CT-Mechanical

Windows Application

USER GUIDE

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

Table of Contents

Overview

CT-Mechanical is a computational set of tools to analyze and determine the cooling capability and thermal performance of mechanical draft cooling towers (counterflow and crossflow, induced and forced draft).

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.

- **Mechanical Draft** : Numerical calculation and graphical display of cooling capability and thermal performance of mechanical draft cooling towers based on the Acceptance Test Code CTI ATC-105 using the characteristic curve method (counterflow and crossflow, induced and forced draft).

- **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.

Mechanical Draft

- Numerical calculation and graphical display of cooling capability and thermal performance of mechanical draft cooling towers based on the Acceptance Test Code CTI ATC-105 using the characteristic curve method (counterflow and crossflow, induced and forced draft).
- Calculation of cooling capability for each data test added to a project.
- Calculation and graphical display of demand curves following the integration of Merkel´s equation.
- Complete validation of input variables, informing the user of the correct range of variables for a valid test data calculation.
- Creation of projects in a database to save a particular set of design and test input data together with the calculated demand curves, test data and calculation results for later retrieval or recalculation.
- Generation of high-quality pdf files of demand curve plots and the corresponding design, test and result points for a particular project.
- Generation of excel and pdf files of numerical results from data tests.
- Supports input variables and calculation results in SI (metric) and I-P (english) 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-Mechanical.** 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-Mechanical.

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.

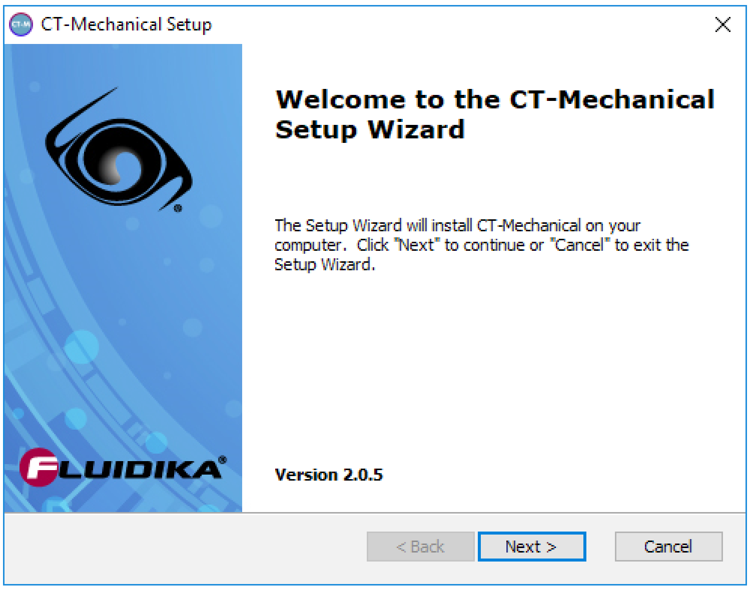


Figure 1.1 Installation screen of CT-Mechanical.

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

> 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-Mechanical**. 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-Mechanical** (Figure 1.2).
2. Click on the ACTIVATE button to start the activation process. The activation screen of **CT-Mechanical** 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.

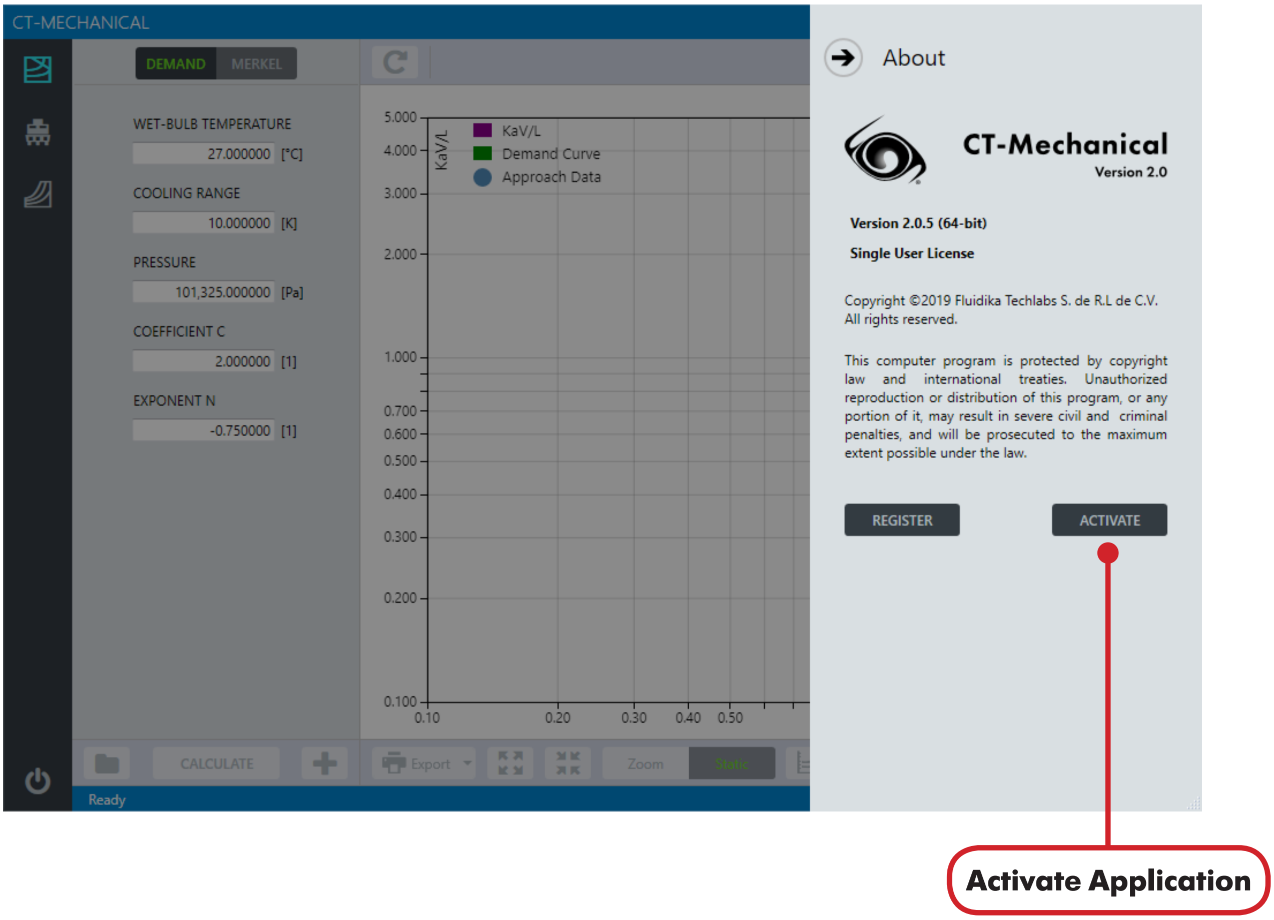


Figure 1.2 About screen of CT-Mechanical.

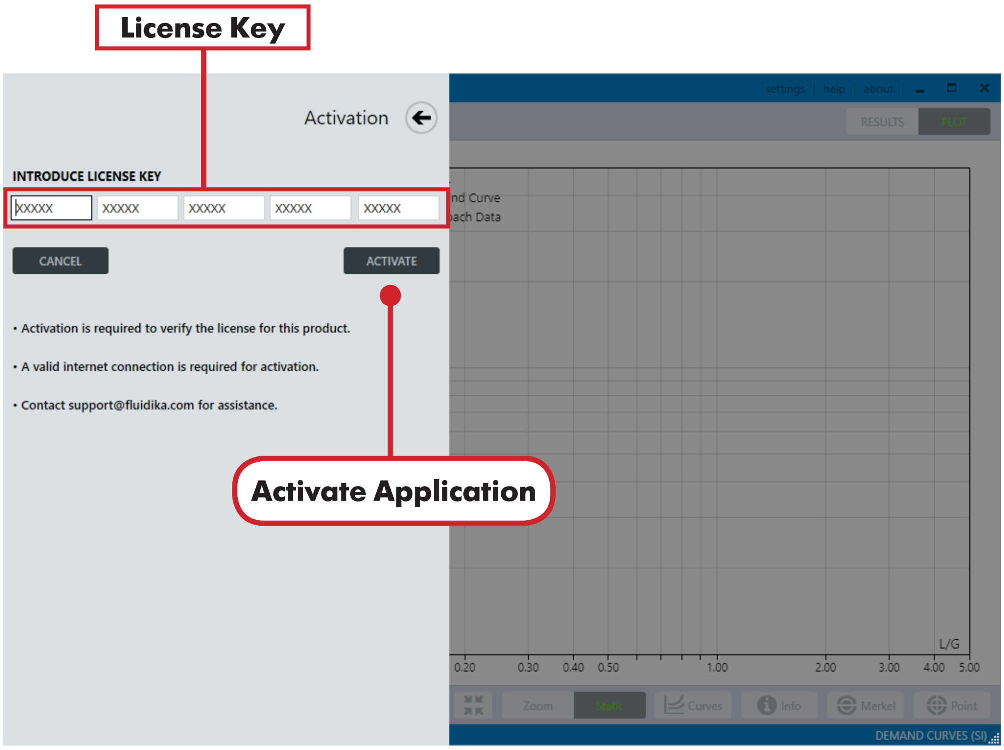


Figure 1.3 Activation screen of CT-Mechanical.

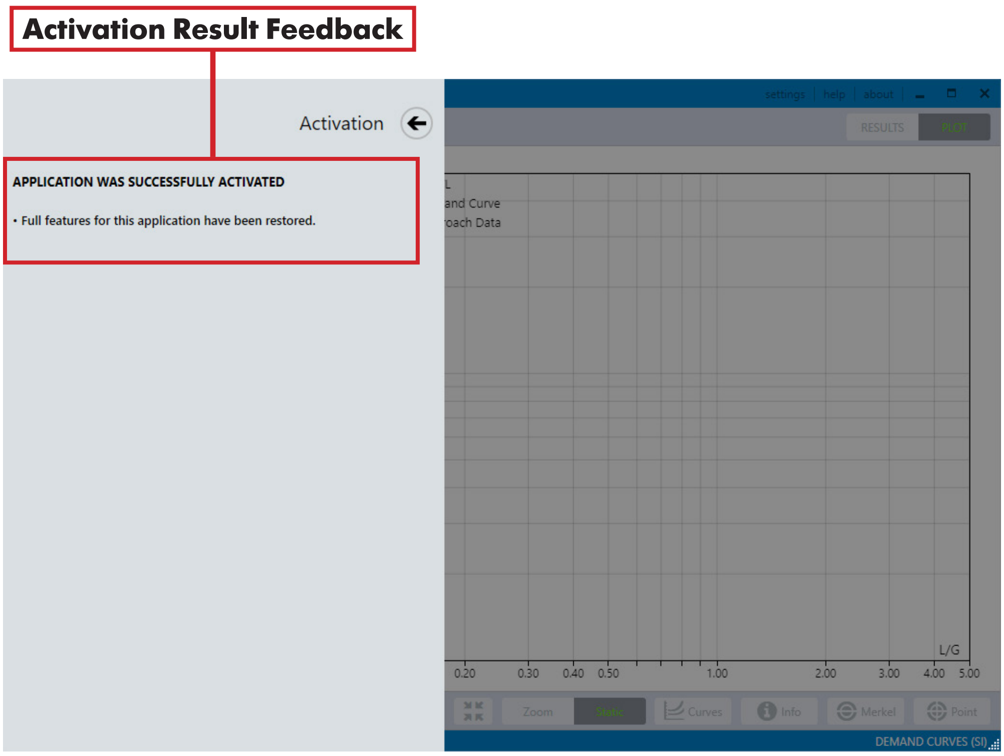


Figure 1.4 Activation feedback screen of CT-Mechanical.

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-Mechanical** (Figure 1.5).
2. Click on the DEACTIVATE button to start the deactivation process. The deactivation screen of **CT-Mechanical** 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.

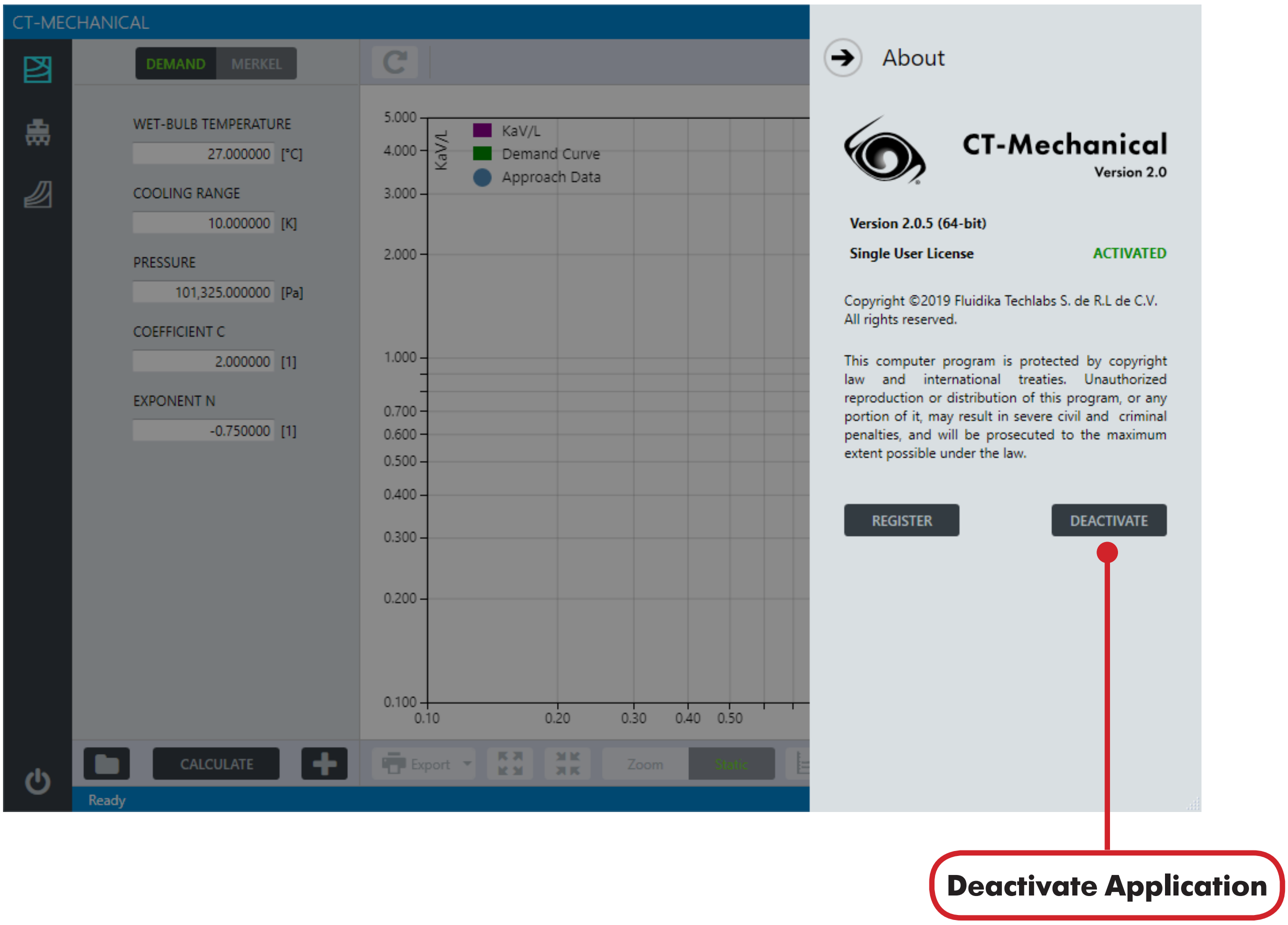


Figure 1.5 About screen of CT-Mechanical.

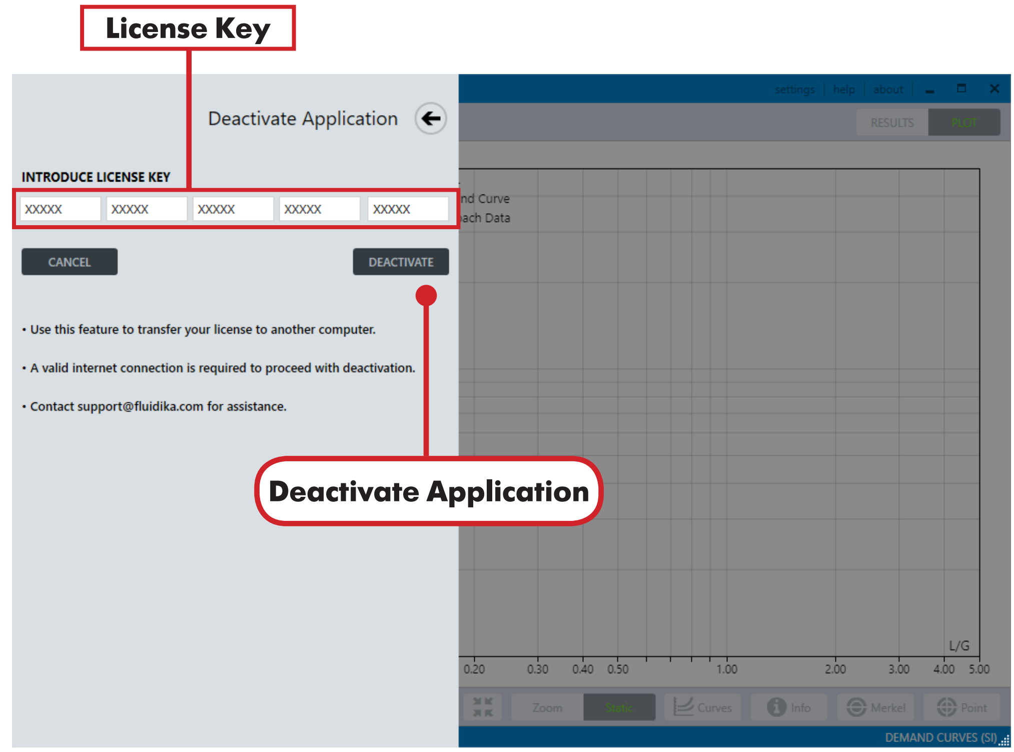


Figure 1.6 Deactivation screen of CT-Mechanical.

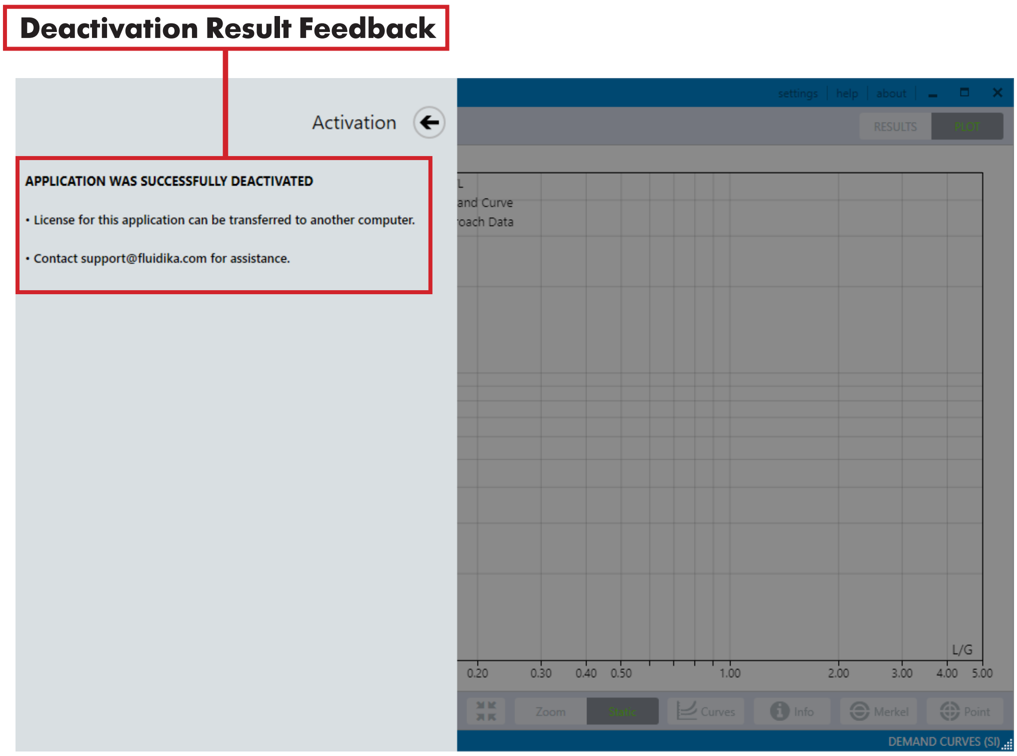


Figure 1.7 Deactivation result feedback screen.

1.6 Registration

Registration of this application is optional. Register in order to receive news about updates and other products related to **CT-Mechanical**. 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-Mechanical** (Figure 1.8).
2. Click on the REGISTER button to start the registration process. The registration screen of **CT-Mechanical** 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.

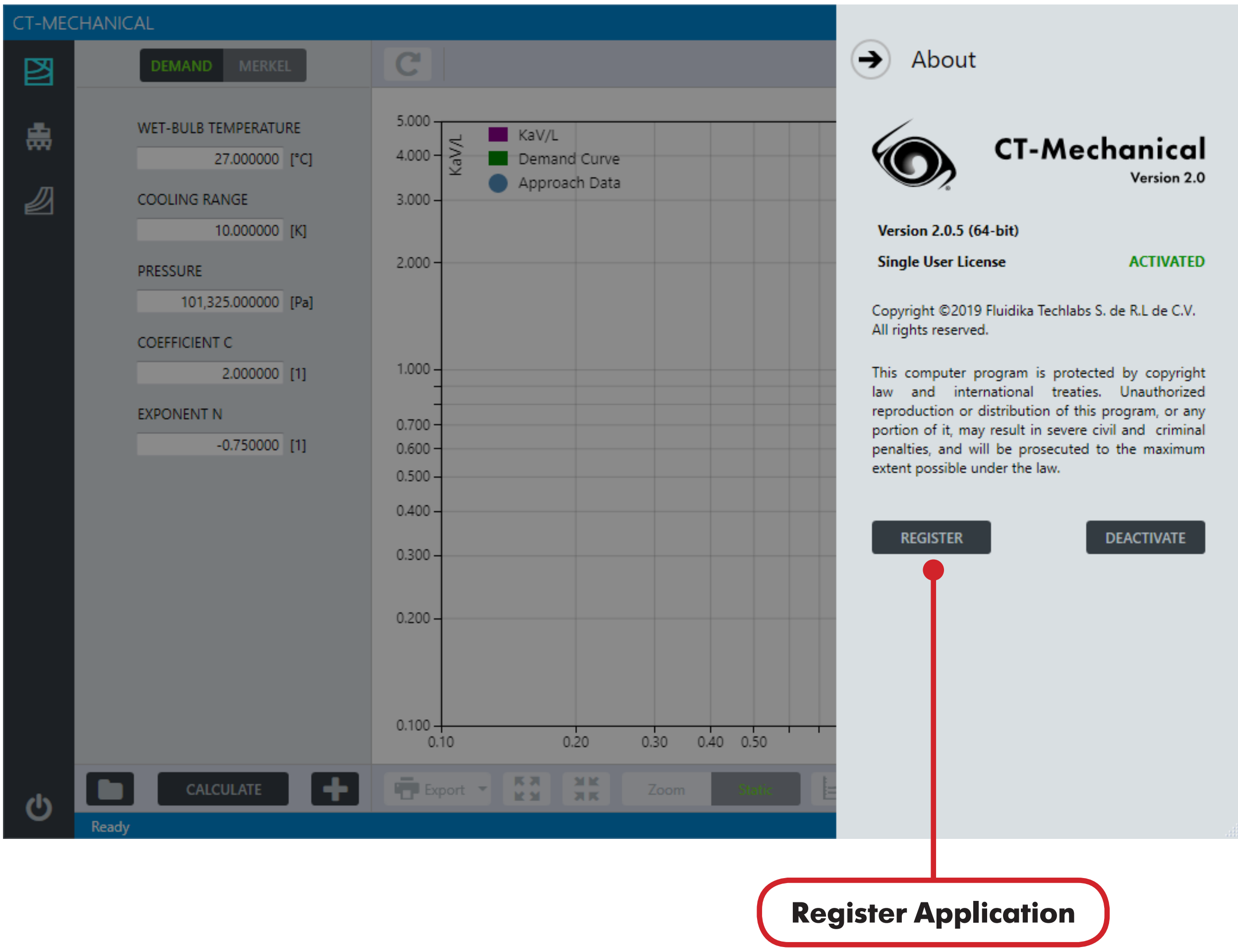


Figure 1.8 About screen of CT-Mechanical.

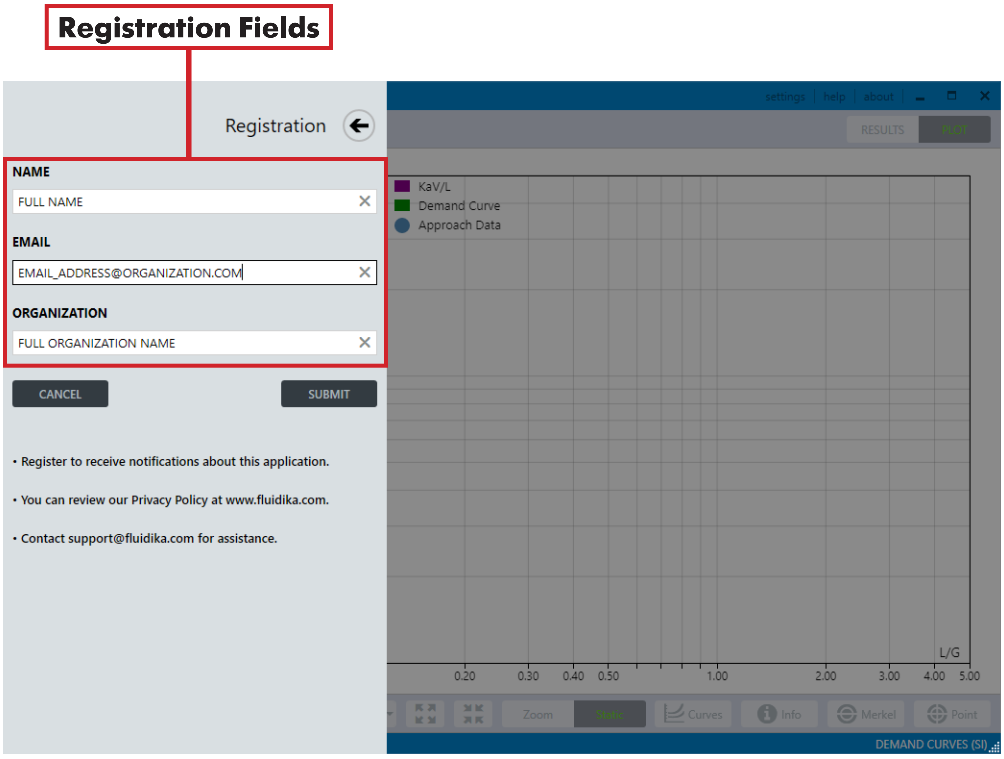


Figure 1.9 Registration screen of CT-Mechanical.

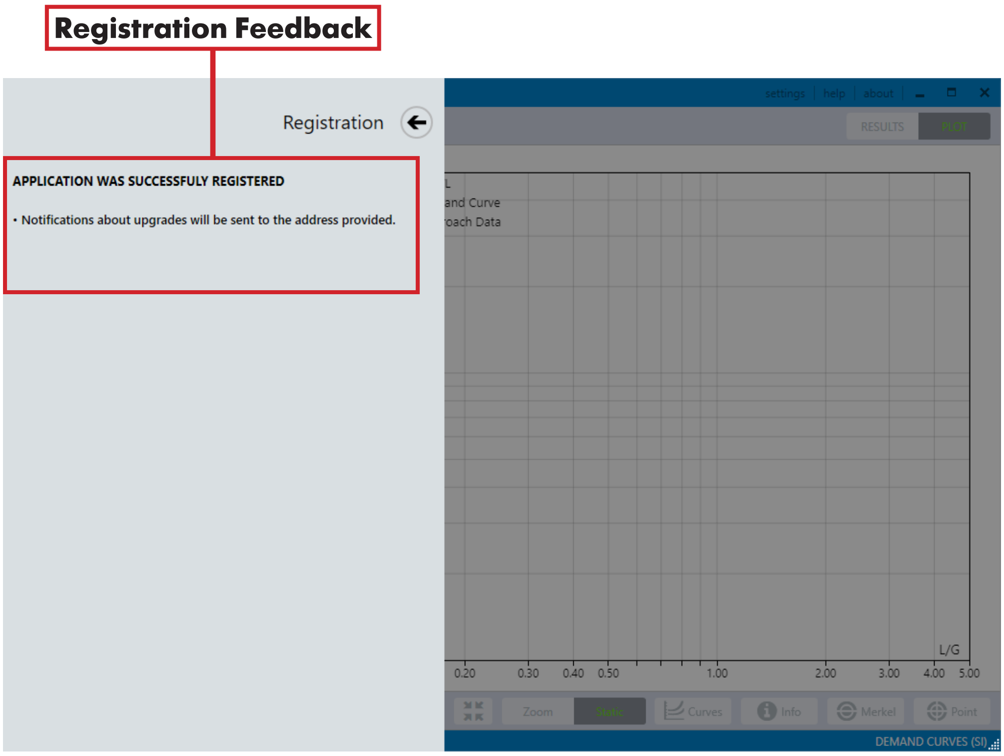


Figure 1.10 Registration feedback screen.

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.

Software

1.8 Uninstalling the software

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

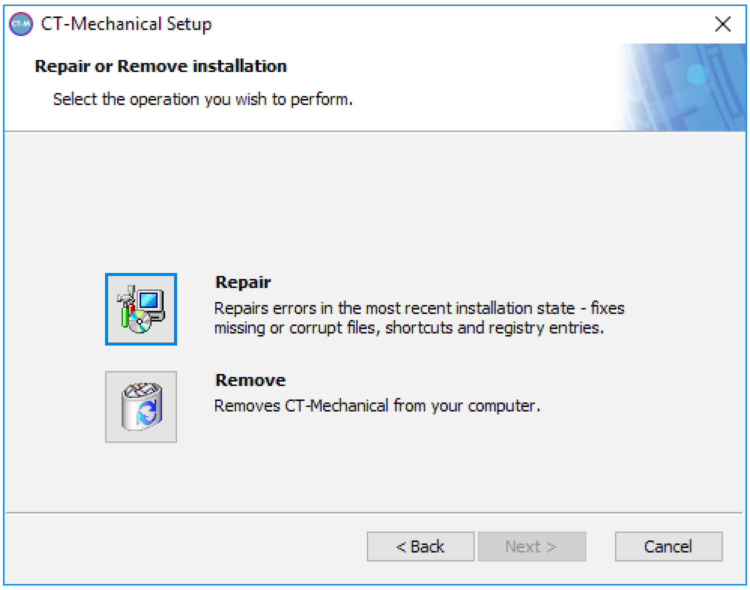


Figure 1.11 Uninstallation of CT-Mechanical.

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

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

Select **CT-Mechanical** 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:

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

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:

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

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.

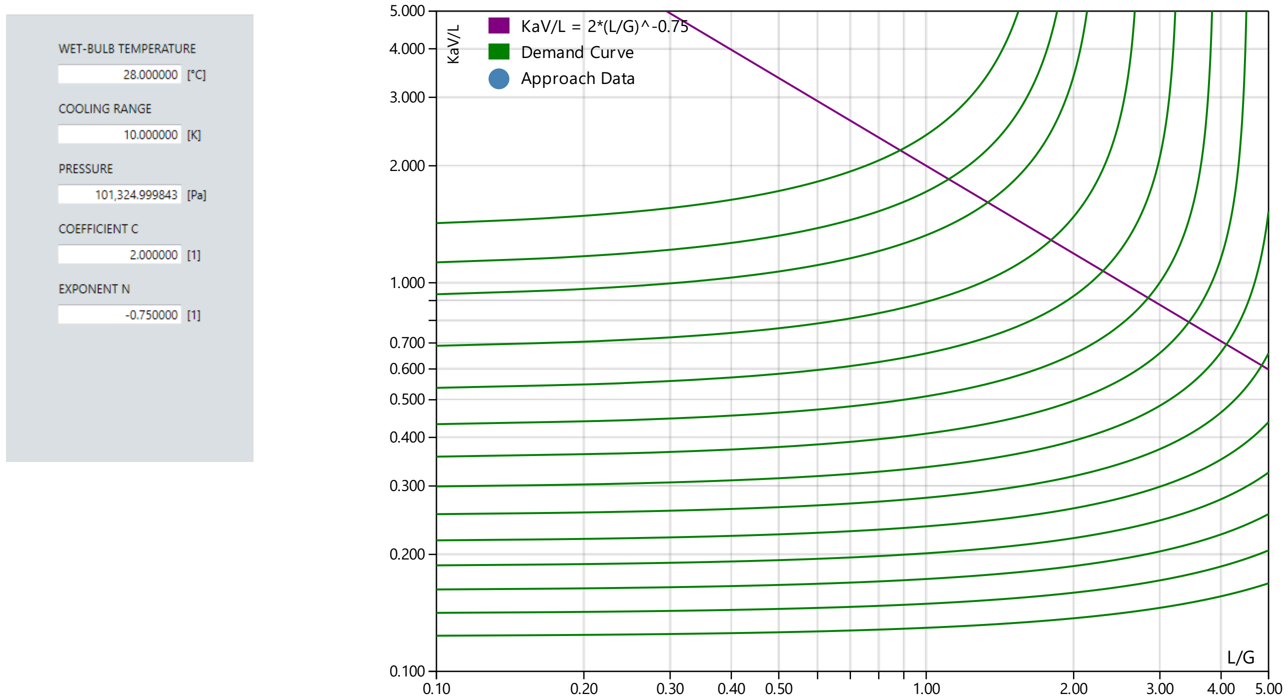


Figure 2.1 Example of input variables in the SI system of units (left).
Demand curves plotted for several values of approach given the input variables (right).

2.2 Range of Input Variables

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-Mechanical** 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).

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.

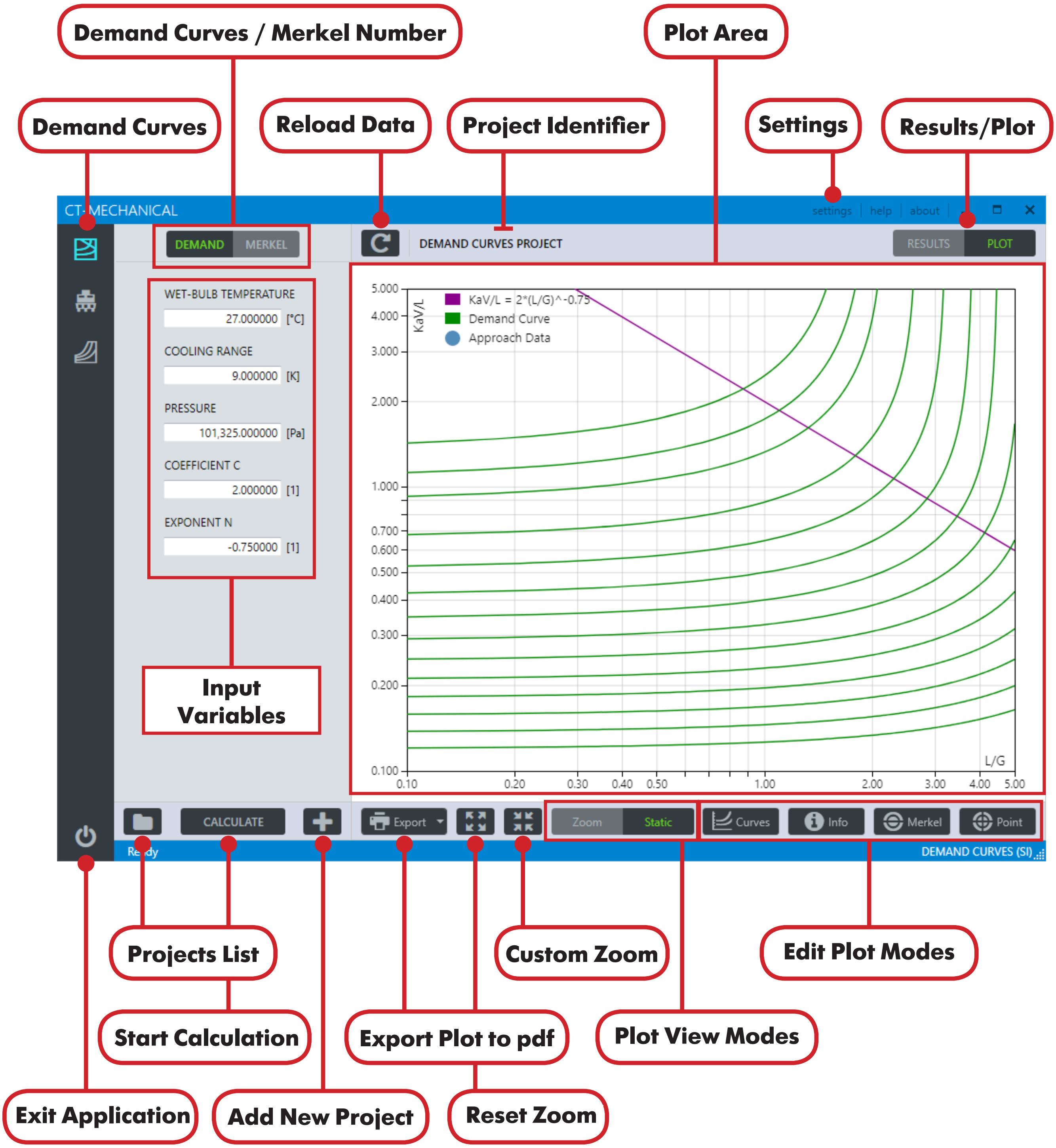


Figure 2.2 Graphical User Interface of Demand Curves.

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.

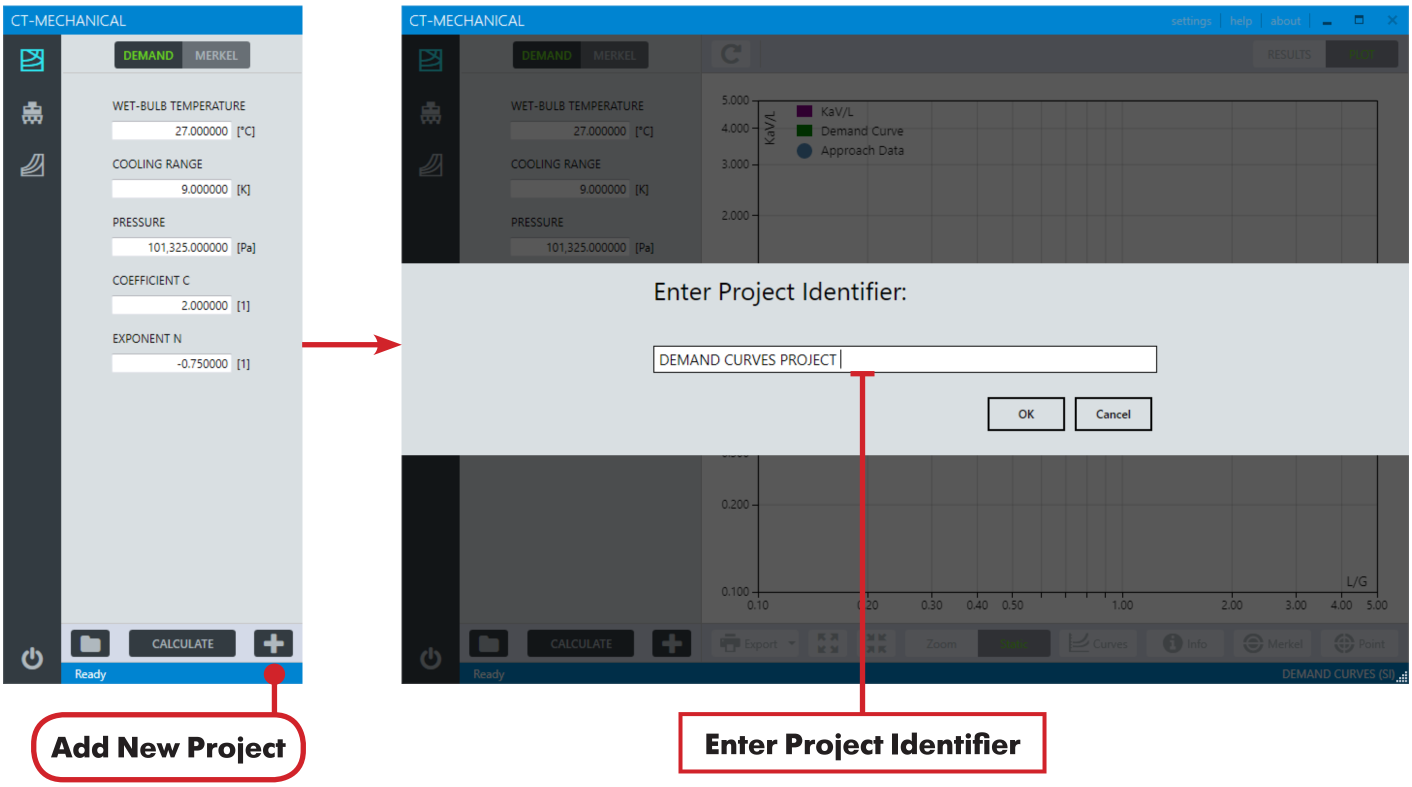


Figure 2.3 Adding a new calculation project in Demand Curves.

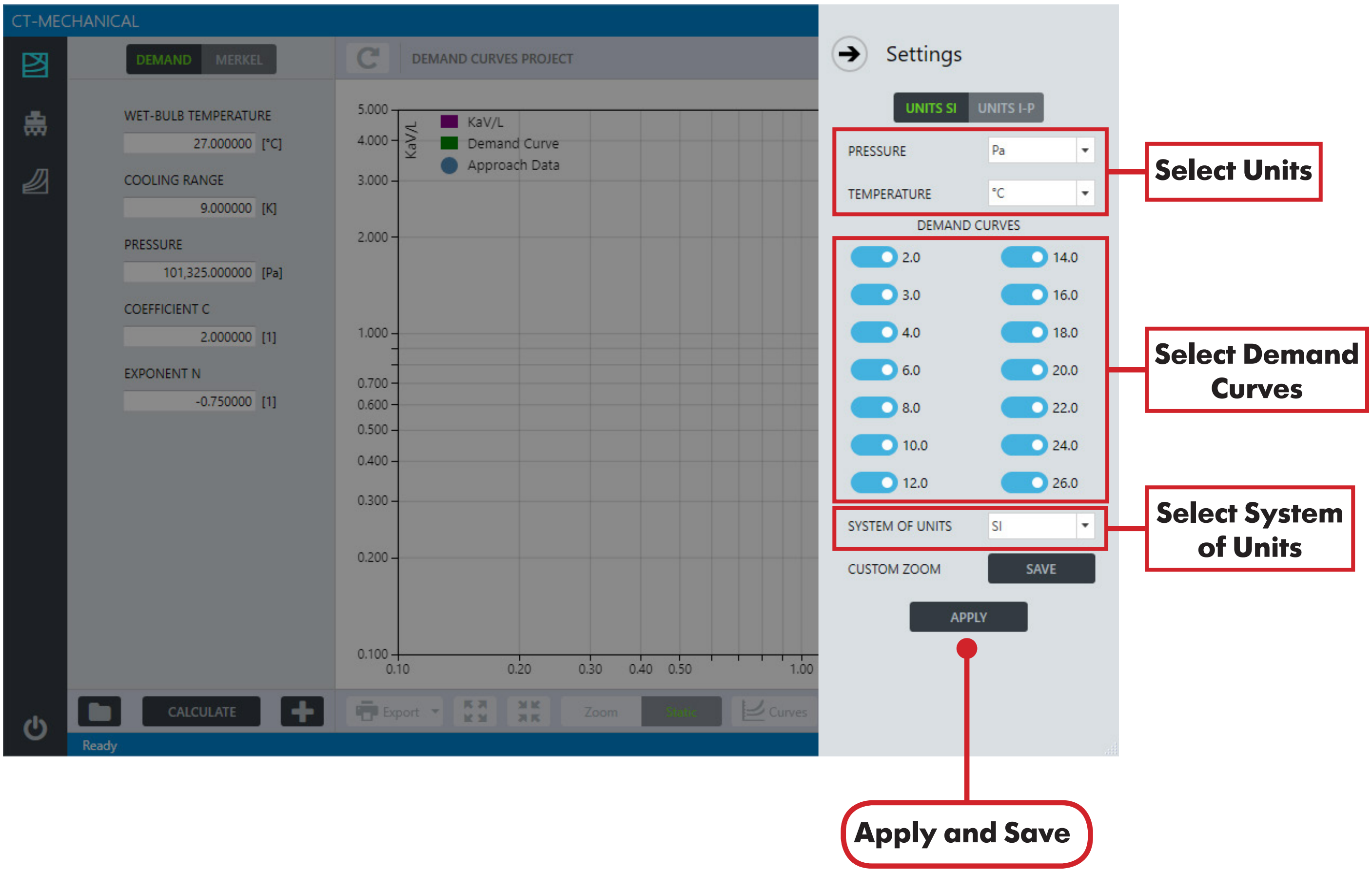


Figure 2.4 Settings for calculation projects in Demand Curves.

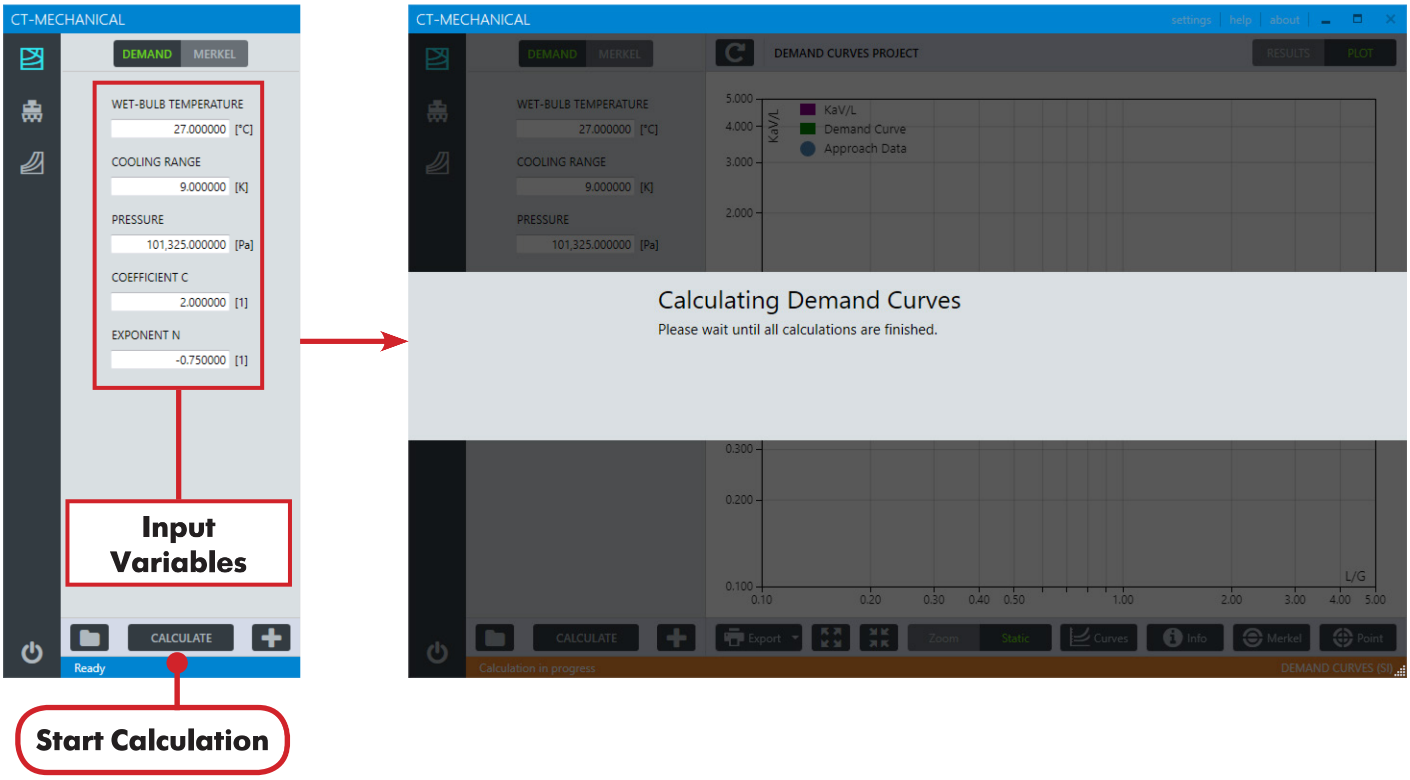


Figure 2.5 Entering input values for a calculation project in Demand Curves.

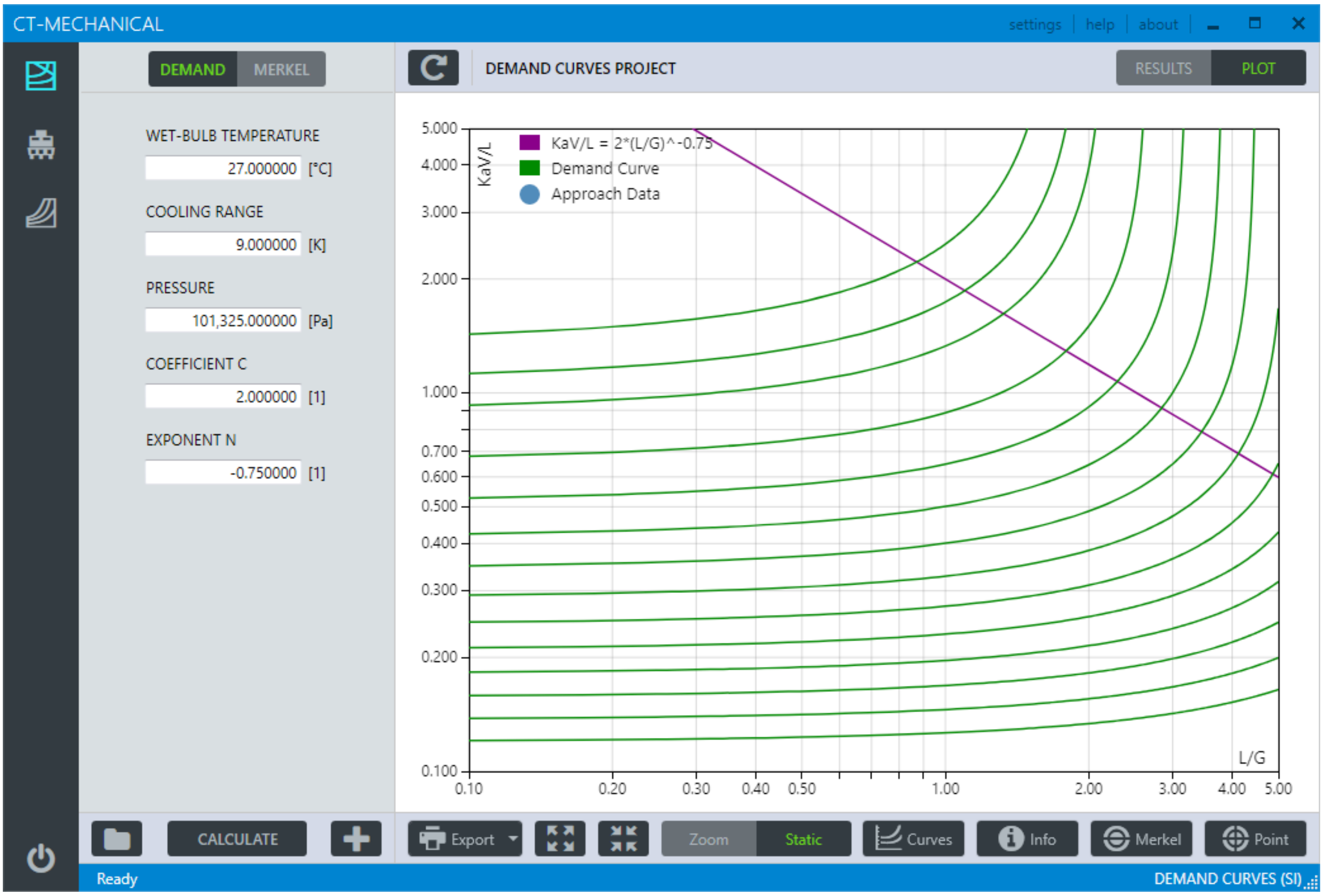


Figure 2.6 Plot Area of Demand Curves after calculations are completed.

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.

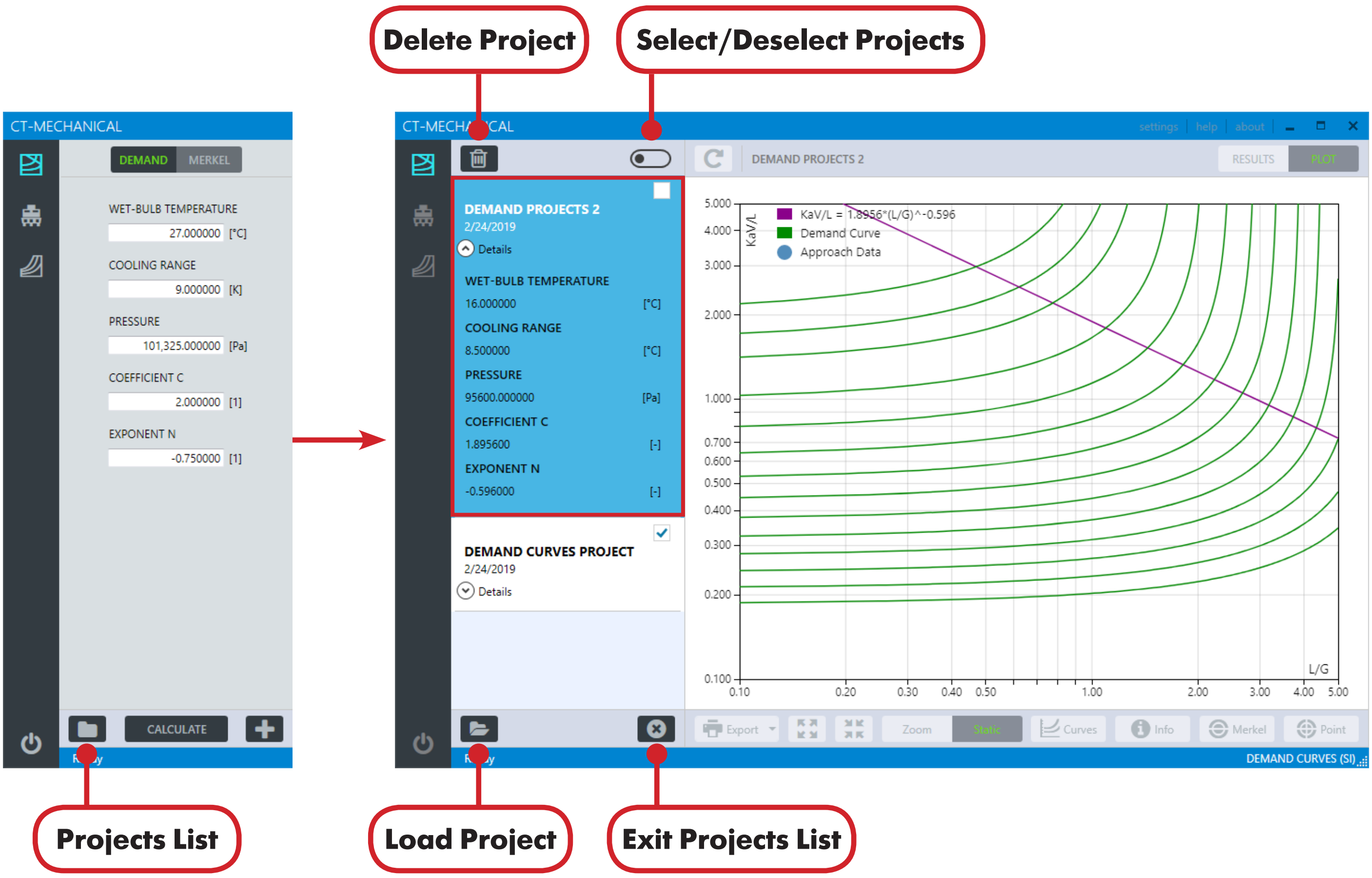


Figure 2.7 List of calculation projects of Demand Curves.

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).

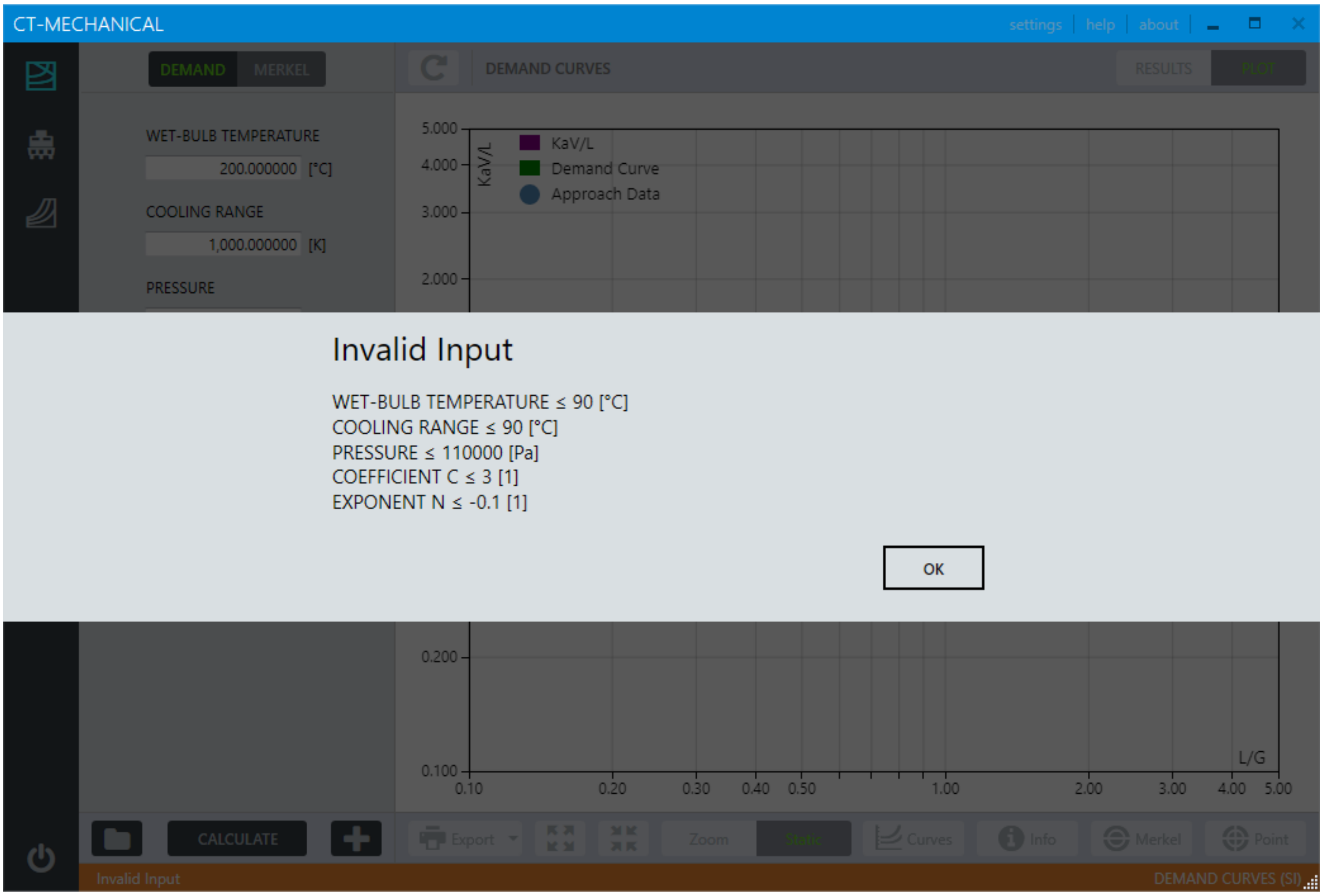


Figure 2.8 Message displaying the correct range of variables for a calculation project in Demand Curves.

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.

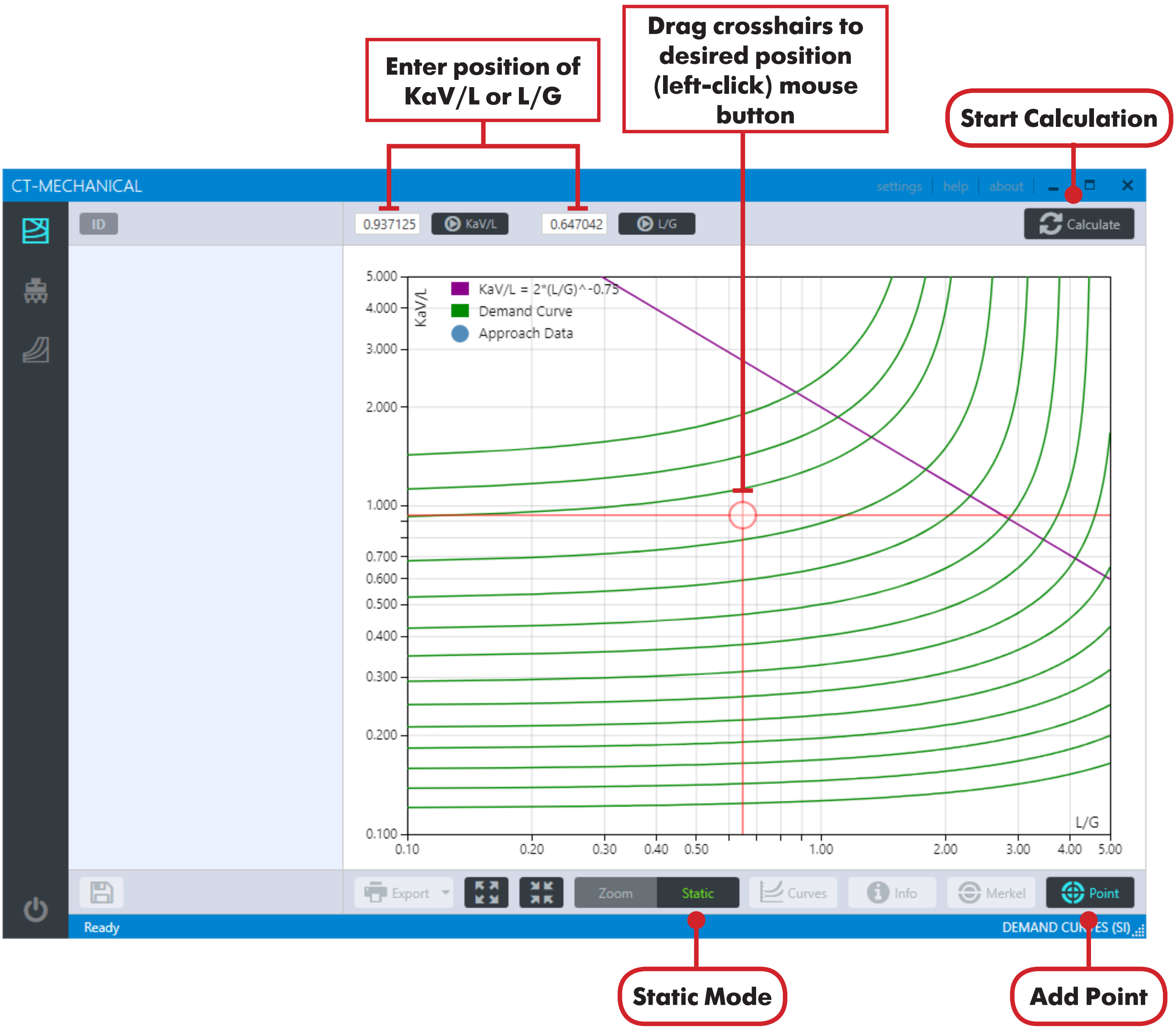


Figure 2.9 Graphical Mode - Adding an approach point to a calculation project in Demand Curves.

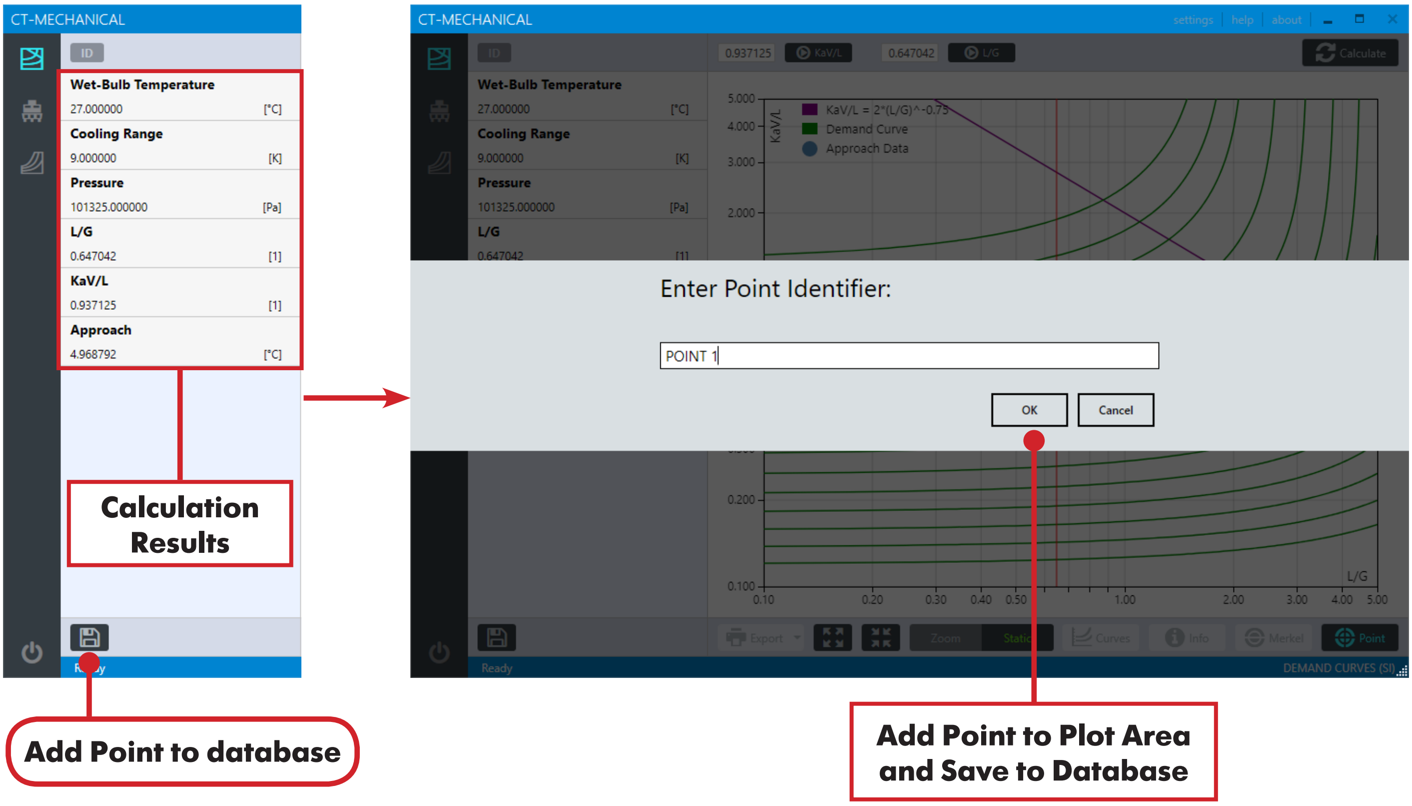


Figure 2.10 Adding an approach data point to the Plot Area and saving it to the database in Demand Curves.

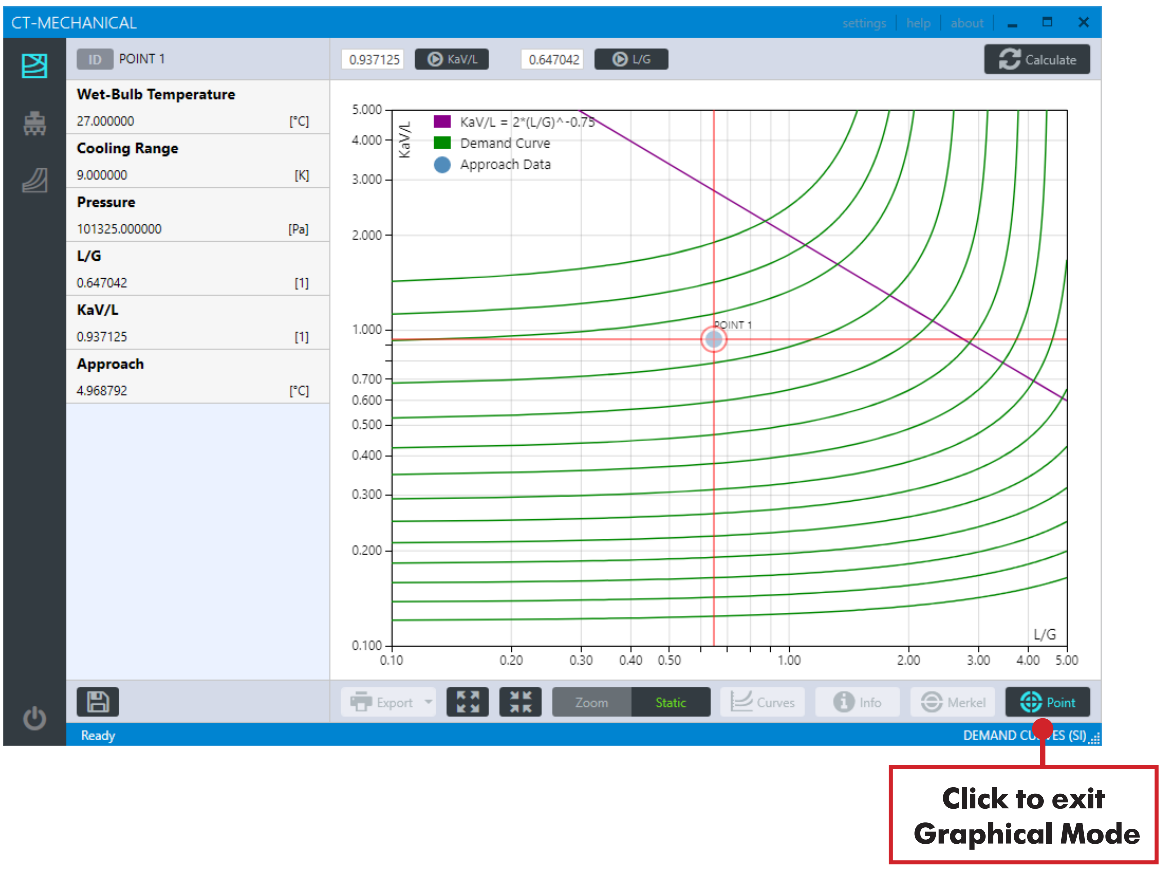


Figure 2.11 Approach data point added to the Plot Area of Demand Curves.

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.

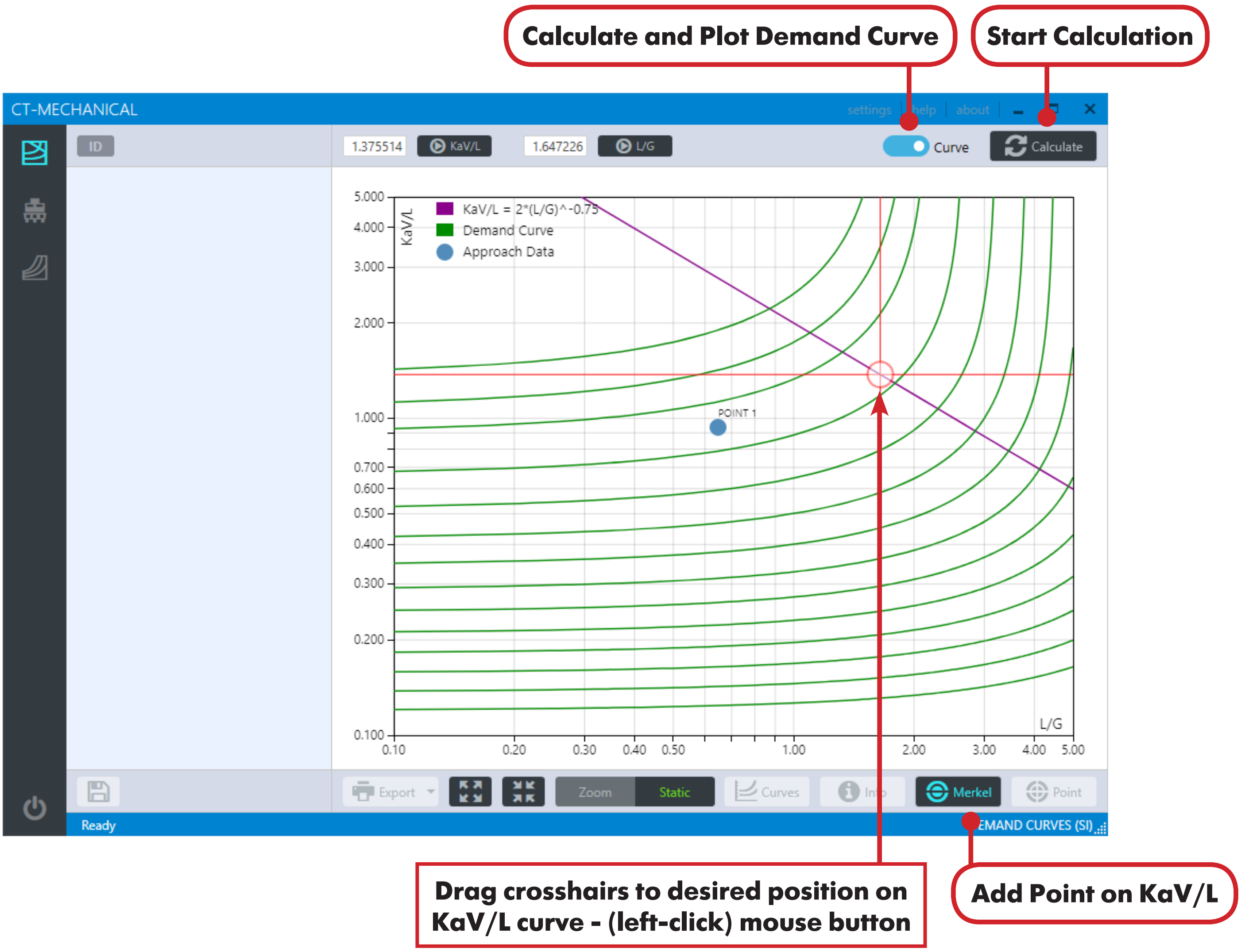


Figure 2.12 Adding an approach data point and demand curve on the KaV/L line.

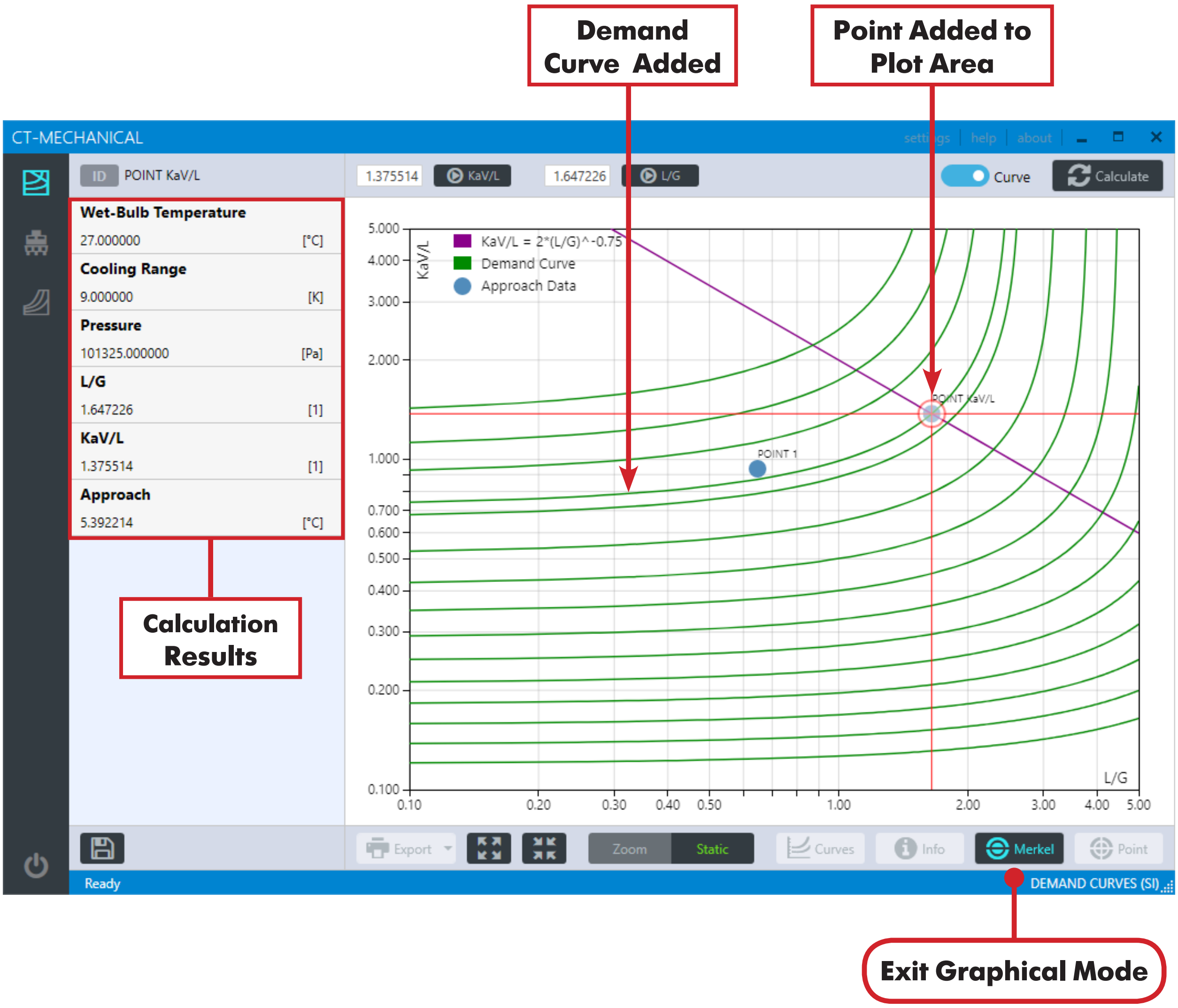


Figure 2.13 Approach data point and demand curve calculated on the KaV/L line and saved to the database.

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.

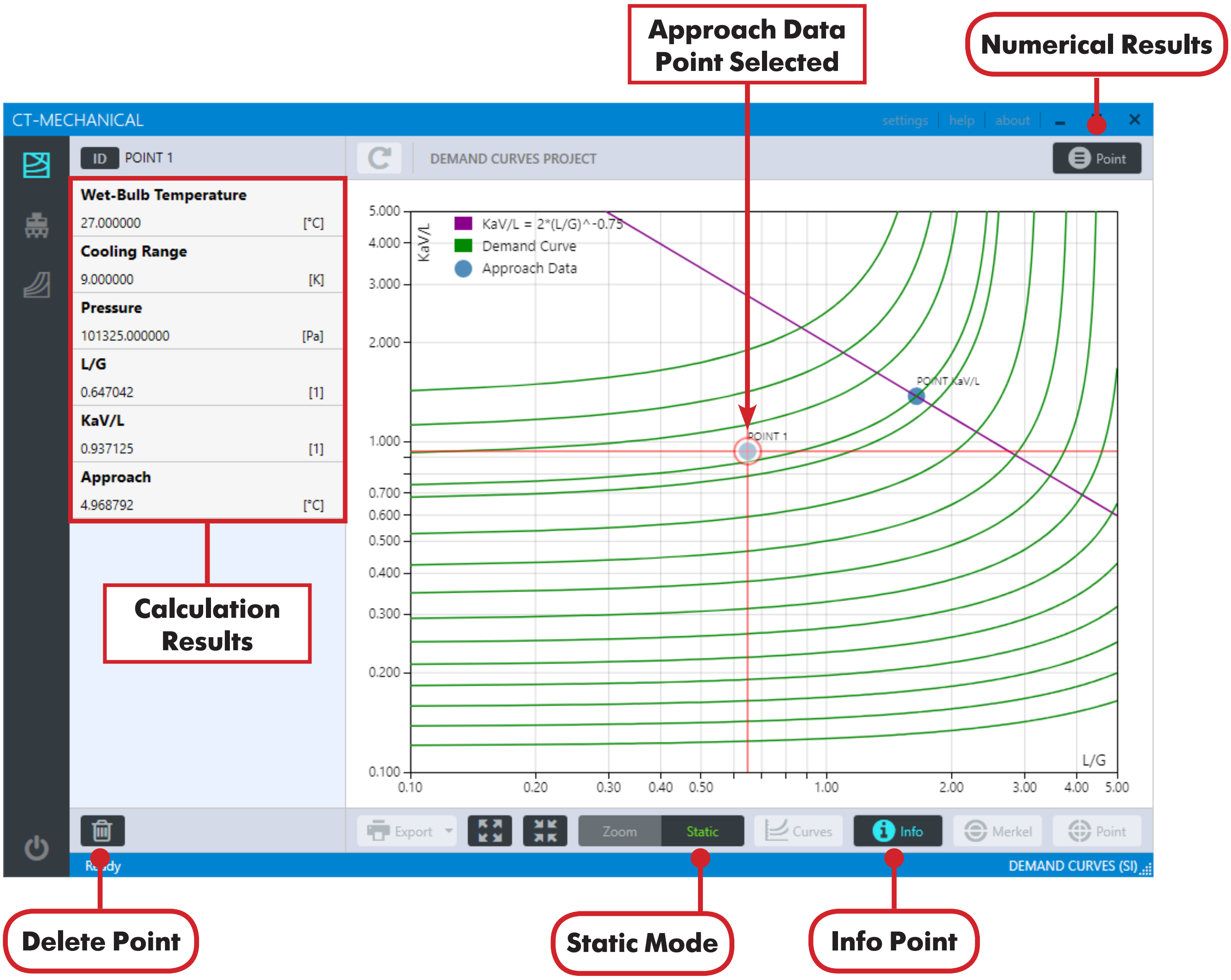


Figure 2.14 Numerical results from individual approach points of Demand Curves.

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).

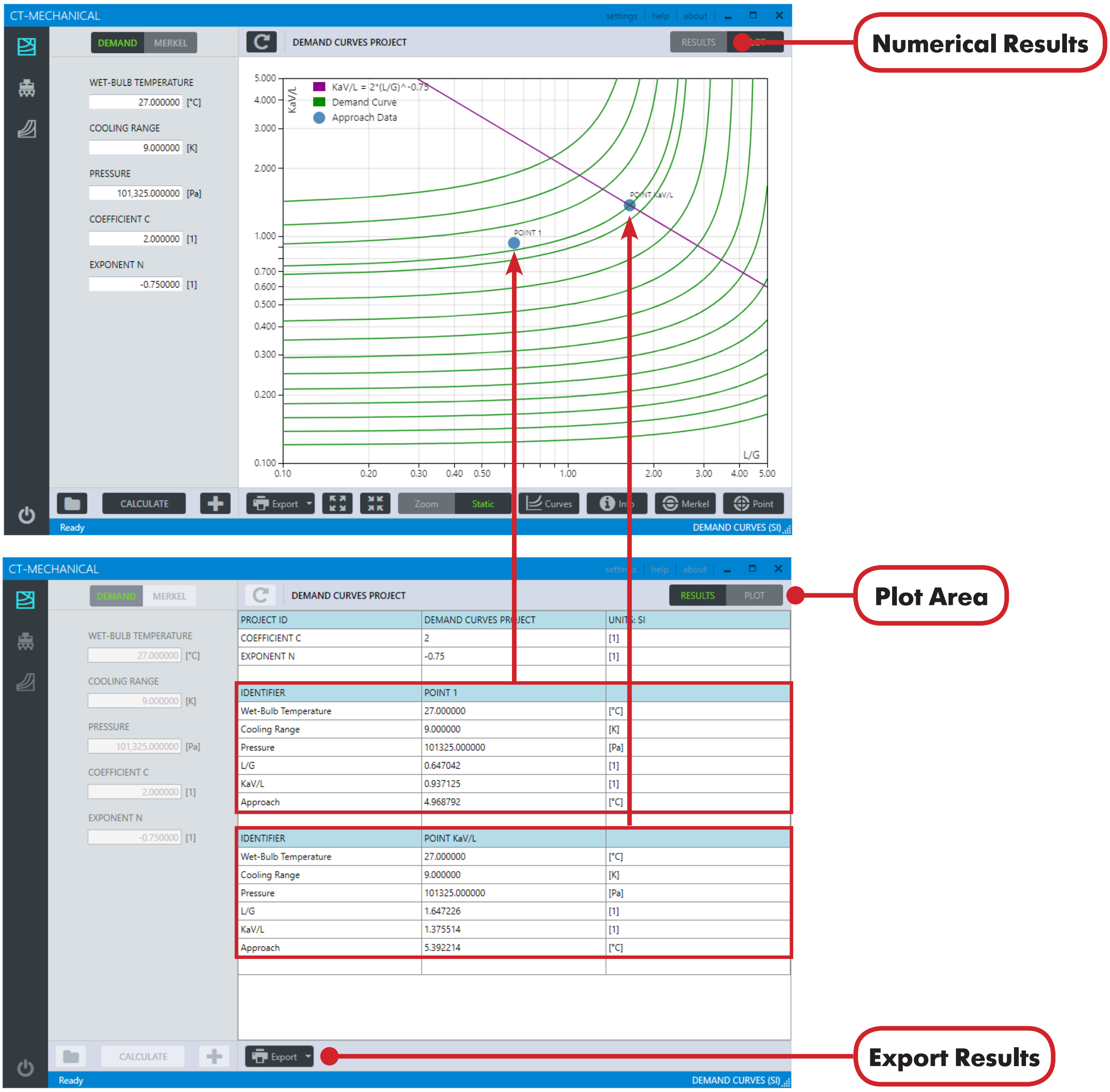
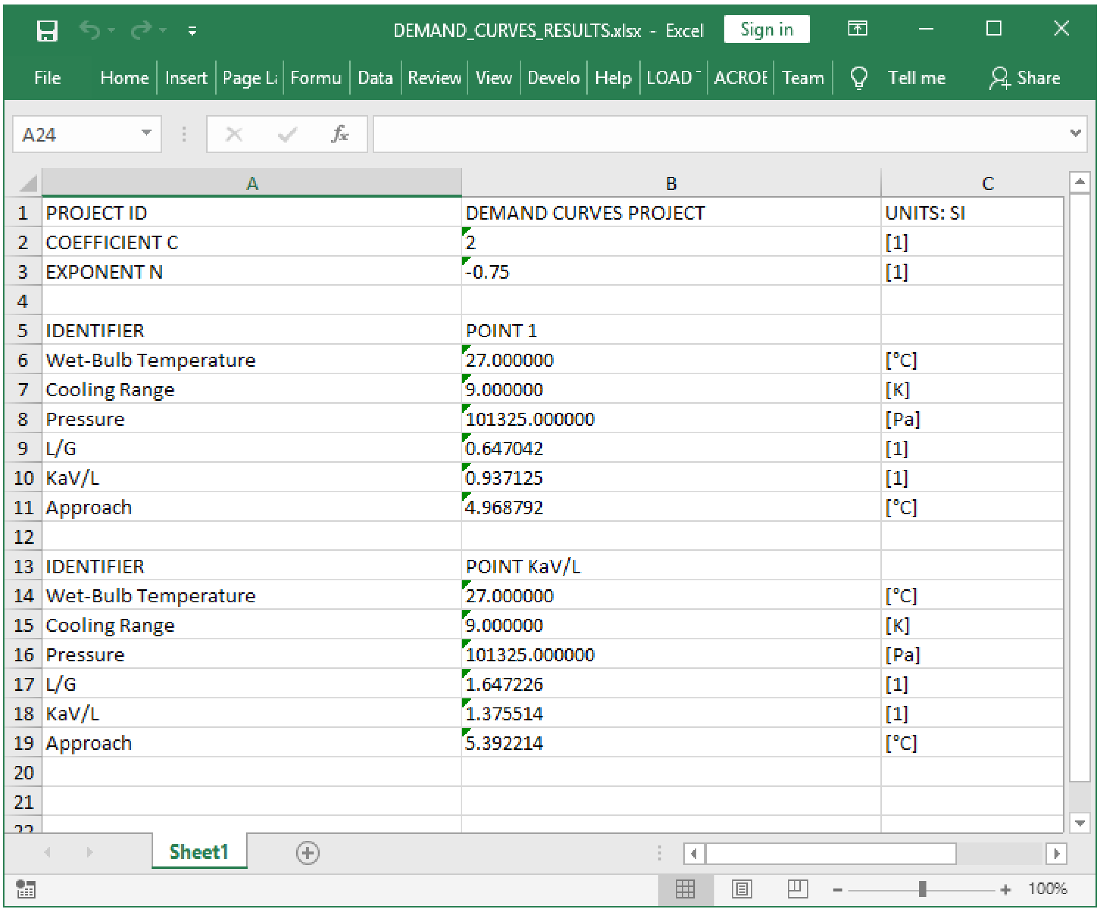


Figure 2.15 Numerical results from all approach points in a project of Demand Curves.

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	0.647042	[1]
KaV/L	0.937125	[1]
Approach	4.968792	[°C]
IDENTIFIER	POINT KaV/L	
Wet-Bulb Temperature	27.000000	[°C]
Cooling Range	9.000000	[K]
Pressure	101325.000000	[Pa]
L/G	1.647226	[1]
KaV/L	1.375514	[1]
Approach	5.392214	[°C]

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



	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	0.647042	[1]
10	KaV/L	0.937125	[1]
11	Approach	4.968792	[°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	1.647226	[1]
18	KaV/L	1.375514	[1]
19	Approach	5.392214	[°C]
20			
21			

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.

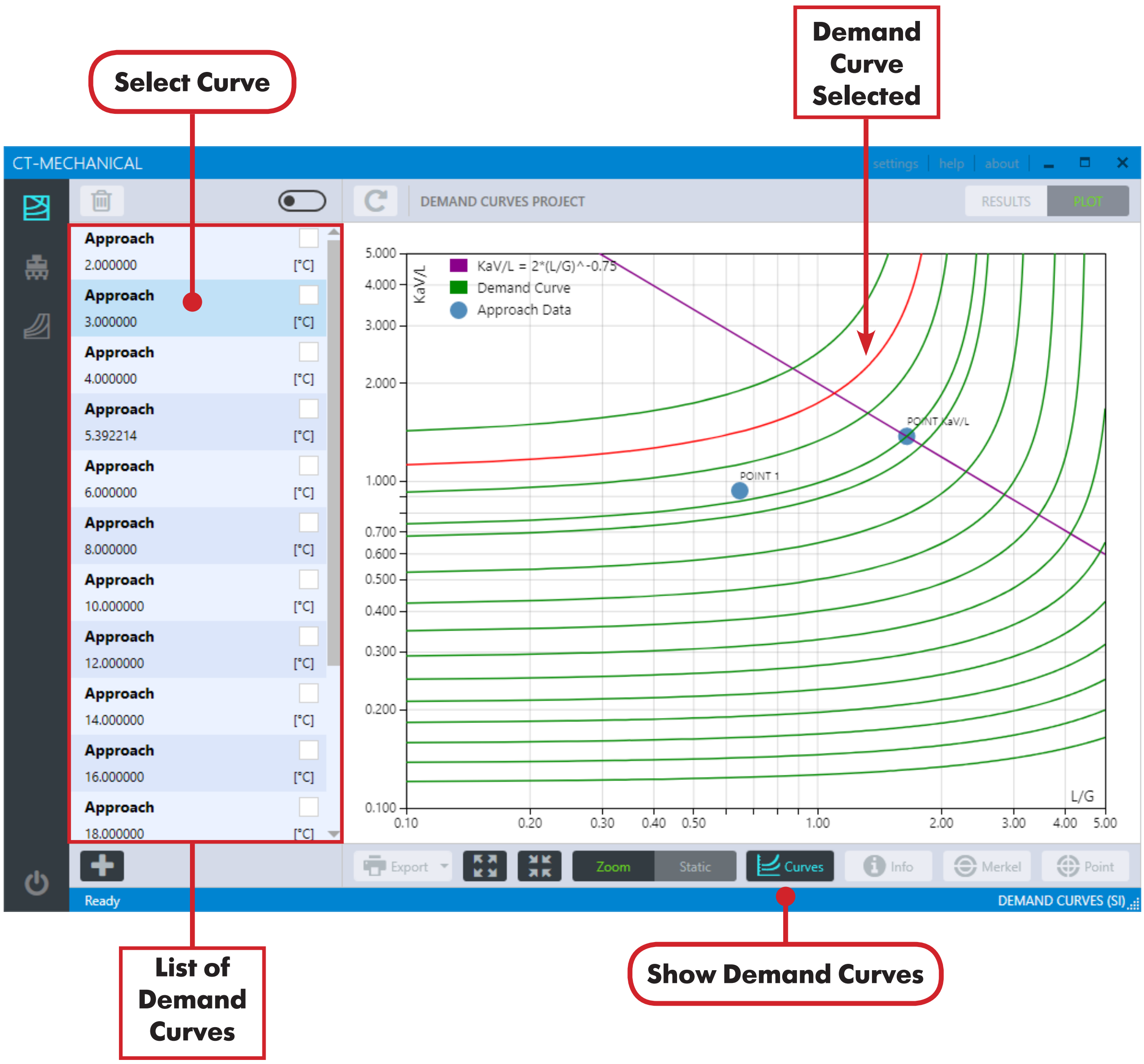


Figure 2.18 Selection of demand curves.

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.

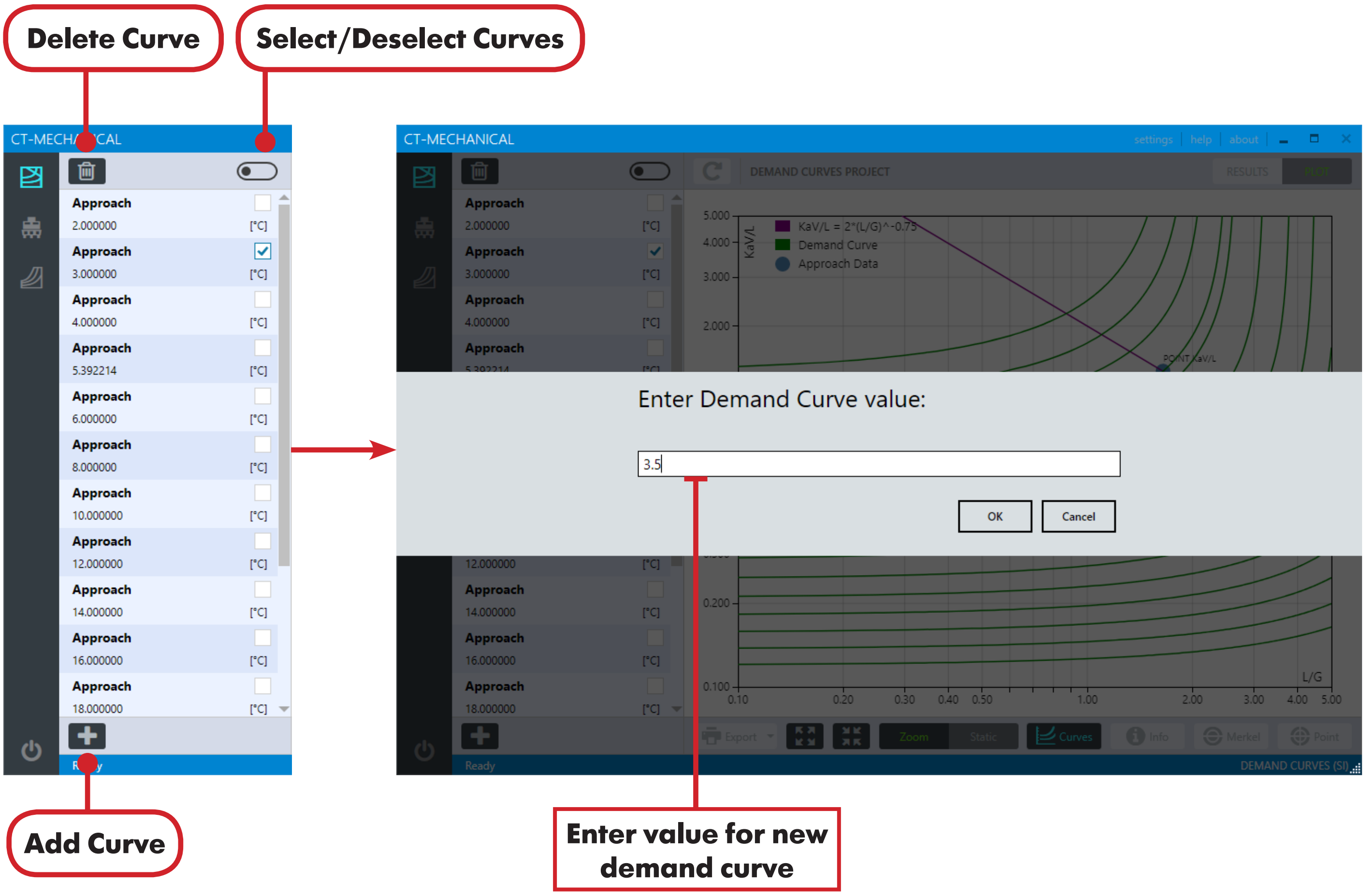


Figure 2.19 Add/Delete a demand curve in a calculation project.

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.

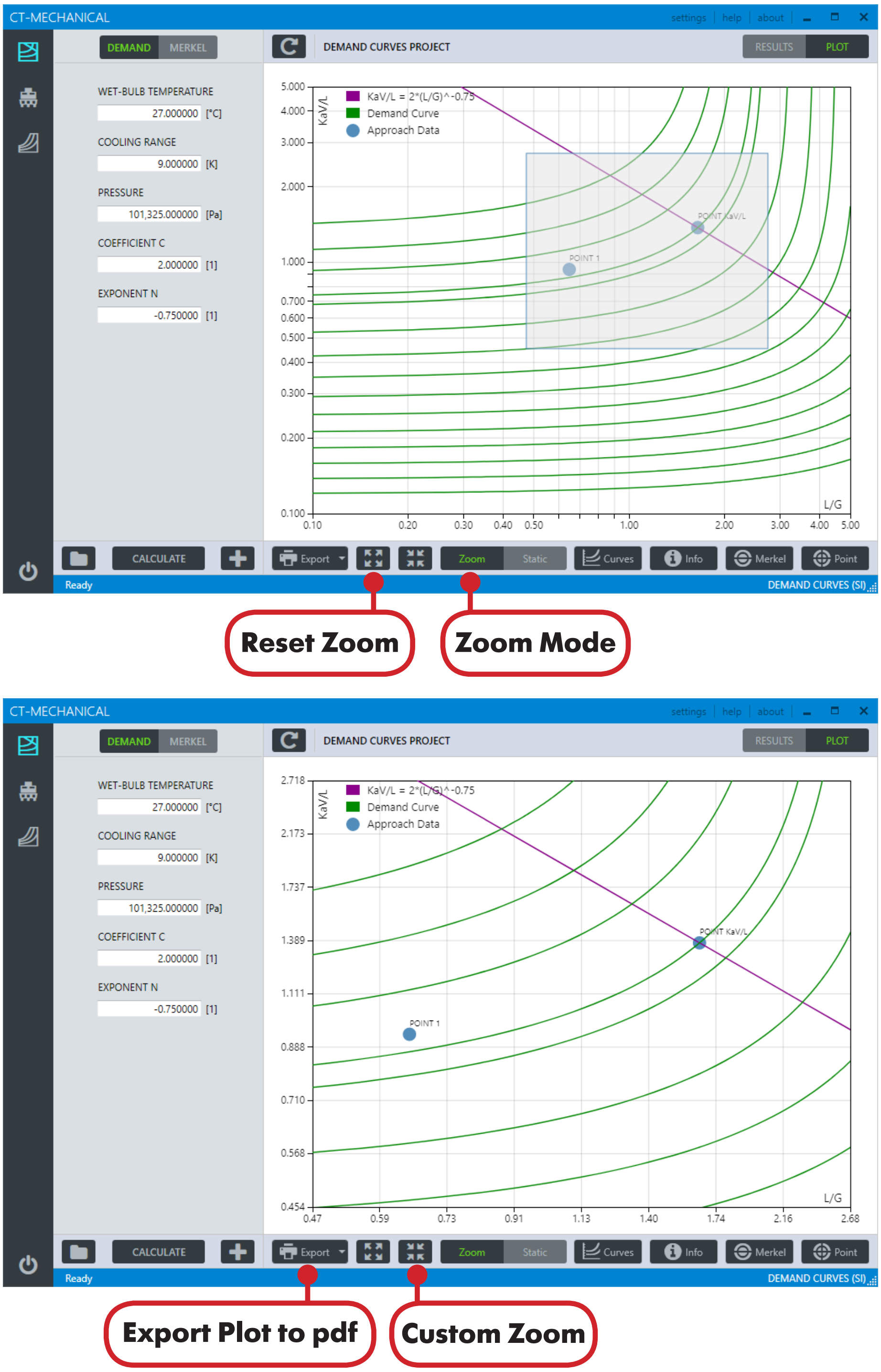


Figure 2.20 Zoom into the Plot Area of Demand Curves.

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.

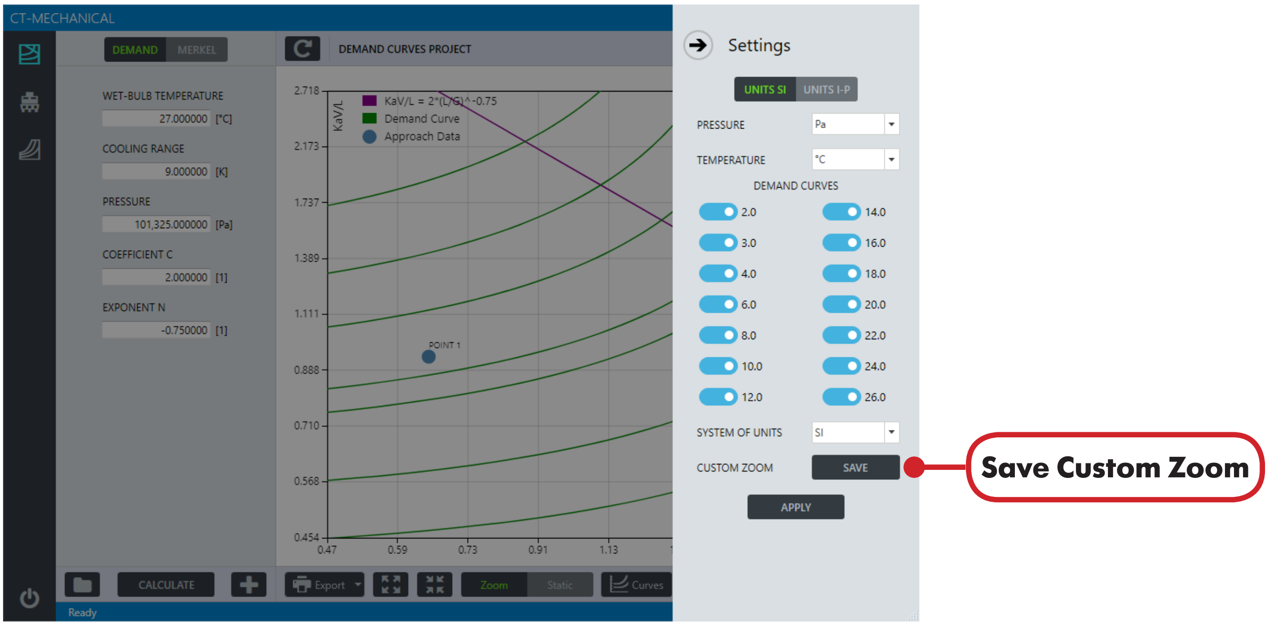


Figure 2.21 Settings for calculation projects of Demand Curves.

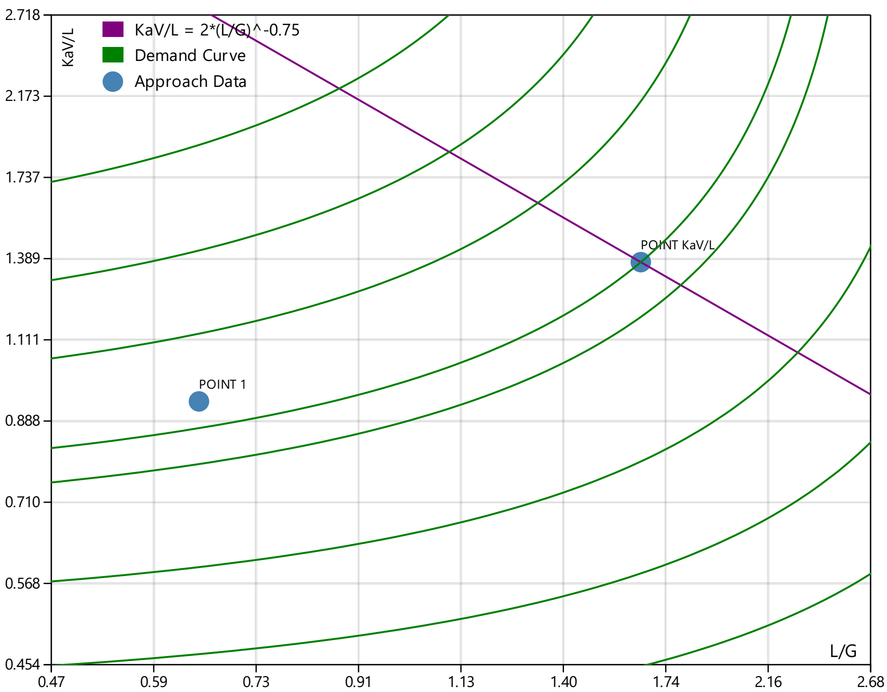


Figure 2.22 Zoom into the Plot Area of Demand Curves (plot exported to pdf).

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.

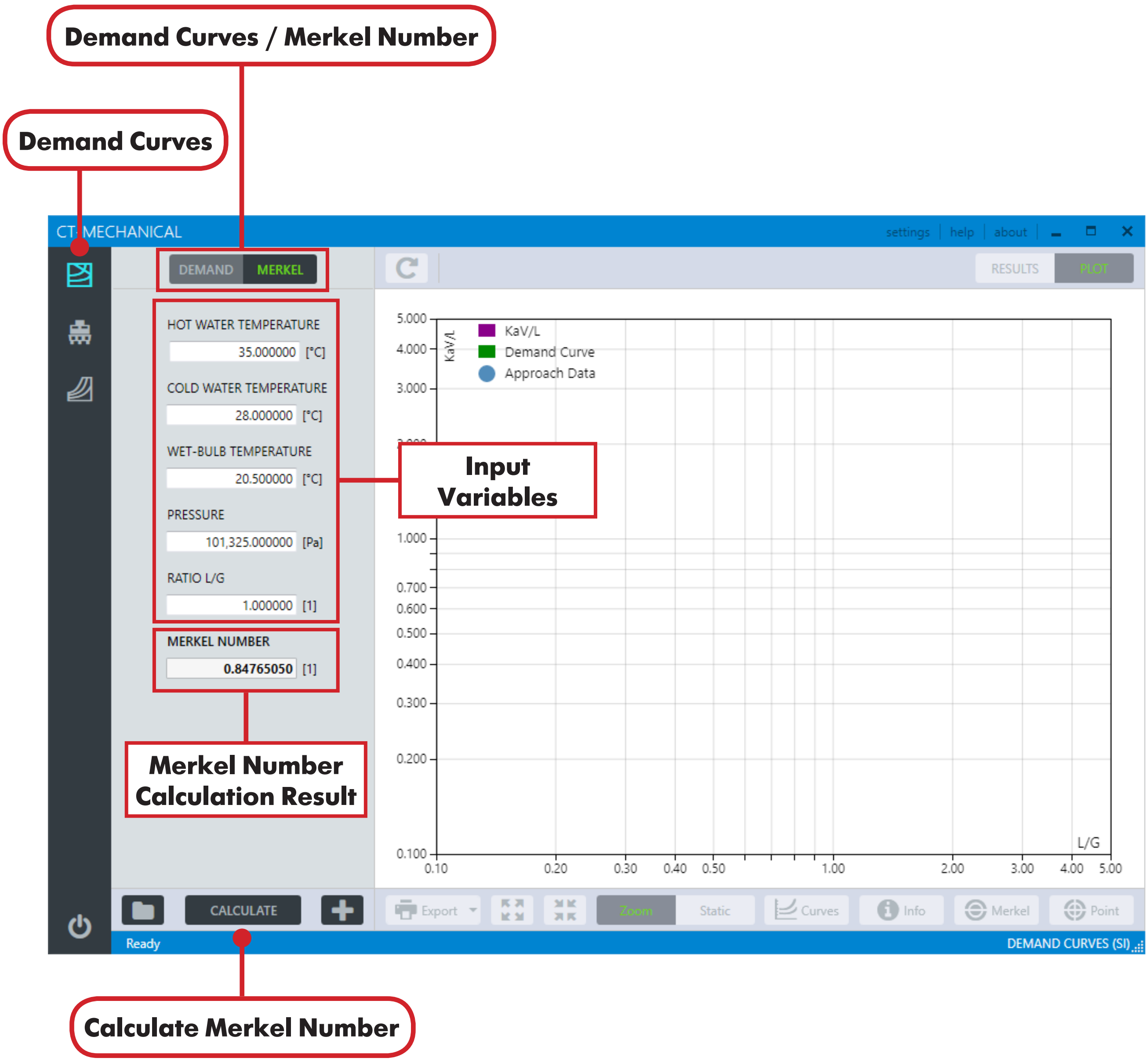


Figure 3.1 Graphical User Interface for the calculation of Merkel Number.

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).

3.4 Validation of Input Variables

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).

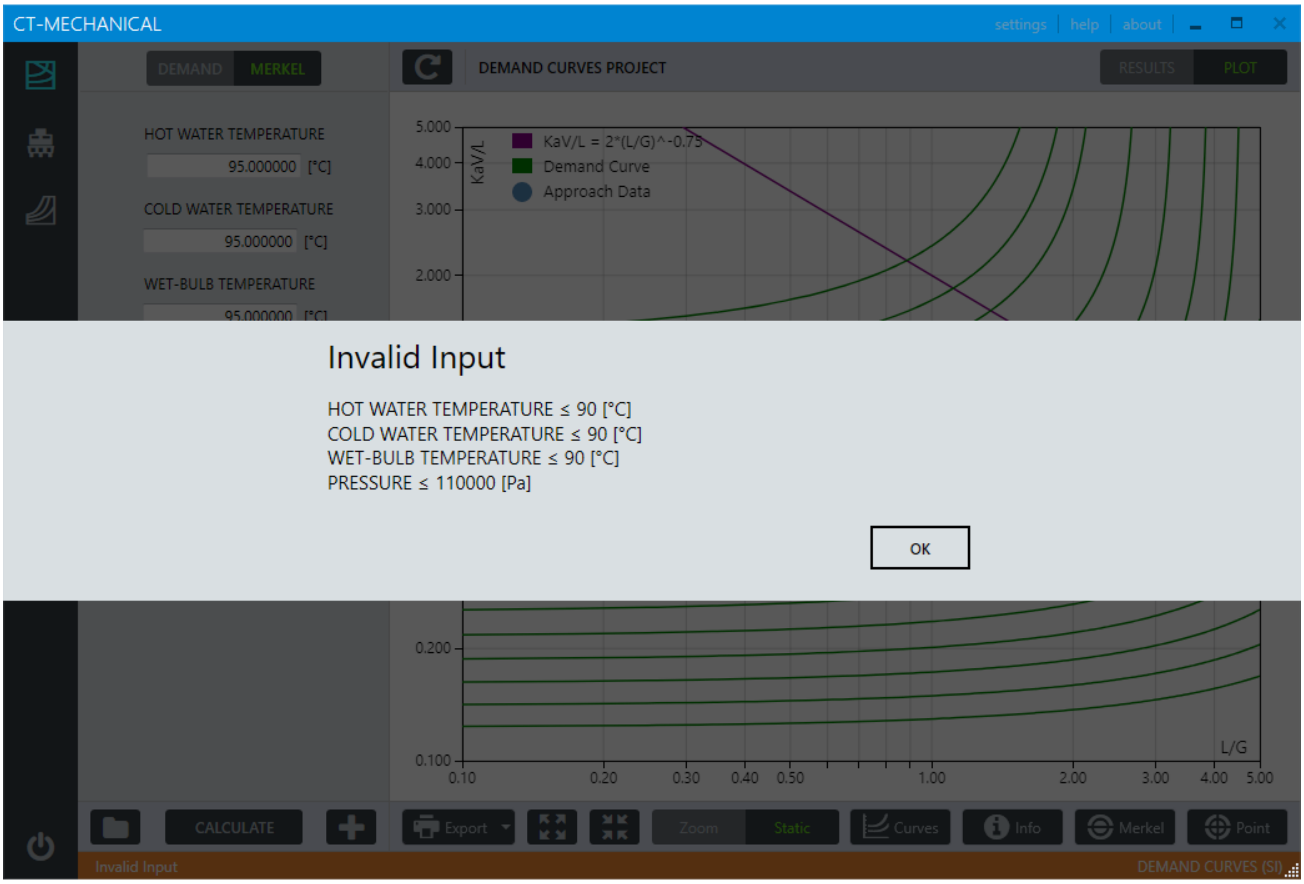


Figure 3.2 Validation of input variables for the calculation of Merkel Number.

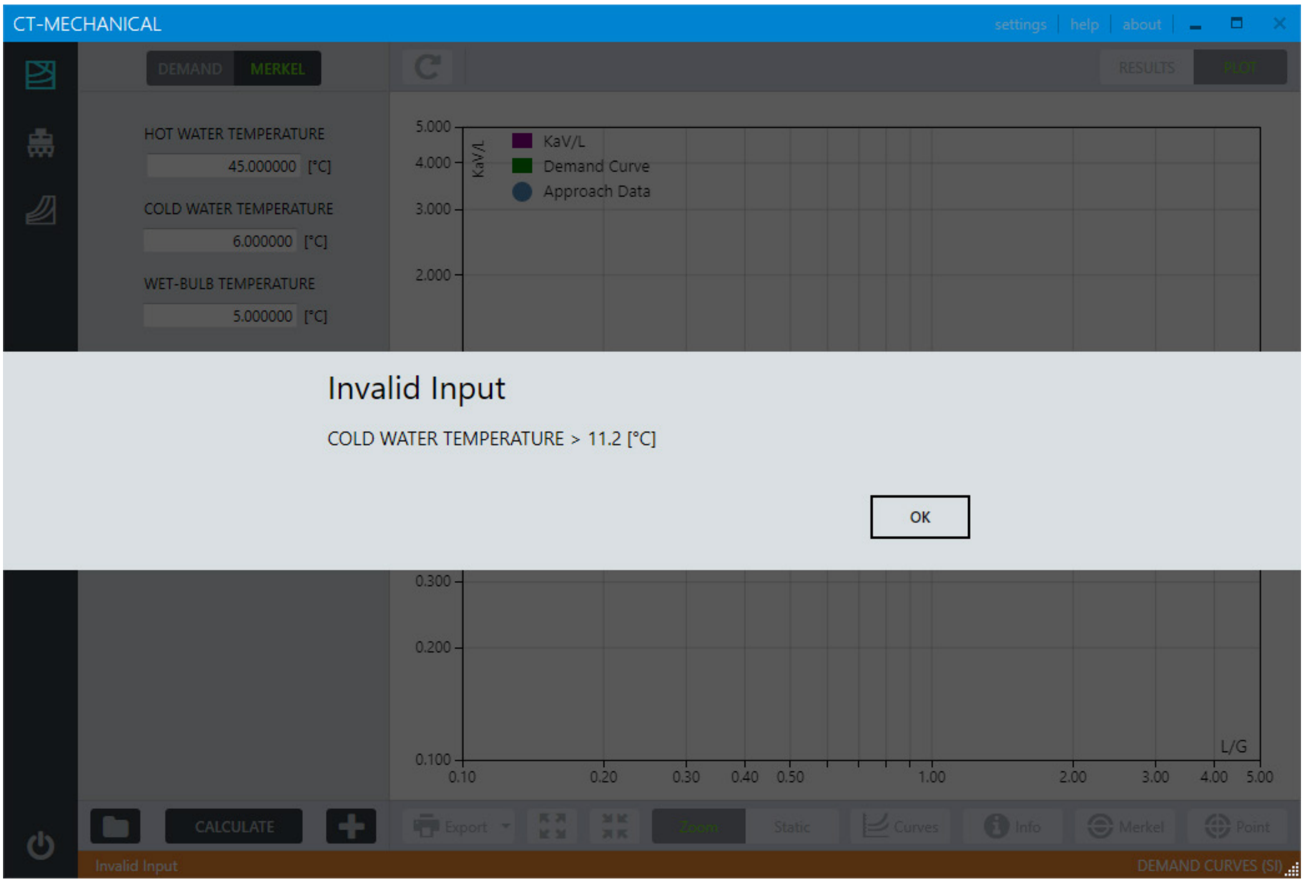


Figure 3.3 Validating the calculation of Merkel Number.

3.5 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.

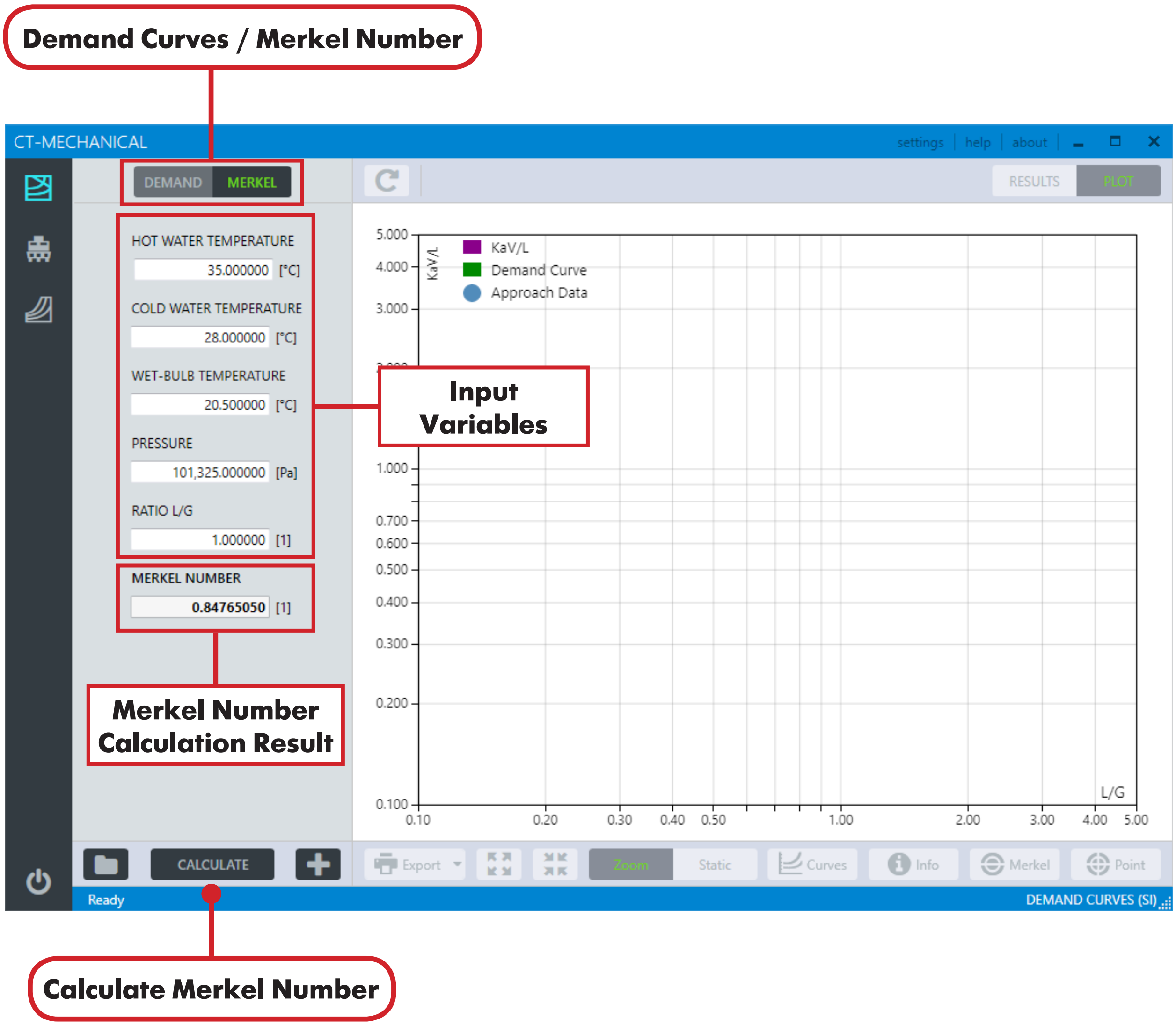


Figure 3.4 Calculation of Merkel Number.

Mechanical Draft allows the evaluation of the cooling capability and thermal performance of mechanical draft cooling towers based on the Acceptance Test Code CTI ATC-105 from test data points using the characteristic curve method.

By determining design and test conditions for a particular mechanical draft cooling tower, the manufacturer´s characteristic curve parameters and a design liquid to gas ratio (L/G), **Mechanical Draft** calculates the cooling capability given design conditions, plotting in a log-log graph each of the input data conditions as well as the resulting intercept results (denoted as a *result data*) given as a pair of values determined by KaV/L and L/G both in SI and I-P.

Mechanical Draft solves the energy equation by numerically integrating the Merkel equation (1-1) using the four-point Chebyshev numerical method and employing the following models for the calculation of water, steam and humid 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

The input variables for a calculation project in Mechanical Draft includes the design data conditions and one set of test data conditions to evaluate the tower capability. Table 4.1 describes these variables. Additional sets of test data conditions can be included in the project in relation to the design data conditions.

Calculation Results

Each set of test data conditions in a calculation project is used as input data in the numerical implementation of the characteristic curve method in relation to the design data conditions. Table 4.2 describes the result variables calculated for each test data.

INPUT VARIABLE	DEFINITION
WATER FLOW RATE	Quantity of hot water flowing into the tower.
HOT WATER TEMPERATURE	Temperature of inlet water.
COLD WATER TEMPERATURE	Average temperature of the cold water basin discharge (outlet).
WET-BULB TEMPERATURE	Temperature of air wet-bulb entering the cooling tower.
DRY-BULB TEMPERATURE	Temperature of air dry-bulb entering the cooling tower.
FAN POWER	Power input to the fan drive assembly, excluding power losses in the driver.
PRESSURE	Total pressure referred to atmospheric.
COEFFICIENT C	Constant defined for a particular packing design.
EXPONENT N	Exponent defined for a particular packing design.
DESIGN L/G RATIO	Ratio of water flow rate to airflow rate at design
TOWER TYPE	Forced draft: fan located near the bottom, forcing the air from bottom to top. Induced draft: fan located at the top inducing suction from the tower and discharging it into the atmosphere.

Table 4.1 Definition of input variables in Mechanical Draft.

RESULT VARIABLE	DEFINITION
APPROACH	Approach calculated at design data.
INTERCEPT L/G AT APPROACH	L/G ratio calculated at result point (L/G value of the intersection of the demand curve calculated on the approach at design and the curve parallel to the characteristic curve defined on the test point).
INTERCEPT KaV/L	KaV/L ratio calculated at result point (KaV/L value of the intersection of the demand curve calculated on the approach at design and the curve parallel to the characteristic curve defined on the test point).
TOWER CAPABILITY	Cooling capability result calculated for a test data.

Table 4.2 Definition of calculation result variables in Mechanical Draft.

The full ranges of input variables for Mechanical Draft projects in SI and I-P system of units:

Property	Range in SI Units	SI Units
WATER FLOW RATE	0.5 ≤ Flow ≤ 100000.0	kg/s
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
DRY-BULB TEMPERATURE	1.0 ≤ T ≤ 90.0	°C
FAN POWER	1.0 ≤ Power ≤ 1.0E6	W
PRESSURE	60000 ≤ P ≤ 110000	Pa
COEFFICIENT C	1.0 ≤ C ≤ 3.0	1
EXPONENT N	-2.0 ≤ N ≤ -0.1	1
DESIGN L/G RATIO	0.1 ≤ L/G ≤ 5.0	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
WATER FLOW RATE	7.92 ≤ Flow ≤ 1585032.22	gpm
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
DRY-BULB TEMPERATURE	33.8 ≤ T ≤ 194.0	°F
FAN POWER	0.001342 ≤ Power ≤ 1341.022	bhp
PRESSURE	8.702264 ≤ P ≤ 15.954151	psia
COEFFICIENT C	1.0 ≤ C ≤ 3.0	1
EXPONENT N	-2.0 ≤ N ≤ -0.1	1
DESIGN L/G RATIO	0.1 ≤ L/G ≤ 5.0	1
KaV/L	0.1 ≤ KaV/L ≤ 5.0	1
L/G	0.1 ≤ L/G ≤ 5.0	1
APPROACH	1.0 ≤ T ≤ 140.0	°F

Table 4.3 Full Ranges of input variables in Mechanical Draft.

Certain limitations are imposed in each project in order to improve the graphical performance on **Mechanical Draft** calculations. These are described in Table 4.4. The number of projects is limited just by the memory available on the computer on which **CT-Mechanical** is installed.

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

Table 4.4 Limitations on Calculation Projects of Mechanical Draft.

The full ranges of input variables for **Mechanical Draft** (Evaluation Version) projects in SI and I-P:

Property	**Range in SI Units**	**SI Units**
WATER FLOW RATE	200.0 ≤ Flow ≤ 230.0	kg/s
HOT WATER TEMPERATURE	33.0 ≤ T ≤ 43.0	°C
COLD WATER TEMPERATURE	27.0 ≤ T ≤ 31.0	°C
WET-BULB TEMPERATURE	21.0 ≤ T ≤ 26.0	°C
DRY-BULB TEMPERATURE	22.0 ≤ T ≤ 33.0	°C
FAN POWER	55.0 ≤ Power ≤ 65.0	kW
PRESSURE	99000 ≤ P ≤ 102000	Pa
COEFFICIENT C	2.0 ≤ C ≤ 2.1	1
EXPONENT N	-2.0 ≤ N ≤ -0.1	1
DESIGN L/G RATIO	0.1 ≤ L/G ≤ 5.0	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**
WATER FLOW RATE	440.9 ≤ Flow ≤ 507.1	lb/s
HOT WATER TEMPERATURE	91.4 ≤ T ≤ 109.4	°F
COLD WATER TEMPERATURE	80.6 ≤ T ≤ 87.8	°F
WET-BULB TEMPERATURE	69.8 ≤ T ≤ 78.8	°F
DRY-BULB TEMPERATURE	71.6 ≤ T ≤ 91.4	°F
FAN POWER	73.8 ≤ Power ≤ 87.2	bhp
PRESSURE	14.358736 ≤ P ≤ 14.793849	psia
COEFFICIENT C	2.0 ≤ C ≤ 2.1	1
EXPONENT N	-2.0 ≤ N ≤ -0.1	1
DESIGN L/G RATIO	0.1 ≤ L/G ≤ 5.0	1
KaV/L	0.1 ≤ KaV/L ≤ 5.0	1
L/G	0.1 ≤ L/G ≤ 5.0	1
APPROACH	1.0 ≤ T ≤ 108.0	°F

Table 4.5 Ranges of input variables for Mechanical Draft (Evaluation Version).

Certain limitations are imposed for each project in order to improve the graphical performance on **Mechanical Draft** (Evaluation Version) calculations. These are described in Table 4.6.

Maximum Number of Projects	3

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

Table 4.6 Limitations on calculation projects of Mechanical Draft (Evaluation Version).

The Graphical User Interface for **Mechanical Draft** is shown in Figure 4.1. By selecting the button Mechanical Draft **on the left side of the application, the user is presented with the interface.**

Selecting the buttons denoted DESIGN / TEST / CURVE **allows the user to enter the input variables to determine a calculation project.**

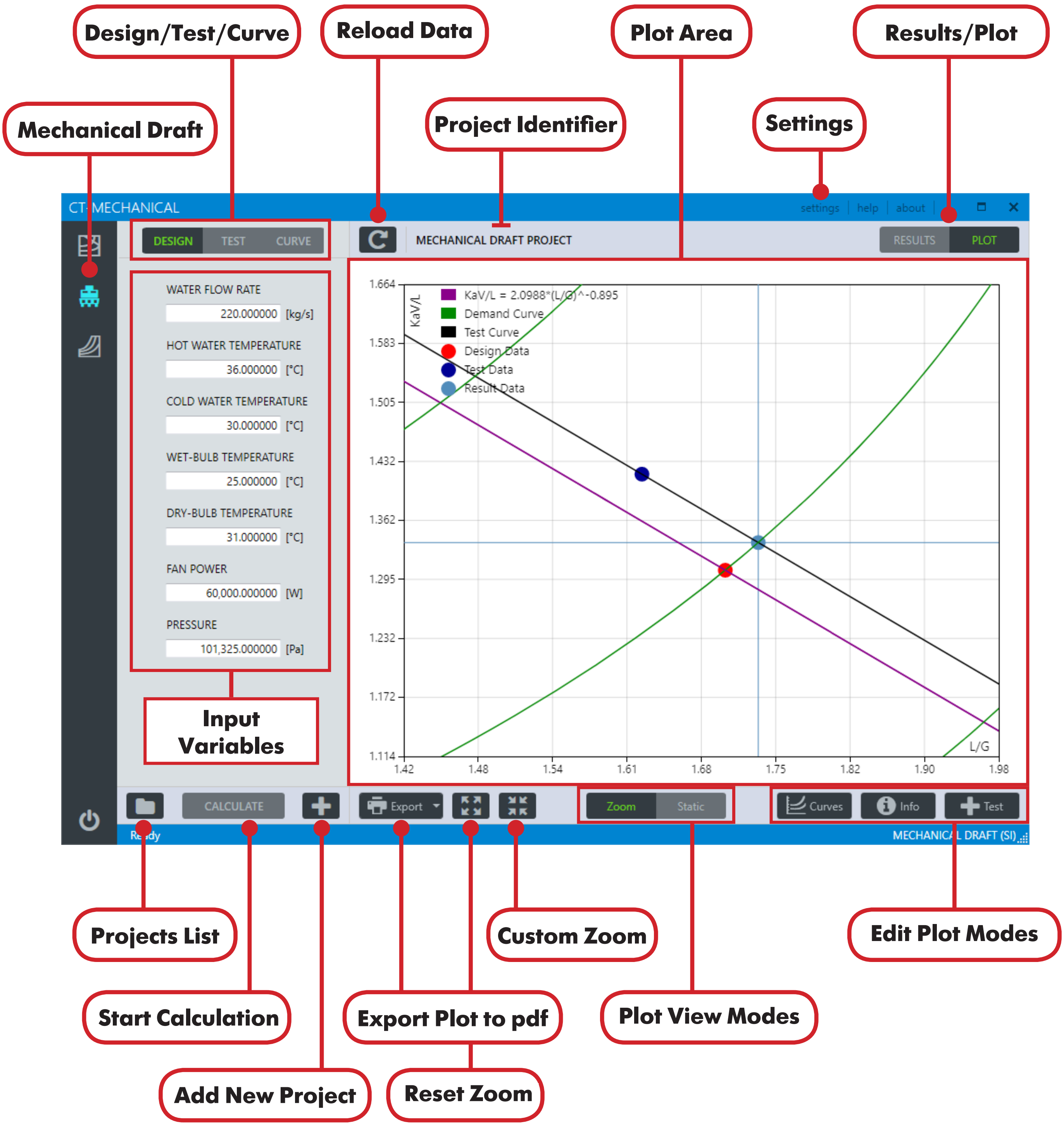


Figure 4.1 Graphical User Interface for Mechanical Draft.

Add Calculation Project

1. Click on the Add New Project button to add a new calculation project. Type a project identifier and click the button OK (Figure 4.2). The project will be created in the database and the application will be ready for including additional test data calculations.
2. Click on the Settings button to select the units used for this particular project, as well as the demand curves that will be calculated and plotted (Figure 4.3). Click on the APPLY button to save the selections.
3. Enter the input variables for the calculation.
4. Click on the CALCULATE button to start the calculations (Figure 4.4).

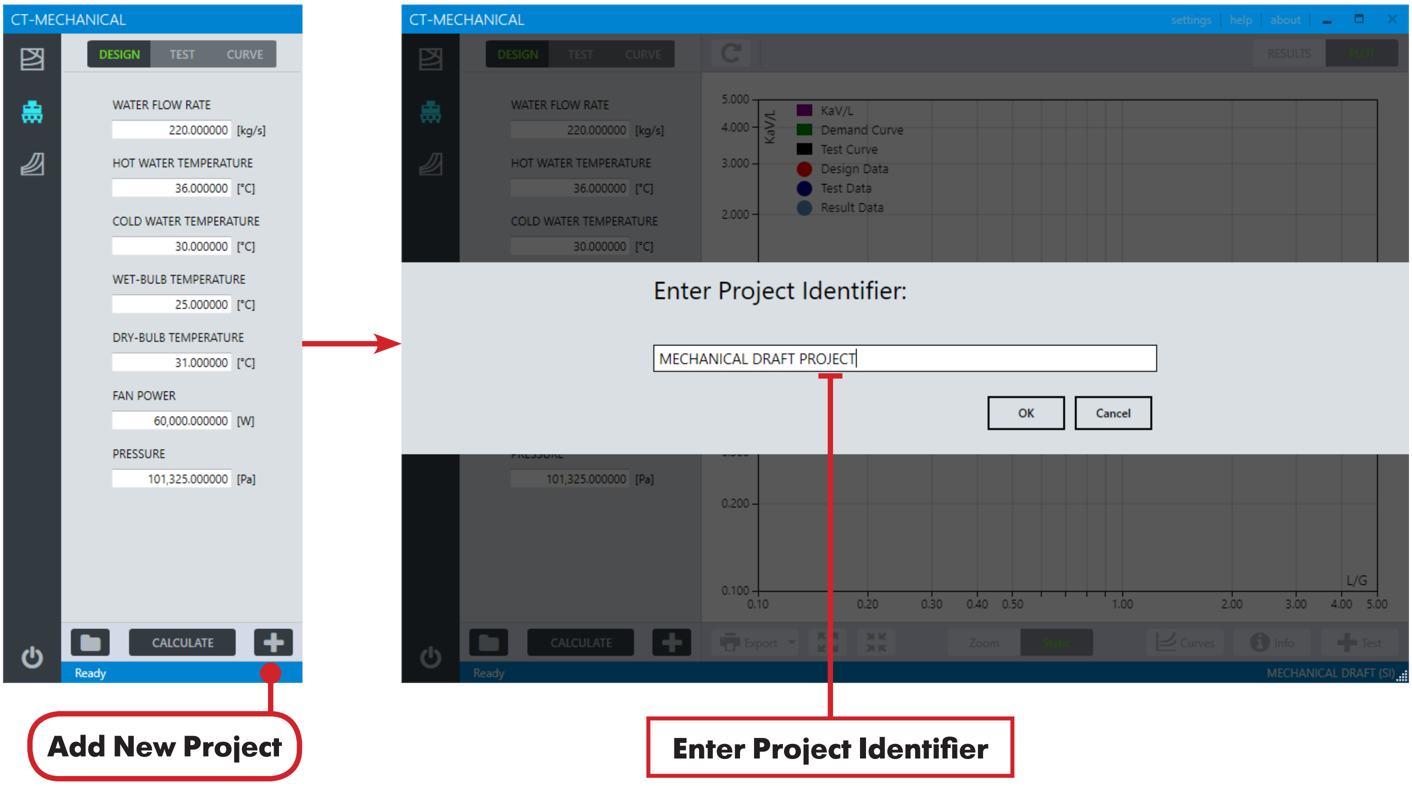


Figure 4.2 Adding a calculation project to Mechanical Draft.

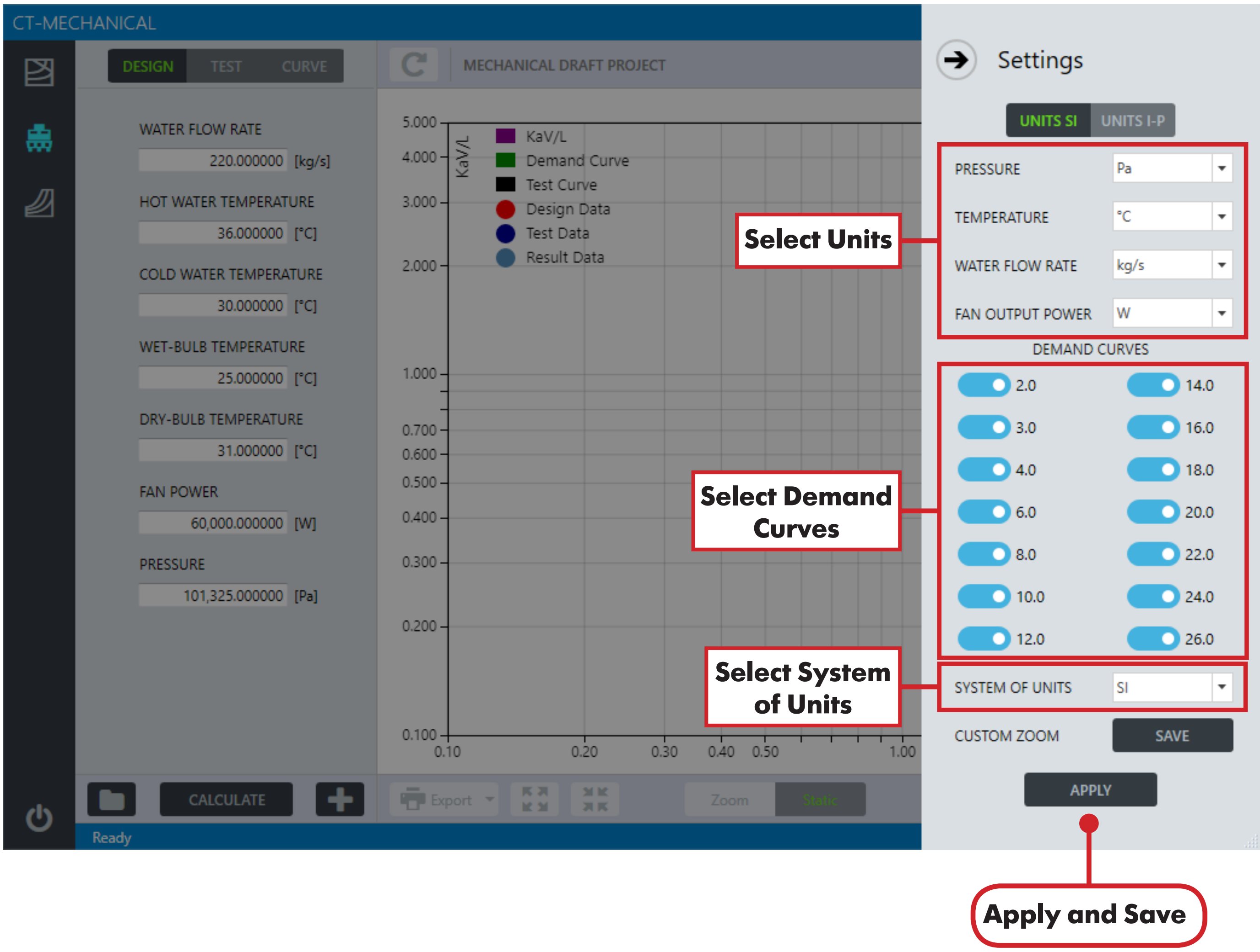


Figure 4.3 Settings for calculation projects of Mechanical Draft.

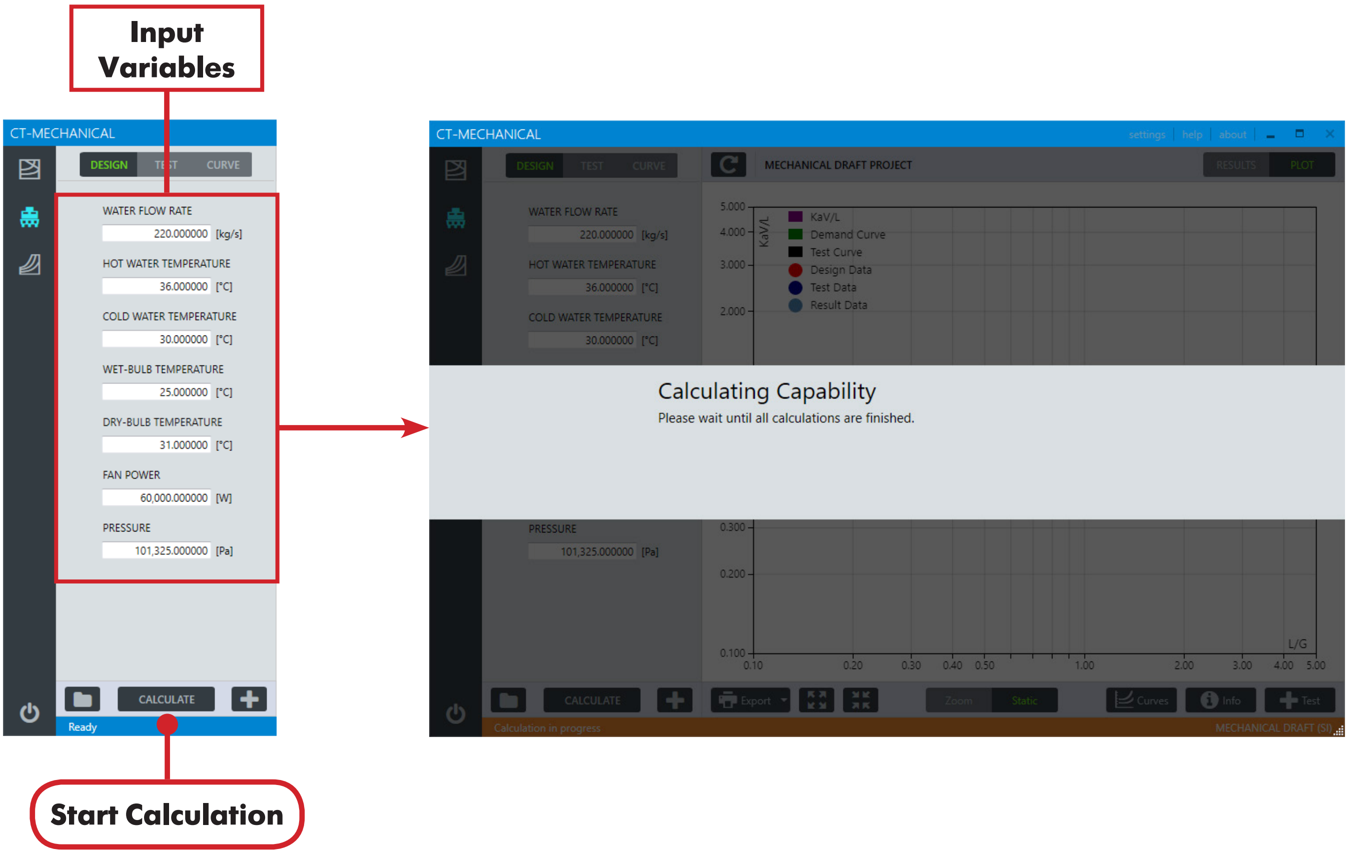


Figure 4.4 Calculation project in Mechanical Draft.

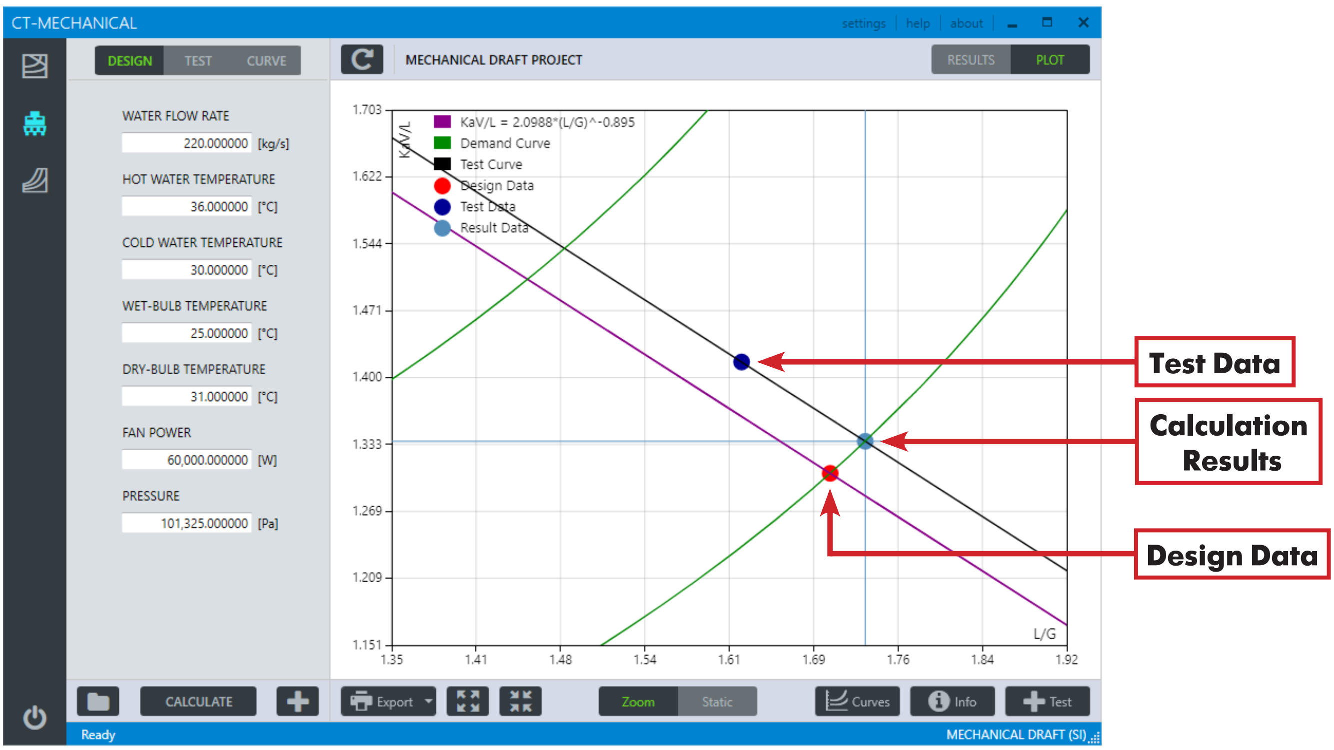


Figure 4.5 Plot Area of Mechanical Draft after calculations are completed.

4.5 Calculation Projects

Load Calculation Project from Database

1. Click on the Projects List button to load all the projects saved in the database (Figure 4.6).
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 test calculations or demand curves.

Delete Calculation Project from Database

1. Click on the Projects List button to load all the projects saved in the database.
2. Select the project(s) by checking on the checkbox. Click on the Select Projects button to check/uncheck all projects enabling their deletion.
3. Click on the Delete Project button to delete the project(s) from the database and the Plot Area. When deleting a project, all the demand curves and test calculations that belong to that project will also be deleted.

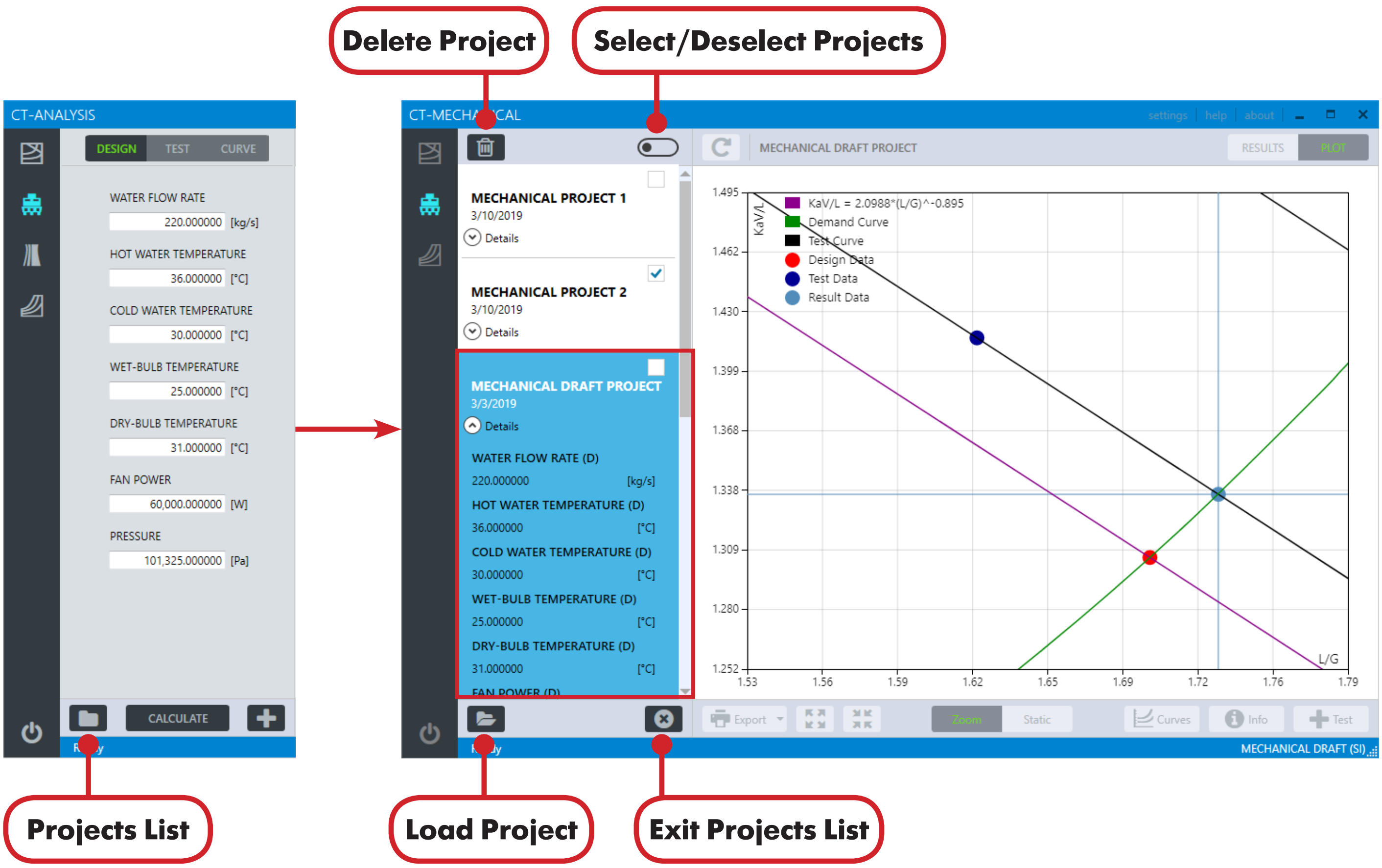


Figure 4.6 List of calculation projects in Mechanical Draft.

Add Test Data Calculation to a Project

1. Click on the Test button to add a new test data calculation to a project (Figure 4.7). Introduce an identifier for the test data (optional).
2. Introduce the input variables for the new test data calculation.
3. Click on the CALCULATE button to start the calculation of the test data (Figure 4.8).
4. Once the calculation has finished, the calculation results will be added to the Plot Area as a Test Point and a Result Point with their corresponding Test Curve.
5. Click on the Test button to return to the Plot Area default mode.

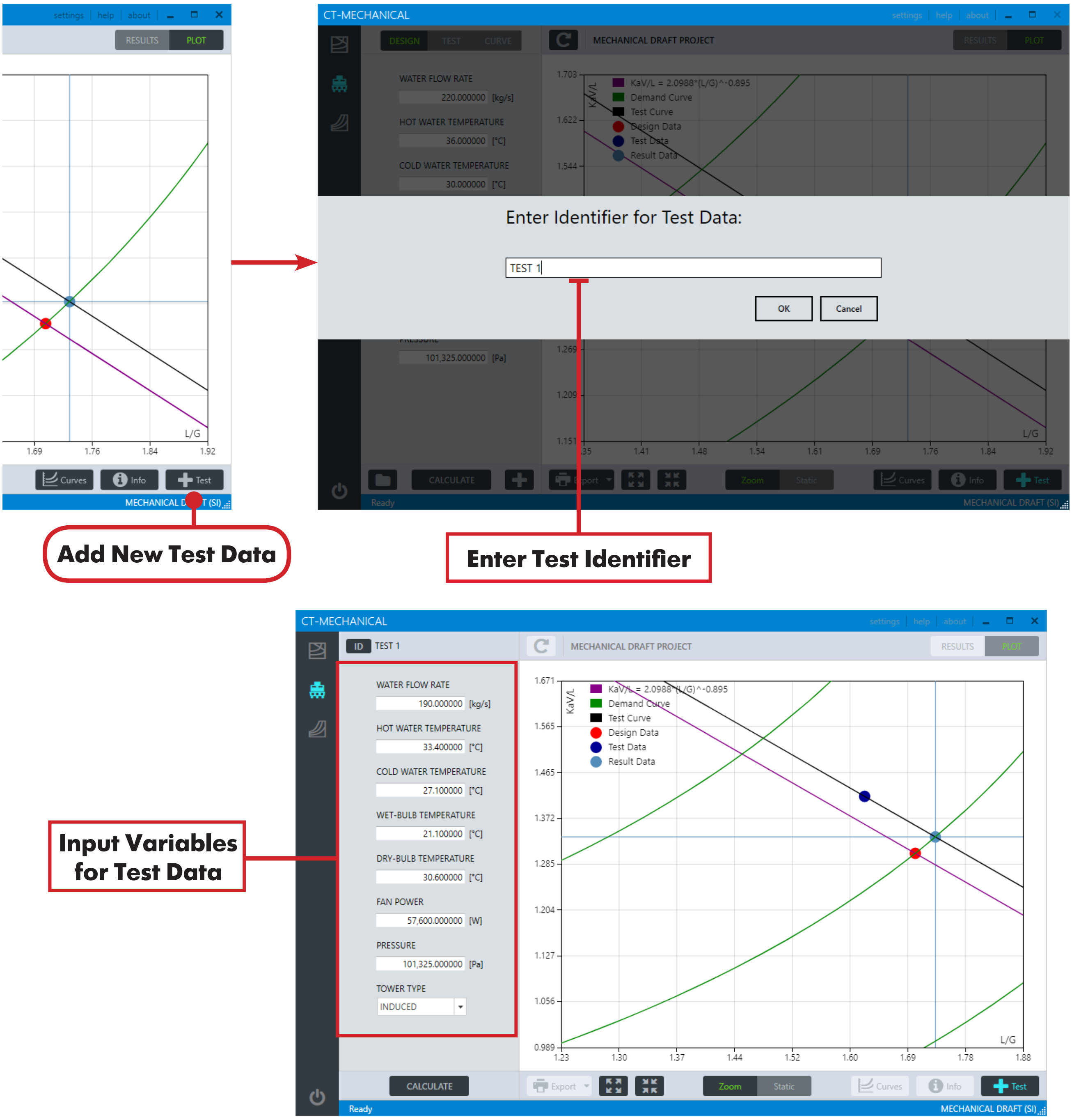


Figure 4.7 Add Test Data in Mechanical Draft.

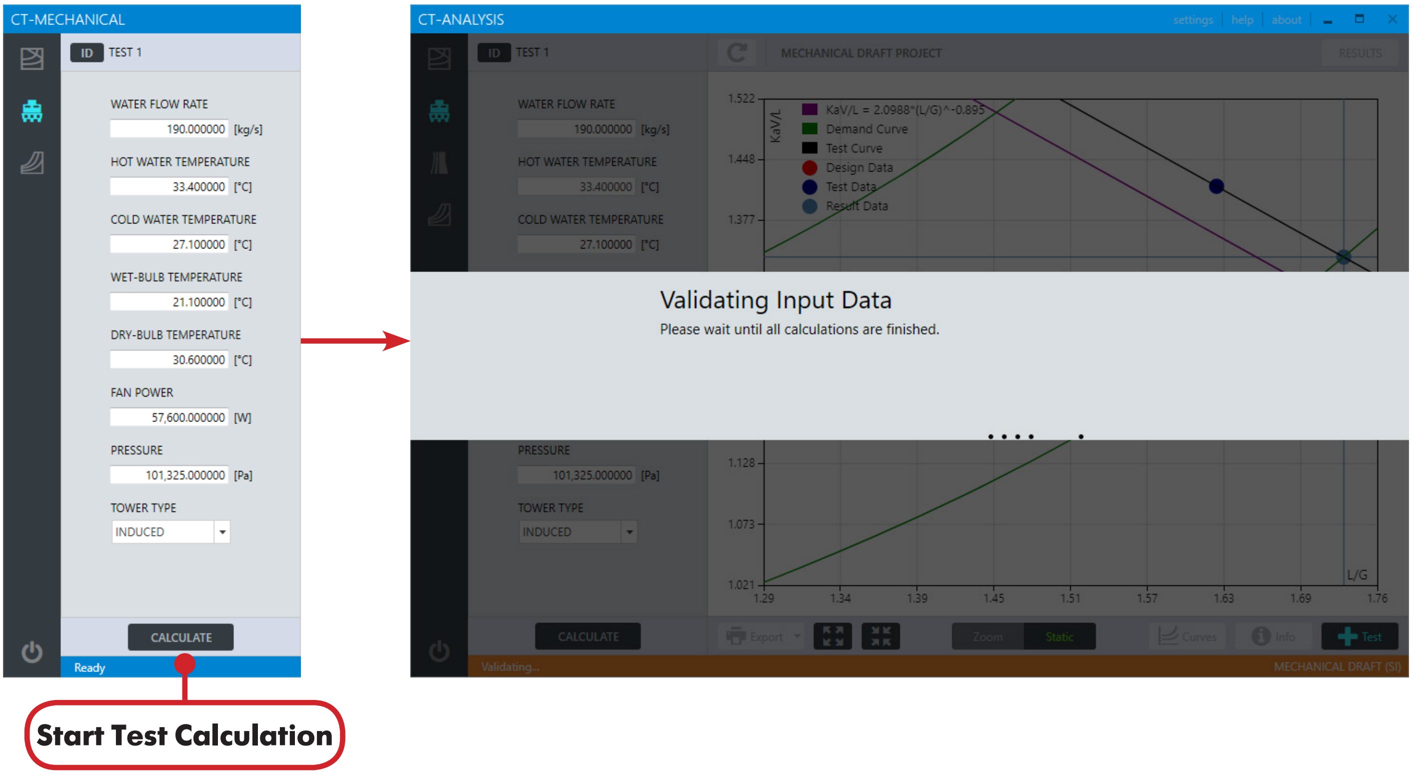


Figure 4.8 Calculation of test data in Mechanical Draft.

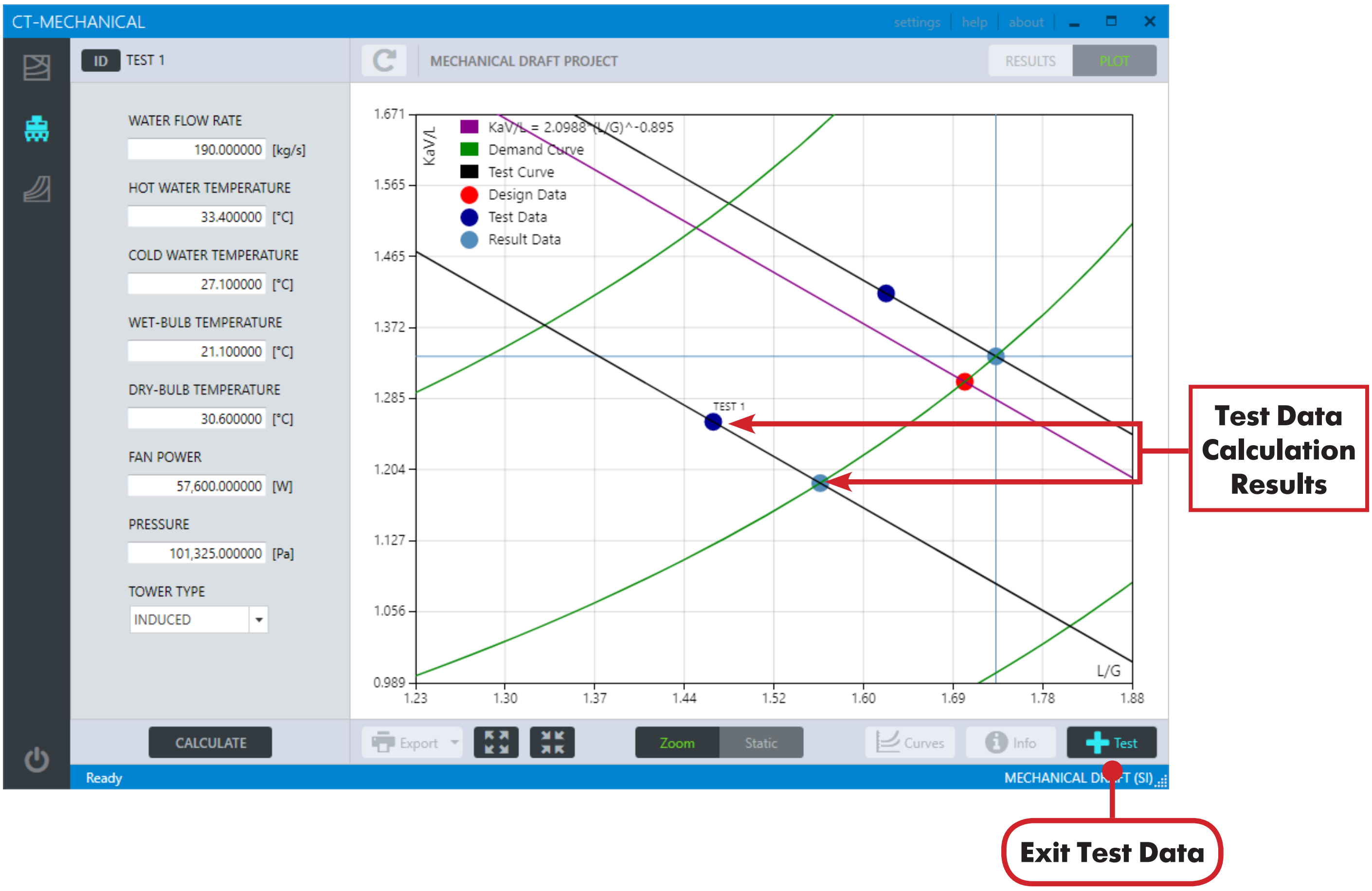


Figure 4.9 Plot Area (with zooming) after test data has been added to a Mechanical Draft project.

Validating Input Variables and Calculations

All input variables in SI or I-P are bounded by the ranges described in Table 4.1. In case that input variables are introduced that are out of these ranges, and a new test 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.

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 (Figure 4.10). Calculations that are within these ranges, but not do satisfy the conditions for a valid test data calculation, also display a message (Figure 4.11).

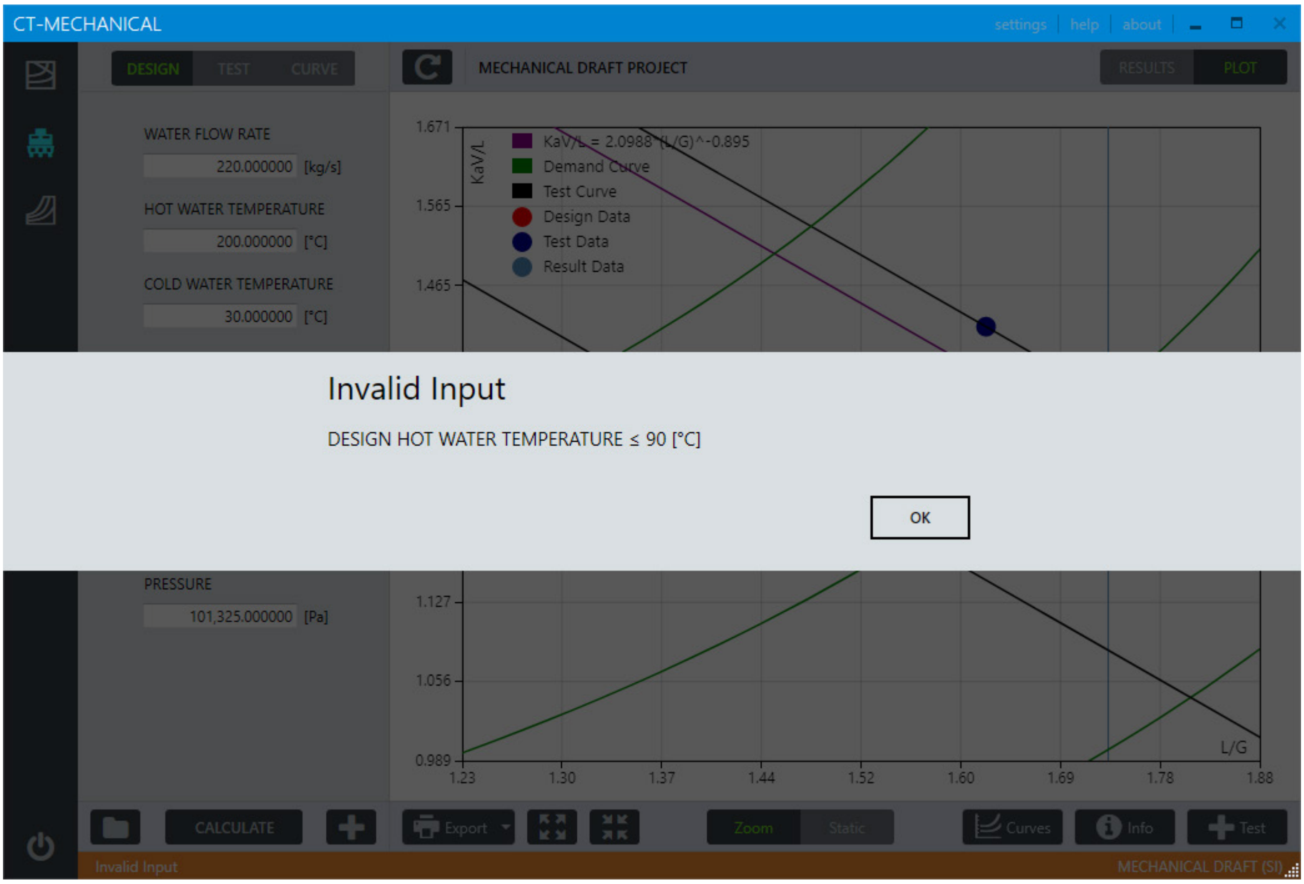


Figure 4.10 Validation of input variables of test data in Mechanical Draft.

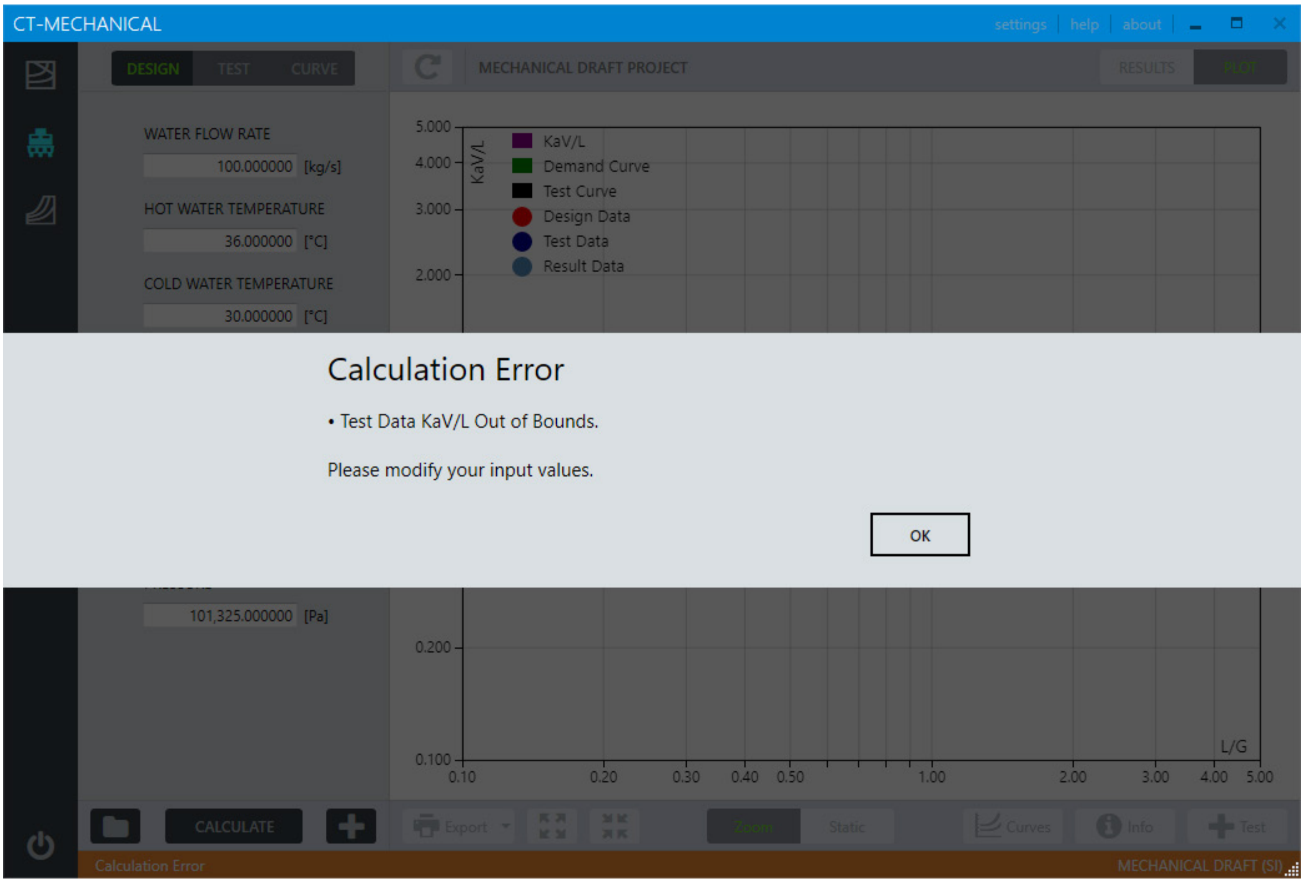


Figure 4.11 Validating the calculation of test data in Mechanical Draft.

Get Calculation Results Graphically

1. Click on the Info button to start the Graphical Mode. Allow the selection of points by selecting 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 test/result 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 delete it from the database.

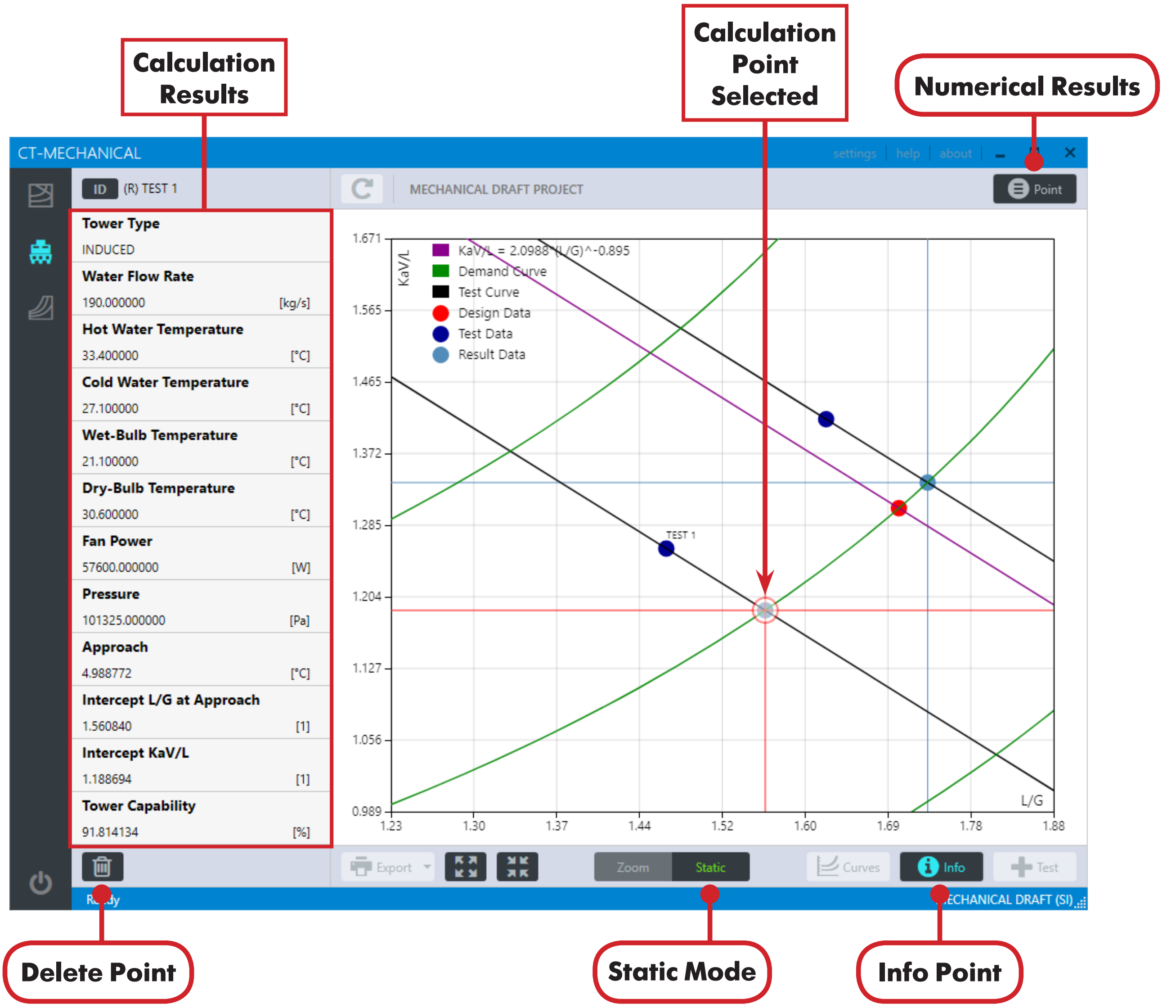


Figure 4.12 Numerical results from calculation data points in Mechanical Draft.

Get Numerical Results from a Project

1. Click on the RESULTS button to load all the design/test/result point calculations for a particular project. All the numerical results will be displayed in a table format.
2. Click on the PLOT button to return to the Plot Area (Figure 4.13).

Export Numerical Results

1. Click on the Export Results button to export the numerical calculation results of all the design/test/result points for a particular project. These can be exported to excel / pdf formats.

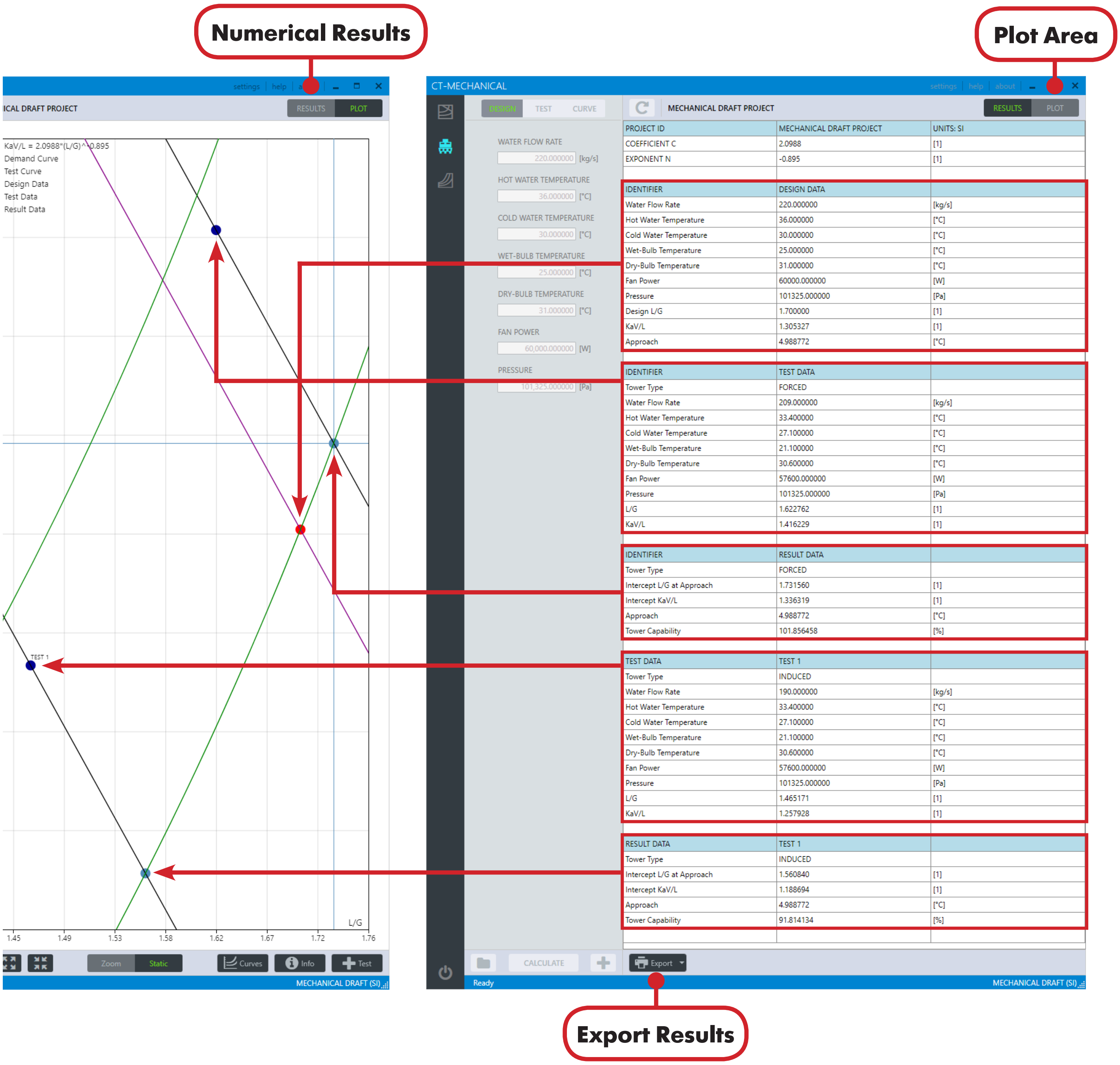
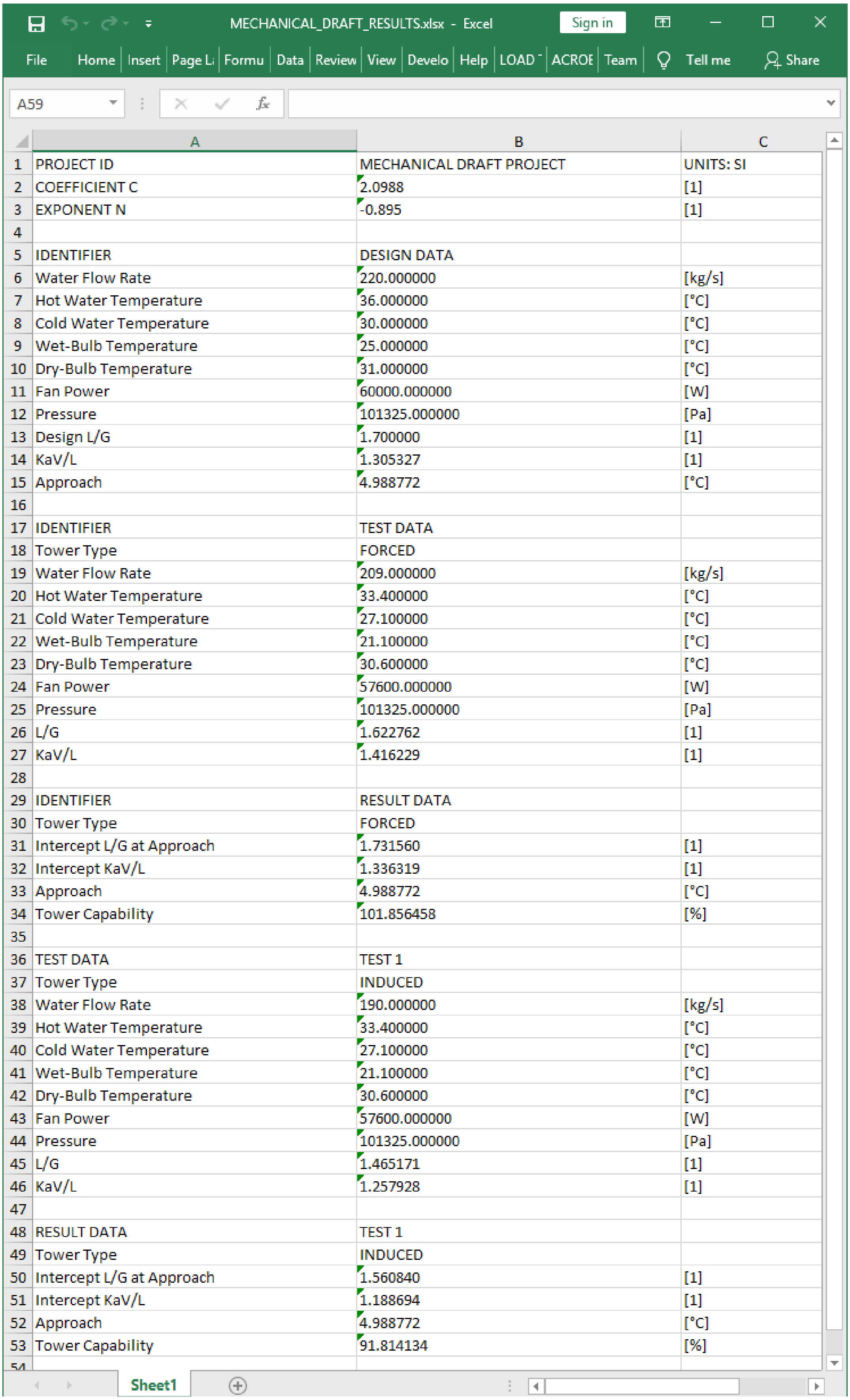


Figure 4.13 Numerical results from calculations in a project of Mechanical Draft.

PROJECT ID	MECHANICAL DRAFT PROJECT	UNITS: SI
COEFFICIENT C	2.0988	[1]
EXPONENT N	-0.895	[1]
IDENTIFIER	DESIGN DATA	
Water Flow Rate	220.000000	[kg/s]
Hot Water Temperature	36.000000	[°C]
Cold Water Temperature	30.000000	[°C]
Wet-Bulb Temperature	25.000000	[°C]
Dry-Bulb Temperature	31.000000	[°C]
Fan Power	60000.000000	[W]
Pressure	101325.000000	[Pa]
Design L/G	1.700000	[1]
KaV/L	1.305327	[1]
Approach	4.988772	[°C]
IDENTIFIER	TEST DATA	
Tower Type	FORCED	
Water Flow Rate	209.000000	[kg/s]
Hot Water Temperature	33.400000	[°C]
Cold Water Temperature	27.100000	[°C]
Wet-Bulb Temperature	21.100000	[°C]
Dry-Bulb Temperature	30.600000	[°C]
Fan Power	57600.000000	[W]
Pressure	101325.000000	[Pa]
L/G	1.622762	[1]
KaV/L	1.416229	[1]
IDENTIFIER	RESULT DATA	
Tower Type	FORCED	
Intercept L/G at Approach	1.731560	[1]
Intercept KaV/L	1.336319	[1]
Approach	4.988772	[°C]
Tower Capability	101.856458	[%]
TEST DATA	TEST 1	
Tower Type	INDUCED	
Water Flow Rate	190.000000	[kg/s]
Hot Water Temperature	33.400000	[°C]
Cold Water Temperature	27.100000	[°C]
Wet-Bulb Temperature	21.100000	[°C]
Dry-Bulb Temperature	30.600000	[°C]
Fan Power	57600.000000	[W]
Pressure	101325.000000	[Pa]
L/G	1.465171	[1]
KaV/L	1.257928	[1]
RESULT DATA	TEST 1	
Tower Type	INDUCED	
Intercept L/G at Approach	1.560840	[1]
Intercept KaV/L	1.188694	[1]
Approach	4.988772	[°C]
Tower Capability	91.814134	[%]

Figure 4.14 Example of pdf file results from calculations in a project of Mechanical Draft.



	A	B	C
1	PROJECT ID	MECHANICAL DRAFT PROJECT	UNITS: SI
2	COEFFICIENT C	2.0988	[1]
3	EXPONENT N	-0.895	[1]
4			
5	IDENTIFIER	DESIGN DATA	
6	Water Flow Rate	220.000000	[kg/s]
7	Hot Water Temperature	36.000000	[°C]
8	Cold Water Temperature	30.000000	[°C]
9	Wet-Bulb Temperature	25.000000	[°C]
10	Dry-Bulb Temperature	31.000000	[°C]
11	Fan Power	60000.000000	[W]
12	Pressure	101325.000000	[Pa]
13	Design L/G	1.700000	[1]
14	KaV/L	1.305327	[1]
15	Approach	4.988772	[°C]
16			
17	IDENTIFIER	TEST DATA	
18	Tower Type	FORCED	
19	Water Flow Rate	209.000000	[kg/s]
20	Hot Water Temperature	33.400000	[°C]
21	Cold Water Temperature	27.100000	[°C]
22	Wet-Bulb Temperature	21.100000	[°C]
23	Dry-Bulb Temperature	30.600000	[°C]
24	Fan Power	57600.000000	[W]
25	Pressure	101325.000000	[Pa]
26	L/G	1.622762	[1]
27	KaV/L	1.416229	[1]
28			
29	IDENTIFIER	RESULT DATA	
30	Tower Type	FORCED	
31	Intercept L/G at Approach	1.731560	[1]
32	Intercept KaV/L	1.336319	[1]
33	Approach	4.988772	[°C]
34	Tower Capability	101.856458	[%]
35			
36	TEST DATA	TEST 1	
37	Tower Type	INDUCED	
38	Water Flow Rate	190.000000	[kg/s]
39	Hot Water Temperature	33.400000	[°C]
40	Cold Water Temperature	27.100000	[°C]
41	Wet-Bulb Temperature	21.100000	[°C]
42	Dry-Bulb Temperature	30.600000	[°C]
43	Fan Power	57600.000000	[W]
44	Pressure	101325.000000	[Pa]
45	L/G	1.465171	[1]
46	KaV/L	1.257928	[1]
47			
48	RESULT DATA	TEST 1	
49	Tower Type	INDUCED	
50	Intercept L/G at Approach	1.560840	[1]
51	Intercept KaV/L	1.188694	[1]
52	Approach	4.988772	[°C]
53	Tower Capability	91.814134	[%]

Figure 4.15 Example of excel file results from calculations in a project of Mechanical Draft.

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 4.16).
2. Click on a particular demand curve in the Approach 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.

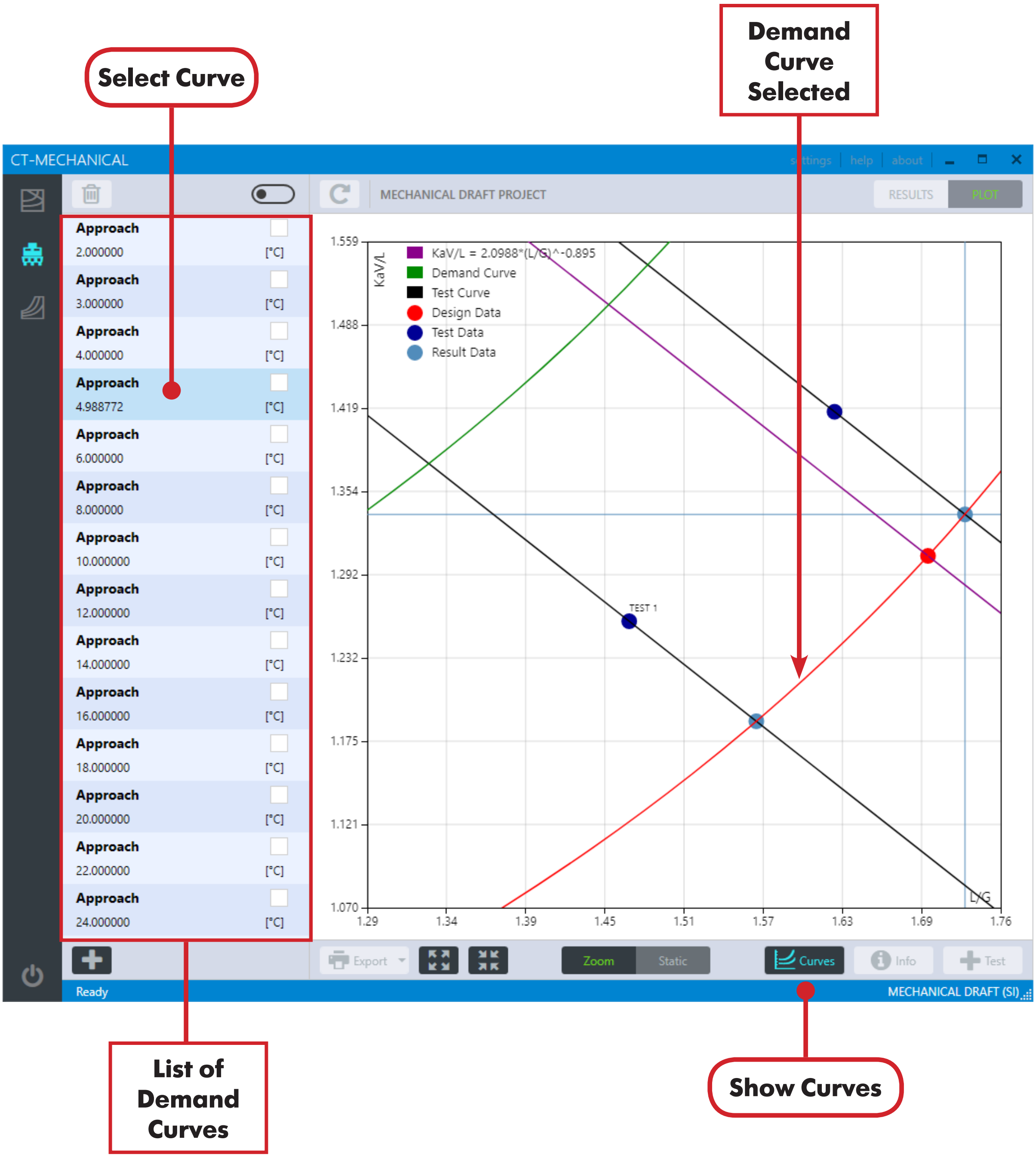


Figure 4.16 Demand curve selection in Mechanical Draft.

Add Demand Curve

1. Click on the Add Demand Curve button to introduce the value for a new demand curve.
2. After entering the demand curve value, 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 and added to the curve's list.

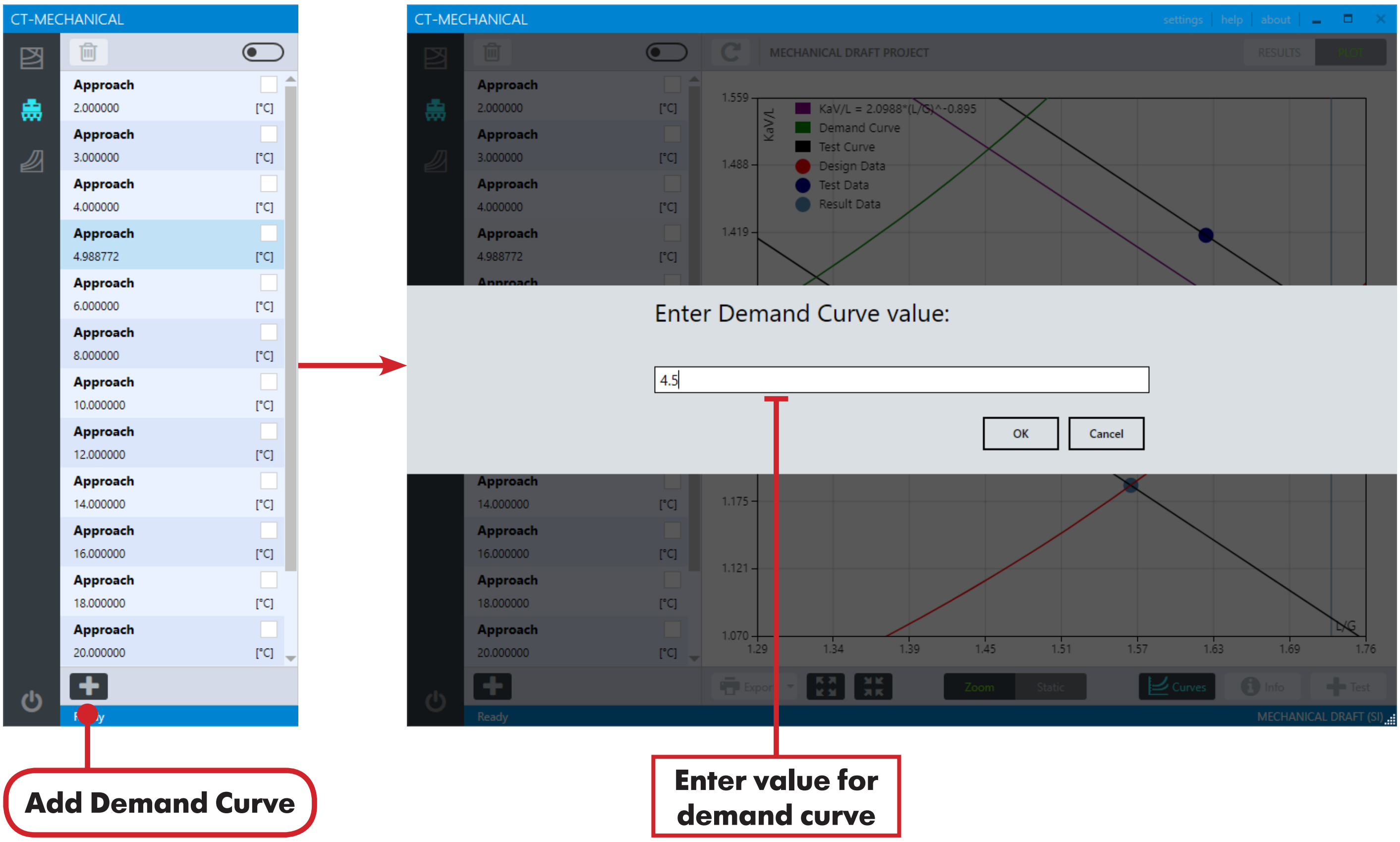


Figure 4.17 Adding a demand curve in a Mechanical Draft project.

Delete Demand Curve

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

Figure 4.18 Plot Area of Mechanical Draft after addition and selection of a demand curve.

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 Plot button to export the current Plot Area to a pdf file (Figure 4.21).

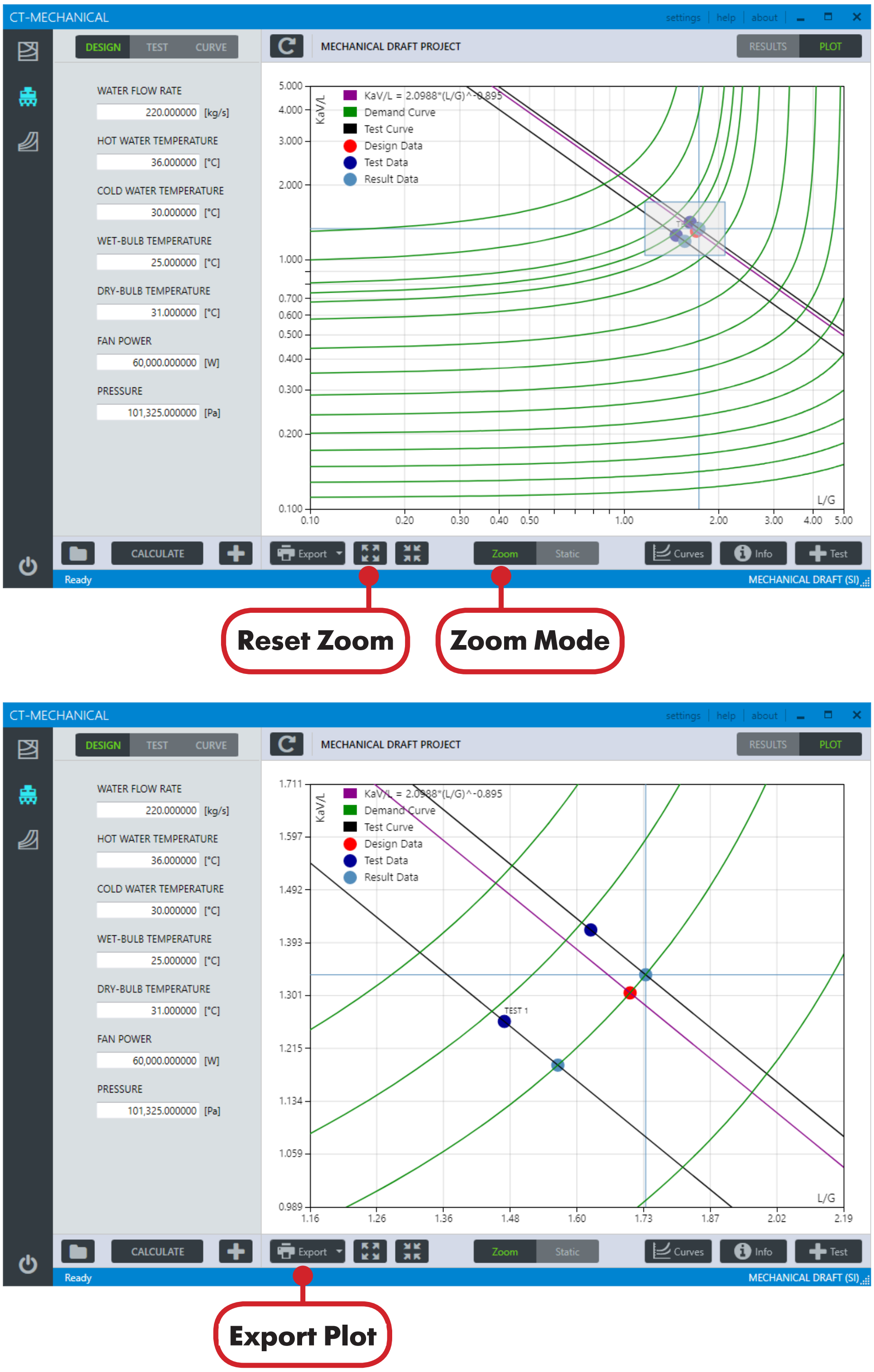


Figure 4.19 Zoom into the Plot Area of a Mechanical Draft project.

Save Current Zoom

1. Click on the Settings button of the **Mechanical Draft** application.
2. Click on the SAVE button to save the current zoom to the project (Figure 4.20).

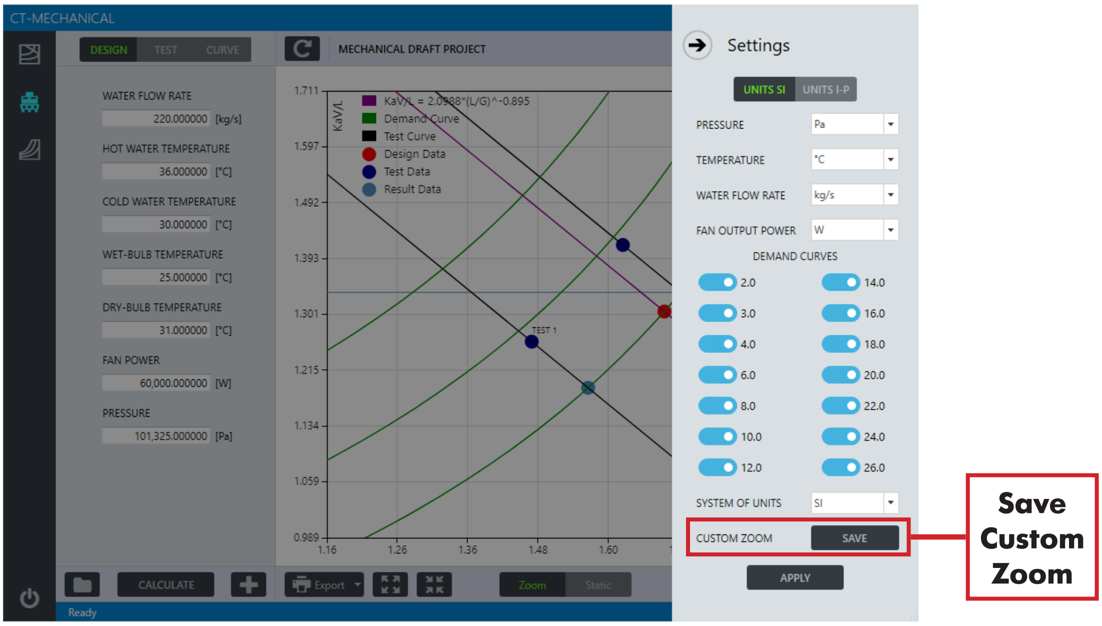


Figure 4.20 Settings of Mechanical Draft projects.

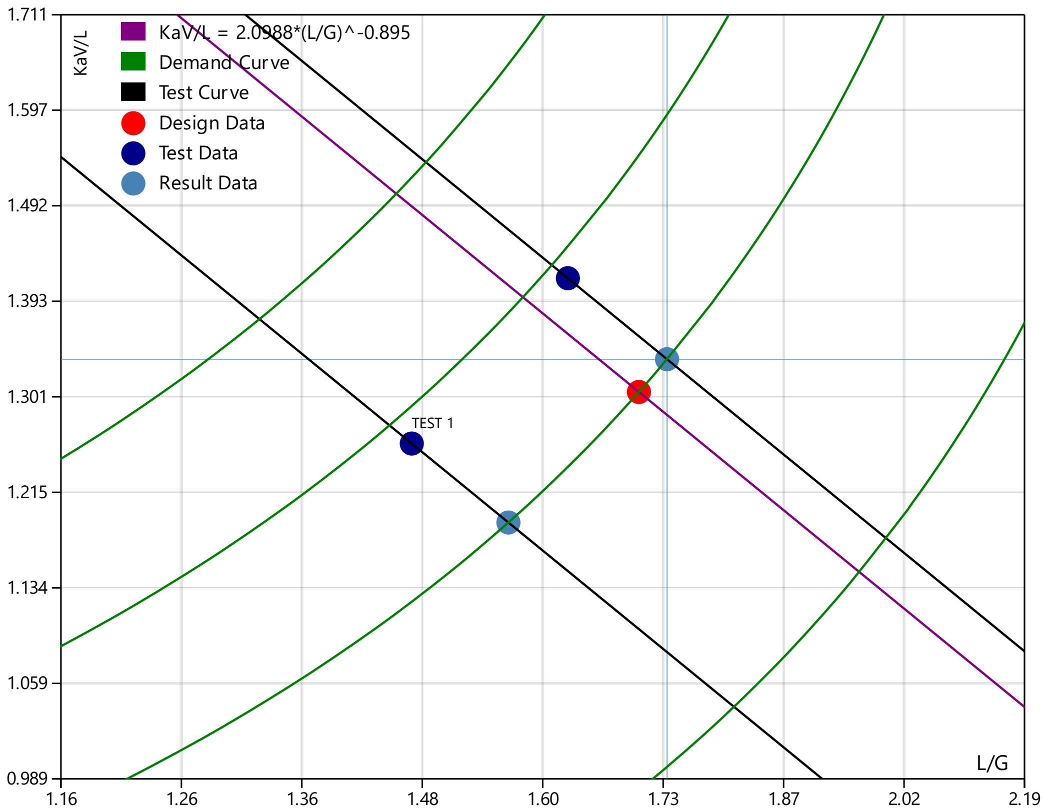


Figure 4.21 Zoom into the Plot Area of a Mechanical Draft project (plot exported to pdf).

4.11 Calculation Example (SI Units)

An example to illustrate a calculation project of **Mechanical Draft** in SI units is set by considering the design and test data for the mechanical draft cooling tower operation shown in Table 4.7. Figure 4.22 shows screenshots of the graphical user interface once the data described in Table 4.7 was introduced as a project.

The Characteristic Curve for this example (usually submitted by the manufacturer of the cooling tower) is:

$$KaV/L = 2.0988 * (L/G)^{-0.8950} \quad (4.1)$$

	DESIGN	TEST
WATER FLOW RATE	220 [kg/s]	209 [kg/s]
HOT WATER TEMPERATURE	36 [°C]	33.4 [°C]
COLD WATER TEMPERATURE	30 [°C]	27.1 [°C]
WET BULB TEMPERATURE	25 [°C]	21.1 [°C]
DRY BULB TEMPERATURE	31 [°C]	30.6 [°C]
FAN DRIVER POWER	60000 [W]	57600 [W]
PRESSURE	101325.0 [Pa]	101325.0 [Pa]
LIQUID TO GAS RATIO (L/G)	1.7	
TOWER TYPE DRAFT	INDUCED	

Table 4.7 Design and Test conditions for the calculation example of Mechanical Draft (SI Units).

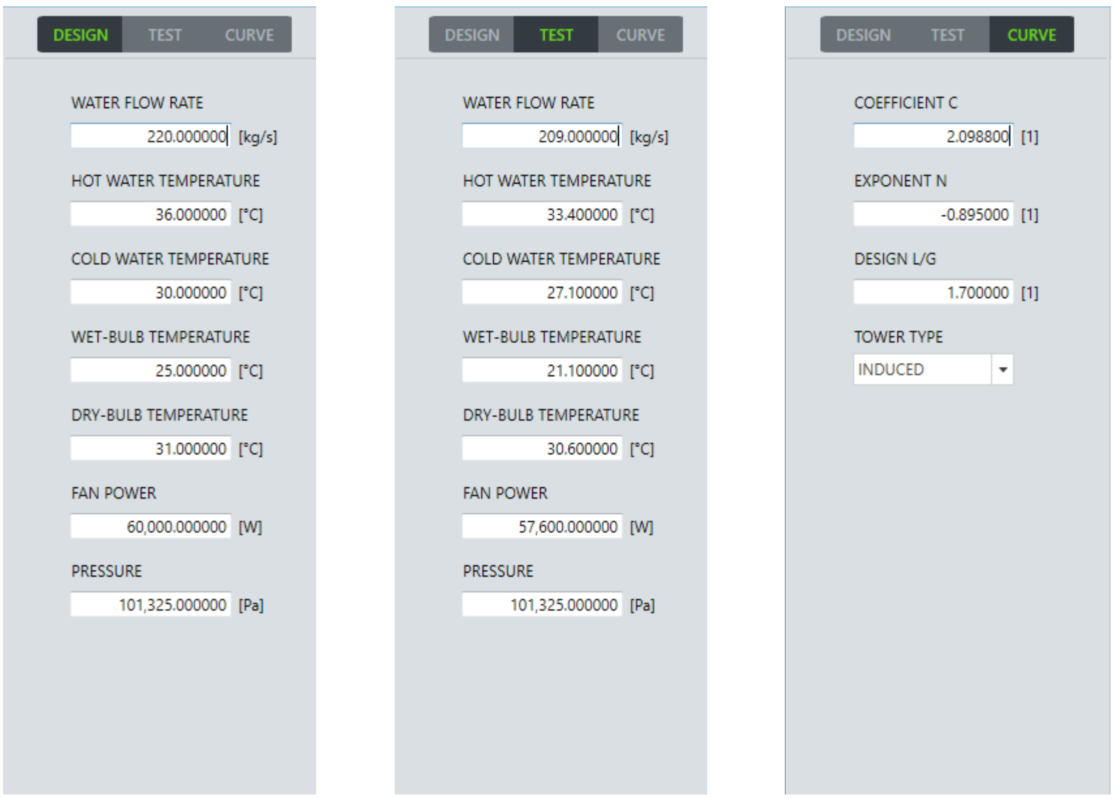


Figure 4.22 Design, Test conditions and Characteristic Curve introduced as a Mechanical Draft project from Table 4.7.

Graphical and numerical results for the calculation example set by the design and test conditions described in Table 4.7 are shown in Figures 4.23 and 4.24.

From the numerical results the Tower Capability is found to be **101.4939%**. Considering the design and test conditions set for this example, the mechanical cooling tower with the Characteristic Curve (4.1) is capable of cooling under the design conditions data.

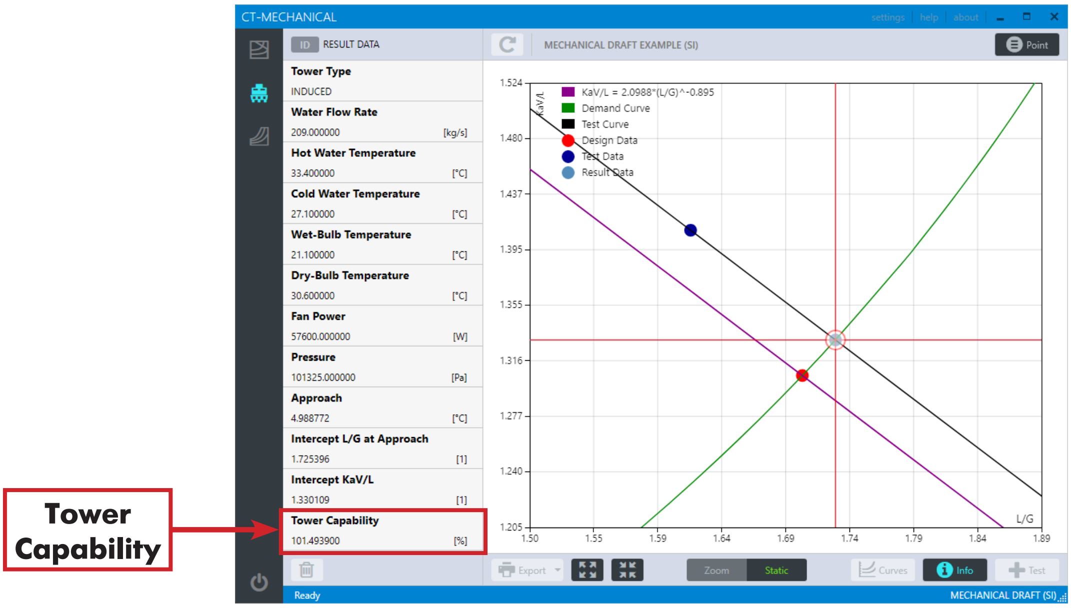


Figure 4.23 Graphical results for the calculation example in SI units.

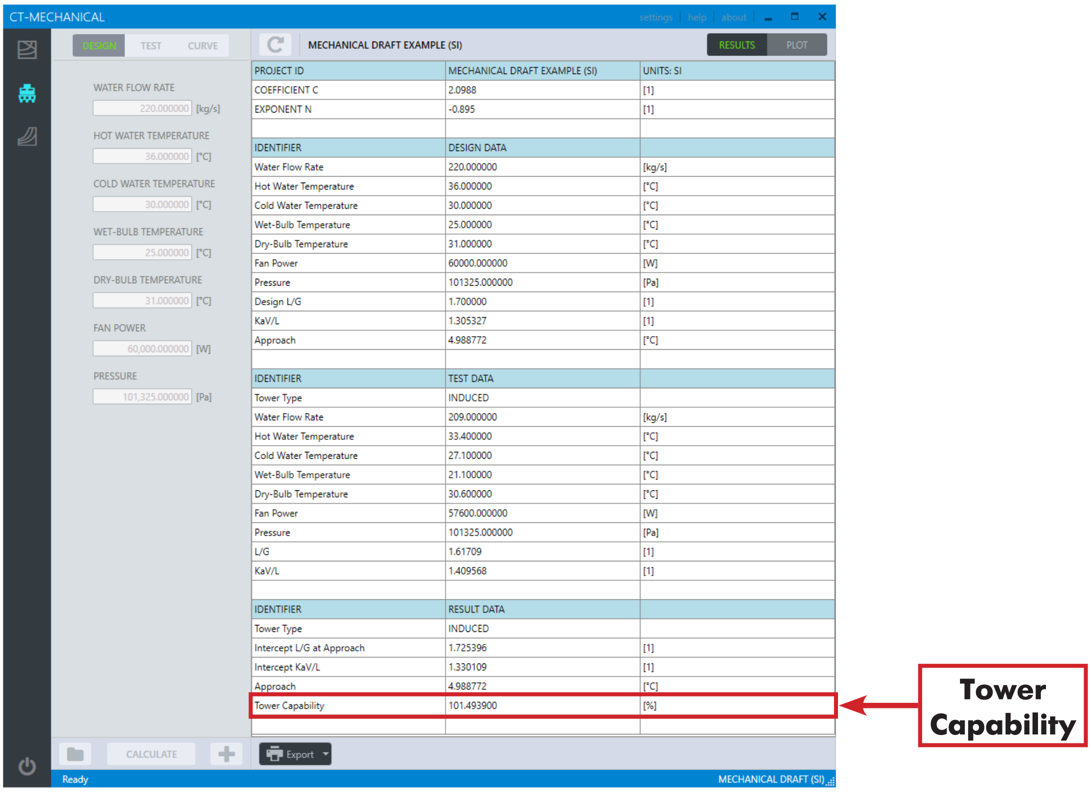


Figure 4.24 Numerical results for the calculation example in SI units.

4.12 Calculation Example (I-P Units) — Mechanical Draft

An example to illustrate a calculation project of **Mechanical Draft** in I-P units is set by considering the design and test data for the mechanical draft cooling tower shown in Table 4.8. Figure 4.25 shows screenshots of the graphical user interface once the data described in Table 4.8 was introduced as a project.

The Characteristic Curve for this example (usually submitted by the manufacturer of the cooling tower) is:

$$KaV/L = 2.0114 * (L/G) \text{^} {-0.5350} \tag{4.2}$$

	DESIGN	TEST
WATER FLOW RATE	9500 [gpm]	9150 [gpm]
HOT WATER TEMPERATURE	115 [°F]	104.7 [°F]
COLD WATER TEMPERATURE	85 [°F]	79.3 [°F]
WET BULB TEMPERATURE	80 [°F]	73.1 [°F]
DRY BULB TEMPERATURE	90 [°F]	85.2 [°F]
FAN DRIVER POWER	240 [bhp]	216 [bhp]
PRESSURE	14.695949 [psi]	14.695949 [psi]
LIQUID TO GAS RATIO (L/G)	0.810	-
TOWER TYPE DRAFT	INDUCED	

Table 4.8 Design and Test conditions for the calculation example of Mechanical Draft (I-P Units).

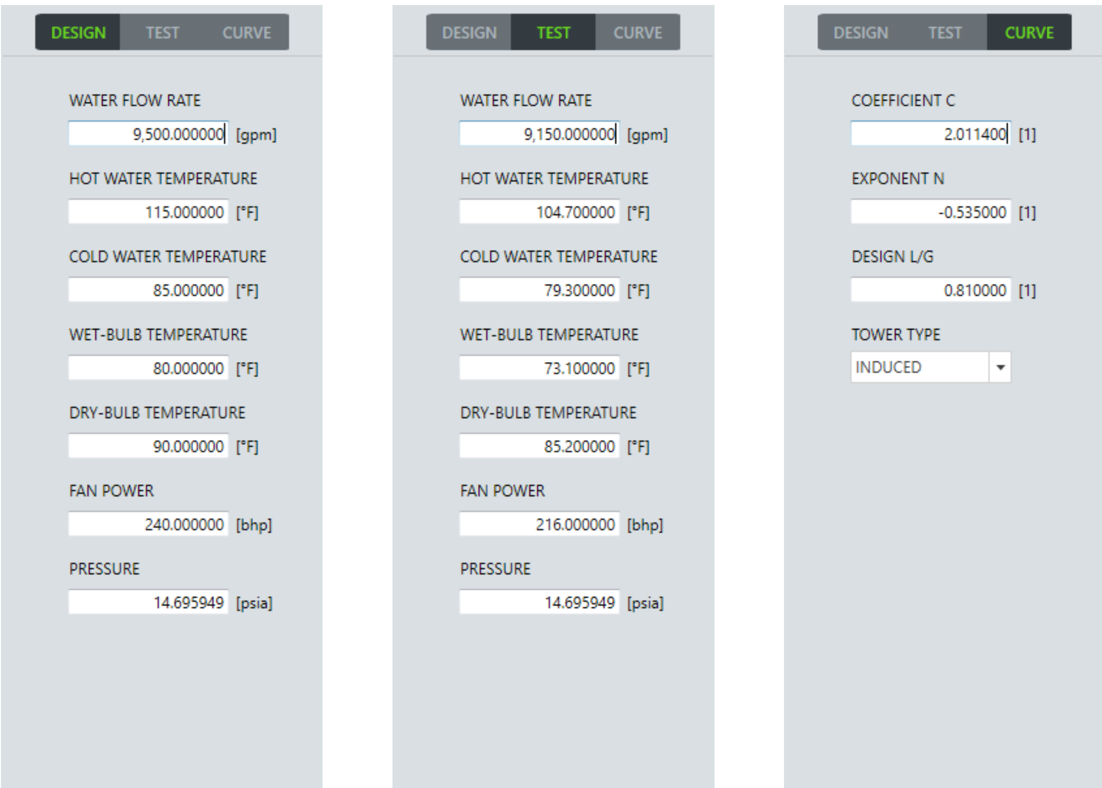


Figure 4.25 Design, Test conditions and Characteristic Curve introduced as a Mechanical Draft project from Table 4.8.

Graphical and numerical results for the calculation example set by the design and test conditions described in Table 4.8 are shown in Figures 4.26 and 4.27.

From the numerical results the Tower Capability is found to be **100.6928%**. Considering the design and test conditions set for this example, the mechanical cooling tower with the Characteristic Curve (4.2) is capable of cooling under the design conditions data.

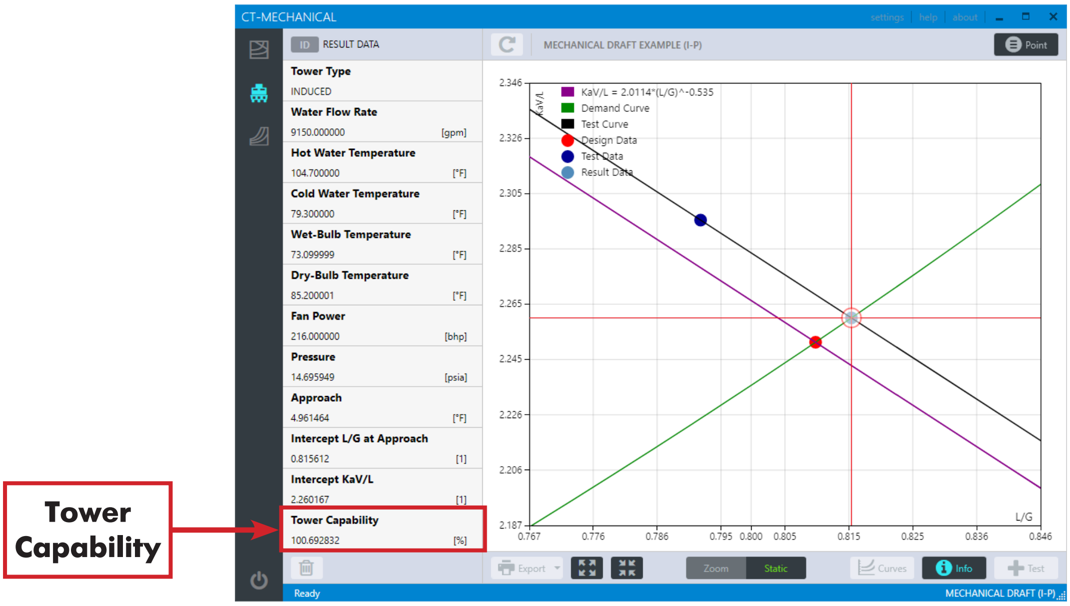


Figure 4.26 Graphical results for the calculation example in I-P units.

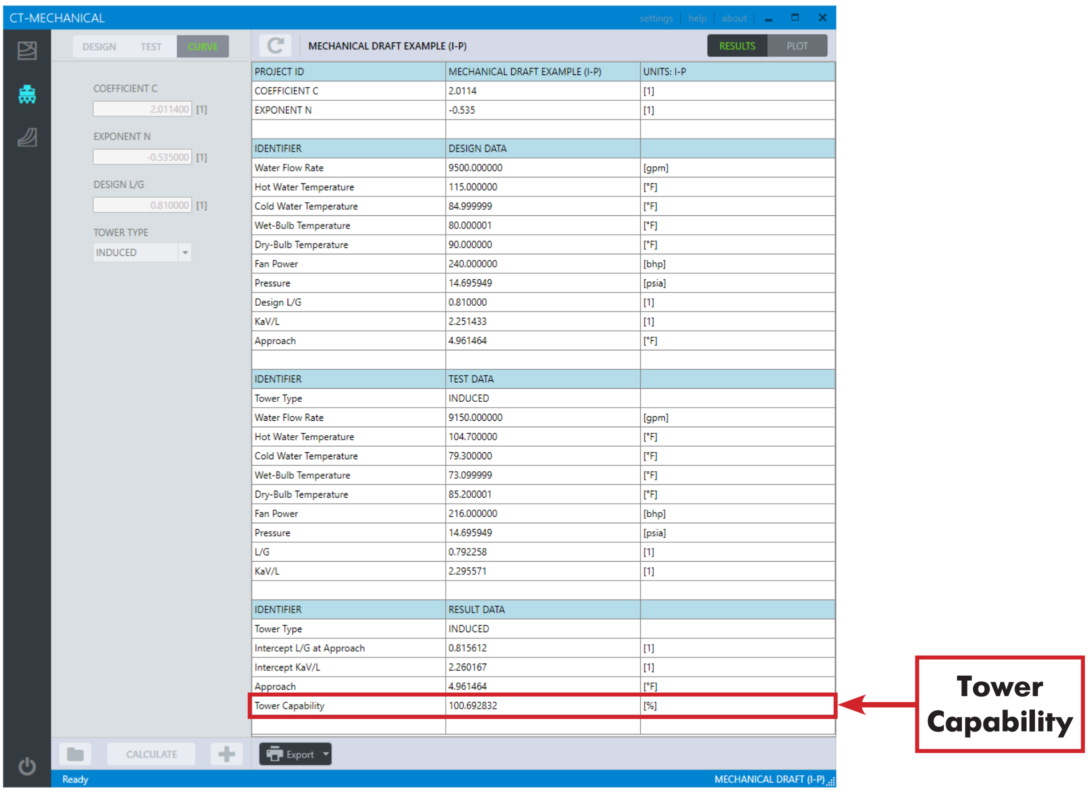


Figure 4.27 Numerical results for the calculation example in I-P units.

Comparison with Literature Data

The input data for the mechanical draft examples calculated in the SI and I-P system of units are taken from the CTI Code ATC-105 []. Tables 4.9 and 4.10 compare the numerical results of the Tower Capability calculated in Mechanical Draft with the results shown in []. A strong agreement can be established by considering the low relative error in both cases.

	CASE SI (CTI CODE RESULT)	CASE SI (CALCULATED)	RELATIVE ERROR
Tower Capability [%]	101.6	101.4939	***0.104%***

Table 4.9 Comparison of Tower Capability result between the CTI Code ATC-105 and Mechanical Draft in SI units.

	CASE I-P (CTI CODE RESULT)	CASE I-P (CALCULATED)	RELATIVE ERROR
Tower Capability [%]	101.0	100.69	***0.307%***

Table 4.10 Comparison of Tower Capability result between the CTI Code ATC-105 and Mechanical Draft in I-P units.

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	$kg(w)/m^3$	$lb(w)/ft^3$
Parts per million by weight	ppmw	ppmw
Parts per million by volume	ppmv	ppmv
Enhancement Factor	[-]	[-]
Specific Volume of Dry Air	m^3/kg, cm^3/kg	ft^3/lb, in^3/lb
Specific Volume of Humid Air	m^3/kg, cm^3/kg	ft^3/lb, in^3/lb
Specific Volume of Saturated Water	m^3/kg, cm^3/kg	ft^3/lb, in^3/lb
Specific Volume of Saturated Ice	m^3/kg, cm^3/kg	ft^3/lb, in^3/lb
Specific Volume of Water Vapor	m^3/kg, cm^3/kg	ft^3/lb, in^3/lb
Density of Dry Air	kg/m^3, g/m^3	lb/ft^3, lb/in^3
Density of Humid Air	kg/m^3, g/m^3	lb/ft^3, lb/in^3
Density of Saturated Water	kg/m^3, g/m^3	lb/ft^3, lb/in^3
Density of Saturated Ice	kg/m^3, g/m^3	lb/ft^3, lb/in^3
Density of Water Vapor	kg/m^3, g/m^3	lb/ft^3, lb/in^3
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 ≤ 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	10.0 ≤ P ≤ 10.0E6	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	0.00145 ≤ P ≤ 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.

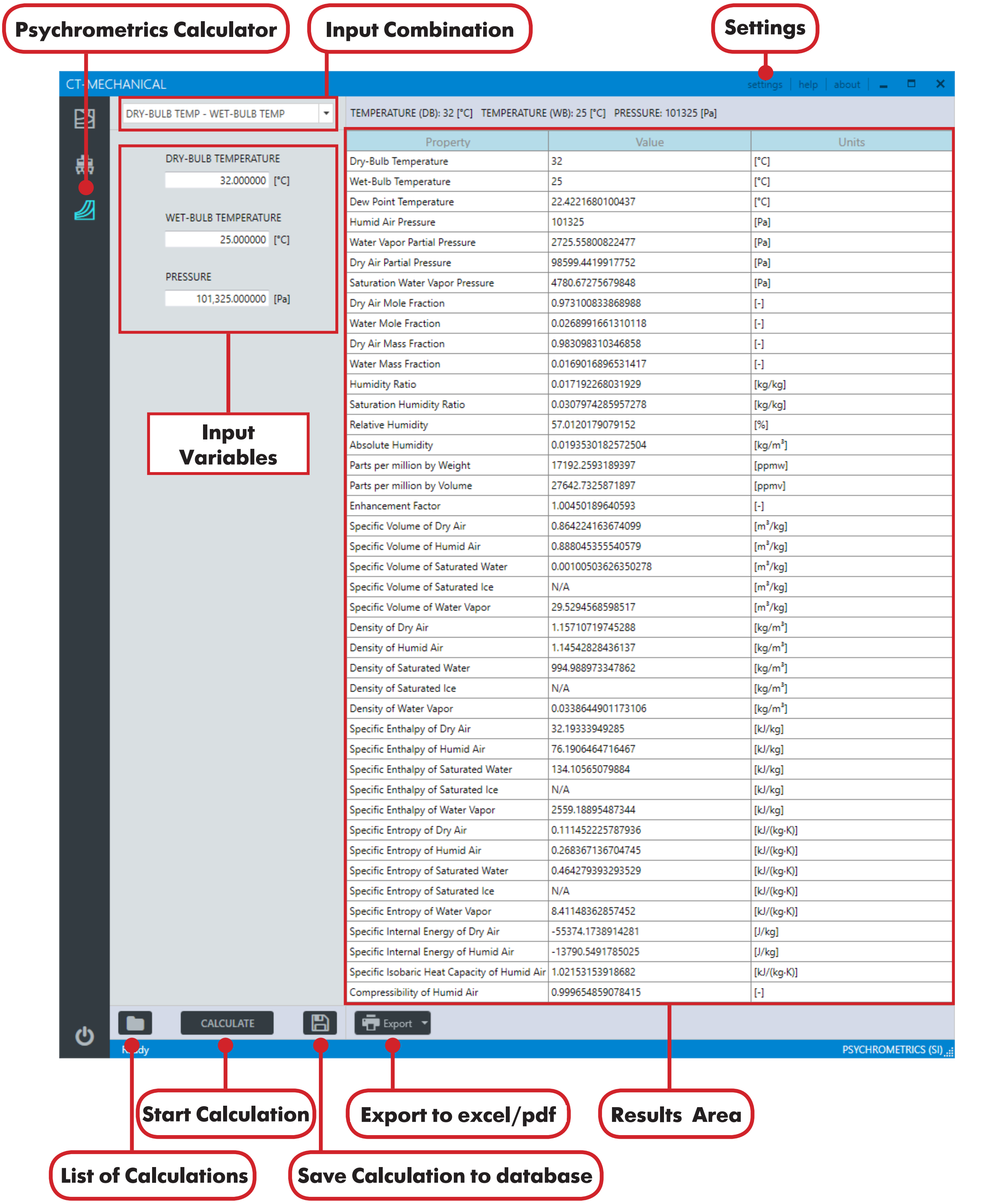


Figure 5.1 Graphical User Interface for Psychrometrics Calculator.

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.

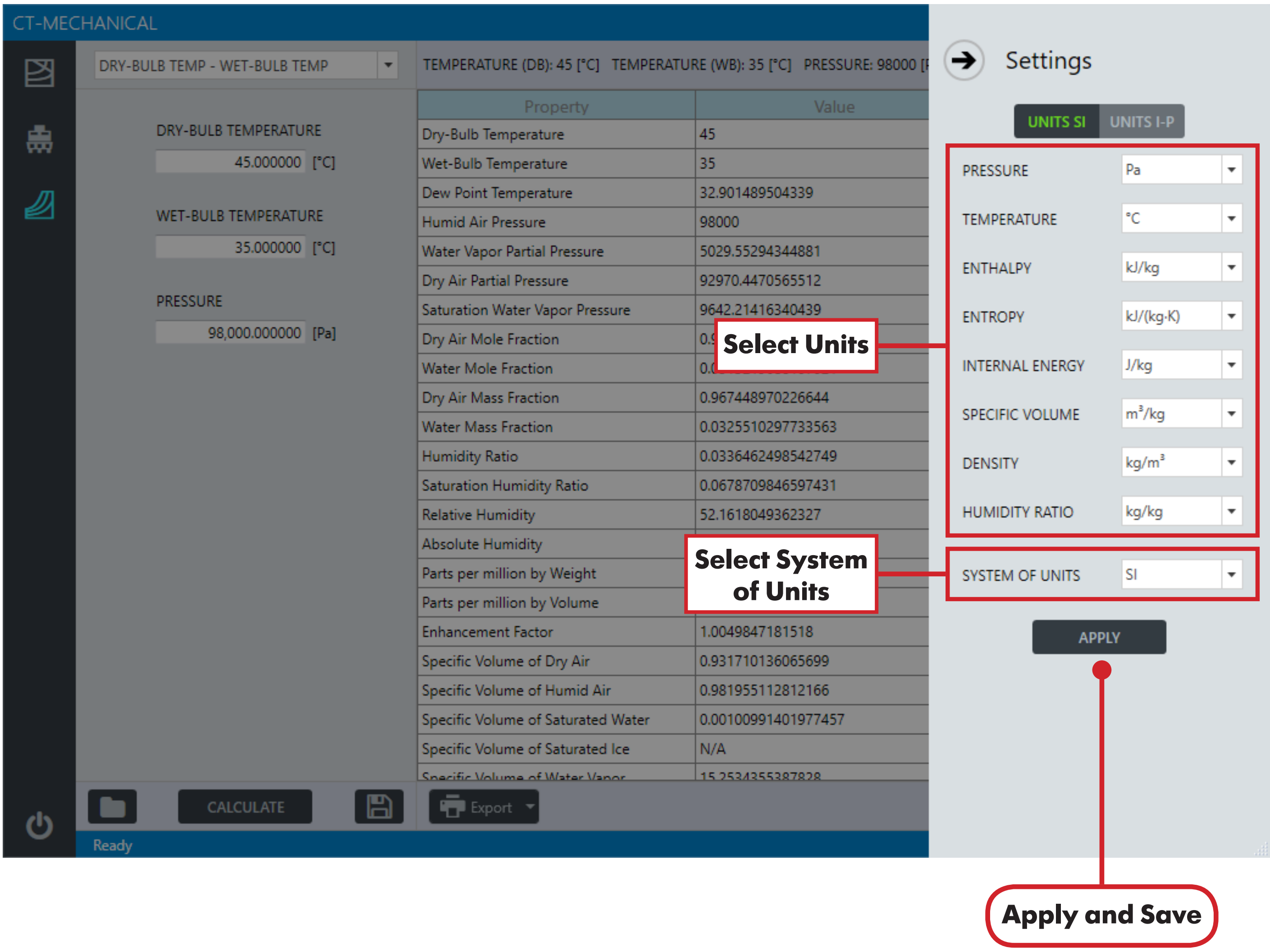


Figure 5.2 Settings for Psychrometrics Calculator.

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.

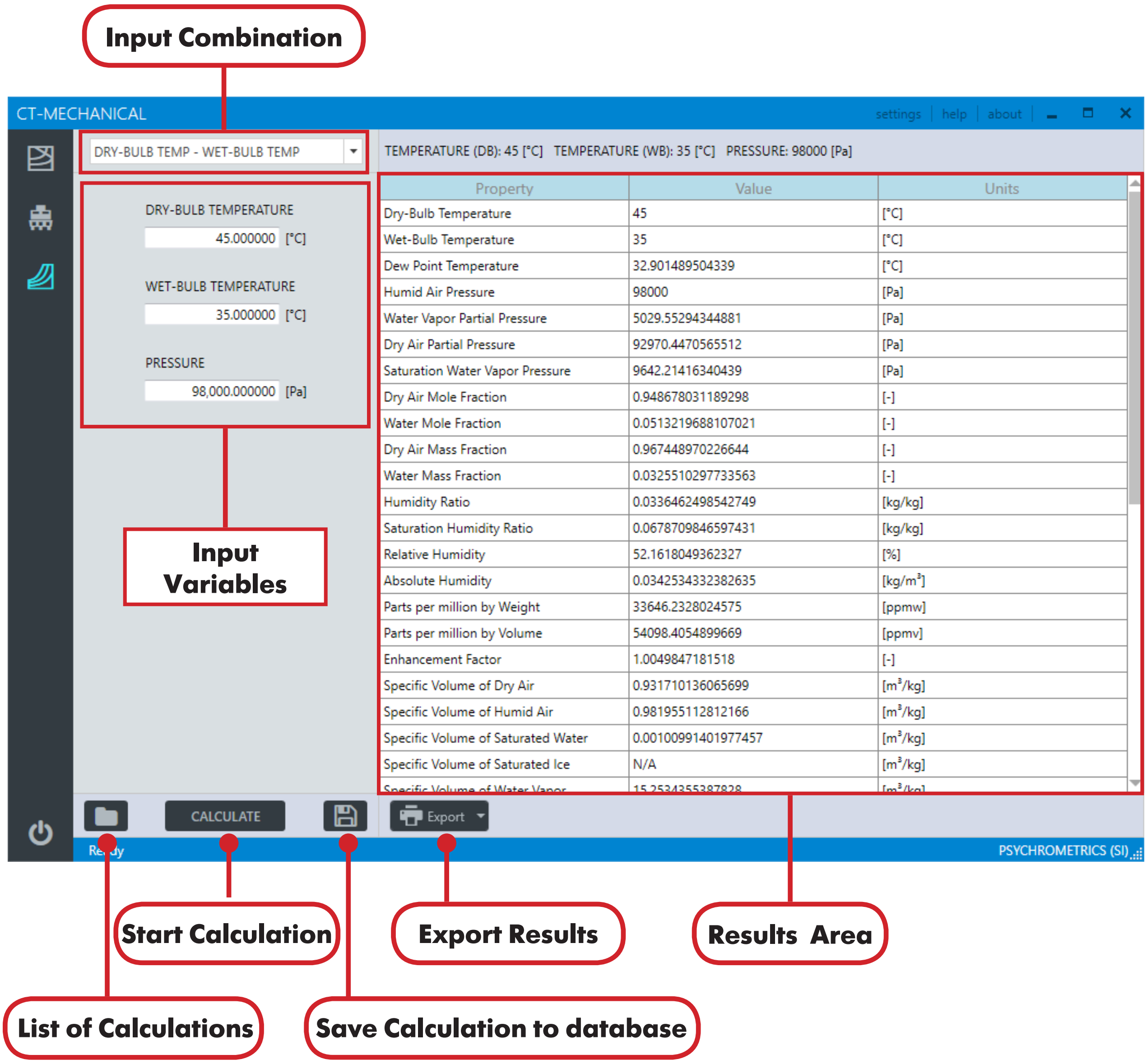


Figure 5.3 Calculation of properties in Psychrometrics Calculator.

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).

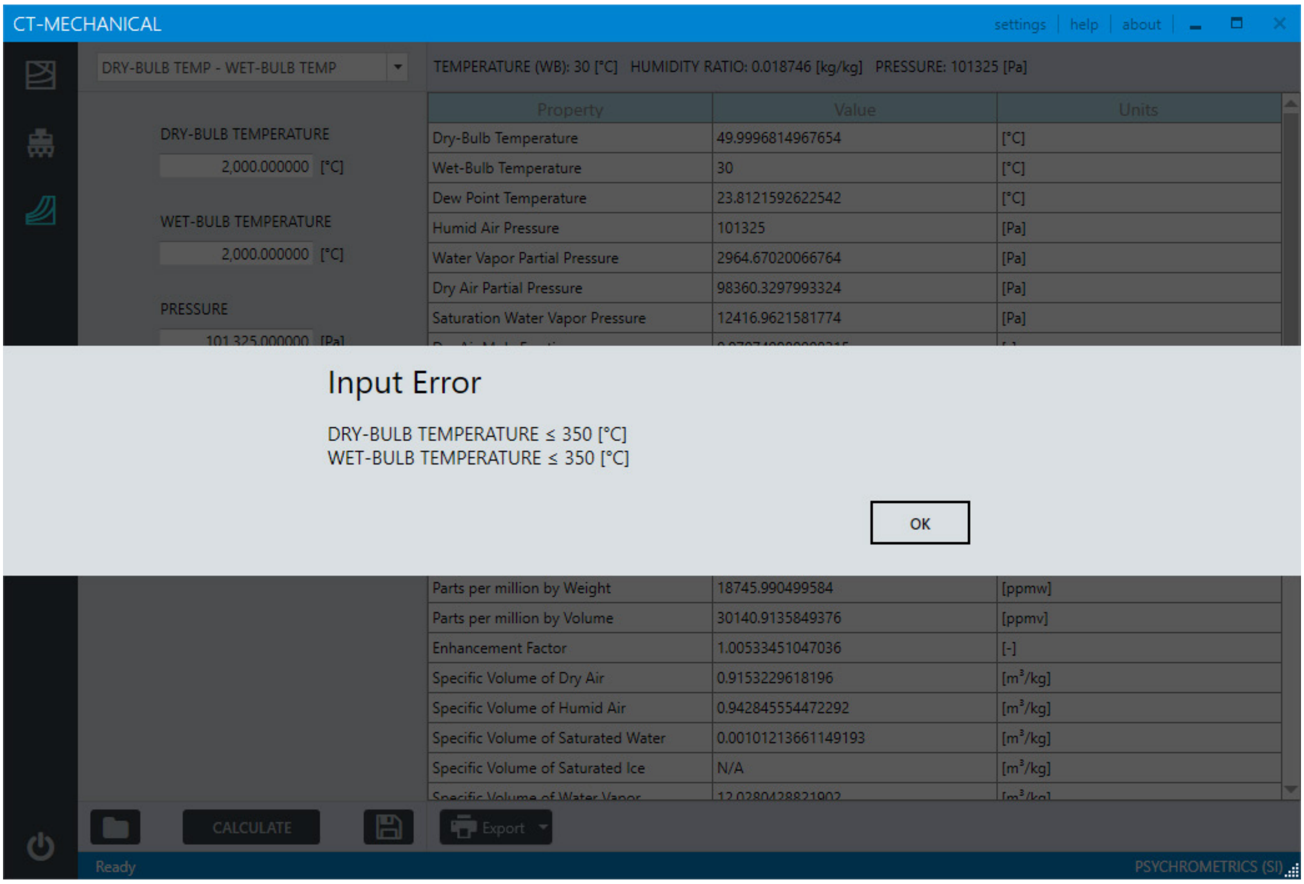


Figure 5.4 Validation of input variables in Psychrometrics Calculator.

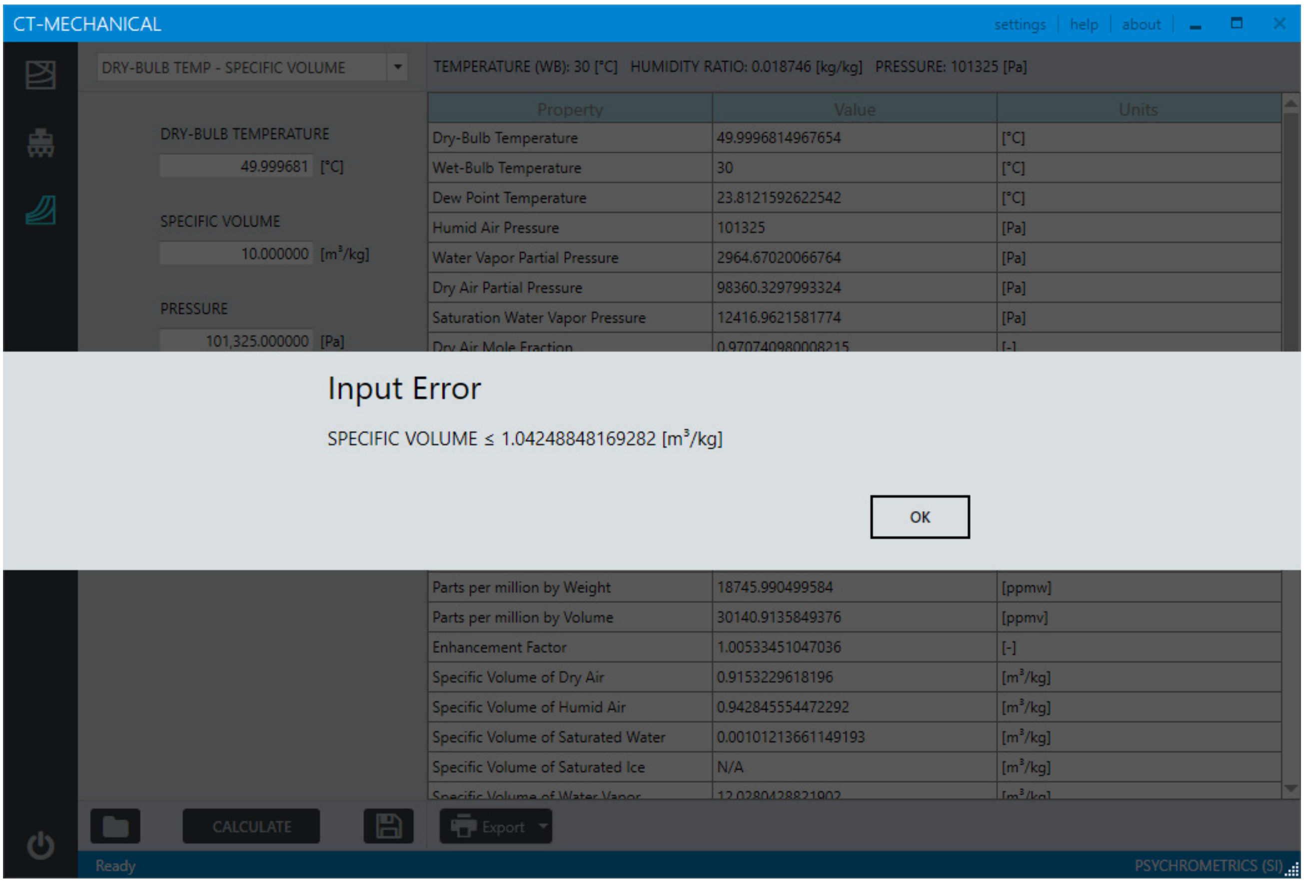


Figure 5.5 Validation of calculations in Psychrometrics Calculator.

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.

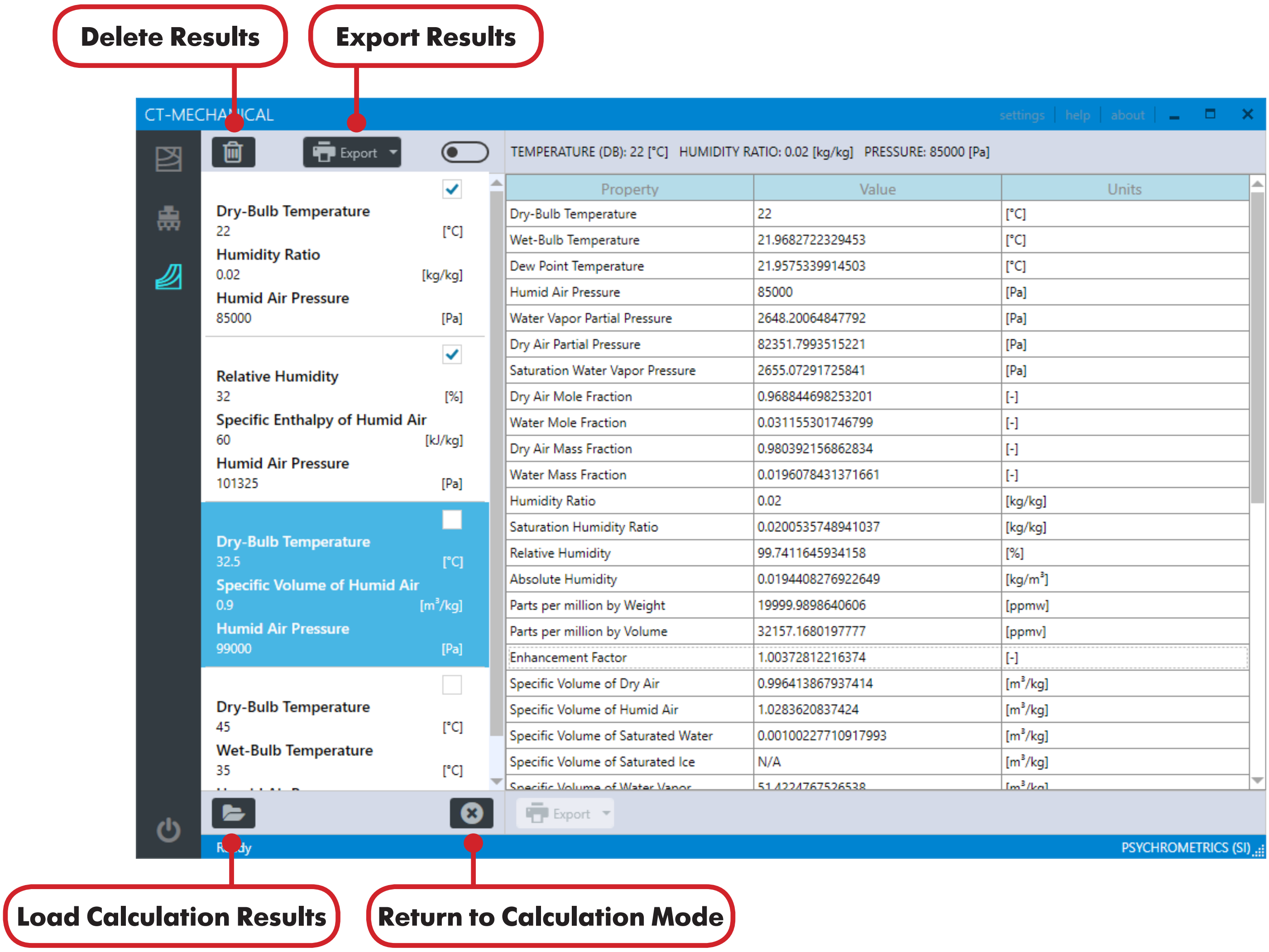
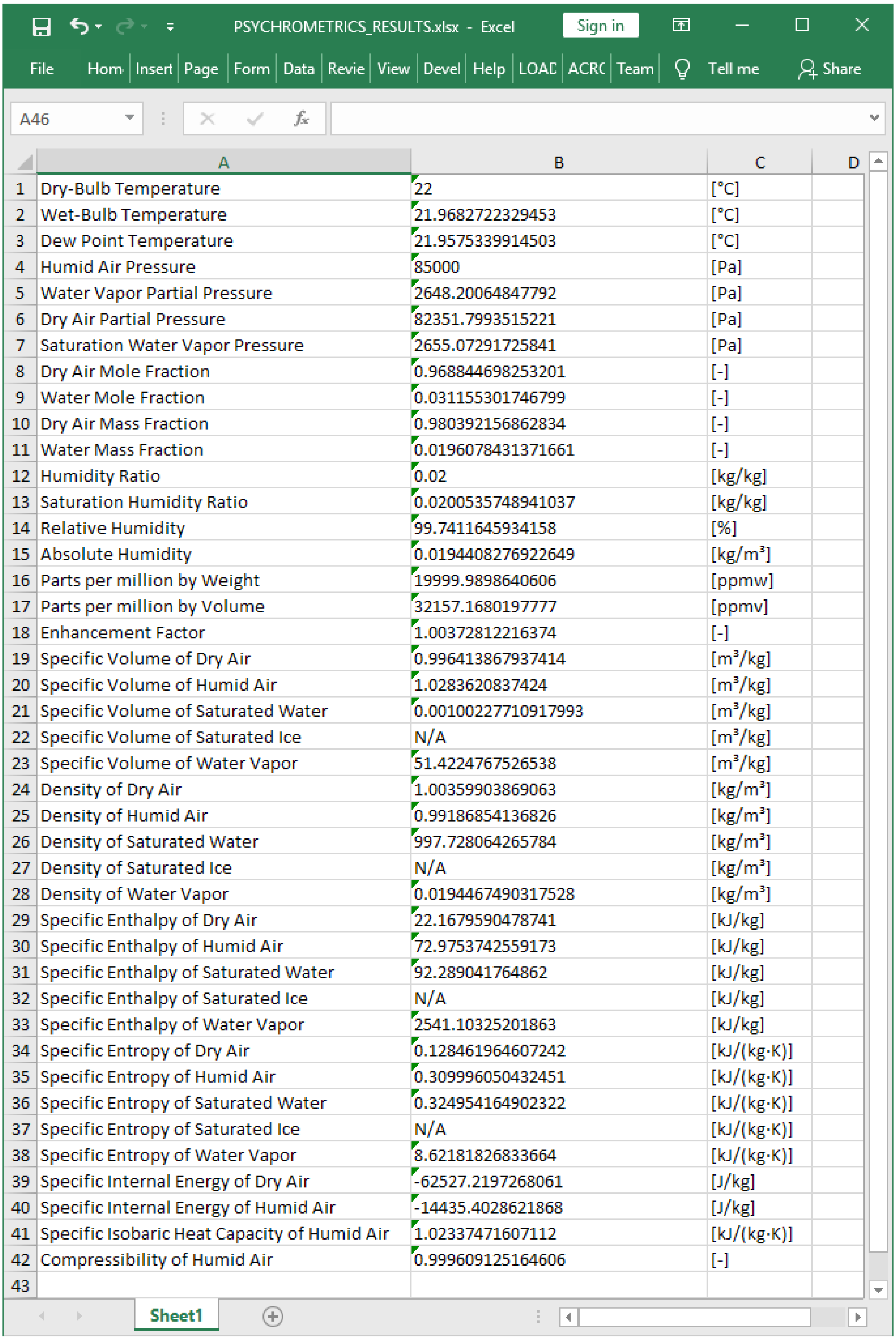


Figure 5.6 Calculation results from the Psychrometrics Calculator.

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/m³]
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	[m³/kg]
20	Specific Volume of Humid Air	1.0283620837424	[m³/kg]
21	Specific Volume of Saturated Water	0.00100227710917993	[m³/kg]
22	Specific Volume of Saturated Ice	N/A	[m³/kg]
23	Specific Volume of Water Vapor	51.4224767526538	[m³/kg]
24	Density of Dry Air	1.00359903869063	[kg/m³]
25	Density of Humid Air	0.99186854136826	[kg/m³]
26	Density of Saturated Water	997.728064265784	[kg/m³]
27	Density of Saturated Ice	N/A	[kg/m³]
28	Density of Water Vapor	0.0194467490317528	[kg/m³]
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	[-]

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

References

[1] Benton, D. J., and Waldrop, W. R., Computer Simulation of Transport Phenomena in Evaporative Cooling Towers, ASME J. Eng. for Gas Turbines and Power, vol. 10, pp. 190–196, 988.

[2] British Standard 4485,Water Cooling Towers, Part 2: Methods for Performance Testing, British Standards Institution, 1988.

[3] Cooling Tower Institute, Cooling Tower Performance Curves, The Cooling Tower Institute, Houston, 1967.

[4] Cooling Tower Institute, CTI Code Tower, Standard Specifications, Acceptance Test Code for Water-Cooling Towers, Vol. 1, CTI Code ATC-105(97), Revised, February 1997.

[5] Fisenko, S.P., Petruchik, A.I. and Solodukhin, A.D., Evaporative Cooling of Water in a Natural Draft Cooling Tower, International Journal of Heat and Mass Transfer, Vol. 45, pp. 4683-4694, 2002.

[6] Hellett, G.F.. (1975). Performance curves for mechanical draft cooling towers. J. Eng. Power; (United States). 97

[7] Klimanek, A., Bialecki, R. A., Solution of Heat and Mass Transfer in Counterflow Wet-Cooling Tower Fills, International Communications in Heat and Mass Transfer, 36 (2009), 6, pp. 547-553

[8] Kloppers, J. C., and Kroger, D.G., Loss Coefficient Correlation for Wet-Cooling Tower Fills, Applied Thermal Engineering, vol. 23, no. 17, pp. 2201–2211, 2003.

[9] Kroger, D. G., Air-Cooled Heat Exchangers and Cooling Towers, PennWell Corp., Tulsa, USA, 2004.

[10] Majumdar, A.K., Singhal, A.K. and Spalding, D.B., Numerical Modeling of Wet Cooling Towers – Part 1: Mathematical and Physical Models, Transactions of the ASME, Journal of Heat Transfer, Vol. 105, pp. 728-735, November 1983.

[11] Majumdar, A.K., Singhal, A.K., Reilly, H.E. and Bartz, J.A., Numerical Modeling of Wet Cooling Towers – Part 2: Application to Natural and Mechanical Draft Towers, Transactions of the ASME, Journal of Heat Transfer, Vol. 105, pp. 736-743, November 1983.

[12] Milosavljevic, N., and Heikkila, P., A Comprehensive Approach to Cooling Tower Design, Applied Thermal Engineering, vol. 21, pp. 899–915, 2001.

[13] Merkel, F., Verdunstungskuhlung. VDI-Zeitchrift, Vol. 70, 123–128, 1925

[14] IAPWS , Revised Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam, Germany, 2007.

References

[15] IAPWS , Release on the IAPWS Formulation 2008 for the Viscosity of Ordinary Water Substance, 2008.

[16] IAPWS , Release on the IAPWS Formulation 2011 for the Thermal Conductivity of Ordinary Water Substance, 2011.

[17] Supplementary Release on Backward Equations for Pressure as a Function of Enthalpy and Entropy p(h,s) to the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam, IAPWS 2001.

[18] Wagner, W.; Pruß, A.: The IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use. J. Phys. Chem. Ref. Data 31, 387-535, 2002.

[19] Wagner, W.; Kretzschmar, H.-J.: International Steam Tables. Springer, Berlin, 2008.

[20] Wang, Wei & Zeng, Deliang & Hu, Yong & Liu, Jizhen & Niu, Yuguang. (2015). Coupling model and solving approach for performance evaluation of natural draft counter-flow wet cooling towers. Thermal Science. 20. 6-6.