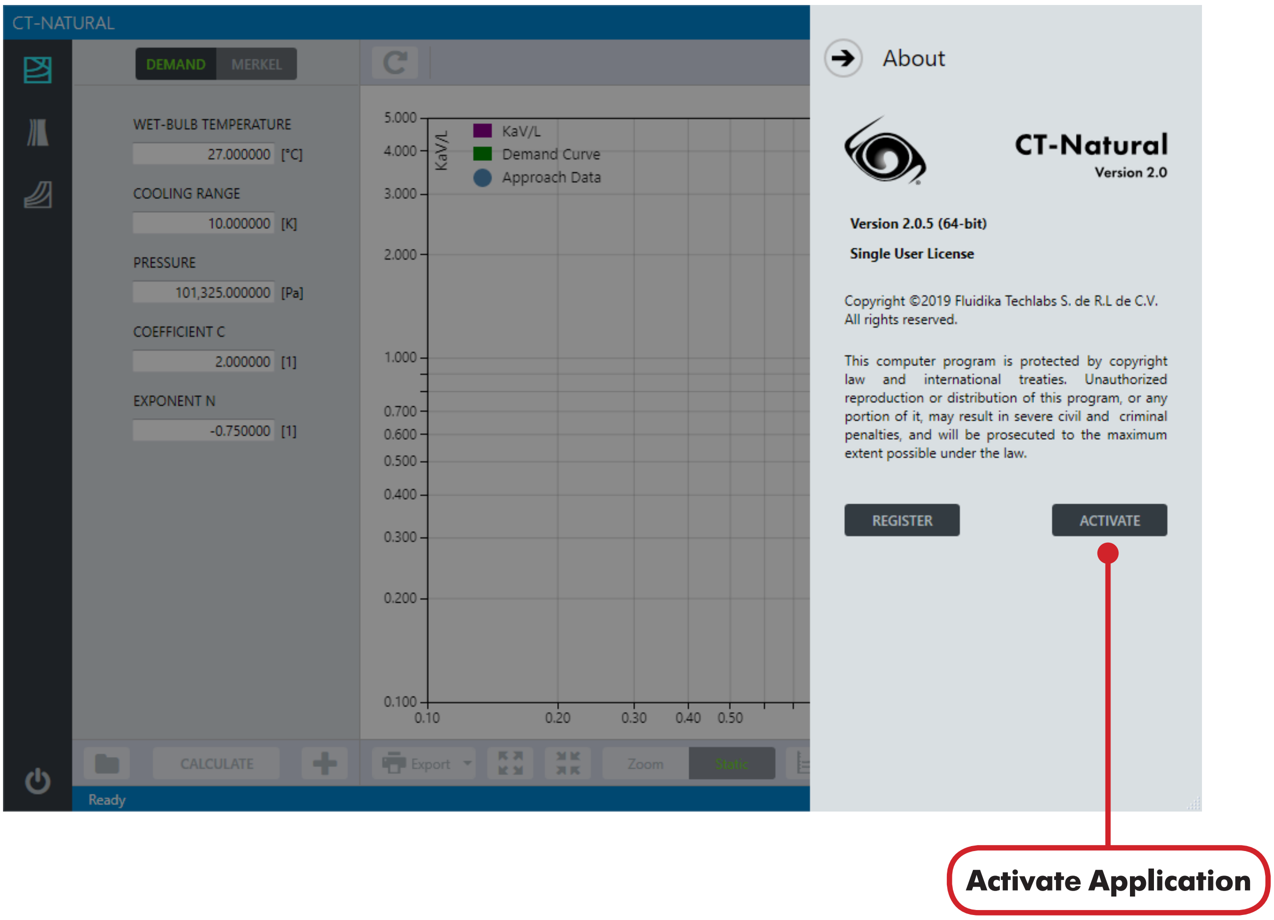


Figure 1.2 About screen of CT-Natural.

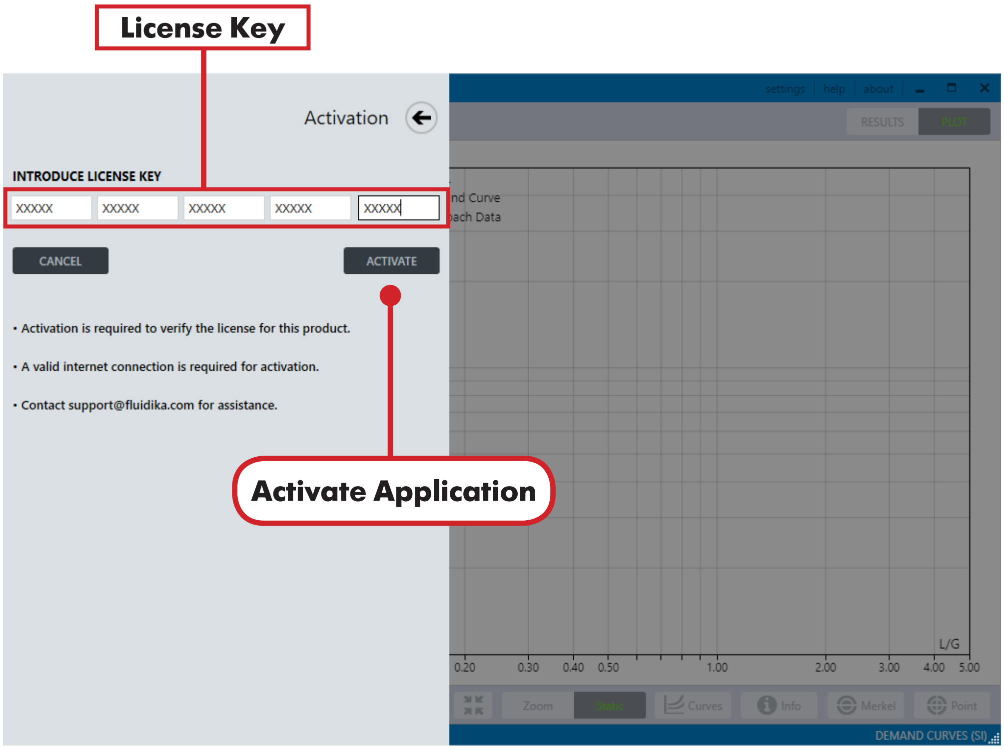


Figure 1.3 Activation screen of CT-Natural.

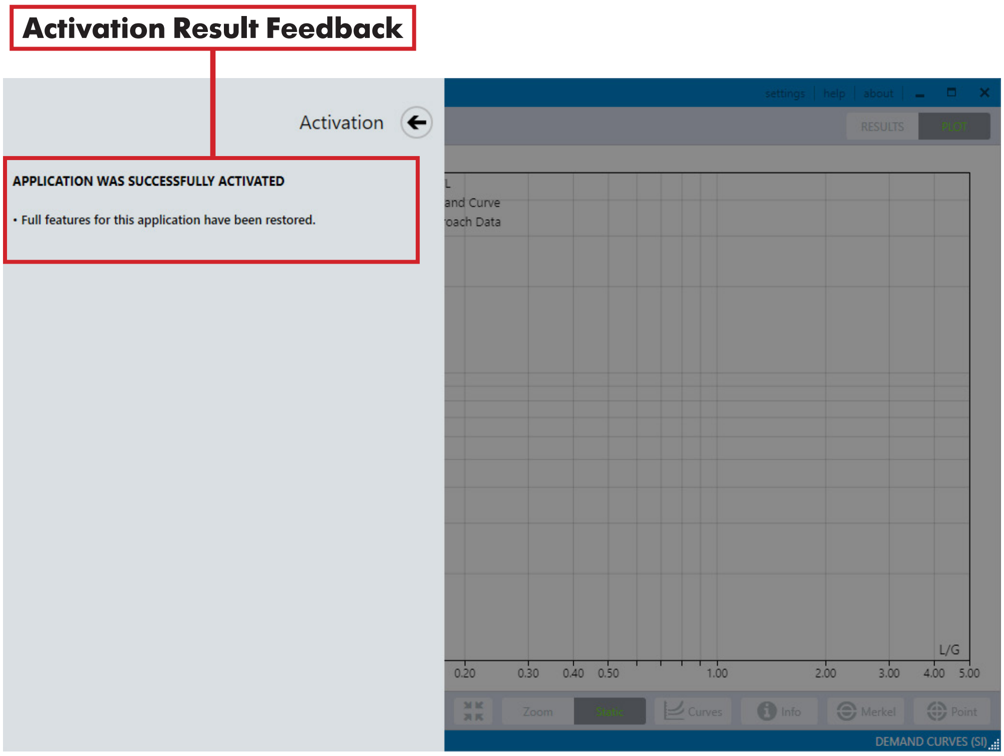


Figure 1.4 Activation feedback screen of CT-Natural.

1.5 License Deactivation

Deactivation of this software requires direct access to the Internet. Make sure that you are not connected to a proxy and that your firewall or network is not configured to block access to the Internet.

The License Key that was provided with this application is only valid for a single-seat computer. In order to transfer this license to another computer, deactivation via internet is required. The procedure to deactivate the license is as follows:

1. Click on the About button located on the upper right hand side of the application. This will bring the about screen of **CT-Natural** (Figure 1.5).
2. Click on the DEACTIVATE button in order to start the deactivation process. The deactivation screen of **CT-Natural** appears on the left hand side of the application's window (Figure 1.6).
3. Introduce the **License Key** that was provided to you to install the application. Once all the fields of the license key are validated, click on the DEACTIVATE button.
4. A message will be shown (Figure 1.7) displaying the result of the deactivation process. If successful, you can install the application in another computer using the License Key that was acquired.

Contact **support@fluidika.com** if you require assistance to deactivate this application.

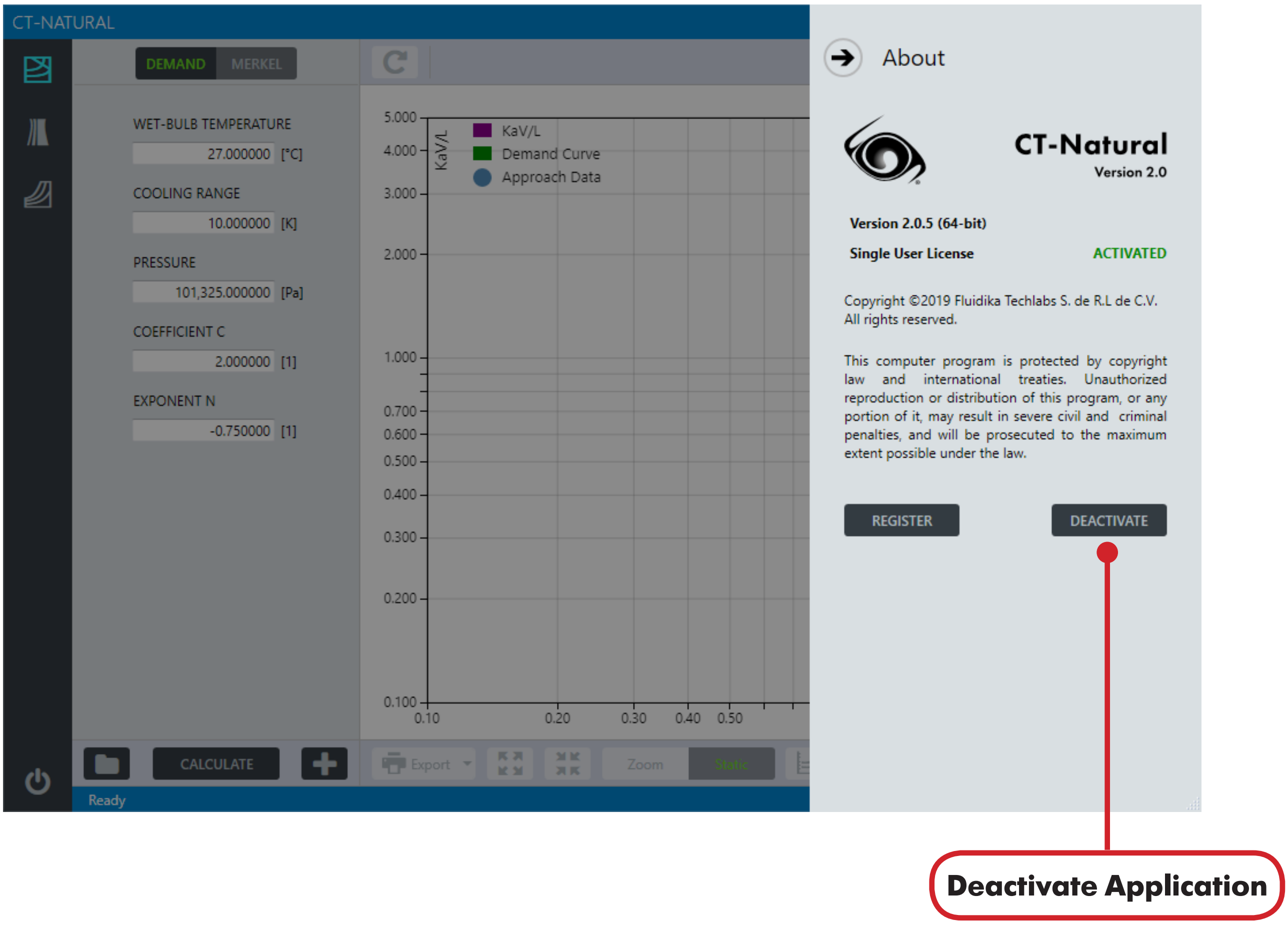


Figure 1.5 About screen of CT-Natural.

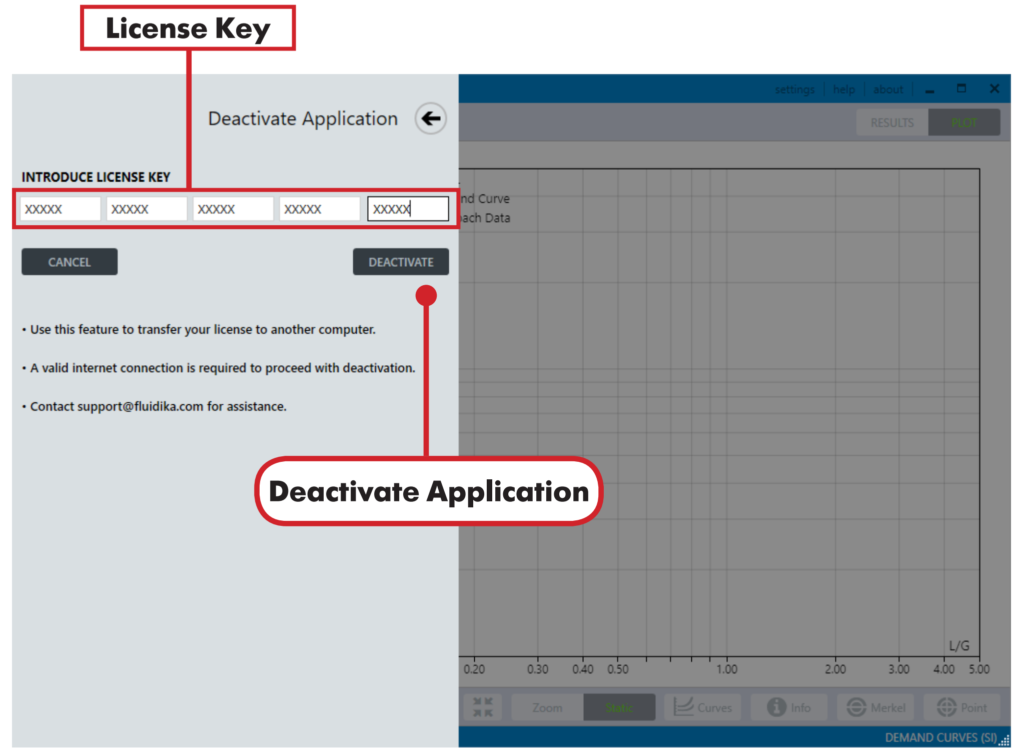


Figure 1.6 Deactivation screen of CT-Natural.

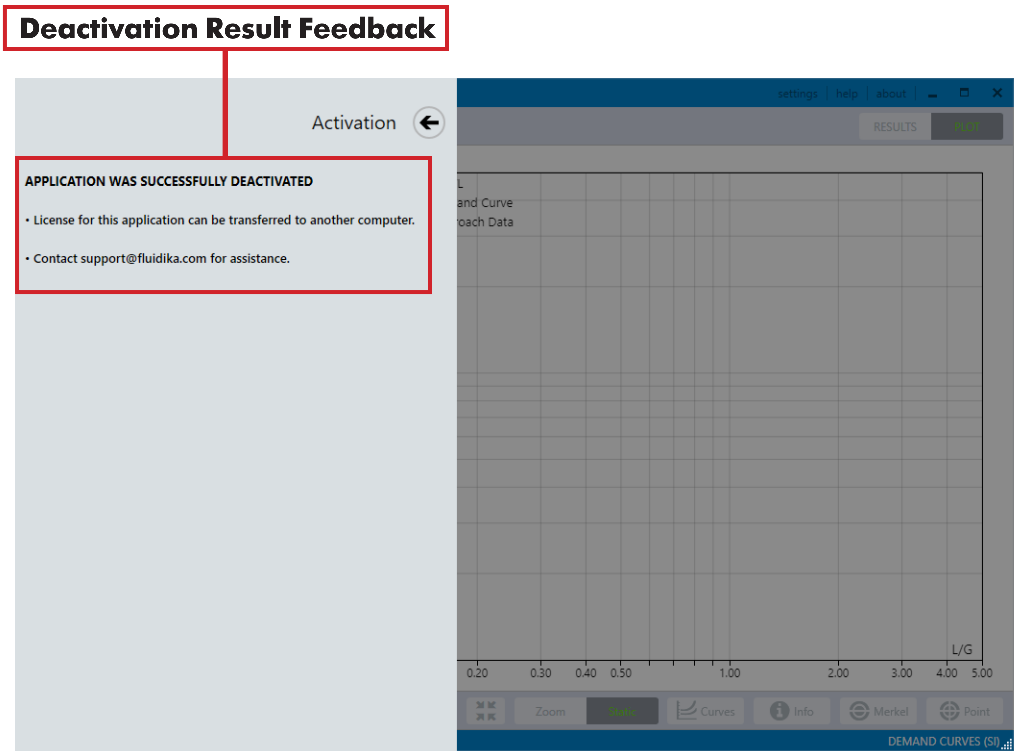


Figure 1.7 Deactivation result feedback screen.

Registration of this application is optional. Register in order to receive news about updates and other products related to **CT-Natural**. All your data is managed with the utmost confidentiality. Please review our privacy policy at *www.fluidika.com*. The procedure to register is as follows:

1. Click on the About button located on the upper right hand side of the application. This will bring the about screen of **CT-Natural** (Figure 1.8).
2. Click on the REGISTER button to start the registration process. The registration screen of **CT-Natural** appears on the left hand side of the application's window (Figure 1.9).
3. Introduce the registration fields, and then click on the SUBMIT button.
4. A message will be shown (Figure 1.10) displaying the result of the registration process.

Registration of this software requires direct access to the Internet. Make sure that you are not connected to a proxy and that your firewall or network is not configured to block access to the Internet.

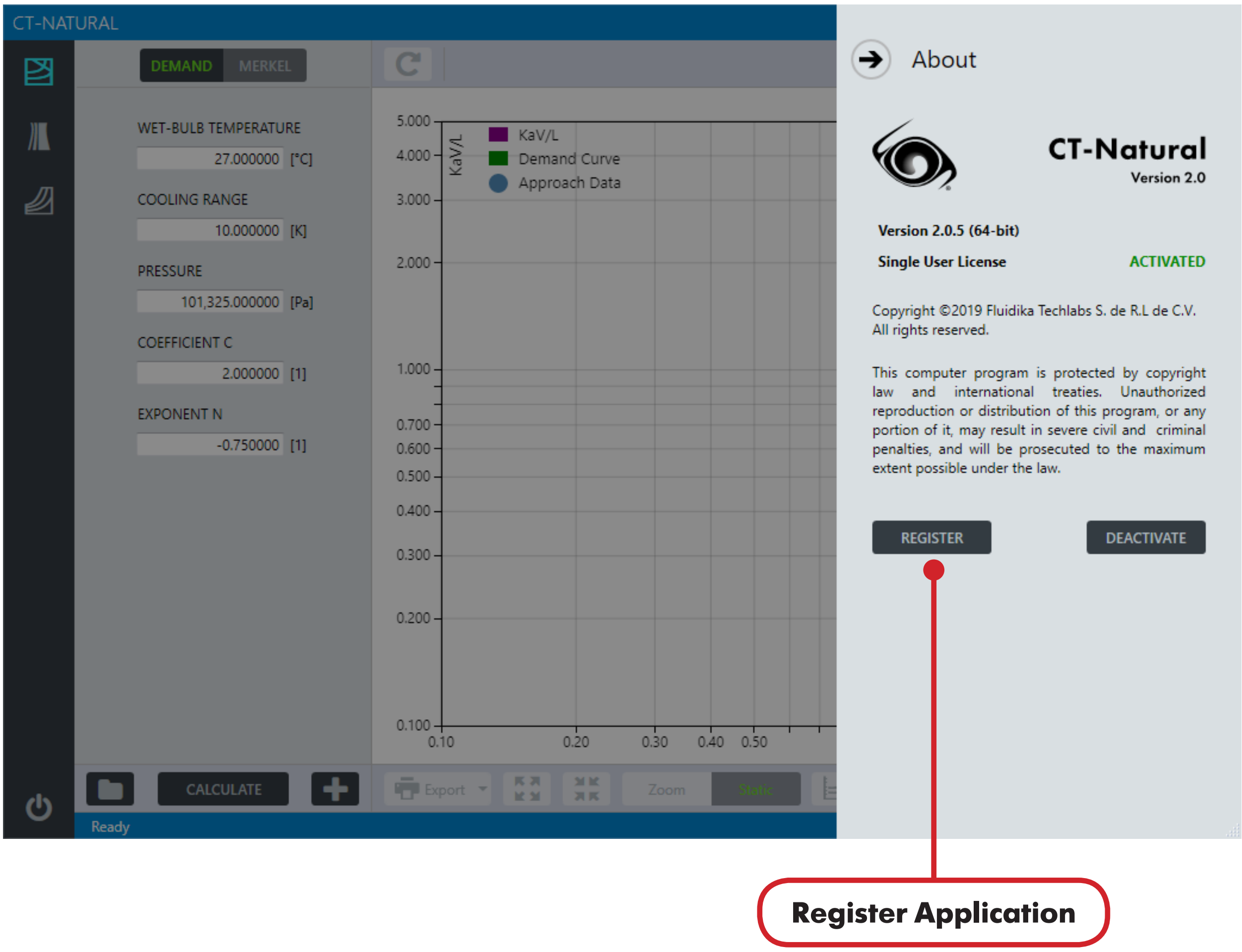


Figure 1.8 About screen of CT-Natural.

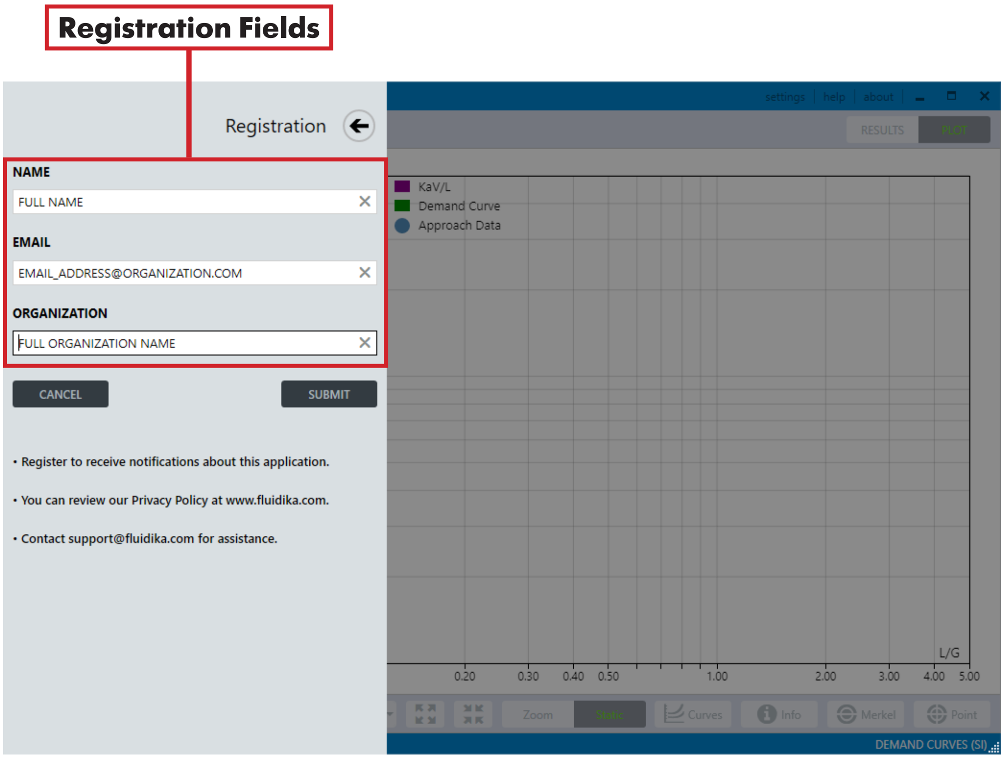


Figure 1.9 Registration screen of CT-Natural.

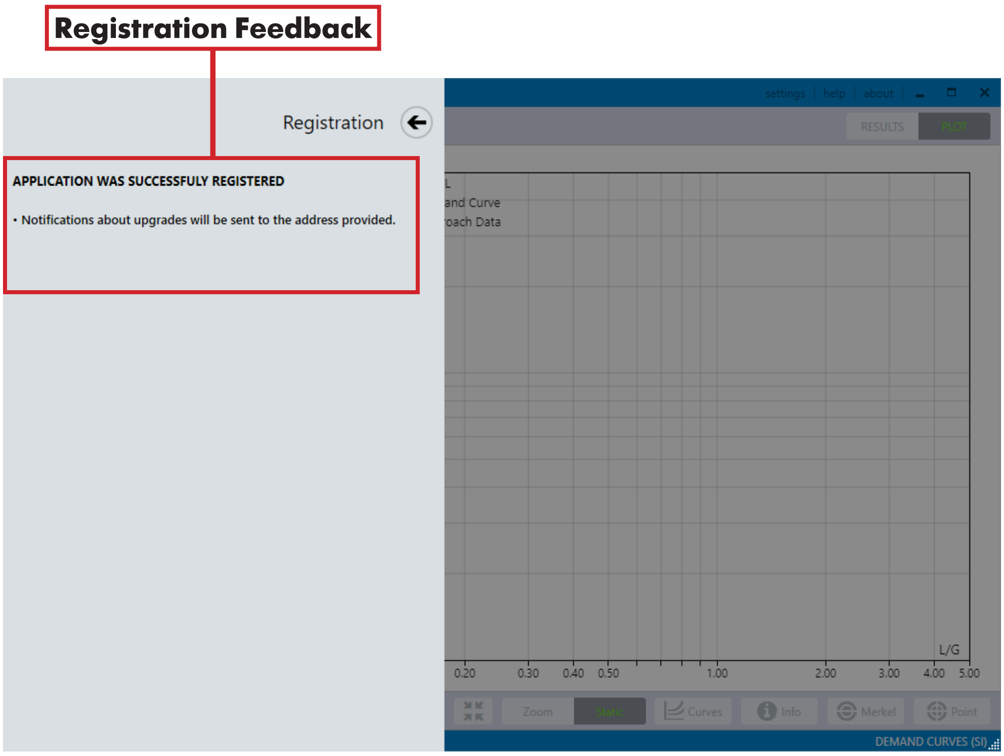


Figure 1.10 Registration feedback screen.

1.7 Upgrades

Information and the procedure about upgrades will be sent to the email address that was provided when the license for this software was acquired. If you would like to modify this information, please contact **support@fluidika.com** with your request.

1.8 Uninstalling the software

Software

To uninstall **CT-Natural**, double-click the installation file and follow the on-screen instructions, then choose the Remove button (Figure 1.11).

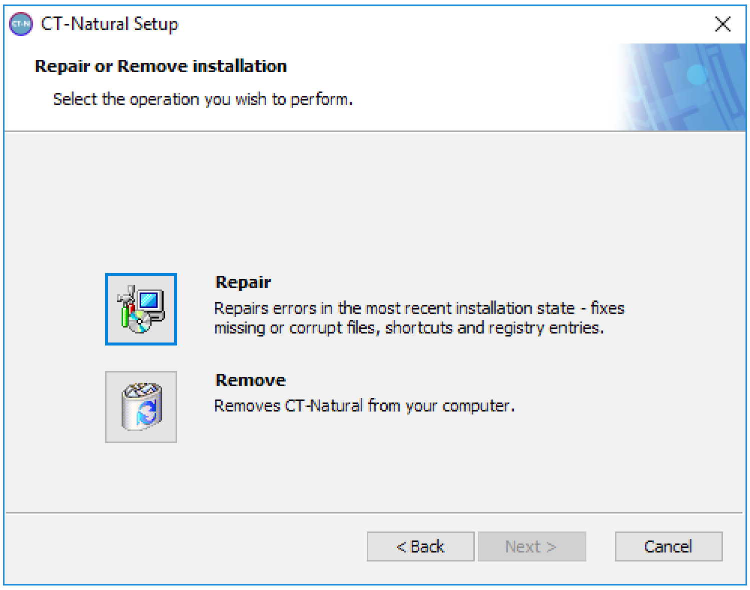


Figure 1.11 Uninstallation of CT-Natural.

It is also possible to uninstall **CT-Natural** using the standard windows uninstaller, usually located by navigating in your windows operating system:

Control Panel → *Programs* → *Programs and Features*

Select **CT-Natural** from the list of programs and click on the Uninstall button. This will remove the application from your operating system.

The Merkel Equation

An evaporative cooling tower is a device that is used to remove waste heat from the water used in an industrial process equipment or a machinery by rejecting that waste heat into the environment. When water is mixed with air in a cooling tower configuration, a heat transfer process takes places that involves a latent heat transfer due to the vaporization of a small amount of water and a sensible heat transfer reflecting the difference in temperatures of water and air.

Based on the theory developed by Merkel, the heat transfer process that occurs in a cooling tower by considering the enthalpy potential difference as the driving force is described by the Merkel equation:

$$\frac{KaV}{L} = \int_{T_2}^{T_1} \frac{c_{pw} dT_w}{h' - h} \qquad (1.1)$$

Where:

$\frac{KaV}{L}$ = Tower characteristic

T_1 = Hot water temperature (inlet)

T_2 = Cold water temperature (outlet)

h' = Enthalpy of saturated air at water temperature

h = Enthalpy of main air stream

c_{pw} = Specific heat capacity of water

dT_w = Temperature differential of water

For a specific tower packing, there is a characteristic curve in the form of a plot of tower characteristic, KaV/L, versus water to air flow ratio, L/G. This plot is described with an equation of the following form:

$$\frac{KaV}{L} = c\left(\frac{L}{G}\right)^{-n} \qquad (1.2)$$

Where L = water flow rate; G = airflow rate; c = constant defined for a particular packing design, or the intercept of the characteristic curve at $L/G = 1$; n = exponent related to packing design determined from test data.

The **Demand Curves** application solves the equation (1.1) numerically using the four-point Chebyshev numerical method employing the following models for the calculation of water and air properties:

Properties of Water and Steam

- Formulations from the IAPWS (International Association for the Properties of Water and Steam) IAPWS-IF97 Industrial formulation (Revision 2007) and related models.

Properties of Humid Air

- Thermodynamic and psychrometric property algorithms from the ASHRAE Research Project 1485.
- Scientific Formulation IAPWS-95, IAPWS Formulation 2008 and IAPWS Formulation 2006. Properties of dry air are from the NIST Reference equation of Lemmon et al.

Input Variables

Demand Curves allows to calculate and plot in a log-log graph isolines resulting from the integration of equation (1.1) using as a parameter an *approach* value. It also calculates the approach given a pair of values determined by KaV/L and L/G, in the SI and I-P system of units. The definition of input variables for the calculation of demand curves is given in Table 2.1.

Input Variable	Definition
WET-BULB TEMPERATURE	Temperature of air wet-bulb entering the cooling tower.
COOLING RANGE	Difference between hot water temperature and cold water temperature.
PRESSURE	Total pressure referred to atmospheric.
COEFFICIENT C	Constant defined for a particular packing design.
EXPONENT N	Exponent defined for a particular packing design.

Table 2.1 Definition of input variables for Demand Curves.

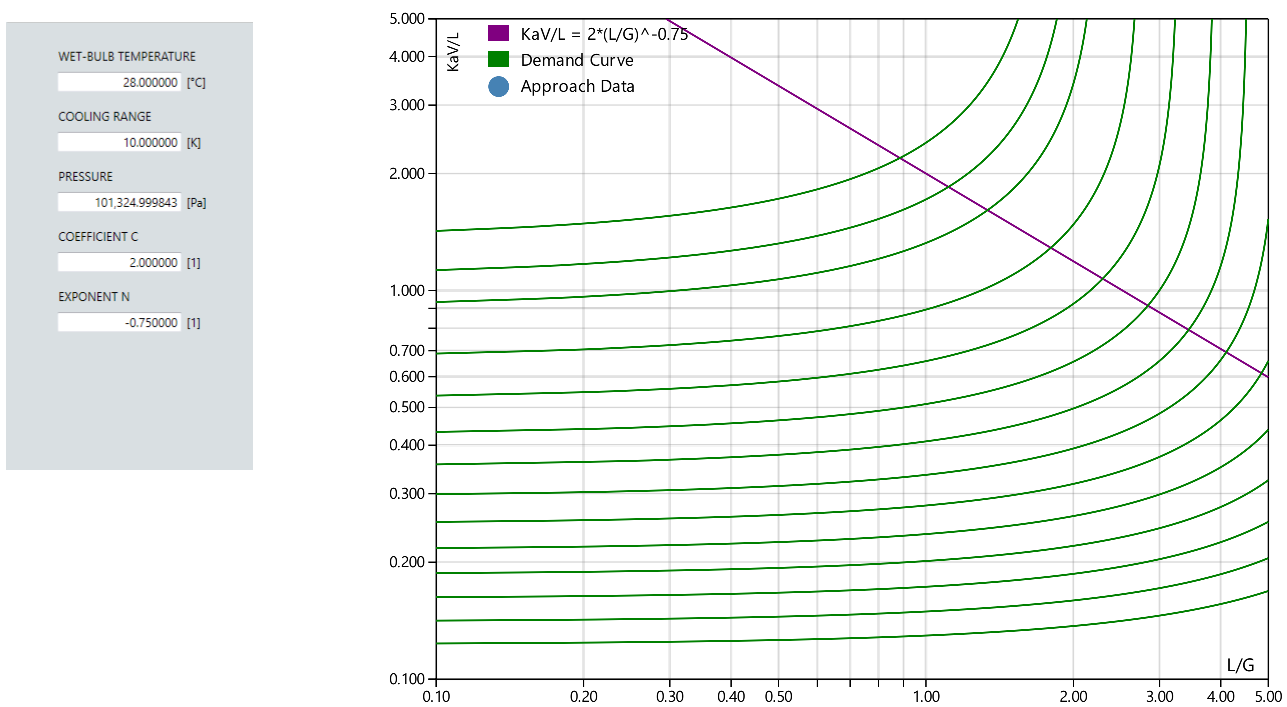


Figure 2.1 Example of input variables in the SI system of units (left).
Demand curves plotted for several values of approach given the input variables (right).

The ranges of values of input variables for the calculation projects of **Demand Curves** are shown in Table 2.2 for SI and I-P system of units.

Property	**Range in SI Units**	**SI Units**
WET-BULB TEMPERATURE	1.0 ⩽ T ⩽ 90.0	°C
COOLING RANGE	0.1 ⩽ Range ⩽ 90.0	K
PRESSURE	60000 ⩽ P ⩽ 110000	Pa
COEFFICIENT C	1.0 ⩽ C ⩽ 3.0	1
EXPONENT N	-2.0 ⩽ N ⩽ -0.1	1
KaV/L	0.1 ⩽ KaV/L ⩽ 5.0	1
L/G	0.1 ⩽ L/G ⩽ 5.0	1
Approach	1.0 ⩽ T ⩽ 60.0	°C

Property	**Range in I-P Units**	**I-P Units**
WET-BULB TEMPERATURE	33.8 ⩽ T ⩽ 194.0	°F
COOLING RANGE	0.1 ⩽ Range ⩽ 162.0	°F
PRESSURE	8.70226426 ⩽ P ⩽ 15.95415115	psia
COEFFICIENT C	1.0 ⩽ C ⩽ 3.0	1
EXPONENT N	-2.0 ⩽ N ⩽ -0.1	1
KaV/L	0.1 ⩽ KaV/L ⩽ 5.0	1
L/G	0.1 ⩽ L/G ⩽ 5.0	1
Approach	1.0 ⩽ Approach ⩽ 140.0	°F

Table 2.2 Full Ranges of input variables for Demand Curves.

Certain limitations are imposed for each project in order to improve the graphical performance on **Demand curves** calculations. These are described in Table 2.3. The number of projects is limited just by the memory available on the computer on which **CT-Natural** is installed.

	Number of Items per Project
Demand Curves	100
Approach Data Points	100

Table 2.3 Limitations on calculation projects of Demand Curves.

The ranges of values for input variables in calculation projects of the Evaluation Version of **Demand Curves** are shown in Table 2.4.

Property	Range in SI Units	SI Units
WET-BULB TEMPERATURE	25.0 ⩽ T ⩽ 28.0	°C
COOLING RANGE	0.1 ⩽ Range ⩽ 90.0	K
PRESSURE	99000 ⩽ P ⩽ 102000	Pa
COEFFICIENT C	2.0 ⩽ C ⩽ 2.1	1
EXPONENT N	-2.0 ⩽ N ⩽ -0.1	1
KaV/L	0.1 ⩽ KaV/L ⩽ 5.0	1
L/G	0.1 ⩽ L/G ⩽ 5.0	1
Approach	1.0 ⩽ T ⩽ 60.0	°C

Property	Range in I-P Units	I-P Units
WET-BULB TEMPERATURE	77.0 ⩽ T ⩽ 82.4	°F
COOLING RANGE	0.1 ⩽ Range ⩽ 162.0	°F
PRESSURE	14.358736 ⩽ P ⩽ 14.793849	psia
COEFFICIENT C	2.0 ⩽ C ⩽ 2.1	1
EXPONENT N	-2.0 ⩽ N ⩽ -0.1	1
KaV/L	0.1 ⩽ KaV/L ⩽ 5.0	1
L/G	0.1 ⩽ L/G ⩽ 5.0	1
Approach	1.0 ⩽ Approach ⩽ 140.0	°F

Table 2.4 Ranges of input variables for Demand Curves (Evaluation Version).

Certain limitations are imposed for each project in order to improve the graphical performance of **Demand Curves** (Evaluation Version) calculations. These are described in Table 2. 5.

Maximum Number of Projects	3

	Number of Items per Project
Demand Curves	15
Approach Data Points	3

Table 2.5 Limitations on calculation projects of Demand Curves (Evaluation Version).

2.4 Graphical User Interface

The Graphical User Interface for **Demand Curves** is shown in Figure 2.2. By selecting the button denoted Demand Curves on the left side of the application, the user is presented with the interface.

Select the denoted DEMAND button selector to display the Demand Curves main interface.

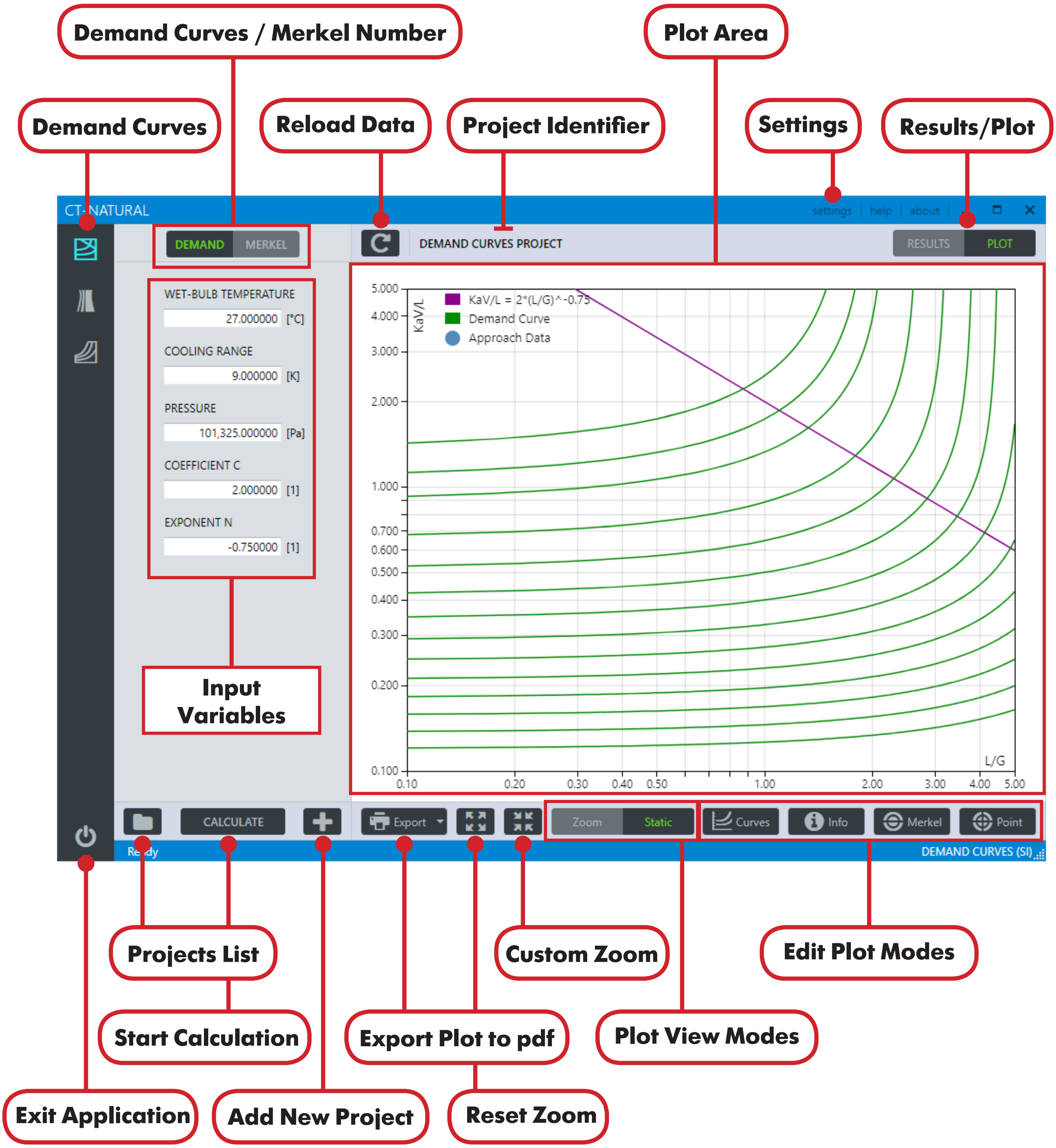


Figure 2.2 Graphical User Interface of Demand Curves.

Add Calculation Project

1. Click on the Add New Project button to add a new project (Figure 2.3). Enter the identifier for the project and click the button OK. The project will be created in the database and the application will be ready for a new numerical calculation.
2. Click on the Settings button located on the upper right-hand side of the application to select the units used for this particular project, as well as the demand curves that will be calculated and plotted (Figure 2.4). Changes are preserved for any new projects being added. Click on the APPLY button in order to save the selections.
3. Introduce the input variables for the calculation (Figure 2.5).
4. Click on the CALCULATE button to start the calculations.

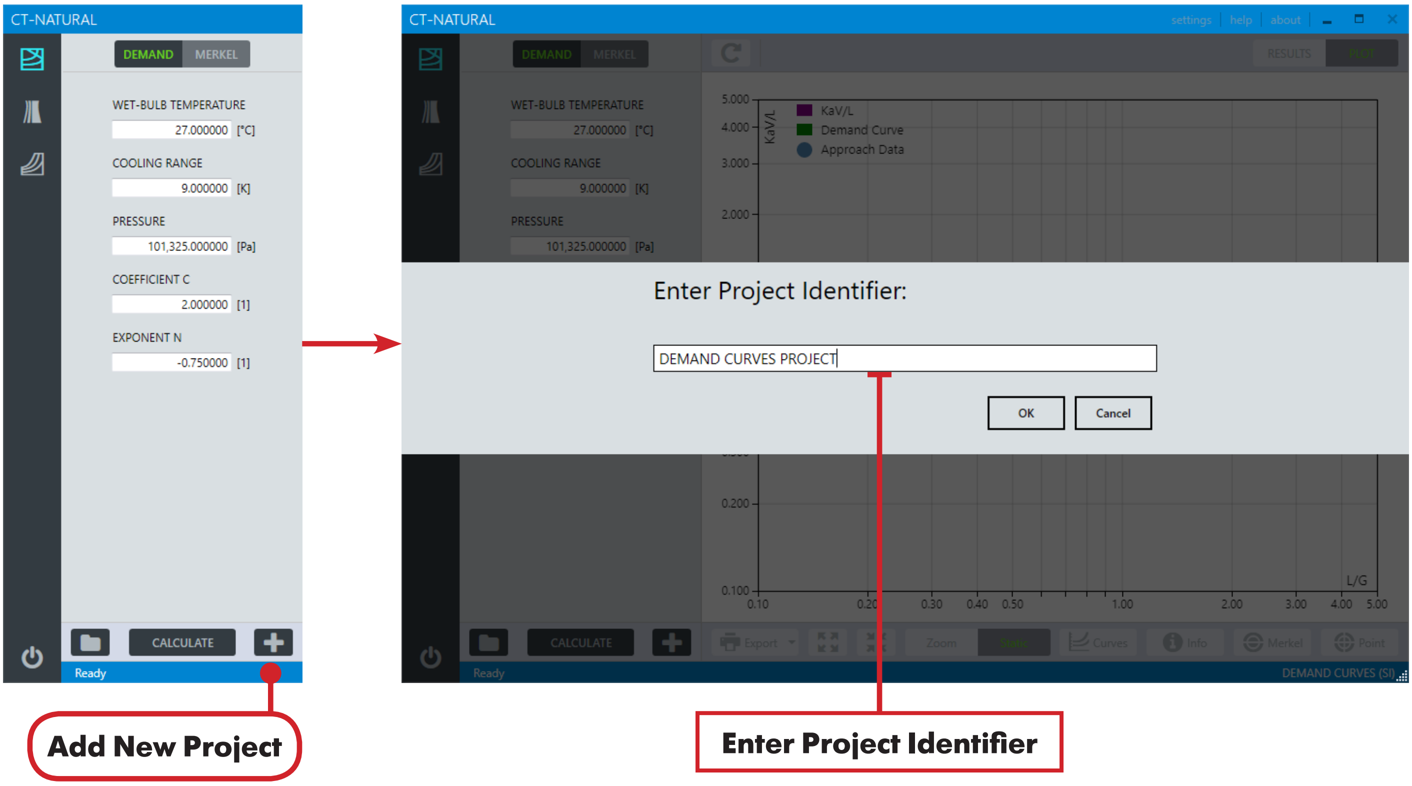


Figure 2.3 Adding a new calculation project in Demand Curves.

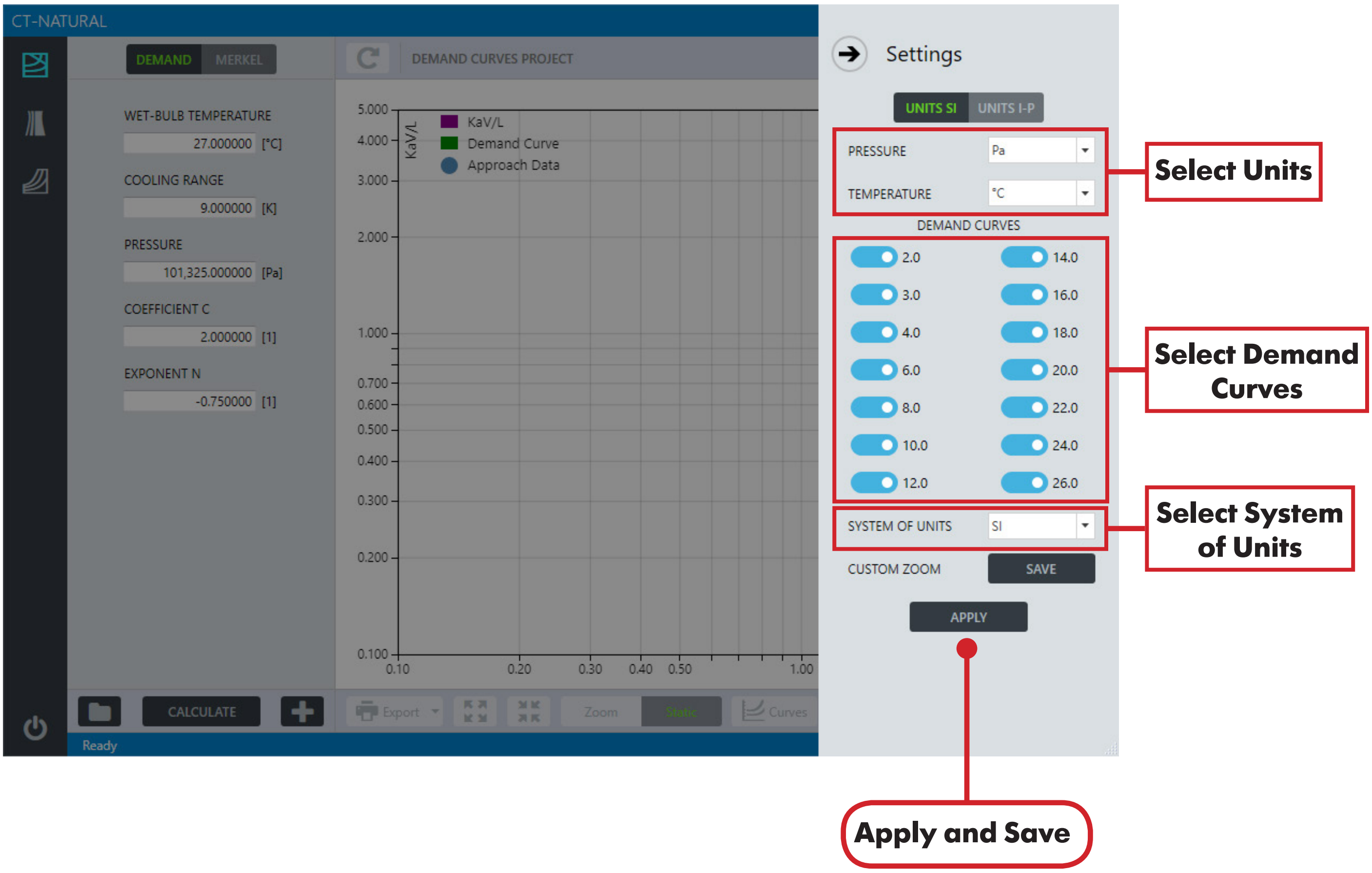


Figure 2.4 Settings for calculation projects in Demand Curves.

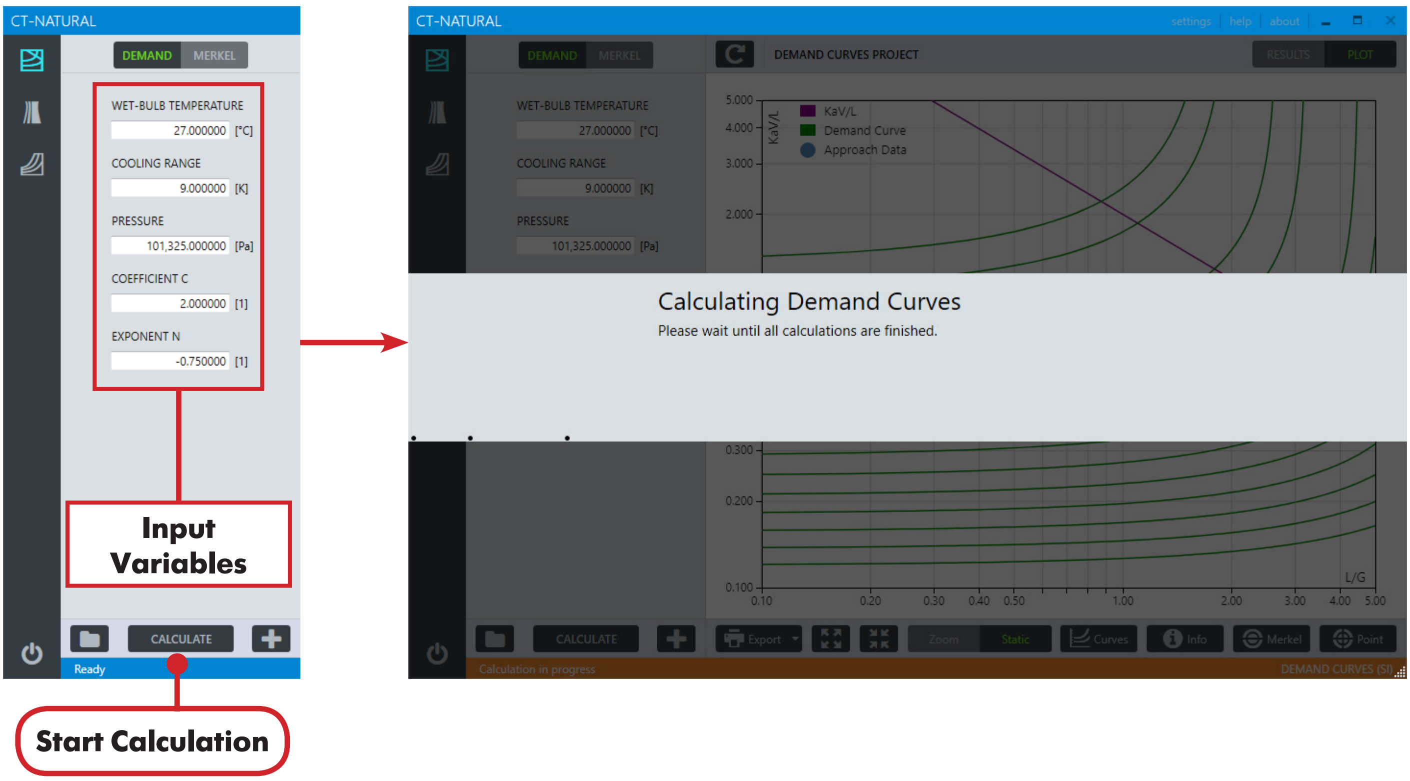


Figure 2.5 Entering input values for a calculation project in Demand Curves.

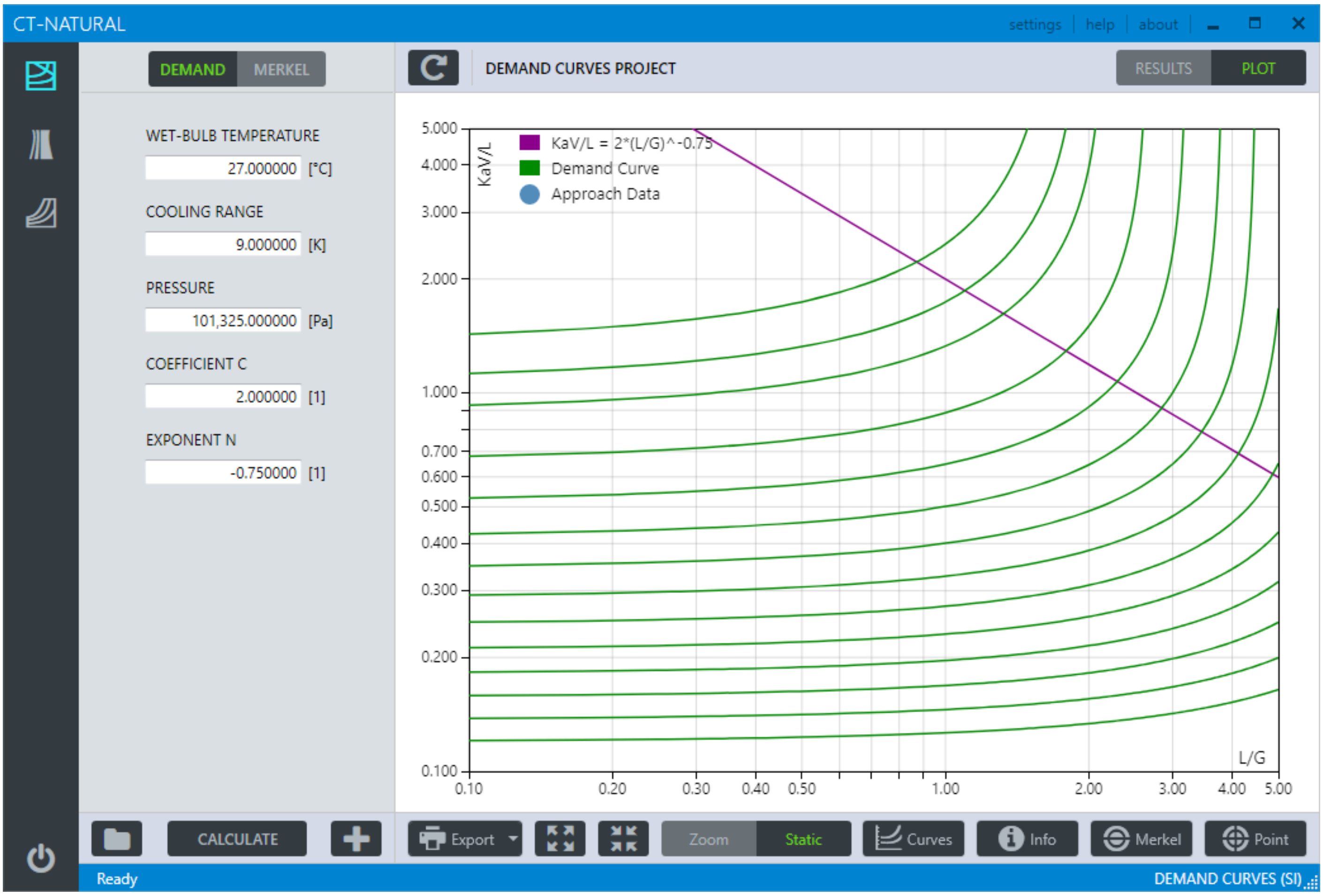


Figure 2.6 Plot Area of Demand Curves after calculations are completed.

Load Project from Database

1. Click on the Projects List button to load all the projects saved in the database.
2. Click on the Details button of a particular project to show the detailed input variables that were saved for that project.
3. After selecting the project, click on the Load Project button to load all the curves and data calculations for the selected project. The project is ready to add approach data points or demand curves.

Delete Project from Database

1. Click on the Projects List button to load all the projects saved in the database (Figure 2.7).
2. Click on the checkbox of a particular project to enable its deletion. Any number of projects can be selected. Click on the Delete Project button to delete the project(s) from the database and the plot area. By deleting a project, all the demand curves and points that belong to that project will also be deleted.
3. By clicking on the Select Projects button, all the projects are checked/unchecked.
4. Click on the Exit Projects Lists button to return to the project main interface.

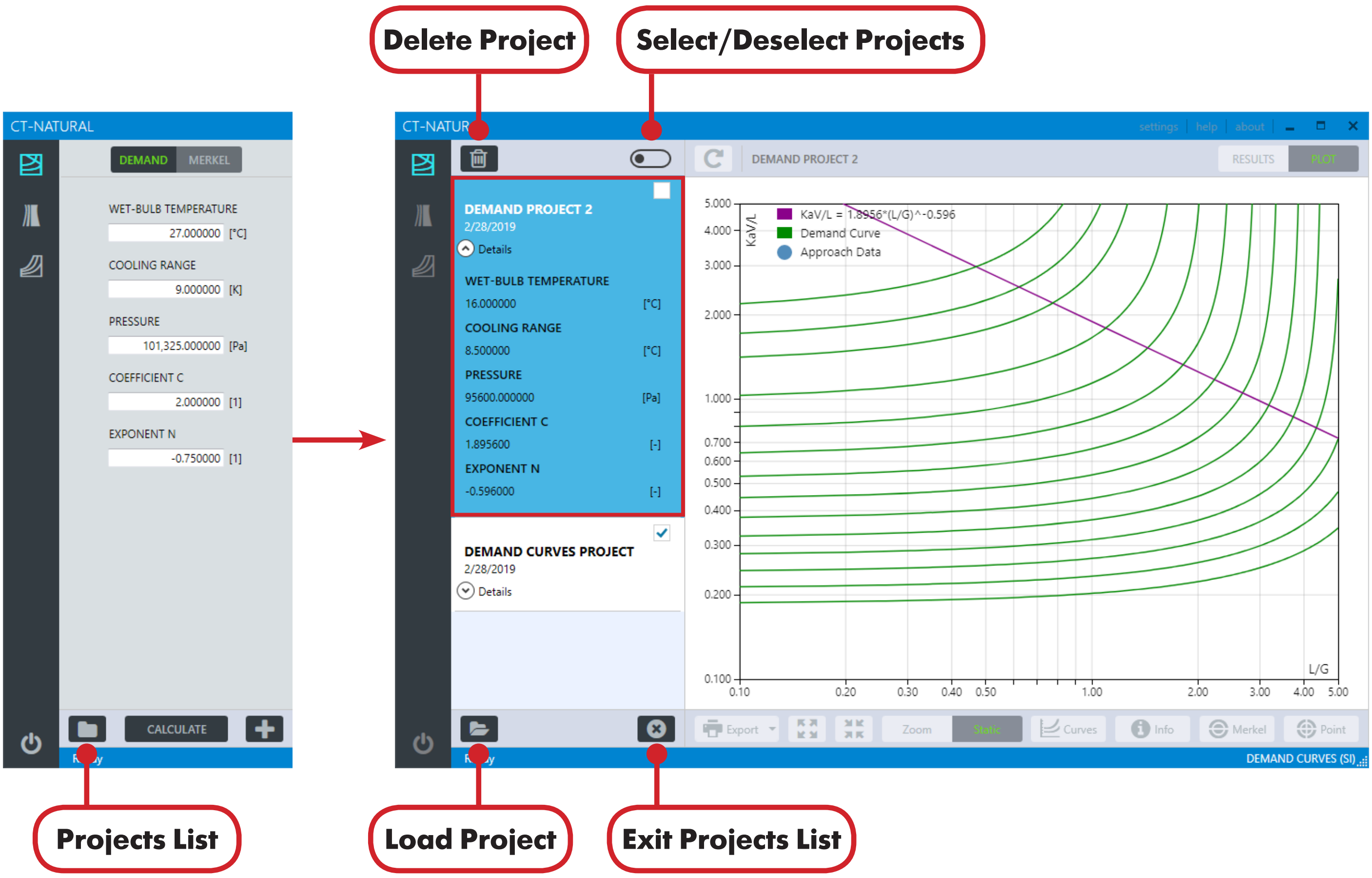


Figure 2.7 List of calculation projects of Demand Curves.

Validating Input Variables

All input variables in the SI or I-P system of units are bounded by the ranges described in Table 2.2. When input variables are introduced that are out of these ranges, and a new calculation project is attempted by clicking on the CALCULATE button, the application will first check that all variables are within their range, and if any variable does not satisfy the range condition it will prevent the application from continuing.

A message is displayed specifying the variables that do not satisfy this condition, showing the correct range of variables that must be entered for the calculation to proceed (Figure 2.8).

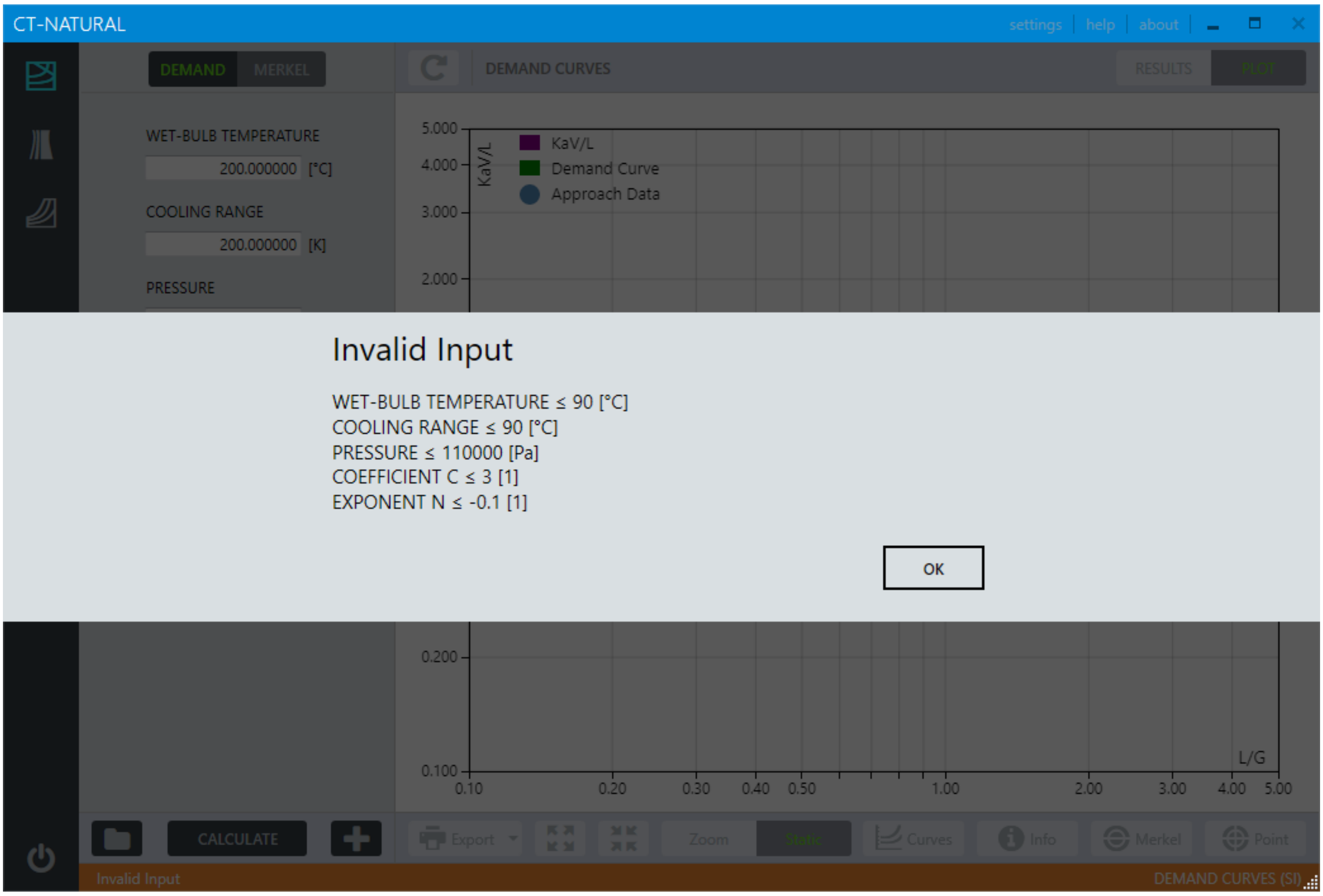


Figure 2.8 Message displaying the correct range of variables for a calculation project in Demand Curves.

Add Approach Data Point to a Project

1. Click on the Point button to start the Graphical Mode (Figure 2.9). Left-click the button on the centre of the crosshairs to drag it to your desired location, or introduce the coordinates on the KaV/L or L/G buttons to move the crosshairs to a precise value. The location on the Plot Area will be used as the value of both KaV/L and L/G to calculate the approach.
2. Click on the Calculate button over the plot area to start the calculation of the approach data point.
3. Once the calculation has finished, the numerical results will be shown on the left side of the Plot Area. To add the point to the Plot Area and save it to the database, click on the Add Point to database button. Enter an identifier for the point (optional) and click OK (Figure 2.10).
4. To exit the Graphical Mode, click on the Point button.

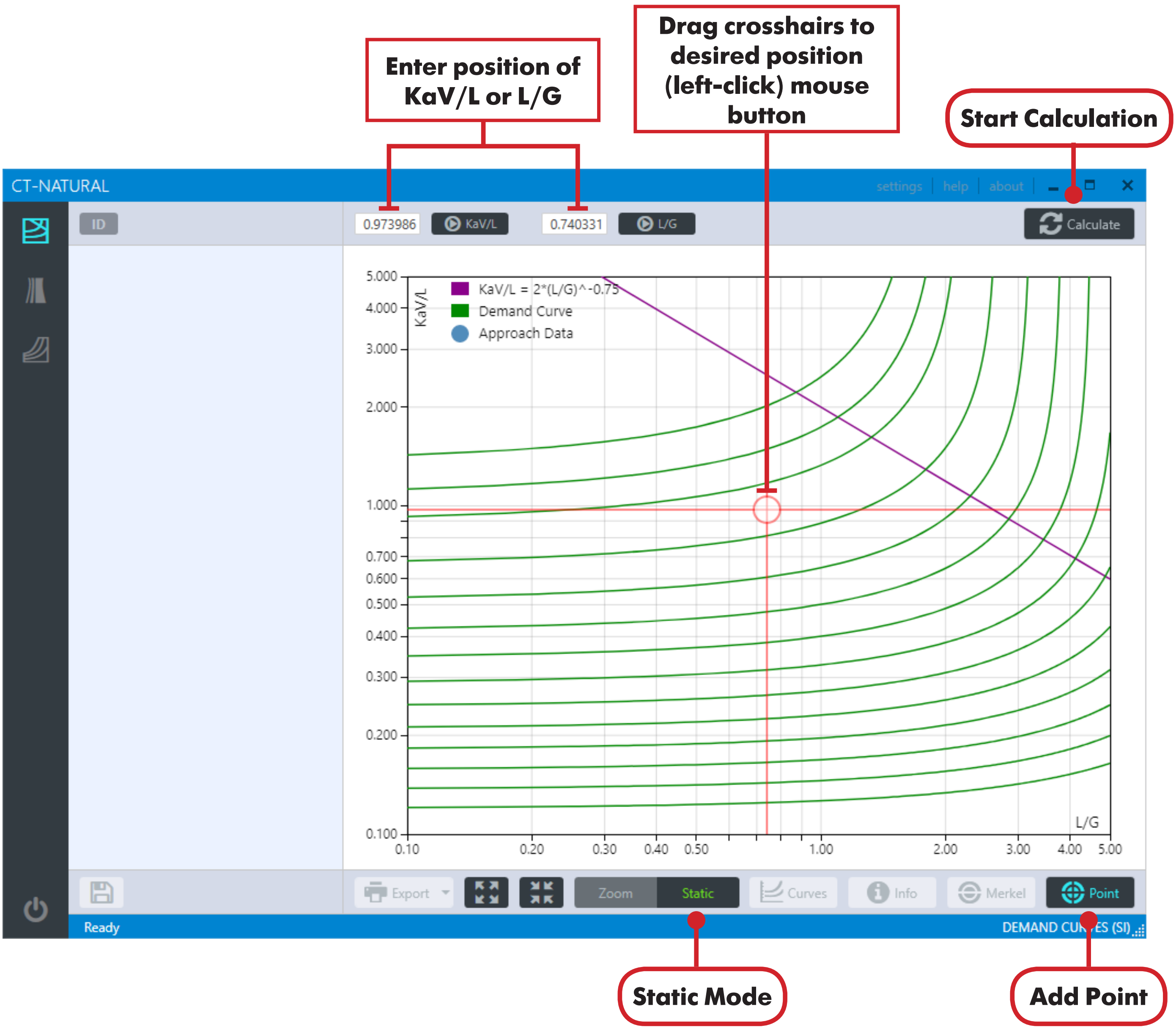


Figure 2.9 Graphical Mode - Adding an approach point to a calculation project in Demand Curves.

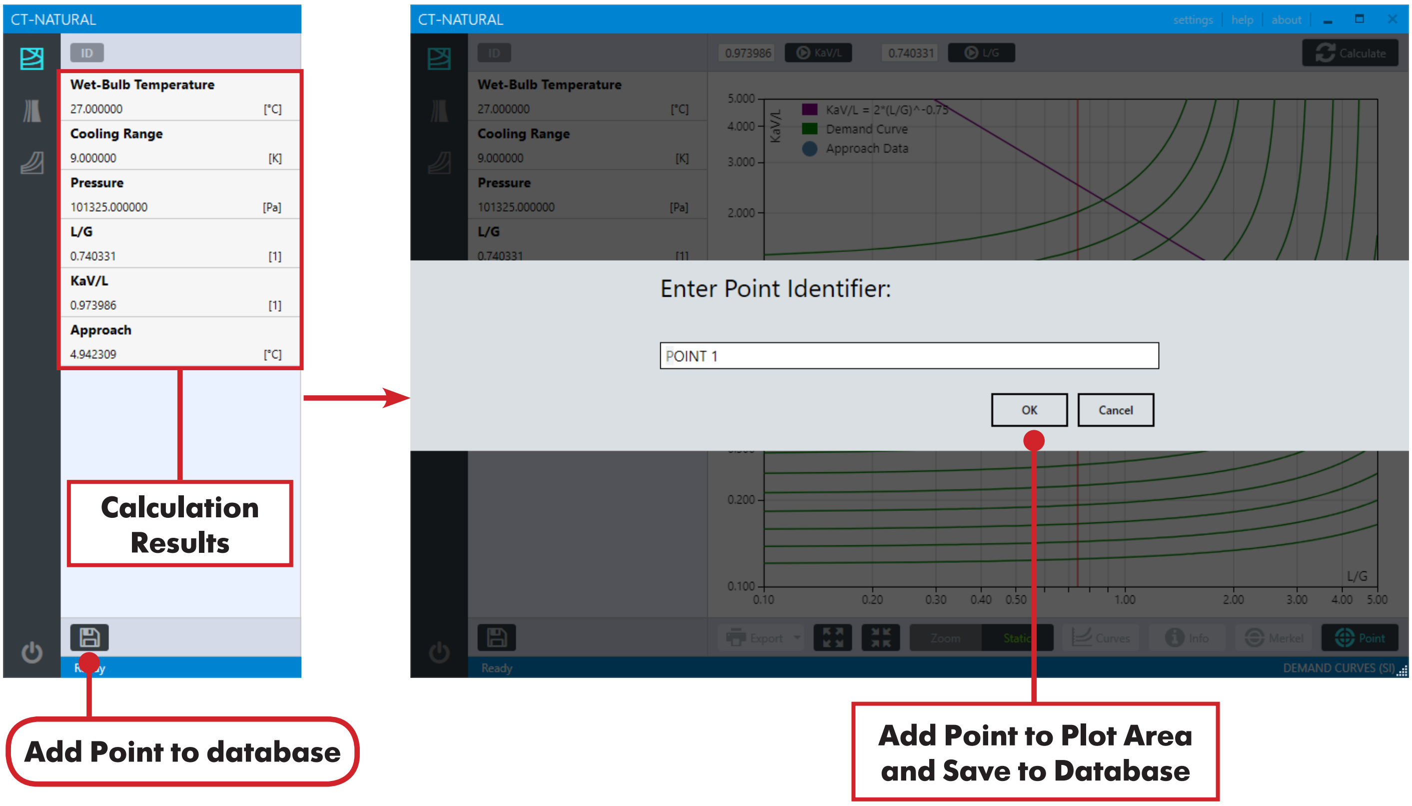


Figure 2.10 Adding an approach data point to the Plot Area and saving it to the database in Demand Curves.

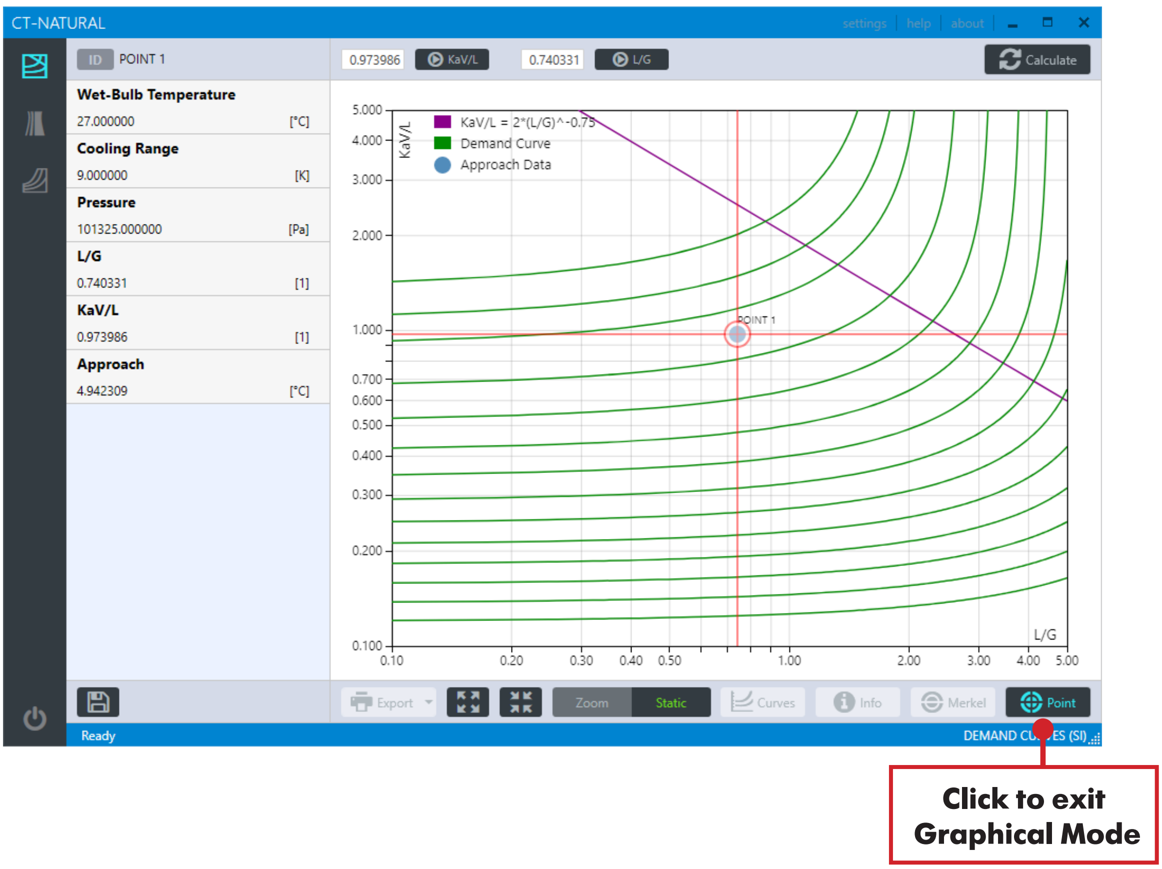


Figure 2.11 Approach data point added to the Plot Area of Demand Curves.

Add Approach Data Point on KaV/L line

1. Click on the Merkel button to start the Graphical Mode (Figure 2.12). Select the Curve switch next to the Calculate button to calculate and plot the demand curve that results from the calculation. Left-click the button on the centre of the crosshairs to drag it to your desired location on the KaV/L line, or introduce the coordinates on the KaV/L or L/G buttons to move the crosshairs to some precise value. The coordinate position of the crosshairs is restricted to satisfy the Merkel (KaV/L) equation. The location on the Plot Area will be used as the value of both KaV/L and L/G to calculate the approach.
2. Click on the Calculate button over the plot area to start the calculation of the approach data point.
3. Once the calculation has finished, the numerical results will be shown on the left side of the Plot Area. To add the point to the Plot Area and save it to the database, click on the Add Point to database button. Enter an identifier for the point (optional) and click OK.
4. To exit the Graphical Mode, click on the Merkel button.

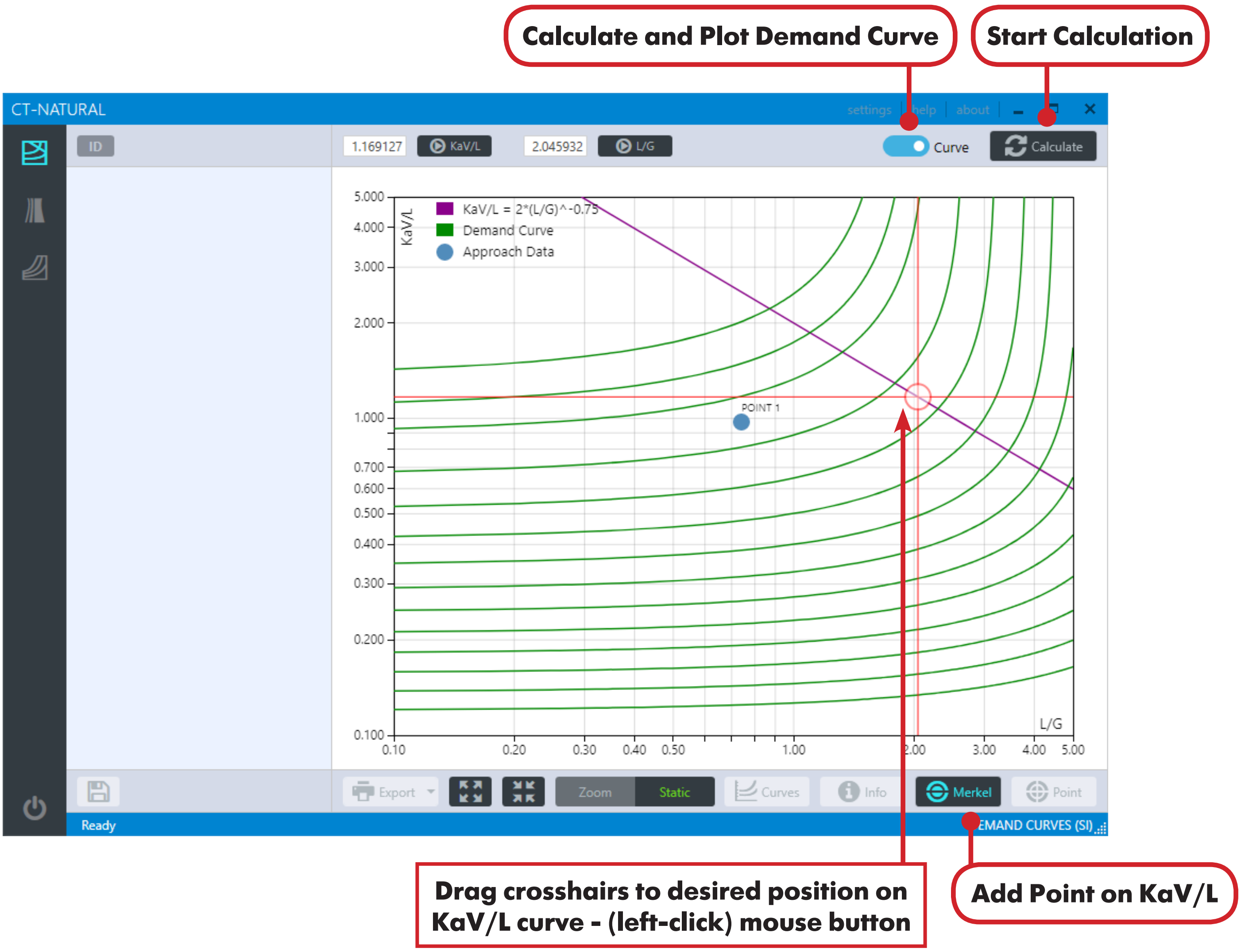


Figure 2.12 Adding an approach data point and demand curve on the KaV/L line.

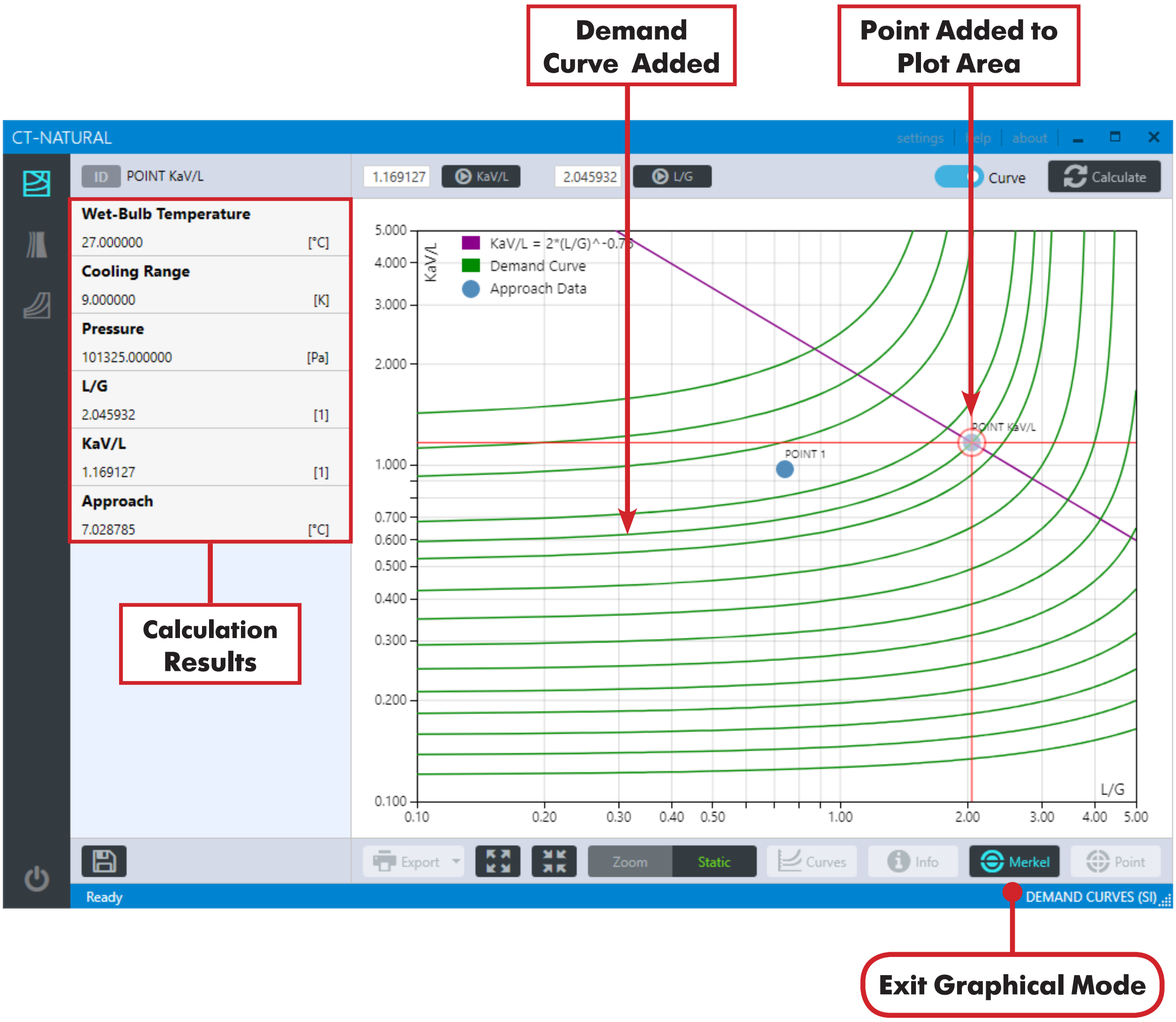


Figure 2.13 Approach data point and demand curve calculated on the KaV/L line and saved to the database.

Load Approach Data Point Results

1. Click on the Info button to start the Graphical Mode. To allow the selection of data points on the Plot Area, select the Static mode of the plot view mode selector (Figure 2.14).
2. Click on a point (left-click mouse button) to select it. The crosshairs will be positioned on it, indicating that is selected. Click on the Point button to load the numerical results calculated for the selected point. These results will be displayed on the left side of the Plot Area.
3. To exit the Graphical Mode, click on the Info button.

Delete Approach Data Points

1. Once an approach data point has been selected and its numerical results loaded from the database, click on the Delete Point button to remove the point from the Plot Area and to delete it from the database.

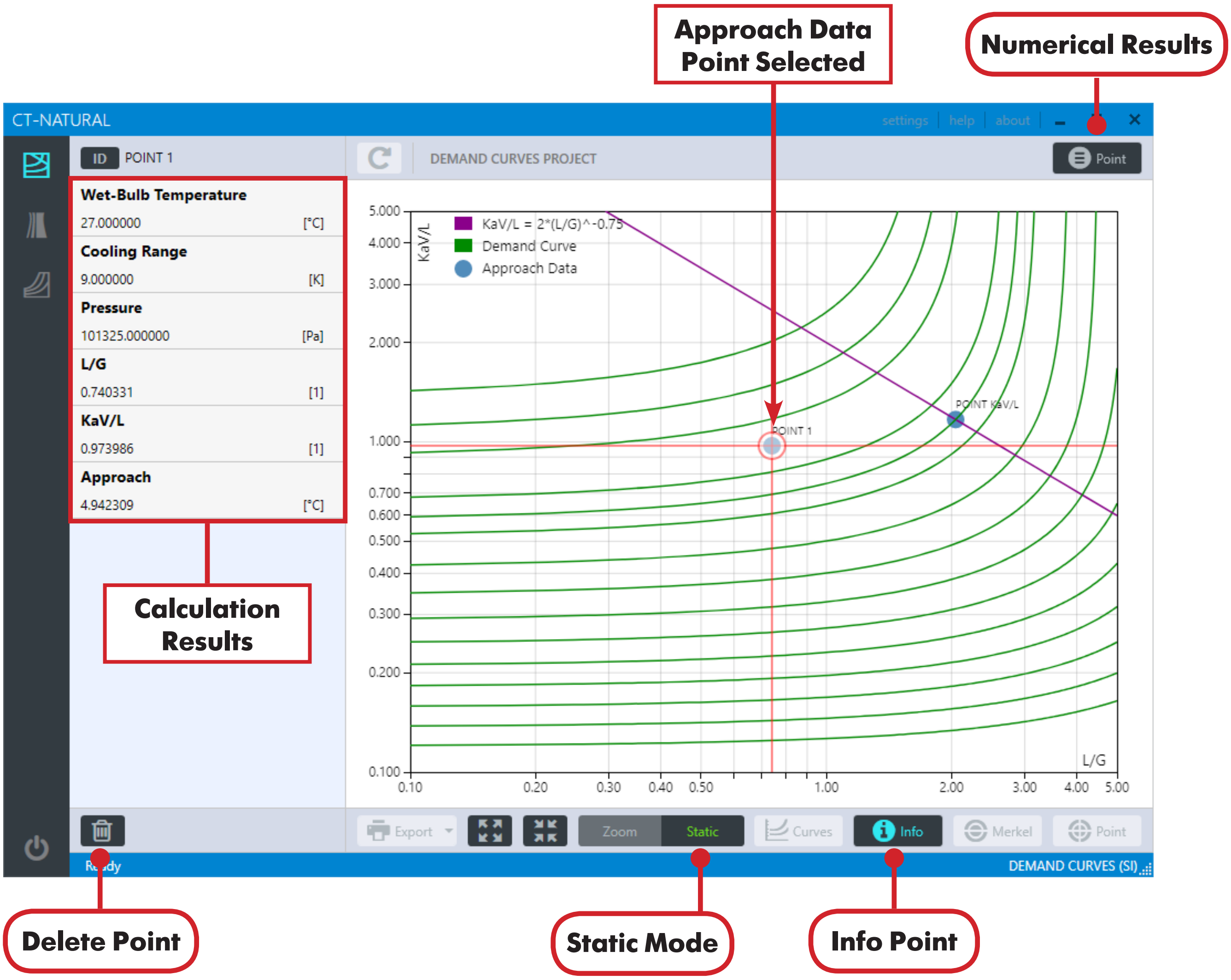


Figure 2.14 Numerical results from individual approach points of Demand Curves.

Get Numerical Results from a Project

1. Click on the RESULTS button to load all the approach points calculations for a particular project.
2. Click on the PLOT button to return to the Plot Area (Figure 2.15).

Export Numerical Results

1. Click on the Export Results button to export the numerical calculation results of the approach points of a particular project. These can be exported to excel / pdf formats (Figures 2.16, 2.17).

Figure 2.15 Numerical results from all approach points in a project of Demand Curves.

PROJECT ID	DEMAND CURVES PROJECT	UNITS: SI
COEFFICIENT C	2	[1]
EXPONENT N	-0.75	[1]
IDENTIFIER	POINT 1	
Wet-Bulb Temperature	27.000000	[°C]
Cooling Range	9.000000	[K]
Pressure	101325.000000	[Pa]
L/G	0.740331	[1]
KaV/L	0.973986	[1]
Approach	4.942309	[°C]
IDENTIFIER	POINT KaV/L	
Wet-Bulb Temperature	27.000000	[°C]
Cooling Range	9.000000	[K]
Pressure	101325.000000	[Pa]
L/G	2.045932	[1]
KaV/L	1.169127	[1]
Approach	7.028785	[°C]

Figure 2.16 Numerical results from approach points in a project of Demand Curves (pdf file).

DEMAND_CURVES_RESULTS.xlsx - Excel

	A	B	C
1	PROJECT ID	DEMAND CURVES PROJECT	UNITS: SI
2	COEFFICIENT C	2	[1]
3	EXPONENT N	-0.75	[1]
4			
5	IDENTIFIER	POINT 1	
6	Wet-Bulb Temperature	27.000000	[°C]
7	Cooling Range	9.000000	[K]
8	Pressure	101325.000000	[Pa]
9	L/G	0.740331	[1]
10	KaV/L	0.973986	[1]
11	Approach	4.942309	[°C]
12			
13	IDENTIFIER	POINT KaV/L	
14	Wet-Bulb Temperature	27.000000	[°C]
15	Cooling Range	9.000000	[K]
16	Pressure	101325.000000	[Pa]
17	L/G	2.045932	[1]
18	KaV/L	1.169127	[1]
19	Approach	7.028785	[°C]
20			

Sheet1

Figure 2.17 Numerical results from approach points in a project of Demand Curves (excel file).

Select Demand Curve in the Plot Area

1. Click on the Curves button to show a list of all the approach values that correspond to the demand curves on the Plot Area (Figure 2.18).
2. Click on a particular curve in the demand curve´s list to select it on the Plot Area (the selected demand curve will change its color to red).
3. Click on the Curves button to return to the Plot Area.

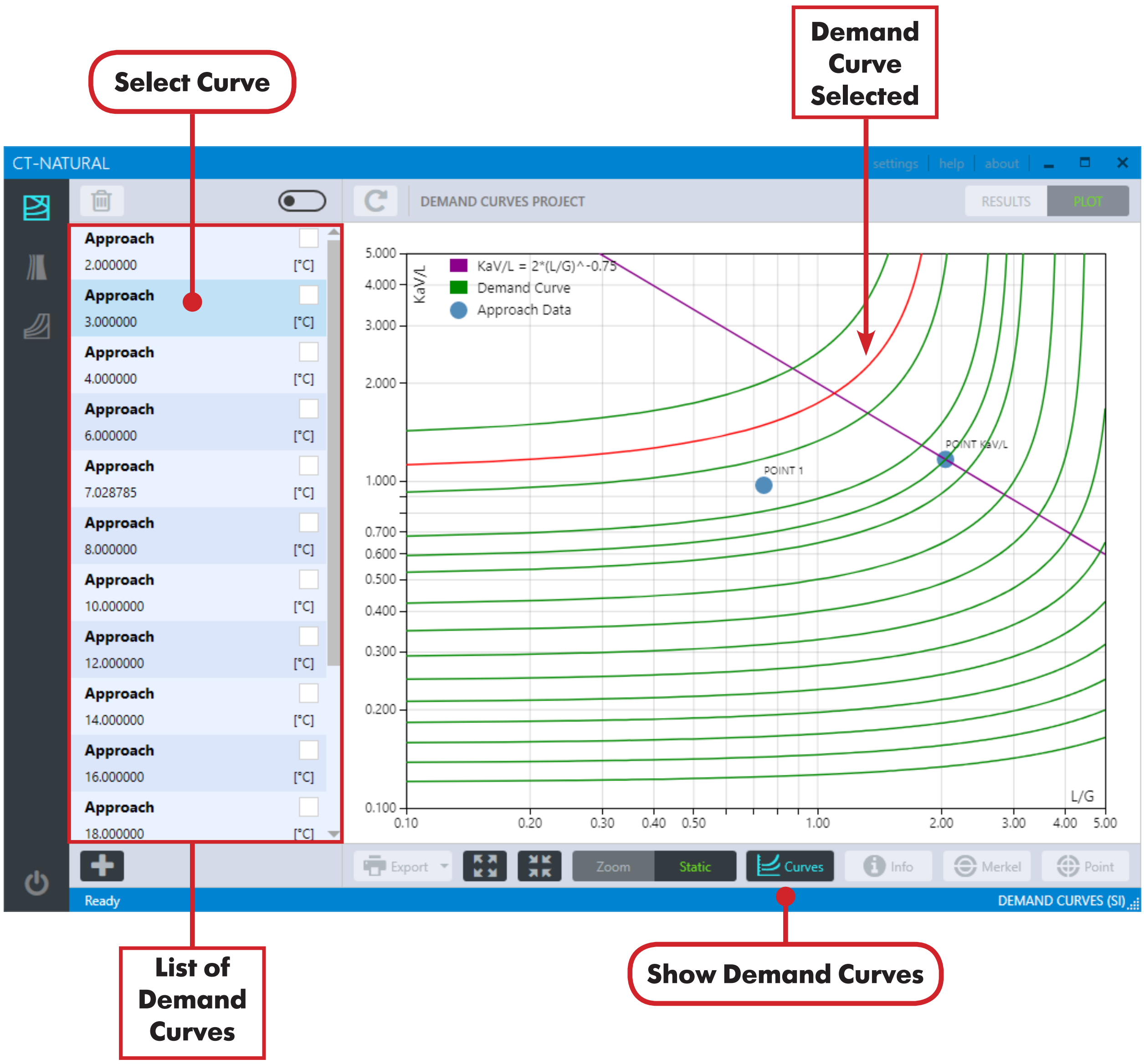


Figure 2.18 Selection of demand curves.

Add Demand Curve

1. Click on the Add Curve button to introduce the value for a new demand curve (Figure 2.19).
2. Click on the OK button to start the calculation for the new demand curve. Once the curve has been calculated, it will be saved to the database for that project.

Delete Demand Curve

1. Select the demand curve(s) by checking on the checkbox. Click on the Select Curves button to select/deselect all demand curves.
2. Click on the Delete Curve button to remove the demand curve(s) from the Plot Area and to delete it(them) from the database.

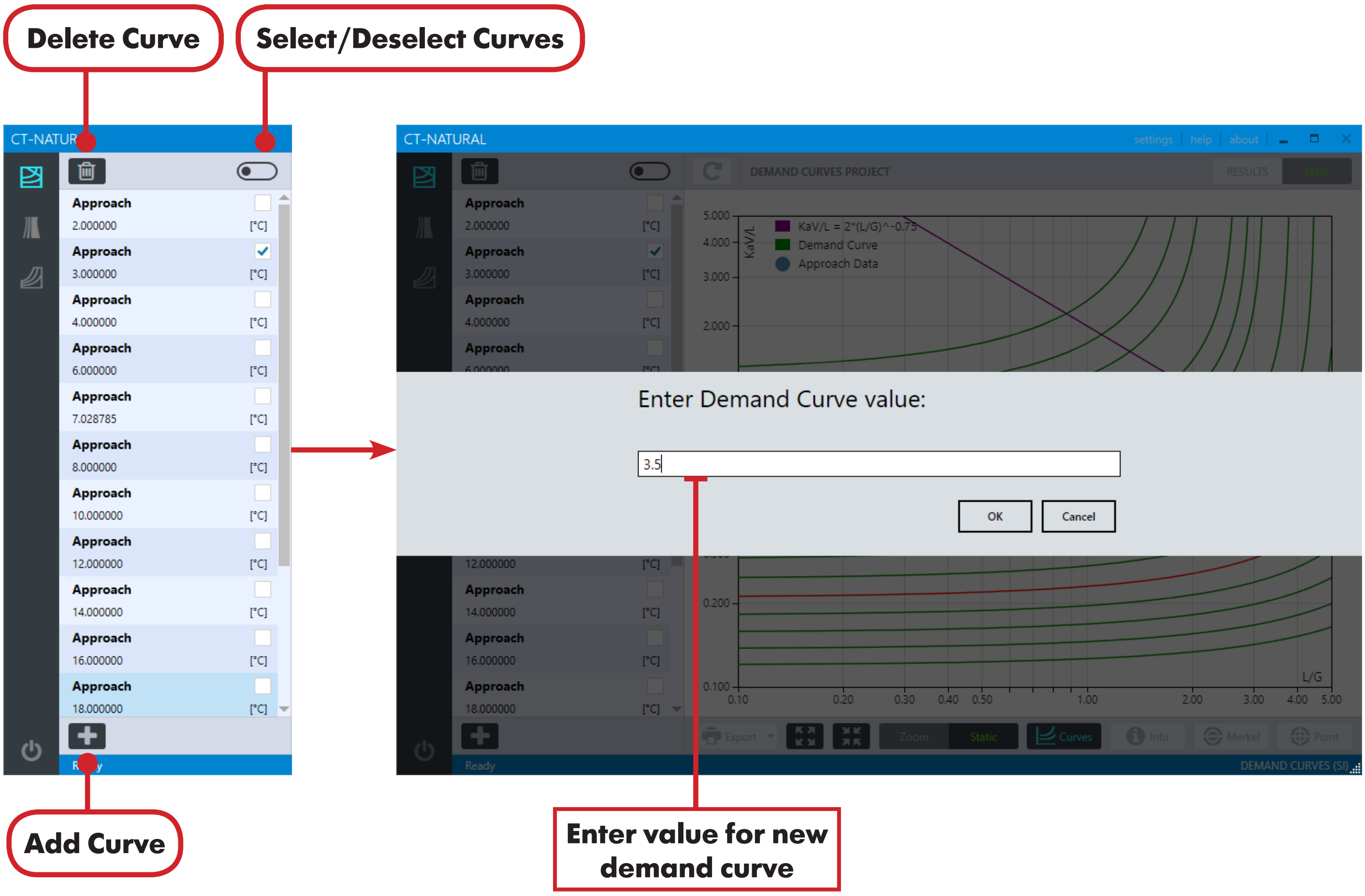


Figure 2.19 Add/Delete a demand curve in a calculation project.

Zoom Plot Area

1. Select the Zoom Mode of the Plot View Mode selector (Figure 2.20).
2. Push the left-click button on the mouse and drag it to select a zoom rectangle around the area of interest.
3. To reset the zoom to default values, click on the Reset Zoom button.

Export the Plot Area to a pdf file

1. Click on the Export Plot to pdf button to export the current Plot Area to a pdf file.

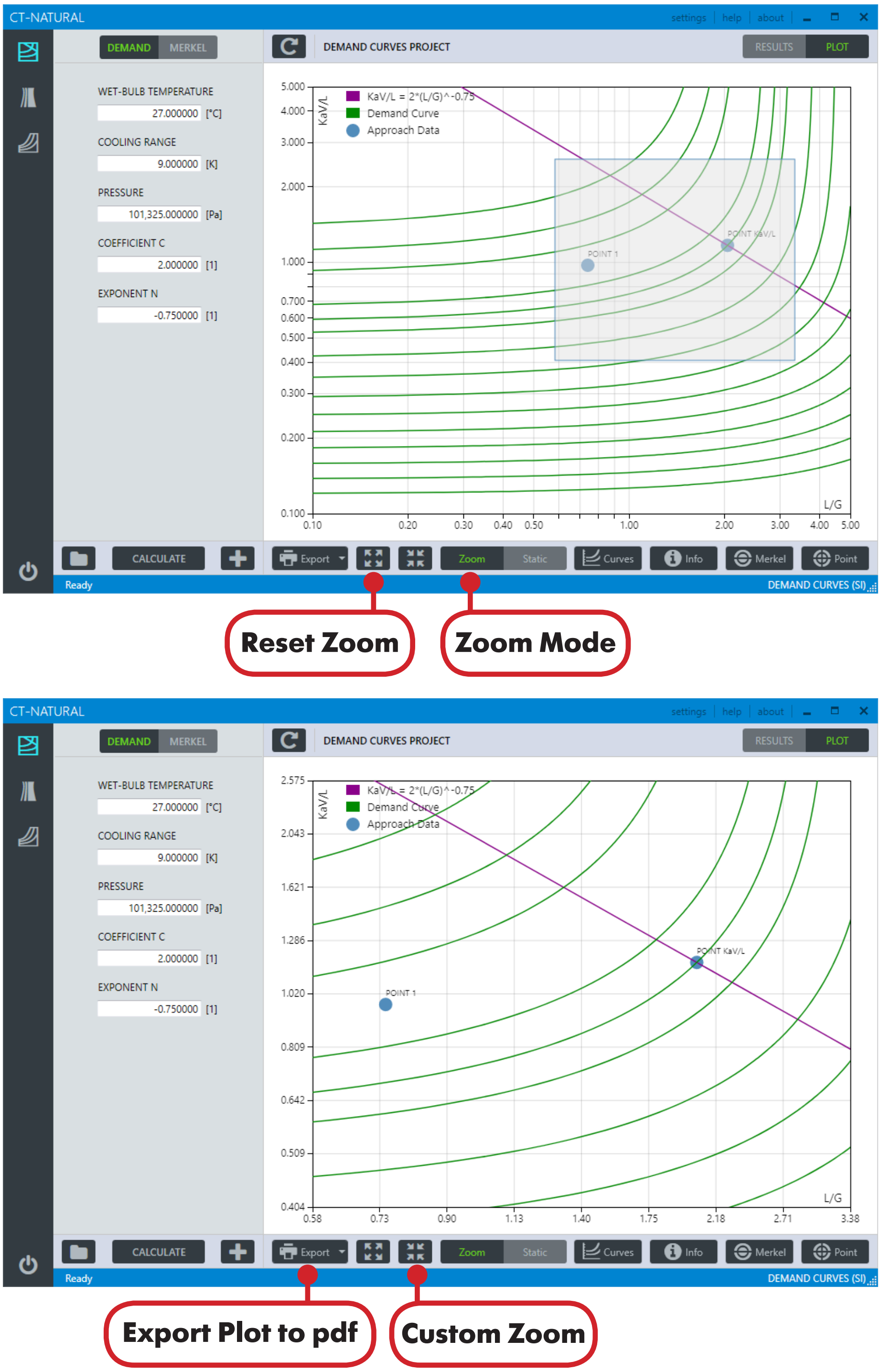


Figure 2.20 Zoom into the Plot Area of Demand Curves.

Save/Load Custom Zoom of the Plot Area

1. Click on the Settings button located on the upper right-hand side of the application (Figure 2.21).
2. Click on the SAVE button next to CUSTOM ZOOM to save the current zoom (Plot Area bounds) into the database for this particula project.

Click on the Custom Zoom button at any time to return the Plot Area bounds to the previously custom zoom saved to the datase.

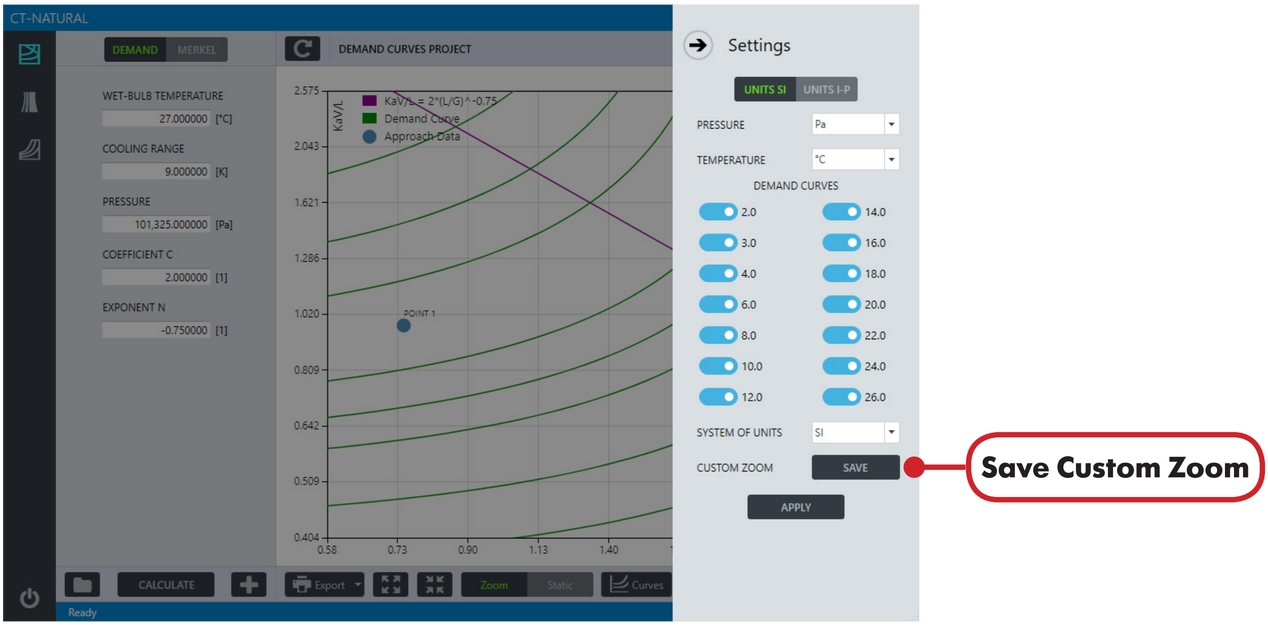


Figure 2.21 Settings for calculation projects of Demand Curves.

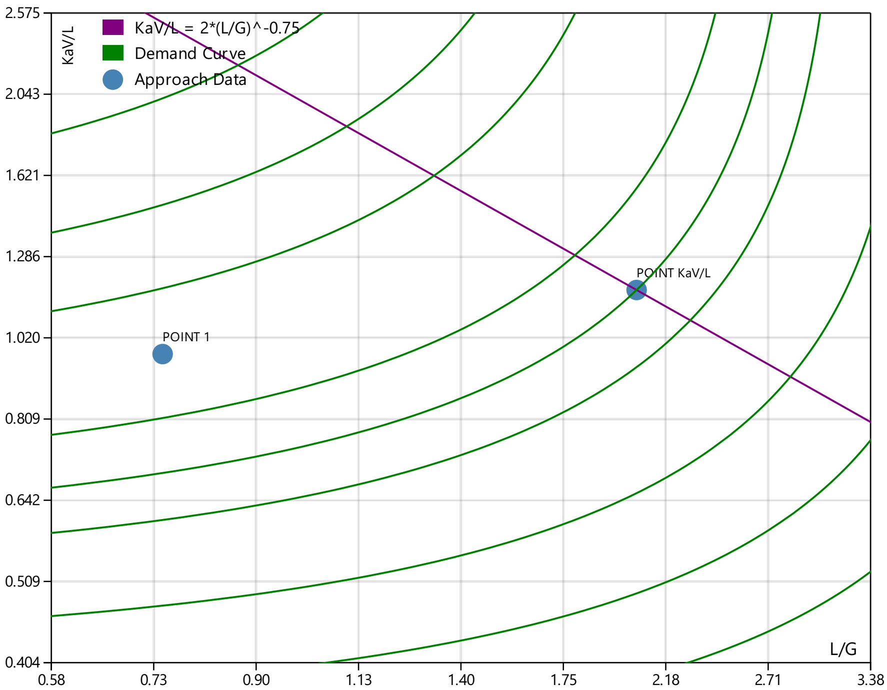


Figure 2.22 Zoom into the Plot Area of Demand Curves (plot exported to pdf).

3.1 Introduction

The Graphical User Interface for **Merkel Number** is shown in Figure 3.1. By selecting the button denoted Demand Curves on the left side of the application, the user is presented with the interface.

Select the denoted MERKEL button selector to display the Merkel Number main interface.

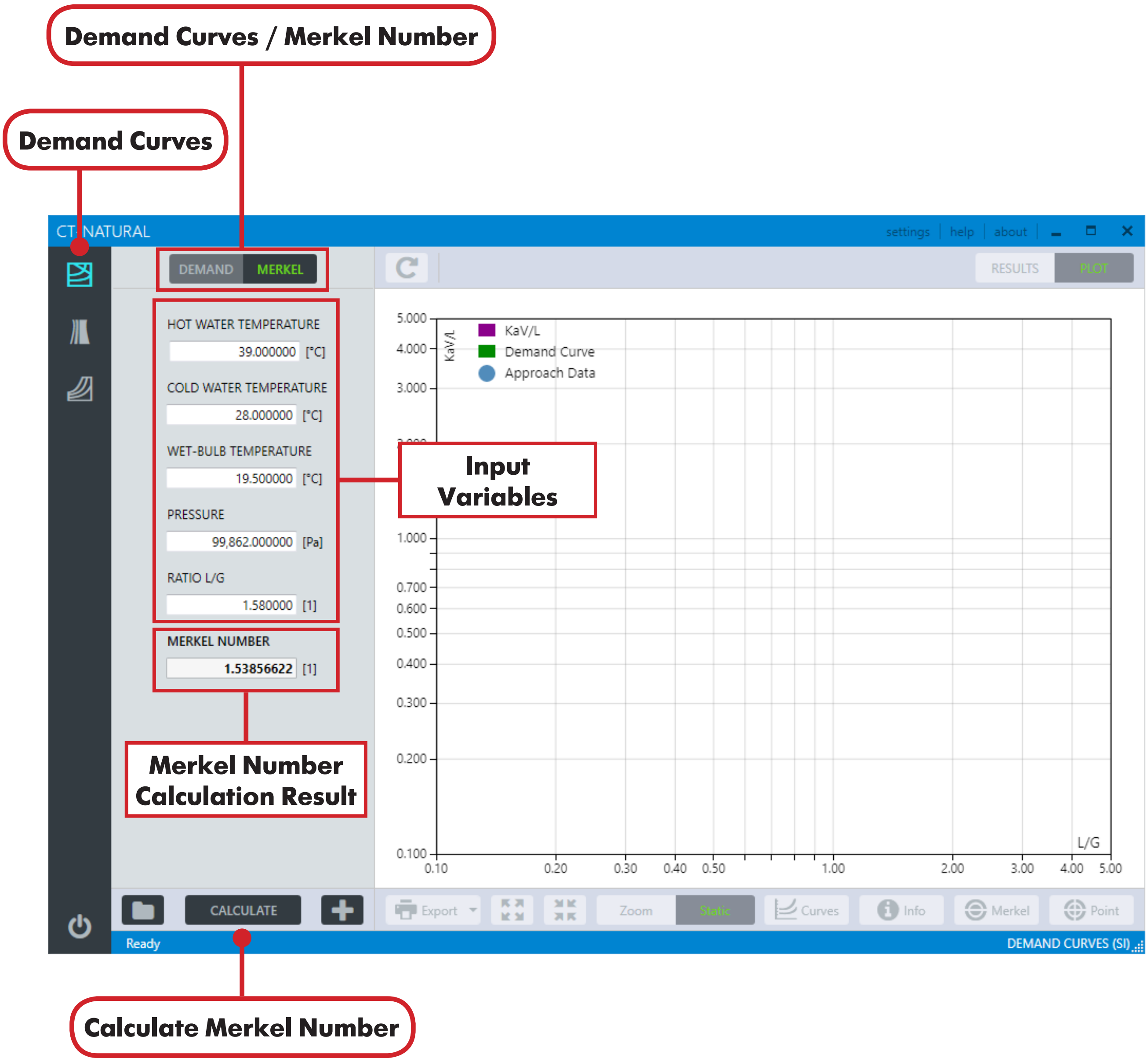


Figure 3.1 Graphical User Interface for the calculation of Merkel Number.

3.2 Range of Input Variables — Merkel Number

The full ranges of input variables for calculation of the Merkel Number in SI and I-P system of units:

Property	Range in SI Units	SI Units
HOT WATER TEMPERATURE	1.0 ≤ T ≤ 90.0	°C
COLD WATER TEMPERATURE	1.0 ≤ T ≤ 90.0	°C
WET-BULB TEMPERATURE	1.0 ≤ T ≤ 90.0	°C
PRESSURE	60000 ≤ P ≤ 110000	Pa
RATIO L/G	0.01 ≤ L/G ≤ 5.0	1

Property	Range in I-P Units	I-P Units
HOT WATER TEMPERATURE	33.8 ≤ T ≤ 194.0	°F
COLD WATER TEMPERATURE	33.8 ≤ T ≤ 194.0	°F
WET-BULB TEMPERATURE	33.8 ≤ T ≤ 194.0	°F
PRESSURE	8.70226426 ≤ P ≤ 15.95415115	psia
RATIO L/G	0.01≤ L/G ≤ 5.0	1

Table 3.1 Full ranges of input variables for Merkel Number.

3.3 Range of Input Variables (Evaluation Version) — Merkel Number

The full ranges of input variables for calculation of the Merkel Number (Evaluation Version) in SI and I-P system of units are:

Property	Range in SI Units	SI Units
HOT WATER TEMPERATURE	44.0 ≤ T ≤ 53.0	°C
COLD WATER TEMPERATURE	28.0 ≤ T ≤ 31.0	°C
WET-BULB TEMPERATURE	25.0 ≤ T ≤ 28.0	°C
PRESSURE	99000 ≤ P ≤ 102000	Pa
RATIO L/G	0.01 ≤ L/G ≤ 5.0	1

Property	Range in I-P Units	I-P Units
HOT WATER TEMPERATURE	111.2 ≤ T ≤ 127.4	°F
COLD WATER TEMPERATURE	82.4 ≤ T ≤ 87.8	°F
WET-BULB TEMPERATURE	77.0 ≤ T ≤ 82.4	°F
PRESSURE	14.358736 ≤ P ≤ 14.793849	psia
RATIO L/G	0.01≤ L/G ≤ 5.0	1

Table 3.2 Ranges of input variables for Merkel Number (Evaluation Version).

Validating Input Variables and Calculations

All input variables in SI or I-P are bounded by the ranges described in Table 3.1. In case that the input variables that are introduced are out of these ranges, and a new calculation is attempted by clicking on the CALCULATE button, the application first checks that all variables are within its range, and if any variable does not satisfy the range condition it will prevent the application from continuing. (Figure 3.2).

A message is displayed with the variables that do not satisfy this condition, showing the correct range of variables that must be entered for the calculation to proceed. Calculations that are within these ranges, but not do satisfy the conditions for a valid calculation, also display a message (Figure 3.3).

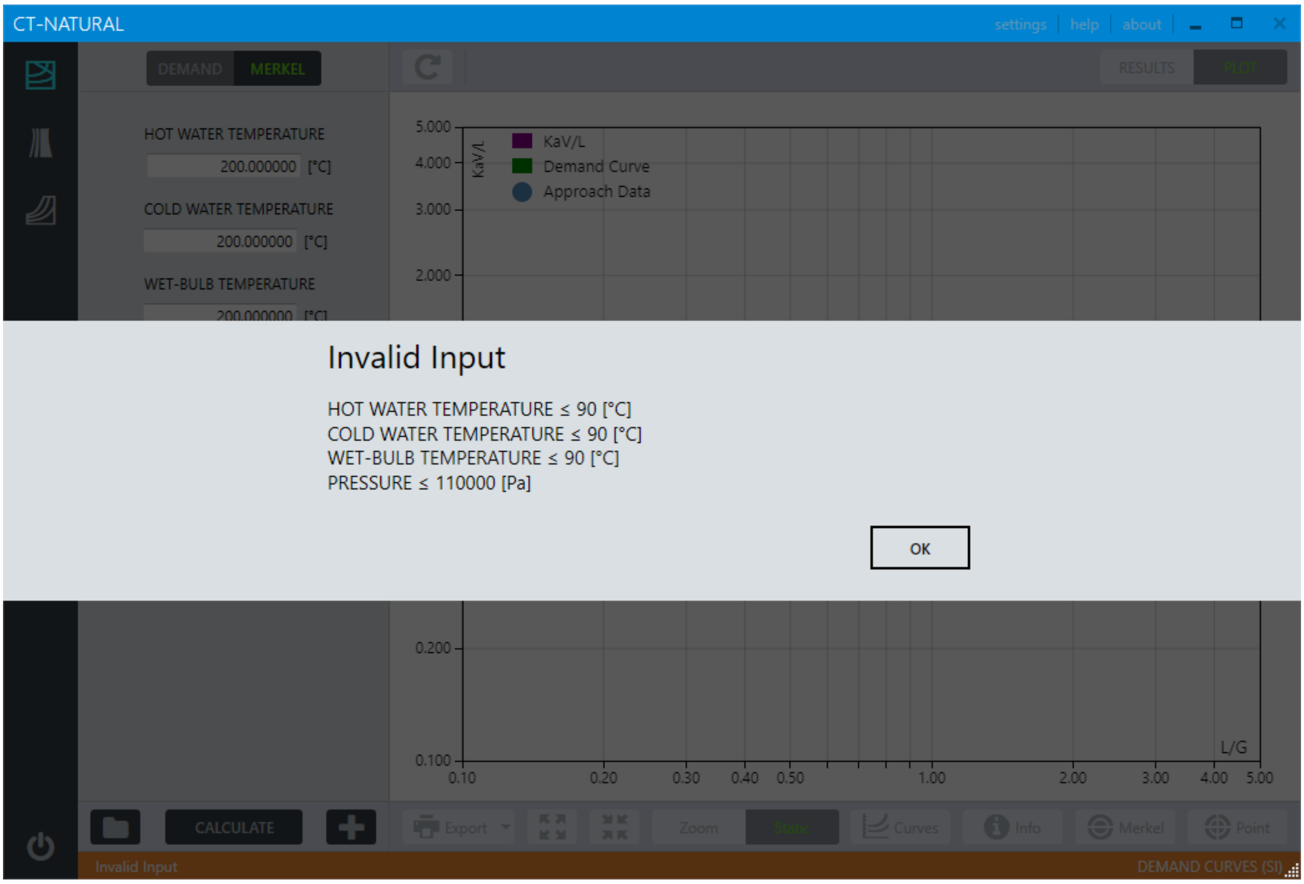


Figure 3.2 Validation of input variables for the calculation of Merkel Number.

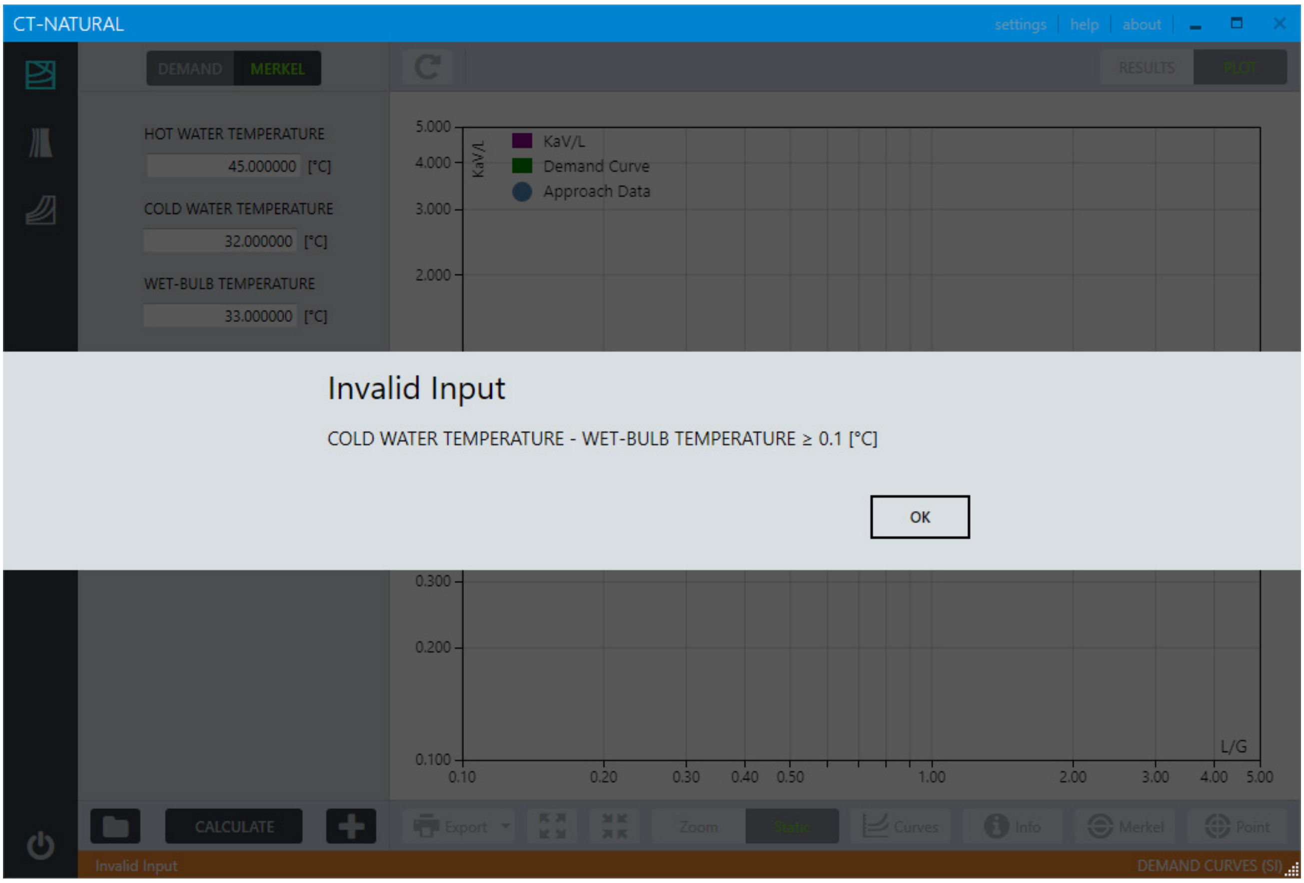


Figure 3.3 Validating the calculation of Merkel Number.

Calculate Merkel Number

1. Click on the MERKEL button selector located on the Demand Curves application.
2. Enter the input variables and click on the CALCULATE button. The Merkel number is displayed below the input variables.

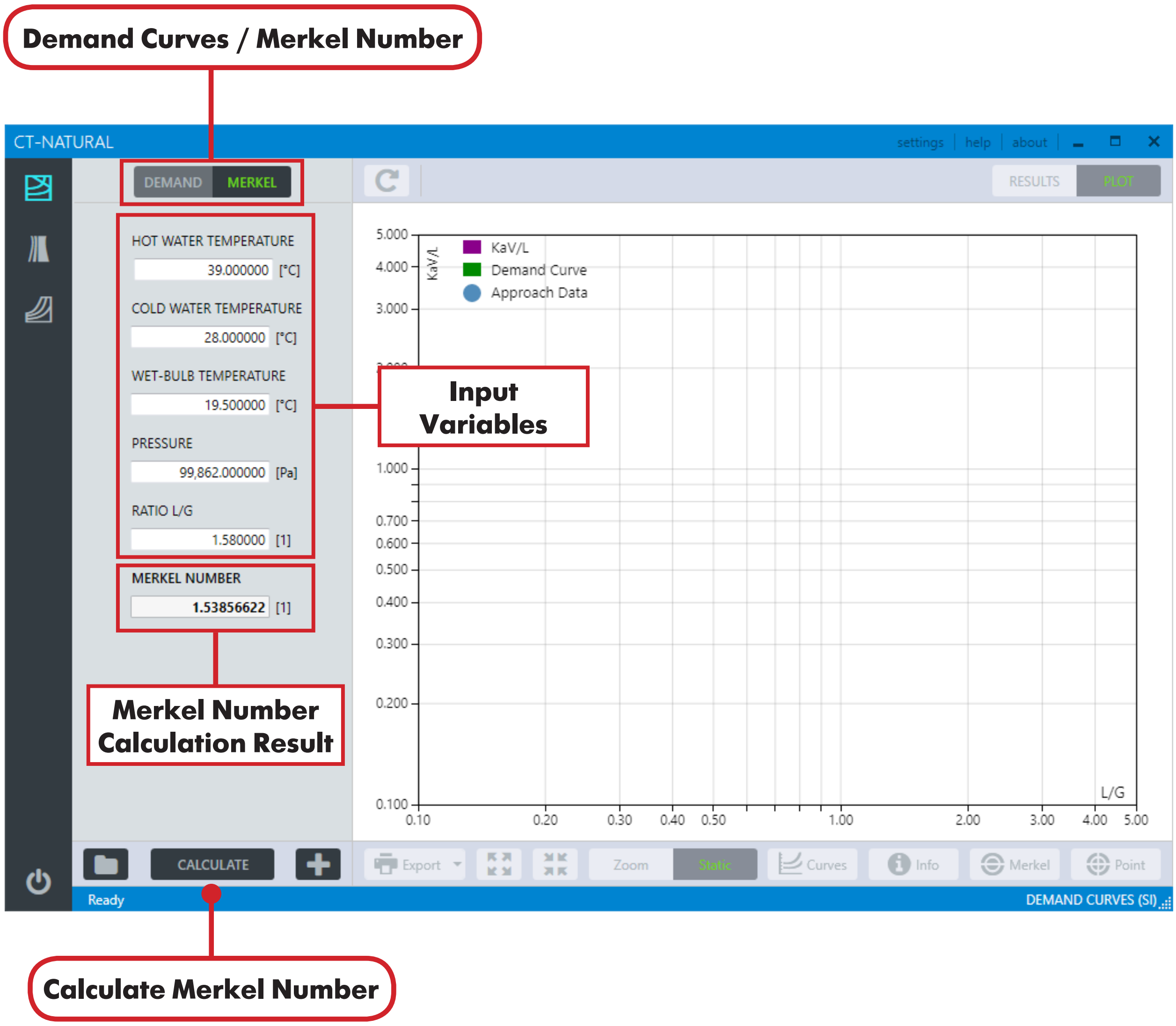


Figure 3.4 Calculation of Merkel Number.

A natural draft counterflow wet cooling tower (NDCWCT) is a device that utilizes the effects of mass and energy transfer to cool water by providing cold air flows "through" a hot water flow. The heat rejected to the atmosphere is in the form of latent and sensible heat and is carried away by the air flow through the tower. The water is cooled first by breaking it up into droplets (or spray), and then by making it flow in the form of thin films inside the cooling fill, allowing it to come into contact with the air which eventually carries the heat away into the atmosphere.

Considering that most of the heat and mass transfer ocurrs in the cooling fill for this type of cooling tower, the numerical calculations performed in **Natural Draft** (version 2.0) are focused only in the cooling fill zone. Figure 4.1 shows an schematic of a NDCWCT and some of the input variables required for the computations of the thermophysical variables and cooling performance.

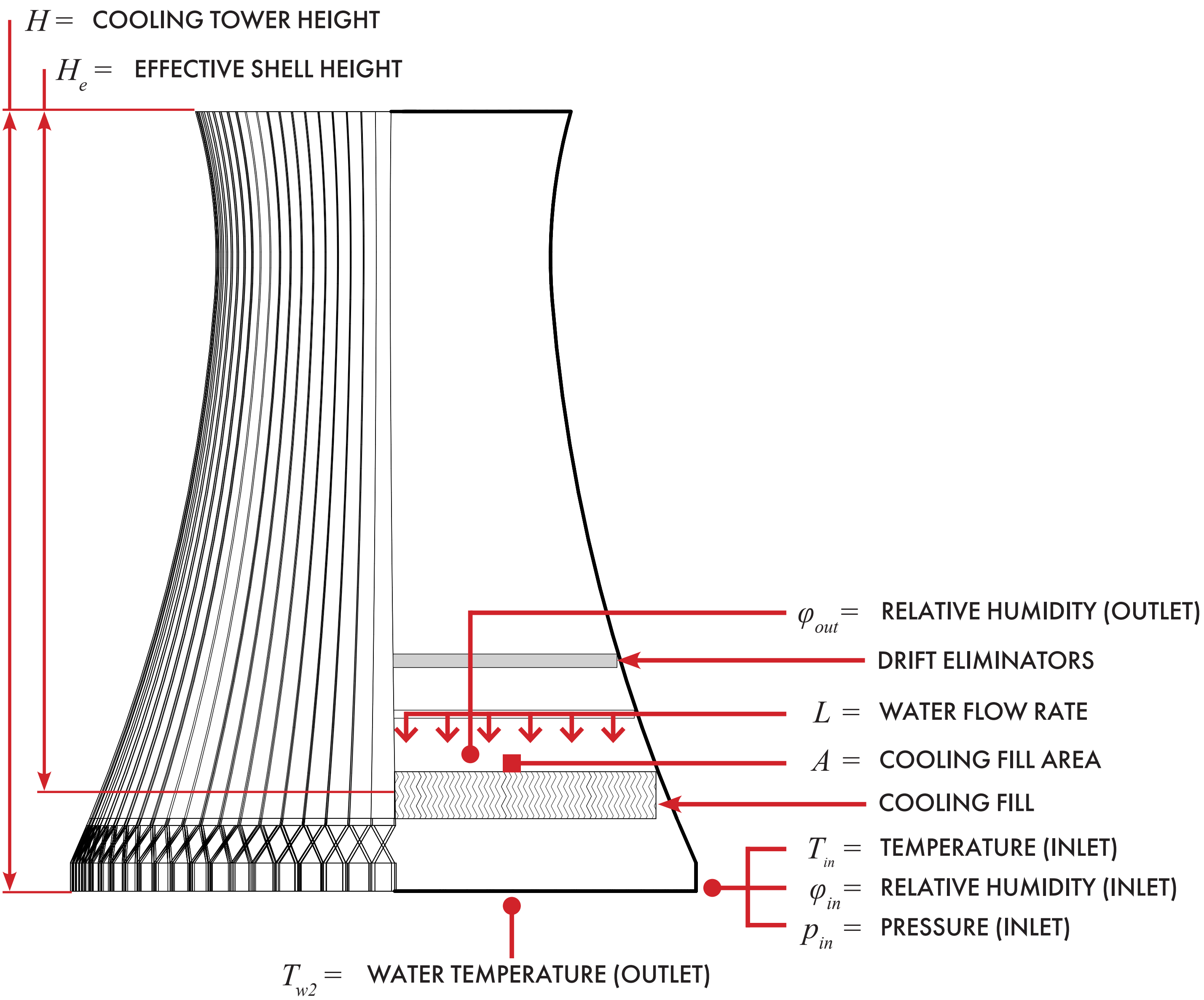


Figure 4.1 Schematic of a NDCWCT and some of the input variables in Natural Draft.

Numerical Model

An energy formulation that incorporates the heat and mass transfer process between water and humid air in the cooling fill is numerically solved to calculate isotherms of the outlet water temperature given a set of atmospheric and operating conditions in a NDCWCT.

Some of the assumptions and simplifications considered in the energy model used in Natural Draft are summarized as follows:

- Calculations of heat and mass transfer are conducted in the cooling fill zone.
- Operation of the cooling tower is under steady-state conditions, without considering wind effects.
- Water and air flow rates are uniform over the cross sections of the cooling tower.
- Humid air is saturated when leaving the cooling fill, i.e., Relative Humidity (Outlet) = 100%.

For the calculation of the thermophysical properties of water, steam and humid air used in the numerical solution of the energy model used in Natural Draft, the following formulations of properties are implemented:

Properties of Water and Steam

- Formulations from the IAPWS (International Association for the Properties of Water and Steam) IAPWS-IF97 Industrial formulation (Revision 2007) and related models.

Properties of Humid Air

- Thermodynamic and psychrometric property algorithms from the ASHRAE Research Project 1485.
- Scientific Formulation IAPWS-95, IAPWS Formulation 2008 and IAPWS Formulation 2006. Properties of dry air are from the NIST Reference equation of Lemmon et al.

Fill Transfer Characteristic

The empirical equations for the transfer characteristic of a particular counterflow splash or film type fill are determined and correlated from experimental measurements. This equation is usually provided by the tower manufacturer. The current correlation used in Natural Draft (version 2.0) is shown in Equation 4.1:

$$\frac{KaV}{L} = c\left(\frac{L}{G}\right)^{n} \quad 4.1$$

where L is the water flow rate, G is the airflow rate, c and n are constants defined for a particular cooling fill.

Loss Coefficient

In order to determine the loss coefficient of a cooling tower fill, during the testing phase the pressure drop over the fill is measured. Empirical equations are then formulated to model it usually as a function of air and water mass flow rates. The loss coefficient (ξ) is defined in Equation 4.2:

$$\xi = \frac{2\Delta p}{\rho \cdot v^2} \qquad 4.2$$

where Δp is the static pressure drop across the cooling fill, ρ is the average humid air density and v is the velocity of humid air. The correlation used by Natural Draft (version 2.0) is

$$\frac{\Delta p}{\rho \cdot v^2} = R\left(\frac{L}{G}\right)^m \qquad 5.3$$

where R and m are constants. Equation 4.4 shows the loss coefficient expressed in terms of the correlation for the pressure drop used in Natural Draft (version 2.0)

$$\frac{\xi}{2} = \frac{R}{2}\left(\frac{L}{G}\right)^m \qquad 4.4$$

The constants used in the equations for the Transfer Characteristic and the Loss Coefficients are part of the definition of a calculation project in Natural Draft. Figure 4.2 shows the location of the input interface for these constants in a calculation project.

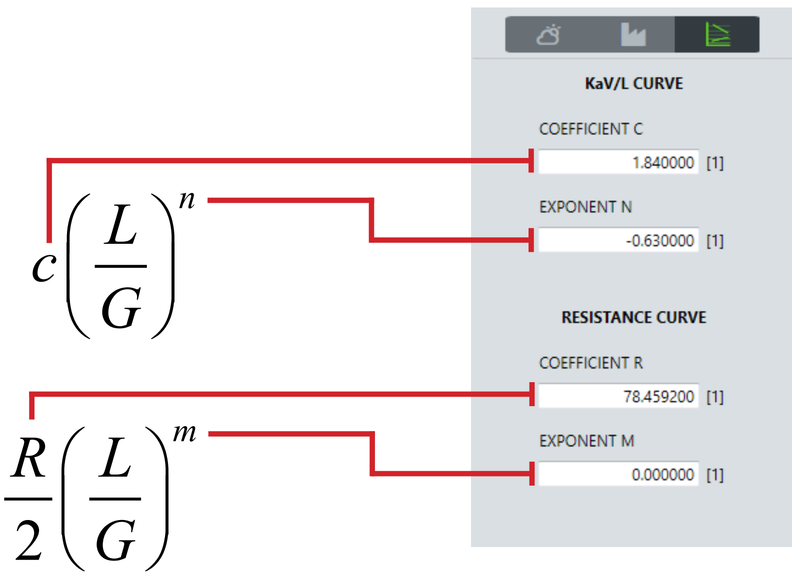


Figure 4.2 Constants used in the Transfer Characteristic and Loss Coefficient equations and the input interface in Natural Draft.

Tower Draft

In a natural draft cooling tower, the tower draft is a function of the fill loss coefficient. Equation 4.5 shows the formulation used in Natural Draft to model the tower draft equated to the loss coefficient.

$$\frac{\xi}{2} = \frac{2gH_e\left(\rho_{in} - \rho_{out}\right)}{v^2\left(\rho_{in} + \rho_{out}\right)} \qquad 4.5$$

where H_e is the effective shell height of the cooling tower, g is the gravity acceleration constant, ρ_{in} is the inlet density, ρ_{out} is the density immediately above the cooling fill and v is the velocity of humid air.

The Transfer Characteristic (KaV/L), Loss Coefficient ($\xi/2$) and Tower Draft (Draft) curves are shown in Figure 4.3 plotted in a log-log graph in the Plot Area of Natural Draft. The ordinate for the KaV/L equation is on the left of the plot, while for the other two equations is on the right.

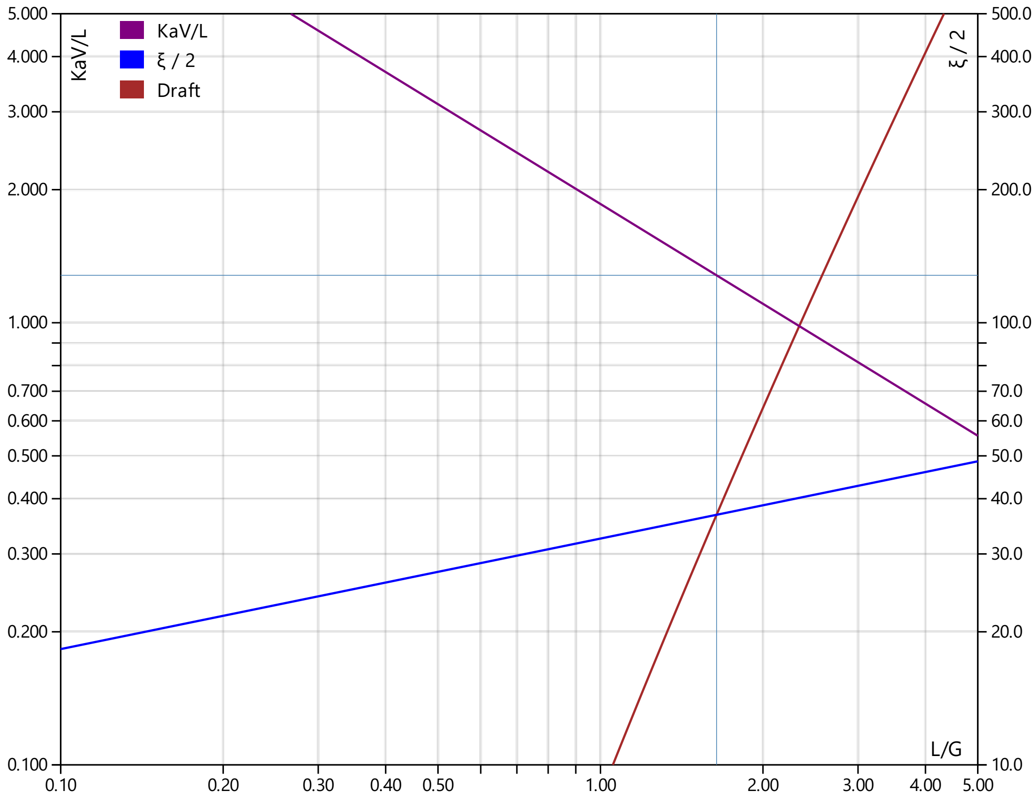


Figure 4.3 Transfer Characteristic, Loss Coefficient and Draft curves in the Plot Area of Natural Draft.

Input Variables

In order to define a calculation project in **Natural Draft** it is necessary to define a given set of atmospheric and operating conditions together with the constants for the Transfer Characteristic and Loss Coefficient curves. The input variables for a calculation project in **Natural Draft** are defined in Table 4.1. Additional calculations of temperature curves and data points in the Plot Area are solved using this set of conditions.

INPUT VARIABLE	DEFINITION
ATMOSPHERIC CONDITIONS	
TEMPERATURE (INLET)	Temperature of dry-bulb air entering the cooling tower.
RELATIVE HUMIDITY (INLET)	Relative humidity of air entering the cooling tower.
PRESSURE (INLET)	Total pressure referred to atmospheric, at the entrance of the cooling tower.
RELATIVE HUMIDITY (OUTLET)	Relative humidity of air leaving the cooling fill.
OPERATING CONDITIONS	
EFFECTIVE SHELL HEIGHT	Normally taken as height from middle of packing to top of tower shell.
COOLING FILL AREA	Total packing area normal to air flow.
WATER FLOW RATE	Mass water flow entering into the cooling tower.
WATER LOADING	Mass water flow per unit plain area of packing (Calculated).
COOLING RANGE	Difference between hot water temperature and cold water temperature.
WATER TEMPERATURE (OUTLET)	Estimated average temperature of the cold water basin discharge (outlet).
HEAT TRANSFER ADJUSTMENT	Adjustment factor for the heat transfer process in the cooling fill.
COEFFICIENTS	
COEFFICIENT C	Constant defined for a particular packing design.
EXPONENT N	Exponent defined for a particular packing design.
COEFFICIENT R	Constant for resistance curve characteristic for a particular cooling tower.
EXPONENT M	Exponent for resistance curve characteristic of a particular cooling tower.

Table 4.1 Definition of input variables in Natural Draft.

Input Water Temperature (Outlet)

An initial estimate of the outlet water temperature, together with a given the set of atmospheric and operating conditions, is required by the numerical method employed in **Natural Draft**. This estimation will be used as an initial value for the internal numerical procedure of the calculation.

Heat Transfer Adjustment

The heat transfer process between water and humid air inside the cooling fill in **Natural Draft** is related to the Heat Transfer Adjustment input variable. Under normal operating circumstances this value is close to 0. Known factors that affect this process can be evaluated by modifying this input variable.

Table 4.2 shows the numerical results of three calculation cases when modifying the Heat Transfer Adjustment variable while all the other input variables are the same. When this value is between -1 and 0 the outlet water temperature is decreased, and when it is between 0 and 1 the outlet water temperature is increased.

TEMPERATURE (INLET)	19	19	19	[°C]
RELATIVE HUMIDITY (INLET)	65	65	65	[%]
PRESSURE (INLET)	96500	96500	96500	[Pa]
RELATIVE HUMIDITY (OUTLET)	100	100	100	[%]
EFFECTIVE SHELL HEIGHT	100	100	100	[m]
COOLING FILL AREA	2500	2500	2500	[m²]
WATER FLOW RATE	5500	5500	5500	[kg/s]
COOLING RANGE	6	6	6	[K]
WATER TEMPERATURE (OUTLET)	24	24	24	[°C]
HEAT TRANSFER ADJUSTMENT	-1	0	1	[1]
COEFFICIENT C	1.8562	1.8562	1.8562	[1]
EXPONENT N	-0.75	-0.75	-0.75	[1]
COEFFICIENT R	65	65	65	[1]
EXPONENT M	0.25	0.25	0.25	[1]
IDENTIFIER	RESULT DATA	RESULT DATA	RESULT DATA	
Inlet Wet-bulb Temperature	14.835108	14.835108	14.835108	[°C]
Inlet Enthalpy	42915.929808	42915.929808	42915.929808	[J/kg]
Inlet Water Mass Fraction	0.009298	0.009298	0.009298	[kg/kg]
Inlet Water Vapor Pressure	1434.548992	1434.548992	1434.548992	[Pa]
Inlet Density	1.144733	1.144733	1.144733	[kg/m³]
Outlet Dry-bulb Temperature	28.090808	28.170464	28.25158	[°C]
Outlet Wet-bulb Temperature	28.090808	28.170464	28.25158	[°C]
Outlet Enthalpy	93654.316627	94054.85149	94464.214886	[J/kg]
Outlet Water Mass Fraction	0.024997	0.025115	0.025236	[kg/kg]
Outlet Water Vapor Pressure	3818.971802	3836.731495	3854.890911	[Pa]
Outlet Density	1.099776	1.099408	1.099033	[kg/m³]
Density Difference	0.044957	0.045325	0.0457	[kg/m³]
Pressure Difference	36.69787	37.042153	37.393267	[Pa]
Airflow Rate	2433.698232	2444.678146	2455.818017	[m³/s]
Heat Energy Flow	138690.451962	138690.451962	138690.451962	[W]
Average Air Velocity	1.013273	1.018186	1.023175	[m/s]
Loss Coefficient	77.04799	76.961332	76.873907	[1]
L/G	1.974203	1.965336	1.956421	[1]
KaV/L	1.114502	1.118271	1.122091	[1]
Inlet Water Temperature	30.768551	30.808109	30.849284	[°C]
Outlet Water Temperature	24.768551	24.808109	24.849284	[°C]

Table 4.2 Numerical results of three calculation cases with different Heat Tansfer Adjustment values.

Calculation Results

Table 4.3 shows the definition of the calculation result variables that **Natural Draft** evaluates numerically for a given pair of (L/G, KaV/L) values in a calculation project.

For a given airflow rate, the driving force acting on the humid air must equal the friction loss through the cooling tower, i.e., when the loss coefficent equals the tower draft. This is shown as the L/G value of the intersection of the Loss Coefficient and Draft curves in Figure 4.3 with a vertical blue line. The solution value for KaV/L (Merkel number) is found by evaluating the Fill Transfer Characteristic equation at this intersection L/G value, drawn in Fig. 4.3 with a horizontal blue line.

RESULT VARIABLE	DEFINITION
Inlet Wet-bulb Temperature	Wet-bulb temperature of air entering the cooling tower.
Inlet Enthalpy	Specific enthalpy of air entering the cooling tower.
Inlet Water Mass Faction	Water mass fraction at the entrance of the cooling tower.
Inlet Water Vapor Pressure	Water vapor pressure at the entrance of the cooling tower.
Inlet Density	Specific density of air entering the cooling tower.
Outlet Dry-bulb Temperature	Dry-bulb temperature of air leaving the cooling fill inside the cooling tower.
Outlet Wet-bulb Temperature	Wet-bulb temperature of air leaving the cooling fill inside the cooling tower.
Outlet Enthalpy	Specific enthalpy of air leaving the cooling fill inside the cooling tower.
Outlet Water Mass Faction	Water mass fraction leaving the cooling fill inside the cooling tower.
Outlet Water Vapor Pressure	Water vapor pressure leaving the cooling fill inside the cooling tower.
Outlet Density	Specific density of air leaving the cooling fill inside the cooling tower.
Density Difference	Density difference of air at the entrance of the cooling tower and air leaving the cooling fill.
Pressure Difference	Pressure difference at the entrance of the cooling tower and leaving the cooling fill.
Airflow Rate	Airflow rate leaving the cooling fill.
Heat Energy Flow	Total amount of heat energy transferred from the cooling tower.
Average Air Velocity	Average velocity of humid air in the cooling fill.
Loss Coefficient	Non-dimensional coefficient referred to the pressure loss in the cooling fill.
L/G	Calculated ratio of water flow rate to airflow rate.
KaV/L	Calculated tower characteristic (Merkel number).
Inlet Water Temperature	Calculated inlet water temperature.
Outlet Water Temperature	Calculated outlet water temperature.

Table 4.3 Definition of calculation result variables in Natural Draft.

The full ranges of input variables for Natural Draft projects in the SI system of units are:

Property	**Range in SI Units**	**SI Units**
TEMPERATURE (INLET)	-20.0 ⩽ T ⩽ 60.0	°C
RELATIVE HUMIDITY (INLET)	0.0 ⩽ R.H. ⩽ 100.0	%
PRESSURE (INLET)	60000.0 ⩽ P ⩽ 110000.0	Pa
RELATIVE HUMIDITY (OUTLET)	R.H. = 100.0	%
EFFECTIVE SHELL HEIGHT	10.0 ⩽ Height ⩽ 300.0	m
COOLING FILL AREA	19.64 ⩽ Area ⩽ 31415.92	m^2
HEAT TRANSFER ADJUSTMENT	-1.0 ⩽ Factor ⩽ 1.0	1
WATER FLOW RATE	0.5 ⩽ Flow ⩽ 100000.0	kg/s
COOLING RANGE	1.0 ⩽ T ⩽ 50.0	°C
WATER TEMPERATURE (OUTLET)	1.0 ⩽ T ⩽ 70.0	°C
COEFFICIENT C	1.0 ⩽ C ⩽ 3.0	1
EXPONENT N	-2.0 ⩽ N ⩽ -0.1	1
COEFFICIENT R	20.0 ⩽ R ⩽ 500.0	1
EXPONENT M	-4.0 ⩽ M ⩽ 4.0	1
KaV/L	0.1 ⩽ KaV/L ⩽ 5.0	1
L/G	0.1 ⩽ L/G ⩽ 5.0	1
CURVE TEMPERATURE	1.0 ⩽ T ⩽ 60.0	°C

Table 4.4 Full range of input variables in Natural Draft.

The full ranges of input variables for Natural Draft (Evaluation Version) in SI:

Property	Range in SI Units	SI Units
TEMPERATURE (INLET)	30.0 ≤ T ≤ 32.0	°C
RELATIVE HUMIDITY (INLET)	65.0 ≤ R.H. ≤ 75.0	%
PRESSURE (INLET)	100000.0 ≤ P ≤ 101000.0	Pa
RELATIVE HUMIDITY (OUTLET)	R.H. = 100.0	%
EFFECTIVE SHELL HEIGHT	138.0 ≤ Height ≤ 140.0	m
COOLING FILL AREA	9160.0 ≤ Area ≤ 9200.0	m^2
HEAT TRANSFER ADJUSTMENT	-1.0 ≤ Factor ≤ 1.0	1
WATER FLOW RATE	18800.0 ≤ Flow ≤ 19000.0	kg/s
COOLING RANGE	8.0 ≤ T ≤ 9.0	°C
WATER TEMPERATURE (OUTLET)	30.0 ≤ T ≤ 32.0	°C
COEFFICIENT C	1.8 ≤ C ≤ 1.9	1
EXPONENT N	-2.0 ≤ N ≤ -0.1	1
COEFFICIENT R	20.0 ≤ R ≤ 500.0	1
EXPONENT M	-4.0 ≤ M ≤ 4.0	1
KaV/L	0.1 ≤ KaV/L ≤ 5.0	1
L/G	0.1 ≤ L/G ≤ 5.0	1
CURVE TEMPERATURE	1.0 ≤ T ≤ 60.0	°C

Table 4.5 Full range of input variables in Natural Draft (Evaluation Version).

The Graphical User Interface for **Natural Draft** is shown in Figure 4.4. By selecting the button Natural Draft Counterflow on the left side of the application, the user is presented with the interface.

Selecting the buttons denoted ATMOSPHERIC / OPERATING / CURVES allows the user to enter the input variables to determine a calculation project.

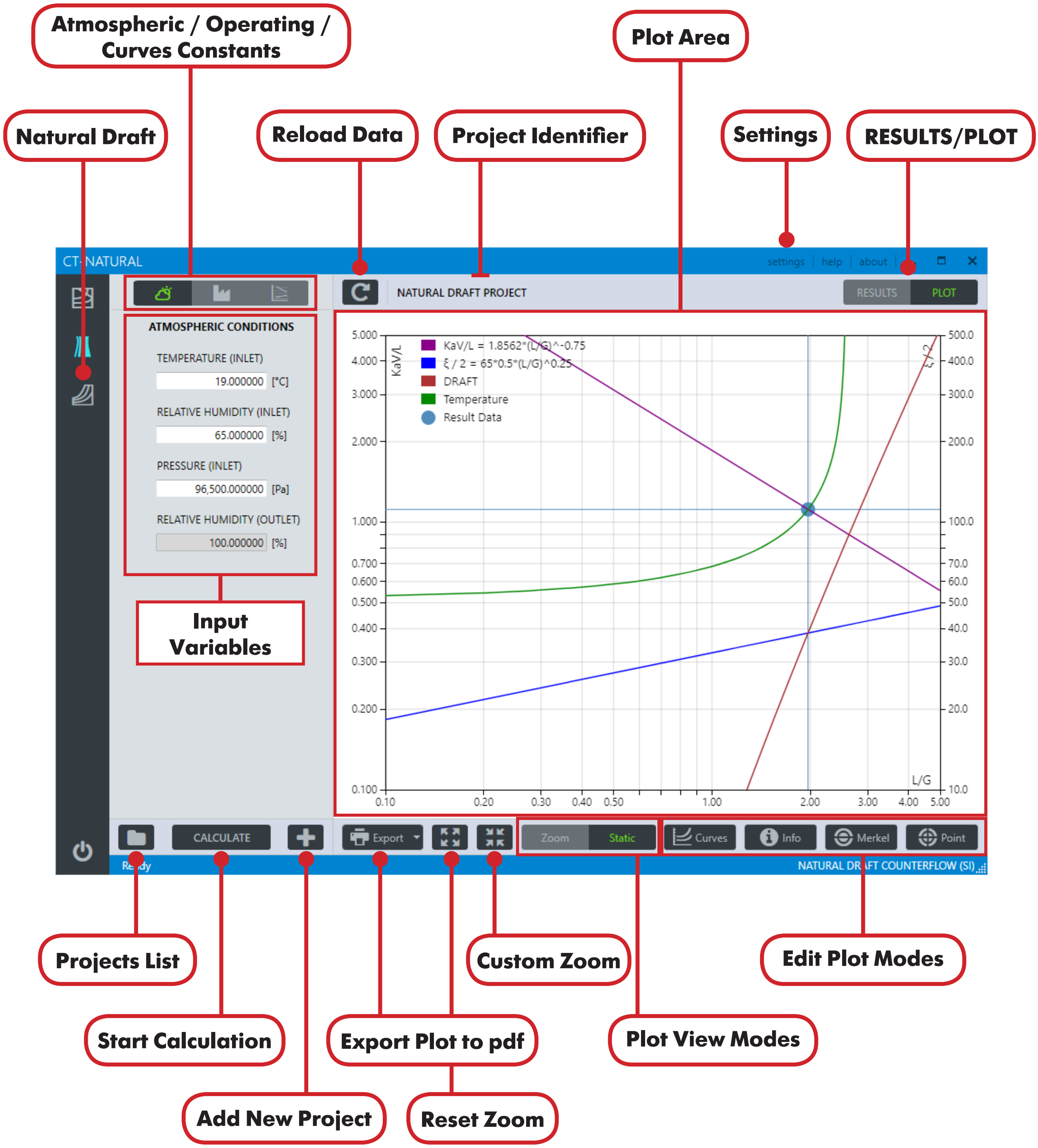


Figure 4.4 Graphical User Interface in Natural Draft.

Add Calculation Project

1. Click on the Add New Project button to add a new project. Type the name for the project and click the button OK. The project will be created in the database and the application ready for adding additional calculation points.
2. Click on the Settings button to select the units used for this particular project (Figure 4.4).
3. Click on the APPLY button to save the selections.
4. Enter the input variables for the calculation.
5. Click on the CALCULATE button to start the calculations.

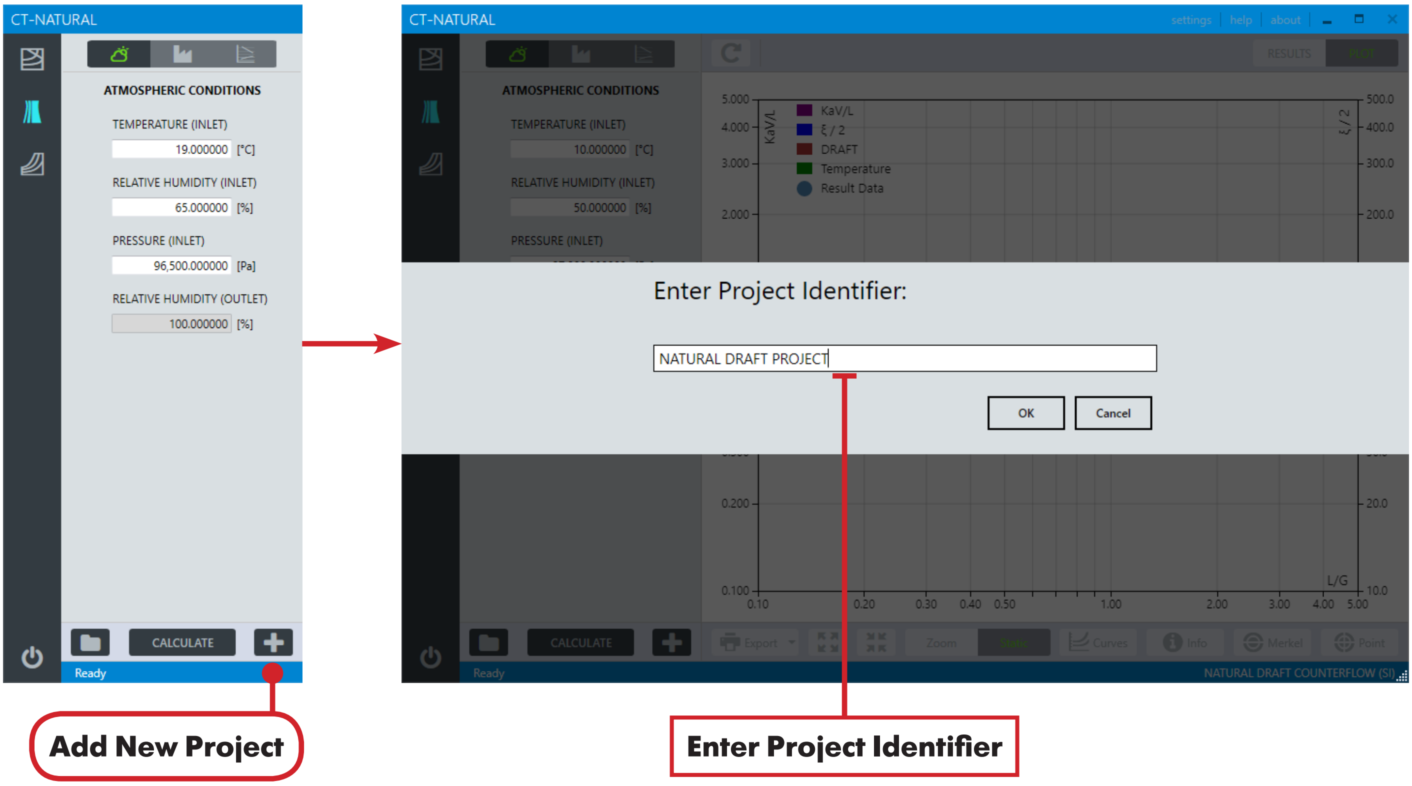


Figure 4.5 Adding a calculation project in Natural Draft.

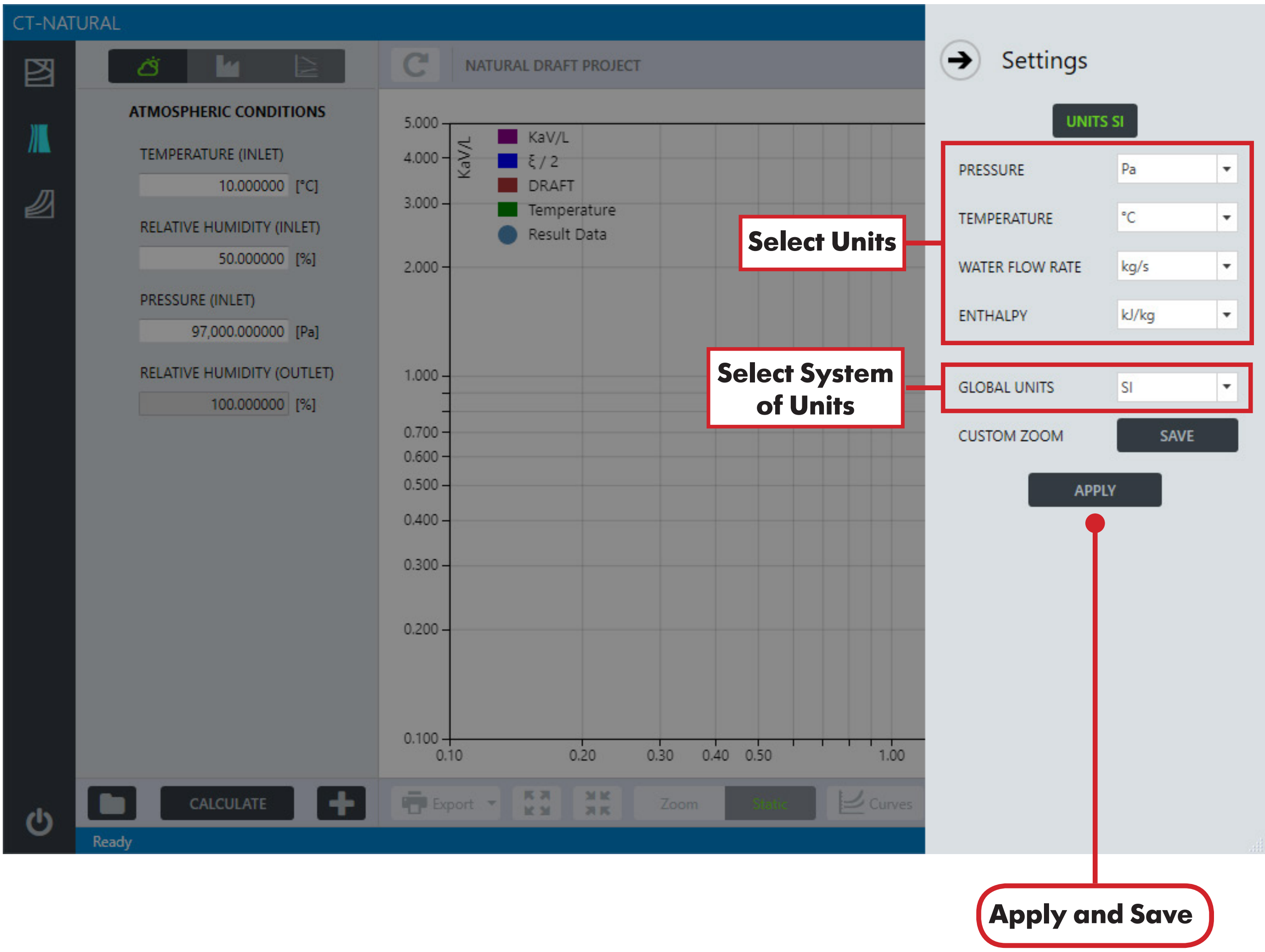


Figure 4.6 Settings for calculation projects in Natural Draft.

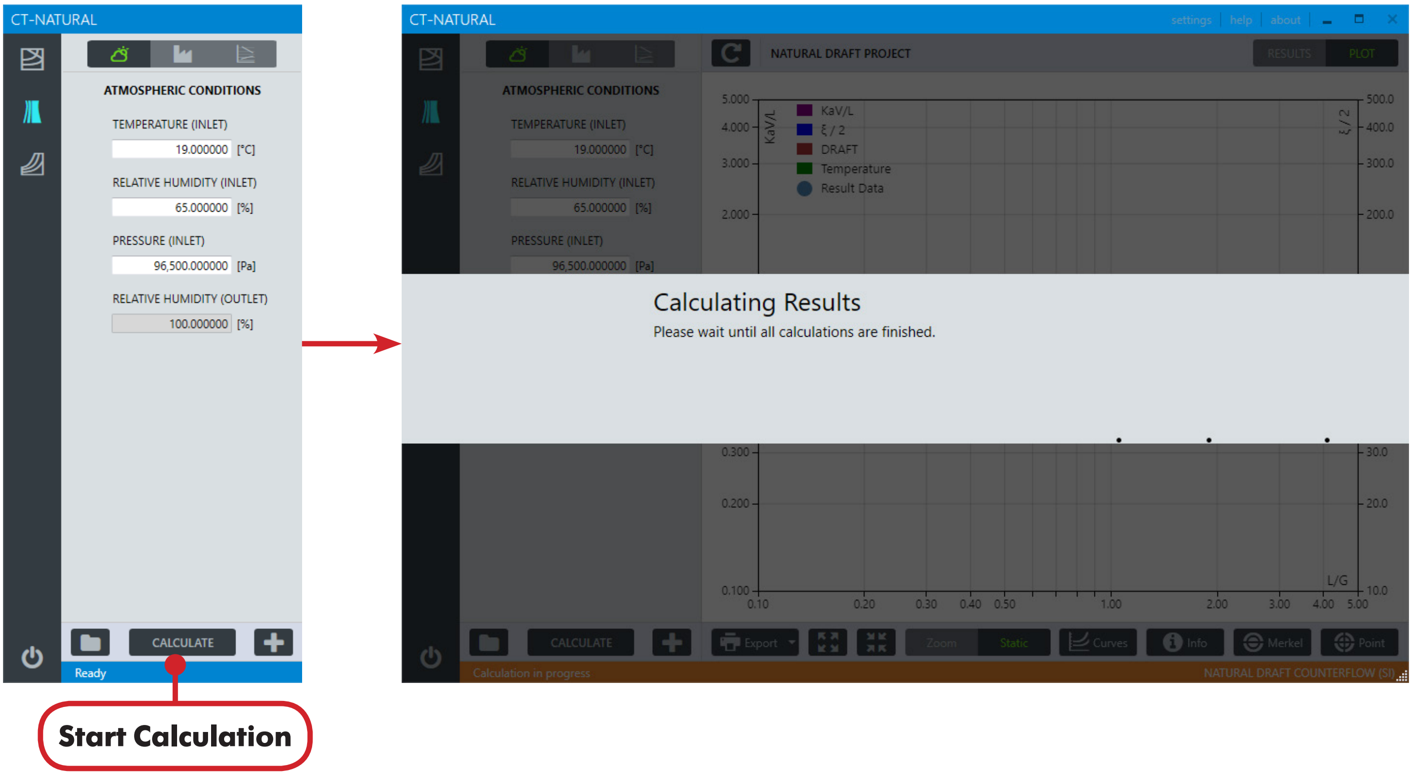


Figure 4.7 Start calculation project in Natural Draft.

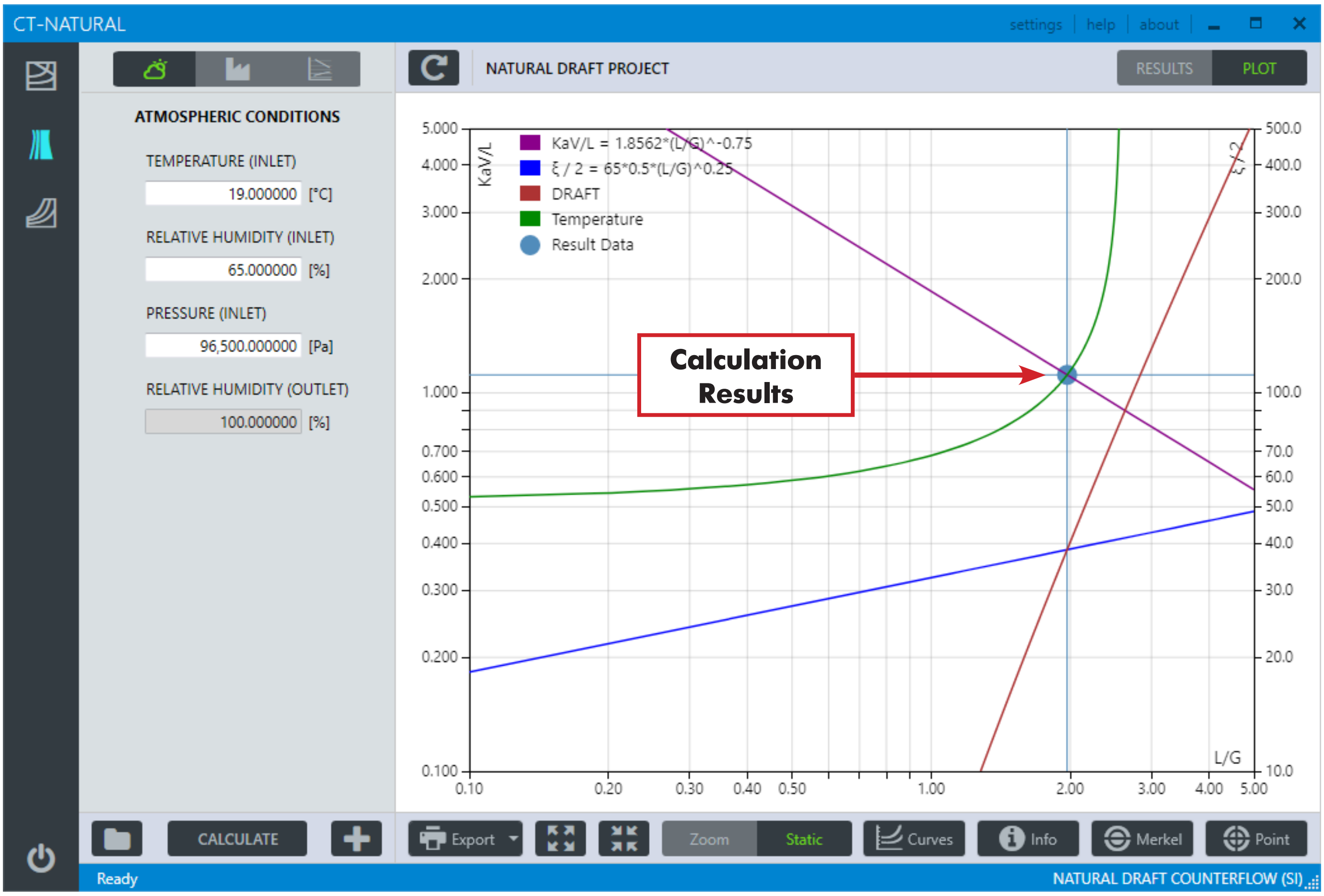


Figure 4.8 Plot Area after calculations are completed in Natural Draft.

Load Project from Database

1. Click on the Projects List button to load all the projects saved in the database (Figure 4.7).
2. Click on the Details button of a particular project to show the detailed input variables that were saved for that calculation project.
3. Click on the Load Project button to load all the curves and test calculations for the selected project. The project is ready to add data point calculations or curves.

Delete Project from Database

1. Click on the Projects List button to load all the projects saved in the database.
2. Click on the Delete Project button to delete the project from the database and the plot area.
   By deleting a project, all the temperature curves and point calculations that belong to that project will also be deleted.

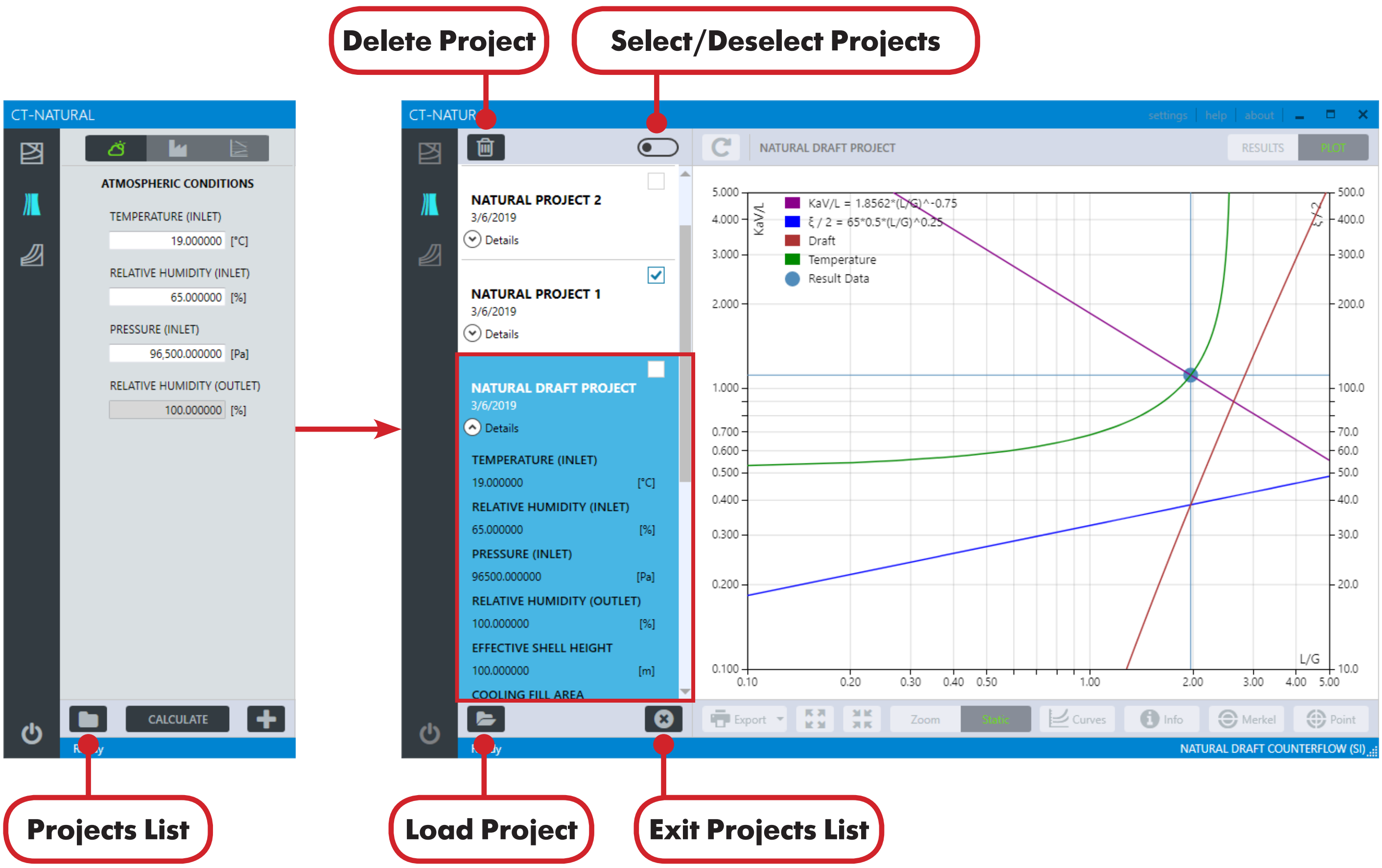


Figure 4.9 List of calculation projects in Natural Draft.

Add Calculation Point to a Project

1. Click on the Point button to start the Graphical Mode. Left-click the button on the center of the crosshairs to drag to your desired location, or introduce the coordinates on the KaV/L or L/G buttons to move the crosshairs to a precise location. The location on the Plot Area will be used as the the value of both KaV/L and L/G to calculate the point.
2. Click on the Calculate button over the plot area to start the calculation of the data point.
3. Once the calculation has finished, the numerical results will be shown on the left side of the Plot Area. To add the point to the Plot Area and save it to the database, click on the Add Point to Database button (Figure 4.9). Enter an identifier for the point (optional) and click OK.
4. To exit the Graphical Mode, click on the Point button.

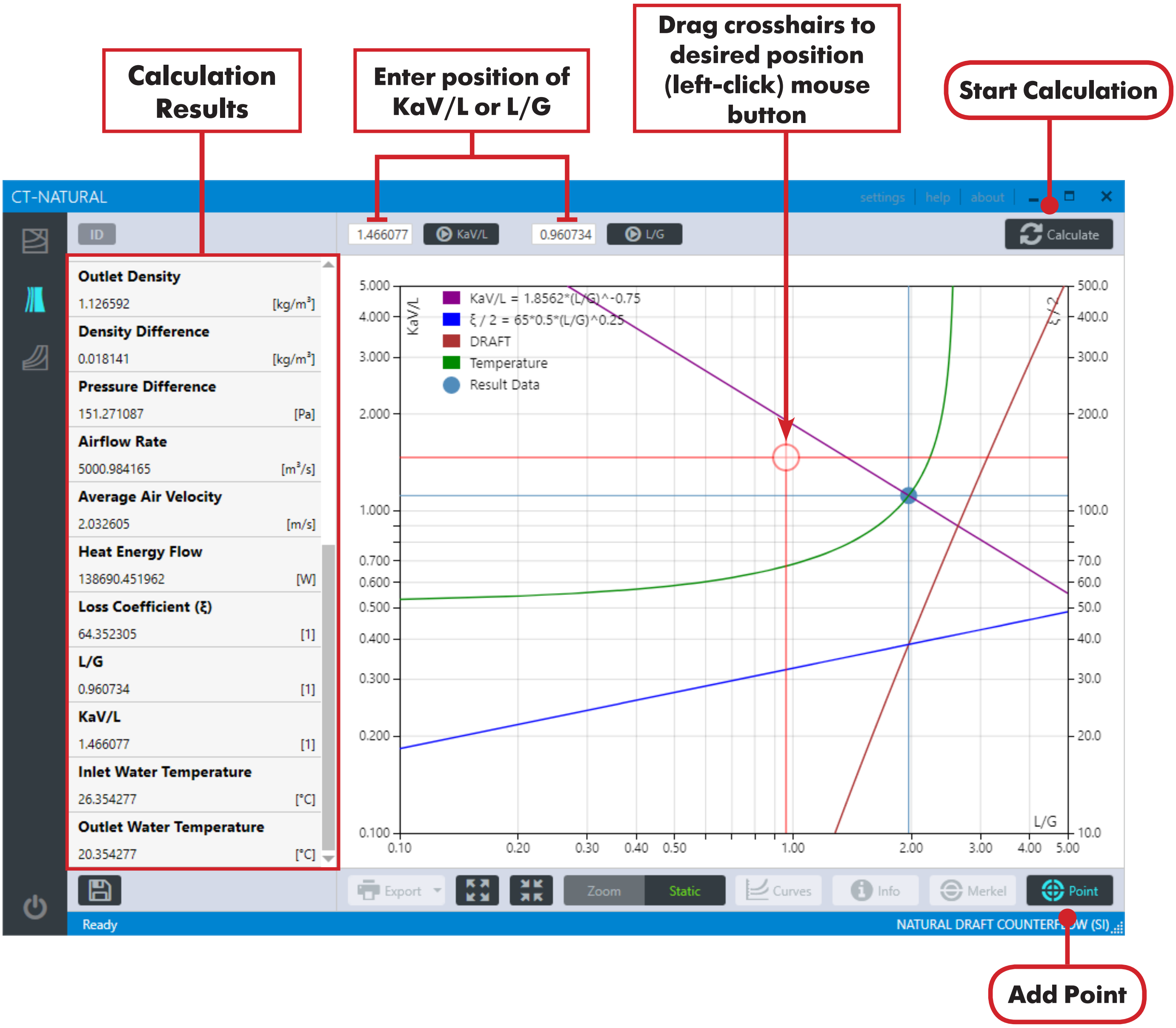


Figure 4.10 Adding a calculation data point in Natural Draft.

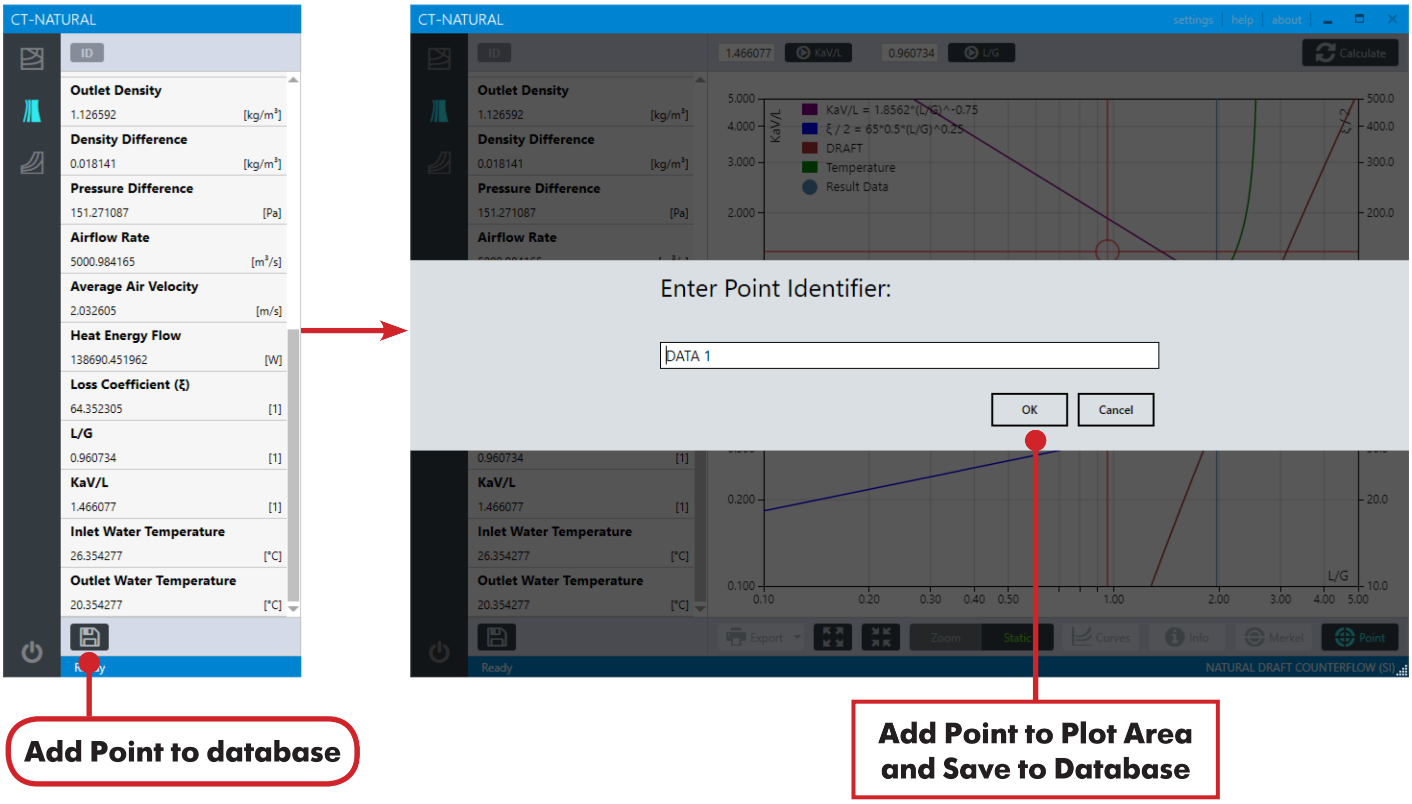


Figure 4.11 Adding an approach data point to the Plot Area and saving it to the database in Natural Draft.

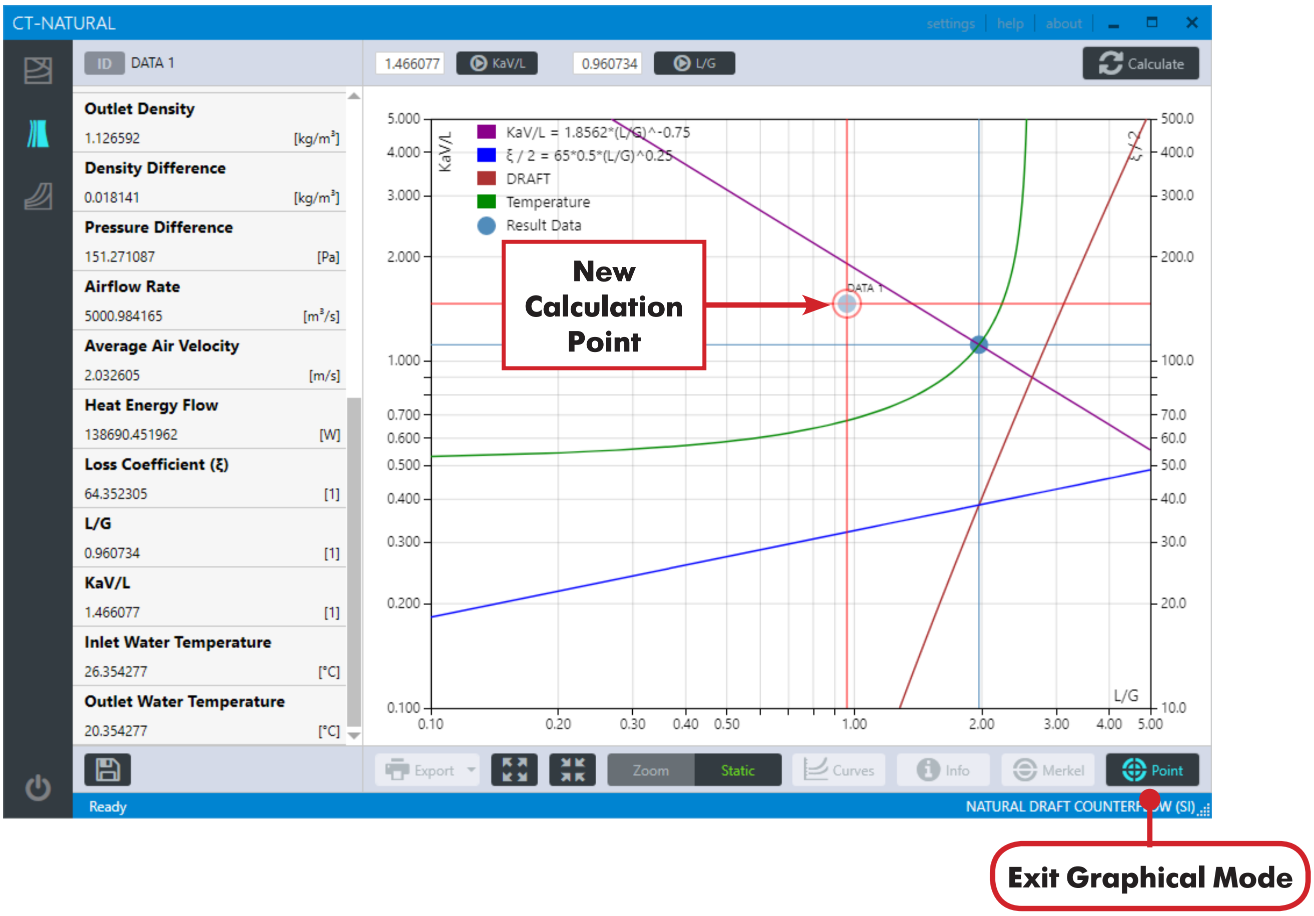


Figure 4.12 Plot Area in Natural Draft after calculation point has been added.

Add Calculation Point on KaV/L line

1. Click on the Merkel button to start the Graphical Mode. Select the Curve switch next to the Calculate button to calculate and plot the temperature curve that results from the calculation. Left-click the button on the center of the crosshairs to drag to your desired location on the KaV/L line, or introduce the coordinates on the KaV/L or L/G buttons to move the crosshairs to a precise location. The coordinate position of the croshairs is restricted to satisfy the Merkel (KaV/L) equation. The location on the Plot Area will be used as the the value of both KaV/L and L/G for data calculations.
2. Click on the Calculate button over the plot area to start the calculation of the data point.
3. Once the calculation has finished, the numerical results will be shown on the left side of the Plot Area. To add the data point to the Plot Area and save it to the database, click on the Add Point to Database button (Figure 4.9). Enter an identifier for the data point (optional) and click OK.
4. To exit the Graphical Mode, click on the Merkel button.

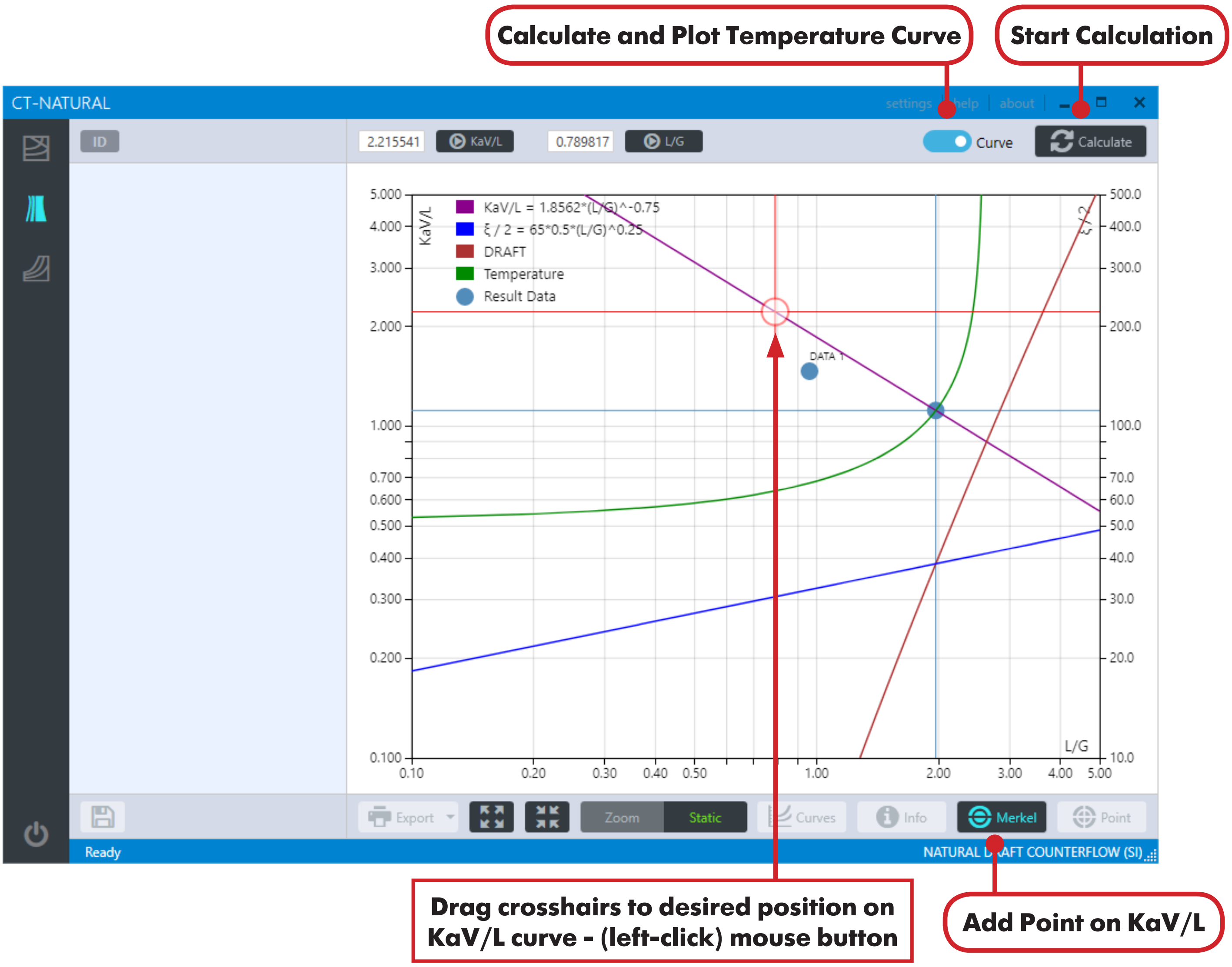


Figure 4.13 Adding a calculation point on the KaV/L curve in Natural Draft.

4.8 Calculation Points

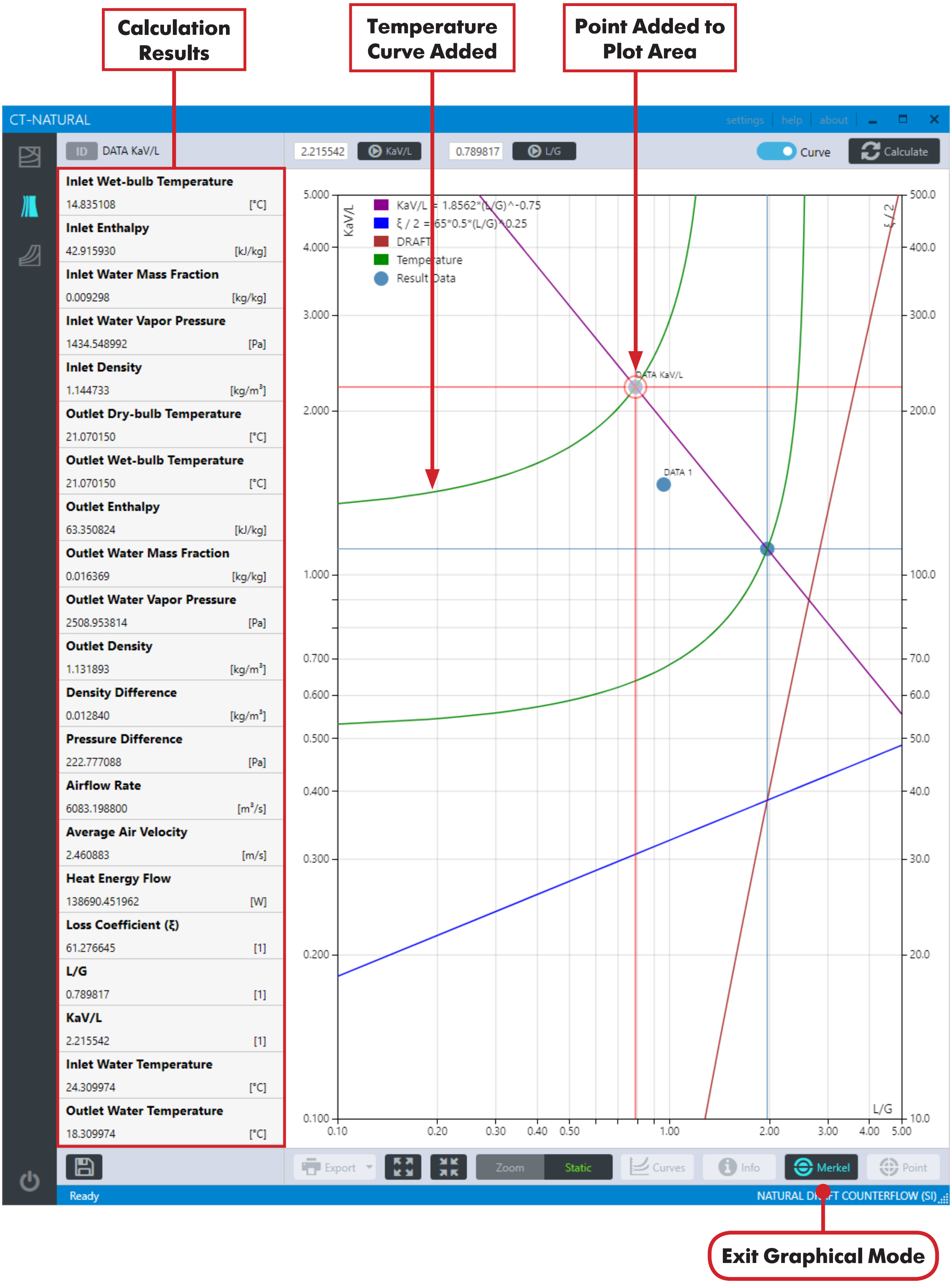


Figure 4.14 Calculation point and temperature curve after calculation on the KaV/L curve in Natural Draft.

Validating Input Variables and Calculations

All input variables in SI are bounded by the ranges described in Table 4.3. In the case that the input variables that are introduced are out of these ranges, and a new calculation project is attempted by clicking on the CALCULATE button, the application will first check that all variables are within its range, and if any variable does not satisfy the range condition it will prevent the application from continuing. (Figure 4.15).

A message is displayed with the variables that do not satisfy this condition, showing the correct range of variables that must be entered for the calculation to proceed. Calculations that are within these ranges, but not do satisfy the conditions for a valid calculation, also display a message (Figure 4.16).

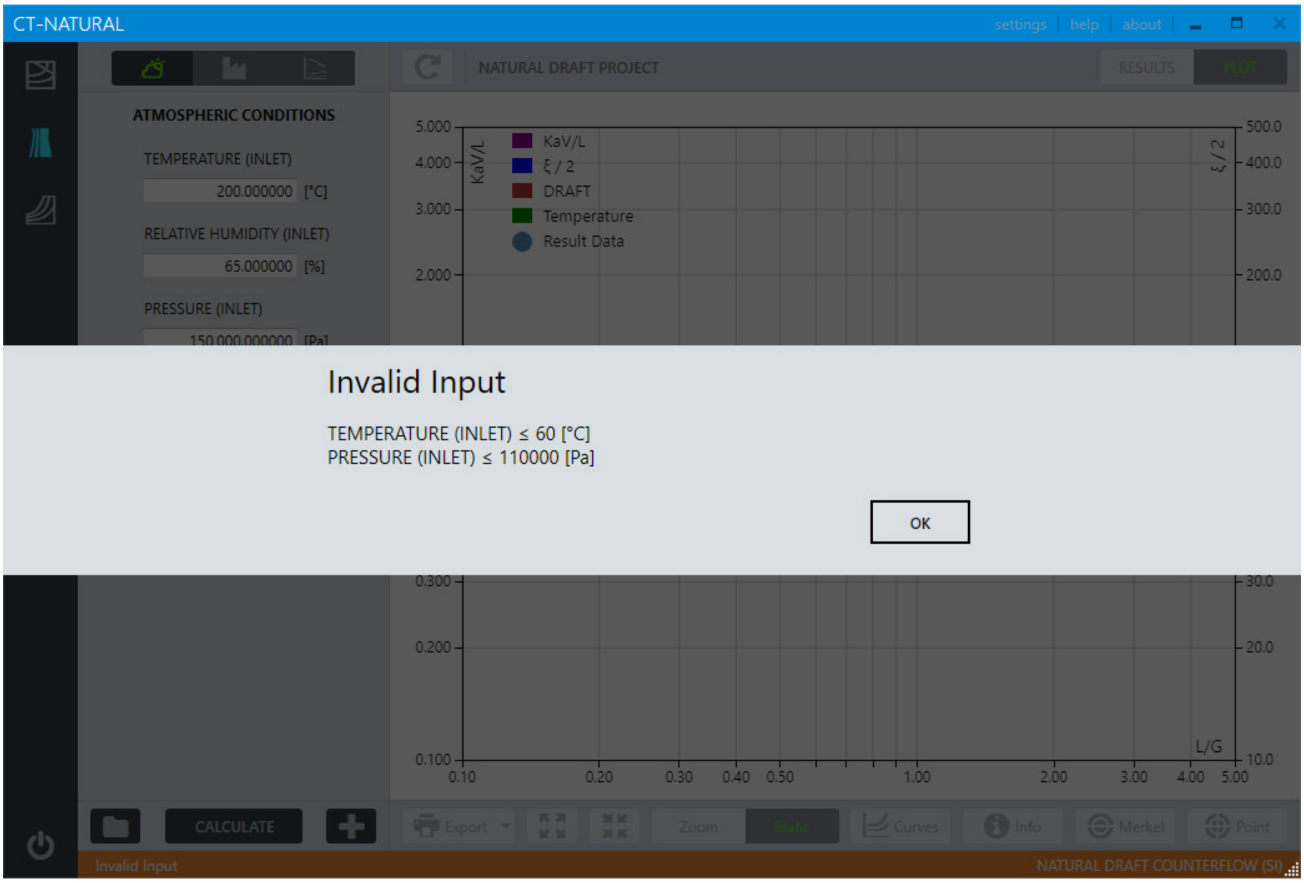


Figure 4.15 Validation of input variables for the calculation of Natural Draft projects.

4.9 Validation of Input Variables

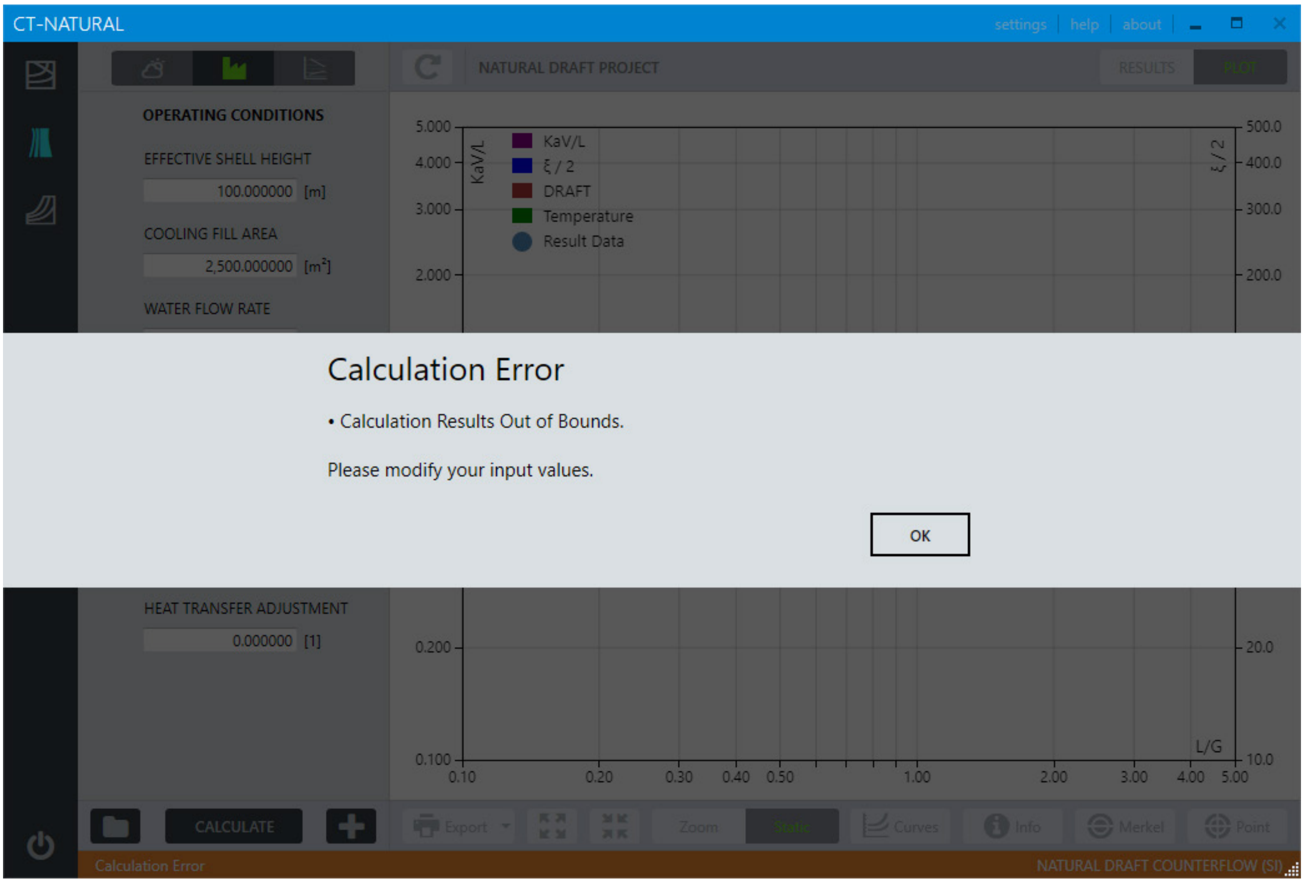


Figure 4.16 Message displaying the correct range of variables for a calculation project of Natural Draft.

Get Calculation Results Graphically

1. Click on the Info button to start the Graphical Mode (Figure 4.17). Select the Static mode of the Plot View Mode selector.
2. Click on a point (left-click mouse button) to select it. The crosshairs will be positioned on it, indicating that is selected. Click on the Point button to load the numerical results calculated for the selected point. This will be shown on the left side of the Plot Area.
3. To exit the Graphical Mode, click on the Info button.

Delete Calculation Results

1. Once a calculation point has been selected and its numerical results loaded from the database, click on the Delete Point button to remove the point from the Plot Area and to delete it from the database.

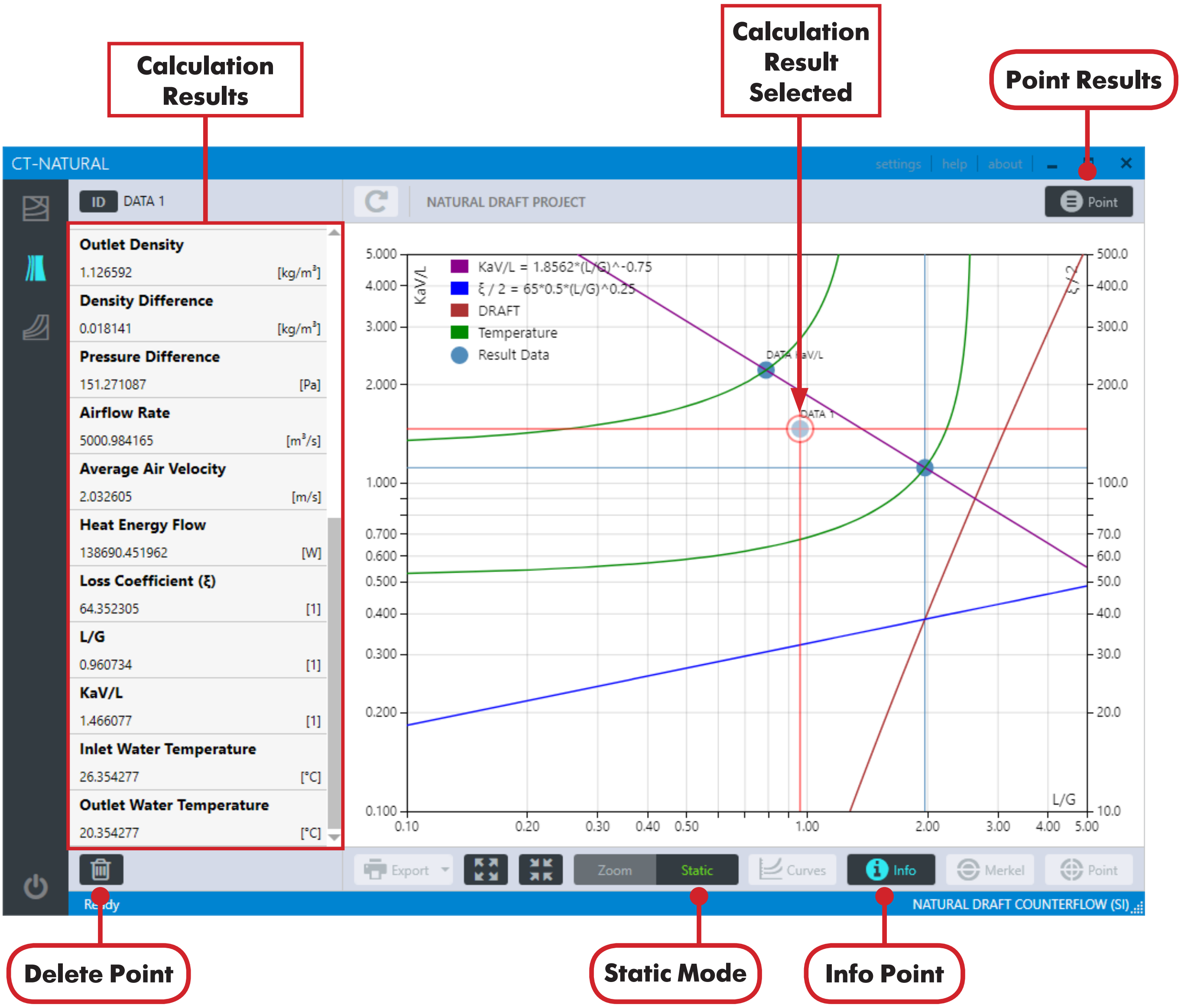


Figure 4.17 Calculation results from Plot Area in Natural Draft.

Get Numerical Results from a Project

1. Click on the RESULTS button to load all the numerical results calculations of a particular project. All the results will be displayed in a table format.
2. Click on the PLOT button to return to the Plot Area.

Export Numerical Results

1. Click on the Export button to export the numerical calculation results of all data points for a particular project. These can be exported to excel / pdf files.

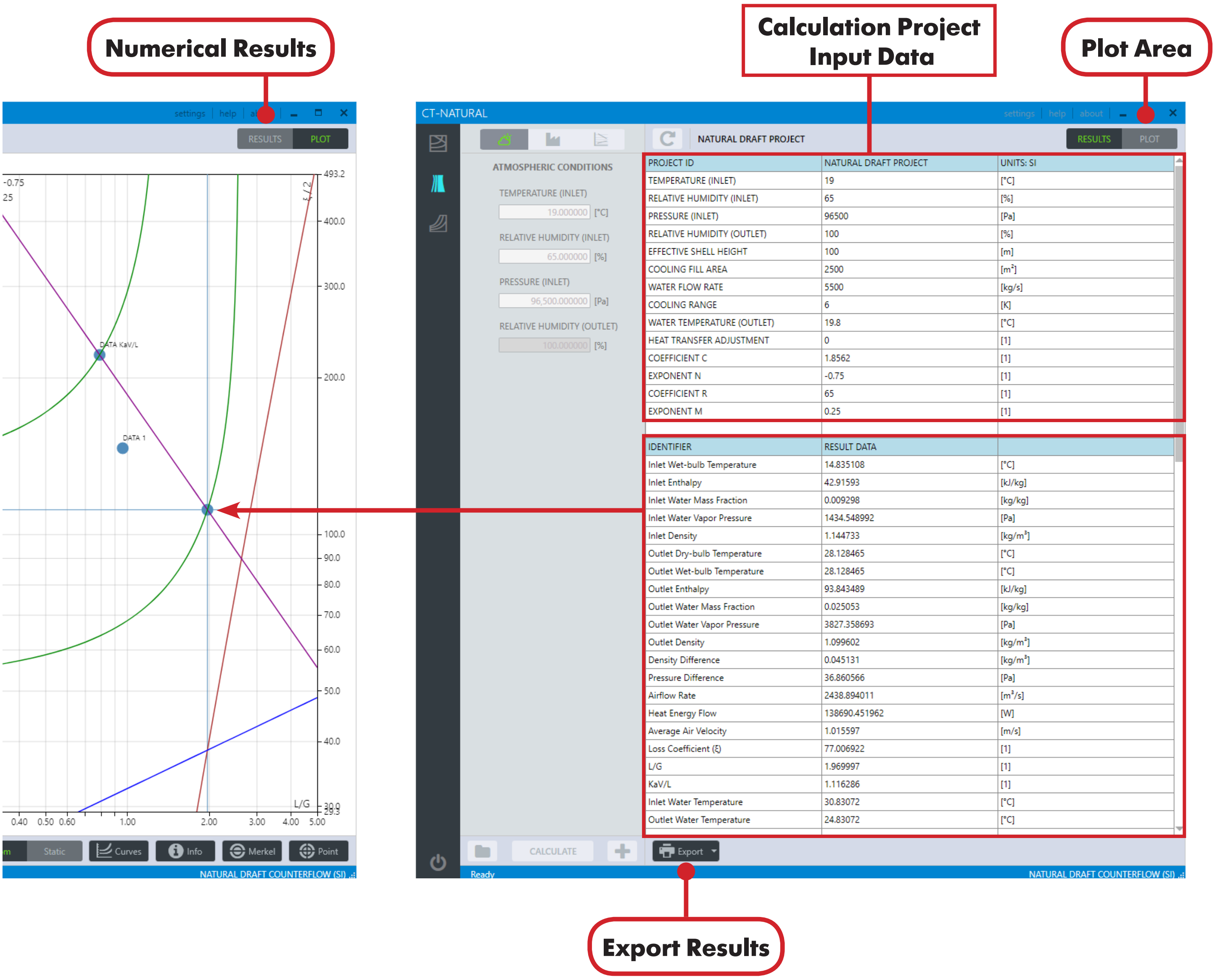
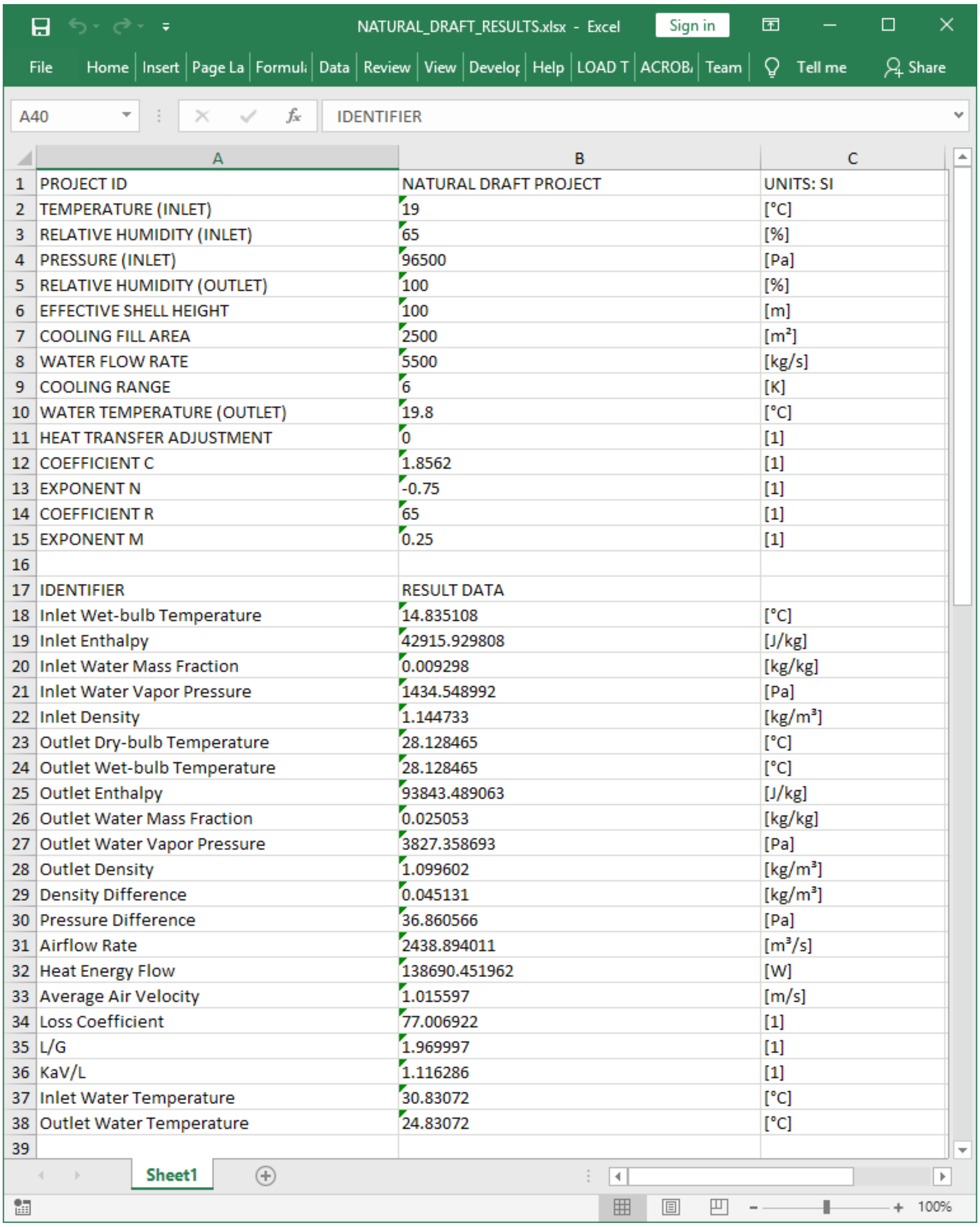


Figure 4.18 Numerical results from calculation project in Natural Draft.

PROJECT ID	NATURAL DRAFT PROJECT	UNITS: SI
TEMPERATURE (INLET)	19	[°C]
RELATIVE HUMIDITY (INLET)	65	[%]
PRESSURE (INLET)	96500	[Pa]
RELATIVE HUMIDITY (OUTLET)	100	[%]
EFFECTIVE SHELL HEIGHT	100	[m]
COOLING FILL AREA	2500	[m²]
WATER FLOW RATE	5500	[kg/s]
COOLING RANGE	6	[K]
WATER TEMPERATURE (OUTLET)	19.8	[°C]
HEAT TRANSFER ADJUSTMENT	0	[1]
COEFFICIENT C	1.8562	[1]
EXPONENT N	-0.75	[1]
COEFFICIENT R	65	[1]
EXPONENT M	0.25	[1]
IDENTIFIER	RESULT DATA	
Inlet Wet-bulb Temperature	14.835108	[°C]
Inlet Enthalpy	42915.929808	[J/kg]
Inlet Water Mass Fraction	0.009298	[kg/kg]
Inlet Water Vapor Pressure	1434.548992	[Pa]
Inlet Density	1.144733	[kg/m³]
Outlet Dry-bulb Temperature	28.128465	[°C]
Outlet Wet-bulb Temperature	28.128465	[°C]
Outlet Enthalpy	93843.489063	[J/kg]
Outlet Water Mass Fraction	0.025053	[kg/kg]
Outlet Water Vapor Pressure	3827.358693	[Pa]
Outlet Density	1.099602	[kg/m³]
Density Difference	0.045131	[kg/m³]
Pressure Difference	36.860566	[Pa]
Airflow Rate	2438.894011	[m³/s]
Heat Energy Flow	138690.451962	[W]
Average Air Velocity	1.015597	[m/s]
Loss Coefficient	77.006922	[1]
L/G	1.969997	[1]
KaV/L	1.116286	[1]
Inlet Water Temperature	30.83072	[°C]
Outlet Water Temperature	24.83072	[°C]

Figure 4.19 Example of pdf file results from calculations in a project of Natural Draft.



	A	B	C
1	PROJECT ID	NATURAL DRAFT PROJECT	UNITS: SI
2	TEMPERATURE (INLET)	19	[°C]
3	RELATIVE HUMIDITY (INLET)	65	[%]
4	PRESSURE (INLET)	96500	[Pa]
5	RELATIVE HUMIDITY (OUTLET)	100	[%]
6	EFFECTIVE SHELL HEIGHT	100	[m]
7	COOLING FILL AREA	2500	[m²]
8	WATER FLOW RATE	5500	[kg/s]
9	COOLING RANGE	6	[K]
10	WATER TEMPERATURE (OUTLET)	19.8	[°C]
11	HEAT TRANSFER ADJUSTMENT	0	[1]
12	COEFFICIENT C	1.8562	[1]
13	EXPONENT N	-0.75	[1]
14	COEFFICIENT R	65	[1]
15	EXPONENT M	0.25	[1]
16			
17	IDENTIFIER	RESULT DATA	
18	Inlet Wet-bulb Temperature	14.835108	[°C]
19	Inlet Enthalpy	42915.929808	[J/kg]
20	Inlet Water Mass Fraction	0.009298	[kg/kg]
21	Inlet Water Vapor Pressure	1434.548992	[Pa]
22	Inlet Density	1.144733	[kg/m³]
23	Outlet Dry-bulb Temperature	28.128465	[°C]
24	Outlet Wet-bulb Temperature	28.128465	[°C]
25	Outlet Enthalpy	93843.489063	[J/kg]
26	Outlet Water Mass Fraction	0.025053	[kg/kg]
27	Outlet Water Vapor Pressure	3827.358693	[Pa]
28	Outlet Density	1.099602	[kg/m³]
29	Density Difference	0.045131	[kg/m³]
30	Pressure Difference	36.860566	[Pa]
31	Airflow Rate	2438.894011	[m³/s]
32	Heat Energy Flow	138690.451962	[W]
33	Average Air Velocity	1.015597	[m/s]
34	Loss Coefficient	77.006922	[1]
35	L/G	1.969997	[1]
36	KaV/L	1.116286	[1]
37	Inlet Water Temperature	30.83072	[°C]
38	Outlet Water Temperature	24.83072	[°C]
39			

Figure 4.20 Example of excel file results from calculations in a project of Natural Draft.

4.11 Temperature Curves

Select Temperature Curve in the Plot Area

1. Click on the Curves button to show a list of all the temperature values that correspond to the curves on the Plot Area (Figure 4.21).
2. Click on a particular curve in the Temperature Curve´s list to select it on the Plot Area (the selected curve will change its color to red).
3. Click on the Curves button to return to the Plot Area.

Delete Temperature Curve

1. Click on the checkbox of the temperature curves to allow their deletion.
2. Click on the Delete Curve button to remove the temperature curves from the Plot Area and to delete them from the database.

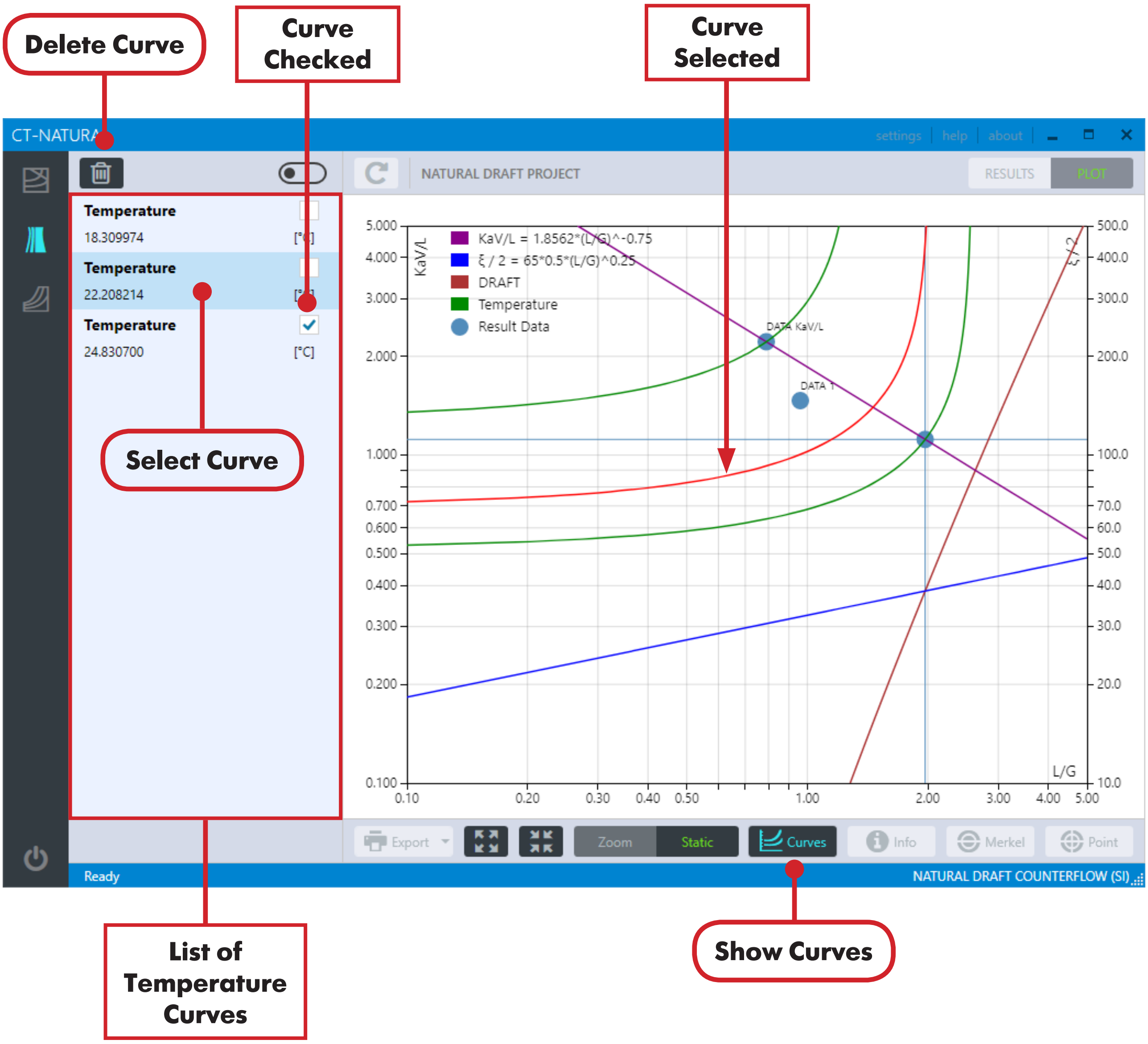


Figure 4.21 Temperature curve selection in Natural Draft.

Zoom Plot Area

1. Select the Zoom Mode of the Plot View Mode selector.
2. Push the left-click button on the mouse to select a zoom rectangle around the area of interest.
3. To reset the zoom to default values, click on the Reset Zoom button.

Export the Plot Area to pdf

1. Click on the Export button to export the current Plot Area to a pdf file.

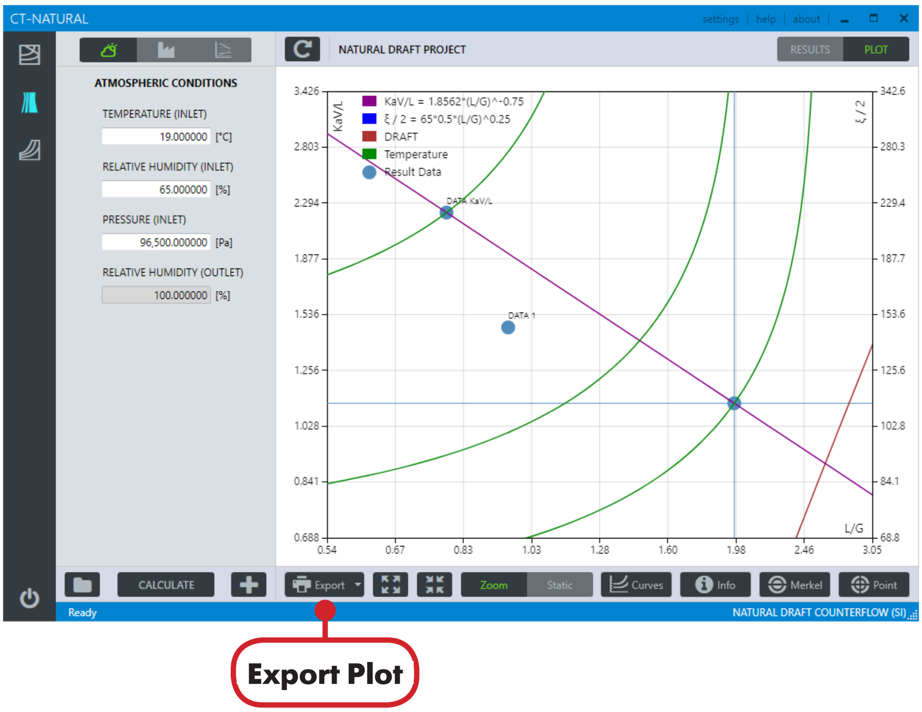


Figure 4.22 Zoom into the Plot Area of a Natural Draft project.

Save Current Zoom

1. Click on the Settings button of Natural Draft application.
2. Click on the SAVE button to save the current zoom to the project.

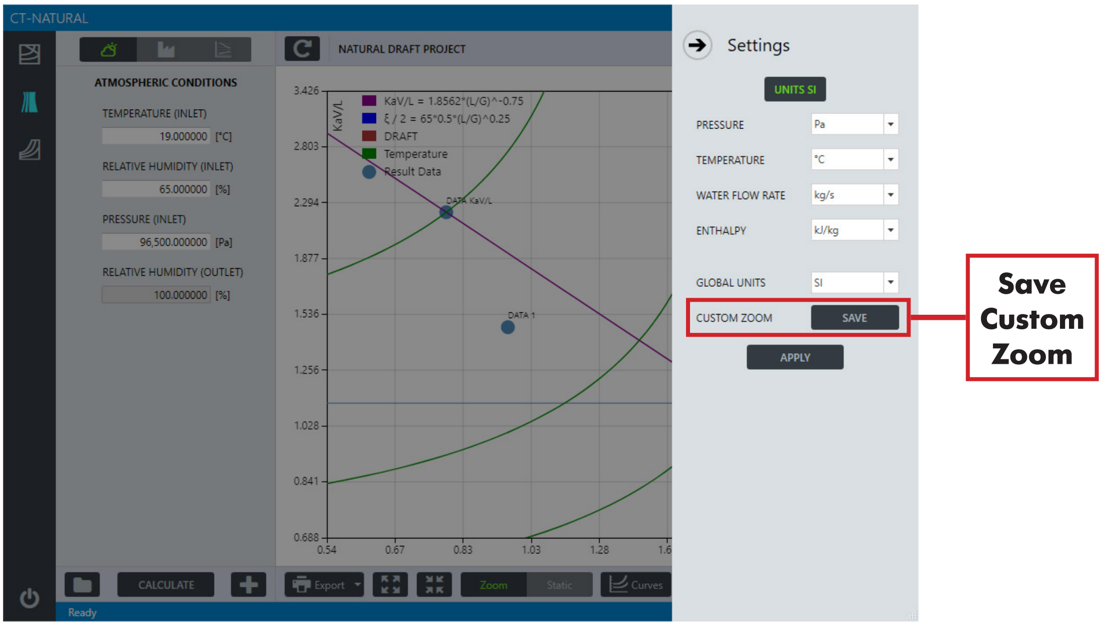


Figure 4.23 Settings of Natural Draft calculation projects.

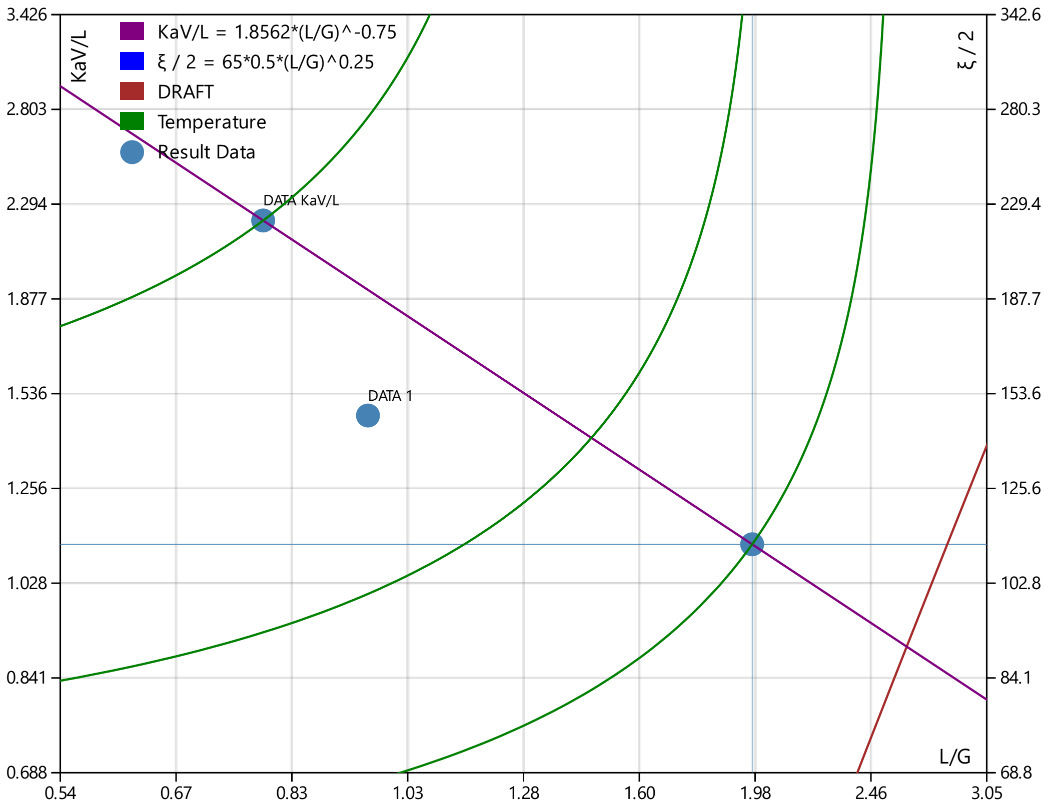


Figure 4.24 Zoom into the Plot Area of a Natural Draft project.

In order to illustrate the calculation capabilities of **Natural Draft** in SI units, three calculation cases of NDCWCTs with different atmospheric and operating conditions are calculated and their results compared with literature data. All the input data for these test cases has been previously presented in the publication from Wang et al [20].

Table 4.6 presents the input data for these cases as calculation projects in Natural Draft. Some modifications to the original data are necessary in order to allow the calculations. These are:

- The atmospheric conditions in the original data specifies the *Dry* and *Wet-bulb* temperatures and the barometric pressure at the inlet. **Natural Draft** requires the *Dry-bulb* temperature and the *Relative Humidity*. This value is found by the use of the **Psychrometrics Calculator** application.
- The value of the Inlet Water Temperature is specified in the original data. In **Natural Draft**, the value of the Inlet Water Temperature = Outlet Water Temperature + Cooling Range. So, in order to set the value of Cooling Range, the following formula is used:
  Cooling Range = Inlet Water Temperature - Outlet Water Temperature
- The equation of the Fill Transfer Characteristic is of the form $c\lambda^n$, where $\lambda = G/L$. **Natural Draft** requires the form $\lambda = L/G$. The *Exponent N* input variable is modified according to:

$$c\left(G/L\right)^n = c\left(L/G\right)^{-n}$$

- The Loss Coefficient curve (Resistance Curve) is not specified. The *Coefficient R* is considered to be the constant value of the Resistance Curve in **Natural Draft**.

Input Variable	CASE 1	CASE 2	CASE 3
ATMOSPHERIC CONDITIONS			
TEMPERATURE (INLET) [°C]	30	30.57	32.25
RELATIVE HUMIDITY (INLET) [%]	67.064828	66.247146	69.391536
PRESSURE (INLET) [Pa]	100000.0	99750.0	100800.0
RELATIVE HUMIDITY (OUTLET) [%]	100.0	100.0	100.0
OPERATING CONDITIONS			
EFFECTIVE SHELL HEIGHT [m]	138.5	139.6	124.0
COOLING FILL AREA [m²]	9161.0	9075.0	6533.0
WATER FLOW RATE [kg/s]	18889.0	19694.0	16250.0
COOLING RANGE [K]	8.66	8.72	9.03
WATER TEMPERATURE (OUTLET) [°C]	31.34	31.26	33.52
HEAT TRANSFER ADJUSTMENT [1]	0	0	0
COEFFICIENTS			
COEFFICIENT C [1]	1.84	1.616	1.74
EXPONENT N [1]	-0.63	-0.607	-0.68
COEFFICIENT R [1]	78.4592	49.0025	51.1345
EXPONENT M [1]	0	0	0

Table 4.6 Examples of input data for calculation projects, from Wang et al [], with adaptations to Natural Draft.

Figures 4.25 to 4.27 depict the graphical user interface in Natural Draft with the input variables for the calculation examples set in Table 4.6.

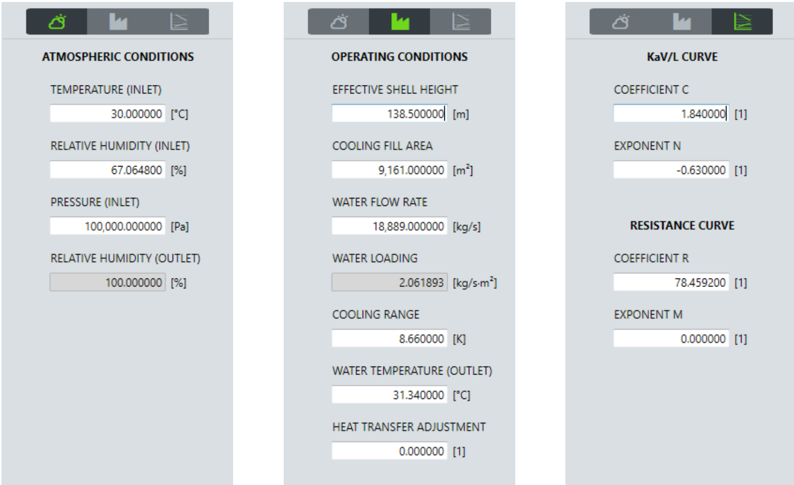


Figure 4.25 Input variables in Natural Draft for example calculation case 1.

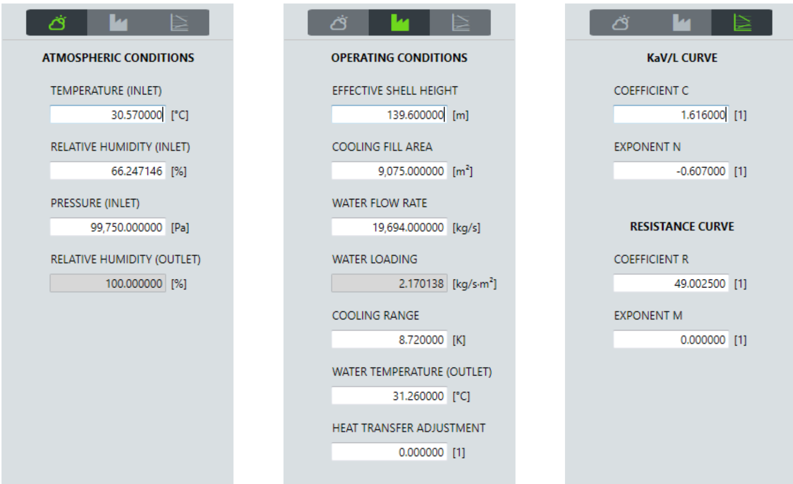


Figure 4.26 Input variables in Natural Draft for example calculation case 2.

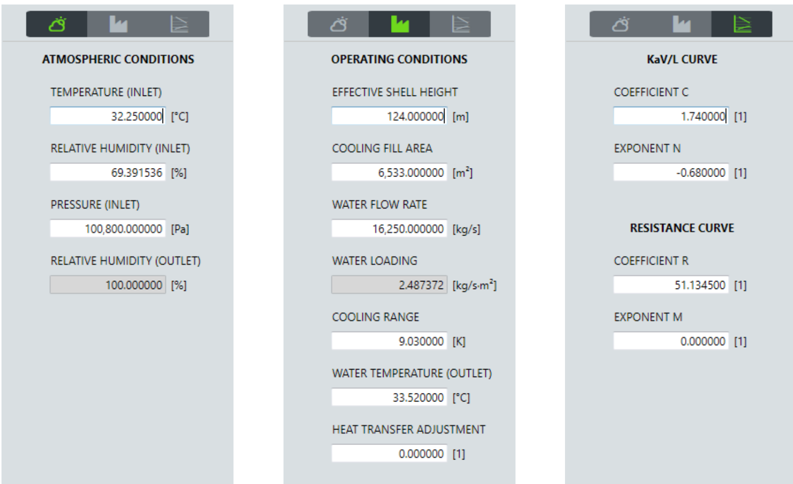


Figure 4.27 Input variables in Natural Draft for example calculation case 3.

Calculation Results

The calculation results for the examples set in Table 4.6 are condensed in Table 4.7. Figures 4.28 to 4.33 present the numerical and graphical calculation results as presented by **Natural Draft** for the three cases.

RESULT VARIABLE	CASE 1	CASE 2	CASE 3
Inlet Wet-bulb Temperature [°C]	24.999995	25.369992	27.439994
Inlet Enthalpy [J/kg]	76983.605017	78694.360817	87412.415624
Inlet Water Mass Fraction [kg/kg]	0.017986	0.018407	0.021025
Inlet Water Vapor Pressure [Pa]	2860.549935	2919.487563	3364.550667
Inlet Density [kg/m³]	1.13719	1.131928	1.13577
Outlet Dry-bulb Temperature [°C]	36.715777	36.041484	38.867906
Outlet Wet-bulb Temperature [°C]	36.715777	36.041484	38.867906
Outlet Enthalpy [J/kg]	142720.214874	138183.316839	158121.354556
Outlet Water Mass Fraction [kg/kg]	0.039598	0.038223	0.044267
Outlet Water Vapor Pressure [Pa]	6213.957684	5988.540793	6983.29708
Outlet Density [kg/m³]	1.098407	1.098937	1.096547
Density Difference [kg/m³]	0.038783	0.032991	0.039223
Pressure Difference [Pa]	50.666229	43.368128	45.544191
Airflow Rate [m³/s]	9594.972168	11181.641247	8039.156522
Heat Energy Flow [W]	686642.827341	720848.382561	615857.371176
Average Air Velocity [m/s]	1.084353	1.269126	1.274562
Loss Coefficient [1]	78.4592	49.0025	51.1345
L/G [1]	1.73114	1.556	1.779724
KaV/L [1]	1.302173	1.235639	1.175735
Inlet Water Temperature [°C]	40.202271	40.222692	42.813686
Outlet Water Temperature [°C]	31.542271	31.502692	33.783686

Table 4.7 Calculation results in Natural Draft for calculation examples in Table 5.6.

IDENTIFIER	RESULT DATA	
Inlet Wet-bulb Temperature	24.999995	[°C]
Inlet Enthalpy	76983.605017	[J/kg]
Inlet Water Mass Fraction	0.017986	[kg/kg]
Inlet Water Vapor Pressure	2860.549935	[Pa]
Inlet Density	1.13719	[kg/m³]
Outlet Dry-bulb Temperature	36.715777	[°C]
Outlet Wet-bulb Temperature	36.715777	[°C]
Outlet Enthalpy	142720.214874	[J/kg]
Outlet Water Mass Fraction	0.039598	[kg/kg]
Outlet Water Vapor Pressure	6213.957684	[Pa]
Outlet Density	1.098407	[kg/m³]
Density Difference	0.038783	[kg/m³]
Pressure Difference	50.666229	[Pa]
Airflow Rate	9594.972168	[m³/s]
Heat Energy Flow	686642.827341	[W]
Average Air Velocity	1.084353	[m/s]
Loss Coefficient	78.4592	[1]
L/G	1.73114	[1]
KaV/L	1.302173	[1]
Inlet Water Temperature	40.202271	[°C]
Outlet Water Temperature	31.542271	[°C]

Figure 4.28 Numerical calculation results in Natural Draft for calculation case 1.

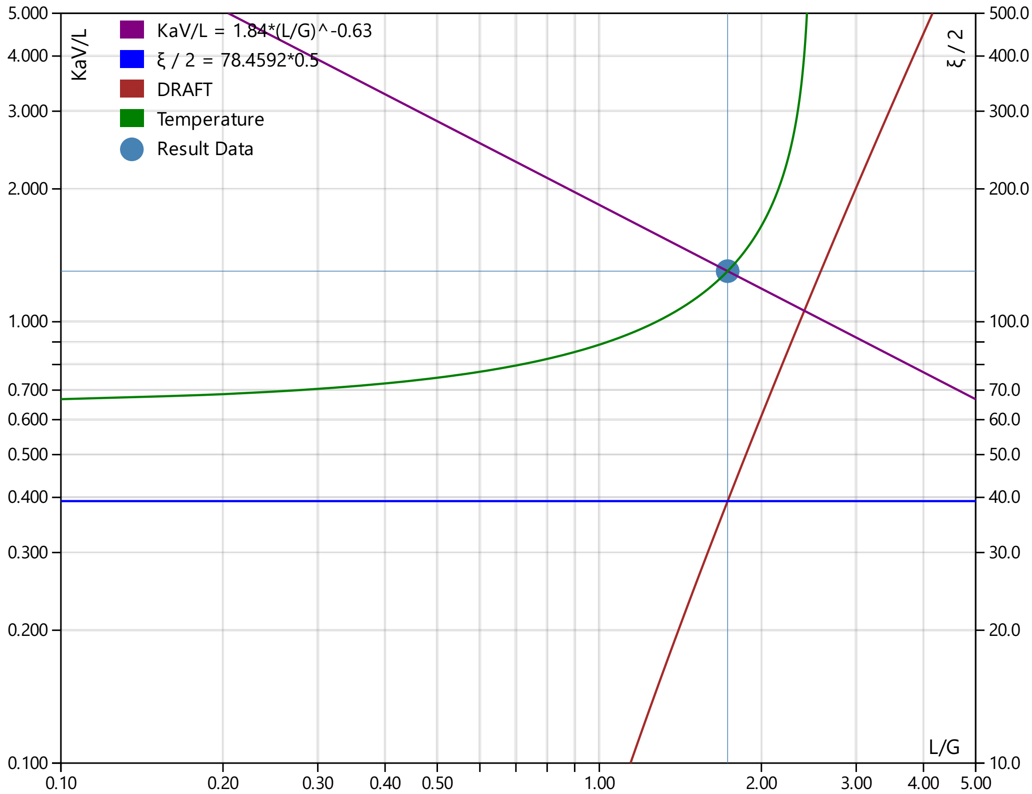


Figure 4.29 Graphical results in Natural Draft for calculation case 1.

IDENTIFIER	RESULT DATA	
Inlet Wet-bulb Temperature	25.369992	[°C]
Inlet Enthalpy	78694.360817	[J/kg]
Inlet Water Mass Fraction	0.018407	[kg/kg]
Inlet Water Vapor Pressure	2919.487563	[Pa]
Inlet Density	1.131928	[kg/m³]
Outlet Dry-bulb Temperature	36.041484	[°C]
Outlet Wet-bulb Temperature	36.041484	[°C]
Outlet Enthalpy	138183.316839	[J/kg]
Outlet Water Mass Fraction	0.038223	[kg/kg]
Outlet Water Vapor Pressure	5988.540793	[Pa]
Outlet Density	1.098937	[kg/m³]
Density Difference	0.032991	[kg/m³]
Pressure Difference	43.368128	[Pa]
Airflow Rate	11181.641247	[m³/s]
Heat Energy Flow	720848.382561	[W]
Average Air Velocity	1.269126	[m/s]
Loss Coefficient	49.0025	[1]
L/G	1.556	[1]
KaV/L	1.235639	[1]
Inlet Water Temperature	40.222692	[°C]
Outlet Water Temperature	31.502692	[°C]

Figure 4.30 Numerical calculation results in Natural Draft for calculation case 2.

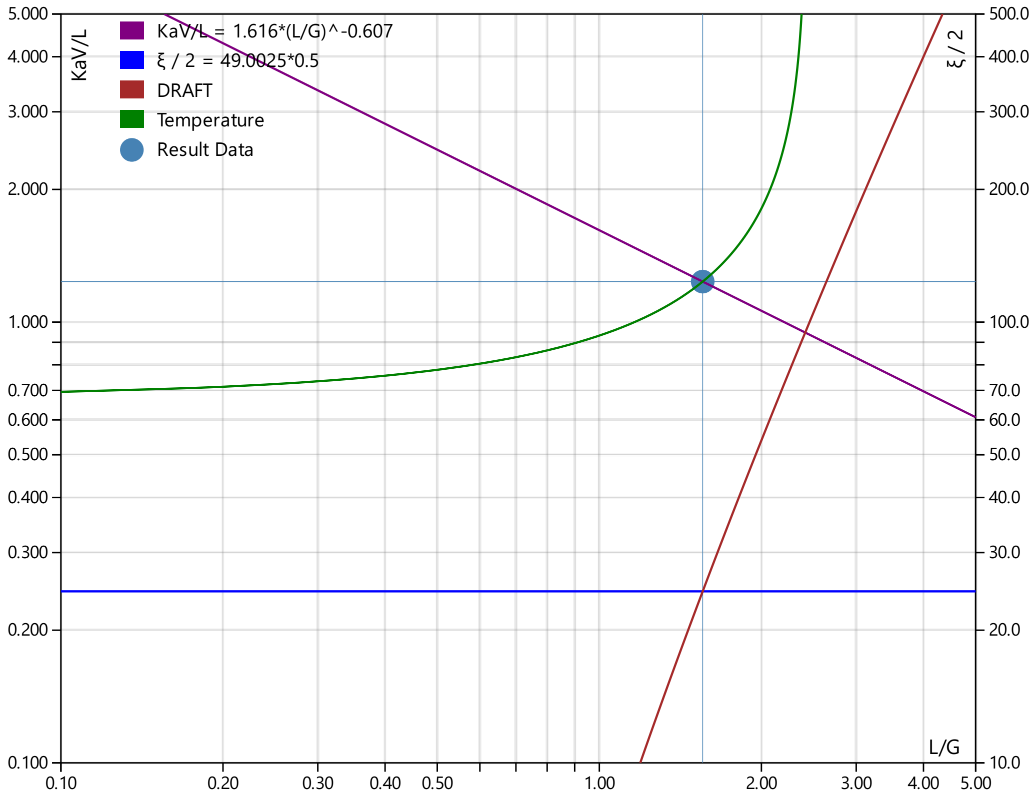


Figure 4.31 Graphical results in Natural Draft for calculation case 2.

IDENTIFIER	RESULT DATA	
Inlet Wet-bulb Temperature	27.439994	[°C]
Inlet Enthalpy	87412.415624	[J/kg]
Inlet Water Mass Fraction	0.021025	[kg/kg]
Inlet Water Vapor Pressure	3364.550667	[Pa]
Inlet Density	1.13577	[kg/m³]
Outlet Dry-bulb Temperature	38.867906	[°C]
Outlet Wet-bulb Temperature	38.867906	[°C]
Outlet Enthalpy	158121.354556	[J/kg]
Outlet Water Mass Fraction	0.044267	[kg/kg]
Outlet Water Vapor Pressure	6983.29708	[Pa]
Outlet Density	1.096547	[kg/m³]
Density Difference	0.039223	[kg/m³]
Pressure Difference	45.544191	[Pa]
Airflow Rate	8039.156522	[m³/s]
Heat Energy Flow	615857.371176	[W]
Average Air Velocity	1.274562	[m/s]
Loss Coefficient	51.1345	[1]
L/G	1.779724	[1]
KaV/L	1.175735	[1]
Inlet Water Temperature	42.813686	[°C]
Outlet Water Temperature	33.783686	[°C]

Figure 4.32 Numerical calculation results in Natural Draft for calculation case 3.

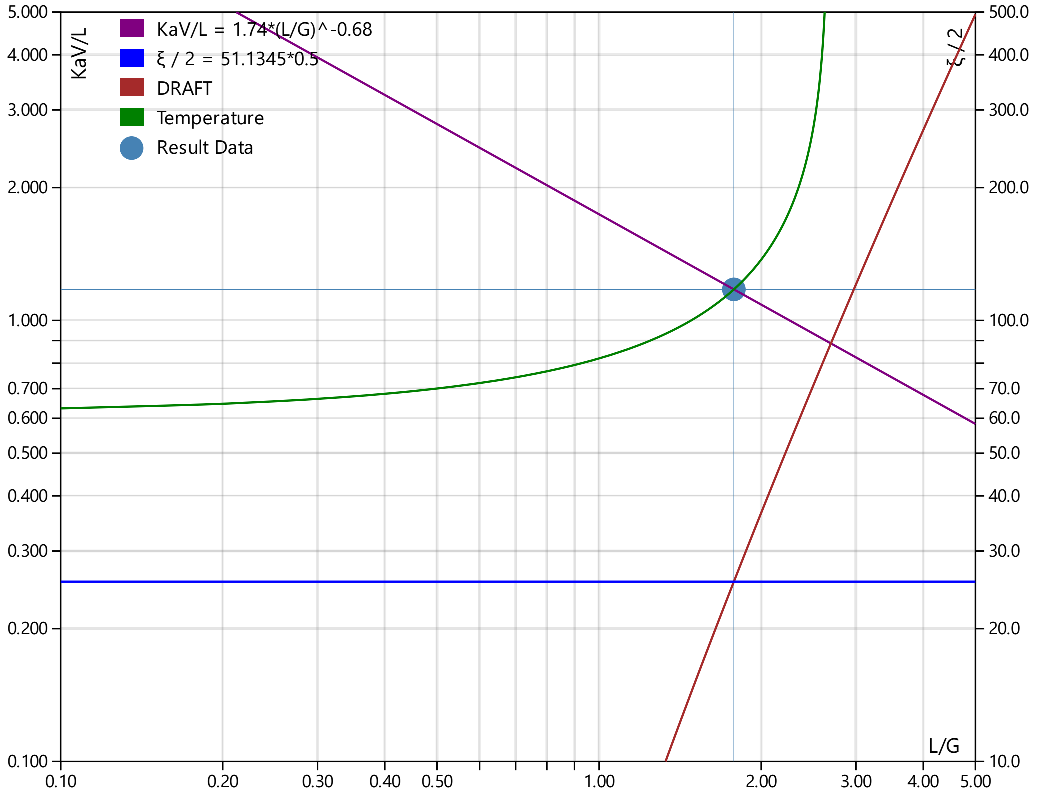


Figure 4.33 Graphical results in Natural Draft for calculation case 3.

Comparison with Literature Data

Tables 4.8, 4.9 and 4.10 present the comparison between the numerical results of the *Inlet and Outlet Water Temperature* calculated with **Natural Draft** and the field data presented in the publication by Wang et al [20]. A strong agreement can be established by considering the low relative error in both cases.

VARIABLE	CASE 1 (LITERATURE)	CASE 1 (CALCULATED)	RELATIVE ERROR
Inlet Water Temperature [°C]	40.0	40.202271	***0.506%***
Outlet Water Temperature [°C]	31.34	31.542271	***0.63%***

Table 4.8 Comparison between field data as reported by Wang et al [20] and numerical results for calculation case 1.

VARIABLE	CASE 2 (LITERATURE)	CASE 2 (CALCULATED)	RELATIVE ERROR
Inlet Water Temperature [°C]	39.98	40.222692	***0.607%***
Outlet Water Temperature [°C]	31.26	31.502692	***0.77%***

Table 4.9 Comparison between field data as reported by Wang et al [20] and numerical results for calculation case 2.

VARIABLE	CASE 3 (LITERATURE)	CASE 3 (CALCULATED)	RELATIVE ERROR
Inlet Water Temperature [°C]	42.55	42.813686	***0.619%***
Outlet Water Temperature [°C]	33.52	33.783686	***0.77%***

Table 4.10 Comparison between field data as reported by Wang et al [20] and numerical results for calculation case 3.

Overview

Psychrometrics Calculator allows the calculation of physical properties of humid air, water, steam, ice and psychrometrics commonly used in the design and operation of cooling towers.

Description

- Calculation of 42 properties of humid air, water, steam, ice and psychrometrics.
- It allows for 17 combinations of two thermodynamic properties to be entered as input variables:
  - Dry-bulb Temperature / Wet-bulb Temperature
  - Dry-bulb Temperature / Dew Point Temperature
  - Dry-bulb Temperature / Relative Humidity
  - Dry-bulb Temperature / Humidity Ratio
  - Dry-bulb Temperature / Specific Enthalpy
  - Dry-bulb Temperature / Specific Volume
  - Wet-bulb Temperature / Dew Point Temperature
  - Wet-bulb Temperature / Relative Humidity
  - Wet-bulb Temperature / Humidity Ratio
  - Dew Point Temperature / Relative Humidity
  - Dew Point Temperature / Specific Enthalpy
  - Dew Point Temperature / Specific Volume
  - Relative Humidity / Humidity Ratio
  - Relative Humidity / Specific Enthalpy
  - Relative Humidity / Specific Volume
  - Humidity Ratio / Specific Enthalpy
  - Humidity Ratio / Specific Volume
- Supports input parameters and calculation results in both SI (metric) and I-P (english) system of units.
- For each combination of input thermodynamic variables, it calculates and provides the user with information about the appropriate values in the valid range of computations.
- Calculation results can be saved to a to a database for later retrieval.
- Calculation results can be exported to excel/pdf file formats .

Mathematical Models

Calculation of the properties of humid air, water, steam, ice and psychrometrics are based on the precision provided by the numerical formulations for the evaluation of their thermodynamic and transport properties:

Properties of Humid Air

- Thermodynamic and psychrometrics property algorithms from the ASHRAE Research Project 1485.
- Scientific Formulation IAPWS-95, IAPWS Formulation 2008 and IAPWS Formulation 2006. Properties of dry air are from the NIST Reference equation of Lemmon et al.

Properties of Water and Steam

- Formulations from the IAPWS (International Association for the Properties of Water and Steam) IAPWS-IF97 Industrial formulation (Revision 2007) and related models.

Table 5.1 shows the properties calculated by **Psychrometrics Calculator** and their corresponding possible calculation units in SI or I-P.

Property	SI Units	I-P Units
Dry-Bub Temperature	°C	°F
Wet-Bulb Temperature	°C	°F
Dew Point Temperature	°C	°F
Humid Air Pressure	Pa, kPa, bar, mmHg	psia, inHg, inH2O, atm
Water Vapor Partial Pressure	Pa, kPa, bar, mmHg	psia, inHg, inH2O, atm
Dry Air Partial Pressure	Pa, kPa, bar, mmHg	psia, inHg, inH2O, atm
Saturation Water Vapor Pressure	Pa, kPa, bar, mmHg	psia, inHg, inH2O, atm
Dry Air Mole Fraction	[-]	[-]
Water Mole Fraction	[-]	[-]
Dry Air Mass Fraction	[-]	[-]
Water Mass Fraction	[-]	[-]
Humidity Ratio	kg(w)/kg)(da), g(w)/kg(da)	lb(w)/lb(da), gr(w)/lb(da)
Saturation Humidity Ratio	kg(w)/kg)(da), g(w)/kg(da)	lb(w)/lb(da), gr(w)/lb(da)
Relative Humidity	[%]	[%]
Absolute Humidity	kg(w)/m³	lb(w)/ft³
Parts per million by weight	ppmw	ppmw
Parts per million by volume	ppmv	ppmv
Enhancement Factor	[-]	[-]
Specific Volume of Dry Air	m³/kg, cm³/kg	ft³/lb, in³/lb
Specific Volume of Humid Air	m³/kg, cm³/kg	ft³/lb, in³/lb
Specific Volume of Saturated Water	m³/kg, cm³/kg	ft³/lb, in³/lb
Specific Volume of Saturated Ice	m³/kg, cm³/kg	ft³/lb, in³/lb
Specific Volume of Water Vapor	m³/kg, cm³/kg	ft³/lb, in³/lb
Density of Dry Air	kg/m³, g/m³	lb/ft³, lb/in³
Density of Humid Air	kg/m³, g/m³	lb/ft³, lb/in³
Density of Saturated Water	kg/m³, g/m³	lb/ft³, lb/in³
Density of Saturated Ice	kg/m³, g/m³	lb/ft³, lb/in³
Density of Water Vapor	kg/m³, g/m³	lb/ft³, lb/in³
Specific Enthalpy of Dry Air	J/kg, kJ/kg	Btu/lb, ft lbf/lb
Specific Enthalpy of Humid Air	J/kg, kJ/kg	Btu/lb, ft lbf/lb
Specific Enthalpy of Saturated Water	J/kg, kJ/kg	Btu/lb, ft lbf/lb
Specific Enthalpy of Saturated Ice	J/kg, kJ/kg	Btu/lb, ft lbf/lb
Specific Enthalpy of Water Vapor	J/kg, kJ/kg	Btu/lb, ft lbf/lb
Specific Entropy of Dry Air	J/(kg·K), kJ/(kg·K)	Btu/(lb·°R), ft lbf/ (lb·°R)
Specific Entropy of Humid Air	J/(kg·K), kJ/(kg·K)	Btu/(lb·°R), ft lbf/ (lb·°R)
Specific Entropy of Saturated Water	J/(kg·K), kJ/(kg·K)	Btu/(lb·°R), ft lbf/ (lb·°R)
Specific Entropy of Saturated Ice	J/(kg·K), kJ/(kg·K)	Btu/(lb·°R), ft lbf/ (lb·°R)
Specific Entropy of Water Vapor	J/(kg·K), kJ/(kg·K)	Btu/(lb·°R), ft lbf/ (lb·°R)
Specific Internal Energy of Dry Air	J/kg, kJ/kg	Btu/lb, ft lbf/lb
Specific Internal Energy of Humid Air	J/kg, kJ/kg	Btu/lb, ft lbf/lb
Specific Isobaric Heat Capacity of Humid Air	kJ/(kg·K)	Btu/(lb·°R)
Compressibility of Humid Air	[-]	[-]

Table 5.1 Properties and their units calculated in Psychrometrics Calculator.

The full ranges of input variables for the Psychrometrics Calculator in SI and I-P system of units:

Property	Range in SI Units	SI Units
DRY-BULB TEMPERATURE	$-143.15 \leqslant Tdb \leqslant 350.0$	°C
WET-BULB TEMPERATURE	$-143.15 \leqslant Twb \leqslant 350.0$	°C
DEW POINT TEMPERATURE	$-143.15 \leqslant Tdp \leqslant 350.0$	°C
RELATIVE HUMIDITY	$0 .0 \leqslant RH \leqslant 100.0$	[%]
HUMIDITY RATIO	$0.0 \leqslant W \leqslant 10.0$	kg/kg
SPECIFIC ENTHALPY	$-311.357 \leqslant h \leqslant 32135.848$	kJ/kg
SPECIFIC VOLUME	$1.469E-3 \leqslant v \leqslant 3.055E5$	m^3/kg
PRESSURE	$10.0 \leqslant P \leqslant 10.0E6$	Pa

Property	Range in I-P Units	I-P Units
DRY-BULB TEMPERATURE	$-225.67 \leqslant Tdb \leqslant 662.0$	°F
WET-BULB TEMPERATURE	$-225.67 \leqslant Twb \leqslant 662.0$	°F
DEW POINT TEMPERATURE	$-225.67 \leqslant Tdp \leqslant 662.0$	°F
RELATIVE HUMIDITY	$0 .0 \leqslant RH \leqslant 100.0$	[%]
HUMIDITY RATIO	$0.0 \leqslant W \leqslant 10.0$	lb/lb
SPECIFIC ENTHALPY	$-126.174 \leqslant h \leqslant 13823.61$	Btu/lb
SPECIFIC VOLUME	$2.353E-2 \leqslant v \leqslant 4.893E6$	ft^3/lb
PRESSURE	$0.00145 \leqslant P \leqslant 1450.4$	psia

Table 5.2 Full ranges of input variables in Psychrometrics Calculator.

The full ranges of input variables for the Psychrometrics Calculator (Evaluation Version) in SI and I-P system of units:

Property	Range in SI Units	SI Units
DRY-BULB TEMPERATURE	-143.15 ≤ Tdb ≤ 350.0	°C
WET-BULB TEMPERATURE	-143.15 ≤ Twb ≤ 350.0	°C
DEW POINT TEMPERATURE	-143.15 ≤ Tdp ≤ 350.0	°C
RELATIVE HUMIDITY	0.0 ≤ RH ≤ 100.0	[%]
HUMIDITY RATIO	0.0 ≤ W ≤ 10.0	kg/kg
SPECIFIC ENTHALPY	-311.357 ≤ h ≤ 32135.848	kJ/kg
SPECIFIC VOLUME	1.469E-3 ≤ v ≤ 3.055E5	m^3/kg
PRESSURE	P = 100000.0	Pa

Property	Range in I-P Units	I-P Units
DRY-BULB TEMPERATURE	-225.67 ≤ Tdb ≤ 662.0	°F
WET-BULB TEMPERATURE	-225.67 ≤ Twb ≤ 662.0	°F
DEW POINT TEMPERATURE	-225.67 ≤ Tdp ≤ 662.0	°F
RELATIVE HUMIDITY	0.0 ≤ RH ≤ 100.0	[%]
HUMIDITY RATIO	0.0 ≤ W ≤ 10.0	lb/lb
SPECIFIC ENTHALPY	-126.174 ≤ h ≤ 13823.61	Btu/lb
SPECIFIC VOLUME	2.353E-2 ≤ v ≤ 4.893E6	ft^3/lb
PRESSURE	P = 14.503774	psia

Table 5.3 Ranges of input variables in Psychrometrics Calculator (Evaluation Version).

The Graphical User Interface for **Psychrometrics Calculator** is shown in Figure 5.1. By selecting the button denoted as Psychrometrics on the left side of the application, the interface is presented.

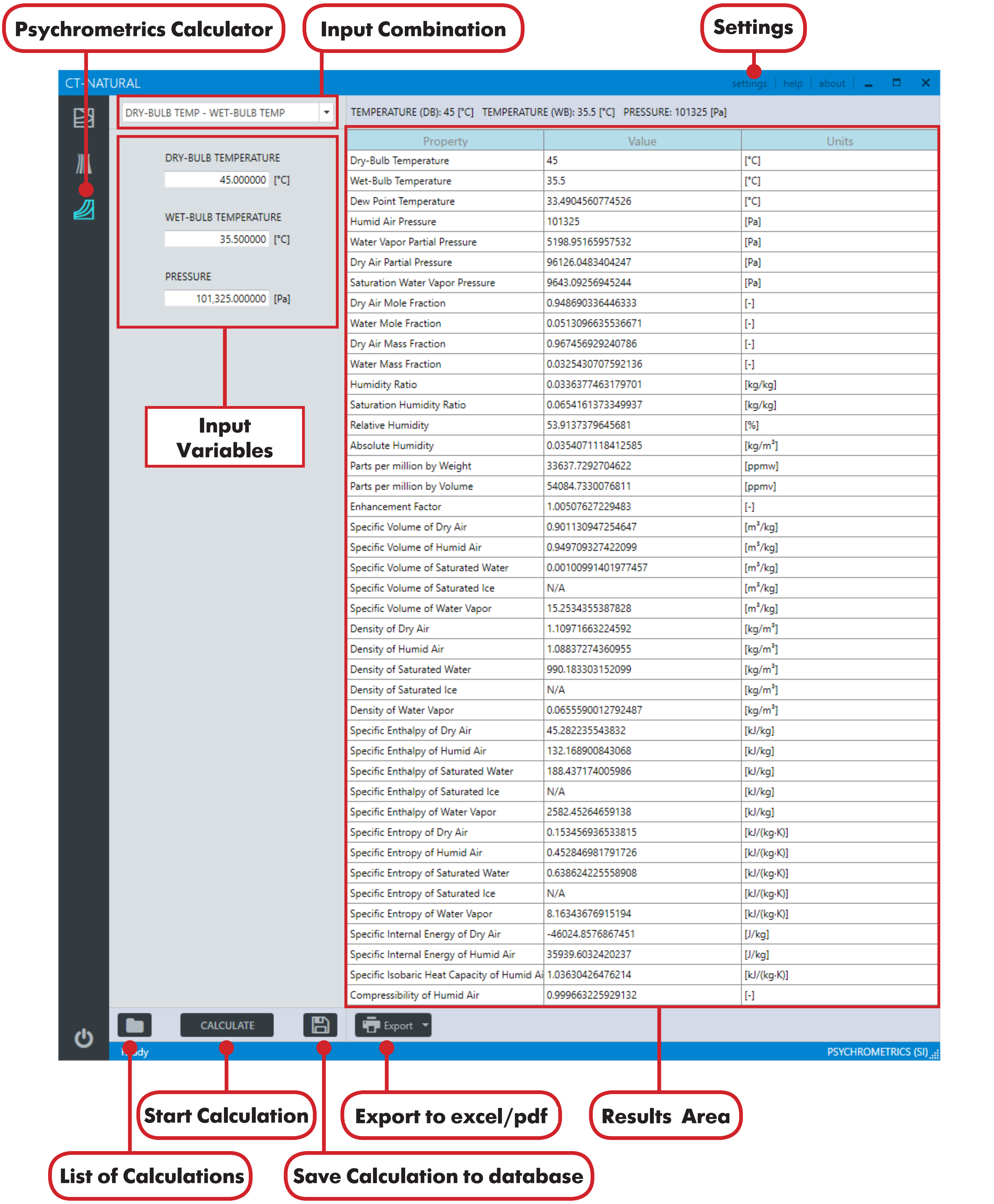


Figure 5.1 Graphical User Interface for Psychrometrics Calculator.

Settings

1. Click on the Settings button to show the settings screen for Psychrometrics Calculator (Figure 5.2).
2. Select the System of Units for calculations and their corresponding units. Click on the APPLY button to save this settings configuration.
3. Any new input combination will be calculated using those selected system of units and variable units.

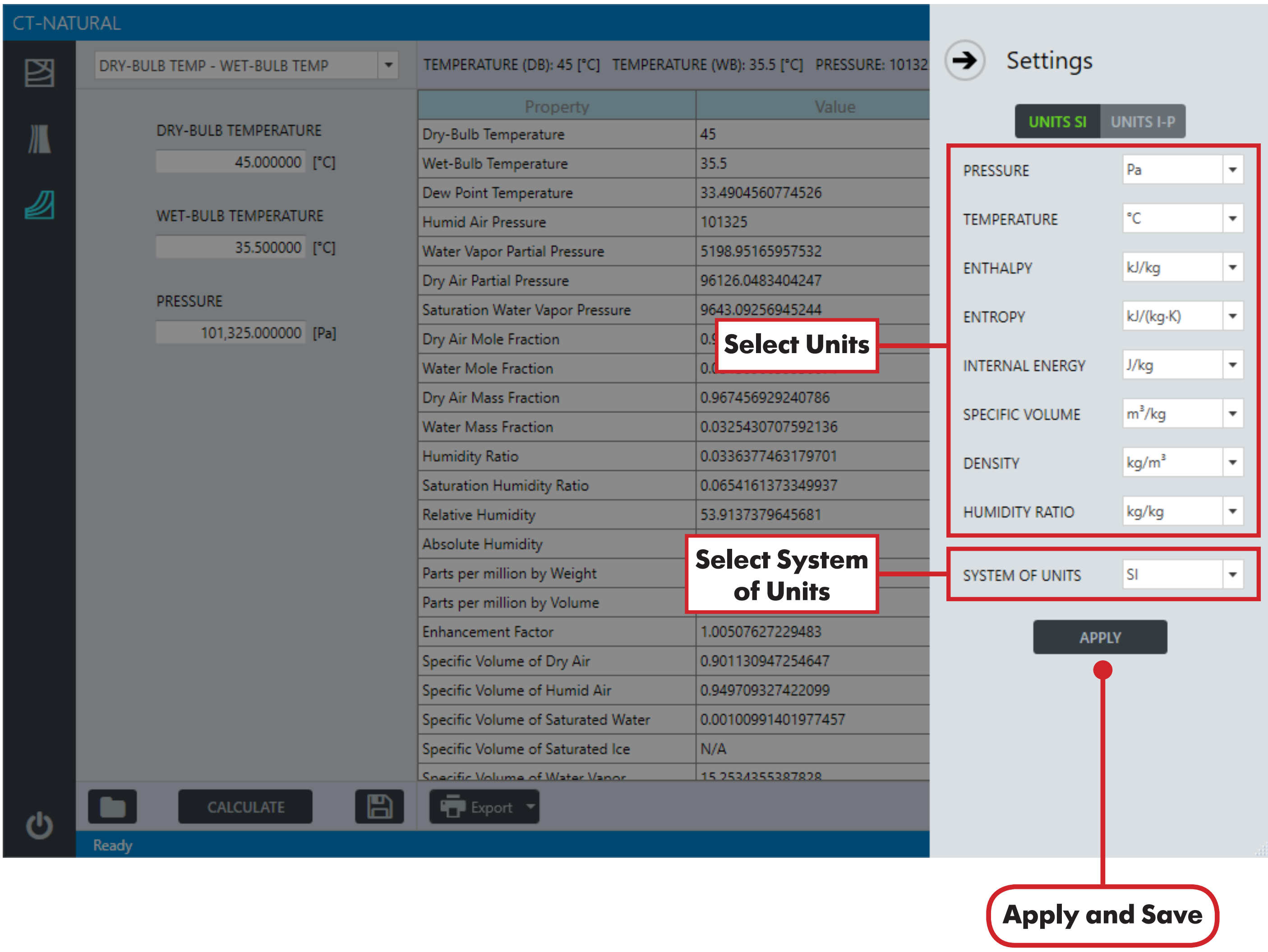


Figure 5.2 Settings for Psychrometrics Calculator.

Calculation of Properties

1. Select an input combination of variables from the drop down list in the main interface (Figure 5.3).
2. Enter the input variables and the pressure in their corresponding units.
3. Click on the CALCULATE button to start the calculation.

Exporting Results from the Main Interface

Once a psychrometrics calculation has been completed, the numerical results that are shown on the Results Area can be exported to an excel / pdf file format by clicking on the Export button.

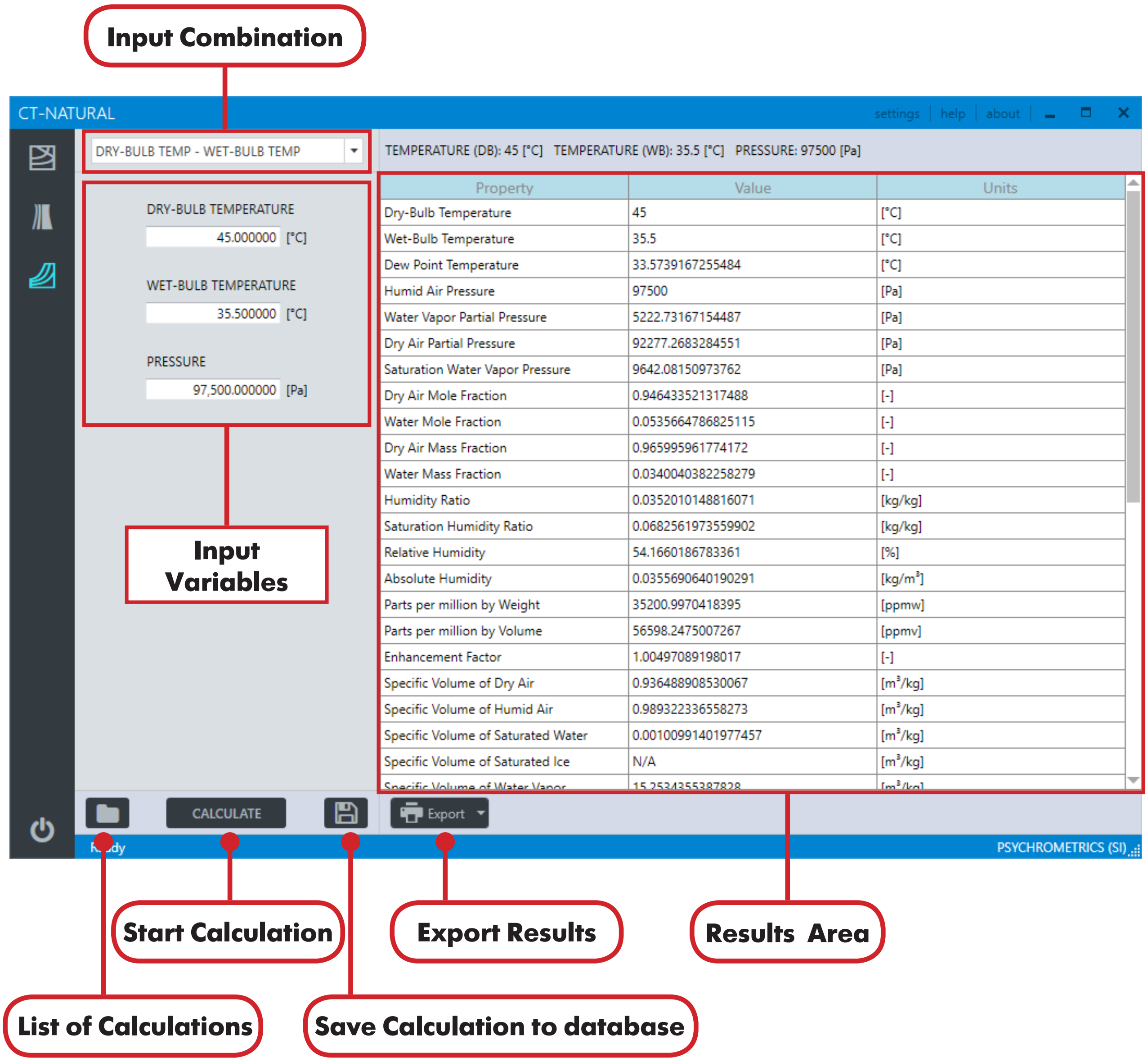


Figure 5.3 Calculation of properties in Psychrometrics Calculator.

Validating Input Variables and Calculations

All input variables in SI or I-P are bounded by the ranges described in Table 5.2. In the case that input variables are introduced that are out of these ranges, and a new psychrometrics calculation is attempted by clicking on the CALCULATE button, the application first checks that all variables are within its range, and if any variable does not satisfy the range condition, it will prevent the application from continuing. (Figure 5.4).

A message is displayed with the variables that do not satisfy this condition, showing the correct range of variables that must be entered for the calculation to proceed. Calculations that are within these ranges, but not do satisfy the conditions for a valid psychrometrics calculation, also display a message (Figure 5.5).

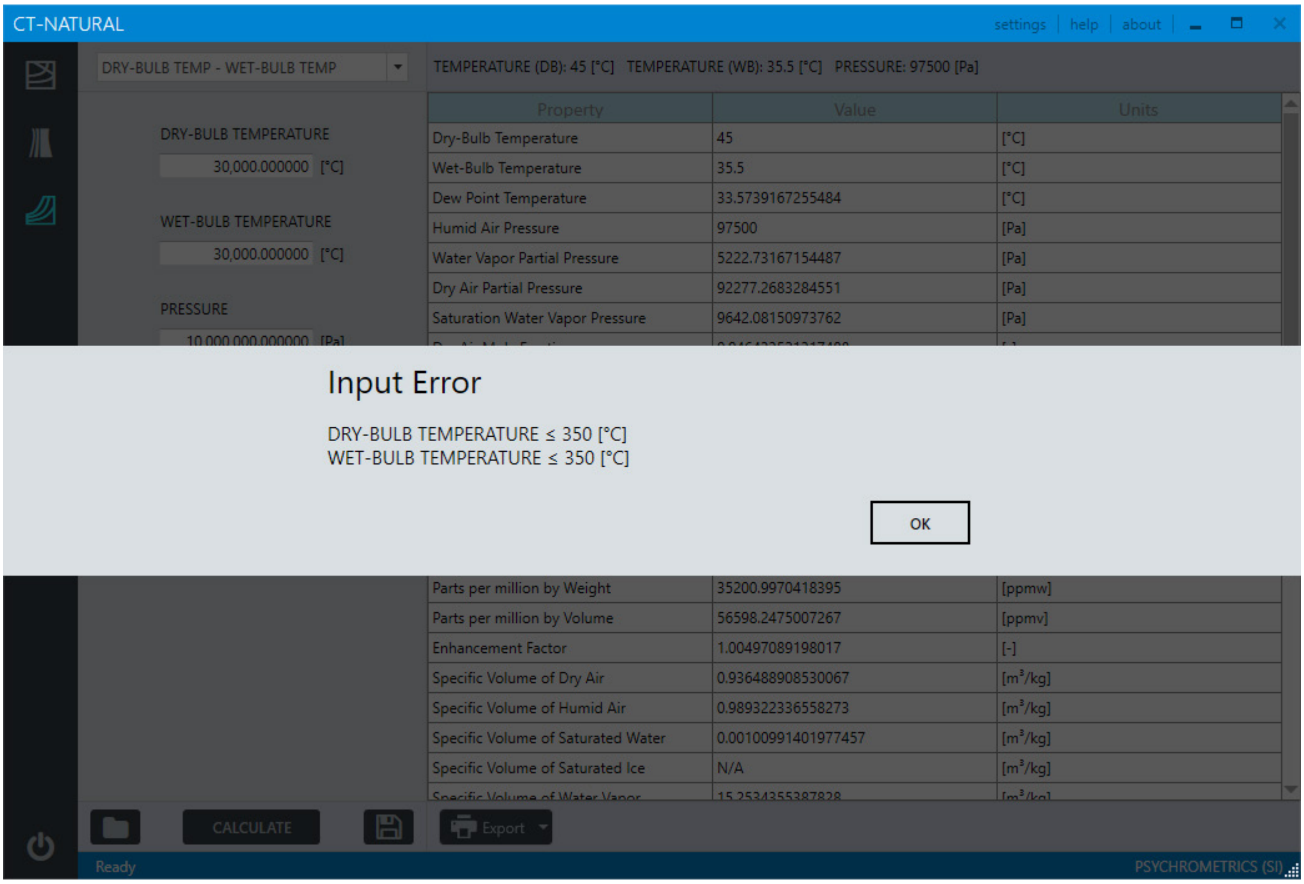


Figure 5.4 Validation of input variables in Psychrometrics Calculator.

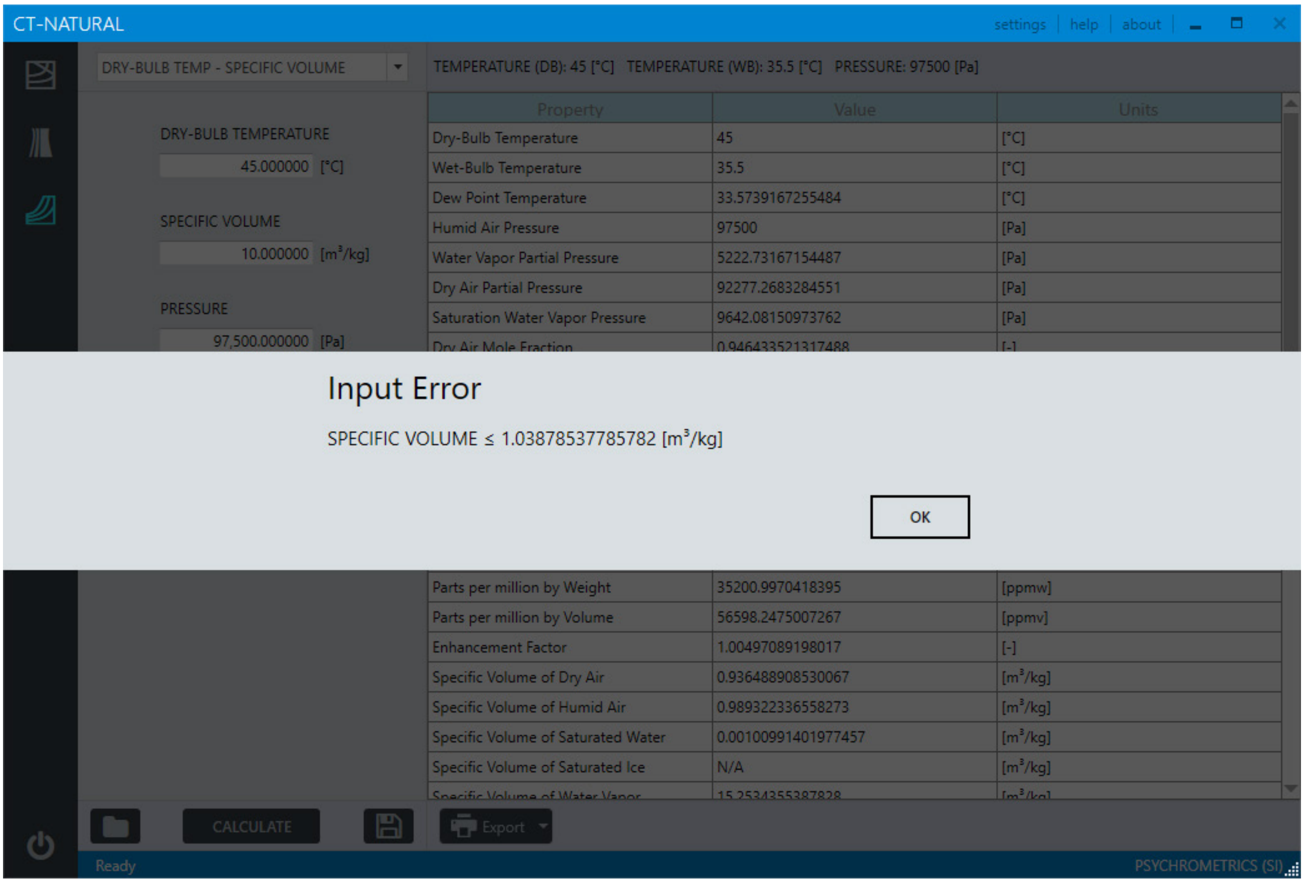


Figure 5.5 Validation of calculations in Psychrometrics Calculator.

Save Calculation Results to the database

Calculation results can be saved to a database by clicking on the Save Calculation to database button (Figure 5.3). This will add the current calculation to a database where the identifier will be the variables and their values used in the input combination that was used to calculate that particular set of results.

Load Calculation Results

Click the List of Calculations button (Figure 5.3) to load all the calculation results in the database. Select a particular calculation from the list and click the Load Calculation Results button to load the results to the Results Area (Figure 5.6). Results can be selected/deselected by unchecking the box in the list of calculations, which then can be deleted using the Delete Results button, or exported to excel/pdf by clicking on the Export button.

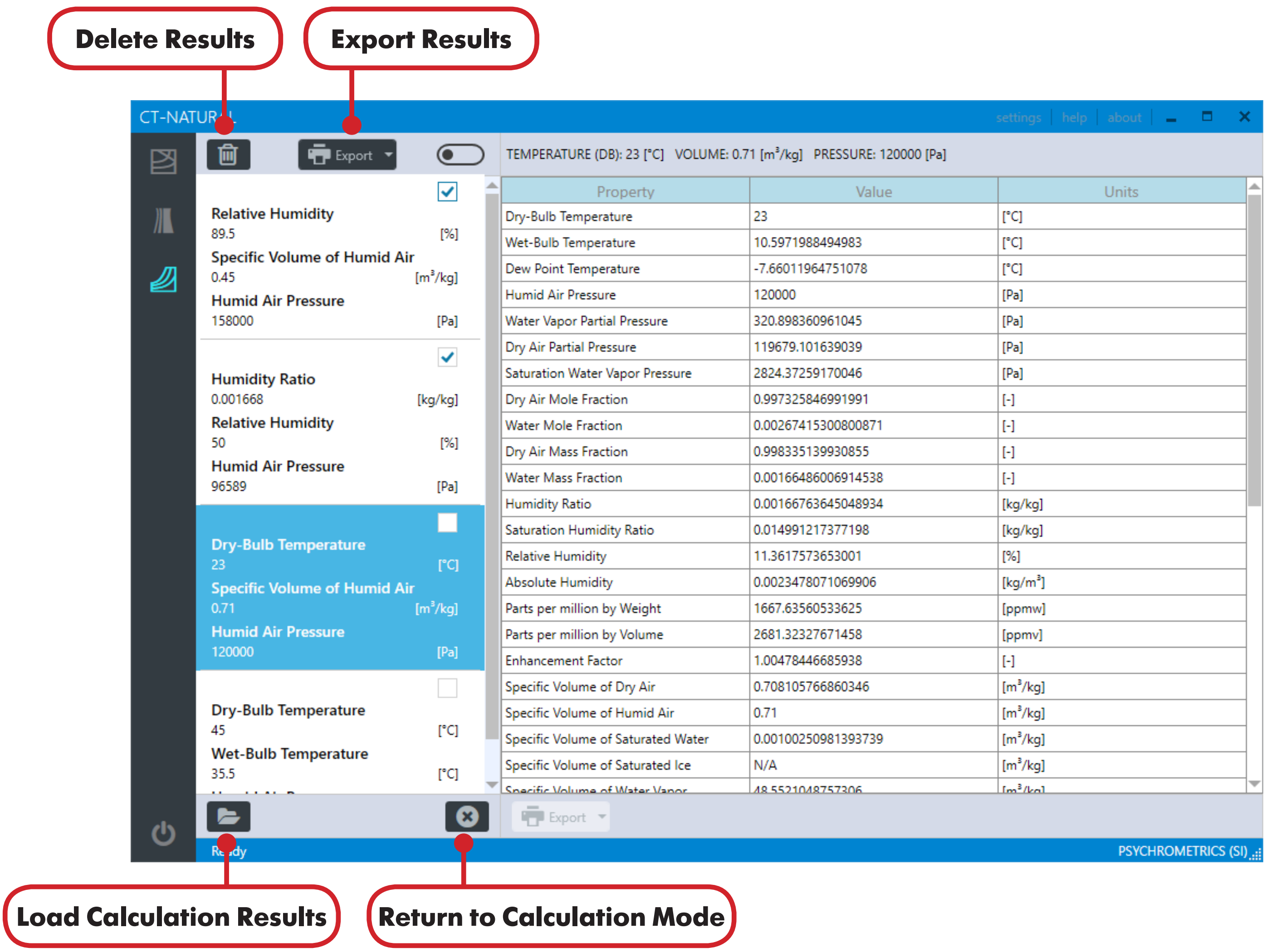
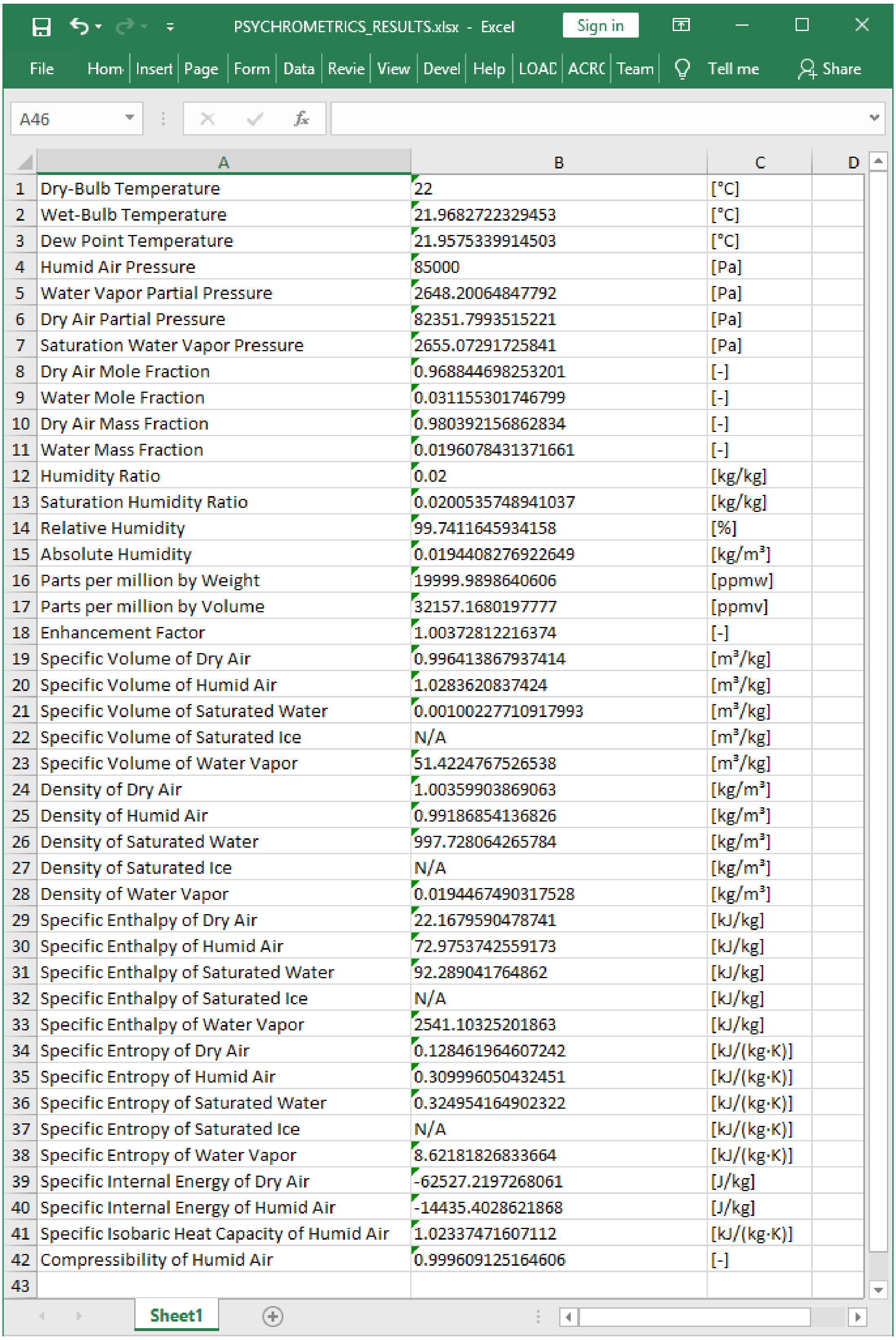


Figure 5.6 Calculation results from the Psychrometrics Calculator.

Dry-Bulb Temperature	22	[°C]
Wet-Bulb Temperature	21.9682722329453	[°C]
Dew Point Temperature	21.9575339914503	[°C]
Humid Air Pressure	85000	[Pa]
Water Vapor Partial Pressure	2648.20064847792	[Pa]
Dry Air Partial Pressure	82351.7993515221	[Pa]
Saturation Water Vapor Pressure	2655.07291725841	[Pa]
Dry Air Mole Fraction	0.968844698253201	[-]
Water Mole Fraction	0.031155301746799	[-]
Dry Air Mass Fraction	0.980392156862834	[-]
Water Mass Fraction	0.0196078431371661	[-]
Humidity Ratio	0.02	[kg/kg]
Saturation Humidity Ratio	0.0200535748941037	[kg/kg]
Relative Humidity	99.7411645934158	[%]
Absolute Humidity	0.0194408276922649	[kg/m³]
Parts per million by Weight	19999.9898640606	[ppmw]
Parts per million by Volume	32157.1680197777	[ppmv]
Enhancement Factor	1.00372812216374	[-]
Specific Volume of Dry Air	0.996413867937414	[m³/kg]
Specific Volume of Humid Air	1.0283620837424	[m³/kg]
Specific Volume of Saturated Water	0.00100227710917993	[m³/kg]
Specific Volume of Saturated Ice	N/A	[m³/kg]
Specific Volume of Water Vapor	51.4224767526538	[m³/kg]
Density of Dry Air	1.00359903869063	[kg/m³]
Density of Humid Air	0.99186854136826	[kg/m³]
Density of Saturated Water	997.728064265784	[kg/m³]
Density of Saturated Ice	N/A	[kg/m³]
Density of Water Vapor	0.0194467490317528	[kg/m³]
Specific Enthalpy of Dry Air	22.1679590478741	[kJ/kg]
Specific Enthalpy of Humid Air	72.9753742559173	[kJ/kg]
Specific Enthalpy of Saturated Water	92.289041764862	[kJ/kg]
Specific Enthalpy of Saturated Ice	N/A	[kJ/kg]
Specific Enthalpy of Water Vapor	2541.10325201863	[kJ/kg]
Specific Entropy of Dry Air	0.128461964607242	[kJ/(kg·K)]
Specific Entropy of Humid Air	0.309996050432451	[kJ/(kg·K)]
Specific Entropy of Saturated Water	0.324954164902322	[kJ/(kg·K)]
Specific Entropy of Saturated Ice	N/A	[kJ/(kg·K)]
Specific Entropy of Water Vapor	8.62181826833664	[kJ/(kg·K)]
Specific Internal Energy of Dry Air	-62527.2197268061	[J/kg]
Specific Internal Energy of Humid Air	-14435.4028621868	[J/kg]
Specific Isobaric Heat Capacity of Humid Air	1.02337471607112	[kJ/(kg·K)]
Compressibility of Humid Air	0.999609125164606	[-]

Figure 5.7 Example of calculation results in pdf format of Psychrometrics Calculator.



	A	B	C
1	Dry-Bulb Temperature	22	[°C]
2	Wet-Bulb Temperature	21.9682722329453	[°C]
3	Dew Point Temperature	21.9575339914503	[°C]
4	Humid Air Pressure	85000	[Pa]
5	Water Vapor Partial Pressure	2648.20064847792	[Pa]
6	Dry Air Partial Pressure	82351.7993515221	[Pa]
7	Saturation Water Vapor Pressure	2655.07291725841	[Pa]
8	Dry Air Mole Fraction	0.968844698253201	[-]
9	Water Mole Fraction	0.031155301746799	[-]
10	Dry Air Mass Fraction	0.980392156862834	[-]
11	Water Mass Fraction	0.0196078431371661	[-]
12	Humidity Ratio	0.02	[kg/kg]
13	Saturation Humidity Ratio	0.0200535748941037	[kg/kg]
14	Relative Humidity	99.7411645934158	[%]
15	Absolute Humidity	0.0194408276922649	[kg/m^3]
16	Parts per million by Weight	19999.9898640606	[ppmw]
17	Parts per million by Volume	32157.1680197777	[ppmv]
18	Enhancement Factor	1.00372812216374	[-]
19	Specific Volume of Dry Air	0.996413867937414	[m^3/kg]
20	Specific Volume of Humid Air	1.0283620837424	[m^3/kg]
21	Specific Volume of Saturated Water	0.00100227710917993	[m^3/kg]
22	Specific Volume of Saturated Ice	N/A	[m^3/kg]
23	Specific Volume of Water Vapor	51.4224767526538	[m^3/kg]
24	Density of Dry Air	1.00359903869063	[kg/m^3]
25	Density of Humid Air	0.99186854136826	[kg/m^3]
26	Density of Saturated Water	997.728064265784	[kg/m^3]
27	Density of Saturated Ice	N/A	[kg/m^3]
28	Density of Water Vapor	0.0194467490317528	[kg/m^3]
29	Specific Enthalpy of Dry Air	22.1679590478741	[kJ/kg]
30	Specific Enthalpy of Humid Air	72.9753742559173	[kJ/kg]
31	Specific Enthalpy of Saturated Water	92.289041764862	[kJ/kg]
32	Specific Enthalpy of Saturated Ice	N/A	[kJ/kg]
33	Specific Enthalpy of Water Vapor	2541.10325201863	[kJ/kg]
34	Specific Entropy of Dry Air	0.128461964607242	[kJ/(kg·K)]
35	Specific Entropy of Humid Air	0.309996050432451	[kJ/(kg·K)]
36	Specific Entropy of Saturated Water	0.324954164902322	[kJ/(kg·K)]
37	Specific Entropy of Saturated Ice	N/A	[kJ/(kg·K)]
38	Specific Entropy of Water Vapor	8.62181826833664	[kJ/(kg·K)]
39	Specific Internal Energy of Dry Air	-62527.2197268061	[J/kg]
40	Specific Internal Energy of Humid Air	-14435.4028621868	[J/kg]
41	Specific Isobaric Heat Capacity of Humid Air	1.02337471607112	[kJ/(kg·K)]
42	Compressibility of Humid Air	0.999609125164606	[-]
43			

Figure 5.8 Example of calculation results in excel format of Psychrometrics Calculator.

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