


Heat Sink Optimization Example for Solar Cell Applications using Qfin4

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March 2008

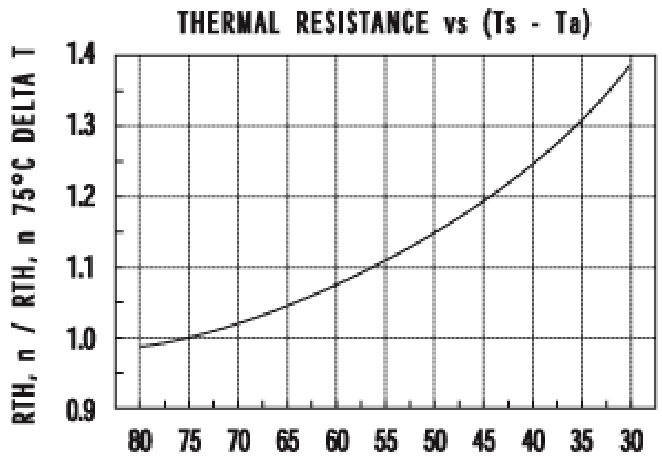
APPLIED THERMAL TECHNOLOGIES, LLC

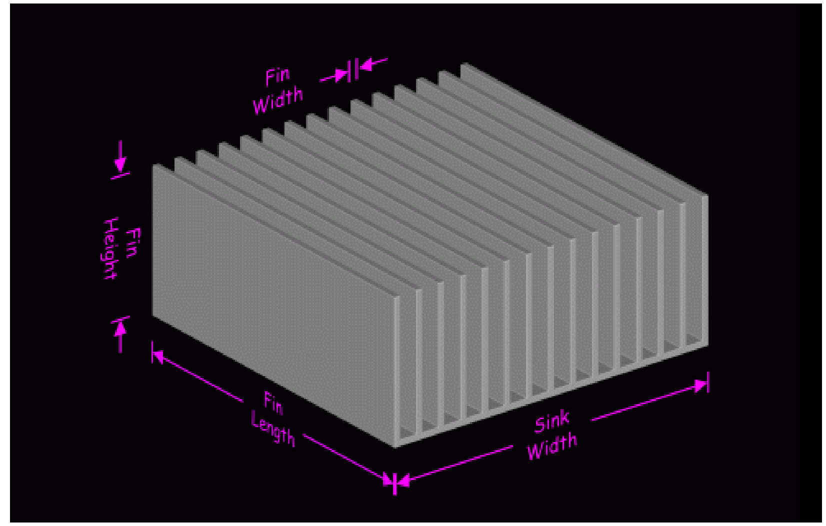
Motivation – Solar Cell Applications

- In solar cell applications collectors often concentrate solar energy into a small surface area (device), where this energy is converted into electrical energy
- This area got to be cooled to prevent device failures and to ensure its effective device operation
- Solar cells are deployed in the open field, often situated in hot areas with little wind and ambient above 40 deg. C
- Solar cells has 25 years of warranty as installed
- No existing active cooling system (heat pipes, liquid, etc) can presently match this warranty requirements
- Solar array has multiple concentrators, so probability of failure grows with the number of concentrators (and conversion devices) in each array

At present only reliable way of cooling concentrator devices is to use natural convection heat sinks (radiators). These devices are reliable, but inefficient, hence they will be large in size.

Natural Convection Heat Sink - Effectiveness





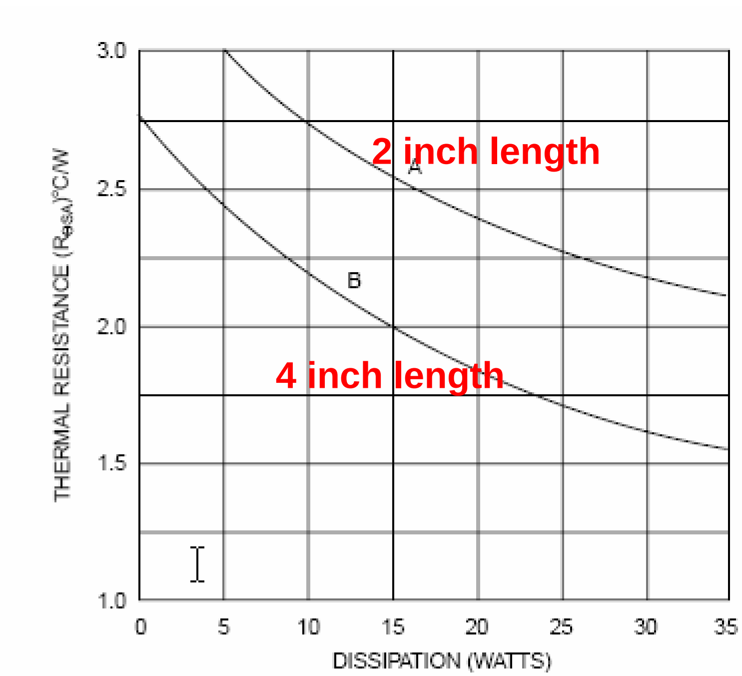
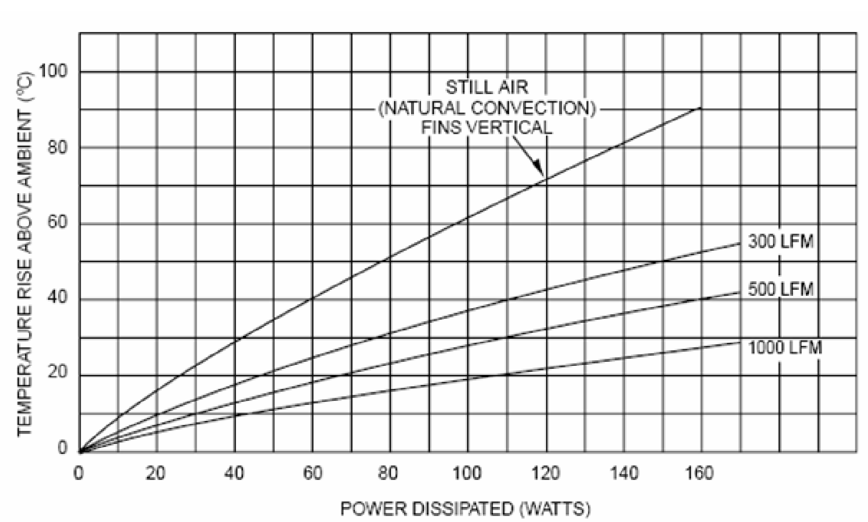


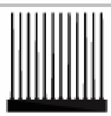
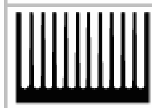
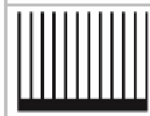
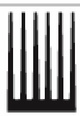
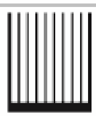
Fig. 21 Typical heat sink characteristics

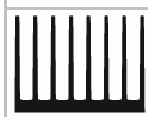
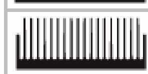
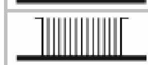


Typical free-moving air characteristics of a heavy duty heat sink, temperature rise versus power dissipated

FOR NATURAL CONVECTION EFFECTIVENESS IS HIGHER IF FIN Temperature is higher

Natural Convection Heat Sinks – Aavid Thermalloy

Profile	Part Number	Thermal Resistance °C/W at 3.00 in 999 max	Width 0-999 in	Height 0-999 in	Surface Area in?in	Part Class
	83115	3.07	0.98	0.99	22.8	C
	83120	3.81	1.16	0.79	18.4	C
	83130	3.00	1.28	0.99	23.4	C
	83135	3.08	1.30	1.92	22.7	C
	83140	2.10	1.41	1.68	33.3	C

Profile	Part Number	Thermal Resistance °C/W at 3.00 in 999 max	Width 0-999 in	Height 0-999 in	Surface Area in?in	Part Class
	73925	1.45	2.88	1.00	48.2	A
	63730	1.88	3.00	2.25	37.1	A
	65605	0.71	6.96	2.79	98.3	A
	62625	0.89	7.20	2.39	78.2	A

Examples of thermal resistances for natural convection extrusion heat sinks

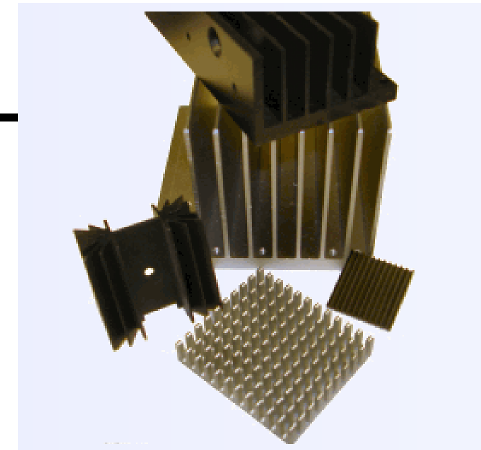
R= dT/Pw, dT= R*W,
Pw=40W; Tamb=40 deg. C
Tdevice=dT+Tamb

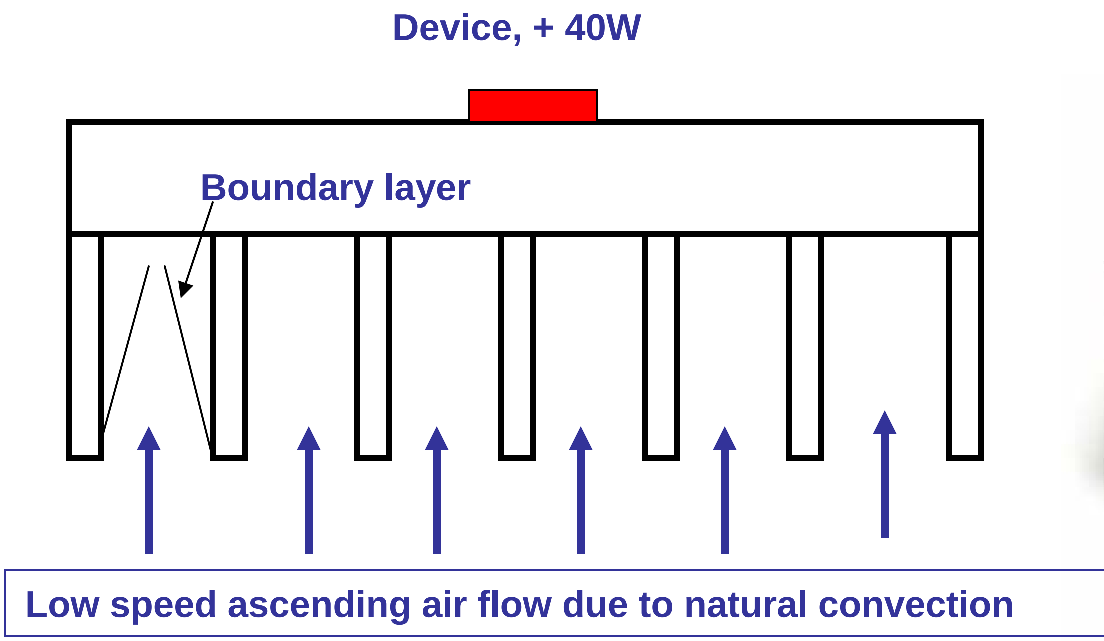
R	dT, deg
3	120
2	40
1.5	60
1	40
0.9	36
0.7	28

HEAT SINK GOT TO BE OPTIMIZED FOR BEST PERFORMANCE

Evaluate Plate Fin Heat Sink

- in this study we will evaluate and optimize basic plate fin heat sink configuration operating at natural convection conditions
- We will find operational range required to dissipate 40 W of energy
- We will presume that heat sink is oriented vertically with fins looking downward and heat release being specified on top surface

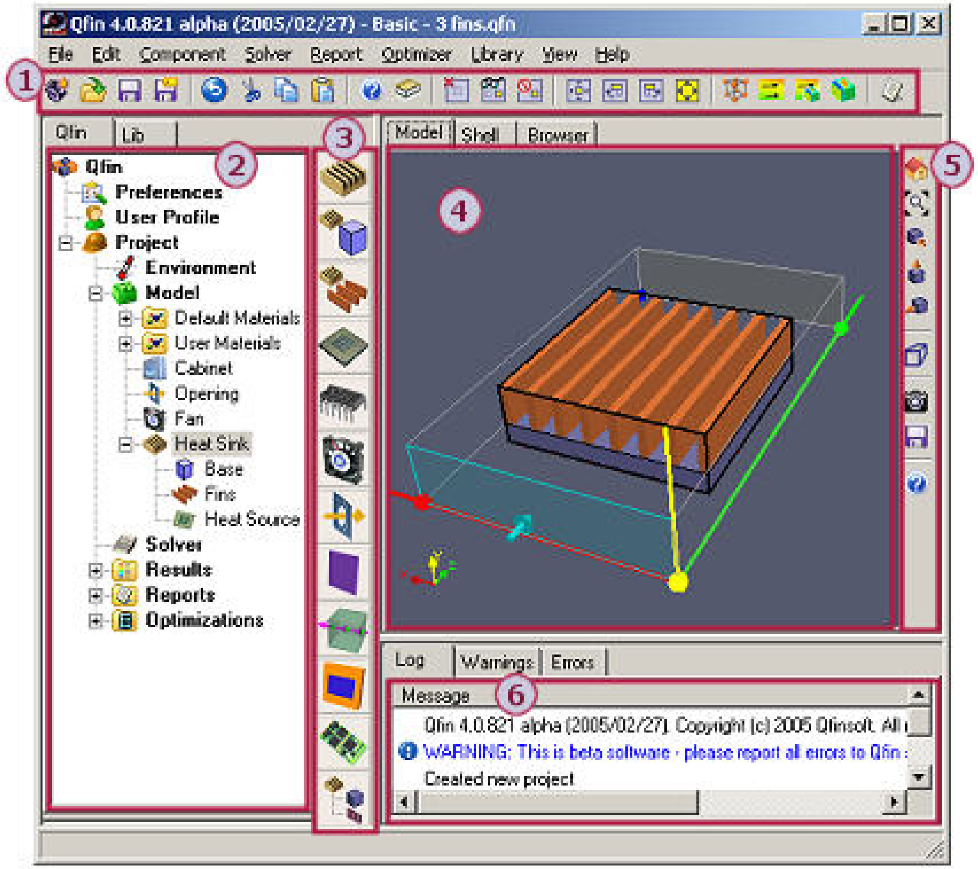




No forced convection (fan), no external wind

We want to find optimum number of fins, fin thickness, length, width, height – to maximize thermal efficiency and to minimize dimensions, volume , mass. Material – aluminum.

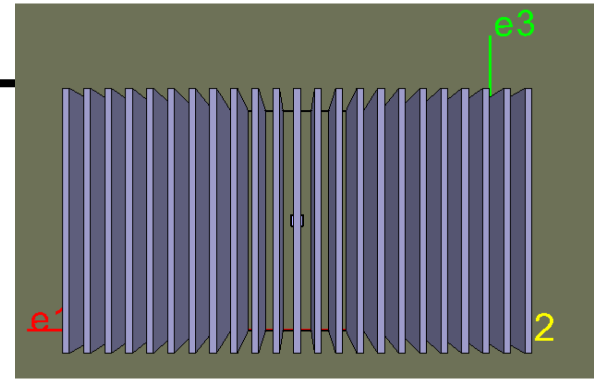
Qfin4 overview

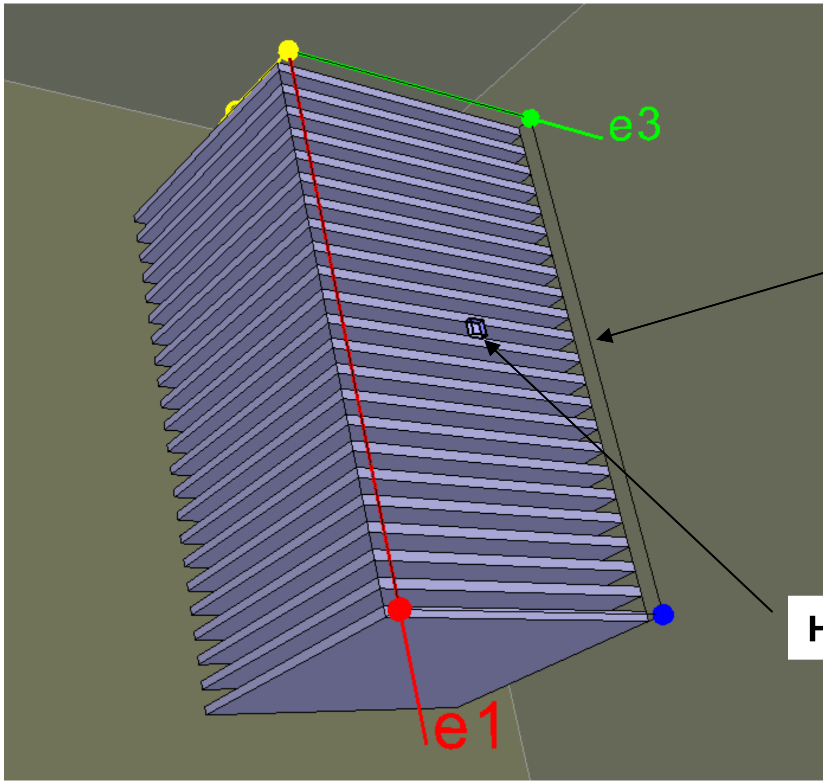


- **(1) Main Toolbar** - Often used menu commands are also present on the main toolbar.
- **(2) Simulation Manager** - Hierarchical representation of all objects in Qfin, including your project and all the components in your model.
- **(3) Component Toolbar** - All the component types that can be added to a model.
- **(4) 3D Model View** - 3D graphical display of the model and its solution.
- **(5) 3D Toolbar** - Commands for manipulating the 3D model view.
- **(6) Message Window** - Displays informative messages about Qfin's actions, including warnings and errors about problems such as invalid geometries.

Model Setup

Bottom up view:





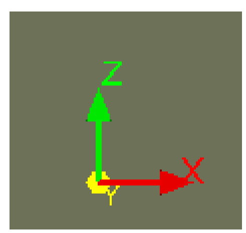
Heat sink base plate "base"
(only wireframe is shown)

Heated device (40..70 W)

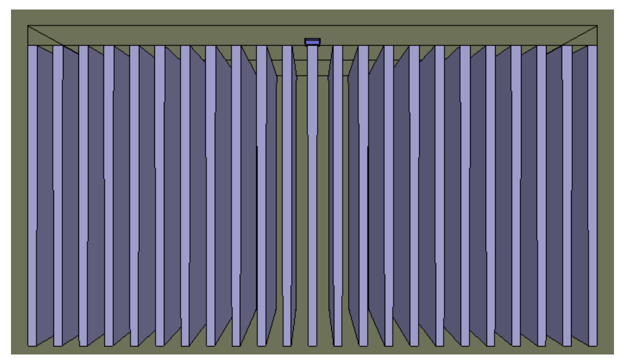
Base thickness -height (e2) can vary,
base width e1 and e3

Natural convection conditions are specified.

g

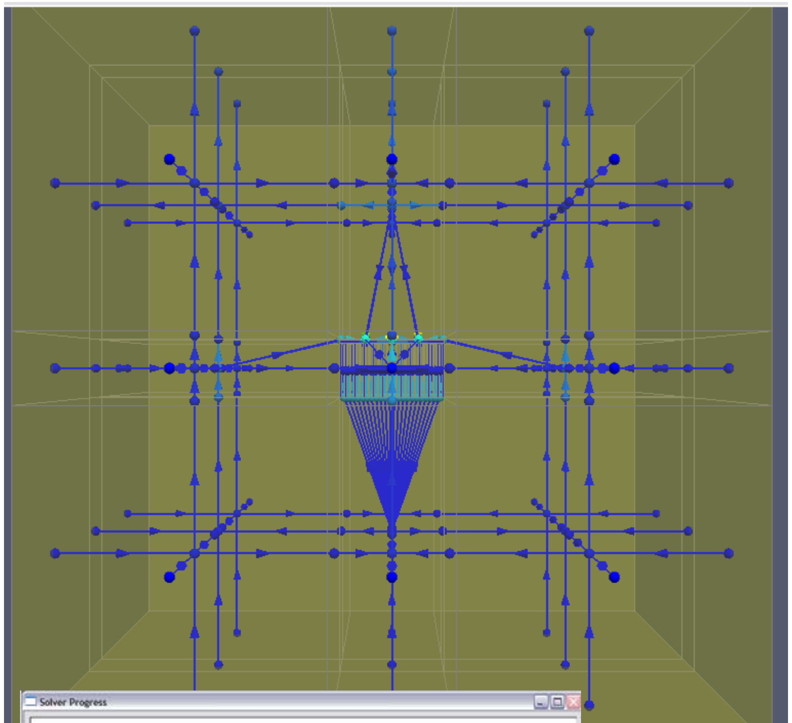


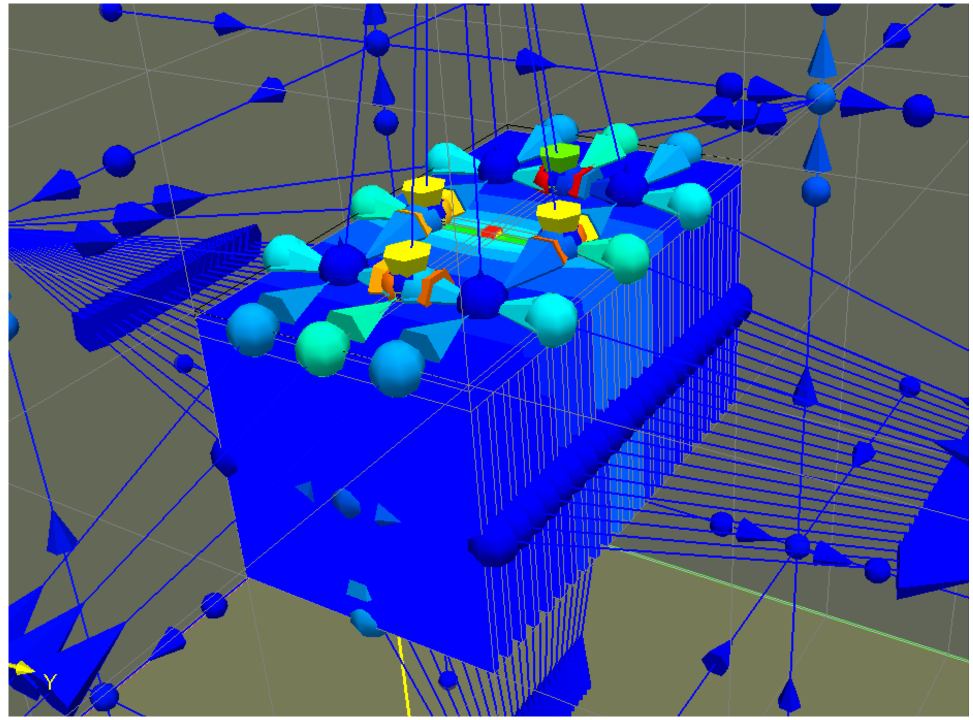
Vertical View:

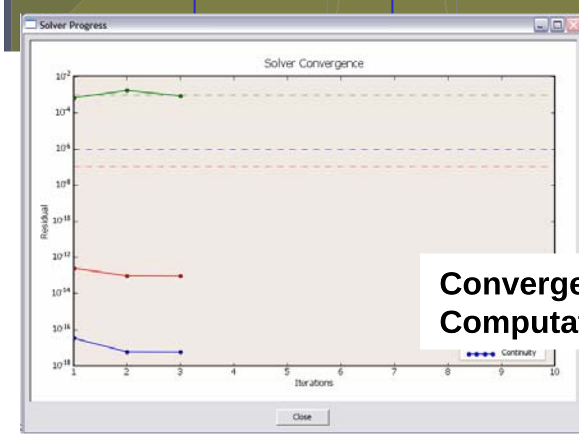


Solution: Flow Networks – Close up look

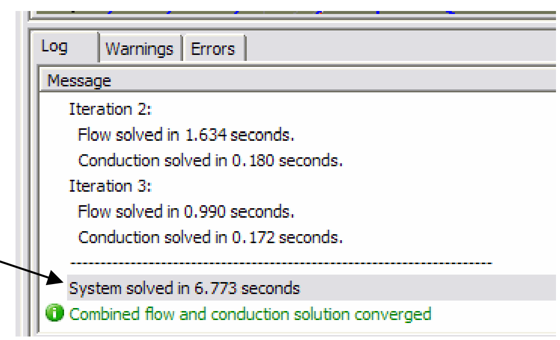
Elementary flow network is build representing fluid domain as a set of 1-dimensional channels with effective characteristics from hydraulics and heat transfer theory. Structural portion is solved as fully 3D heat transfer problem and can also account for surface to surface radiation.



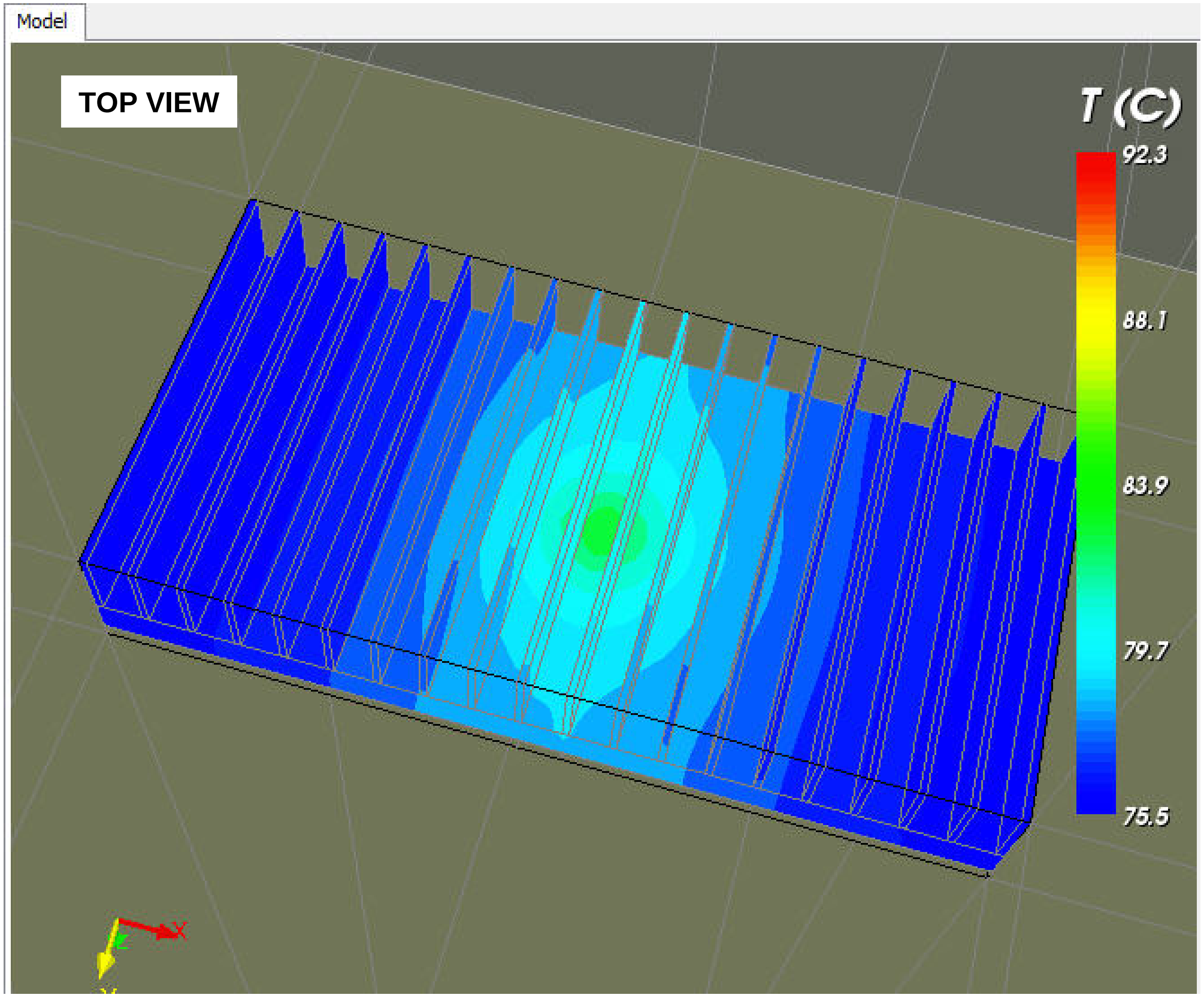




Convergence is within several iterations, Computational time – several seconds



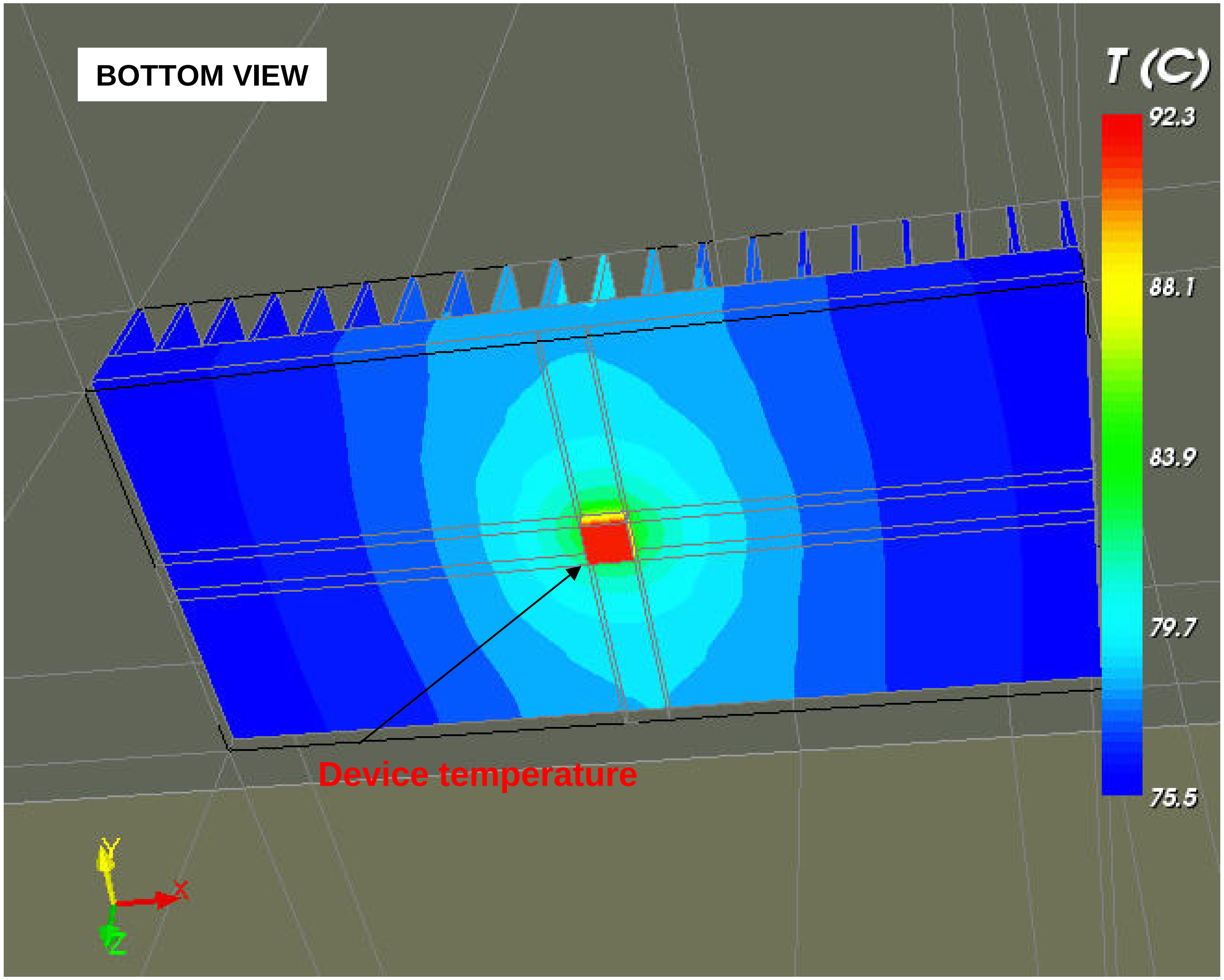
Results: baseline (1st guess) setup – 40 Watts



Baseline analysis – done in 63 sec, Tambient=25 deg. C

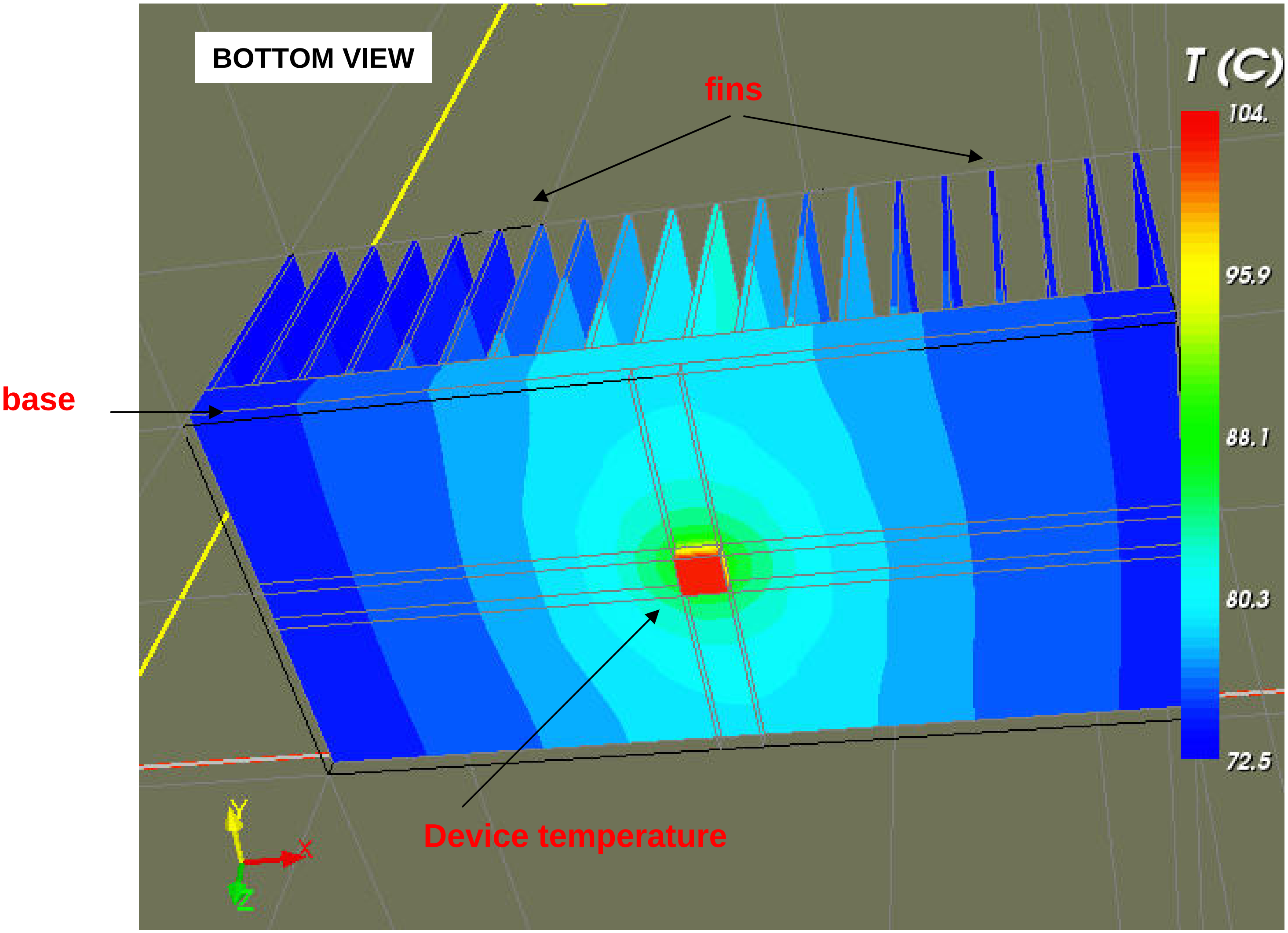
Results: baseline (1st guess) setup – 40 Watts

Tamb=25 deg. C



Optimize (size) heat sink to further reduce device temperature.

Results: 70W dissipated power



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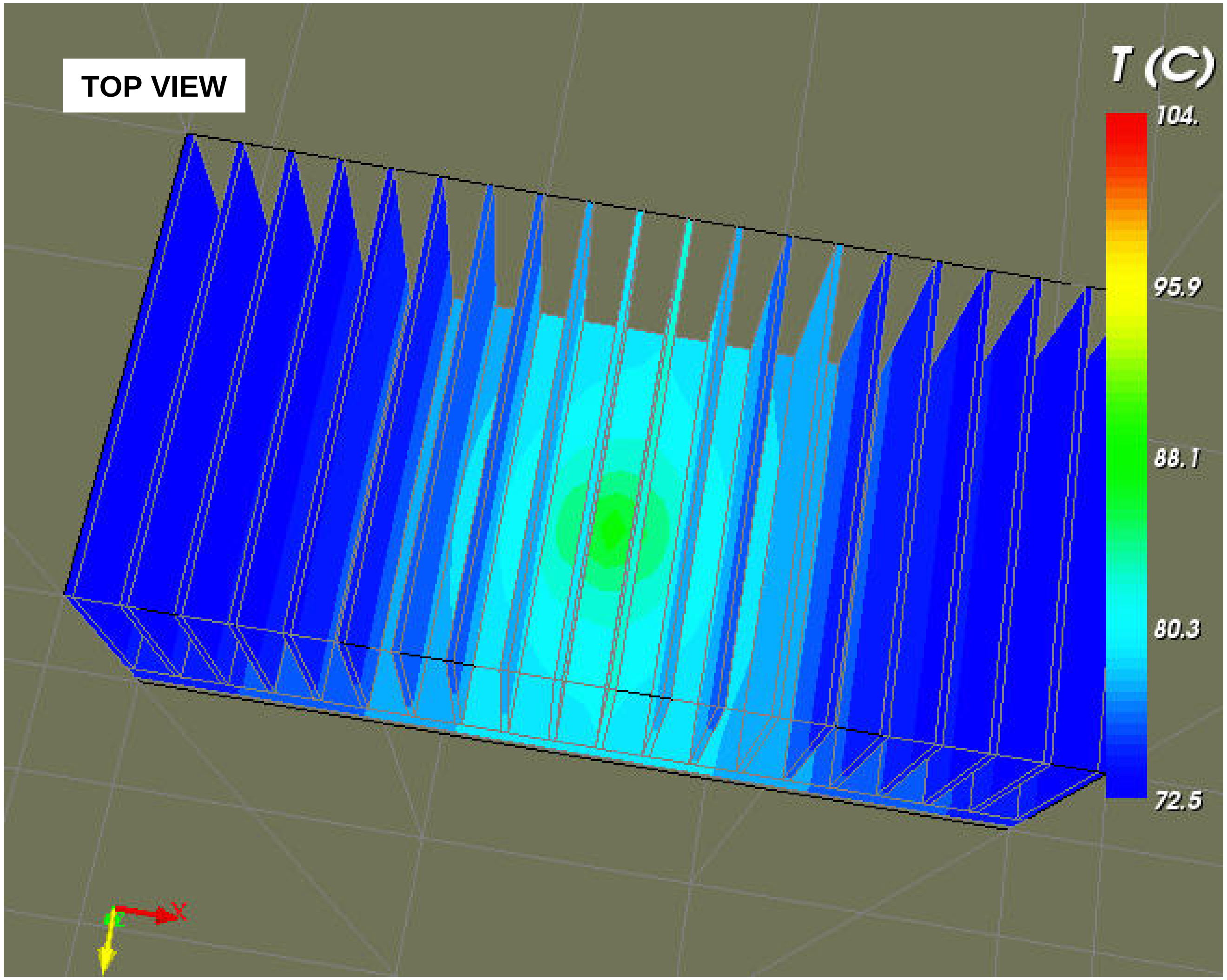
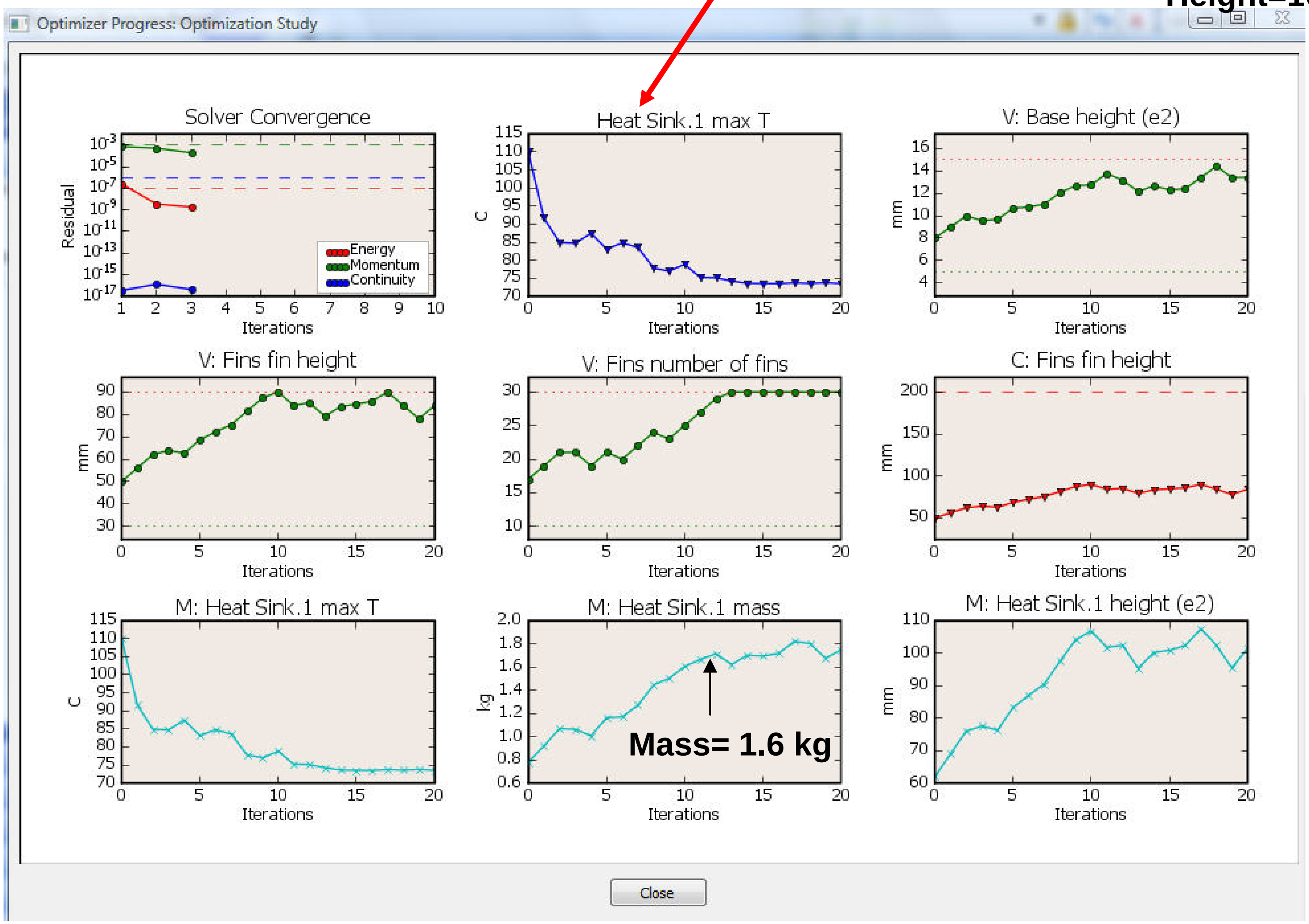


$1^{st\ round}$: Heat sink optimization results using Qfin4

Tambient=25 deg. C; 40 W

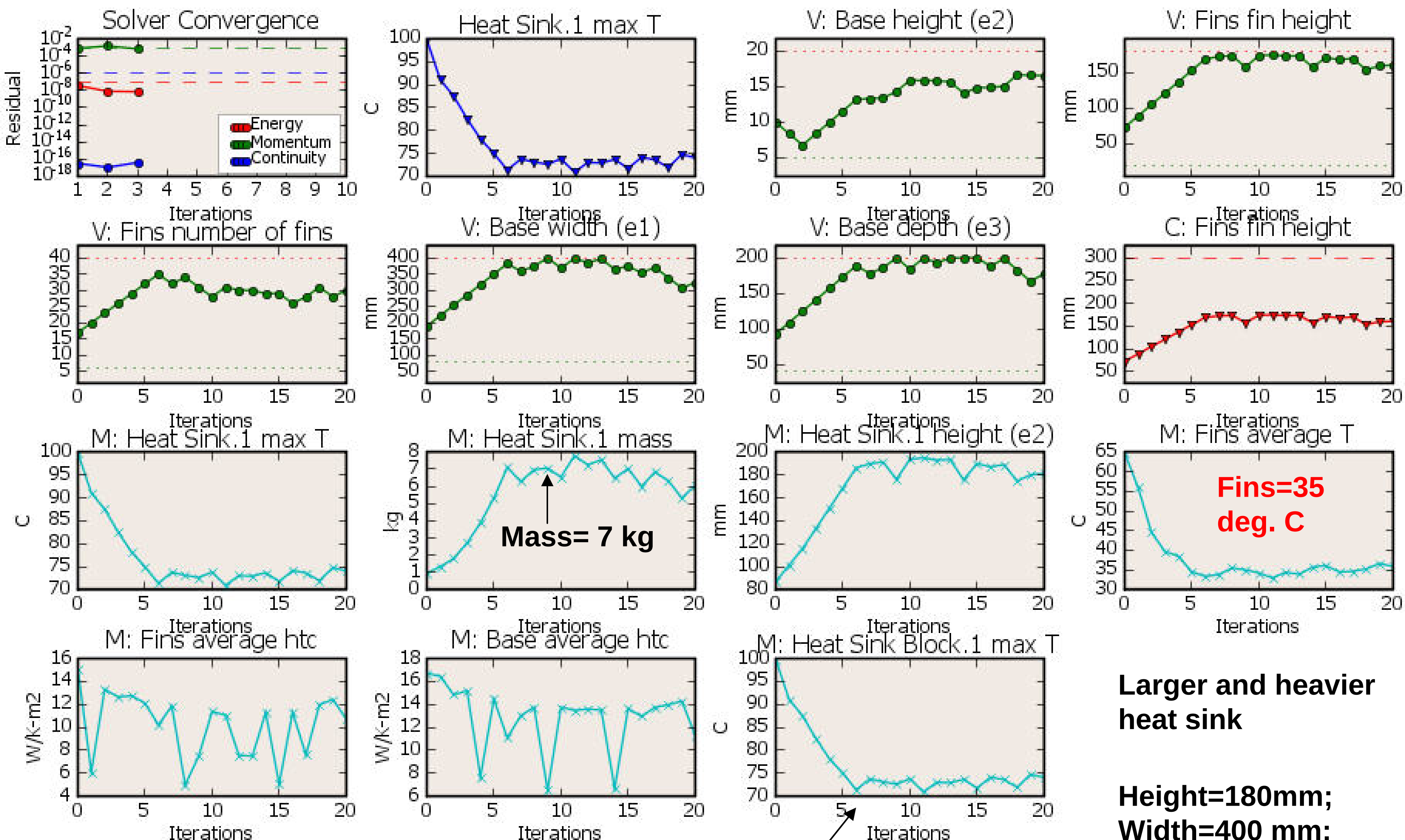
Device temperature dropped significantly
Down to 75 deg. C

Height=100; Nf=30



Each iteration corresponds to a design change in one of design variables – all driven with the objective to optimize the target function

2^{nd} round: Heat sink optimization results – 70W



fins **base**

Heat transfer coefficient

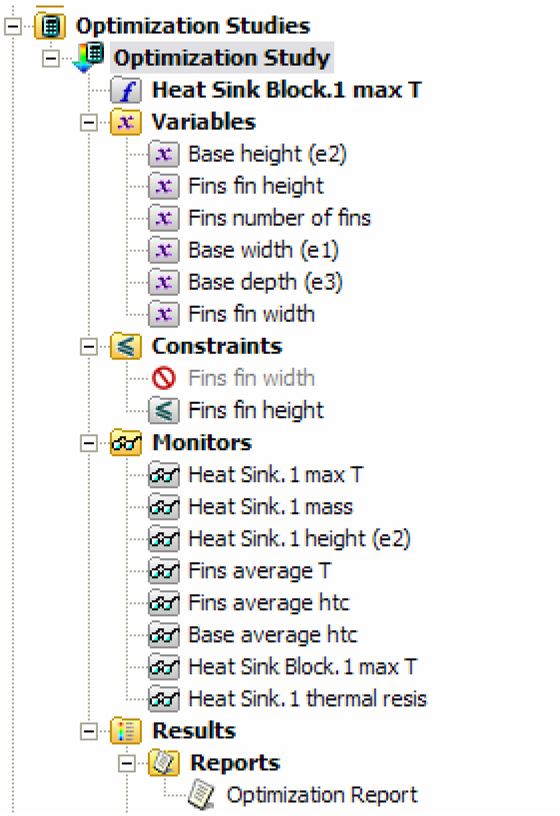
Device temperature dropped significantly down to 70 deg. C

Larger and heavier heat sink

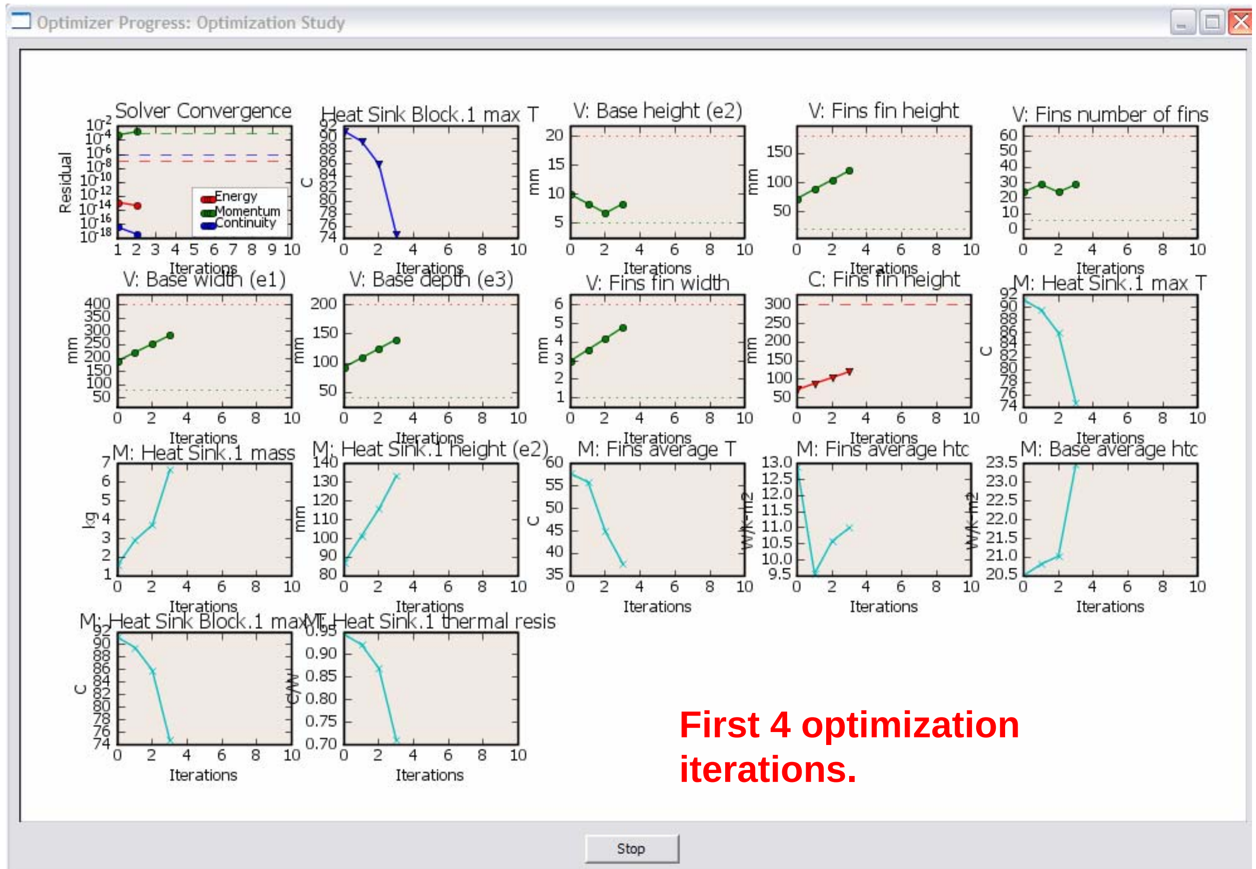
Height=180mm;
Width=400 mm;
depth=200 mm;
Nf=25…30

3rd round: Optimization Run, 70 W power

Optimization setup:



Expanded heat sink envelope



First 4 optimization iterations.

3rd round : Optimization Results

Tamb=25 deg. C

Designs/Iterations

- Start: 91.21 C (21st)
- Iter1: 89.57 C (20th)
- Iter2: 85.91 C (19th)
- Iter3: 74.72 C (4th)
- Iter4: 81.35 C (16th)
- Iter5: 77.67 C (13th)
- Iter6: 76.85 C (8th)
- Iter7: 79.27 C (15th)
- Iter8: 82.15 C (18th)
- Iter9: 82.03 C (17th)
- Iter10: 76.17 C (6th)
- Iter11: 78.93 C (14th)
- Iter12: 77.05 C (10th)
- Iter13: 77.40 C (11th)
- Iter14: 75.72 C (5th)
- Iter15: 76.85 C (9th)
- Iter16: 71.61 C (1st)
- Iter17: 77.48 C (12th)
- Iter18: 72.10 C (3rd)
- Iter19: 71.76 C (2nd)
- Iter20: 76.17 C (7th)

Device maximum temperature 71.6 deg C (best result)

Design
Iteration: 0
Rank: 21
Feasible: YES
Objective function:
Heat Sink Block.1 max T = 91.21 C
Variables:
1: Base height (e2) = 10.0 mm
2: Fins fin height = 73.0 mm
3: Fins number of fins = 24
4: Base width (e1) = 190.0 mm
5: Base depth (e3) = 93.0 mm
6: Fins fin width = 3.0 mm
Constraints:
1: Fins fin height = 73.0 mm
Monitors:
1: Heat Sink.1 max T = 91.21 C
2: Heat Sink.1 mass = 1.58 kg
3: Heat Sink.1 height (e2) = 87.0 mm
4: Fins average T = 57.78 C
5: Fins average htc = 12.9 W/K-m2
6: Base average htc = 20.5 W/K-m2
7: Heat Sink Block.1 max T = 91.21 C
8: Heat Sink.1 thermal resis = 0.946 C/W

Design
Iteration: 3
Rank: 4
Feasible: YES
Objective function:
Heat Sink Block.1 max T = 74.72 C
Variables:
1: Base height (e2) = 8.4 mm
2: Fins fin height = 121.0 mm
3: Fins number of fins = 29
4: Base width (e1) = 286.0 mm
5: Base depth (e3) = 141.0 mm
6: Fins fin width = 4.8 mm
Constraints:
1: Fins fin height = 121.0 mm
Monitors:
1: Heat Sink.1 max T = 74.72 C
2: Heat Sink.1 mass = 6.66 kg
3: Heat Sink.1 height (e2) = 133.4 mm
4: Fins average T = 37.72 C
5: Fins average htc = 11.0 W/K-m2
6: Base average htc = 23.5 W/K-m2
7: Heat Sink Block.1 max T = 74.72 C
8: Heat Sink.1 thermal resis = 0.710 C/W

Design
Iteration: 6
Rank: 8
Feasible: YES
Objective function:
Heat Sink Block.1 max T = 76.85 C
Variables:
1: Base height (e2) = 8.1 mm
2: Fins fin height = 119.9 mm
3: Fins number of fins = 30
4: Base width (e1) = 280.6 mm
5: Base depth (e3) = 141.9 mm
6: Fins fin width = 4.6 mm
Constraints:
1: Fins fin height = 119.9 mm
Monitors:
1: Heat Sink.1 max T = 76.85 C
2: Heat Sink.1 mass = 6.53 kg
3: Heat Sink.1 height (e2) = 132.0 mm
4: Fins average T = 39.02 C
5: Fins average htc = 10.9 W/K-m2
6: Base average htc = 21.6 W/K-m2
7: Heat Sink Block.1 max T = 76.85 C
8: Heat Sink.1 thermal resis = 0.741 C/W

R=dt/W

Design
Iteration: 10
Rank: 6
Feasible: YES
Objective function:
Heat Sink Block.1 max T = 76.17 C
Variables:
1: Base height (e2) = 8.5 mm
2: Fins fin height = 161.9 mm
3: Fins number of fins = 23
4: Base width (e1) = 308.5 mm
5: Base depth (e3) = 155.6 mm
6: Fins fin width = 6.0 mm
Constraints:
1: Fins fin height = 161.9 mm
Monitors:
1: Heat Sink.1 max T = 76.17 C
2: Heat Sink.1 mass = 9.71 kg
3: Heat Sink.1 height (e2) = 174.4 mm
4: Fins average T = 37.09 C
5: Fins average htc = 8.8 W/K-m2
6: Base average htc = 21.0 W/K-m2
7: Heat Sink Block.1 max T = 76.17 C
8: Heat Sink.1 thermal resis = 0.731 C/W

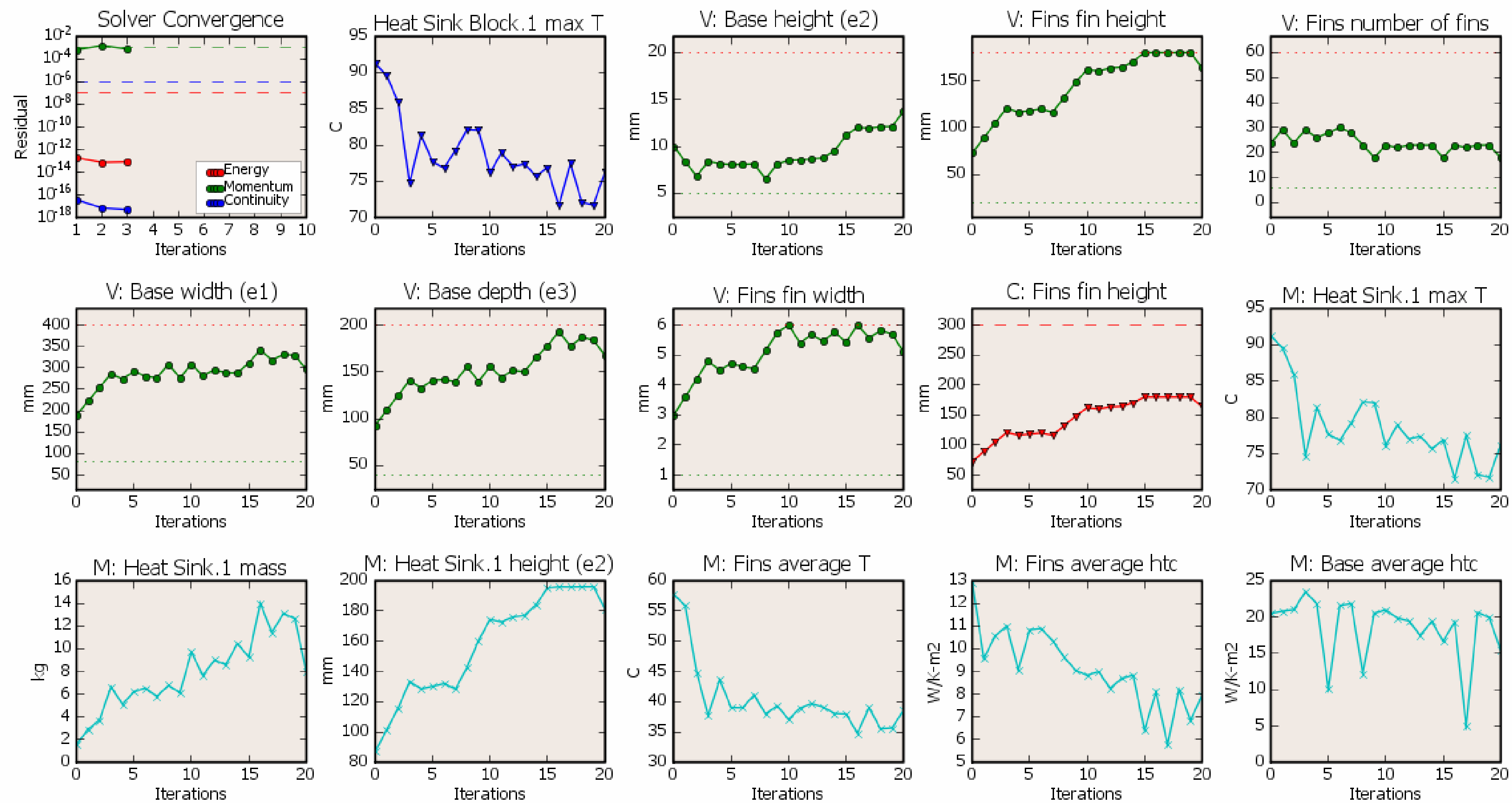
Design
Iteration: 16
Rank: 1
Feasible: YES
Objective function:
Heat Sink Block.1 max T = 71.61 C
Variables:
1: Base height (e2) = 12.0 mm
2: Fins fin height = 180.0 mm
3: Fins number of fins = 23
4: Base width (e1) = 342.7 mm
5: Base depth (e3) = 193.3 mm
6: Fins fin width = 6.0 mm
Constraints:
1: Fins fin height = 180.0 mm
Monitors:
1: Heat Sink.1 max T = 71.61 C
2: Heat Sink.1 mass = 14.0 kg
3: Heat Sink.1 height (e2) = 196.0 mm
4: Fins average T = 34.80 C
5: Fins average htc = 8.1 W/K-m2
6: Base average htc = 19.3 W/K-m2
7: Heat Sink Block.1 max T = 71.61 C
8: Heat Sink.1 thermal resis = 0.666 C/W

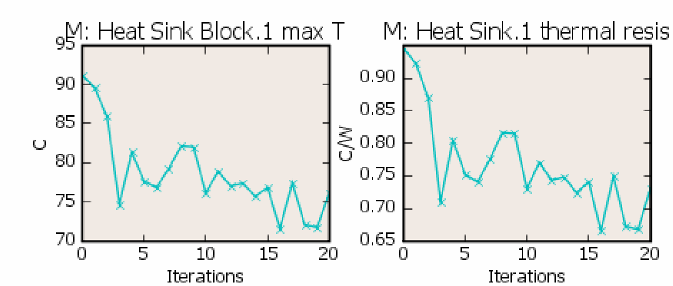
Design
Iteration: 19
Rank: 2
Feasible: YES
Objective function:
Heat Sink Block.1 max T = 71.76 C
Variables:
1: Base height (e2) = 12.1 mm
2: Fins fin height = 180.0 mm
3: Fins number of fins = 23
4: Base width (e1) = 328.9 mm
5: Base depth (e3) = 183.9 mm
6: Fins fin width = 5.7 mm
Constraints:
1: Fins fin height = 180.0 mm
Monitors:
1: Heat Sink.1 max T = 71.76 C
2: Heat Sink.1 mass = 12.7 kg
3: Heat Sink.1 height (e2) = 196.1 mm
4: Fins average T = 35.67 C
5: Fins average htc = 6.9 W/K-m2
6: Base average htc = 19.9 W/K-m2
7: Heat Sink Block.1 max T = 71.76 C
8: Heat Sink.1 thermal resis = 0.668 C/W

Every optimization case can be separately exported for additional runs, both in Qfin and in Icepak.

Optimization Results - Plots

Tamb=25 deg. C



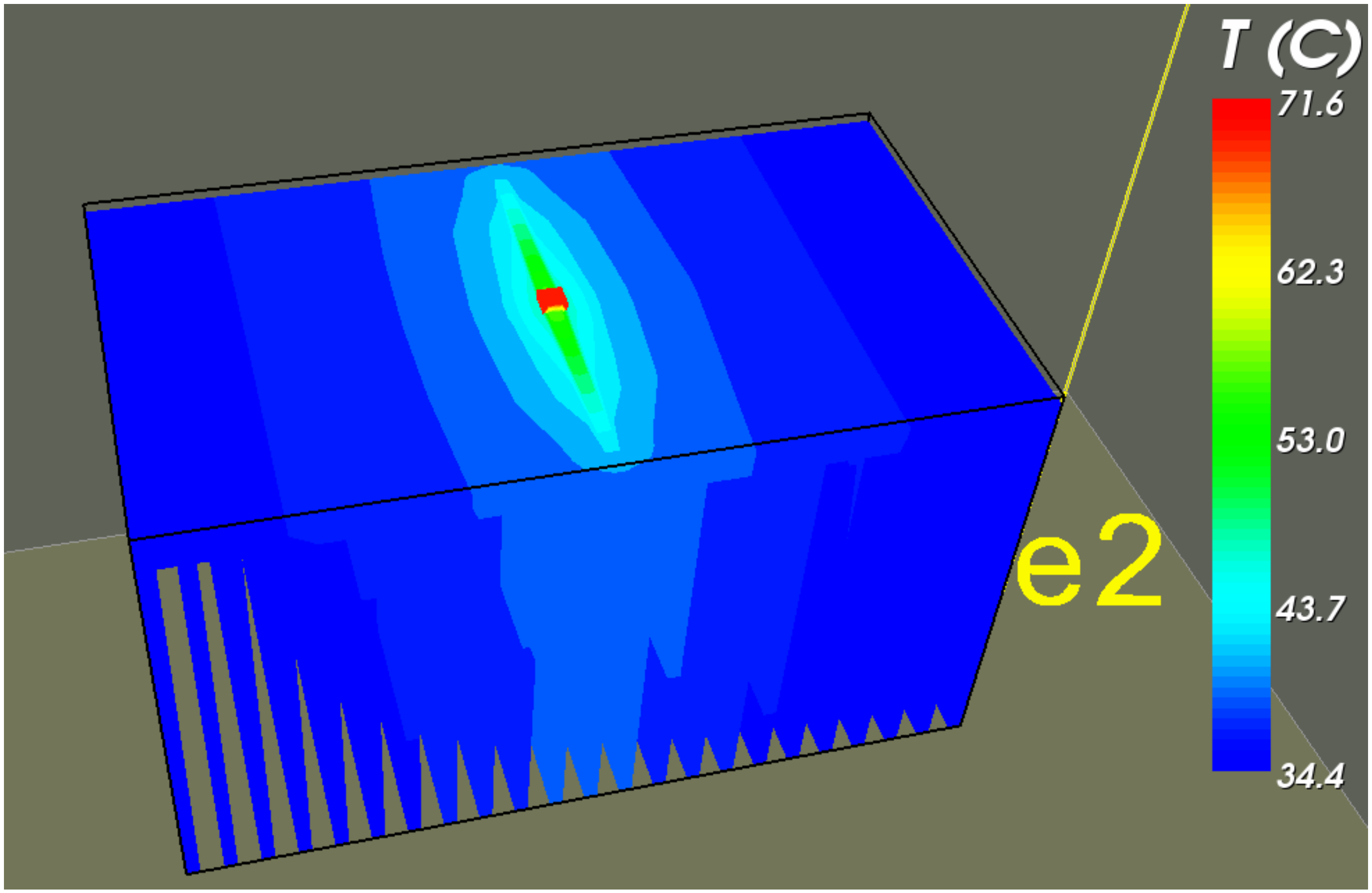


Thermal resistance dropped significantly, but heat sink mass increased almost 7 times.

Additional optimization restrictions may be required for mass and for fin thickness.

3rd round : Thermal Distribution (1st rank)

Tamb=25 deg. C



Third round analysis, best ranking (lowest device temperature)

Heat Sink optimization process provides best result (rank) within the system of constraints, it is not necessarily absolutely best solution, many rounds of optimization can be performed. However, considerable improvement is usually achieved in the first round.

Conclusions:

- Large solar cell heat sink can be optimized for natural convection applications to meet target temperature in the 40 ..70 W range
- Temperature can be limited to 72 deg. C, at 25 deg ambient), but heat sink mass will vary between 2kg (91 deg. C) to 14 kg at 72 deg. C
- Further improvement may be possible by optimizing fin width
- Fin heat transfer coefficient varies between 7 to 11 W/(mK)
- Qfin4 is a very powerful and practical optimization tool that allows easy multi-variable optimization and also parametric trials.
- Virtually every heat sink characteristic can be part of optimization process (variable or target function).