Liquid Cooled Cold Plate Trade Study

1.0 Design Parameters

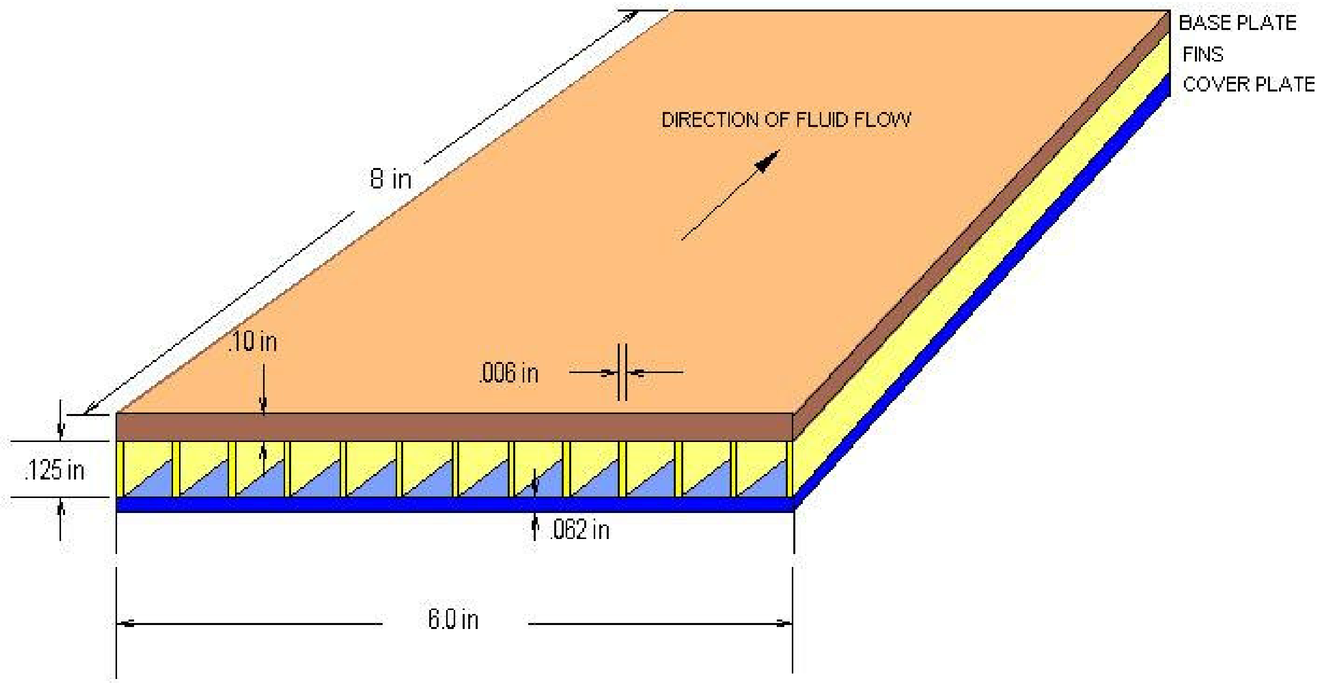
In this example we will perform a trade study of the temperature and pressure drop performance of different cold plate designs needed to cool high power electronics that dissipate 12,000 Watts. The trade study will examine finned, pinned and a tube/channel design. The parameters used in the trade study are listed below.

The purpose of this example is not to select the optimum design, but to demonstrate the flexibility of COLDPLATE and the ease with which to do this.

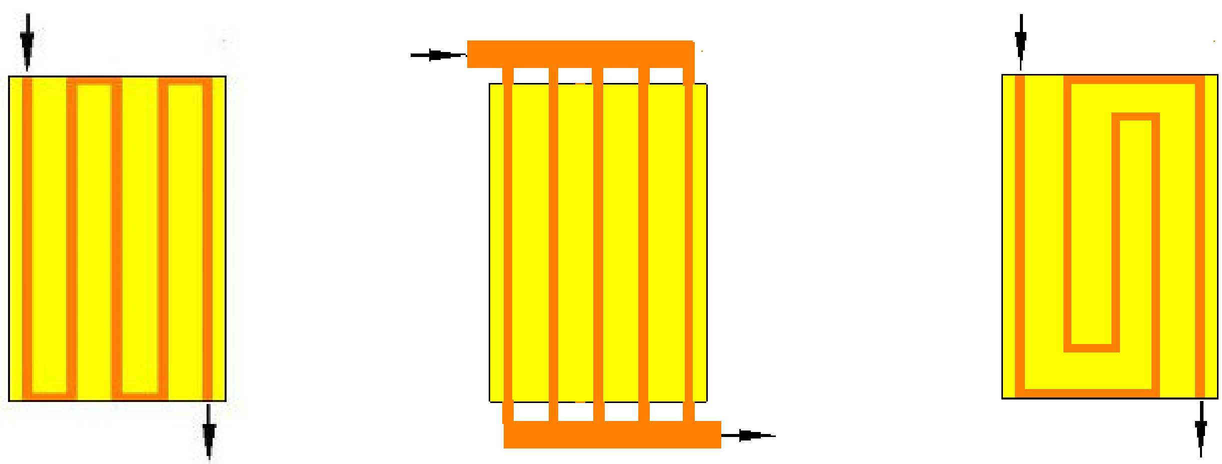
- Cold plate length L is 8 inches
- Cold plate width W is 6 inches
- Cooling fluid is water
- The inlet water temperature is 20C
- The exit fluid pressure is 100 PSI
- Vary the volume flow rate from 1 to 8 gal/minute
- 12000 Watts is uniformly distributed across the cold plate
- Base, fins and cover are made of aluminum, 6061-T6
- For the fin design, assume they are 1/8-13.95 lanced and offset fins from Kays and London's book, Compact Heat Exchangers :
  - Fin height H is .125 inches
  - Fin density is 14 fins/inch
  - Fin thickness is .006 inches
- For the pin fin design, assume they are PF9 fins from Kays and London's book, Compact Heat Exchangers :
  - Pin height H is .125 inches
  - Transverse pin spacing is .199 inches
  - Lateral pin spacing is .125 inches
- For the tube/channel design:
  - The tube flow path is .25 inches in diameter
  - Assume 100% contact between the tube and base plate and 0.0 thermal resistance between the tube and base plate.
- Base plate thickness is .1 inches for pin and lanced fins, .5 for the tube/channel design
- Cover thickness is .062 inches
- The lanced and offset fin, and pin designs are flow through design (1 pass) and 5 pass serpentine design
- The tube/channel designs will be serpentine, custom and parallel with either 5 passes or 5 parallel paths
- Assume all 5 pass/path designs have a pressure drop loss coefficient of .75 for each 90 degree turn ($Kt = 8 * .75 = 6.0$).

2.0 Sketches

Below is a sketch showing the geometry of the overall dimensions for both the lanced and offset design, and the pin fin designs.

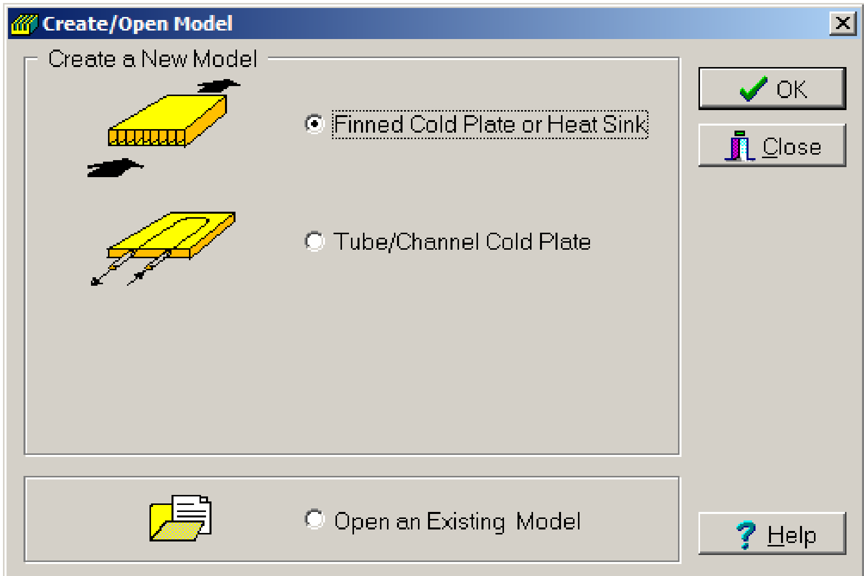


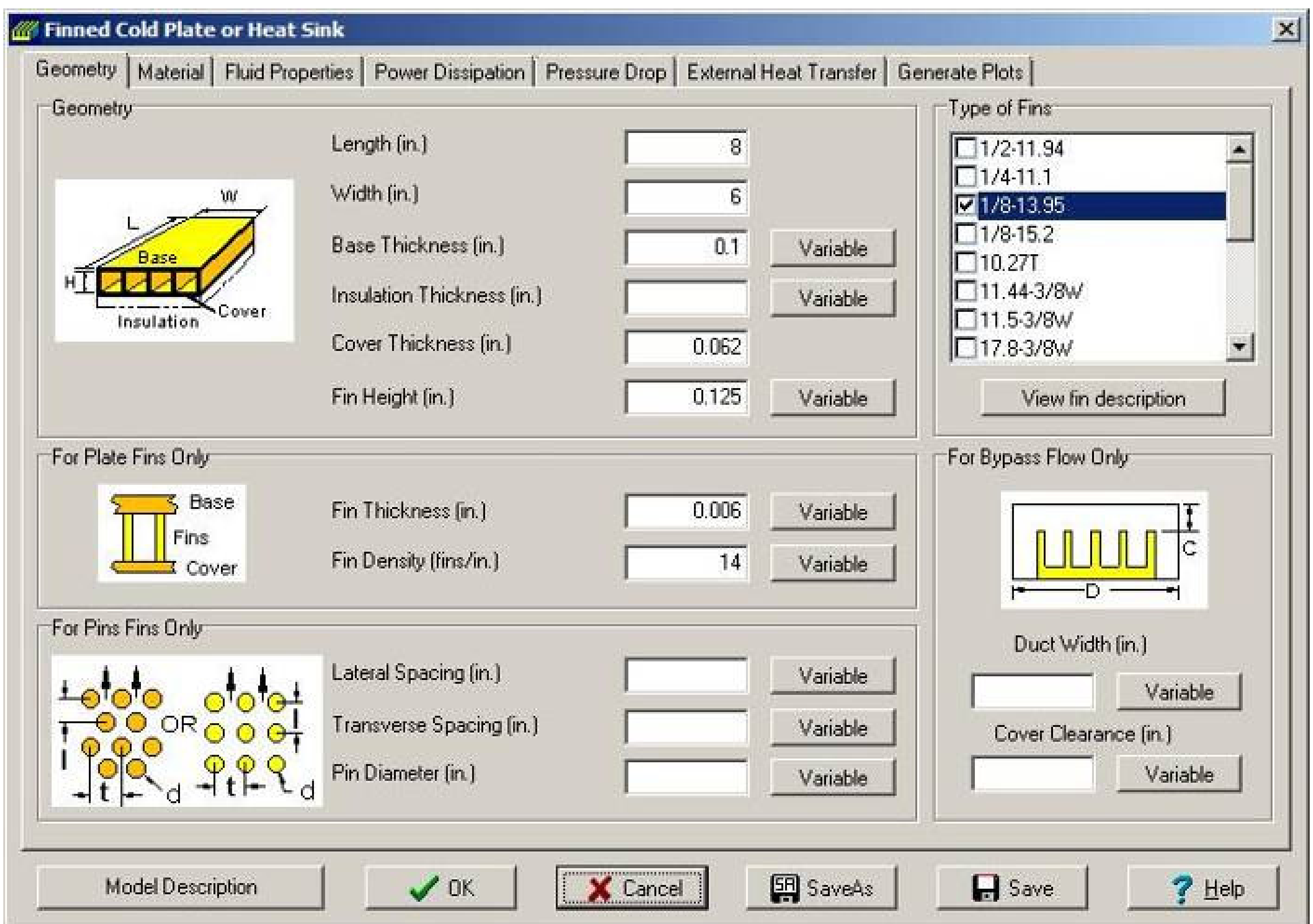
The tube flow designs: serpentine, parallel and custom are shown below. The tubes are assumed to be uniformly spaced as shown (note that this is not a necessity, the spacing can be arbitrary). The inlet and exit headers for the parallel design are assumed to be either large enough or designed so that the flow in each parallel path is equal.



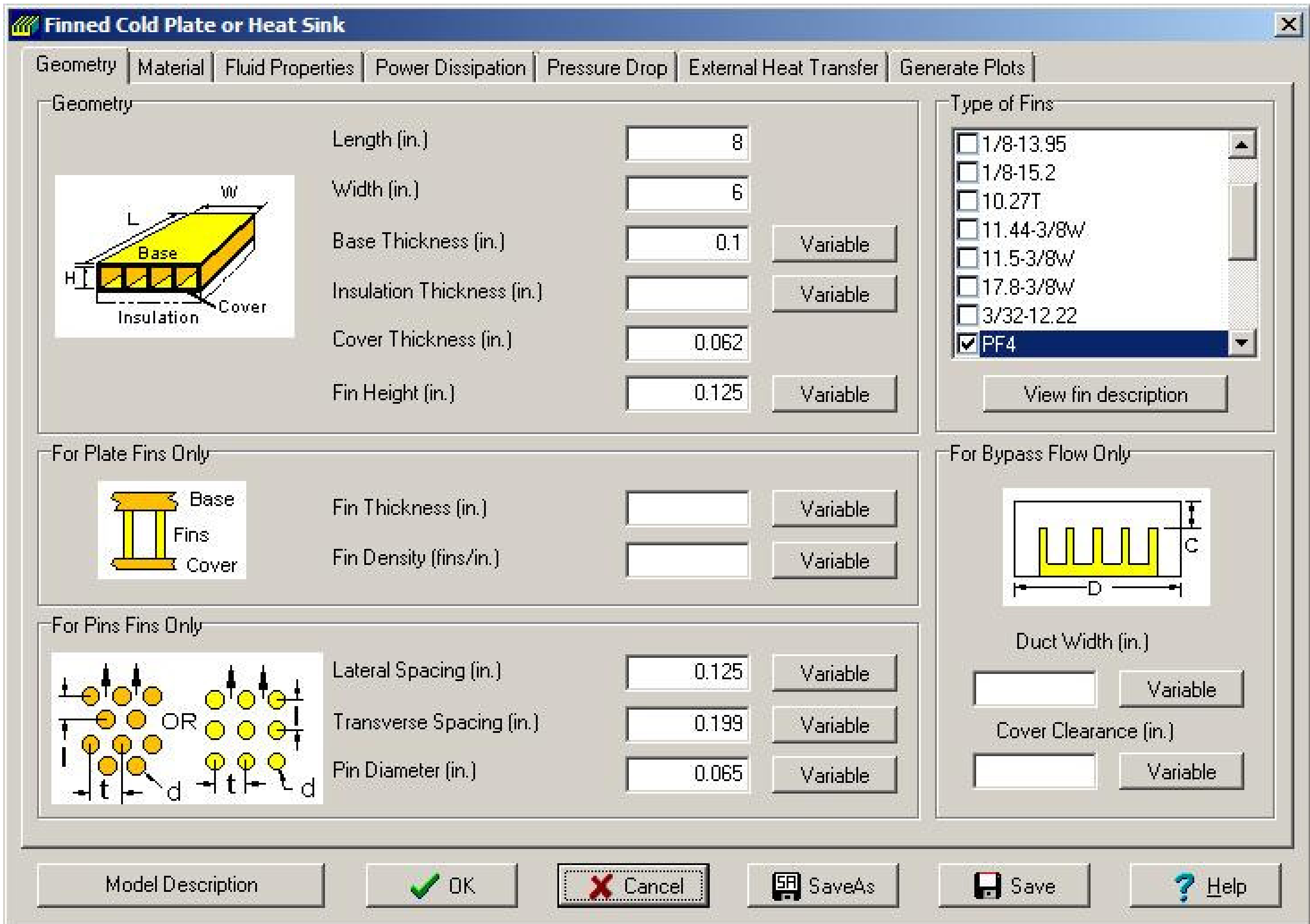
3.1 Lanced and Offset Fins, and Pin Fin Models

The geometry for the lanced and offset fin (1/8-13.95) design is input on Geometry Tab sheet. The pin fin design could also be input here and modeled at the same time. It's not done here for clarity.

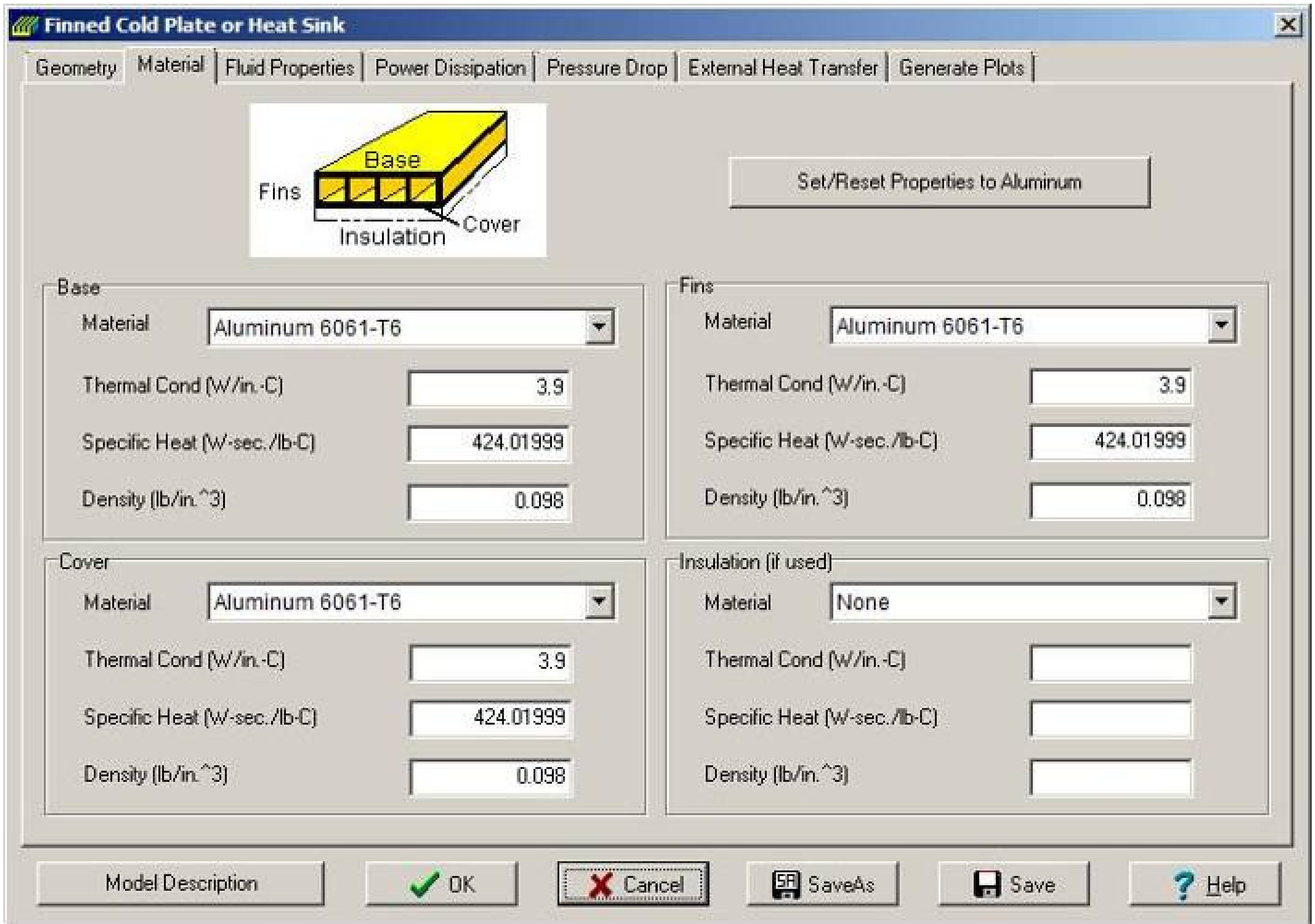




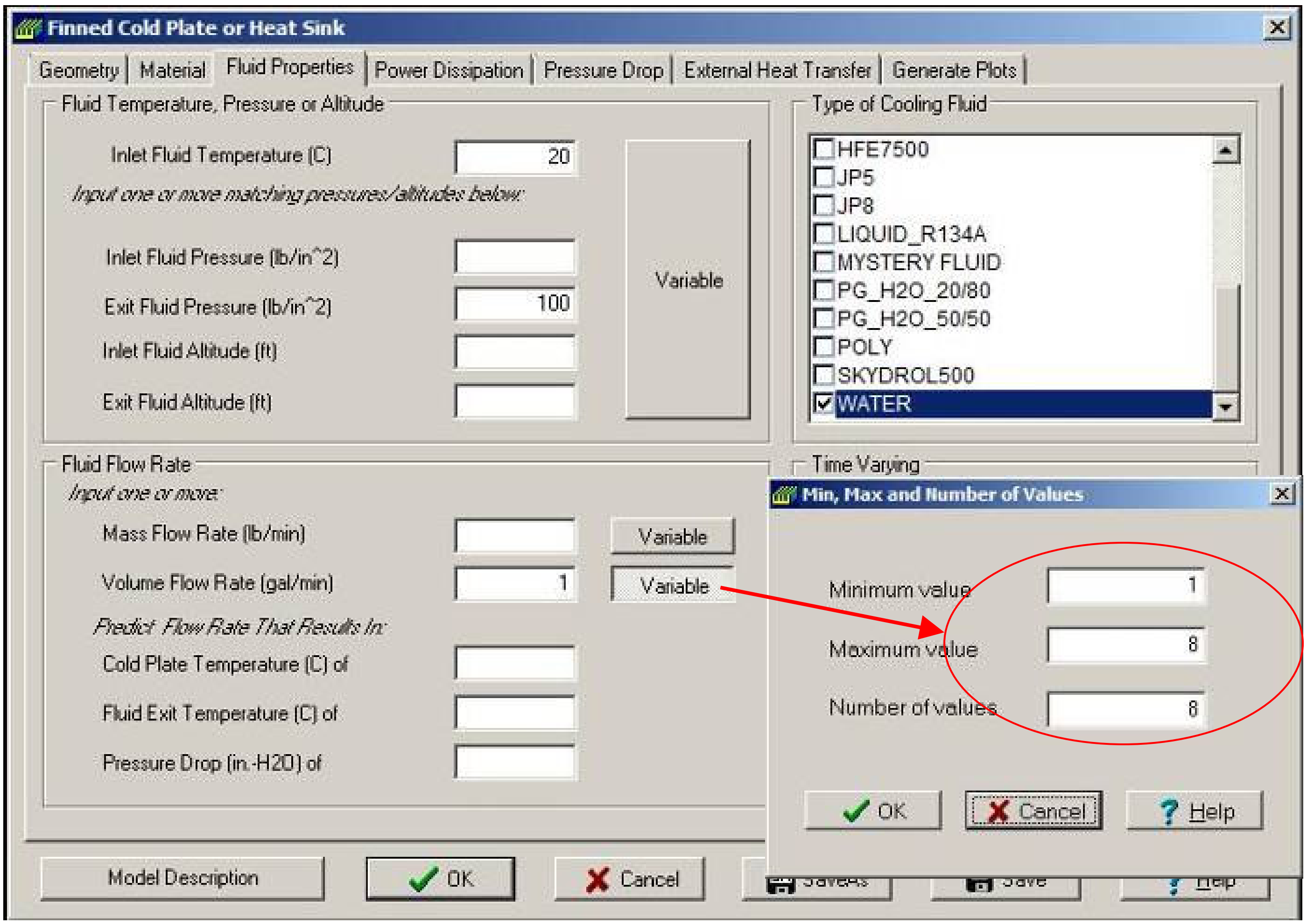
The geometry for the pin fins (PF4) design is input on this tab sheet. Again, the pin fin design could have been inputted with the lanced and offset fins.



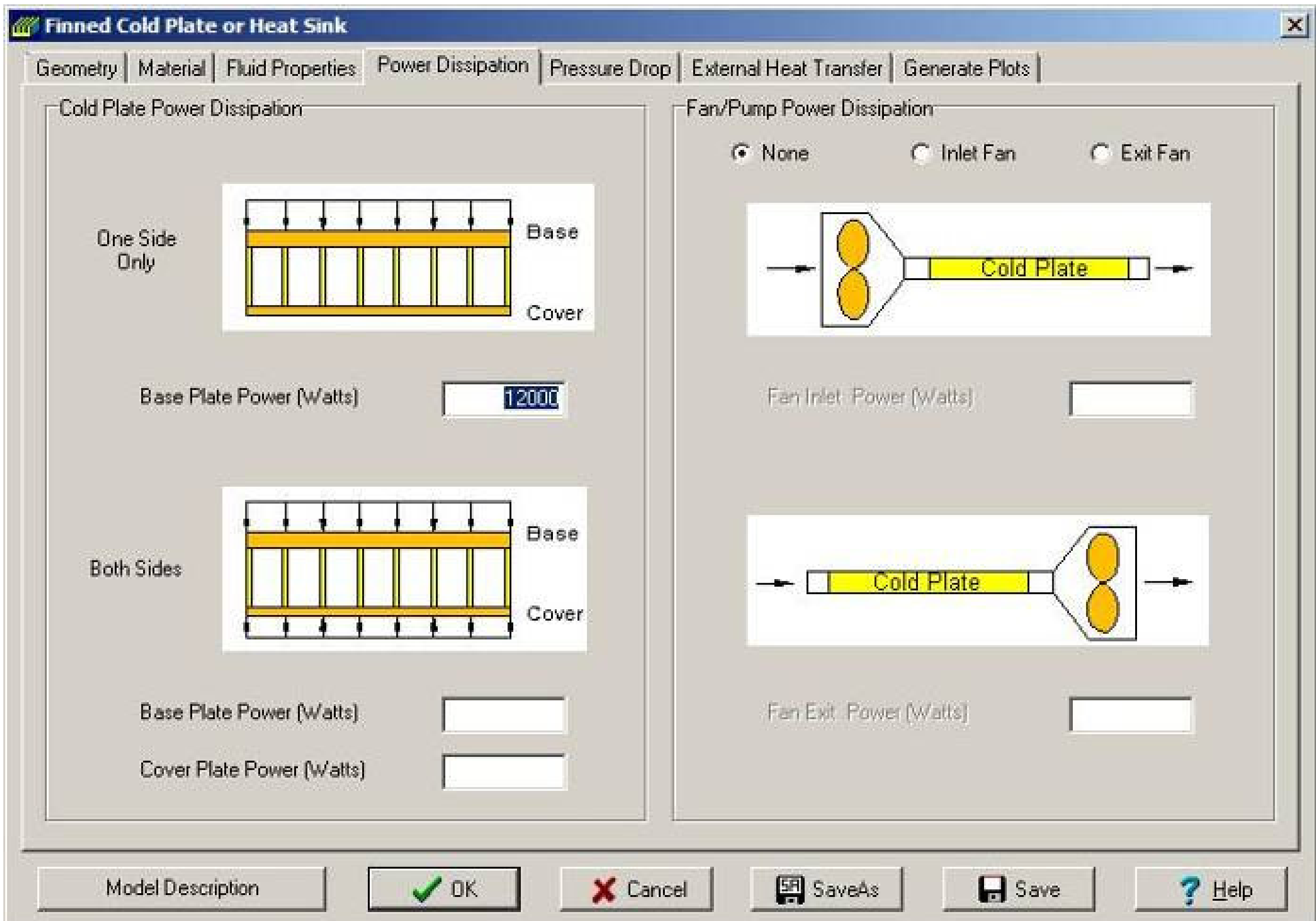
Select 6061-T6 aluminum properties on the Material tab sheet. This is the same for all designs except the cover and fins are not used for the tube designs.



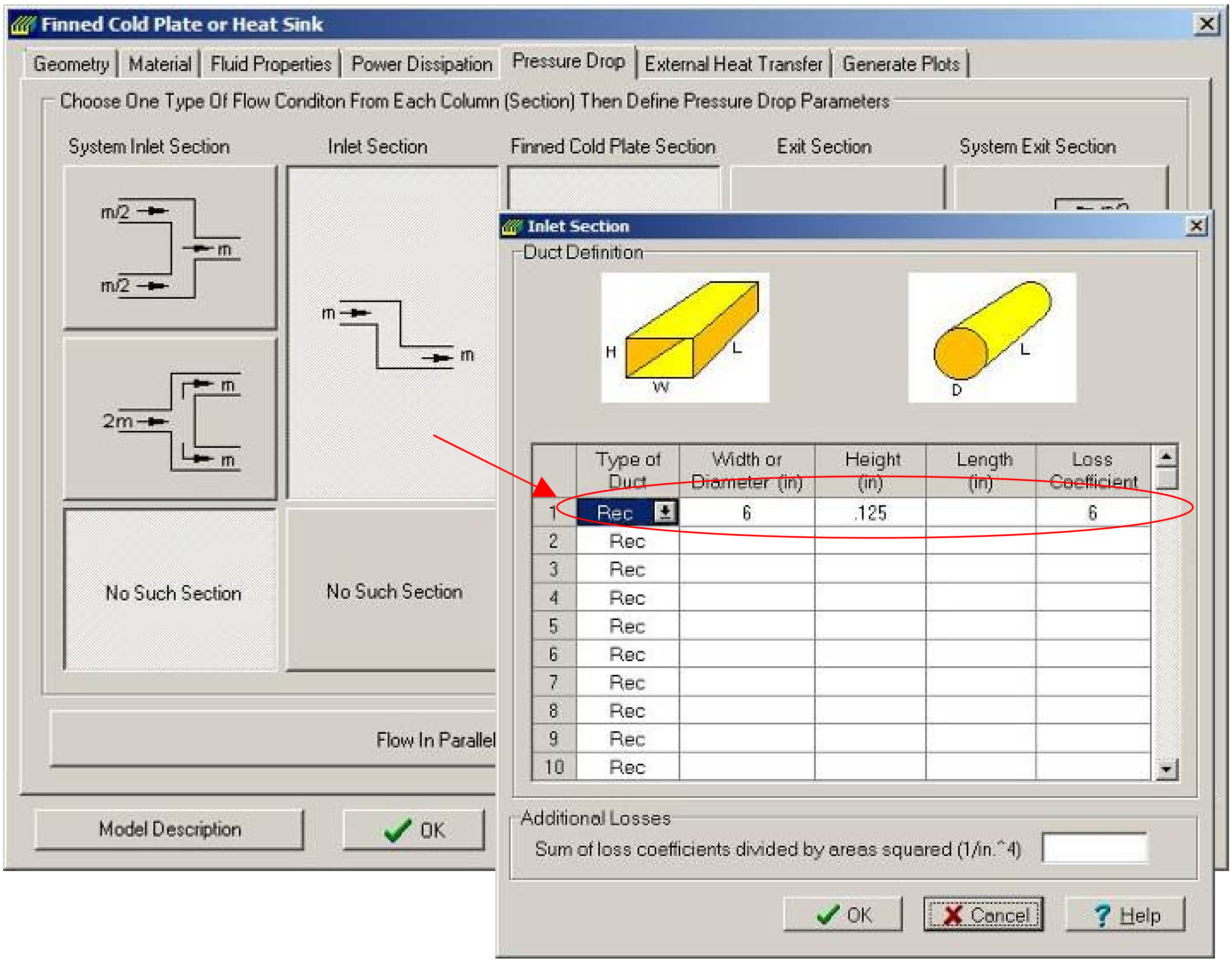
The temperature, pressure, flow rate and water as the fluid are input on the Fluid Properties tab sheet. The variable flow rate from 1 to 8 GPM with 8 different values is input by selecting the variable button next to Volume Flow Rate text box and filling in the values. These inputs are the same for all models.



The 12,000 watts of power dissipation are input on the Power Dissipation tab sheet. It will automatically be uniformly distributed across the cold plate base. Note, that the power does not have to be uniform, it can be non-uniform, temperature or time dependent. These inputs are the same for all models.



To account for the pressure drop due to the turn losses in both the lanced and offset fins, and pin fin serpentine designs, the total loss coefficient of 6.0 along with the inside dimension of 6 by .125 inches of the cold plate are specified on the Inlet Section Duct Definition form, these values also could have been input on the Exit Section. The location chosen only becomes important when modeling hi-speed compressible air flow and density changes need to be accounted for.

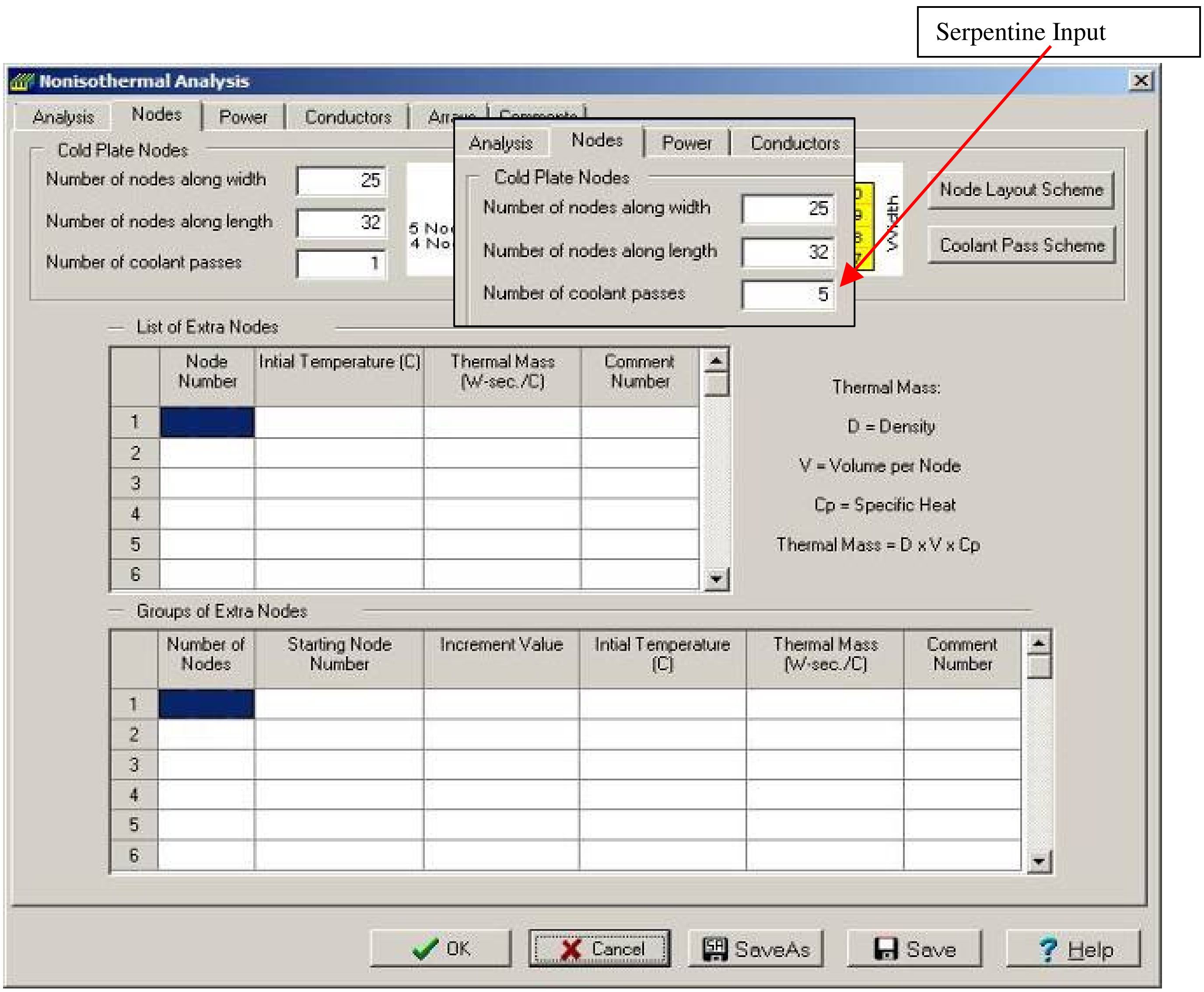


That's all the input needed for the lanced and offset fin, and pin fin models except to specify the number of nodes in the model used in determining the temperatures along the width and length of the cold plate. The Nonisothermal Analysis form as shown below is used to do this.

Because we are going to be modeling both flow through (1 pass) and serpentine cold plates, then the nodes should be kept somewhat square to simulate the correct path length. In addition, since there are 5 passes in the serpentine models and the number of nodes along the width has to be divisible by the number of passes, then 25 nodes along the width is a reasonable value to use. Also, since the length is 8 inches versus a width of 6 inches and we want to keep the nodes somewhat square, then 32 or 33 nodes along the length is appropriate.

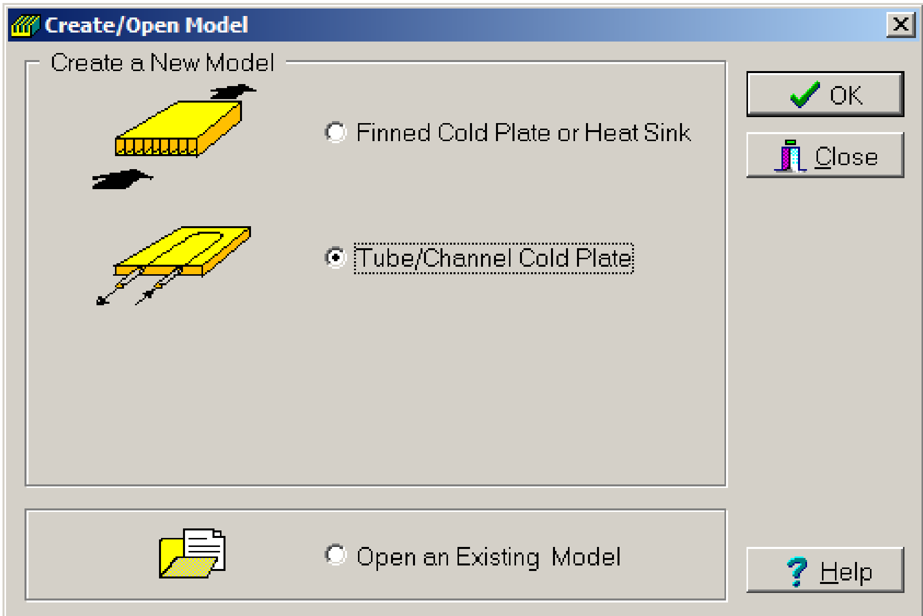
Note as shown below; the only difference between a flow through model and serpentine model other than the pressure drop coefficient is the inputting of 1 versus 5 for the number of coolant passes. With a value of 5, the cold plate will automatically be divided into 5 equal width flow paths (see the color contour output plot later in this paper).

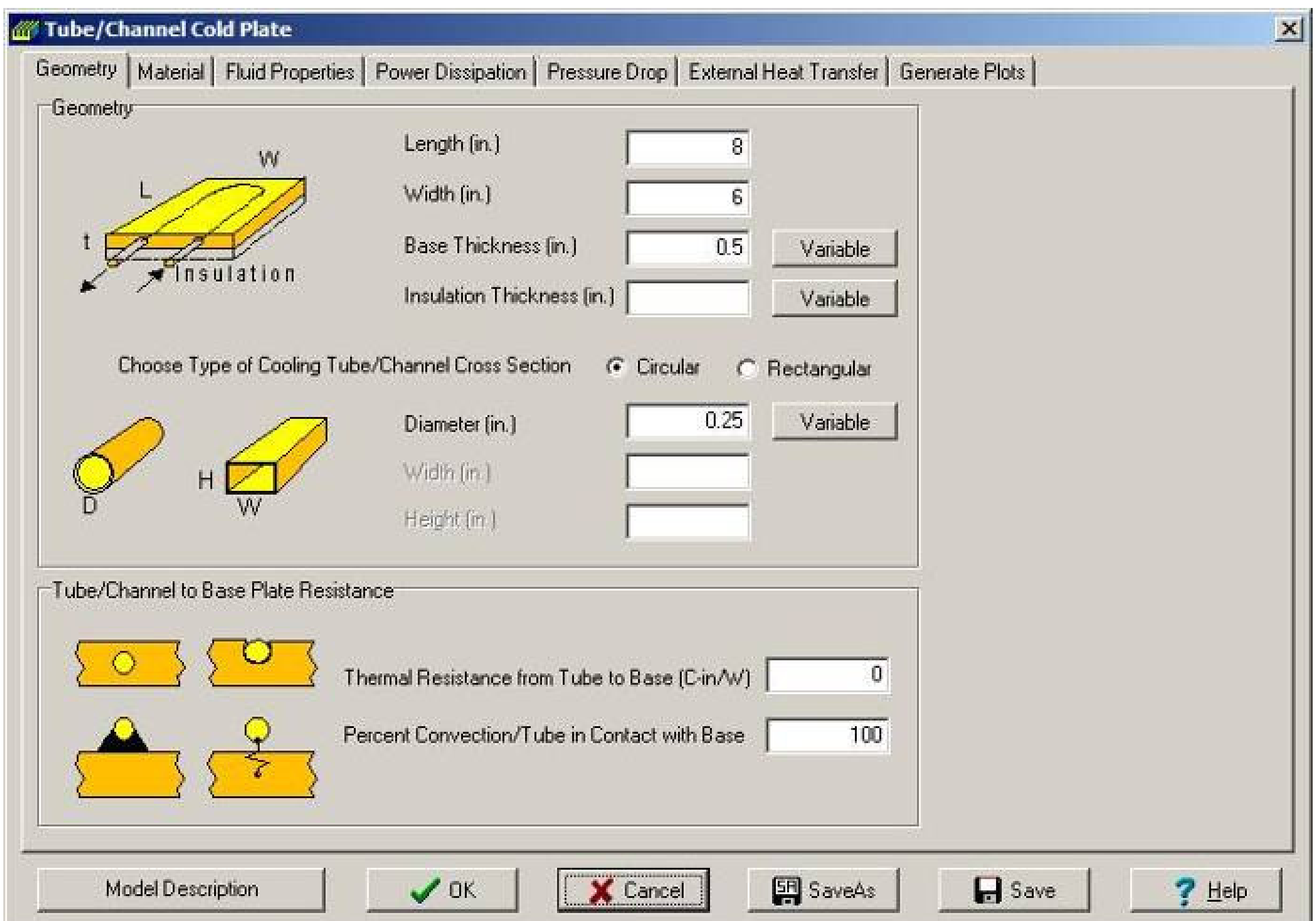
At this point, the lanced and offset fin, and pin fin models with both flow through and serpentine paths are ready to run. The results for these four models are discussed later along with the tube flow models.



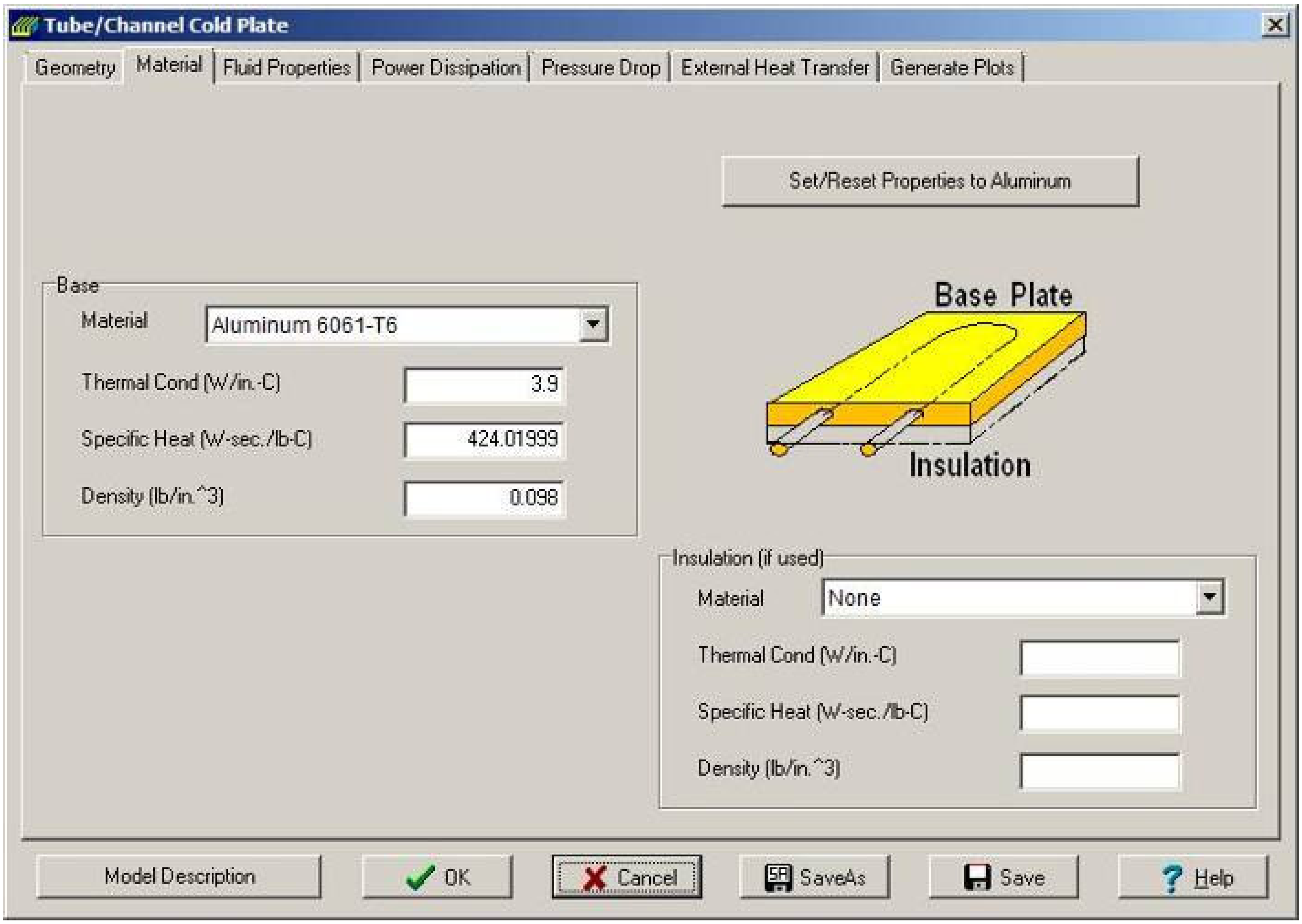
3.2 Tube Models

The geometry and thermal resistance from tube to base plate for the 3 different types of tube models are the same and are input on the Geometry tab sheet shown below.



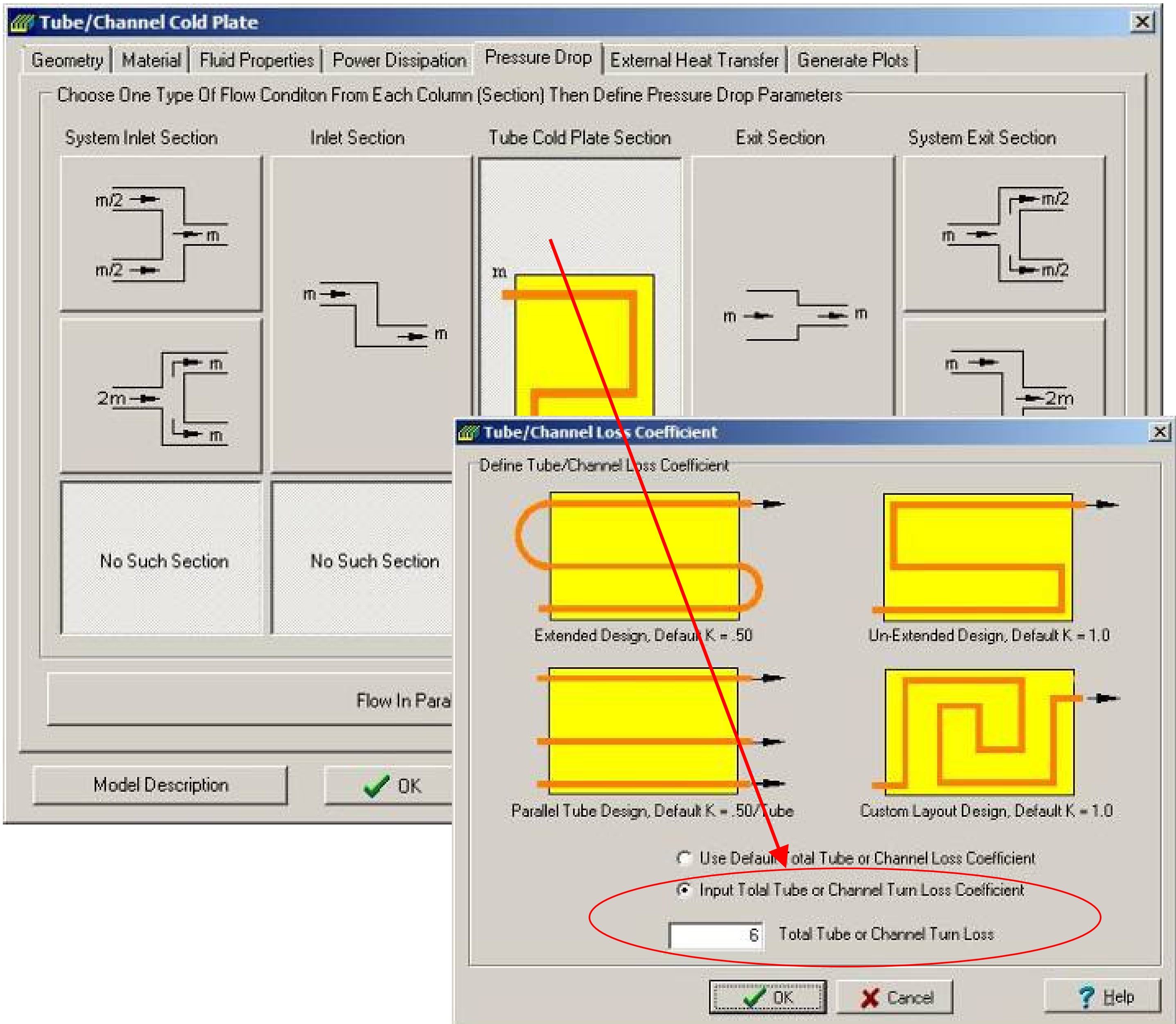


Select 6061-T6 aluminum properties on the Material tab sheet.



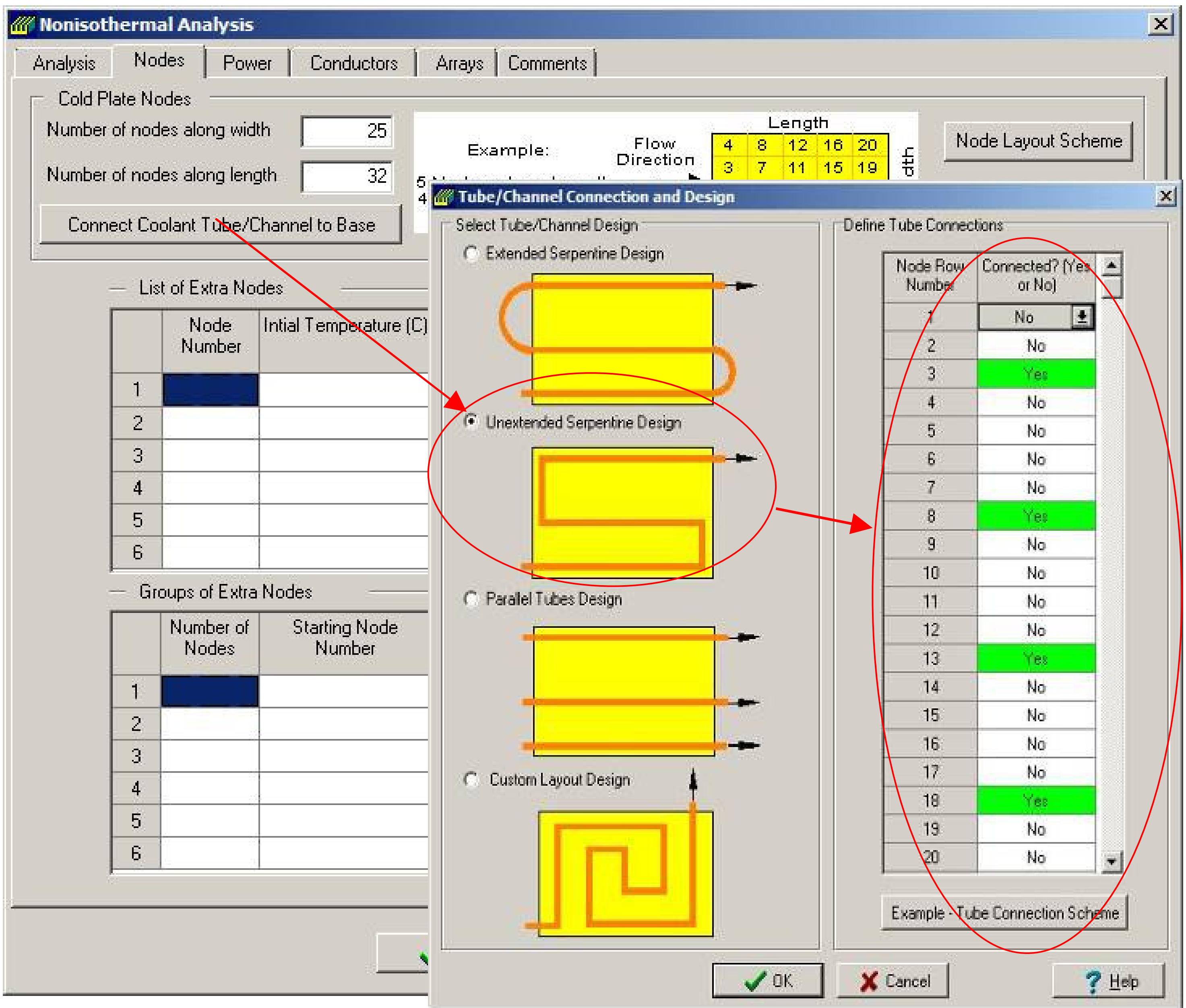
To account for the pressure drop due to the turn losses within the tube model designs, the Pressure Drop tab is selected and then the Tube Cold Plate Section button is selected bringing up the Tube/Channel Loss Coefficient form. The total loss coefficient of 6 is inputted here.

Note that the inside tube diameter will be used in the pressure drop calculations.

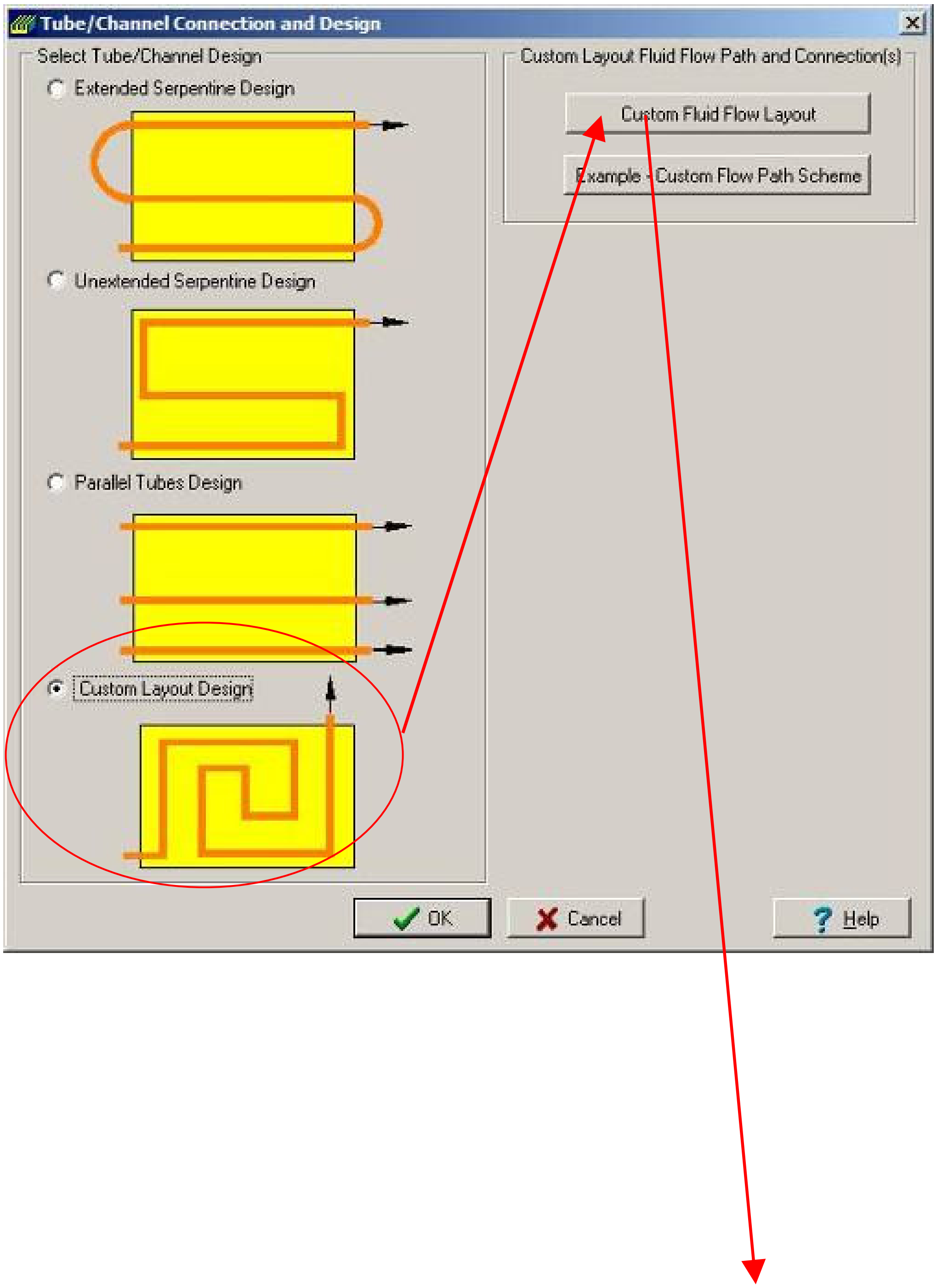


The same number of nodes for both the width and length are used on the Nonisothermal Analysis form. In addition, for the tube models we need to indentify which Node Row Number the fluid flow tube is connected to. This is done by clicking on the Connect Coolant Tube/Channel to Base button, then selecting the appropriate type of tube design radio button and then selecting Yes for Node Row Numbers 3,8,13,18 and 23. The tube will be automatically tied to each node on each of the node row numbers. In addition, for the Serpentine design, the tube will also be tied to nodes between each of the node row numbers. The program will use the resistance values that were input on the Geometry Tab sheet to tie the tube to the base plate.

Both the Serpentine and Parallel tube models are specified in this manner, to switch from one to next, just select the appropriate radio button.

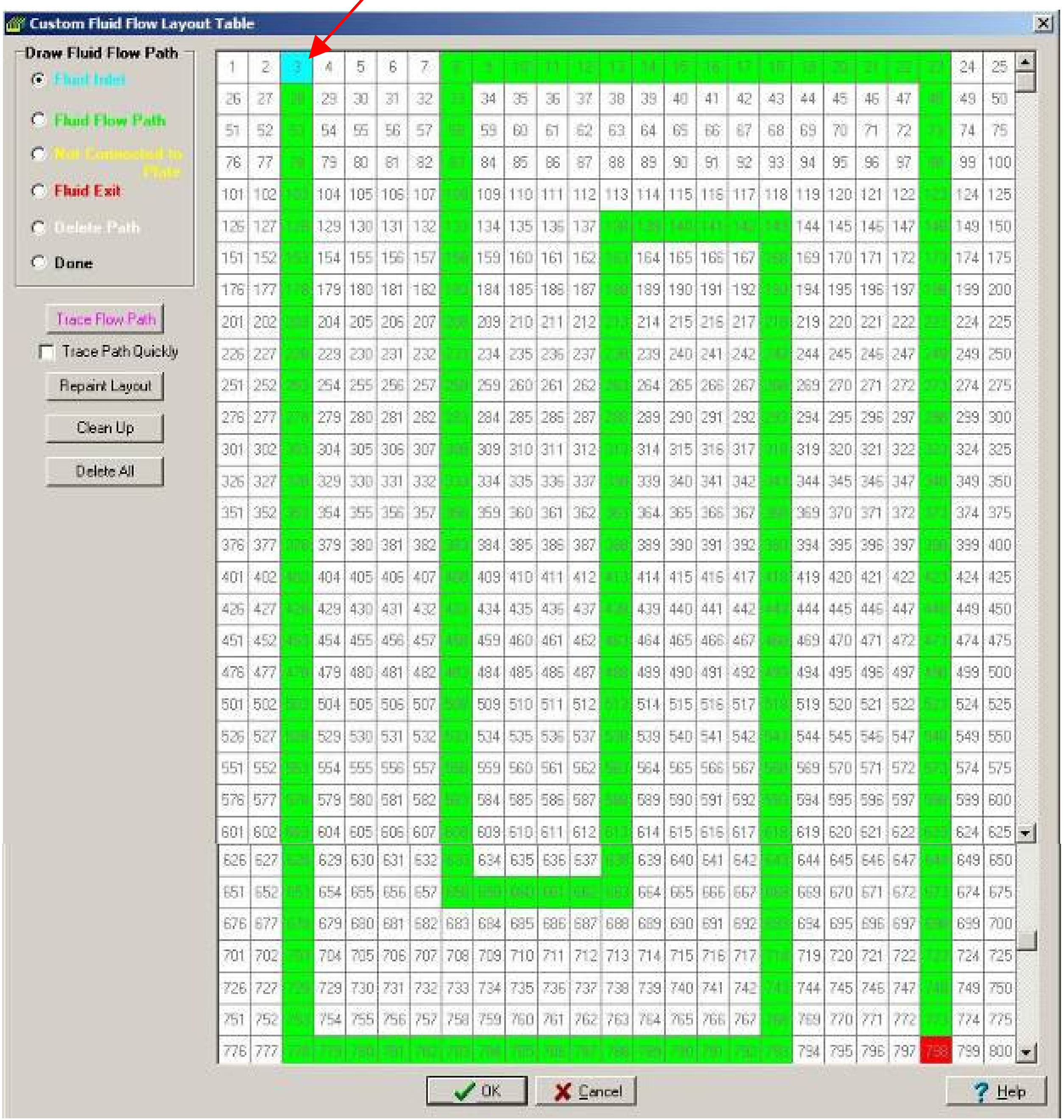


The custom tube design model is setup by selecting the Custom Layout Design radio button, then clicking the Custom Fluid Flow Layout button to bring up the Custom Fluid Flow Layout Table form.



On this form, you draw the tube layout by clicking on or using the up/down/left or right arrow button to route the tube layout. The tube will automatically be tied to each base plate node underneath it. The program will use the resistance values that were input on the Geometry Tab sheet.

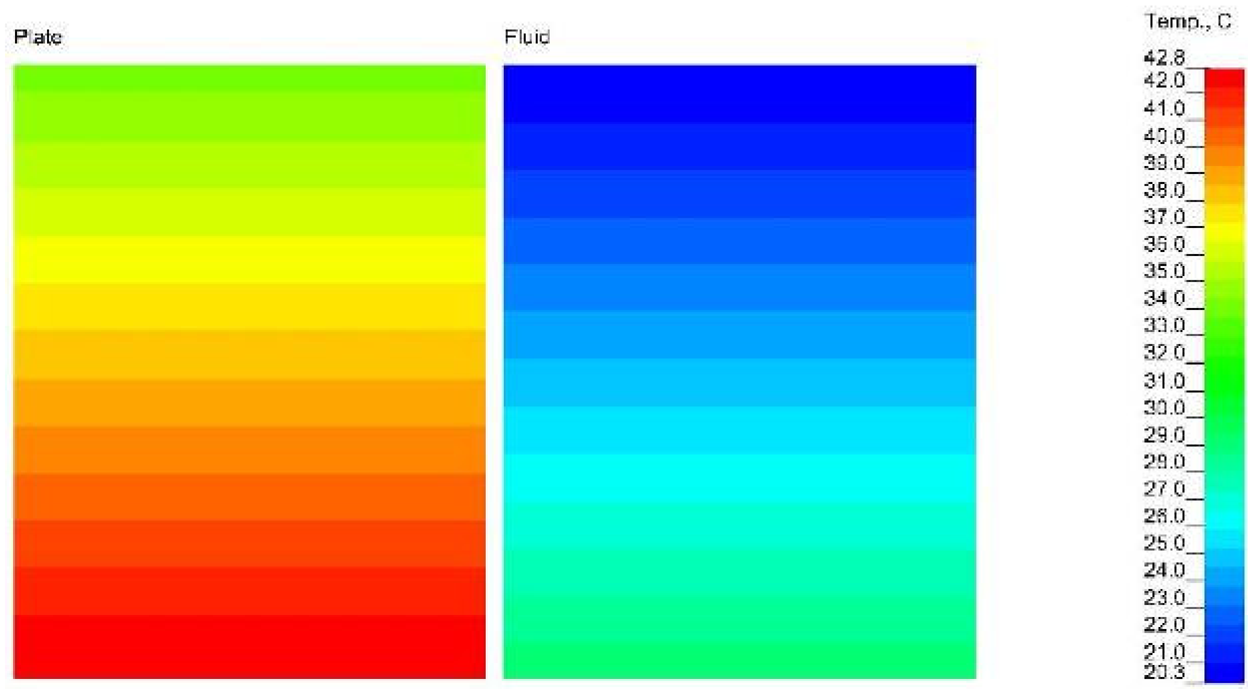
Once you are done with this form and select OK you are returned to the Tube/Channel Connection form. From there you can select any of the radio buttons to toggle between any of the different types of tube models with out have to re-input any data. These model are now finished and ready to run.

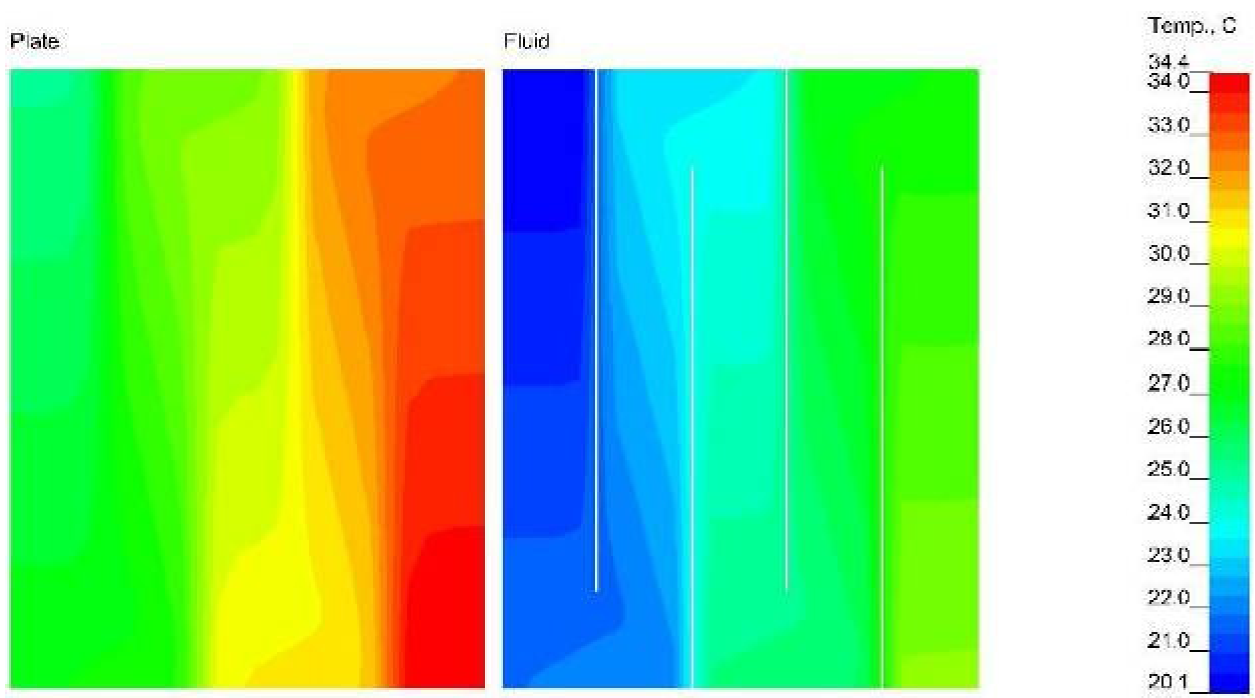


4.1 Color Contour Results at 6 gal/min

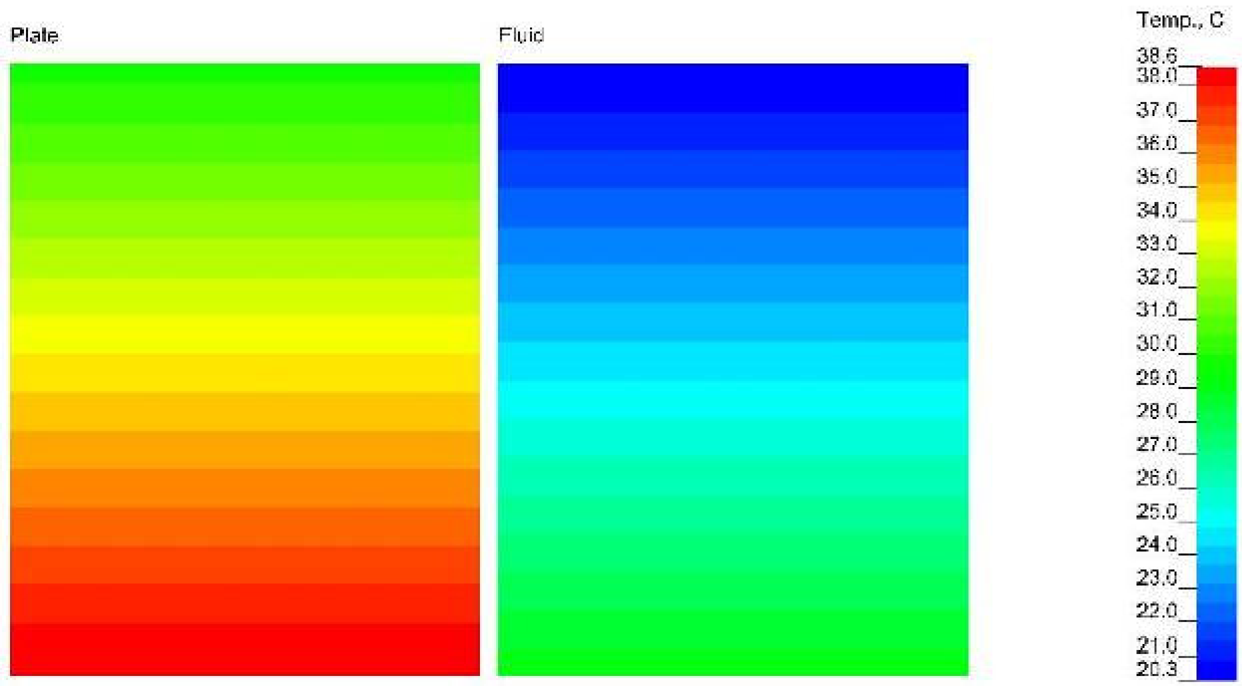
Color contour results at 6 gal/min are shown in the following figures for each type of model.

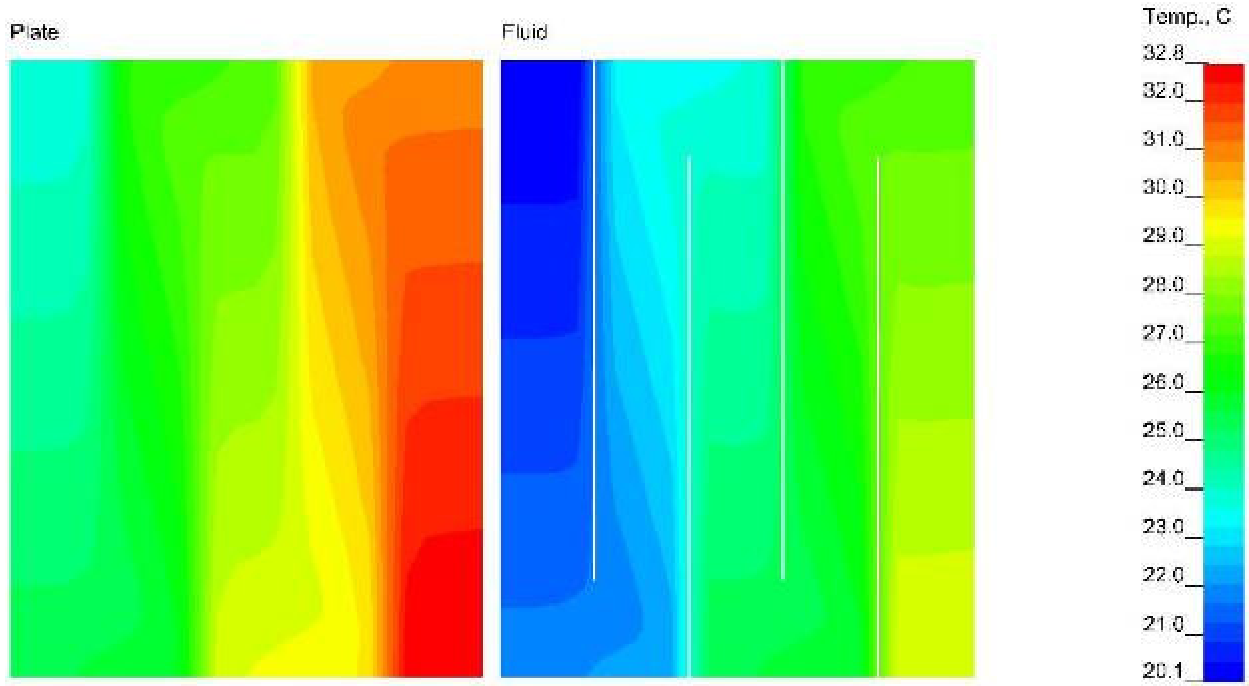
Shown directly below are the lanced and offset models results, the first is the flow through model followed by the 5 pass serpentine model. Since the power was uniformly distributed, the temperature across the width is uniform for the flow through model.



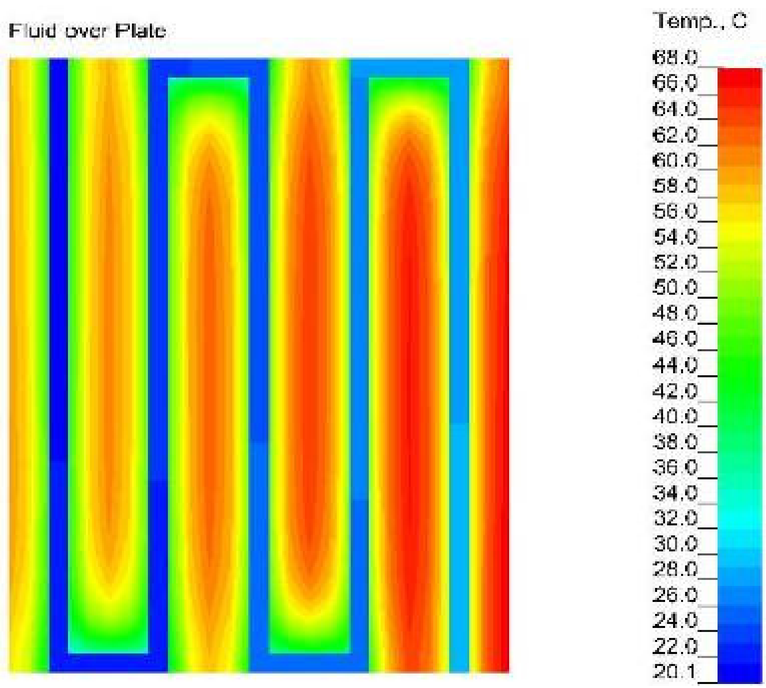


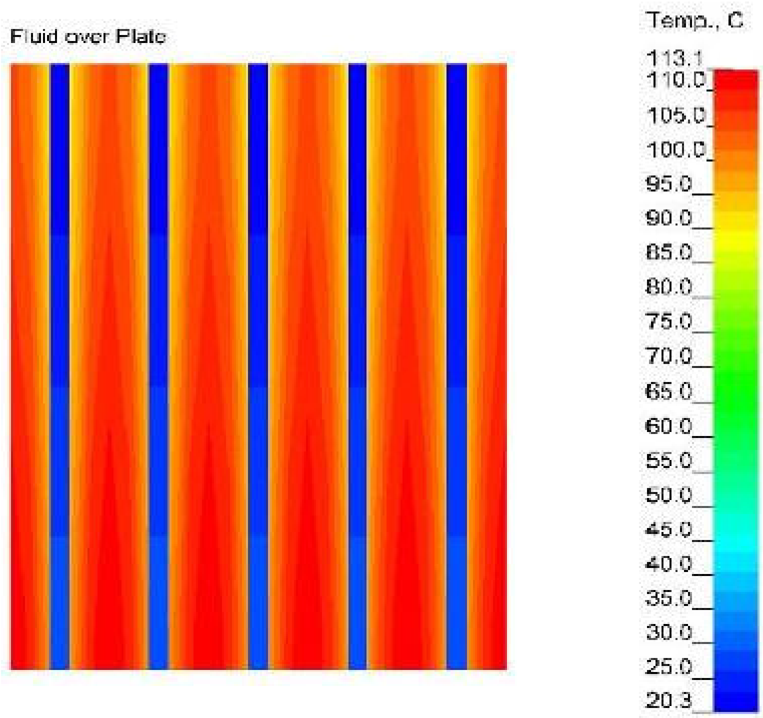
Shown directly below are the pin fin models results, the first are the flow through model followed by the 5 pass serpentine model. Again, since the power was uniformly distributed, the temperature across the width is uniform for the flow through model.



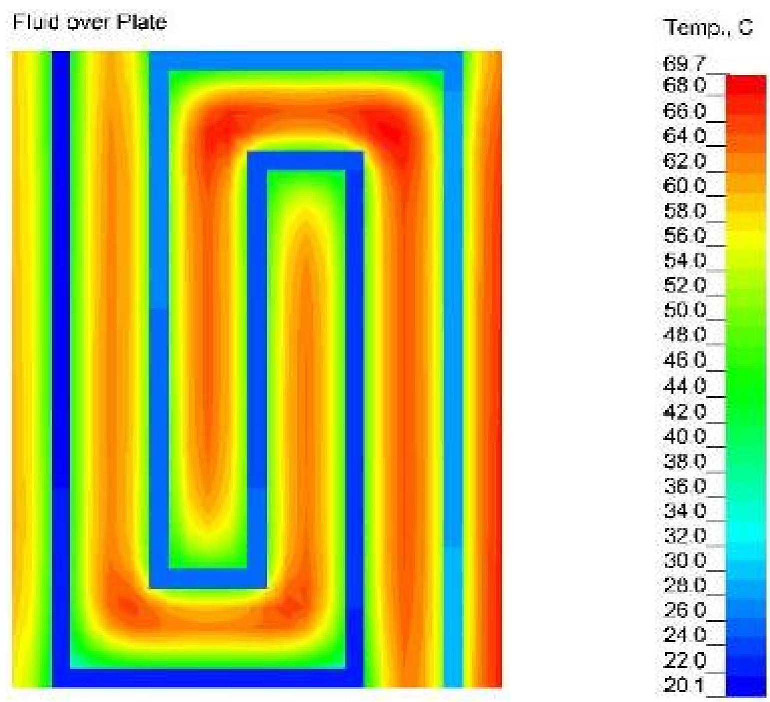


The results shown here are first the serpentine tube model then the parallel tube model.



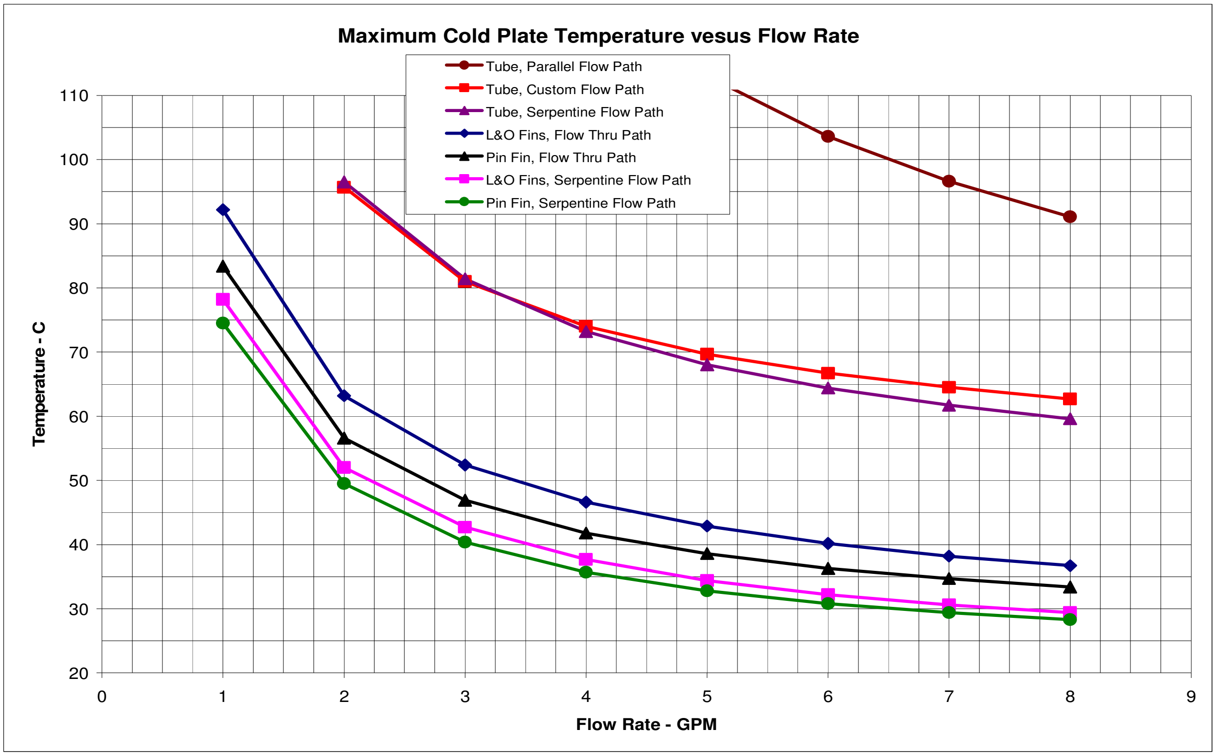


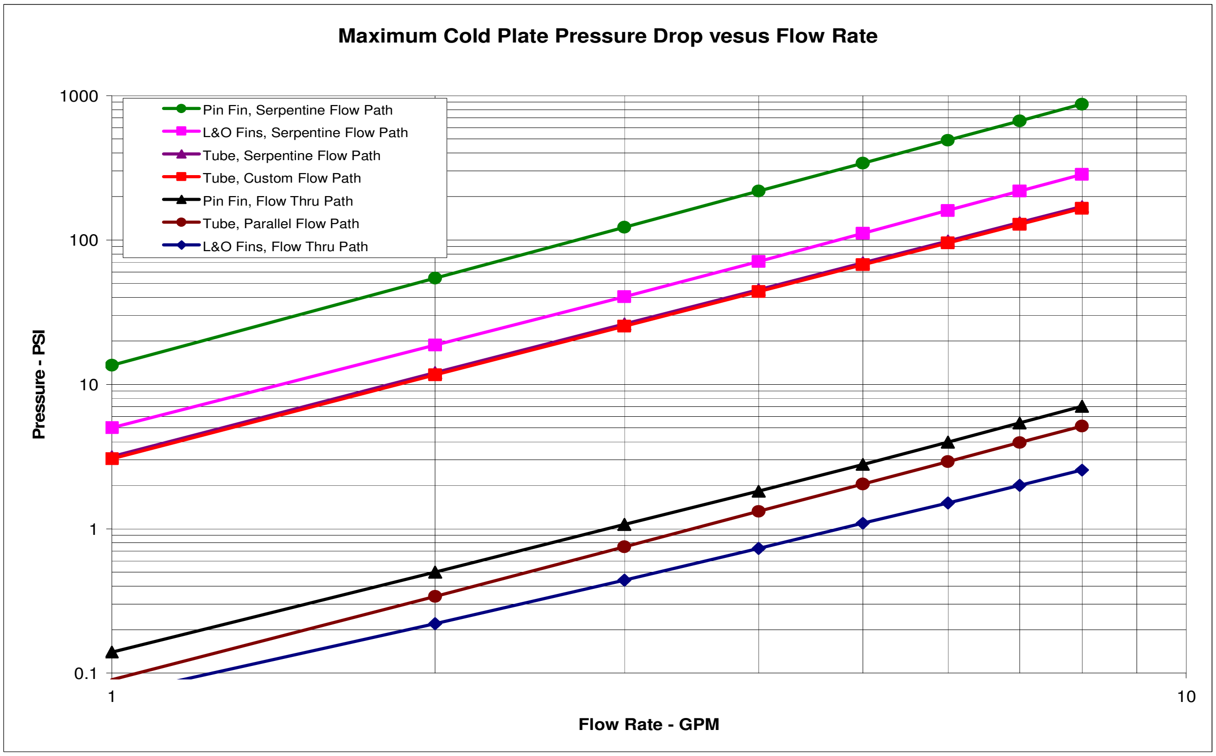
Finally, shown below are the results for the custom tube layout model.



4.2 XY Plot Results

The plots below summarize the temperature and pressure drop results as a function of the water volume flow rate for all models. As stated at the beginning of this report, it was not its purpose to optimize the design; however, it is pretty clear that the best cooling approach must take into account not only the resulting temperature but also the pressure drop. Not only are there limits on allowable temperature but also on allowable or available pressure drop.





5.0 Table Results

For reference, shown here is the summary of results for the Lanced and Offset model with serpentine path. The results cover the entire flow rate range from 1 to 8 gal/min.

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******                                                           ******
******      COLDPLATE     / VERSION 7.0b /    APR 27, 2012       ******
******          www.epac-inc.com        (603) 533-9011           ******
******        EPAC: ELECTRONIC PACKAGING ANALYSIS COMPANY        ******
******                                                           ******
************************************************************************
Water cooled cold plate trade study - Lanced and Offset Fins, Serpentine


        SUMMARY OF INPUTS AND RESULTS FOR ISOTHERMAL ANALYSIS AND MAXIMUM TEMPERATURE FOR NONISOTHERMAL ANALYSIS
 ***************************************************** LEGEND **********************************************************************
        FTYPE                      FIN STYLE               FLOWS                       FLUID              TEMP
   1  RECTANGULAR FINS         F  FIN (CONVOLUTED)     V  VOLUME-FT^3/MIN              1  AIR            S  SINGLE SIDED HEATING
   2  10.27 TRI. FINS          P  PIN FIN              v  VOLUME-GAL/MIN               2  WATER          B  BOTH SIDED HEATING
   3  PF4 PIN FINS             T  TUBE/CHANNEL         M  MASS FLOW-LB/MIN             3  COOLANOL20
   4  PF9 PIN FINS                                     T  RESULTING LB/MIN (TEMP CP)   4  COOLANOL25
   5  11.44-3/8 WAVY FINS                              E  RESULTING LB/MIN (TEMP OUT)  5  EG_H2O_60/40
   6  11.5-3/8 WAVY FINS                               P  RESULTING LB/MIN (DELTA P)   6  EG_H2O_50/50
   7  17.8-3/8 WAVY FINS                               R  RESULTING LB/MIN (RAM FLOW)  7  EG_H2O_40/60
   8  3/32-12.22 L & O FINS                                                            8  EG_H2O_30/70
   9  1/8-13.95 L & O FINS          TEMPERATURE = DEGREE C                             9  FC75
   10 1/8-15.2 L & O FINS           DIMENSIONS = INCHES                                10 GALDEN-HT110
   11 1/4-11.1 L & O FINS           WEIGHT = LBS                                       11 HFE7100
   12 1/2-11.94 L & O FINS          PRESSURE DROP = IN-H20 FOR AIR, LB/IN2 FOR LIQUIDS 12 HFE7500
   13 TRI FIN 12.00T                                                                   13 JP5
   14 TEST                                                                             14 JP8
   15 PLANE FIN 11.1                                                                   15 LIQUID_R134A
                                                                                       16 PG_H2O_20/80
                                                                                       17 POLYALPHAOLEPHIN
                                                                                       18 SKYDROL 500
                                                                                       19 PG_H2O_50/50
                                                                                       20 ENGINE OIL
                                                                                       21 MYSTERY FLUID

         A NUMBER FOLLOWED BY A DASH (-) INDICATES THIS VARIABLE IS NOT USED DURING THIS RUN

****************************************** INPUT *****************************************|****************** RESULTS *********************
                                                                                          |
                ------- FIN STYLE -------                                                 | -------- TEMP --------
FTYPE  FHEIGHT  FTHICK          FDENSITY  ITHICK  TEMPIN  TEMPAMB  TEMPWALL  FLOWS  FLUID| TEMPOUT TCPISO  TCPMAX  DELTAP WEIGHT TMAX/NODE
                PDIA    PSPACET PSPACEL                                                   |
------------------------------------------------------------------------------------------|------------------------------------------------
  9F    0.125   .006F   0.000-  14.000F   0.000-   20.0      0.0-      0.0-     1.0v   2  |  66.0S  67.0S   78.1S    5.00    1.01   78.2/ 800
  9F    0.125   .006F   0.000-  14.000F   0.000-   20.0      0.0-      0.0-     2.0v   2  |  42.9S  44.9S   52.0S   18.70    1.01   52.0/ 800
  9F    0.125   .006F   0.000-  14.000F   0.000-   20.0      0.0-      0.0-     3.0v   2  |  35.2S  37.5S   42.7S   40.39    1.01   42.7/ 800
  9F    0.125   .006F   0.000-  14.000F   0.000-   20.0      0.0-      0.0-     4.0v   2  |  31.4S  33.6S   37.7S   71.03    1.01   37.7/ 800
  9F    0.125   .006F   0.000-  14.000F   0.000-   20.0      0.0-      0.0-     5.0v   2  |  29.1S  31.1S   34.4S  111.01    1.01   34.4/ 800
  9F    0.125   .006F   0.000-  14.000F   0.000-   20.0      0.0-      0.0-     6.0v   2  |  27.6S  29.4S   32.2S  159.88    1.01   32.2/ 800
  9F    0.125   .006F   0.000-  14.000F   0.000-   20.0      0.0-      0.0-     7.0v   2  |  26.5S  28.2S   30.6S  217.64    1.01   30.6/ 800
  9F    0.125   .006F   0.000-  14.000F   0.000-   20.0      0.0-      0.0-     8.0v   2  |  25.7S  27.3S   29.4S  284.28    1.01   29.4/ 800
```