





TRNOPT

Optimal Design with TRNSYS and GenOpt

TRNOPT v16_1 Installation, Run-Time Instructions, and License Agreement

This program is intended for Windows 2000, Windows XP, or Vista users running the TRNSYS Software Package version 16.0 or later.

TRNOPT v16_1 was written by Thermal Energy System Specialists, LLC of Madison, Wisconsin in order to couple the TRNSYS simulation software with the GENOPT optimization algorithms produced by Lawrence Berkeley National Laboratory (LBNL). TRNOPT acts as an interface program between the two software programs and streamlines the optimization process. With TRNOPT, the entire process of optimizing the results from a TRNSYS simulation reduces to choosing the TRNSYS input file, choosing the variables which will be varied to optimize the results, and choosing the simulation result to be optimized.

This program requires that the user download the GENOPT optimization engine from Lawrence Berkeley National Laboratory; instructions for doing this are contained in this document. GENOPT is a generic optimization algorithm developed by LBNL to interface with black-box simulation programs like TRNSYS. GENOPT is freely downloadable.

GENOPT requires that the user have a Java run-time executable version installed on their computer. Java graciously allows for program developers to re-distribute the Java run-time executable program with their package. An installation program for a Java Run-Time executable is included with your installation media. Simplified instructions for installing it can be found in this document. Alternatively, users may download the program directly from the JAVA web site: http://java.com/en/download/index.jsp. Release notes, installation instructions and other useful information can also be found on the web site.

Follow the steps outlined below to install TRNOPT, GENOPT, and the Java Run-Time Executable; all of which are required to optimize TRNSYS input files.

Step 1) Install the TRNOPT Program:

Launch the application ***Setup_TRNOPT16_1.Exe*** located on the installation media that was sent to you. This program will install the TRNOPT16 executable program (the interface between TRNSYS and GENOPT) on the hard drive of your machine as well as several configuration files into an OPTIMIZATION subdirectory of your main TRNSYS directory. It is critical that the user install TRNOPT into the same directory that contains the TRNSYS version 16 software (typically C:\Program Files\Trnsys16_1). Failure to do so will cause the optimization program to fail as the directory structure of TRNSYS has been coded into the program.

Please note: TRNOPT interfaces with GENOPT through your computer's operating system. This installation of TRNOPT does NOT replace any of your computer's system files. In the majority of cases, the system files on your computer will allow TRNOPT and GENOPT to work together. However, if you start using TRNOPT and get error messages that reference certain dll and ocx files, please contact us so that we can send you whatever system files may be missing.

Step 2) Install the Java Run-Time Executable:

As discussed earlier in this document and on the GENOPT web page, GENOPT requires that the user have a Java Run-Time executable installed on their computer. Sun Microsystems generously allows us to supply you with a free Java Runtime Executable (JRE) installation program. This installation program has been added to the installation media which was sent to you with the purchase of TRNOPT. If you do not have a Java Run- Time Executable already installed on your machine, launch the application:

jre-6u7-windows-i586-p.exe

located on your installation media. Follow the directions and this program will install the JRE executable on your machine. By default, this application will be placed into a ***Java*** directory under the ***Program Files*** directory in Windows. Record the location of the file ***java.exe***; this information will be used in the TRNOPT program and is by default:

C:\Program Files\Java\jre1.6.0_07\bin

Step 3) Install the GENOPT Software:

TRNOPT v16_1 is designed to work with the GenOpt version 2.1.0. Use your internet web browser to visit the site: ***http://gundog.lbl.gov/GO/*** and read the information about the GENOPT program. Proceed to the download area by clicking on the ***Download*** tab on the left-side of the web page. Download the GENOPT documentation in PDF format:

http://simulationresearch.lbl.gov/GO/download/manual.pdf

Please take the time to download and read the GENOPT documentation - especially the sections on the various algorithms for important background information on the optimization process. The documentation provides valuable information on the optimization process, things to look out for etc. After downloading the documentation, download the JAR file for the GENOPT install:

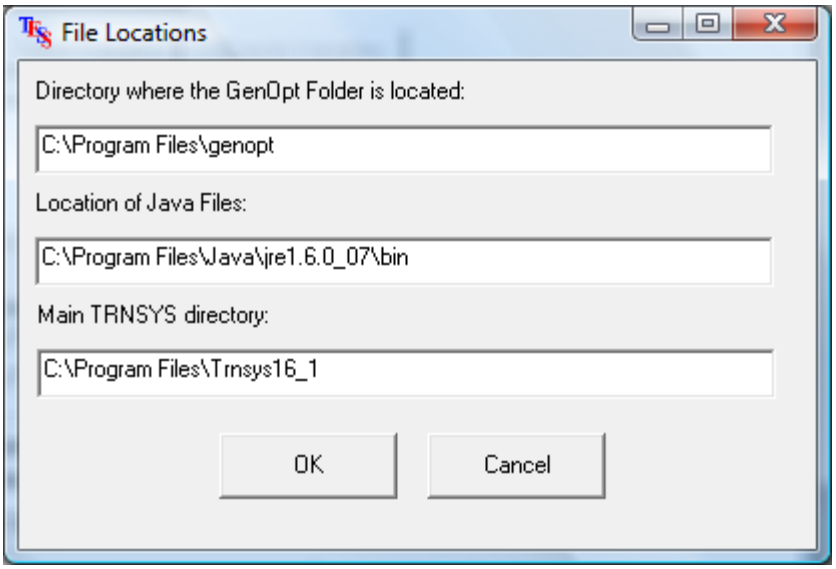
http://simulationresearch.lbl.gov/GO/download/genopt-install.jar

After downloading the GENOPT install, execute the *genopt-install.jar*. The install will walk through a series of steps. Make sure to use the default directory (*C:\Program Files\genopt*) when installing GENOPT.

Step 4) Restart your machine

Step 5) Providing Required Directories

Launch the TRNOPT16_1 executable program from the ***Start*** menu (under the TRNSYS 16 options) or by double clicking on the icon or file name. The TRNOPT program should be located in the main TRNSYS directory (typically ***C:\Program Files\TRNSYS16_1\Optimization\TRNOPT16_1.exe***).



Fill-in the required path information for GenOpt, Java, and TRNSYS by selecting the "Settings" menu from the TRNOPT application.

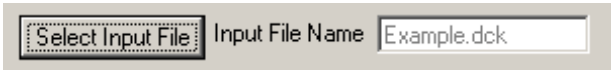
• The "Directory where the GenOpt Folder is located:" is the name of the main folder into which the GENOPT program was extracted. The GenOpt release notes are kept in this directory (README.html). For reference this folder is by default:
C:\Program Files\genopt

• The "Location of Java Files:" is the directory which contains the Java run time file ***java.exe*** and is by default:
C:\Program Files\Java\jre1.6.0_07\bin

• The “Main TRNSYS directory:” is the main directory for TRNSYS and also contains the user.id file and the trnsys.ini file. By default it is located at:
C:\Program Files\Trnsys16_1

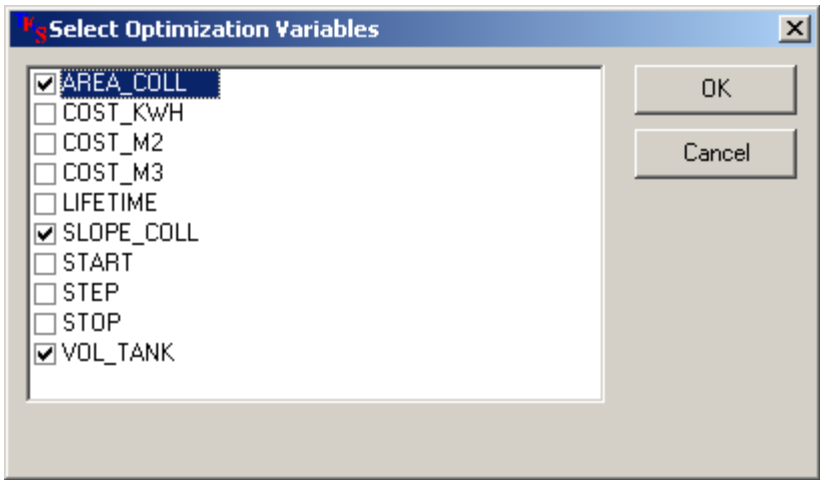
Choosing the Input File:

Pressing the "Select Input File" button will open a browse window allowing the selection of any TRNSYS input file or TRNSED file that the user wishes to optimize. Browse to the desired file and double-click on the file or highlight the file and click on the “Open” button



Choosing the Variables to be Optimized:

Once an input file has been chosen, use the "Select Variables" button to choose which TRNSYS variables will be adjusted in subsequent simulations in order to optimize the results. Available variables are any variables in the selected input file that are simple constants or simple equations (A=10 for example). Select a variable by clicking with the mouse on the box next to the variable name so that a check-mark appears next to the name. Clicking again on the variable box will deselect that variable. Click the OK button to continue.



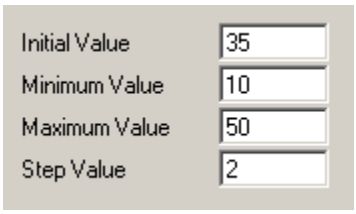
Specifying Variable Information:

Once the optimization variables have been chosen, use the "Specify Variables" button to set the variable data used in the optimization. Variables can be specified as either continuous or discrete. A continuous variable is allowed to take any value between the maximum and minimum specified. A discrete variable can have values that are either at regular intervals between the minimum and maximum or values that are limited to specific entered values. To specify a variable first select the variable from the drop-down box at the top of the screen. A short descriptive name for the variable can be entered in the “Display Description” box just below the selected variable name. This description is used in the GenOpt plot window as the simulation progress.



The radio buttons are used to determine whether the variable is to be continuous or discrete and, if discrete, whether it will be specified or spaced. Select the appropriate radio button(s) to set what type of variable that is being specified. Based on the type of variable that is being specified, appropriate boxes for specifying the variable will be displayed in the window.

For continuous variables:



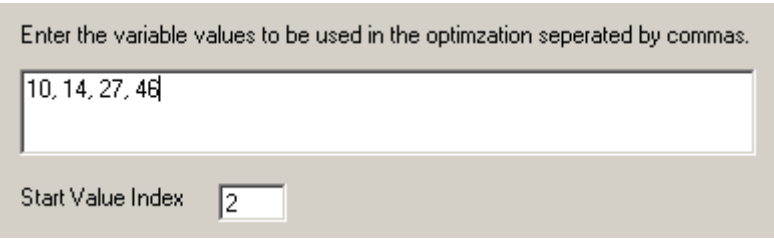
Initial Value A good guess as to where the optimum lies for this variable. The better the guess, the less computational time will be required.

Minimum Value The smallest value that the variable is allowed in the simulations. Refer to the GENOPT manual for a discussion of bounding the answers to an optimization for more information.

Maximum Value The largest value that the variable is allowed in the simulations. If the variable is unbounded, simply set the minimum and maximum values to values of -9999999 and 9999999 for example.

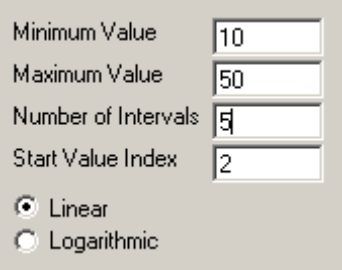
Step Value A representation of the original step size taken away from the initial guess. The smaller the characteristic length, the longer it may take to reach a conclusion. However, an overly large characteristic length can also cause convergence problems. This value is also used differently based on the optimization method selected. Please consult the GenOpt documentation for more information concerning how this value is used.

For discrete specified variables:



The values to be used for the variable should be entered in the text box separated by commas. Strings, as well as numbers, are allowed as input. Set which value will start the optimization by entering its index in the “Start Value index” box.

For discrete spaced variables:



Minimum Value The smallest value that the variable is allowed in the simulations.

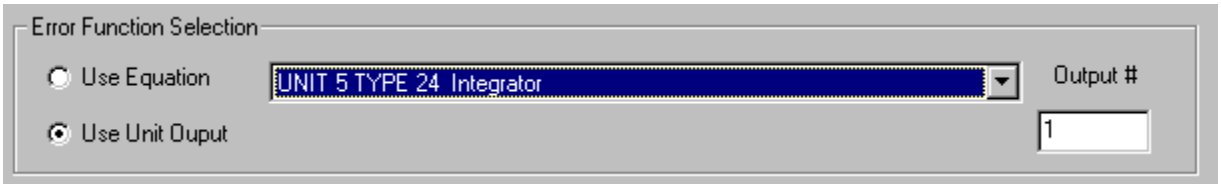
Maximum Value The largest value that the variable is allowed in the simulations.

Number of Intervals The number of intervals between the minimum and maximum used to calculate the values used in the optimization.

Start Value Index Sets which value in the sequence will be used to start the simulation.

Linear/Logarithmic The values between the minimum and the maximum can be spaced either linearly or logarithmically. Select which type of spacing to be used with the radio buttons.

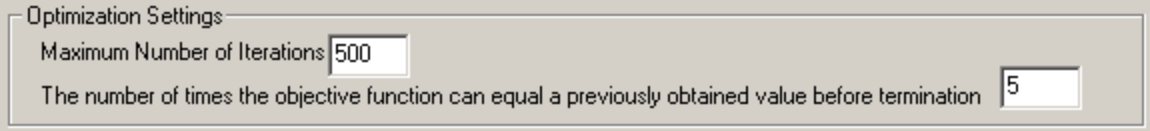
Selecting the Error Function:
Use the radio buttons to select which type of output from the simulation will be minimized during the optimization process. The user has the option of selecting a TRNSYS equation name or any output from any component model contained in the TRNSYS simulation input file.



After choosing one of the two methods, use the combination box control to select an equation name or a Unit/Type combination from the current input file. If a Unit/Type combination is chosen, make sure to specify which output number will be used in the minimization process. Typically, the results to be optimized (minimized) from the simulation will be the outputs of integrators, or equations that use an output from an integrator or summary component. Choose the optimization function well as this value will drive the optimization process.

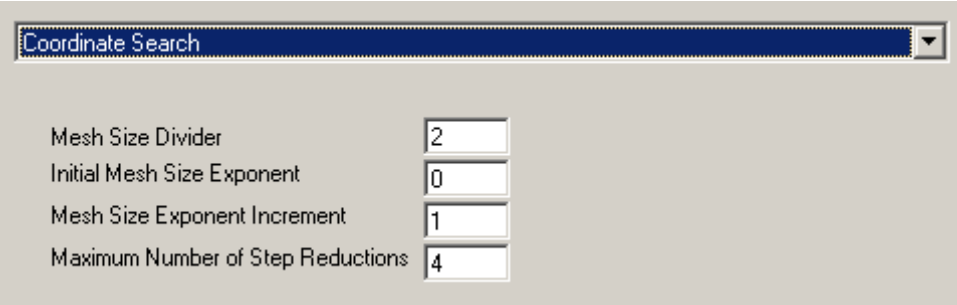
Choosing Optimization Settings:

There are two general settings for optimization. The first is the maximum number of iterations. If the program reaches this number of iterations it terminates with an error message. The second is the number of times that the objective function returns the same value before the program terminates.



Selecting an Optimization Method:

Pressing the "Select Optimization Method" button will open a window allowing the selection of the optimization method to be used. All of the methods available in GenOpt can be use in TrnOpt. However, the choices may be limited by the number and type of variables selected for optimization. The method to be used is selected with the drop-down box at the top of the screen. The optimization parameters that need to be entered for the selected method are then displayed in the screen. For example, if the Coordinate Search method is selected the screen will look like below:



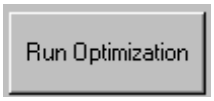
A complete description of the methods available and the parameters that are required of the different methods is contained in the GenOpt documentation and is not repeated here.

Saving your Optimization File:

If you wish to save the settings for the optimization, use the ***Save*** or ***Save As*** options located under the ***File*** menu in TRNOPT. By default, TRNOPT saves and opens files with a .TOP extension.

Starting the Optimization Process:

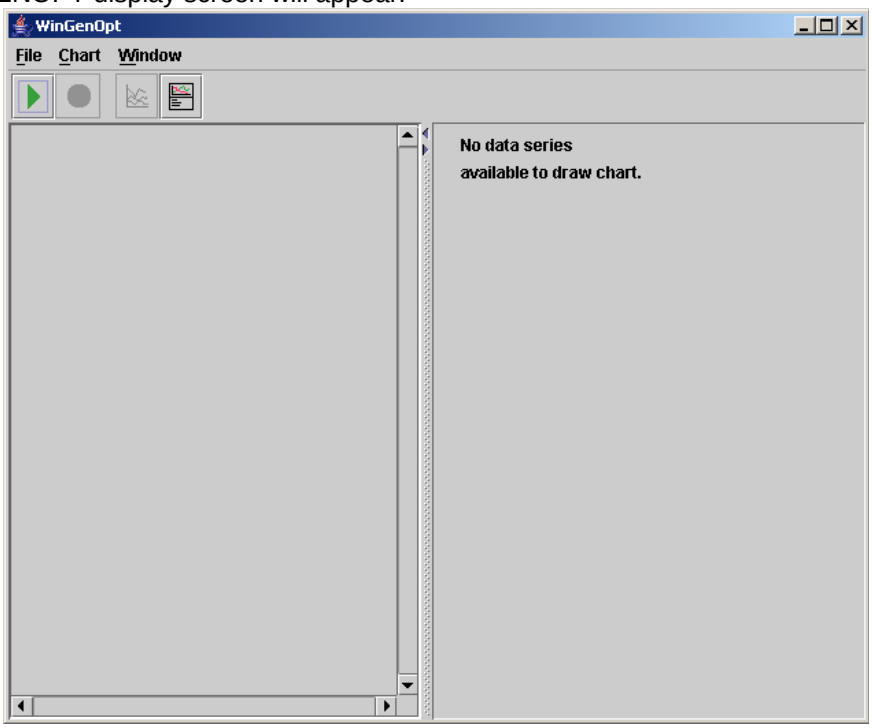
When all the information has been supplied to the program, choose the "Run Optimization" button at the bottom of the program.



TRNOPT will write a new TRNSYS template file for GENOPT (by default this file is ***TRNSYS16_1\Optimization\Genopt\Simulation\Template.dck***) by echoing the current input file and adding some new lines to the file. This new input file tells GENOPT which variables are to be optimized, and also has a specification for the TYPE 758 printer. This printer will write the end-of-simulation results to a specific file which is picked up by GenOpt after each run. Type 758 is contained in a DLL (TESSOptimizationLibrary_ReleaseVersion204.dll) which was placed in the ***TRNSYS16_1\UserLib*** subdirectory when installing the TRNOPT program. TRNOPT then creates several files required by GENOPT for the configuration of TRNSYS, calls the GENOPT program, and then quits. Just before quitting the TRNOPT program will give some last-minute instructions on how to choose the TRNSYS initialization file for GENOPT and how to begin the optimization process.

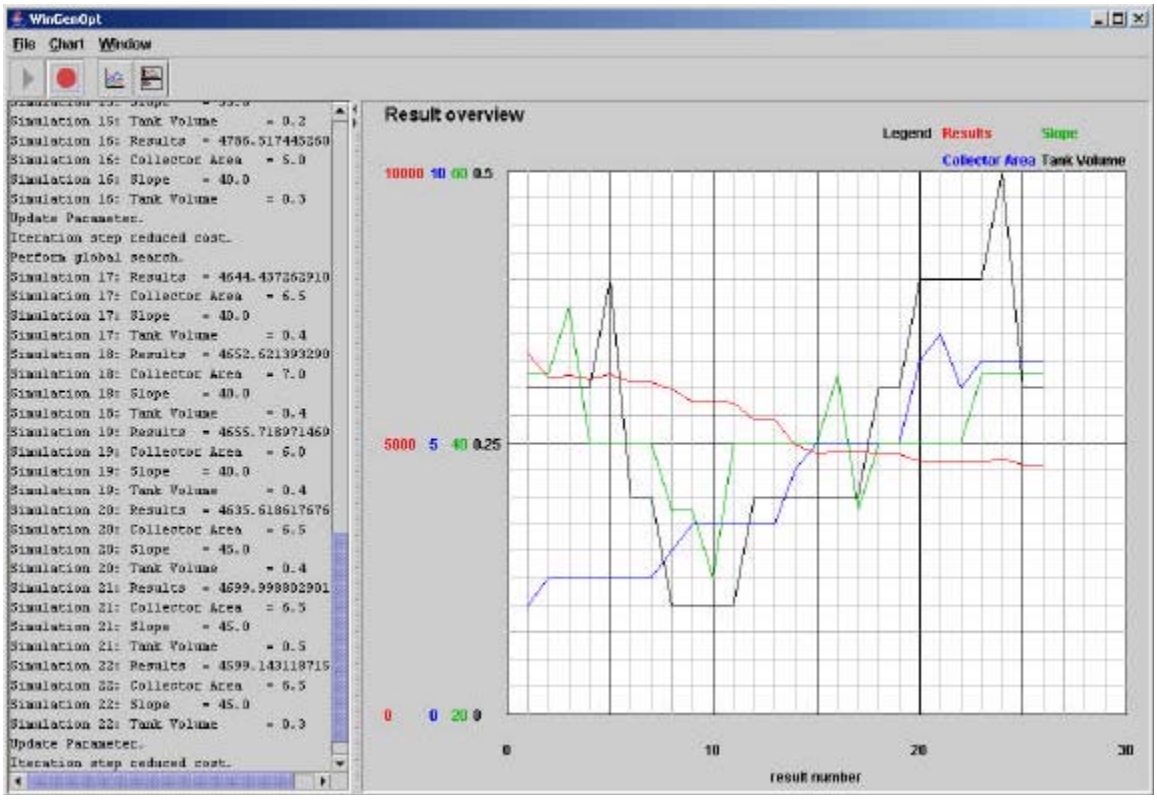


If the directory settings have been successfully entered into TRNOPT, the GENOPT program will start and the main GENOPT display screen will appear.



After the initialization file has been loaded, GENOPT will retrieve the template input file written by TRNOPTand create a TRNSYS input file with the initial values of the optimization variables as the first simulation to be run. The GENOPT program will attempt to call the TRNSYS executable program with the new input file. If errors appear or the program does not run check the ***GENOPT.log*** file (in the ***TRNSYS16_1\Optimization\GenOpt\Configuration*** directory by default) and the TRNSYS list file ***TRNGEN.LST*** (in the ***TRNSYS16_1\Optimization\Simulation*** directory by default) for sources of the problem.

If there are no problems, GENOPT will wait for TRNSYS to finish, evaluate the results from the TRNSYS error file (***TRNSYS16_1\Optimization\GenOpt\Simulation\TRNGEN.OUT*** by default), make a guess as to a better parameter set and repeat the process until the error function converges to the user-specified tolerance. Along the way the user should notice a plot of the optimized variables and the results of the error function in GENOPT's plot window.



Review the Results:

When the optimization process has finished, the program will display the minimum value of the error function that it has found. Note – this may NOT be the minimum value of the error. There are times when an optimization program can get stuck in local “minima” and not find the global minimum. Users are encouraged to re-try the optimization with a different initial point to see if a similar answer is obtained. GENOPT creates two files that contain the results from the analysis; ***OutputListingAll.txt*** and ***OutputListingMain.txt***. Both of these files are located in the ***TRNSYS16_1\Optimization\GenOpt\Configuration*** directory by default. These file contain a synopsis of the runs that were made, the results that were found, and the steps that were taken in the optimization process.

Hints for Users:

1. Turn Off the Online Plotter and Completion Display Indicator in TRNSYS so that the TRNSYS program runs in the background and does not keep taking control every time a new iteration begins.

2. To Maximize results instead of Minimize results, simply create an equation in the TRNSYS input file that subtracts the minimized function from a large number.

3. The user should generate the input file from the project just before starting TRNOPT such that the latest changes to the project are contained in the input file.

4. Provide reasonable initial values and ranges for the variables. For example, allowing the collector area to go below zero will cause a TRNSYS error and the optimization process will be halted.

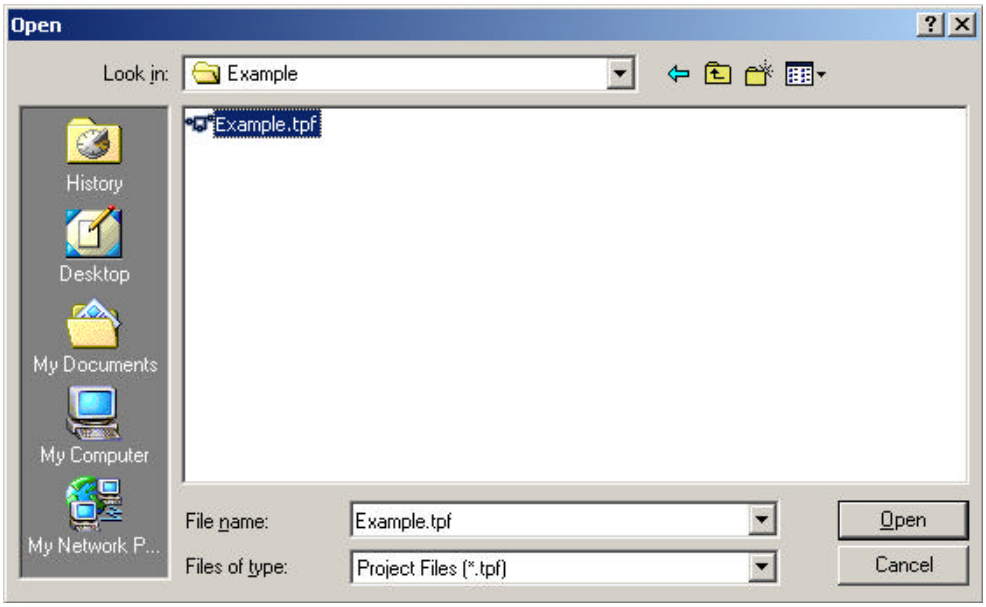
5. The user must provide simple equations (ie A=10) in the input file for the variables that will be used in the optimization process. These simple equations should then be used throughout the simulation where appropriate as parameters and constant inputs through the use of the 'string' variable type.



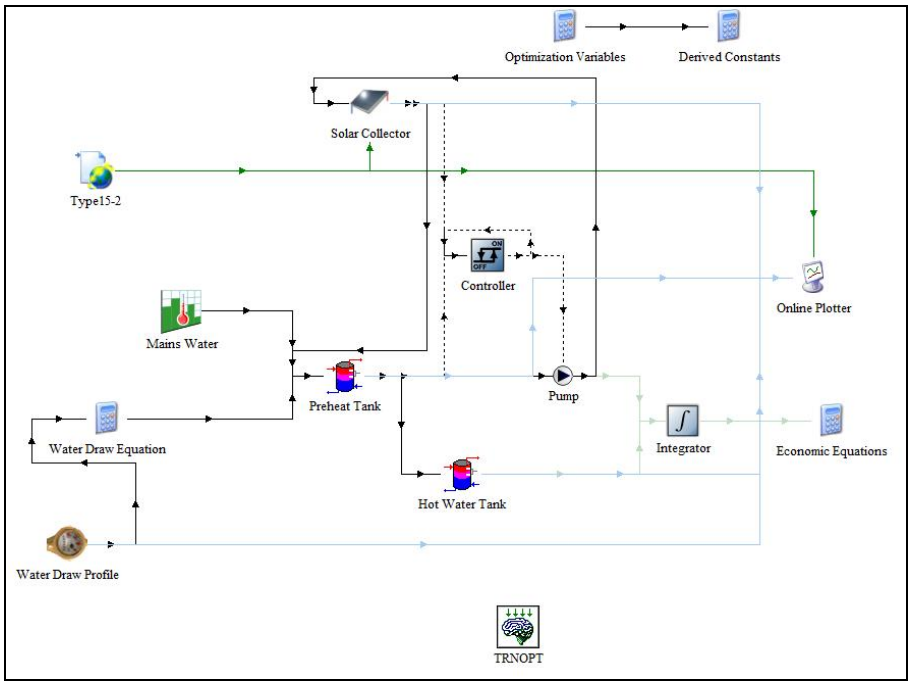
Example

To illustrate the use of the TRNOPT program, a simple example is provided. While the user could run this example without using the simulation studio at all, the authors felt that the majority of users will utilize the studio program for the creation of their simulations. For this reason, the example will utilize the simulation studio.

To begin the example, locate and open the TRNOPT example project. By default, this project will be contained in the TRNSYS16_1\Optimization\Example directory and is titled “Example.tpf”.



The example project will be loaded and the system should be displayed on the screen similar to the figure shown below.



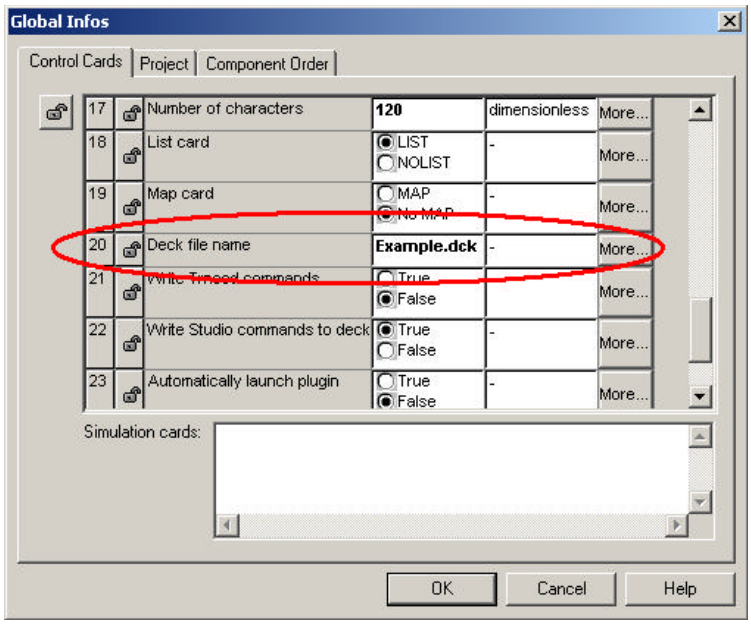
This example illustrates the optimization process for a two-tank solar domestic hot water system in Boulder, Colorado. In this example, the size and slope of the collector array and the size of the preheat storage tank will be manipulated to find the lowest life cycle cost for the system. Larger collector areas and tank sizes will reduce the consumption of the auxiliary heaters located in the hot water tank (and therefore the operating cost), but the savings are contrasted by the higher first costs of the collector and the preheat tank. Please take a minute and review the models and the system information provided below.

 Optimization Variables	These equations are used to set the values of the collector area (AREA_COLL), the preheat storage tank size (VOL_TANK) and the slope (SLOPE) of the solar collector. These variables are used in the parameters for the solar collector model, the radiation processor model, and the storage tank model. TRNOPT will use these variables to drive the simulations towards the minimum 20-year simple cost.
 Derived Constants	This equation block calculates the flow rate for the collector pump based on the current size of the collector.
 Type15-2	TMY 2 Weather information for Boulder, Colorado is being used to drive the simulations. The Type 15 radiation processor calculates the available solar radiation on the plane of a fixed-surface collector with a slope governed by the optimization algorithm (constant for each run) and facing due south.
 Solar Collector	A flat plate solar collector is utilized for the heat source. Representative parameters for a single-cover collector are used in the model.
 Controller	A differential controller is used to turn on the pumps when the collector outlet temperature is 10 C hotter than the bottom of the preheat storage tank. The pump is disabled if the collector outlet temperature falls to only 2 C above the bottom of the preheat storage tank or if the storage tank approaches 100 C.
 Pump	A constant speed pump model provides working fluid to the solar collector and the preheat storage tank. The flow rate of fluid is controlled to be relative to the size of the collector array; thereby providing a constant flow rate per unit collector area.
 Mains Water	A forcing function model is used to provide time-varying mains water temperature to the storage tanks (make- up water). The forcing function is based on published values of monthly mains water temperature.
 Water Draw Profile	A forcing function model is used to provide a schedule of daily hot water consumption. The schedule is based on an hourly distribution totaling 64 gallons per day.

 Water Draw Equation	This equation converts gallons per hour to kilograms per hour of water draw.
 Preheat Tank	This constant volume storage tank acts as the preheat tank for the 2-tank system. Thermal losses are assumed to be uniform over the tank and there are no auxiliary heating devices. Cold mains water enters at the bottom of the storage tank and flows out of the top of the storage tank to the second tank. Warm collector fluid enters at the top of the preheat tank and exits at the bottom of the tank for its return to the collector array.
 Hot Water Tank	This constant volume storage tank acts as the hot tank for the 2-tank system. Thermal losses are assumed to be uniform over the tank and there are 2 auxiliary heating devices. The first auxiliary heater is a 4.5 kW heating element controlled to keep the top half of the tank at 55 C. The second auxiliary heater is a 4.5 kW heating element controlled to keep the bottom half of the storage tank at 45 C. Warm water from the top of the preheat storage tank enters at the bottom of the tank and flows out of the top of the storage tank in order to meet the hot water load.
 Integrator	This component integrates the energy consumption of the pump and the auxiliary heaters in the hot storage tank and provides them to the economic calculations.
 Economic Equations	This equation block provides the first cost information for the collectors ($/ square meter) and for the preheat storage tank ($/cubic meter). The electric utility rate and life of the equipment is also provided. Finally the equation block calculates the simple life-cycle cost of the solar collector system (COST_SOLAR).
 Online Plotter	Plots the system temperatures and hot water load flow rate as a function of time.
 TRNOPT	Provides a method of launching TRNOPT from Simulation Studio through the use of the plug- in feature.

When you are comfortable with the system being studied, click on the “Write Input File” button  in the studio such that the latest system information is represented in the text input file.

The studio will then generate an input file; the location of this input file is dictated by the information in the TRNSYS control cards. The control cards can be accessed by pressing the “Control Cards” button .

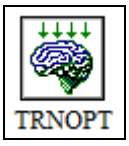


Unless the full path information is provided, the input file is written to the directory containing the project file. By default the input file

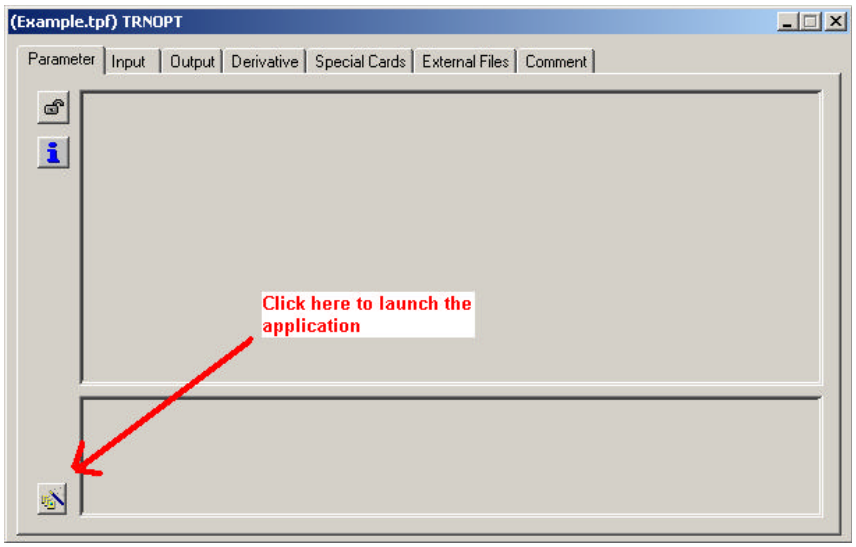
“ TRNSYS16_1\Optimization\Example\Example.dck”

will be written.

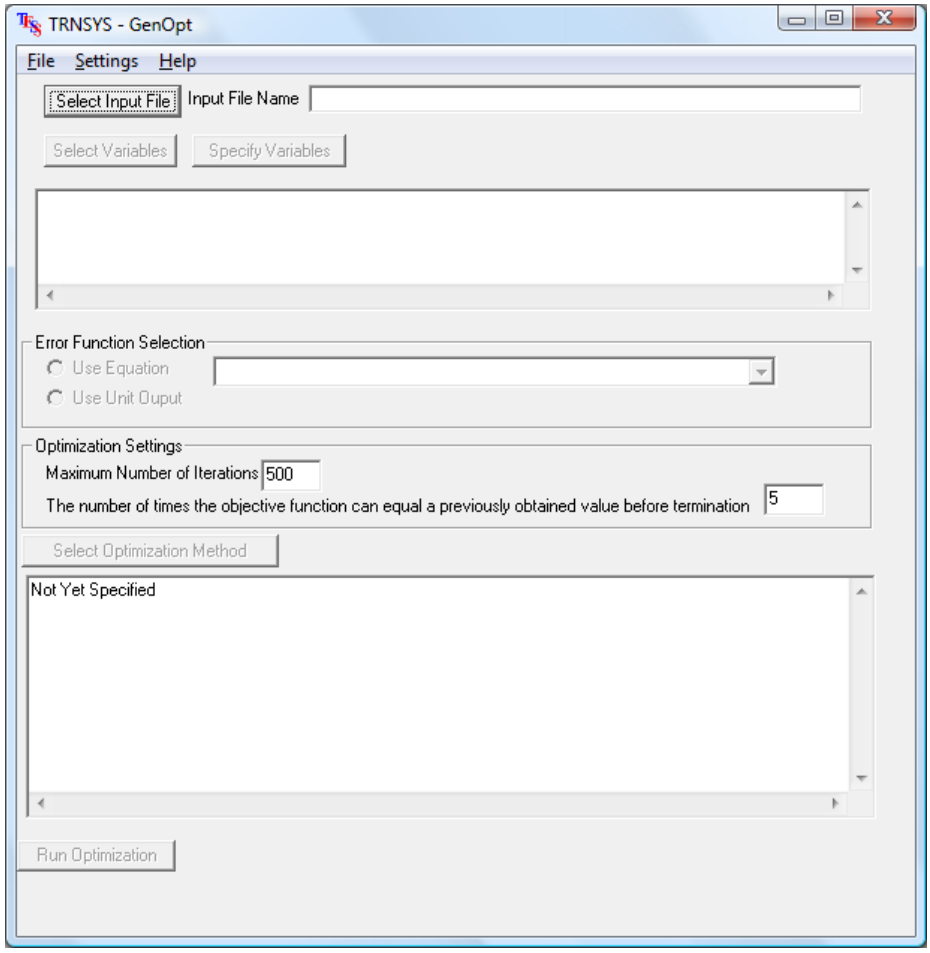
Double-click on the TRNOPT icon located in the project.



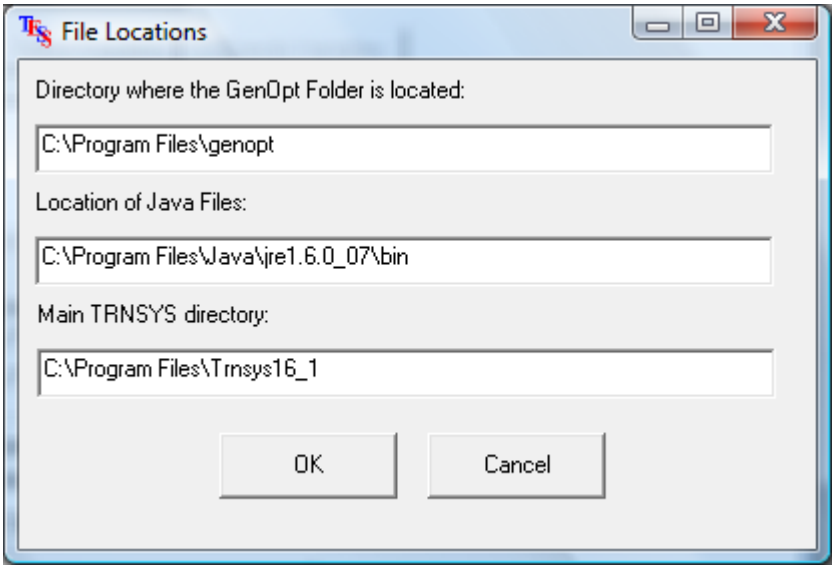
Depending on your settings, the TRNOPT program will either be automatically launched, or the proforma for the TRNOPT model will be displayed. If the TRNOPT application is not automatically launched, simply click on the “plug- in” icon located on the parameters tab of the proforma window to launch the application.



When properly launched, the application should look similar to the figure shown below.



Check to make sure the “Settings” are properly set for your application. Refer to earlier sections of this document for information on setting these values. Default values are shown below.

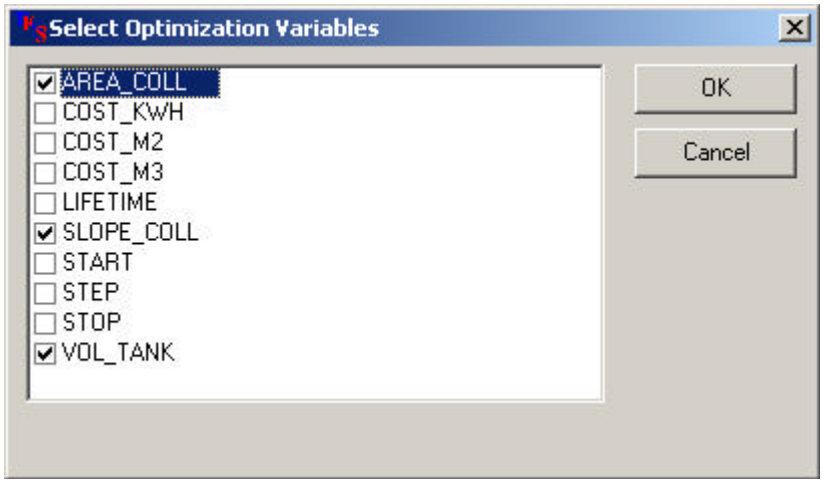


Pressing the "Select Input File" button will open a browse window allowing the selection of any TRNSYS input file or TRNSED file that the user wishes to optimize. Browse to the desired file and double-click on the file or highlight the file and click on the “Open” button. For this example, the input file by default is:

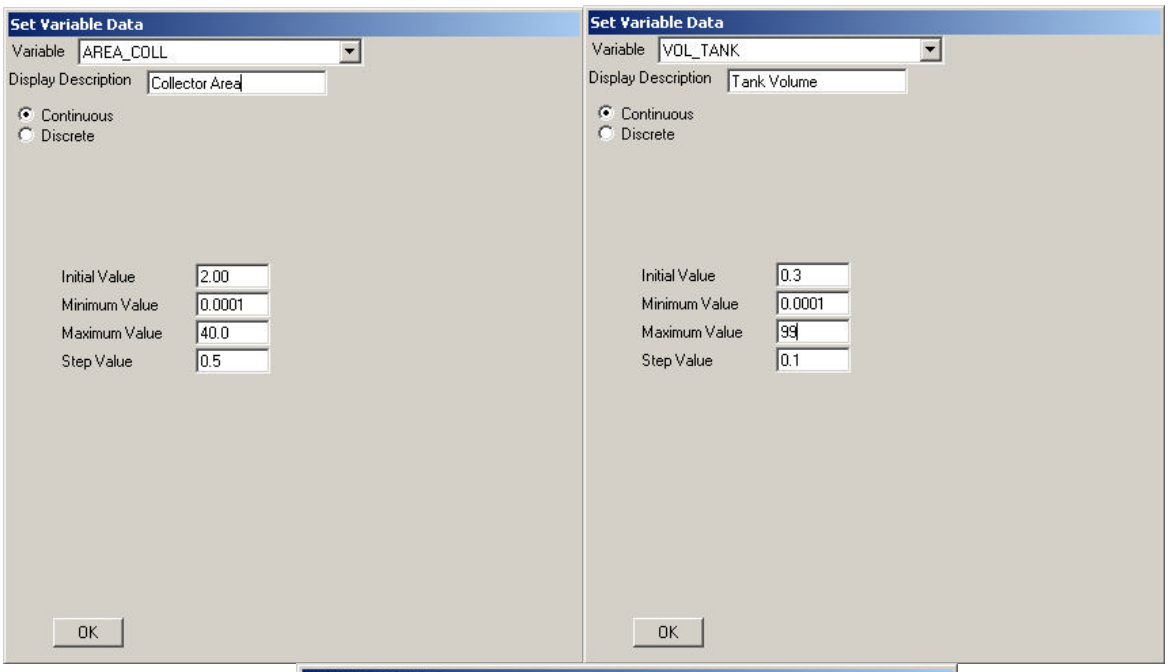
TRNSYS16_1\Optimization\Example\Example.dck

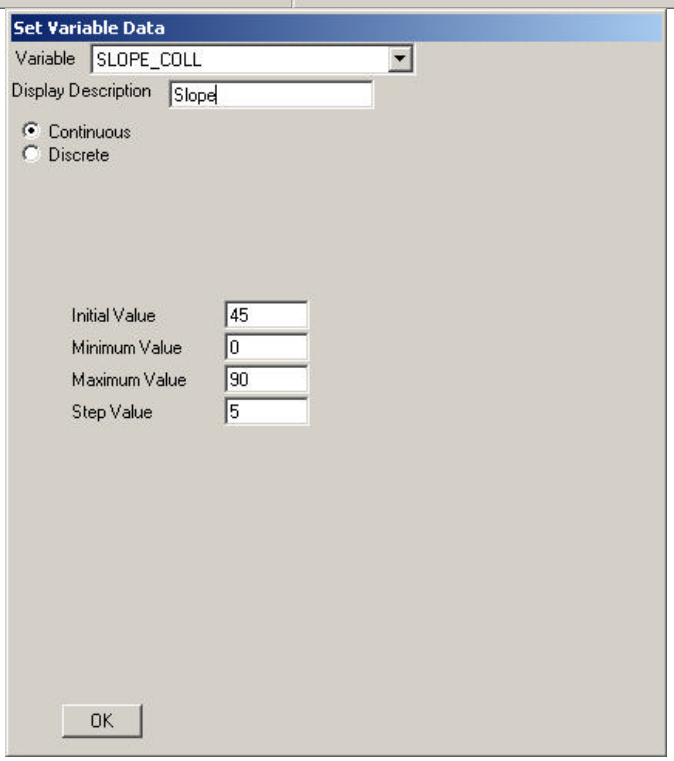


Once the input file has been chosen, use the "Select Variables" button to choose which TRNSYS variables will be adjusted in subsequent simulations in order to optimize the results. Select a variable by clicking with the mouse on the box next to the variable name so that a check- mark appears next to the name. Clicking again on the variable box will deselect that variable. For this example, select the collector area, the tank volume and the slope of the collector. Click the OK button to continue.

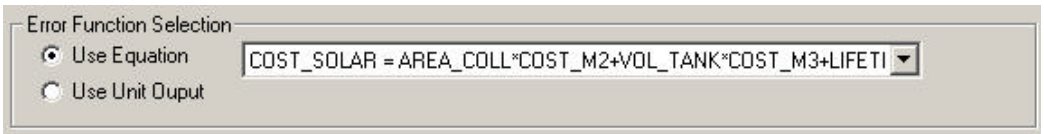


Once the optimization variables have been chosen, use the "Specify Variables" button to set the variable data used in the optimization. To specify a variable first select the variable from the drop-down box at the top of the screen. A short descriptive name for the variable can be entered in the “Display Description” box just below the selected variable name. This description is used in the GenOpt plot window as the simulation progress. For this example, we’ll assume that the tank size, collector area, and collector slope are continuous variables (infinitely adjustable in size). In reality the size of the collectors and tanks may be limited to commonly available sizes and discrete variable could then be used. We’ll limit the collector size between 0.0001 square meters and 40 square meters, the tank volume between 0.001 and 99 cubic meters, and the collector slope between horizontal and vertical in order to bound our results. Set up the three variables as shown below:

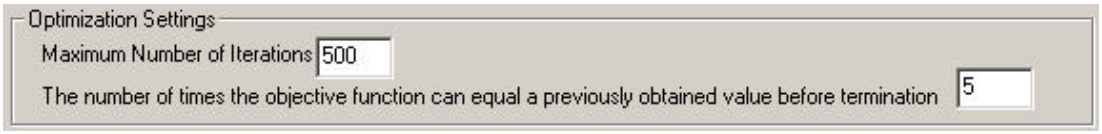




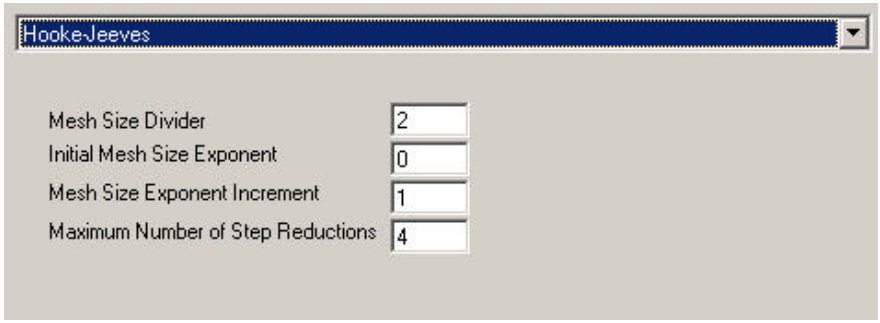
Use the radio buttons to select which type of output from the simulation will be minimized during the optimization process. For this example, the simple life cycle cost is calculated by an equation and we'll use this equation as our error function. Browse to the correct equation in the input file such that your screen matches the figure below.



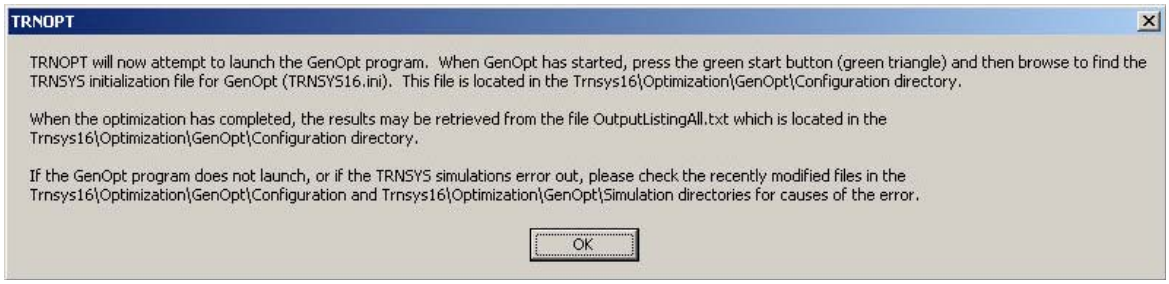
There are two general settings for optimization but we'll leave these to their default settings.



Pressing the "Select Optimization Method" button will open a window allowing the selection of the optimization method to be used. For this example we'll choose the popular Hooke-Jeeves algorithm which optimizes only continuous variables. We'll leave the default settings as they are appropriate for this example:



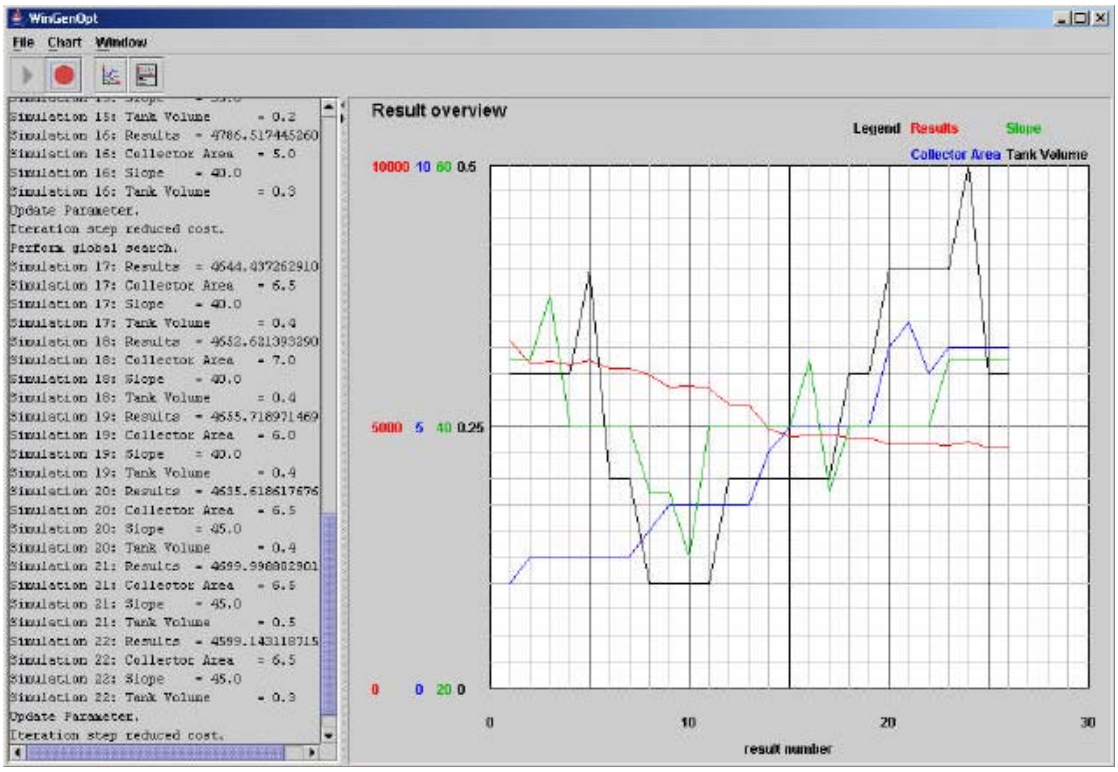
If you wish to save the settings for the optimization, use the ***Save*** or ***Save As*** options located under the ***File*** menu in TRNOPT. By default, TRNOPT saves and opens files with a .TOP extension. This example has already been saved (TRNSYS16_1\Optimization\Example\Example.top) but you may re-save your work if so desired.



If the directory settings have been successfully entered into TRNOPT, the GENOPT program will start and the main GENOPT display screen will appear.

After the initialization file has been loaded, GENOPT will retrieve the template input file written by TRNOPT and create a TRNSYS input file with the initial values of the optimization variables as the first simulation to be run. The GENOPT program will then attempt to call the TRNSYS executable program with the new input file. If errors appear or the program does not run check the ***GENOPT.log*** file (in the ***TRNSYS16_1\Optimization\GenOpt\Configuration*** directory by default) and the TRNSYS list file ***TRNGEN.LST*** (in the ***TRNSYS16_1\Optimization\Simulation*** directory by default) for sources of the problem.

If there are no problems, GENOPT will wait for TRNSYS to finish, evaluate the results from the TRNSYS error file (***TRNSYS16_1\Optimization\GenOpt\Simulation\TRNGEN.OUT*** by default), make a guess as to a better parameter set and repeat the process until the error function converges to the user-specified tolerance. Along the way the user should notice a plot of the optimized variables and the results of the error function in GENOPT's plot window.



When the optimization process has finished, the program will display the minimum value of the error function that it has found. Note – this may NOT be the minimum value of the error. There are times when an optimization program can get stuck in local “minima” and not find the global minimum. Users are encouraged to re-try the optimization with a different initial point to see if a similar answer is obtained.

Checking the OutputListingMain.txt file located in the ***TRNSYS16_1\Optimization\GenOpt\Configuration*** directory we find that the minimum simple life cycle cost of around $4600 was found with a collector area of 6.375 square meters (~69 sqft), a collector slope of 42.8 degrees (a value which is near the latitude which has been shown to be near optimal for DHW collection systems) and a tank volume of 0.2875 cubic meters (~76 gallons). So for this climate and application, a solar domestic hot water system of this size would return the lowest simple life cycle cost.

Contact Information/Technical Support

Purchasers of this TRNOPT program are entitled to one free calendar year of technical support (beginning with the purchase date) from T.E.S.S. If you have problems or comments on this program, please contact:

TRNSYS Coordinator
Thermal Energy System Specialists, LLC
2916 Marketplace Drive – Suite 104
Madison WI 53719 USA
Phone (CST) 1-608-274-2577
Fax 1-608-278-1475
E- mail techsupport@tess-inc.com

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