

# INTRODUCTION TO EES

## OVERVIEW

EES (pronounced 'ease') is an acronym for Engineering Equation Solver. The basic function provided by EES is the numerical solution of non-linear algebraic and differential equations. In addition, EES provides built-in thermodynamic and transport property functions for many fluids, including water, dry and moist air, refrigerants, combustion gases, and others. Additional property data can be added by the user. The combination of equation solving capability and engineering property data makes EES a very powerful tool.

A license for EES is provided to departments of educational institutions that adopt this McGraw-Hill text. If you need more information contact your local McGraw-Hill representative, call 1-800-338-3987, or visit the McGraw-Hill website at <http://www.mhhe.com>. A commercial or professional version of EES can be obtained from:

**F-Chart Software, LLC**


Box 44042

Madison, WI 53744

<http://fchart.com> email: [info@fchart.com](mailto:info@fchart.com)

## BACKGROUND INFORMATION

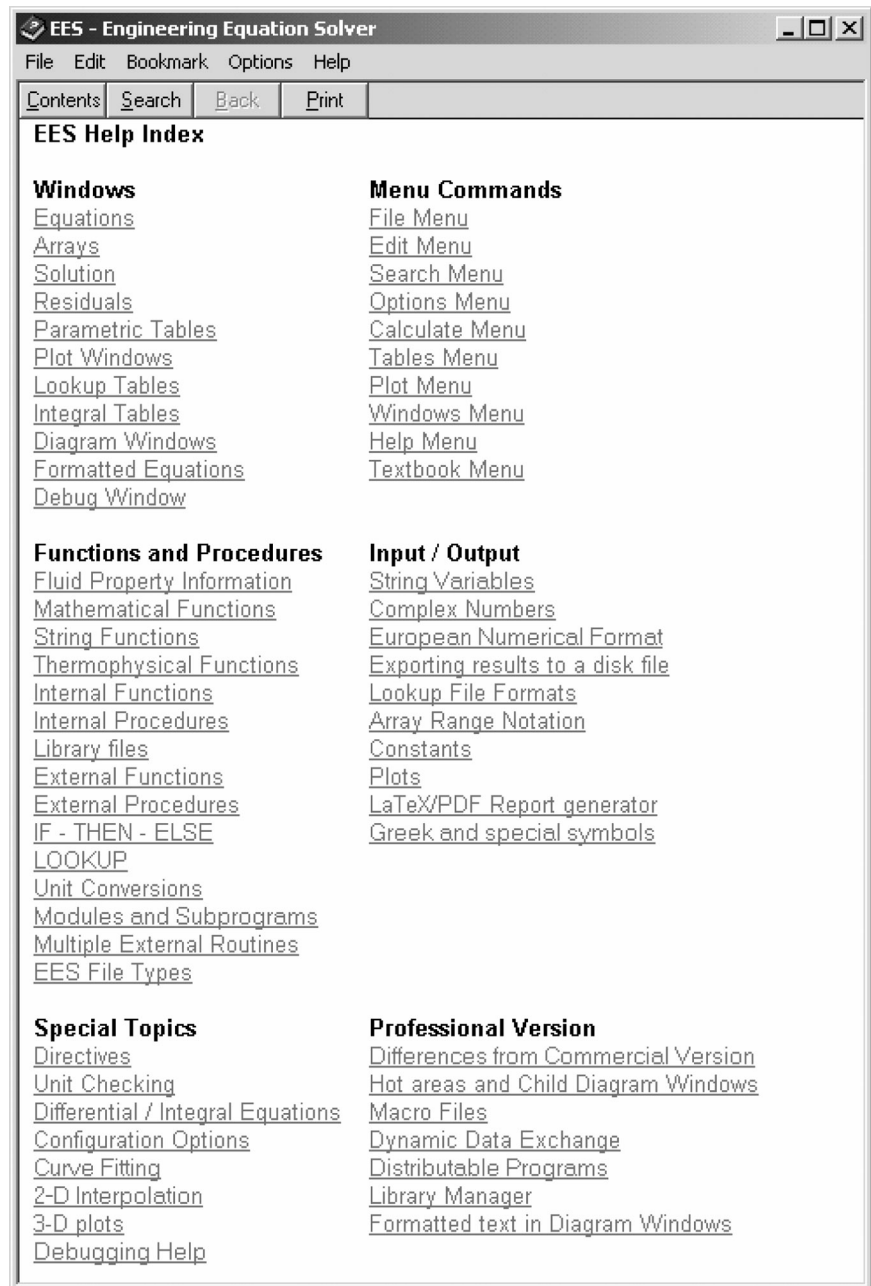
The EES program is probably installed on your departmental computer. In addition, the license agreement for use of EES allows students and faculty in a participating educational department to copy the program for educational use onto their personal computer systems. Ask your instructor for details.

 To start EES, double-click on the EES program icon shown above or on any file created by EES having the .EES filename extension. You can also start EES from the Windows Run command in the Start menu by entering EES clicking the OK button. EES begins by displaying a dialog window, which shows registration information, the version number and other information. Click the OK button to dismiss the dialog window.

Detailed help is available at any point in EES. Pressing the F1 key will bring up a Help window relating to the foremost window. Clicking the Contents button will present the Help index shown below. Clicking on an underlined word (shown in green on color monitors) will provide help relating to that subject.

EES commands are distributed among ten pull-down menus shown above. A brief summary of their functions follows.

The **S**ystem menu is accessible by clicking on the EES icon above the file menu. The System menu is not part of EES, but rather a feature of the



**EES Academic Version:**

File Edit Search Options Calculate Tables Plots Windows Help Heat Transfer

Windows Operating System. It holds commands which allow window moving, resizing, and switching to other applications. The **F i l e** menu provides commands for loading, merging and saving work files and libraries, and printing. The Load Textbook command in this menu

reads the problem disk developed for this text and creates a new menu to the right of the Help menu for easy access to EES problems accompanying this text.

The **Edit** menu provides the editing commands to cut, copy, and paste information.

The **Search** menu provides Find and Replace commands for use in the Equations window.

The **Options** menu provides commands for setting the guess values and bounds of variables, the unit system, default information, and program preferences. A command is also provided for displaying information on built-in and user-supplied functions.

The **Calculate** menu contains the commands to check, format and solve the equation set. A command to check the units of the equations is also provided.

The **Tables** menu contains commands to set up and alter the contents of the Parametric and Lookup Tables and to do linear regression on the data in these tables. The Parametric Table, which is similar to a spreadsheet, allows the equation set to be solved repeatedly while varying the values of one or more variables. The Lookup table holds user-supplied data which can be interpolated and used in the solution of the equation set.

The **Plot** menu provides commands to prepare a new plot of data in the Parametric, Lookup, Array or Integral tables or to modify an existing plot. Curve-fitting capability and thermodynamic property plots are also provided.

The **Windows** menu provides a convenient method of bringing any of the EES windows to the front or to organize the windows.

The **Help** menu provides commands for accessing the online help documentation.

The **Heat Transfer** menu provides access to EES solutions to problems in this text.

A basic capability provided by EES is the solution of a set of non-linear algebraic equations. To demonstrate this capability, start EES and enter this simple example problem in the Equations window.




Text is entered in the same manner as for any word processor. Formatting rules are as follows:

1. Upper and lower case letters are not distinguished. EES will (optionally) change the case of all variables to match the manner in which they first appear.
2. Blank lines and spaces may be entered as desired since they are ignored.
3. Comments must be enclosed within braces { } or within quote marks “ ”. Comments may span as many lines as needed. Comments within braces may be nested in which case only the outermost set of { } are recognized.

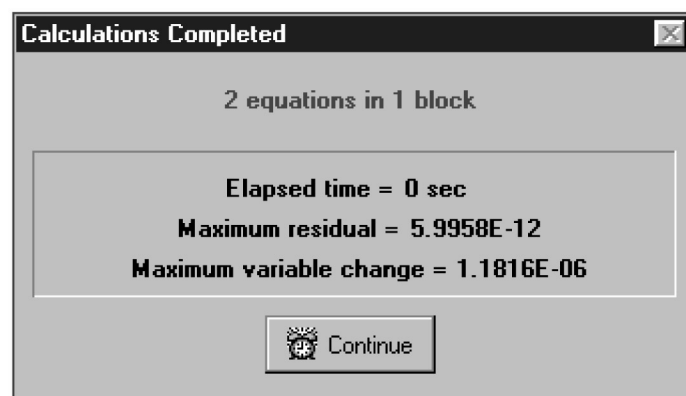
Comments within quotes will also be displayed in the Formatted Equations window.

4. Variable names must start with a letter and consist of any keyboard characters except ( ) | \* / + - ^ { } : " ' ; . Array variables are identified with square braces around the array index or indices, e.g., X[5,3]. The maximum variable length is 30 characters.
5. Multiple equations may be entered on one line if they are separated by a semi-colon (;).
6. The caret symbol (^) or \*\* is used to indicate raising to a power.
7. The order in which the equations are entered does not matter.
8. The position of known and unknown variables in the equation does not matter.

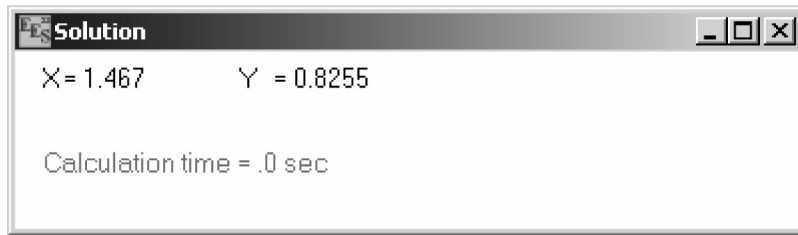
If you wish, you may view the equations in mathematical notation by selecting the **Formatted Equations** command from the **Windows** menu or from the **Formatted Equations** speed button located below the menu bar  or by pressing ctrl-F.



Select the **Solve** command from the **Calculate** menu or press F2. A dialog window will appear indicating the progress of the solution. When the calculations are completed, the button will change from Abort to Continue.



Click the Continue button. The solution to this equation set will then be displayed.



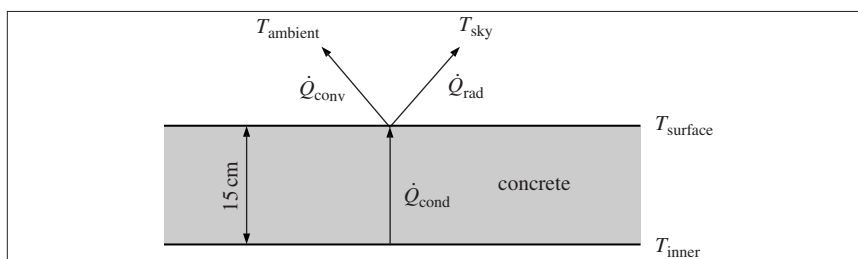
## AN EXAMPLE PROBLEM

In this section, Problem 1–104 from the text is worked from start to finish illustrating some of the capabilities of the EES program. EES is particularly appropriate for this problem since a trial-and-error solution would be required if the problem were done by hand. The problem to be solved is this.

The roof of a house consists of a 15-cm thick concrete slab ( $k = 2 \text{ W/m} \cdot ^\circ\text{C}$ ) that is 15 m wide and 20 m long. The emissivity of the outer surface of the roof is 0.9, and the convection heat transfer coefficient on that surface is estimated to be  $15 \text{ W/m}^2 \cdot ^\circ\text{C}$ . The inner surface of the roof is maintained at  $15^\circ\text{C}$ . On a clear winter night, the ambient air is reported to be at  $10^\circ\text{C}$  while the night sky temperature for radiation heat transfer is 255 K. Considering both radiation and convection heat transfer, determine the outer surface temperature and the rate of heat transfer through the roof.

If the house is heated by a furnace burning natural gas with an efficiency of 85 percent, and the unit cost of natural gas is  $\$0.60/\text{therm}$  (1 therm = 105,500 kJ of energy content), determine the money lost through the roof that night during a 14-hour period.

This problem involves conduction, convection and radiation. The problem is facilitated by an energy flow diagram.



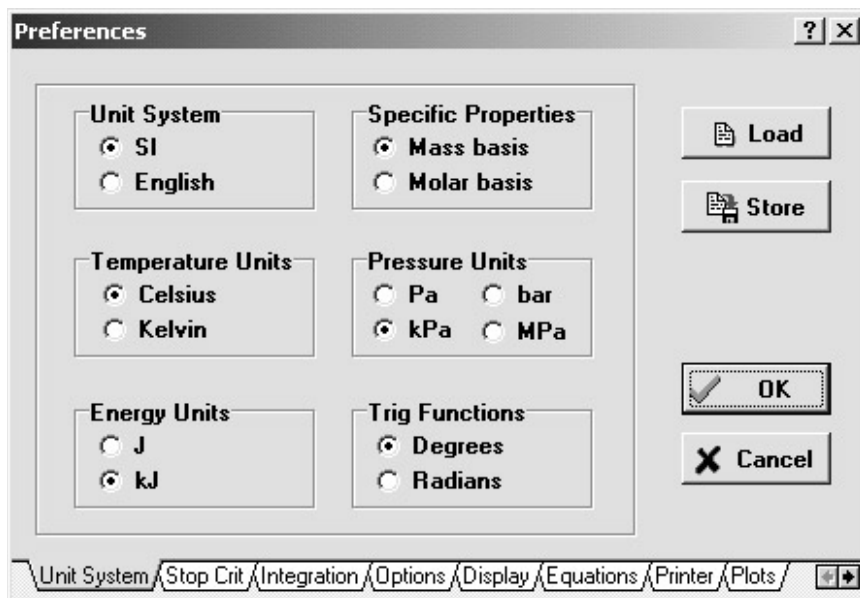
To solve this problem, it is necessary to equate the conduction heat transfer rate through the concrete roof to the combined convective and radiative heat transfer rates from the roof surface.

$$\begin{aligned}\dot{Q}_{\text{cond}} &= kA(T_{\text{inner}} - T_{\text{surface}})/L \\ \dot{Q}_{\text{conv}} &= hA(T_{\text{surface}} - T_{\text{ambient}}) \\ \dot{Q}_{\text{rad}} &= \sigma \varepsilon A(T_{\text{surface}}^4 - T_{\text{sky}}^4) \\ \dot{Q}_{\text{cond}} &= \dot{Q}_{\text{conv}} + \dot{Q}_{\text{rad}}\end{aligned}$$

- $A$  = roof area ( $\text{m}^2$ )  
 $k$  = thermal conductivity ( $\text{W}/\text{m} \cdot \text{K}$ )  
 $h$  = convection coefficient ( $\text{W}/\text{m}^2 \cdot \text{K}$ )  
 $T_{\text{inner}}$  = temperature of the inner surface of the roof (K)  
 $T_{\text{surface}}$  = temperature of the outer surface of the roof (K)  
 $T_{\text{ambient}}$  = temperature of the outdoor air (K)  
 $T_{\text{sky}}$  = effective radiative temperature of the sky (K)  
 $\sigma$  = Stefan-Boltzman constant ( $5.67 \times 10^{-8} \text{W}/\text{m}^2 \cdot \text{K}^4$ )  
 $\varepsilon$  = emissivity of the roof surface  
 $L$  = the thickness of the concrete slab (m)

There are a total of 13 variables in this problem. Of these, 9 ( $A$ ,  $k$ ,  $h$ ,  $T_{\text{inner}}$ ,  $T_{\text{ambient}}$ ,  $L$ ,  $T_{\text{sky}}$ ,  $\sigma$ , and  $\varepsilon$ ) are specified in the problem statement, leaving 4 unknown variables. There are four equations relating these variables, so that the problem is completely specified. However, the equations are nonlinear and as a result, cumbersome to solve. This is where EES can help.

Start EES or select the **New** command from the **File** menu if you have already been using the program. A blank Equations window will appear. Since this problem does not require any of the thermophysical property functions built into EES, it is not necessary to specify the unit system. However, it is good practice to set the unit system at the start of a problem with the **Unit System** command in the **Options** menu.



The equations can now be entered into the Equations window. Formatting rules were discussed earlier in this appendix. After entering the equations for this problem and (optionally) checking the syntax using the **Check/Format** command in the Calculate menu, the Equations window will appear as shown. Comments (within quotes) are normally displayed in blue on a color monitor. Other formatting options are set with the **Preferences**

```

"Problem 1-108 from Heat Transfer: A Practical Approach by Cengel, 2nd edition"

Roof_width=15           "[m]"
Roof_length=20          "[m]"
A=Roof_width*Roof_length "[m^2] area of the roof"
Thickness=0.15          "[m] slab thickness"
k=2                     "[W/m-K]"
h=15                    "[W/m^2-K]"
T_inner=15+273.1        "[K] temperature on the underside of the roof"
T_ambient=10+273.1     "[K] ambient temperature"
T_sky=255               "[K] equivalent sky radiation temperature"
Q_dot_cond=k*A/Thickness*(T_inner-T_surface) "[W] heat transfer rate through concrete"
Q_dot_conv=h*A*(T_surface-T_ambient)         "[W] convective heat transfer rate to ambient"
Q_dot_rad=sigma*epsilon*A*(T_surface^4-T_sky^4) "[W] radiative heat transfer rate to sky"
Q_dot_cond=Q_dot_conv+Q_dot_rad              "[W] total heat transfer rate"
sigma=5.67e-8                               "[W/m^2-K^4] Stefan-Boltzman constant"
epsilon=0.90                                 "emissivity of roof surface"
Time=14                                       "[hr] time period of analysis"
Efficiency=0.85                               "furnace efficiency"
Therms=Q_dot_cond/Efficiency*Time*convert(W-hr,therms) "[therms] required energy for heating"
FuelCost=0.60                                "$/therm fuel cost"
Cost=Therms*FuelCost                         "$ Cost of heating"

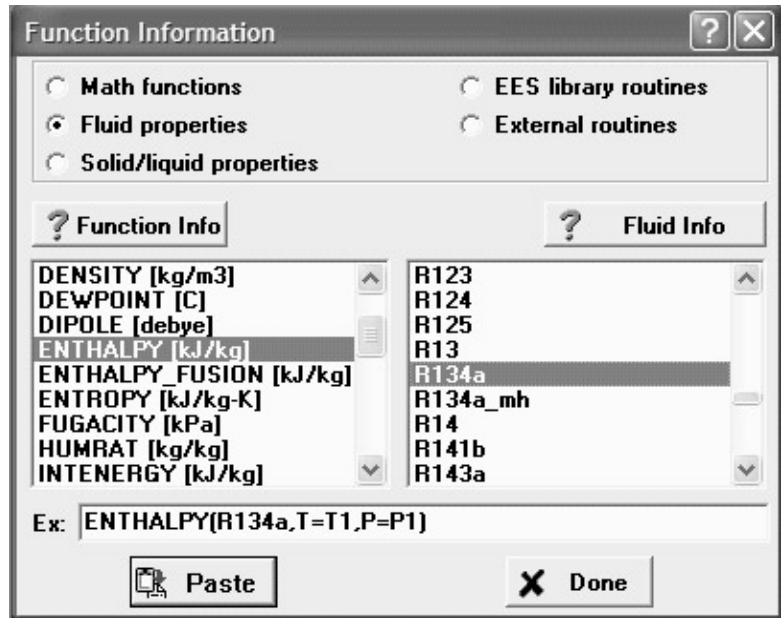
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command in the **Options** menu. Note that the \$TabStops directive has been used here to set tabs so that the comments are lined up.

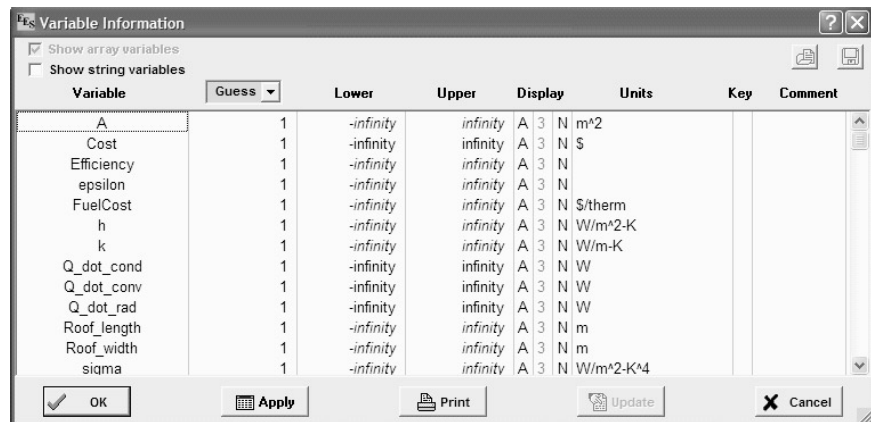
Many of the variable names include an underscore. The underscore is a special formatting character that indicates the start of a subscript. Using underscores is optional, but it improves the display of the Formatted Equations and Solutions window. Note that the units of many of the numerical constants are specified in square braces following the numerical value. The units of each variable can also be specified in the Solution window and with the **Variable Information** command in the **Options** menu. Specifying the units of each variable is very important since it allows EES to check the equations for unit consistency.

Two built-in functions have been used in this problem and they are **ConvertTemp** and **Convert** functions. The **Convert** function should be able to provide any unit conversions you encounter while **ConvertTemp** function is used to convert temperature units. There are many other useful functions in EES, including functions that provide thermodynamic and transport property data. An easy way to enter functions, without needing to recall the format, is to use the **Function Information** command in the **Options** menu. This command will bring up the dialog window as shown. Click on the "Fluid properties" radio button. The list of built-in fluid property function will appear on the left with the list of substances on the right. Select the property function by clicking on its name, using the scroll bar, if necessary, to bring it into view. Select a substance in the same manner. An example of the function showing the format will appear in the Example rectangle at the bottom. The information in the rectangle may be changed, if needed. Clicking the Paste button copies the Example into the Equations window at the cursor position.

It is usually a good idea to set the guess values and (possibly) the lower and upper bounds for the variables before attempting to solve the equations. This is done with the **Variable Information** command in the **Options** menu. Before displaying the Variable Information dialog, EES checks syntax and compiles newly entered and/or changed equations, and then solves all equations with one unknown. The Variable Information dialog will then appear.



The **Variable Information** dialog contains a line for each variable appearing in the Equations window. By default, each variable has a guess value of 1.0 with lower and upper bounds of negative and positive infinity. (The lower and upper bounds are shown in italics if EES has previously calculated the value of the variable. In this case, the Guess value column displays the calculated value. These italicized values can still be edited.)



With nonlinear equations, it is sometimes necessary to provide reasonable guess values and bounds in order to determine the desired solution. (It is not necessary for this problem.) The bounds of some variables are known from the physics of the problem. In this example problem, the roof surface temperature should be between 255 and 285 K. It would be a good practice to set the guess value for T\_surface to something reasonable, for example, 270 K.

The A in the Display options column indicates that EES will automatically determine the display format for numerical value of the variable when it is



displayed in the Solution window. In this case, EES will select an appropriate number of digits, so the digits column to the right of the A is disabled. Automatic formatting is the default. Alternative display options are F (for fixed number of digits to the right of the decimal point) and E (for exponential format). The display and other defaults can easily be changed with the **Default information** command in the **Options** menu. The third Display options column controls the highlighting effects such as normal (default), bold, and boxed. The Units column shows the units assigned to the variable. The units that were specified in comments in the Equations window will appear here. Units can be modified or entered. However, the units set with comments in the Equations window will override the specifications made in the Variable Information dialog. The units will be displayed with the variable in the Solution window and in the Parametric Table. EES does not automatically do unit conversions but it does provide automatic unit consistency checking. Unit errors are frequently the cause of an incorrect solution, so the unit-checking capability is quite important. Variables can be designated as key variables by clicking in the Key column. Key variables will display in a separate Solution window. The final column provides an optional comment for each variable.

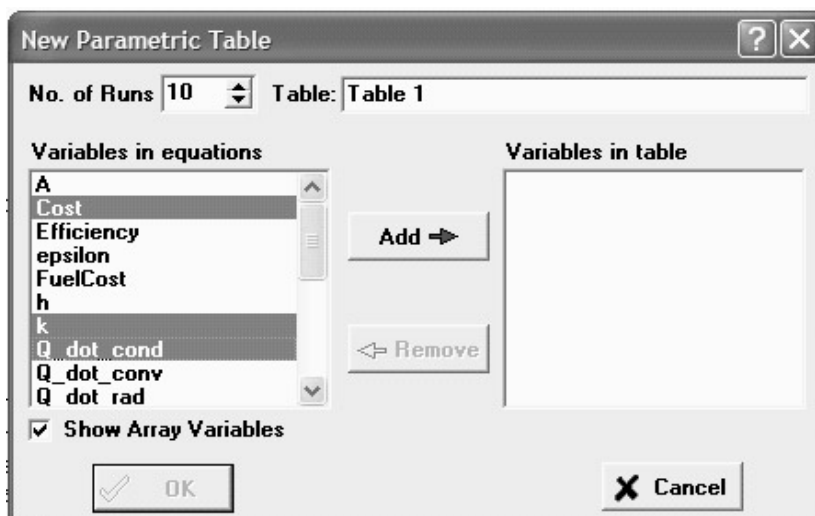
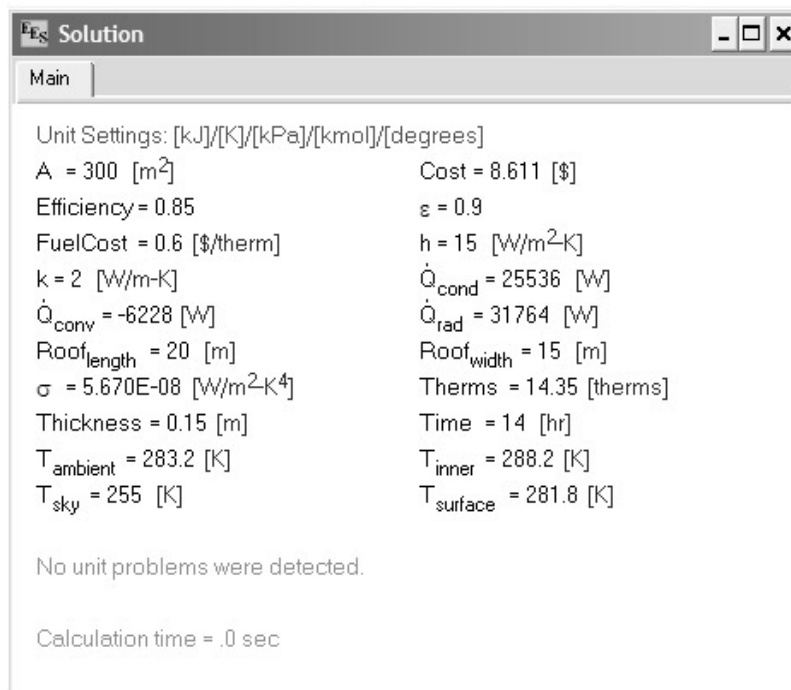
To solve the equation set, select the **Solve** command from the **Calculate** menu and the Solution window will appear. The problem is now completed since the values of T\_surface, Q\_dot\_cond, and Cost are determined. If the Check Units Automatically control in the **Preferences** dialog (**Options** menu) is checked, EES also checks the unit consistency of the equations as it solves them and reports the results in the Solution window. The units, in addition to format information such as the number of significant figures that are displayed, can be entered by clicking the right mouse button (or double-clicking the left mouse button) on the variable name in the Solution Window. If units have not been set for a variable, EES will try to determine the units and will display these units in purple in Solutions Window.


An interesting and unexpected result is evident in the solution. Because of the low sky temperature, the radiant losses cause the roof surface temperature to be lower than the ambient temperature and thus the roof is actually warmed by the convection from the air.

One of the most useful features of EES is its ability to provide parametric studies. For example, in this problem, it may be of interest to see how the heating cost varies with thermal conductivity of the roof material. A series of calculations can be automated and plotted in EES.

Select the **New Parametric Table** command in the Tables menu. A dialog will be displayed listing the variables appearing in the Equations window. In this case, we will construct a table containing the variables k, Q\_dot\_cond, and Cost. Click on k from the variable list on the left. This will cause k to be highlighted and the Add button will become active. Repeat for Q\_dot\_cond and Cost, using the scroll bar to bring the variable into view if necessary. As a short cut, you can double-click on the variable name in the list on the left to move it to the list on the right. You can also select multiple variables at one time. The table setup dialog should now appear as shown. Click the Add button to move the selected variables into the list on the right and then click the OK button to create the table.

The Parametric Table works much like a spreadsheet. You can type numbers directly into the cells. Numbers that you enter are shown in black and produce



the same effect as if you set the variable to that value with an equation in the Equations window. Delete the  $k = 2$  [W/m-K] equation currently in the Equations window or enclose it in comment brackets { }. This equation will not be needed because the value of  $k$  will be set in the table. Now enter values of  $k$  in the table for which  $Q_{dot\_cond}$  and  $Cost$  are to be determined. Values of  $k$  between 2 to 0.2 have been chosen for this example. (The values could also be automatically entered using Alter Values in the Tables menu or by using the Alter Values control  at the upper right of each table column header.) The Parametric Table should now appear as shown.

▶ 1..10	1 Cost [\$]	2 k [W/m-K]	3 $\dot{Q}_{\text{cond}}$ [W]
Run 1		2	
Run 2		1.8	
Run 3		1.6	
Run 4		1.4	
Run 5		1.2	
Run 6		1	
Run 7		0.8	
Run 8		0.6	
Run 9		0.4	
Run 10		0.2	

Now, select **Solve Table** from the **Calculate** menu. The Solve Table dialog window will appear, allowing you to choose the runs for which calculations will be done.

When the Update Guess Values control is selected, as shown, the solution for the last run will provide guess values for the current run. Click the OK button. A status window will be displayed, indicating the progress of the solution. When the calculations are completed, the calculated values of  $\dot{Q}_{\text{cond}}$  and Cost will be entered into the table. The values calculated by EES will be displayed in blue, bold, or italic type depending on the setting made in the Screen Display tab of the **Preferences** dialog window in the **Options** menu.

The relationship between variables such as Cost and  $k$  is now apparent, but it can more clearly be seen with a plot. Select **New Plot Window** from the **Plot** menu. The New Plot Setup dialog window shown will appear.

**Solve Table**

Table: Table 1

First Run Number: 1

Last Run Number: 10

Update guess values

Stop if error occurs

Use input from Diagram

Show unit checking warnings

Solve in reverse order

OK

Cancel

Choose  $k$  to be the X-axis by clicking on  $k$  in the X-axis list. Click on Cost in the Y-axis list. You may wish to adjust the scale limits or add grid lines. When you click the OK button, the plot will be constructed and the plot window will appear as shown.

Once created, there are a variety of ways in which the appearance of the plot can be changed. Double-click the mouse in the plot rectangle or on the plot

EES Parametric Table

▶ 1..10	<sup>1</sup> Cost [ \$ ]	<sup>2</sup> $k$ [ W/m-K ]	<sup>3</sup> $\dot{Q}_{cond}$ [ W ]
Run 1	8.611	2	25536
Run 2	8.077	1.8	23953
Run 3	7.496	1.6	22231
Run 4	6.862	1.4	20351
Run 5	6.167	1.2	18289
Run 6	5.401	1	16018
Run 7	4.553	0.8	13503
Run 8	3.609	0.6	10703
Run 9	2.551	0.4	7566
Run 10	1.358	0.2	4026

New Plot Setup

Tab Name: Plot 1  Print Description with plot

Description:

**X-Axis**

Cost  
**k**  
Q\_dot\_cond

Format: A | 1

Minimum: 0.200

Maximum: 2.000

Interval: 0.200

Linear  Log

Grid lines

**Y-Axis**

Cost  
**k**  
Q\_dot\_cond

Format: A | 4

Minimum: 1.000

Maximum: 9.000

Interval: 1.000

Linear  Log

Grid lines

**Table**

Parametric Table

Table 1

First Run: 1

Last Run: 10

Spline fit

Automatic update

Add legend item

Show array indices

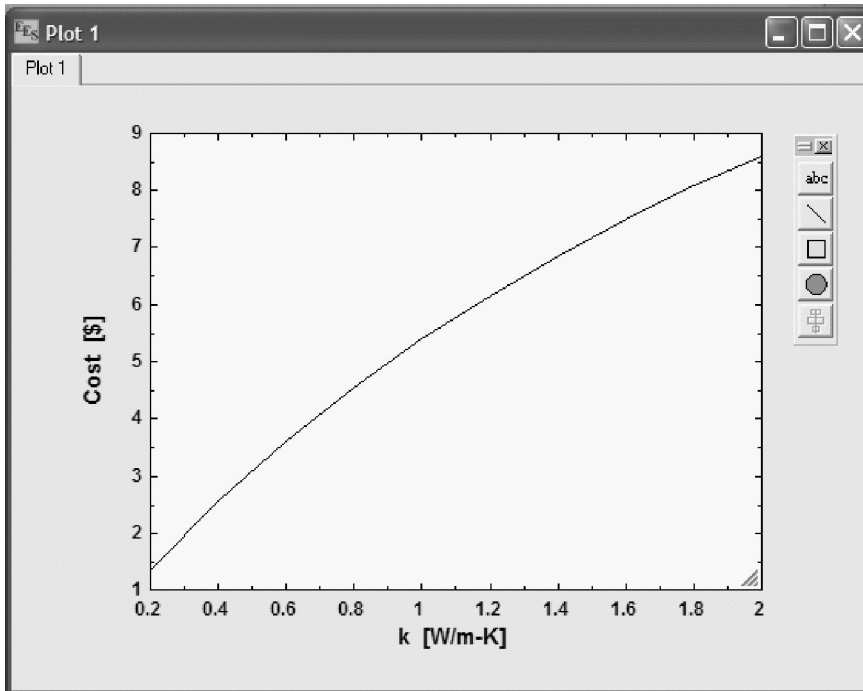
Show error bars

Line: \_\_\_\_\_

Symbol: None

Color: \_\_\_\_\_

OK  Cancel



axis to see some of these options. For example, select the Spline Fit option to smooth the curve.

## USING THE TEXTBOOK MENU

A number of problems from this textbook have been solved using EES. These examples are accessible from the **Heat Transfer** menu to the right of the Help menu. As an example, select Chapter 1 from the **Heat Transfer** menu. A dialog window will appear listing the problems in Chapter 1. Select Problem 1–104. This problem is a modification of the problem you just entered. It provides a Diagram Window in which you can enter the input variables. Enter values and then select the Solve command in the Calculate menu to see their effect on the output properties.

At this point, you should explore. Try whatever you wish. You can't hurt anything. The online help (invoked by pressing F1) will provide details for the EES commands. EES is a powerful tool that you will find very useful in your studies.

