DC-E-WISE (Data Center Energy and Water Information Simulator and Evaluator) User Manual

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1. General Information

The DC-E-WISE is an excel-based tool that we developed to facilitate the comparison of nine cooling systems based on five main criteria: *Energy Use, Onsite Water Use, Total Cooling Water Use, Reliability,* and *Maintenance.*

The nine studied cooling systems are: *Air-cooled chiller, Air-cooled chiller + Air-side economizer (ASE), Pre-cooled-air-cooled chiller, Pre-cooled-air-cooled chiller + ASE, Water-cooled chiller, Water-cooled chiller + ASE, Water-cooled chiller + Water-side economizer (WSE), Water-cooled chiller + ASE + WSE,* and *Evaporative cooling system + ASE.*

The *DC-E-WISE* tool employs the technique for order preference by similarity to ideal solution *(TOPSIS)* method to rank the modeled cooling systems. The tool then presents a tabulated list of the ranked cooling systems, which includes energy and water use data, as the result. By utilizing the *TOPSIS* method, the tool provides a systematic and objective way of comparing and ranking the cooling systems, enabling users to make informed decisions when selecting and optimizing cooling systems for their data centers. The tabulated result provides a concise summary of the ranked cooling systems, allowing users to quickly identify the most efficient and effective options for their specific needs.

1.1. Modeled Energy and Water Use Data for Cooling System

This tool utilizes modeling data for cooling energy, water use (onsite cooling and humidification), and total cooling water use in DCs located in the greater Phoenix area. The power and water use data, which are model outputs, are normalized based on the modeled IT load (in MW) at the uninterrupted power supply (UPS) output. Therefore, the tool can calculate the total energy and onsite and total cooling water use for a given IT load as entered by the user. Along with overall DC power and water use, the tool provides estimates for key DC metrics such as *PUE* (Eq. 1), WUE_{Onsite} (Eq. 2), and WUE_{Source} (Eq. 3a and Eq. 3b). These metrics are defined as follows:

$$\text{PUE} = \frac{\text{Total Facility Energy}}{\text{IT equipment Energy}} \quad \text{Eq. 1}$$

$$\text{WUE}_{Onsite}\left(\frac{\text{gal}}{\text{kWh}}\right) = \frac{\text{Onsite Water Usage (gal)}}{\text{IT equipment Energy (kWh)}} \quad \text{Eq. 2}$$

$$\text{WUE}_{\text{Source}}\left(\frac{\text{gal}}{\text{kWh}}\right) = \frac{\text{Onsite Water Usage (gal)} + \text{Source Water Use for Energy Generation(gal)}}{\text{IT equipment Energy (kWh)}} \quad \text{Eq. 3a}$$

$$\text{Source Water Energy Usage (gal)} = \text{EWIF}\left(\frac{\text{gal}}{\text{kWh}}\right) \times (\text{Total Facility Energy(kWh)}) \quad \text{Eq. 3b}$$

1.2. Reliability and Maintenance

1.2.1. Reliability

The cooling system's reliability criteria is determined by considering five main factors: *Annual Availability, Fluctuation of IT Room Air Supply Affected by Outdoor Condition, Lifetime, IT Room Air Contamination,* and *Complexity*. These factors, except for *Annual Availability*, are assigned a weight ranging from 0 (lowest) to 10 (highest). The Annual Availability factor is given a weight that is five times greater than the other criteria, ranging from 0 (lowest) to 50 (highest). To determine the *overall Reliability* value, a scaling process is applied, resulting in a scale of 0 to 100. For more detailed information regarding the default values for *Reliability*, please refer to the *Reliability Default Values sheet* available in

the *DC-E-WISE* excel file. By considering these factors, the cooling system's reliability can be accurately evaluated, and necessary improvements can be made to ensure its continued effectiveness and efficiency.

1.2.2. Maintenance

The maintenance actions are categorized as *Annual, Semi-Annual, Monthly, Weekly,* and *Daily,* and *Water Treatment Requirement*, with each assigned a weight that corresponds to the severity of the action. The weight assigned to an action is determined by its degree of difficulty, which increases as the frequency of the action decreases. For instance, an annual action has a higher weight than a semi-annual action. Among all maintenance actions, *water treatment requirement* has the highest weight because of the complexity of the water treatment processes. The number of each maintenance action is specified for all cooling systems, and an *overall maintenance* value for each cooling system is determined using Eq. 4. This quantification process enables effective management and monitoring of the maintenance needs of cooling systems, ensuring their continued operation and longevity.

$$Overall\ Maintenance\ Value = \sum(number\ of\ action \times action\ weight) \qquad \text{Eq. 4}$$

Note: The higher maintenance value means higher negative effect on the rank of cooling system in *DC-E-WISE*.

2. DC-E-WISE

2.1. How to Use *DC-E-WISE for DCs*:

1- Open DC-E-WISE excel file.

"This file type is not supported in protected View." You can click *Ok* or skip the message (Figure 1).

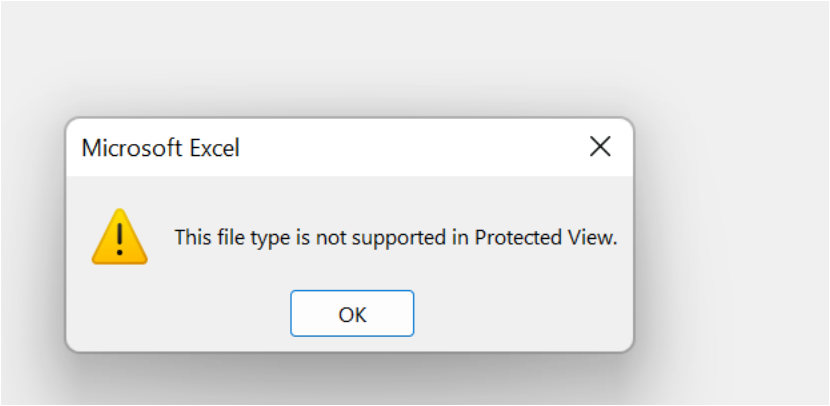

Figure 1. Opening the main file (Section 2.1, Step 1)

Upon opening the file, a window prompt appears asking the user if they wish to remove previous results. The user is given the option to select *Yes* to keep the previous run results, or *No* to delete them (as shown in Figure 2). By providing this option, users have the flexibility to choose whether to retain or remove previous results, enabling them to manage their data more efficiently.

Note: If the user selects *No* option, the old results will be overwritten by the new results.

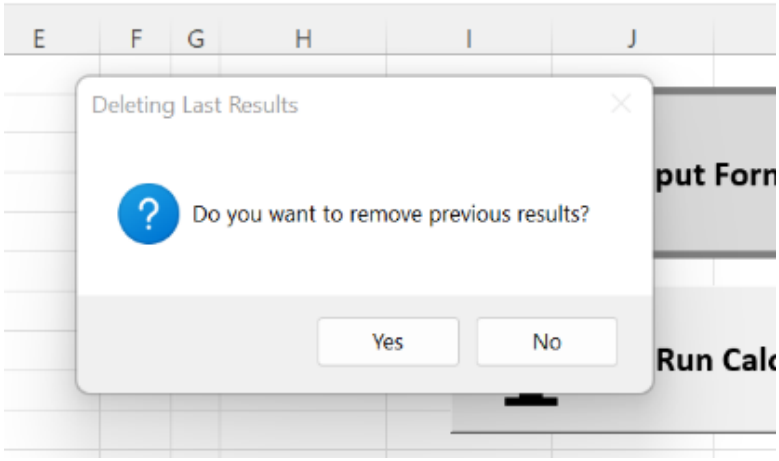

Figure 2. Message for keeping or deleting the previous results (Section 2.1, Step 1)

2- Go to the *File* menu and select *Save As*. Choose the *Excel Macro-Enabled Workbook* format and specify the desired file name and location using the *Save As* icon. The file name should follow the format *filename.xlsm*.
3- Once the file is saved, open it and navigate to the *User-Interaction* sheet to begin using the DC-E-WISE tool (Figure 3).

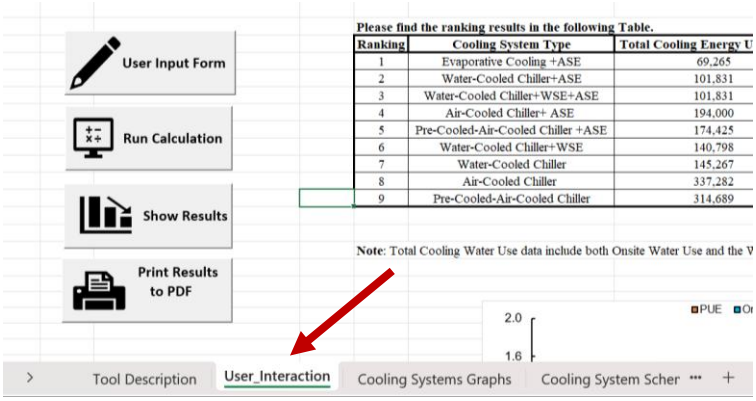

Figure 3. *User-Interaction* sheet (Section 2.1, Step 3)

4- To initiate DC-E-WISE the user should fill the *User Input Form.*
5- Click the *User Input Form* button (Figure 4) in the *User-Interaction* sheet to open the *User Input Form* (Figure 5).

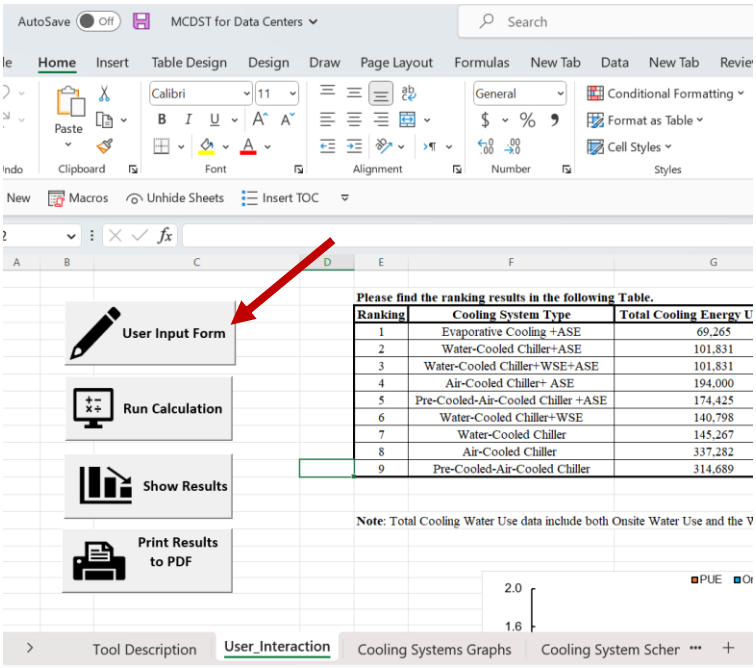

Figure 4. The *User Input Form* button in the *User-Interaction sheet* (Section 2.1, Step 5)

Note: When opening the file or when run *User Input Form*, the user may receive a message similar to the one shown in Figure 5, stating that macros are disabled. In order to use the *DC-E-WISE* tool, they must enable macros in Excel. To do so, click *OK* on the message prompt and close the file without saving any changes. Then, follow the steps 1 through 4 to save the file in Excel Macro-Enabled Workbook format and open the *User-Interaction* sheet.

1. Open Excel
2. Go to file > options > Trust Center > Trust Center Settings…
3. Enable the options as shown in Figure 6, then click *OK*.
4. Close the excel and open *DC-E-WISE* excel file again.

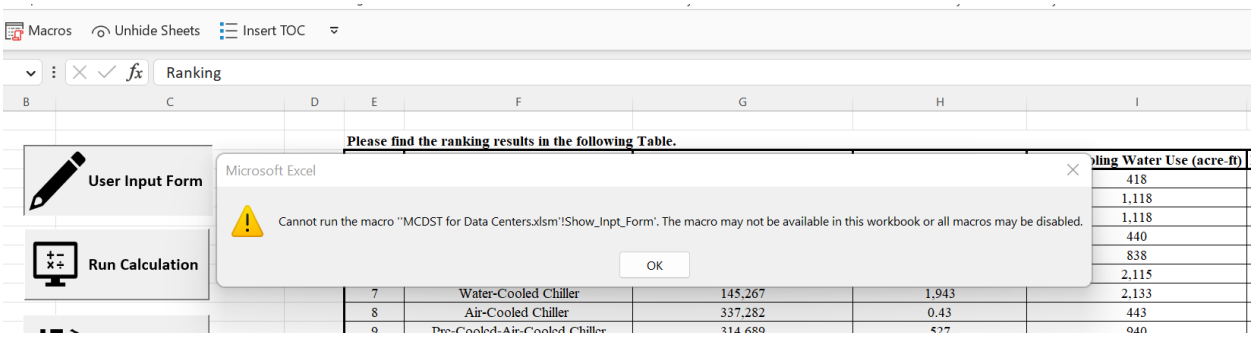

Figure 5. Potential error message after running the *User Input Form* when the macros are disabled in excel (Section 2.1, Step 5, Note)

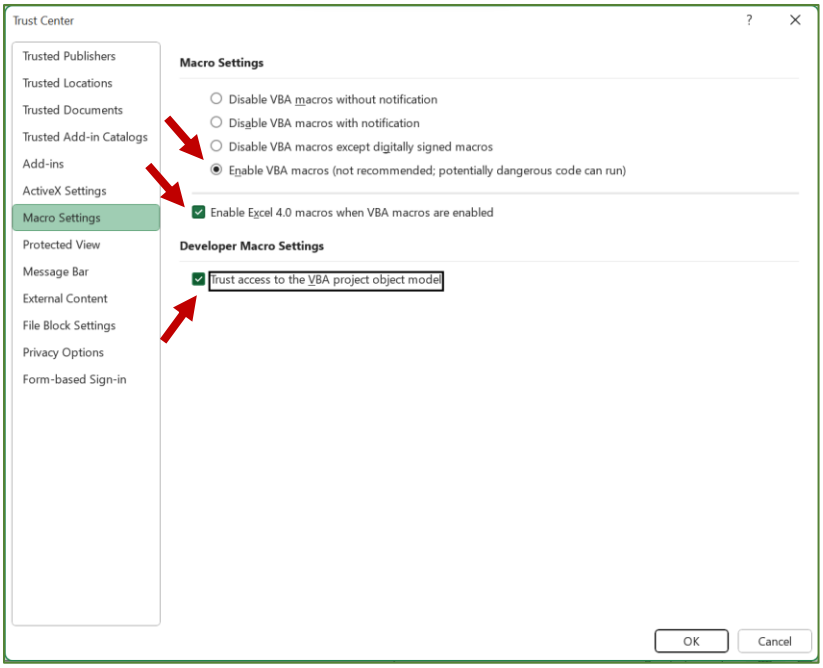

Figure 6. Enable macros in excel to run the tool (Section 2.1, step 5, Note-step 3)

6. Once the user has entered their desired inputs and made their choices in the *User Input Form* (Figure 7), they should click the *Save* button in order to ensure that any changes are saved.

Notes

- The *User Input Form,* contains four tabs, each with its own unique set of required inputs and selections that are explained in Section 2.2 of the *User Input Form.*
- If the user fails to meet the input requirements in any of the tabs and clicks the *Save* button (or Alt+S), they may encounter different pop-up messages, which will be explained in Section 2.2 of this manual.
- To start with a blank user form, the user can click the *Leave* button (or Alt+L) to close the form. However, during the data entry process in the *User Input Form*, clicking the Save button will overwrite any previous input values and selected options with new inputs.

7. The *User Input Form* automatically closes when the data entry is completed in the last tab and the *Save* button is clicked.

8. After the user has entered all the required data in the *User Input Form*, they should go to the *User_Interaction* sheet and click on the *Run Calculation* button (Figure 8) to initiate the *DC-E-WISE* calculation process. Once the calculation is complete, a message will appear saying "The calculation is done!" (Figure 9) and the user will need to confirm to continue. Then, another message will appear prompting the user to click on the *Show Results* button (Figure 10) to view the results.

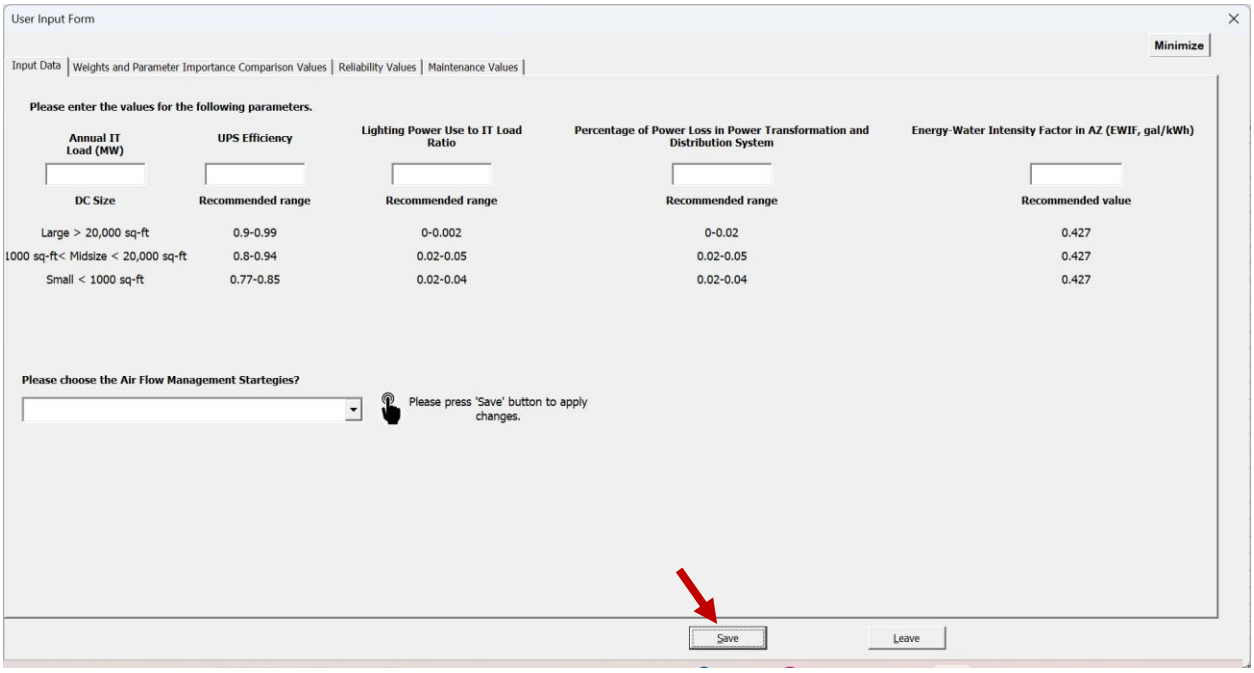

Figure 7. User Input Form (Section 2.1, Step 6 and 7)

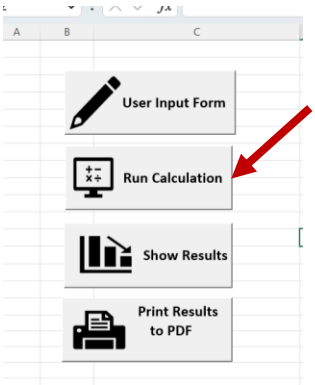

Figure 8. The message shown after clicking *Run Calculation* button (Section 2.1, Step 8)

Notes

- Please note that the calculation in the *DC-E-WISE* tool is performed automatically and the user does not need to perform any manual calculations. The tool is designed to be user-friendly and does not require any advanced technical skills. The user only needs to enter the required inputs in the User Input Form, run the calculation, and view the results. The calculation steps are performed in the background and are not visible to the user. The *DC-E-WISE* spreadsheets are protected to ensure that only the inputs given in the User Input Form can alter the values shown in each spreadsheet for different airflow management strategies.

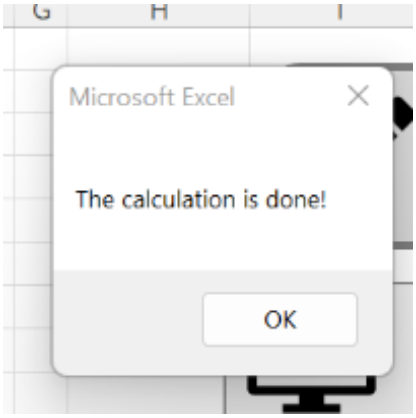

Figure 9. The message shown after clicking *Run Calculation* button in the *User-Interaction* sheet (Section 2.1, Step 8)

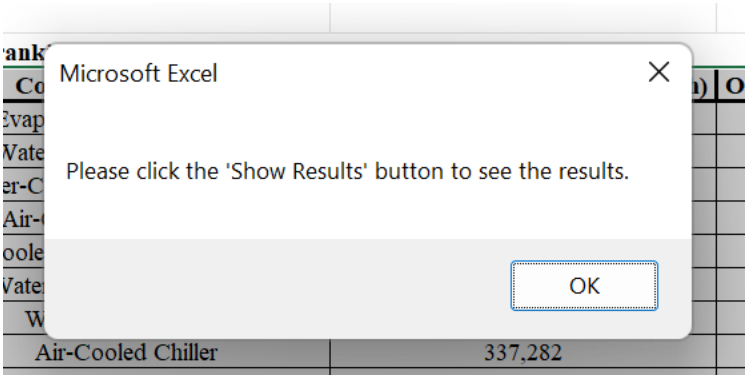

Figure 10. The message showing the instruction to see the results (Section 2.1, Step 8)

9. In the *Use-Interaction* sheet click the *Show Results* button to see the tabulated results of the ranked cooling systems (Figure 11). In addition, a graph is presented in this sheet showing the *PUE*, WUE_{Onsite}, and WUE_{Source} for the ranked cooling systems.

Then a message is shown to remind the user to export the results to a PDF file (Figure 12).

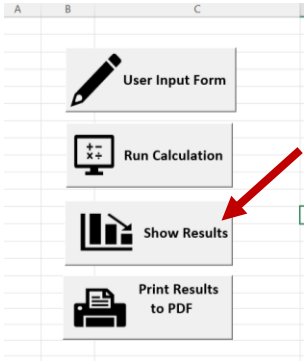

Figure 11. Click the *Show Results* button in the *User_Interaction* sheet to see the results (Section 2.1, Step 9)

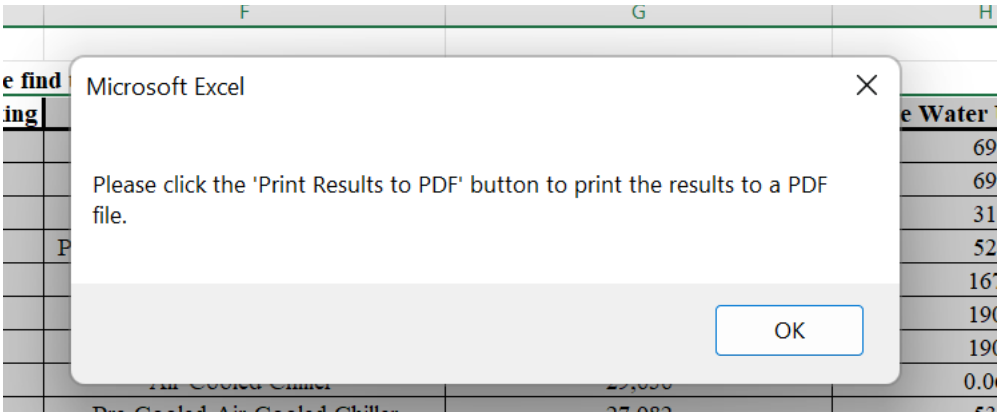

Figure 12. Message to remind the user to export the results (Section 2.1, Step 9)

10. In the *User-Interaction* sheet, click on the *Print Results to PDF* button to save the results shown in the *User_Interaction* sheet as a PDF file (Figure 13). After clicking the button, the user will be prompted to enter a file name and location to save the PDF file (Figure 14).

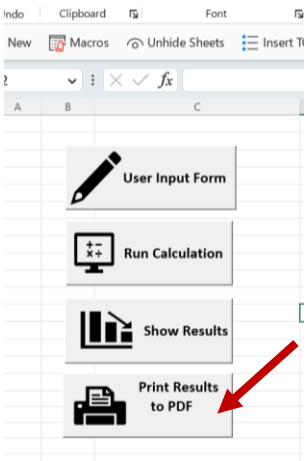

Figure 13. Click the *Print Results to PDF* button in the *User_Interaction* sheet to export the results to a PDF file (Section 2.1, Step 10)

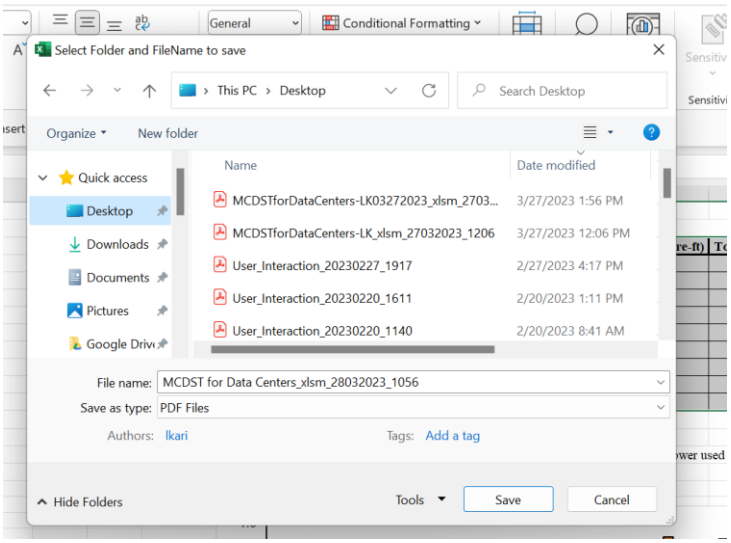

Figure 14. Message asking the user to define the results' PDF file name and saving location (Section 2.1, Step 10)

2.2. User Input Form

The *User Input Form is divided into* four main tabs, each requiring different sets of inputs and selections. The tabs are *Input Data, Weights and Parameter Importance Comparison Values, Reliability Values,* and *Maintenance Values*. Detailed instructions for data entry and selection are provided in Section 2.2 of the User Input Form.

2.2.1. *Input Data* tab

1. In the *Input Data* tab (Figure 15) in the *User Input Form*, locate the *Annual IT Load (MW)* data entry field (Figure 16) and enter the expected annual IT power load in megawatts.
2. In the *Input Data* tab, enter the UPS efficiency for the *UPS Efficiency* data entry (Figure 16). You can either enter a customized value or use the recommended value according to the DC size.
3. In the *Input Data* tab, enter either a customized, or the recommended value according to the DC size, for the *Lighting Power Use to IT Load Ratio* (Figure 16).
4. In the *Input Data* tab, enter either a customized, or the recommended value according to the DC size, for the *Percentage of Power Loss in Power Transformation and Distribution System* (Figure 16).
5. In the *Input Data* tab, enter either a customized, or the recommended value (0.427 for Salt River Project territory in AZ) for the *Energy-Water Intensity Factor (EWIF)* (Figure 16).

   Note: If the user does not enter any of the required inputs as explained in steps 1-5, or if a negative value is entered, an error message will appear asking the user to correct the values (Figure 17).

6. The user should select one of the four desired airflow management strategies by clicking on the *Airflow Management Strategies* dropdown box (Figure 18) in the *Input Data* tab of the *User Input Form.*

Note

- The four air flow management strategies are as follows:
  1. No aisle containment on server rows;
  2. Cold aisle containment (CAC) on server rows;
  3. Hot aisle containment (HAC) or Vertical Exhaust Duct (VED) on server rows. Both HAC and VED are types of hot aisle containment methods and have similar advantages. For more information please review the referred paper [1];
  4. CACs or VEDs/HACs on all server rows.

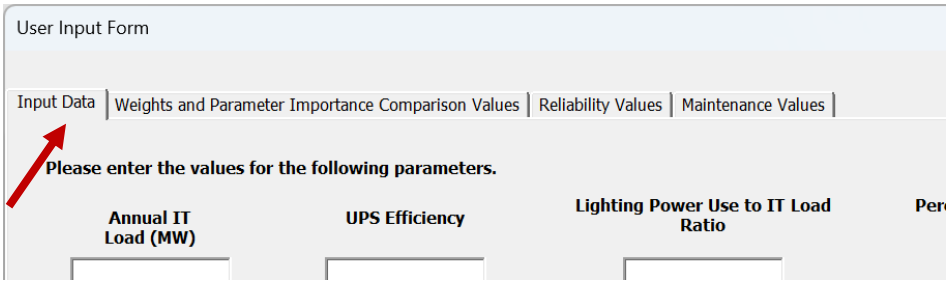

Figure 15. *Input Data* tab in the *User Input Form* (Section 2.2.1, Step 1).

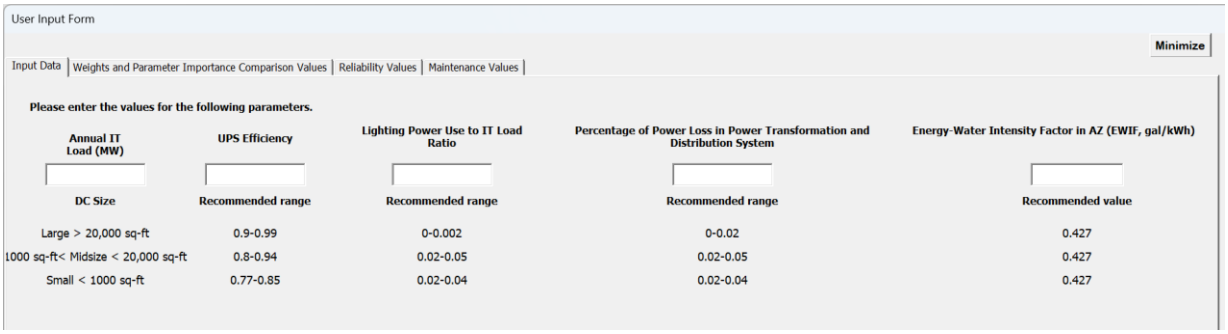

Figure 16. Required inputs in the Input Data tab (Section 2.2.1, steps 1 to 5)

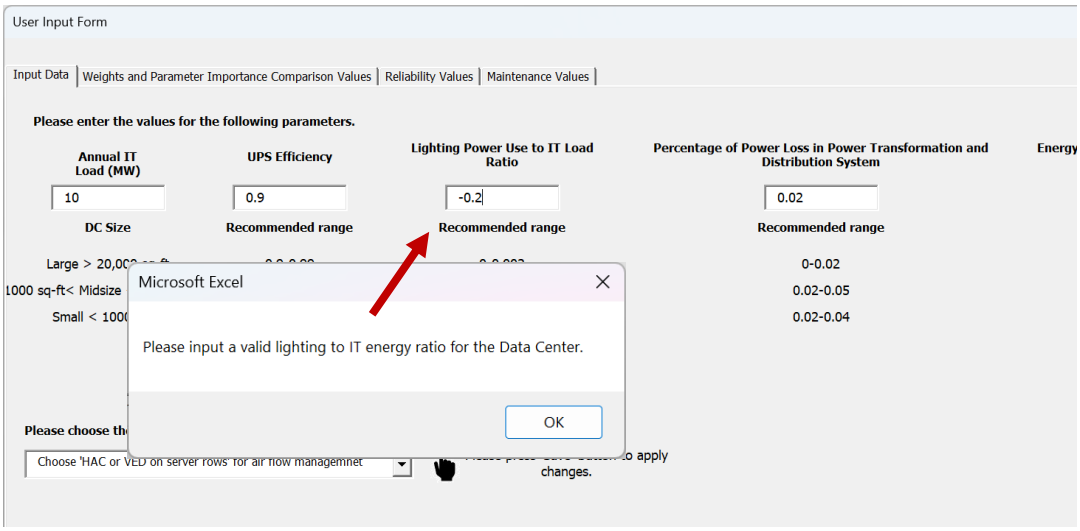

Figure 17. An error message shown because the user entered a negative value for the *Lighting Power Use to IT Load Ratio* (Section 2.2.1, Note to Steps 1 to 5).

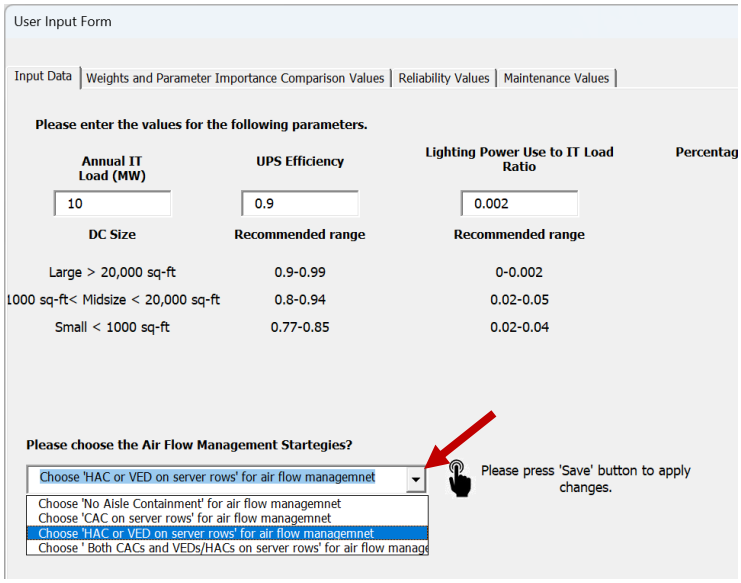

Figure 18. Air flow management strategies choices (Section 2.2.1, Step 6).

2.2.2. *Weights and Parameter Importance Comparison Values* tab

1. In the *Weights and Parameter Importance Comparison Values* tab of the *User Input Form* (Figure 19), the user needs to choose the preferred method to enter the weight percentage values of operating parameters. This can be done by selecting an option from the *Which way would you prefer to enter the operating parameters weight percentage values?* dropdown box (Figure 20), which offers two choices:

a. ***Input the Weight Percentage data my way*:** This approach allows the user to determine the relative importance of each criterion in the comparison of cooling systems. The user assigns weight percentages, ranging from 0 to 100, to each criterion to reflect its importance (Figure 21).

As previously discussed in Section 1, the decision-making criteria have been classified into five groups.

I. *Energy Use*
II. *Onsite Water Use*
III. *Total Cooling Water Use* (The Total Cooling Water Use criterion comprises both onsite cooling water use and the water used in power plants to generate cooling power utilized in the data center).
IV. *Reliability*
V. *Maintenance*

Examples

- If the user prioritizes cooling system energy use as the most important criterion, with a preference for a system that consumes the least amount of energy, it is recommended to assign a large weight percentage to the *Energy Use* criterion (Figure 21).
- In the case where the user places greater emphasis on the onsite water use of the cooling system, it is suggested to assign a large weight percentage to both the *Onsite Water Use* and *Total Cooling Water Use* criteria (Figure 21).

b. ***Calculate the Weight Percentage based on paired parameters' importance comparison values*:** his approach involves the user comparing the importance of criteria in pairs, and the program automatically calculates the weight percentage for each parameter after the user completes the necessary data entry in the subsequent step, as explained in Part 2 of Section 2.2.2.

Note

When the user chooses a weight percentage entry method and clicks the *Save* button, the remaining input boxes that correspond to the other method on the tab are disabled. If the user wishes to switch to the other weight percentage calculation method, they must select the method from the *Which way would you prefer to enter the operating parameters weight percentage values?* dropdown box and click the *Save* button to activate the relevant boxes and deactivate the irrelevant data entry boxes.

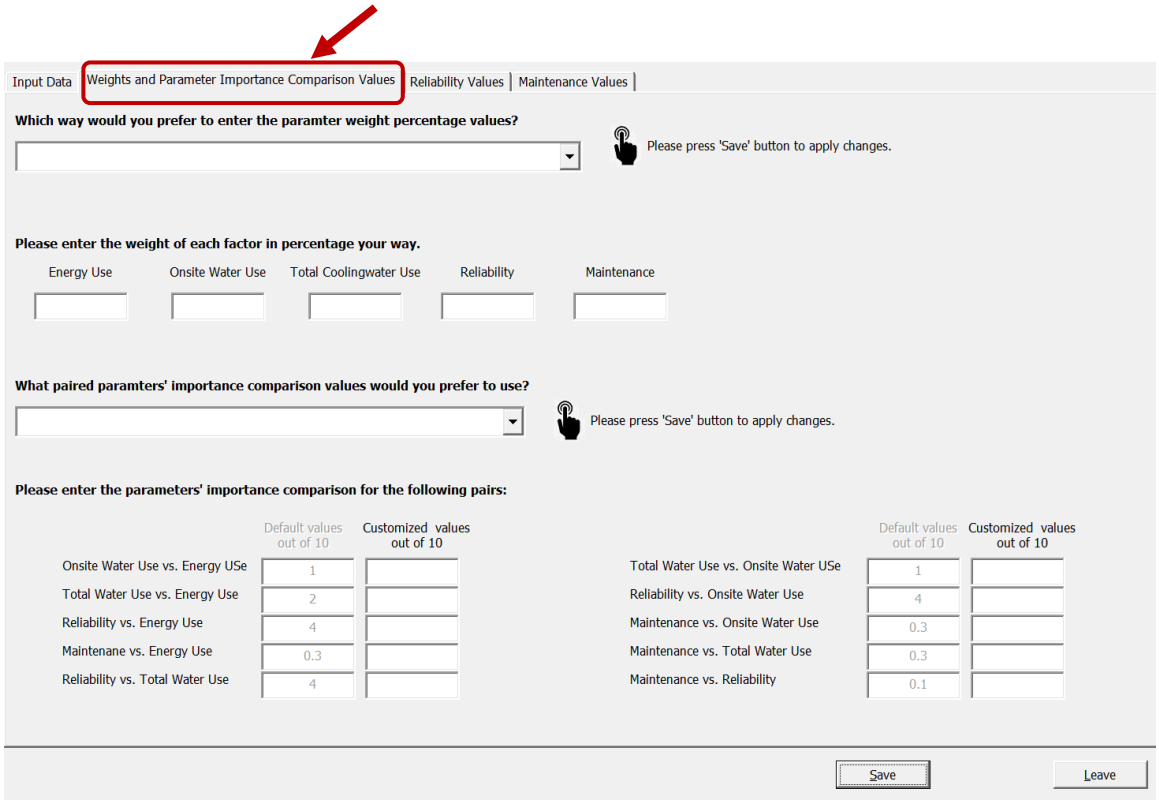

Figure 19. *Weights and Parameter Importance Comparison Values* tab in the *User Input Form* (Section 2.2.2, Step 1).

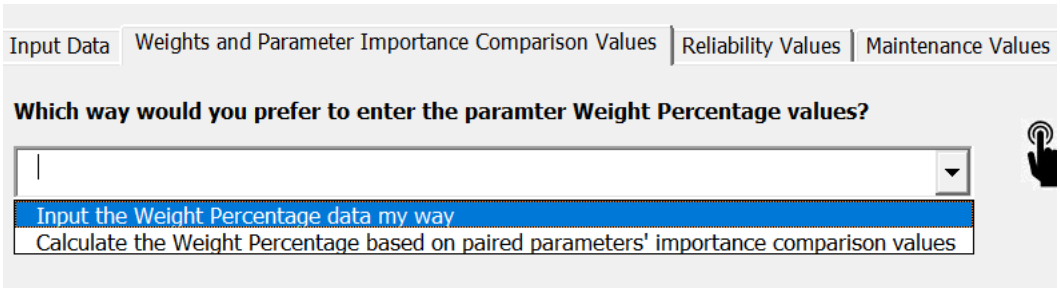

Figure 20. Choosing the weight percentage entry method (Section 2.2.2, Step 1)

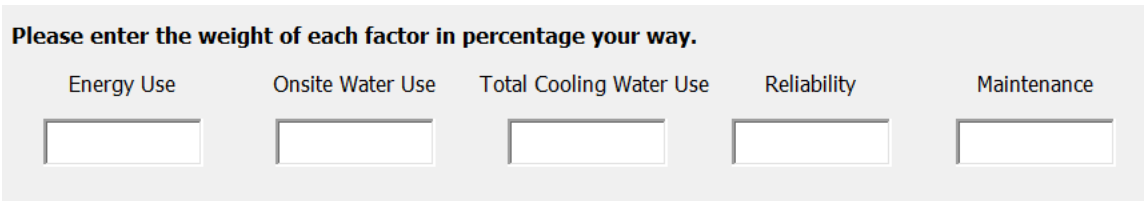

Figure 21. Required weight percentage for five criteria when the user selects *Input the Weight Percentage data my way* in step 1 (Section 2.2.2, Step 1a).

1. If the user selects the second method of weight percentage calculation, which is *Calculate the Weight Percentage based on paired parameters' importance comparison values* in step 1,'the second dropdown box will become active. The user must then choose either *Default paired parameters' importance comparison values* or *Customized Default paired parameters' importance comparison values* (Figure 22). If the user selects the *Choose default paired parameters' importance comparison values* option, they do not need to enter any data. However, if the user selects the *Choose customized paired parameters' importance comparison values* option, they must manually enter the customized values (Figure 23).

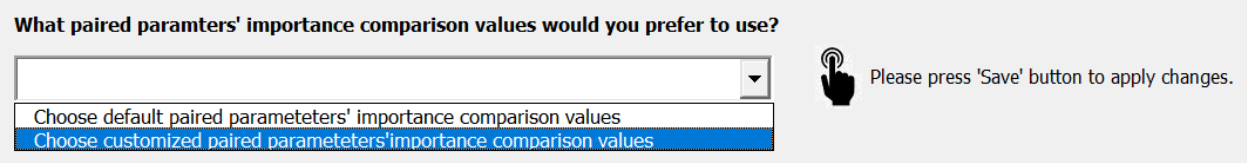

Figure 22. Choosing either default, or customized values for *Paired parameters' importance comparison values*, when the user selects *Calculate the Weight Percentage based on paired parameters' importance comparison values* method in step 1 (Section 2.2.2, Step 2).

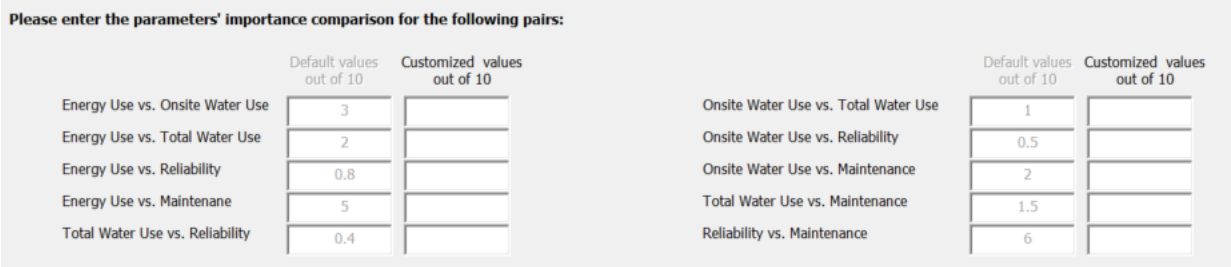

Figure 23. *Parameters' importance comparison* values data entry when the user selects the *Customized paired parameters' importance comparison values* in step 2 (Section 2.2.2, Step 2).

1.2.3. ***Reliability Values*** **tab**

In the *User Input Form*'s *Reliability Values* tab (Figure 24), the user can choose between two methods of calculating the reliability values by clicking on the *What Reliability values would you prefer to use?* dropdown box (Figure 25).

a. **Default *Reliability* values:** The values are pre-calculated based on the defined parameters and can be found in the *Reliability Default Values* sheet within the *DC-E-WISE* Excel file. **Customized *Reliability* values:** This option enables the user to manually input customized values ranging (0 to 50) for *Annual Availability* and (0 to 10) for other reliability factors that are *IT Room Air Fluctuation Due to Outdoor Condition, Lifetime, IT Room Air Contamination,* and *Complexity* for all types of cooling systems in the *Reliability Values* tab of the user form. By doing so, the program will automatically calculate the *Overall Reliability (%)* values for all cooling systems, removing the need for manual calculations (Figure 26).

Note

If any of the customized values entered for the reliability factors, *Annual Availability, IT Room Air Fluctuation Due to Outdoor Condition, Lifetime, IT Room Air Contamination,* and *Complexity*, are not within the defined range or are missing, the program will show an error message and prompt the user to fix the error before proceeding to the next tab. The cursor will then move to the first box (*Annual Availability*) of any cooling system for which the customized values were not entered correctly. The user should review the customized reliability parameters' values for that specific cooling system and make any necessary corrections to ensure accurate data entry (Figure 27).

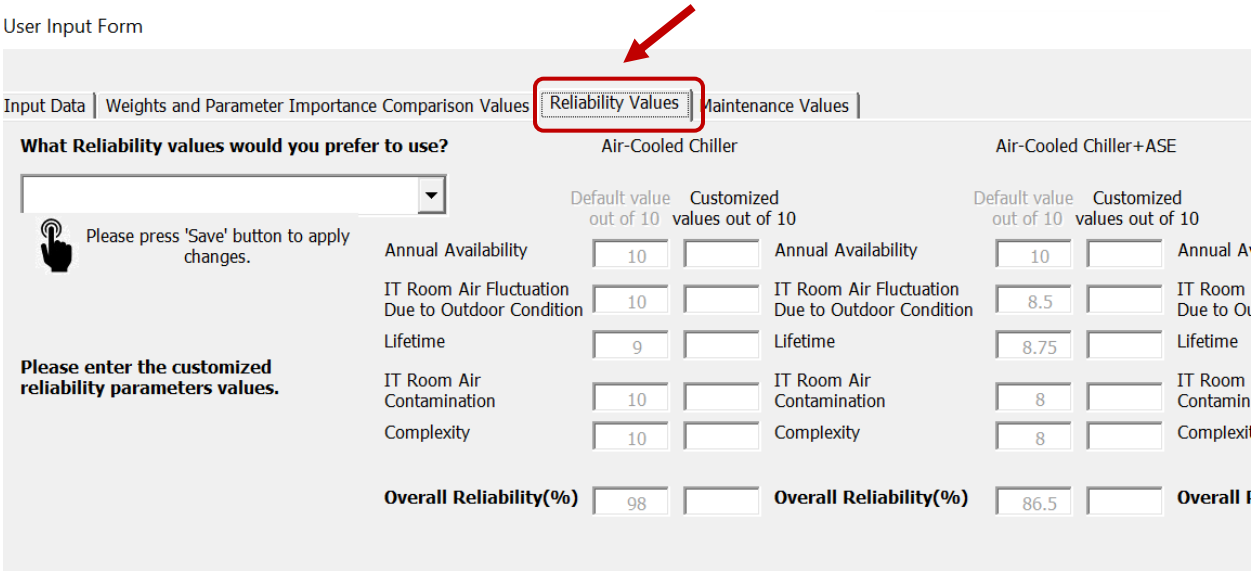

Figure 24. *Reliability Values* tab in the *User Input Form* (Section 2.2.3).

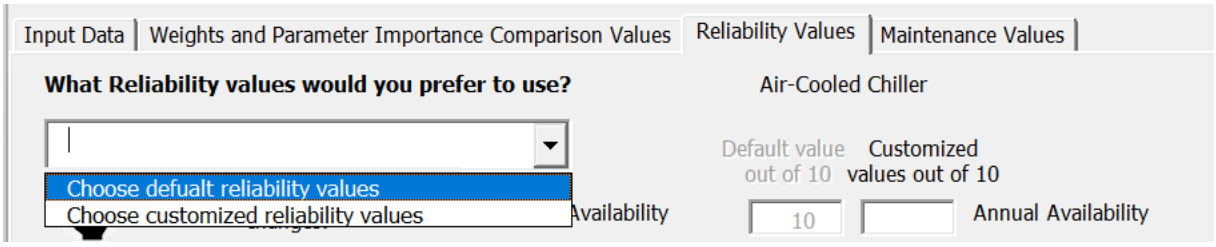

Figure 25. Choosing one of two options, either using default, or customized *Reliability values* (Section 2.2.3).

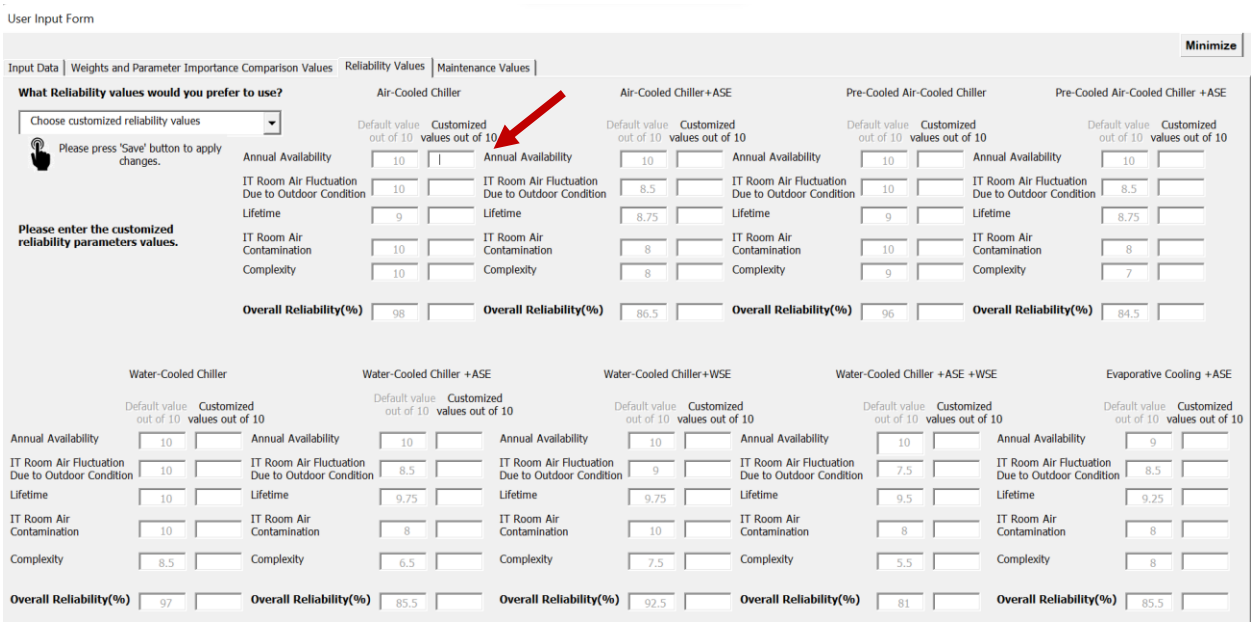

Figure 26. Data entry for the customized *Reliability values* (Section 2.2.3).

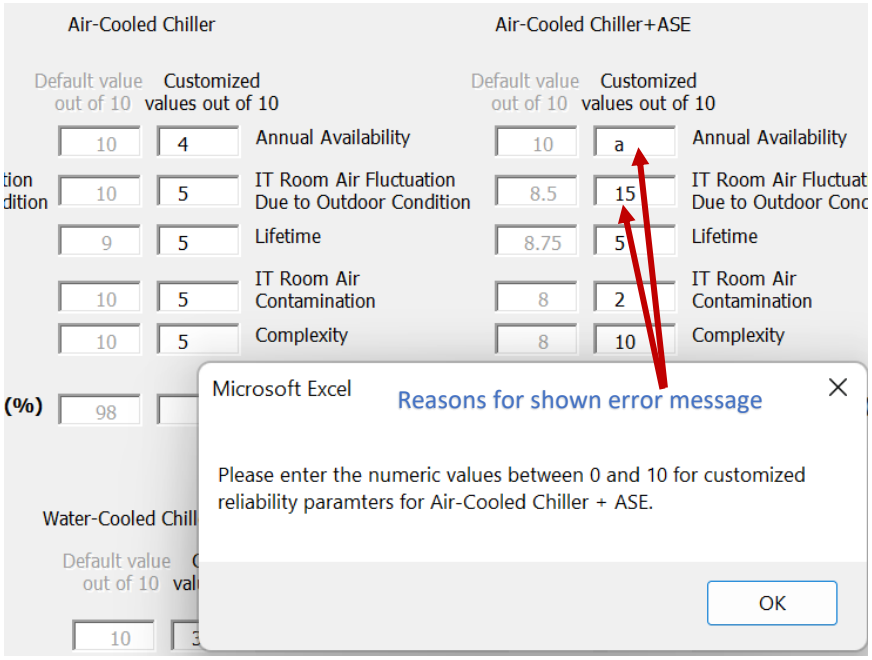

Figure 27. Error message shown because of errors in customized reliability factors values for Air-Cooled Chiller + ASE cooling system (Section 2.2.3, Note)

2.2.4 *Maintenance Values* tab

In the *Maintenance Values* tab (Figure 28) in the *User Input* Form, the user can choose between two methods of calculating the maintenance values by selecting one of the options in the *What Maintenance values would you prefer to use?* dropdown box (Figure 29):

a. **Default *Maintenance* values:** These values are pre-calculated based on the defined *Action Weight* and *Action Frequency*, as described in Section 1.2.2. The *Maintenance Default Values* sheet in the *DC-E-WISE* Excel file provides more details on this calculation.

b. **Customized *Maintenance* values:** If the user selects *Customized Maintenance values* in the *Maintenance Values* tab, they need to manually enter the *Customized Maintenance Action Weight* and *Customized Maintenance Action Frequency* for each maintenance action of all cooling systems. The program then automatically calculates the *Overall Maintenance* values for all cooling systems based on user-assigned weights and action frequencies, removing the need for manual calculations (Figure 30).

Note

1. If any of the *Customized Weight* or *Customized Frequency* values are missing, non-numerical, or less than zero, the program will display an error message and prompt the user to fix the error before proceeding (Figure 31 and 32).

2. If any of the *Customized Weight* or *Customized Frequency* values are missing or are non-numerical, or a value less than zero is entered, an error message is displayed by the program. The cursor will then move to the first box of *Customized Weight* or *Customized Frequency* of the affected cooling system. The user should then check the values entered for that specific cooling system and correct any errors in data entry before proceeding.

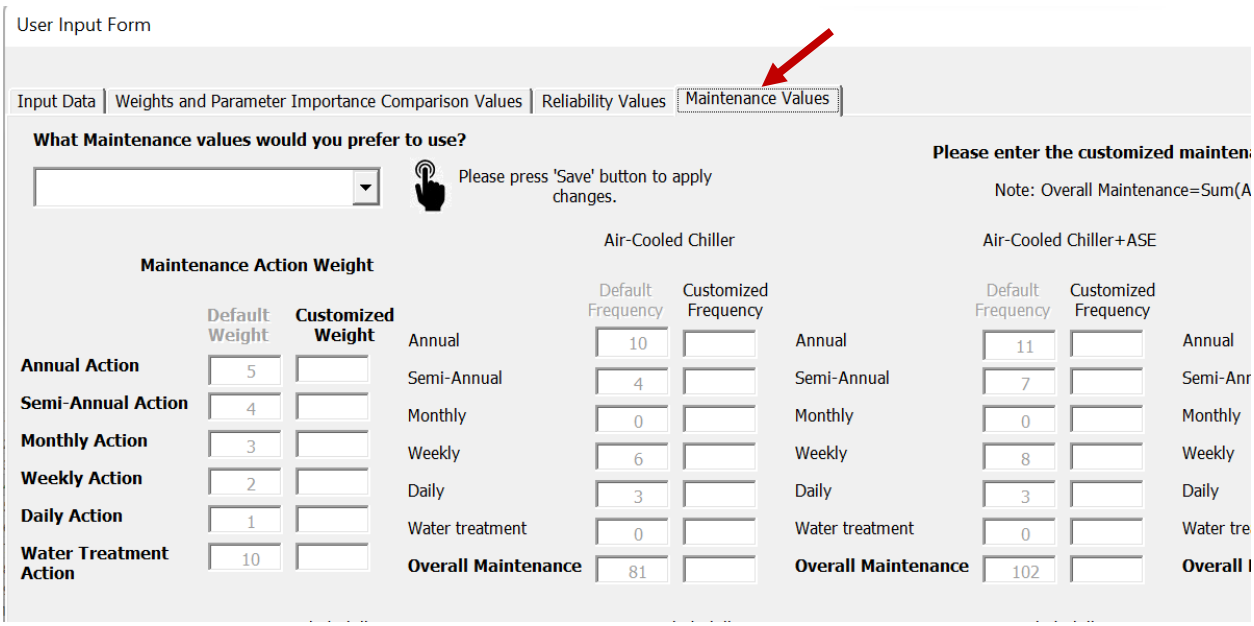

Figure 28. *Maintenance Values* tab in the *User Input Form* (Section 2.2.3).

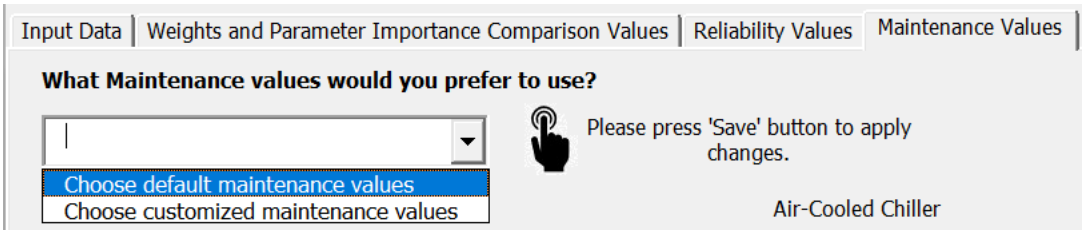

Figure 29. Choosing one of two options, either default, or customized *Maintenance values* (Section 2.2.4).

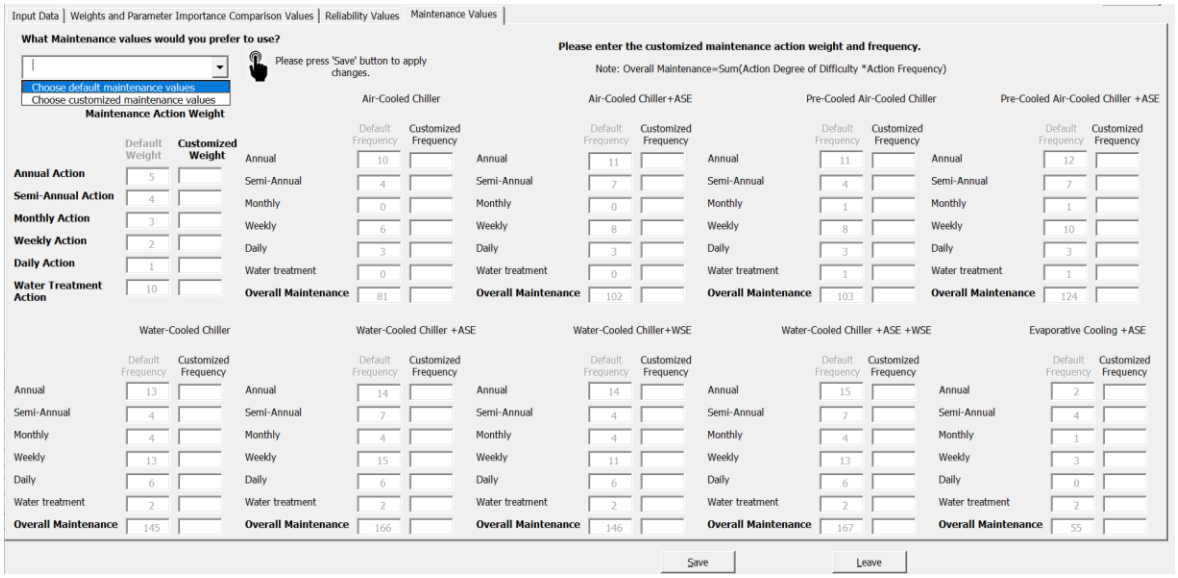

Figure 30. Data entry for the customized *Maintenance Action Weights and Maintenance Action Frequency values* (Section 2.2.4).

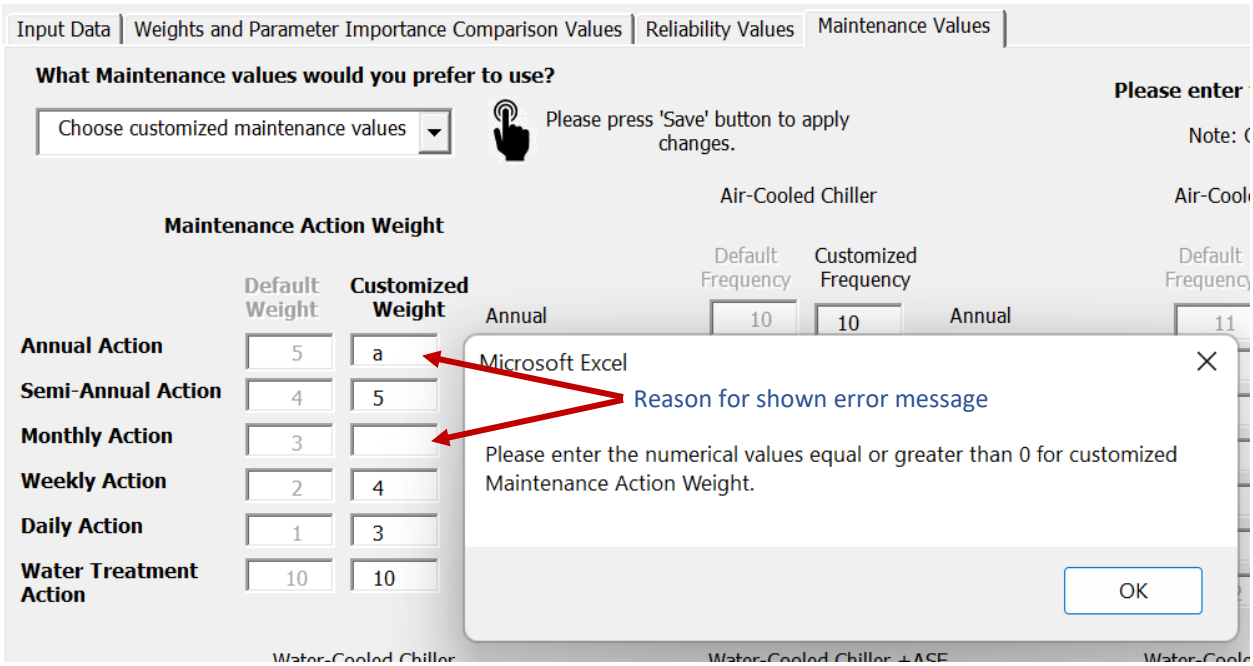

Figure 31. Error message shown because of errors in customized *Maintenance Action Weight* values (Section 2.2.4, Note)

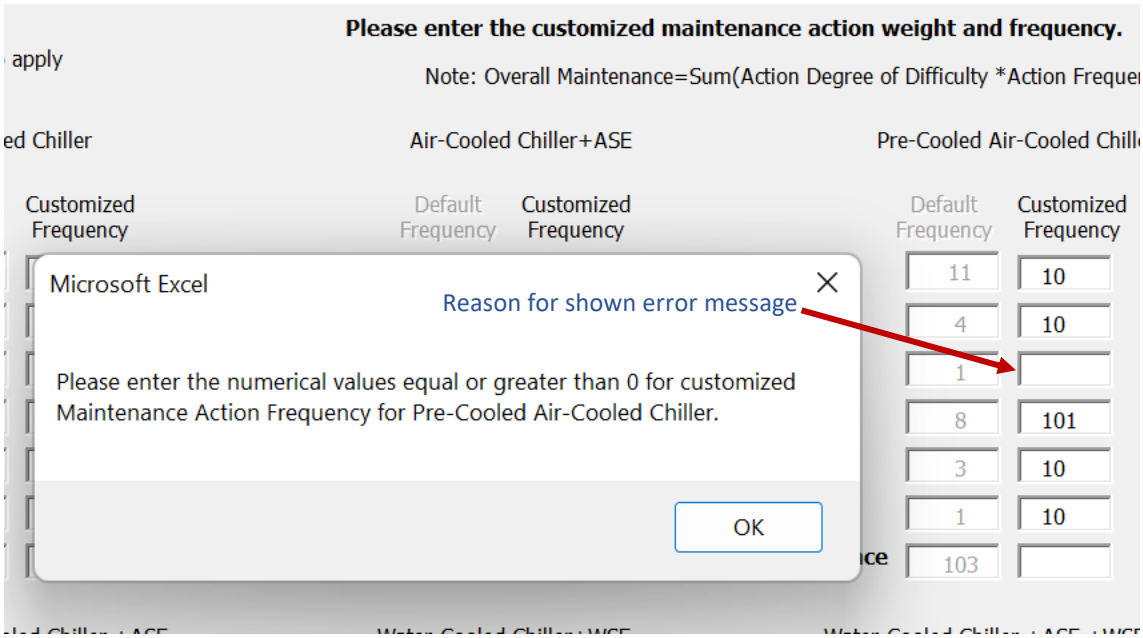

Figure 32. Error message shown because of errors in *customized Maintenance Action Frequency* values for Air-Cooled Chiller + ASE cooling system (Section 2.2.4, Note)

3. Notes

1. The *Cooling System Schematics* sheet in the DC-E-WISE excel file allows the user to review the schematics of the nine discussed cooling systems.
2. The *Cooling System Graphs* sheet in the DC-E-WISE excel file displays plotted normalized values for *Energy, Onsite Water Use*, and *Total Cooling Water Use,* based on IT load, for four different airflow management strategies.
3. The *No Airflow Containment, CAC Airflow, HAC-VED Airflow, and CAC* and *HAC-VED Airflow* sheets in DC-E-WISE excel file, containing modeled data for four airflow management strategies are all protected to prevent manual changes. However, they become writable when the *User Input Form* is active to allow for data entry.
4. Although *DC-E-WISE* is compatible with MAC systems, it is recommended that users run it on a Windows operating system to access all features. VBA codes tend to work better in Windows operating systems.
5. The *User_Interaction* sheet in the DC-E-WISE excel file displays the results of each run and saves them for later review if the user saves changes before closing the file.

4. Reference

[1] S. K. Shrivastava, A. R. Calder, and M. Ibrahim, "Quantitative Comparison of Air Containment Systems," in *13th InterSociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems*, San Diego, CA, 2012, 2012, pp. 68-77, doi: 10.1109/ITHERM.2012.6231415.