# MOSTCOOL Cost Model User Guide

Standalone Demonstration Version 1.0 (V1.0)

COOLERCHIPS
Team C Performers

Version 1.0 is a "demonstration version" of the model. It is provided with sample output files from EnergyPlus that can be loaded and analyzed. Portions of the functionality are disabled in this version of the software because they have not been completed and/or tested. This document provides a user reference for the standalone demonstration version of the software.

## Hardware and Software Requirements

The current executable operates on Windows 10. There are no other relevant software or hardware constraints.

## Using the Model (Model Walkthrough)

The following three files are provided with the demonstration version of the software:

CostModelDemonstrationV1.exe = Windows 10 executable
Reference Case.htm = Example reference case output report from EnergyPlus
Analysis Case.htm = Example analysis case output report from EnergyPlus

The EnergyPlus output reports will not be necessary once the cost model is integrated into the MOSTCOOL software release (the information contained in the EnergyPlus output reports will be automatically transferred to the cost analysis in this case).

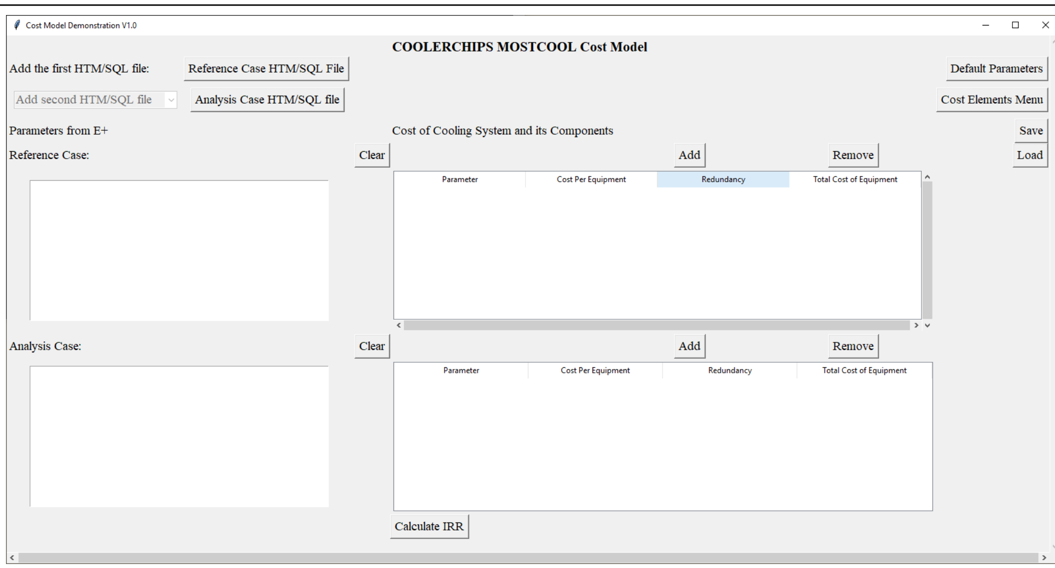


Figure 1 – Initial cost model user interface.

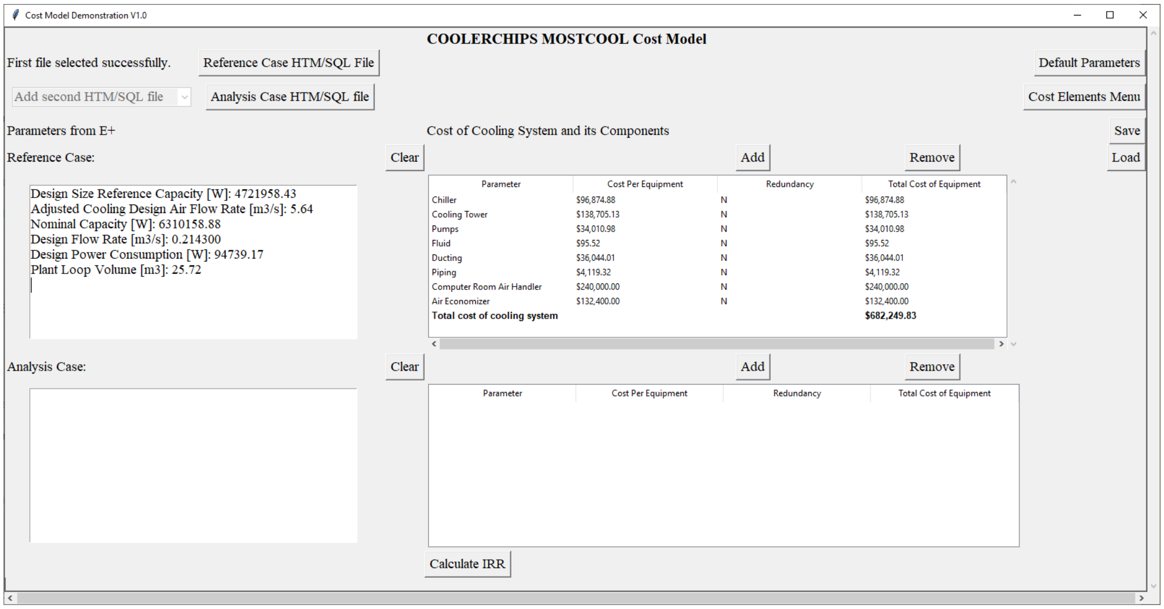


Figure 2 – Cost model user interface with reference file loaded.

When the executable is started a window should appear that looks like Figure 1. Note it may take 15 seconds for the interface screen to appear.

Input the reference case by clicking the <Reference Case HTM/SQL File> button. This will start a file browser from which you can choose to load the provided "Reference Case.htm" file. Once the reference case is loaded, the interface will appear as shown in Figure 2. The field in the upper left of the interface displays the information read from the EnergyPlus input file. The field in the upper right displays the equipment, its capital cost (see Appendix B) and its redundancy.

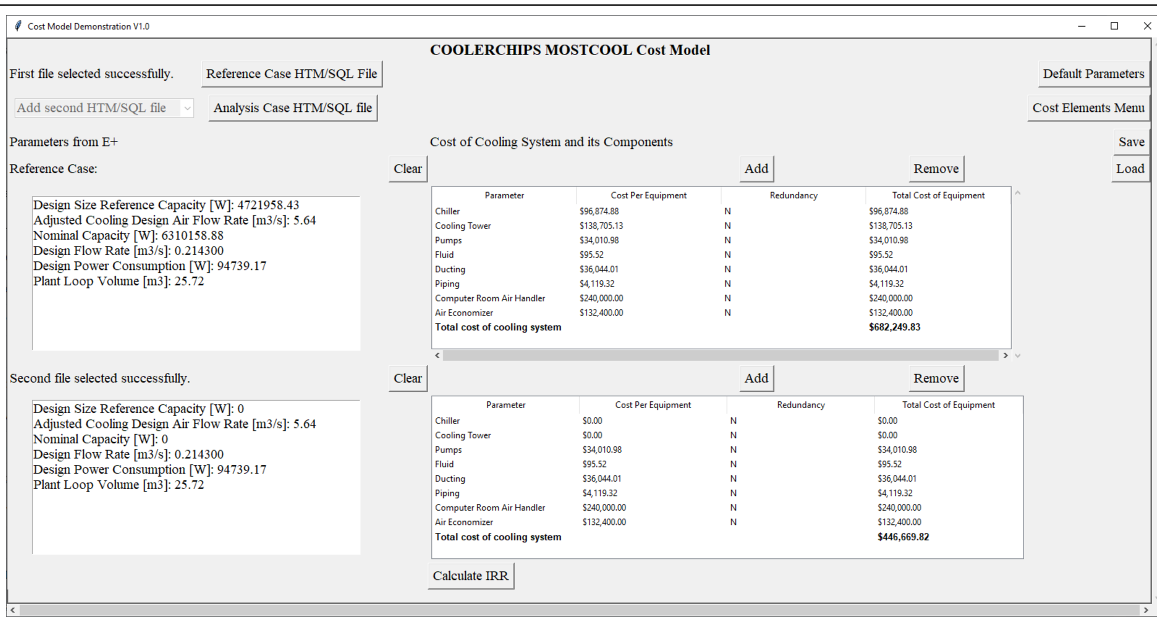


Figure 3 – Cost model user interface with reference and analysis files loaded.

Next the analysis case is loaded from EnergyPlus by clicking on the <Analysis Case HTM/SQL file> button. This will start a file browser from which you can choose to load the provided "Analysis Case.htm" file. Once the analysis case is loaded, the interface will appear as shown in Figure 3. Similar to the reference case, the bottom left and bottom right fields display the information loaded from the EnergyPlus file and the equipment details.

Once both files are loaded click the <Calculate IRR> button (center bottom) to run the cost analysis. Three graphs displaying the ROI (Return on Investment), IRR (Internal Rate of Return), and NPV Difference (NPV = Net Present Value) will appear in separate windows as shown in Figure 4. The ROI, IRR and NPV are all plotted as a function of time in years.

## User Reference

This section provides a complete user reference that documents all buttons, fields and functionality for the cost model.

<Reference Case HTM/SQL File> = displays a file browser that can be used to select an EnergyPlus HTM report or SQL output file to load as the reference case

<Analysis case HTM/SQL File> = displays a file browser that can be used to select an EnergyPlus HTM report or the SQL output file to load as the analysis case

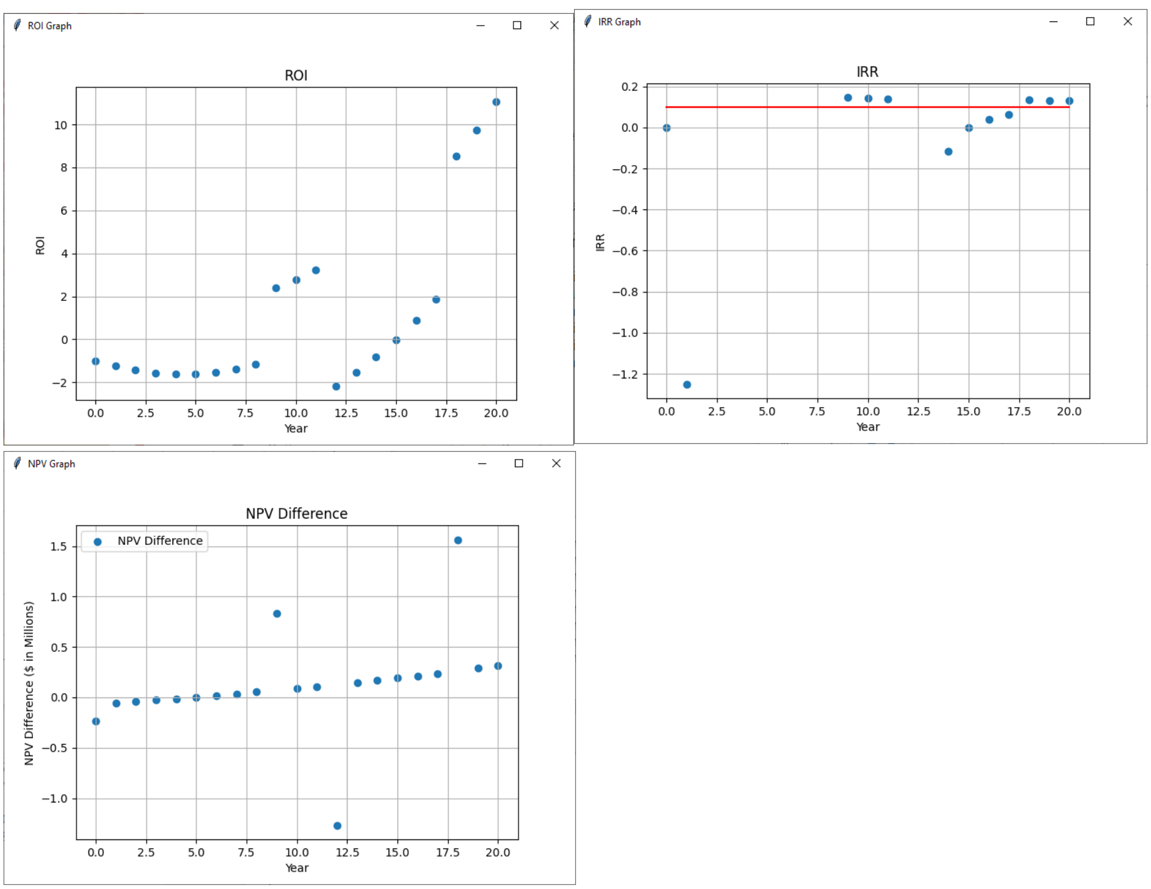


Figure 4 – Cost model analysis outputs.

<Save> = displays a file browser that can be used to save the current version of the data loaded into the tool. This creates a text file that is English readable and can be externally edited.

<Load> = displays a file browser that can be used to select and load a previously saved version of the data loaded into the tool. This will only load files that were previously saved using the <Save> functionality.

<Clear> = clears the data from the associated tables (left and right).

<Add> = displays the dialog box shown in Figure 5 that allows the addition of a piece of equipment to the associated right table. The new equipment is added at the end of the equipment list.

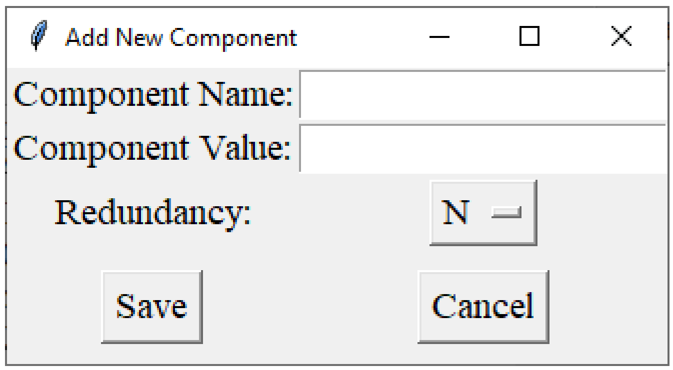


Figure 5 – Add New Component dialog box.

<Remove> = removes the selected piece of equipment from the associated table. A warning box is displayed if no row is selected for removal.

<Calculate IRR> = this button runs an analysis that compares the reference and analysis cases. See Appendix A for calculation details. Separate windows are created for each plot (shown in Figure 4). The window will remain until they are closed by the user using the "X" in the upper right of the window. A new set of windows is created each time the button is clicked.

<Default Parameters> = displays the dialog box shown in Figure 6 that includes the model inputs described in the following. If changes are made in this dialog box, the <Save> button at the bottom of the dialog box must be clicked to save the changes, and the <Calculate IRR> button must be clicked to rerun the analysis with the change(s).

> Duration of Simulation (years) = the duration of the simulation in years used in the simulation. This changes the horizontal axis on the output plots.
>
> Electricity Cost ($/kWh) = the cost of electricity used in the analysis.
>
> Cooling Maintenance Cost (per event) = maintenance cost used for every maintenance event. Used as part of the OPEX calculation. Temporary – will be overridden by equipment-specific maintenance costs that will be collected in the fields with the equipment details.
>
> Energy Inflation (per year) = annual inflation rate used for energy costs. This should be entered as a fraction.

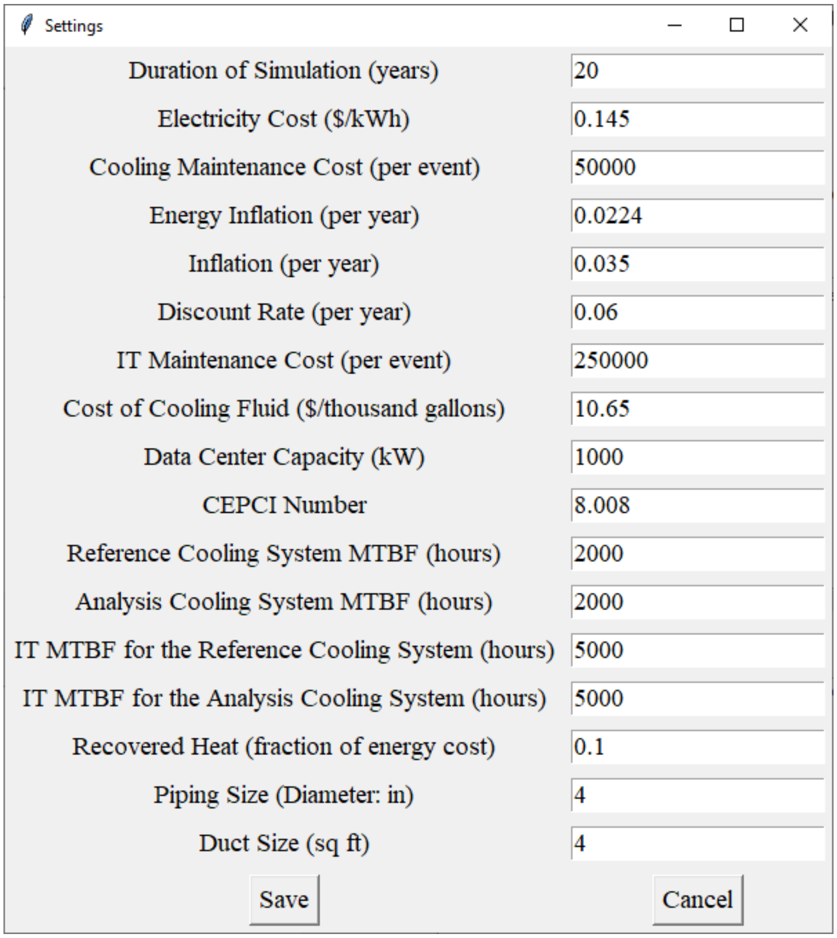


Figure 6 – Default parameter dialog box.

Inflation (per year) = annual inflation rate used for all non-energy costs. This should be entered as a fraction.

Discount Rate (per year) = weighted average cost of capital used to discount all costs to year 0 (present value). This should be entered as a fraction.

IT Maintenance Cost (per event) = cost of each IT maintenance event.

Cost of Cooling Fluid ($/thousand gallons) = cost of fluid used (if any) in the cooling system. Assume to be the same fluid in both the reference and analysis systems.

Data Center Capacity (kW) = data center design size in kW. Used to compute the cost of air handlers.

CEPCI Number = Chemical Engineering Plant Cost Index (CEPCI). Used in equipment costing.

Reference Cooling System MTBF (hours) = mean time between failure (MTBF) of the reference cooling system. Temporary – will be overridden by equipment-specific reliability that will be collected in the fields with the equipment details.

Analysis Cooling System MTBF (hours) = mean time between failure (MTBF) of the analysis cooling system.  Temporary – will be overridden by equipment-specific reliability that will be collected in the fields with the equipment details.

IT MTBF for the Reference Cooling System (hours) = mean time between failure (MTBF) of the IT equipment for the reference cooling system.

IT MTBF for the Analysis Cooling System (hours) = mean time between failure (MTBF) of the IT equipment for the analysis cooling system.

Recovered Heat (fraction of energy cost) = the value of the recovered heat as a faction of the energy cost.

Piping Size (diameter: in) = diameter (in inches) of all pipes used in the cooling systems.

Duct Size (sq ft) = cross sectional area of the ducts in the cooling systems.

<Save> = saves changes made to the parameters and closes the dialog box

<Cancel> = does not change any parameters and closed the dialog box.  Note, pressing the "X" in the upper right corner of the dialog box is the same as Cancel.

<Cost Elements Menu> = displays the dialog box shown in Figure 7.  This dialog box displays difference analyses that are not currently supported, but will be included in future versions of the cost model.

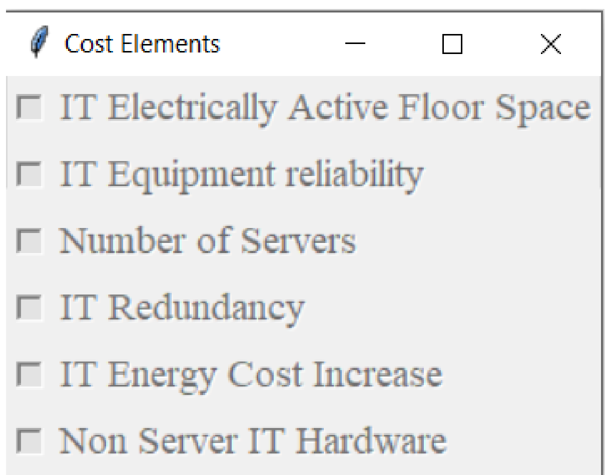


Figure 7 – Cost elements dialog box.

Editing Existing Equipment

An existing piece of equipment can be edited by double clicking on the equipment entry in the table.  This will display the dialog box shown in Figure 8.  The equipment's redundancy and cost can be edited (additional details about the equipment will be editable in future versions).  Note, no redundancy information is provided by EnergyPlus inputs, so all equipment defaults to a redundancy of N.

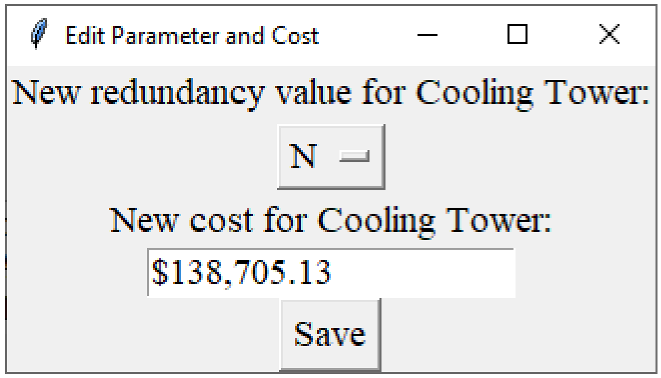


Figure 8 – Equipment property editing dialog box.

**Known Bugs**

- <Calculate IRR> uses last loaded information to perform analyses even after the tables are cleared.

## Appendix A – Cost Analysis Overview

The primary output of the cost modeling is the calculation of the IRR and breakeven point for the proposed new cooling approaches if applicable.  Figure 9 shows the general cost model information flow that is discussed in this Appendix.

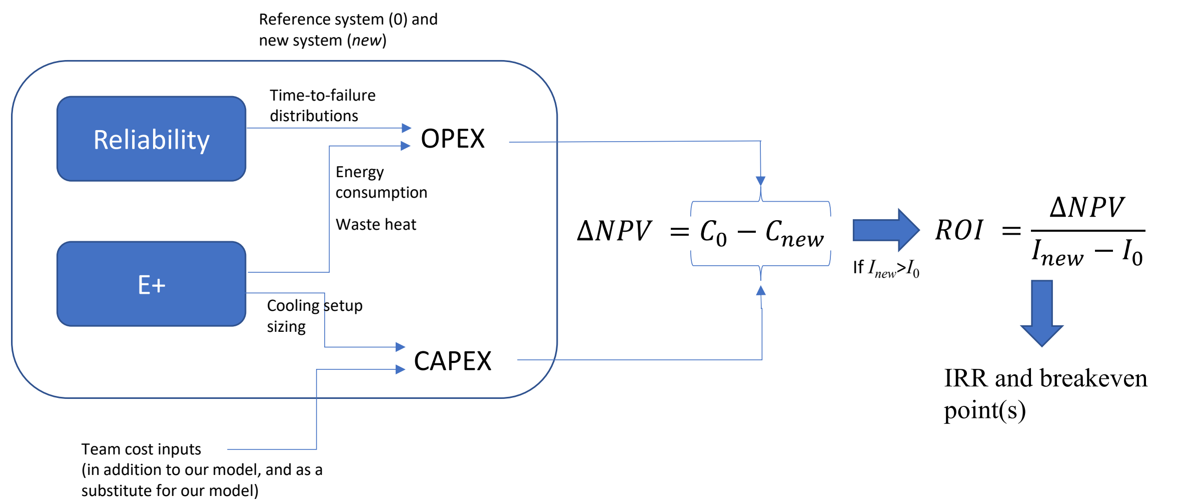

Figure 9 – Cost model flow.

The following two approaches are used depending on the relative investment in the new cooling approach:

### $I_{new} > I_0$ Analysis Model

If the investment in the new cooling approach is larger than (or in addition to) the investment in a reference cooling system, then we use a commonly used cost-avoidance return on investment [1],

$$ROI = \frac{C_0 - C_{new}}{I_{new} - I_0} = \frac{\Delta NPV}{I_{new} - I_0} \tag{1}$$

where,

$C_0$ = total life-cycle cost using the reference approach
$C_{new}$ = total life-cycle cost using the new approach
$I_0$ = investment cost in the reference approach
$I_{new}$ = investment cost in the new approach

The total life-cycle costs and therefore, the *ROI* are time dependent.  All cost contributions within $C_0$ and $C_{new}$ are discounted to present value, $I_0$ and $I_{new}$ are assumed to happen at time 0. *ROI* represents the net return over the entire time period of the investment.[1]  The internal rate of return (*IRR*), which is the annual rate of return, can be calculated from the *ROI* using:

[1] In this case we need a "cost avoidance" *ROI* because the cooling system does not generally earn revenue, rather it avoids future spend (on IT equipment maintenance and replacement).  The heat removed may have value (which we consider), but the cooling system is not a net revenue earning portion of the data center.

$$(1 + ROI)^{1} = (1 + IRR)^{entire\ investment\ period} \quad (2)$$

Breakeven are the points in time when the $IRR = 0$. Note, there may be several points on the timeline where the rate of return transitions from negative to positive and vice versa.

The cost avoidance $ROI$ is the ratio of the total life-cycle cost difference between the data center with the new cooling system and the data center with a reference cooling system, and the difference in the investments in the new and reference cooling systems. This cost avoidance $ROI$ is useful because the numerator and denominator are both differences, therefore, only the life-cycle costs that differ between the new and reference approaches need to be modeled (all other costs subtract out). The life-cycle costs that have to modeled include: capital equipment for cooling, energy for cooling, maintenance of the cooling system, maintenance frequency of the IT equipment (if it is impacted by the new cooling approach), heat removal value from the IT equipment, and other data center properties that vary from the reference case. The model will also depend on discount rate and inflation rates.

### $I_{new} < I_0$ Analysis Model

It is likely that some of the proposed cooling technology changes will result in overall decreases in the investment (in the cooling system) so that $I_{new} < I_0$. When $I_{new} < I_0$ a comparison with the reference case can still be made, but in this case a negative investment is made to get a return, so $ROI$ and $IRR$ are not the appropriate measures to use, i.e., there is no $ROI$ or $IRR$ in these cases. In these cases, an additional suggested measure is $\Delta NPV$, which is the difference in the net present value between the new case and the reference case,

$$\Delta NPV = C_0 - C_{new} \quad (3)$$

where, NPV is time dependent and all cost contributions within $C_0$ and $C_{new}$ are discounted to present value. Note, $I_0$ and $I_{new}$ are not ignored, they are included within $C_0$ and $C_{new}$. Equation (3) is the life-cycle cost difference that appears in the numerator of the $ROI$ in equation (1). Note the $\Delta NPV$ is equal to zero at the breakeven point (the point where $IRR = 0$).

## Appendix B - Cooling Equipment CAPEX Models

The CAPEX model for the cooling equipment requires that a cost be computed for all equipment in the cooling system bill of materials. The cooling equipment list is obtained from EnergyPlus. EnergyPlus also "auto-sizes" the equipment. From the equipment type and its size, the costs of determined from the following parametric models:

Chiller: The size of the chiller capacity is measured in tons. Depending on the chiller capacity the $/ton value will change [2], The design size reference capacity in watts is taken from the EnergyPlus sizing file. This sizing capacity in W is then converted into tons. Depending on the capacity of the chiller the $/ton value will change as shown in the table below.

| tons | $/ton |
|---|---|
| x<50 | 1500 |
| 50<x<150 | 700 |
| x>150 | 450 |

Table 1: x is the capacity of the chiller in tons. The $/ton changes depending on the capacity of the chiller.

$$Chiller\ Cost = (\ tons)(\$/ton) \tag{4}$$

Cooling Tower: The cooling tower like the chiller has the cost adjusted based on the capacity measured in tons [3]. The nominal capacity of the cooling tower in watts is taken from the Energy plus sizing file. Using the capacity of the cooling tower in watts the capacity can be converted into tons,

| tons | $/ton |
|---|---|
| x<10 | 1500 |
| 10<x<50 | 1250 |
| x>50 | 700 |

Table 2: x is the capacity of the cooling tower in tons. The $/ton changes depending on the capacity of the cooling tower.

$$Cooling\ Tower\ Cost = (tons)(\$/ton) \tag{5}$$

Pumps: The cost of the pump is determined by its power consumption [4]. The pump models rely on calculations from the early 2000s, and to adjust for inflation, a Chemical Engineering Plant Cost Index (CEPCI) is applied to the pump costs. The power consumption of the pumps in watts will come from EnergyPlus,

$$Pump\ Cost = \left(9500\ \frac{Power\ Consumption}{23}\right)^{0.79} CEPCI \tag{6}$$

Air Economizer: The air economizer model is based on the size of the data center in square feet [5]. The size of the data center in square meters will be the conditioned area of the building from Energy plus. The size of the data center is converted from square meters to square feet. It was later learned that the conditioned area of a building is different from the electrically active floor area. The electrically active floor area will need to be determined from the Energy plus file

$$Air\ Economizer\ Cost = 132.4(size\ of\ data\ center\ in\ sq\ ft) \tag{7}$$

Computer Room Air Handling Unit (CRAH): The current CRAH model uses the expected capacity of the data center to determine the cost [6]. The data center capacity in Kilowatts is a value that is currently required to be inputted into the program. It is expected that this value will be an input in either the energy or thermal model,

$$CRAH\ Cost = 240(data\ center\ capacity\ in\ kW) \tag{8}$$

Fluid: The current fluid model assumes that there is no loss of fluid throughout the system. The system volume will be taken from Energy plus and will be in cubic meters. The system volume is converted into cubic feet. The cost of the fluid used is currently set to the cost of water, however this value can be adjusted in the default parameter settings as shown in figure 3.

$$Fluid\ Cost = \frac{264.172(System\ volume)}{(12)(10000)}(Cost\ of\ Fluid) \tag{9}$$

In addition to the equipment, we also cost the cooling system infrastructure, i.e., piping and ducting. The size of the piping and ducting system is assumed to be 4-inch diameter for pipes and 4 square feet for the ducting. These values can be adjusted in the default parameters settings and a new piping and ducting.

Piping [7]: Using the diameter an area of the pipe can be calculated that can be used in equation 10. The volume of the piping in cubic meters is taken from the EnergyPlus sizing file. The volume of the piping is then converted into cubic feet,

$$Piping\ Cost = (\frac{80}{pipe\ area})(volume)CEPCI \tag{10}$$

Ducting [7]: Since the ducting size is inputted as an area, no changes need to be made. The volume of ducting in cubic meters is taken from the EnergyPlus sizing file. The volume of the piping is then converted into cubic feet,

$$Ducting\ Cost = (\frac{700}{duct\ area})(volume)CEPCI \tag{11}$$

**References**

[1] Feldman, K., Jazouli, T., and Sandborn, P., 2009. "A Methodology for Determining the Return on Investment Associated with Prognostics and Health Management," *IEEE Trans. on Reliability*, Vol. 58, No. 2, pp. 305-316.

[2] Fisher, J. 2019. "How to Manually Calculate Chiller Capacity for Your Process," https://www.conairgroup.com/resources/resource/chiller-sizing-part-2-the-old-school-way/.

[3] Cooling Tower Products. 2024. "Cooling Tower Costs 2024," https://www.coolingtowerproducts.com/cooling-tower-cost-2024/

[4] Woods, D., 2007. "Rules of Thumb in Engineering Practice," pp. 383-384.

[5] Energy Star, "Use an Air-side Economizer," https://www.energystar.gov/products/data_center_equipment/16-more-ways-cut-energy-waste-data-center/use-air-side-economizer

[6] Shehata, H., 2014. "Data Center Cooling: CRAC/CRAH redundancy, capacity, and selection metrics," https://journal.uptimeinstitute.com/data-center-cooling-redundancy-capacity-selection-metrics/

[7] Woods, D., 2007. "Rules of Thumb in Engineering Practice," pp. 387.