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Multi-objective optimization of a strip-fin microchannel heatsink

Alberto Clarich, Nader Fateh, Rosario Russo*

ESTECO, Trieste, Italy
ESTECO NA, Miami FL, U.S.A.

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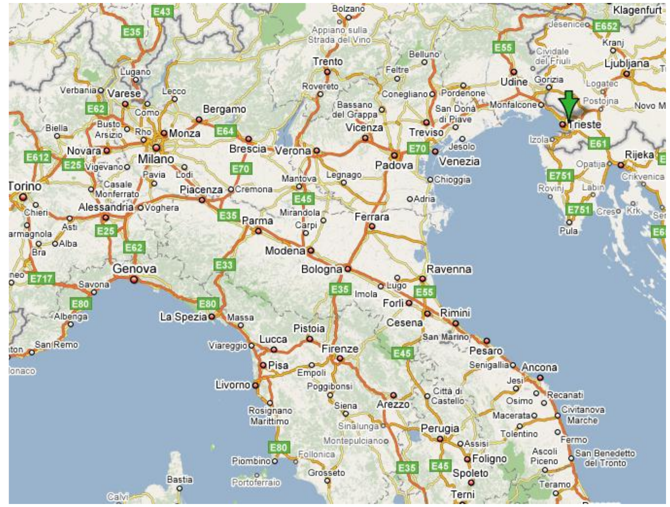

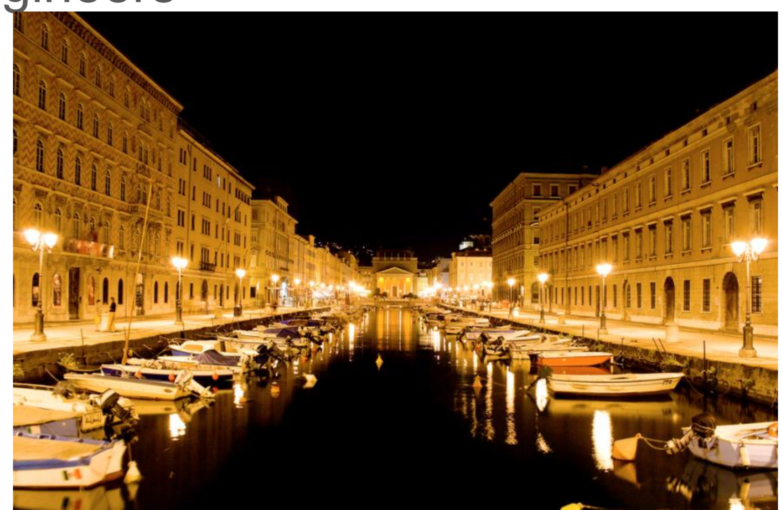

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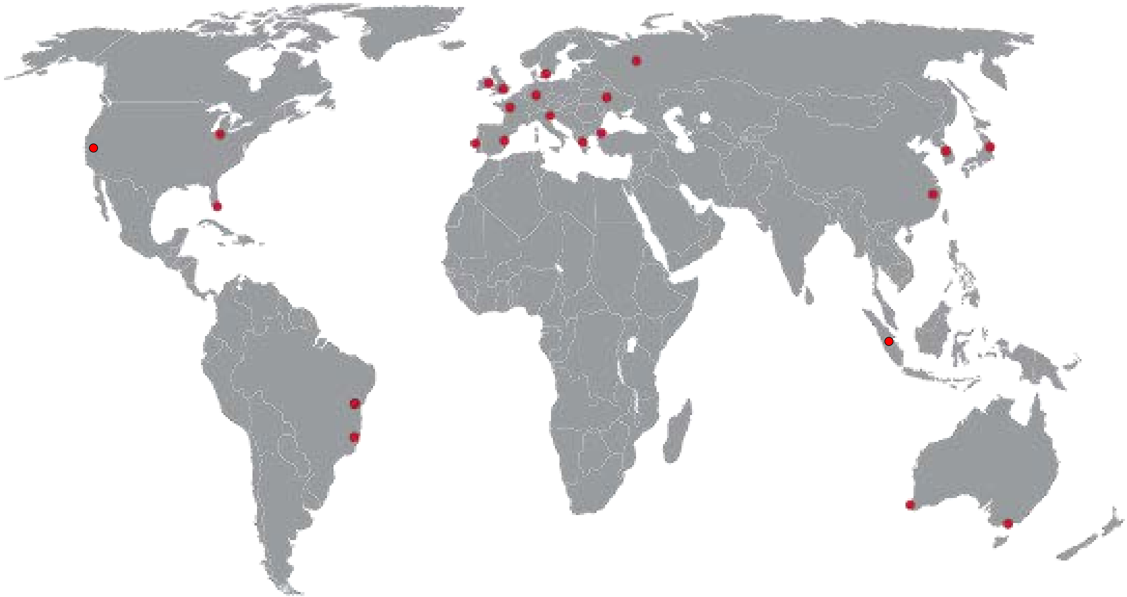
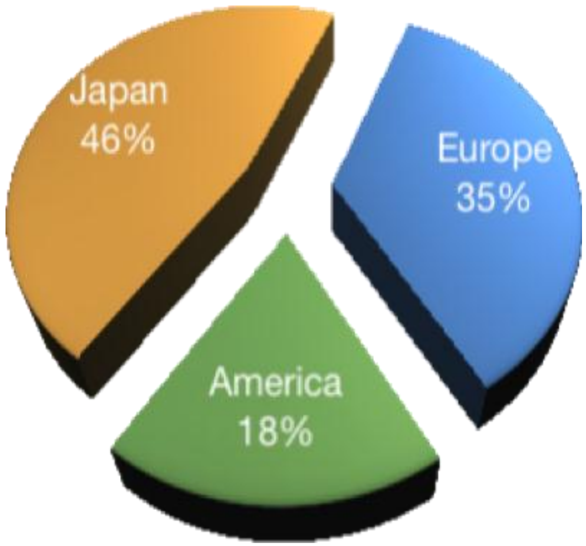
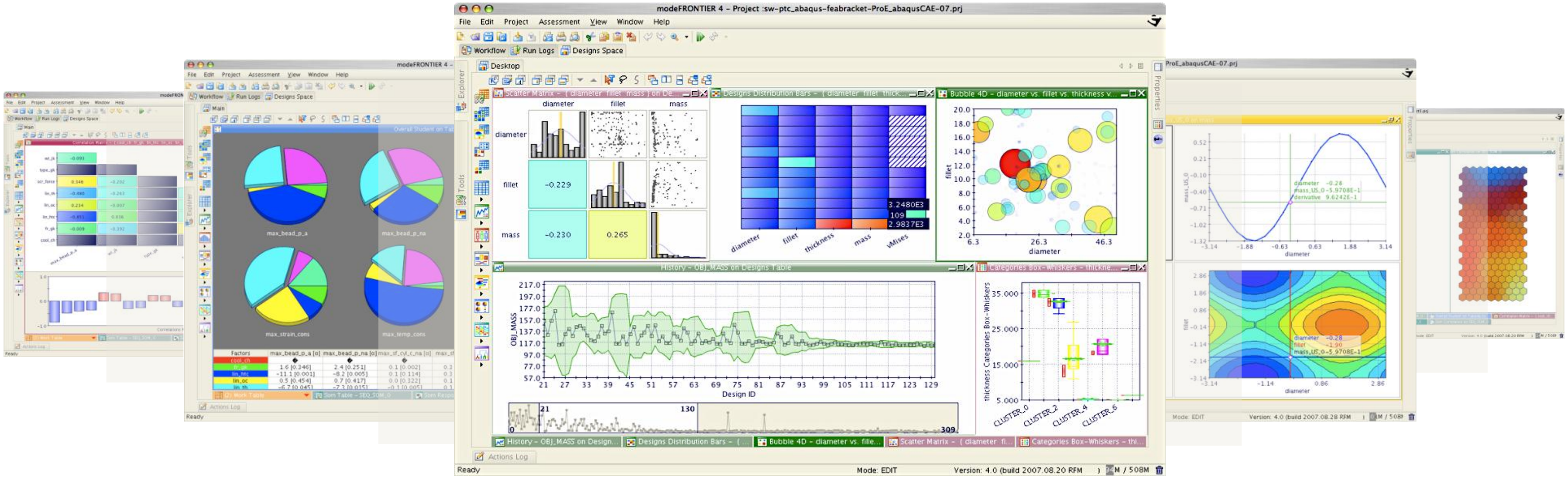




modeFRONTIER



modeFRONTIER is a multi-objective optimization and design environment, written to allow easy coupling to almost any computer aided engineering (CAE) tool, whether commercial or in-house.

The electronic chip temperature control problem

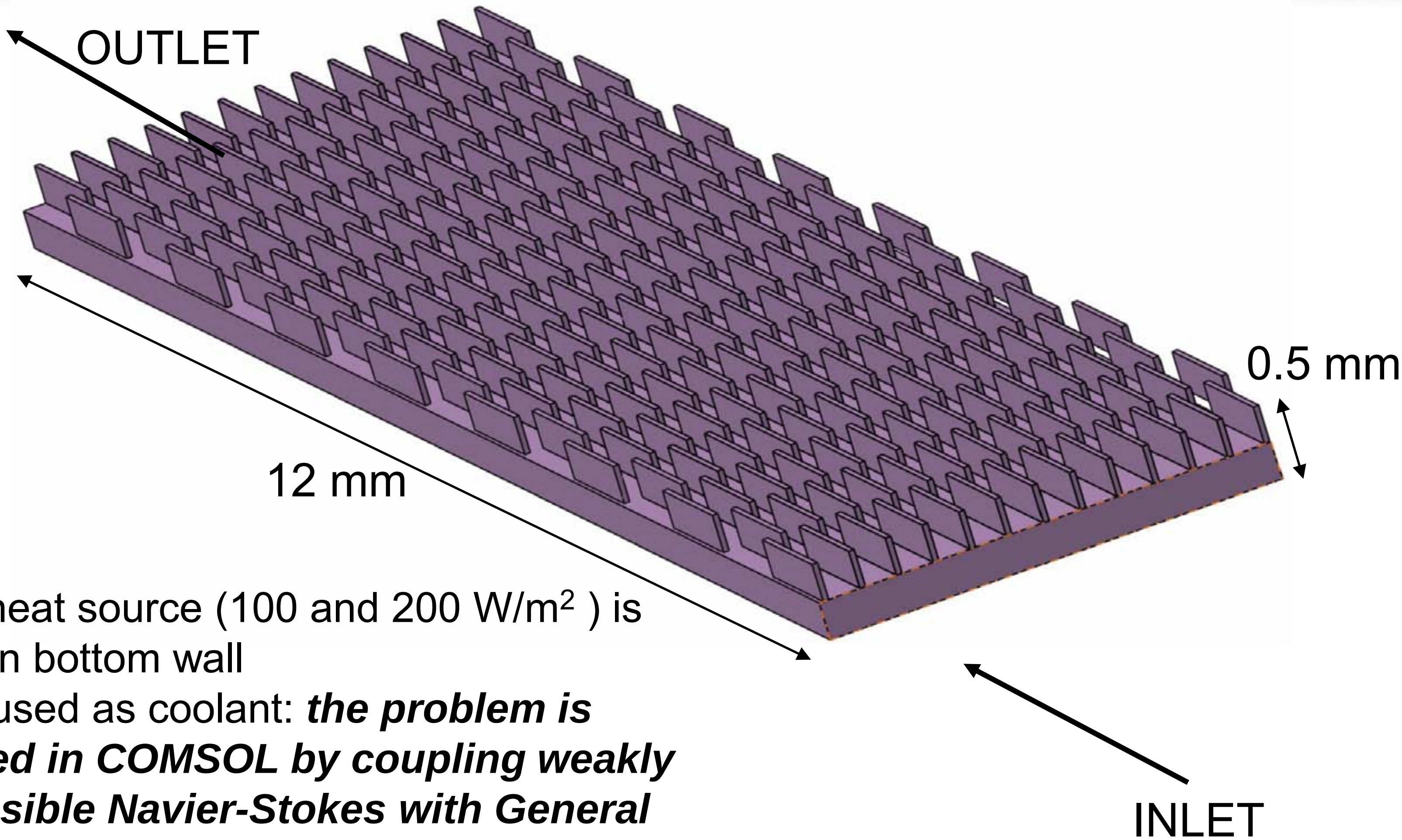
Cooling in micro-electronic devices could become a major problem in the near future.

Different requirements have to be satisfied:

•higher and higher heat fluxes need to be removed in order to avoid component overheating.
•the temperature of the chip must be kept as uniform as possible.

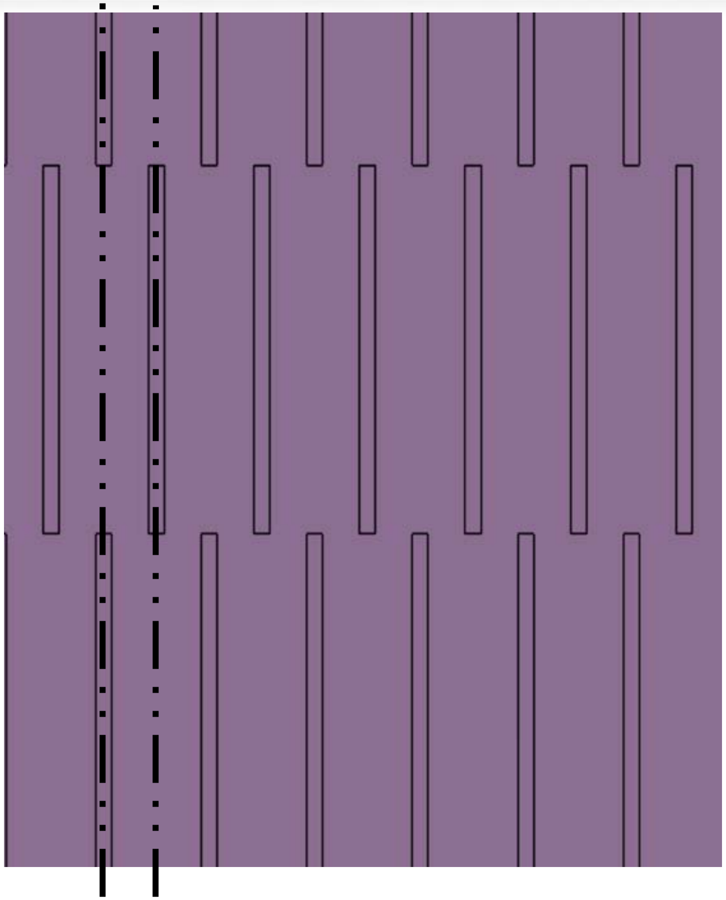
A possible solution is to employ liquid cooled systems, with a coolant flowing across rows of microchannel heatsinks

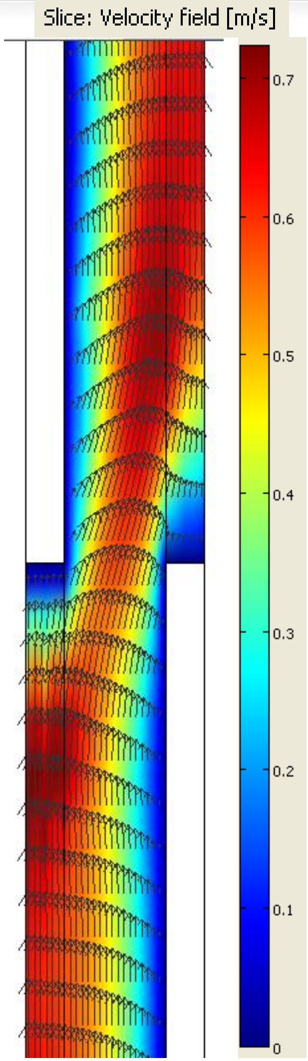
Strip-fin microchannel heat sink: Problem Definition

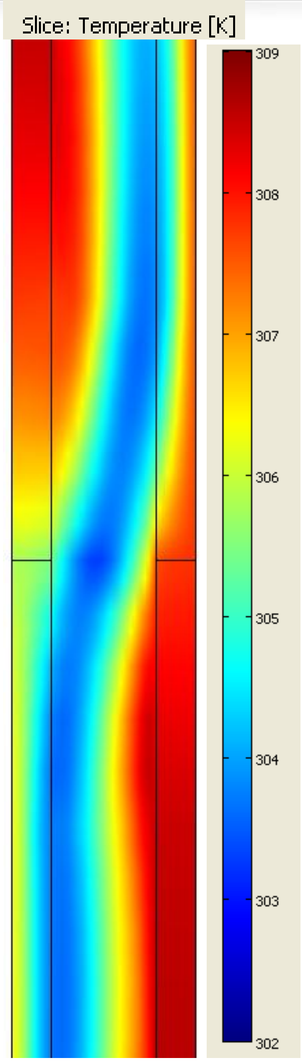


- Uniform heat source (100 and 200 W/m^2) is defined on bottom wall
- Water is used as coolant: ***the problem is addressed in COMSOL by coupling weakly compressible Navier-Stokes with General Heat Transfer models***

Strip-fin microchannel heat sink: COMSOL model







- 1channel is defined in COMSOL (symmetry bounds)
- Hexahedral mesh is used, about 200k degrees of freedom

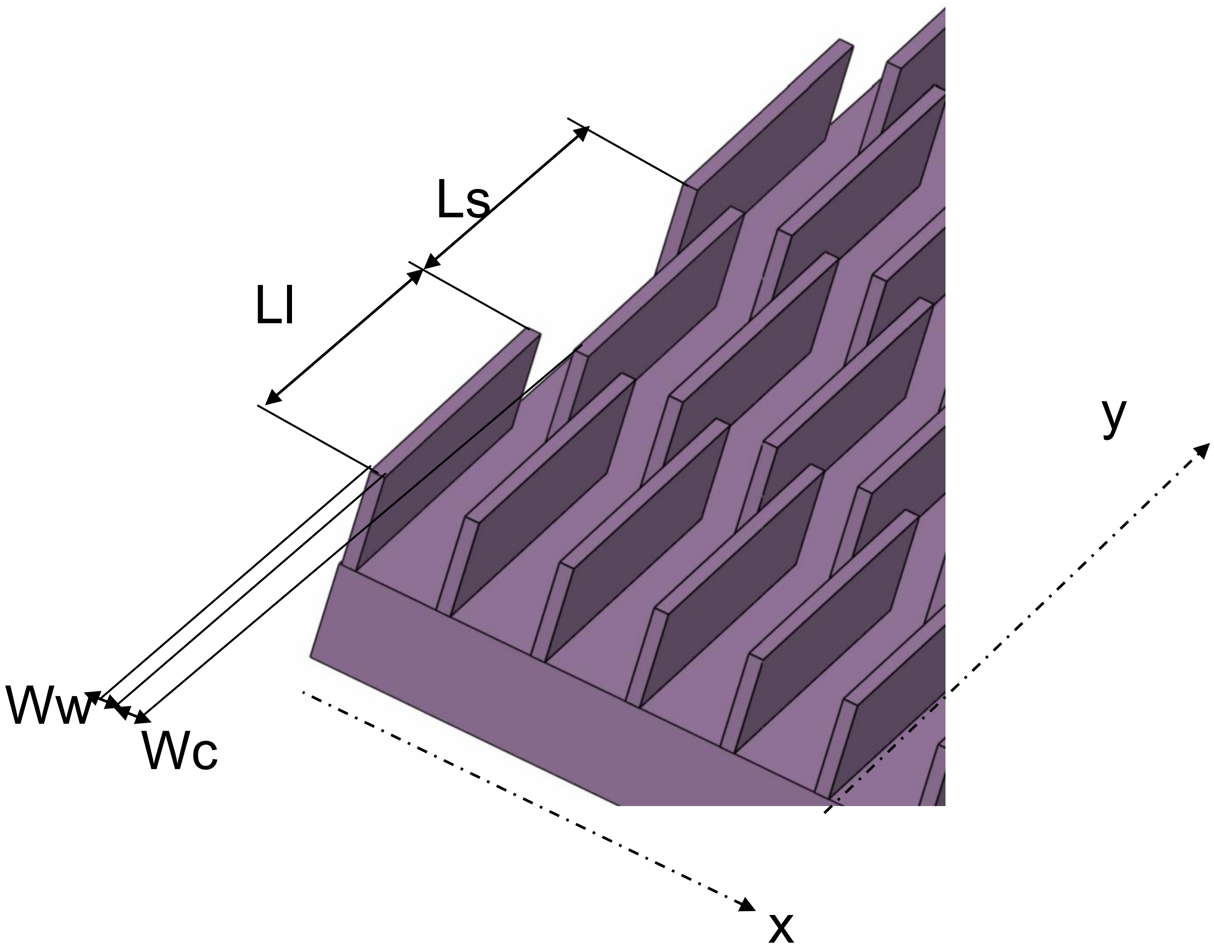
Strip-fin microchannel heat sink: Objectives and constraint

<u>Multi-objective constrained problem</u>

1. **Delta T** between maximum and minimum solid temperature (namely temperature difference on the chip) ***to be minimized***
2. **Requested pump power *to be minimized***
3. **Maximum chip temperature *less than 344 K*** (+ additional constraint on the maximum pump power)

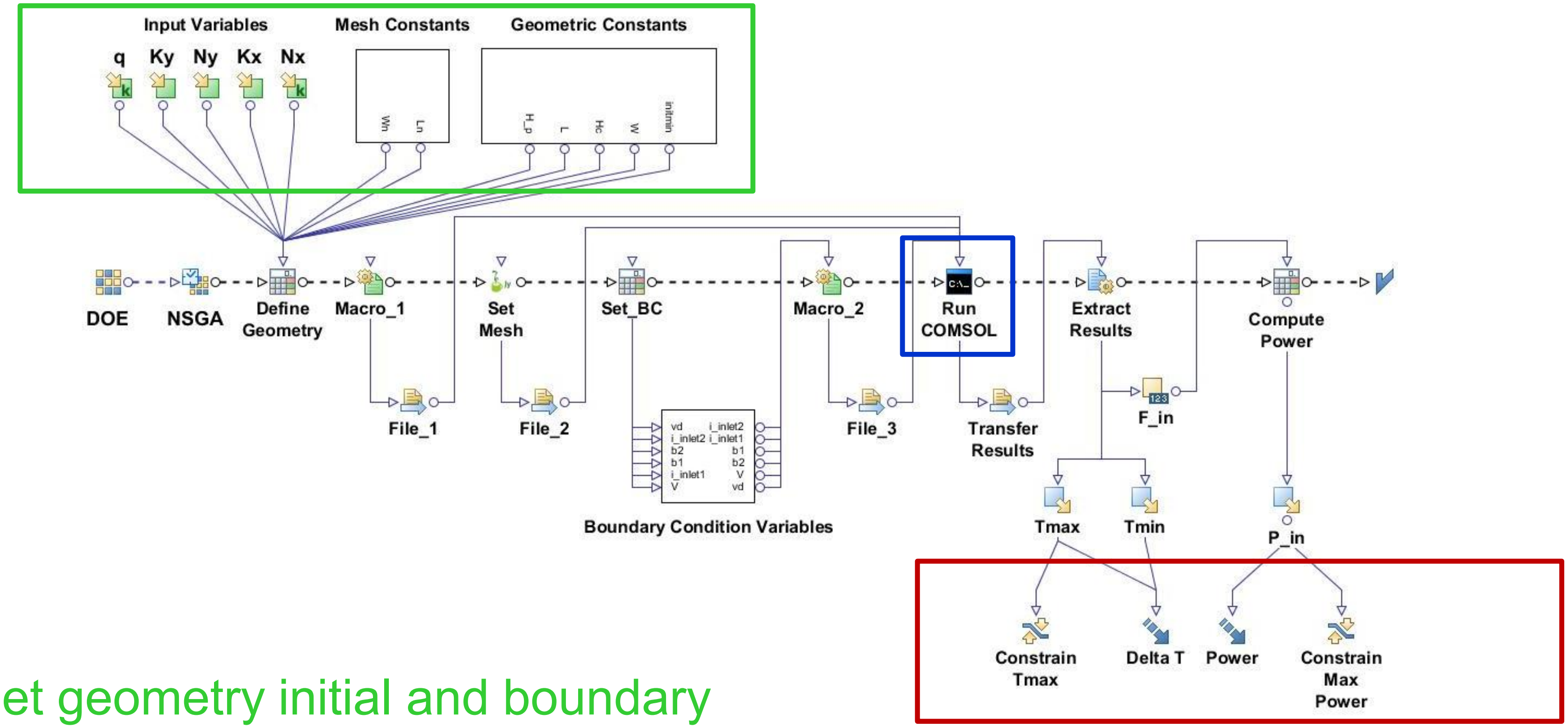
The optimization problem involves a set of *<u>discrete and continuous variables.</u>*

Strip-fin microchannel heat sink: Parameters



- Kx = Ww/Wc
- Ky = Ll/Ls
- Nx = fins nr along x
- Ny = fins nr along y
- M = mass flow [kg/s]

modeFRONTIER workflow for Comsol integration



Set geometry initial and boundary conditions in the .m file according to the free parameters chosen by modeFrontier

Run Comsol in batch mode

Extract corresponding objectives and constraints values

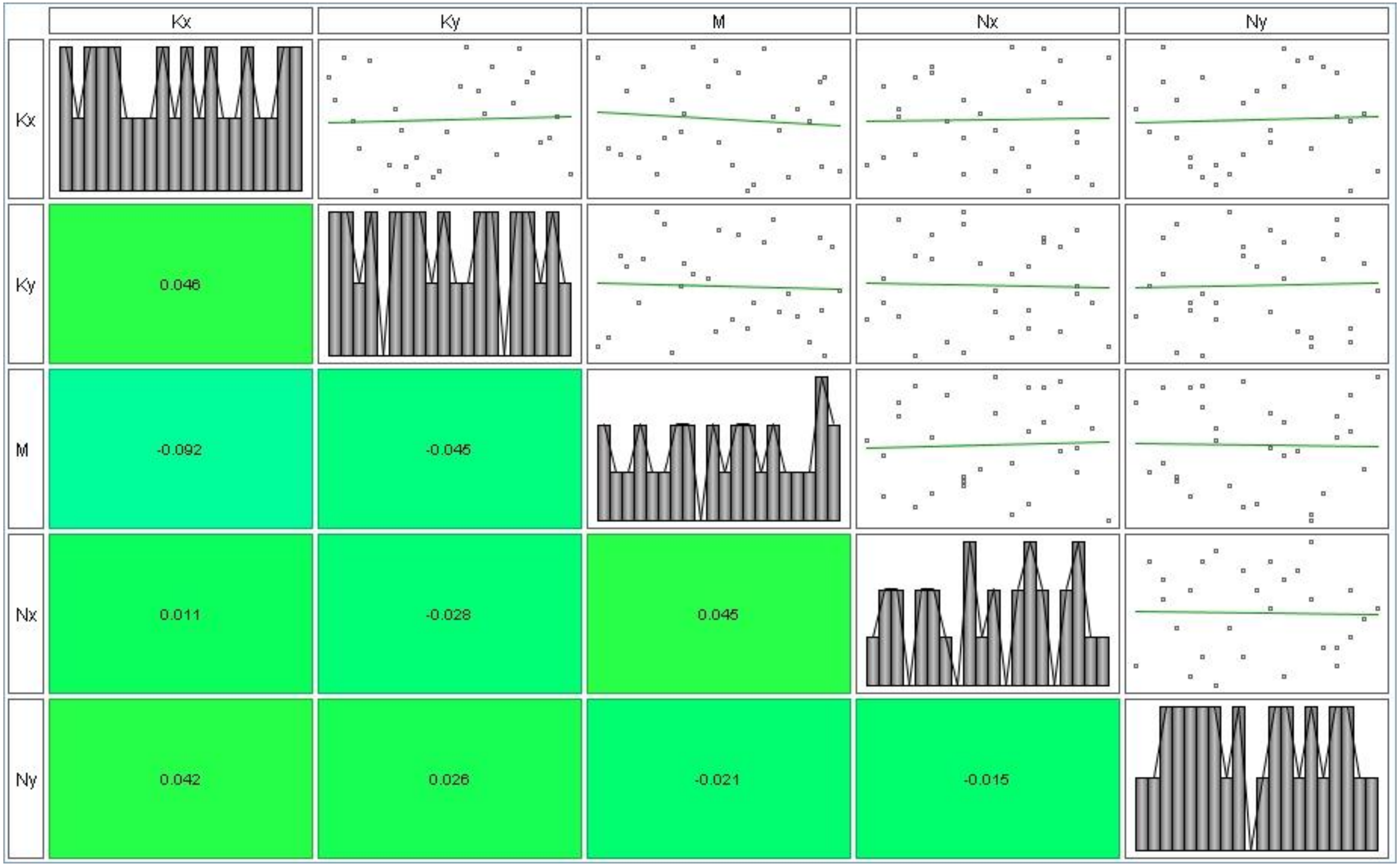
Heat sink optimization: Description of strategy

1. Preliminary Design Exploration → **Design Of Experiments**

2. Selection of best area in the design space → **Correlation analysis**

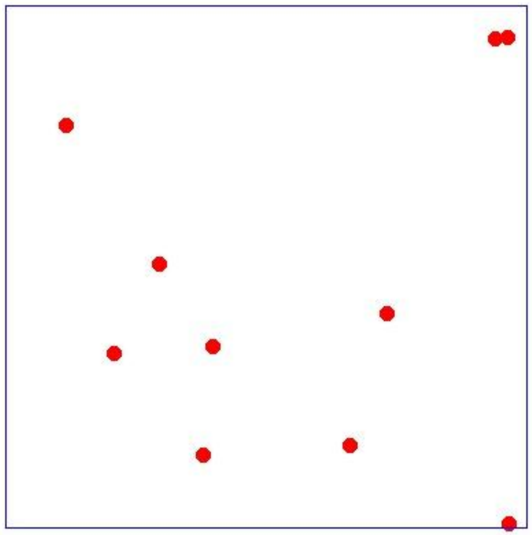
3. Search of optimal solutions → **Optimization**

1. DOE Definition (30 samples by Uniform Latin Hypercube)



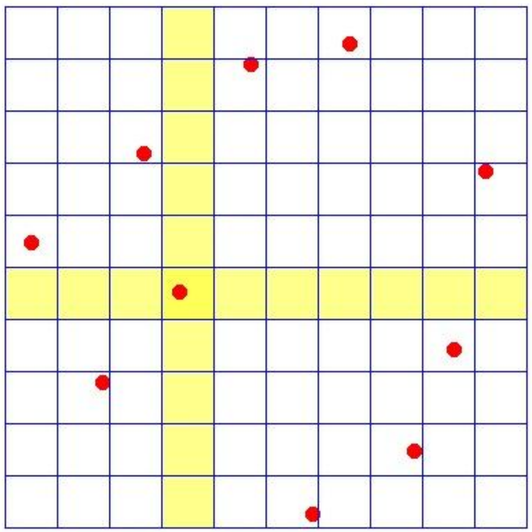
Uniform Latin Hypercube

Random (Monte Carlo)



n = 10

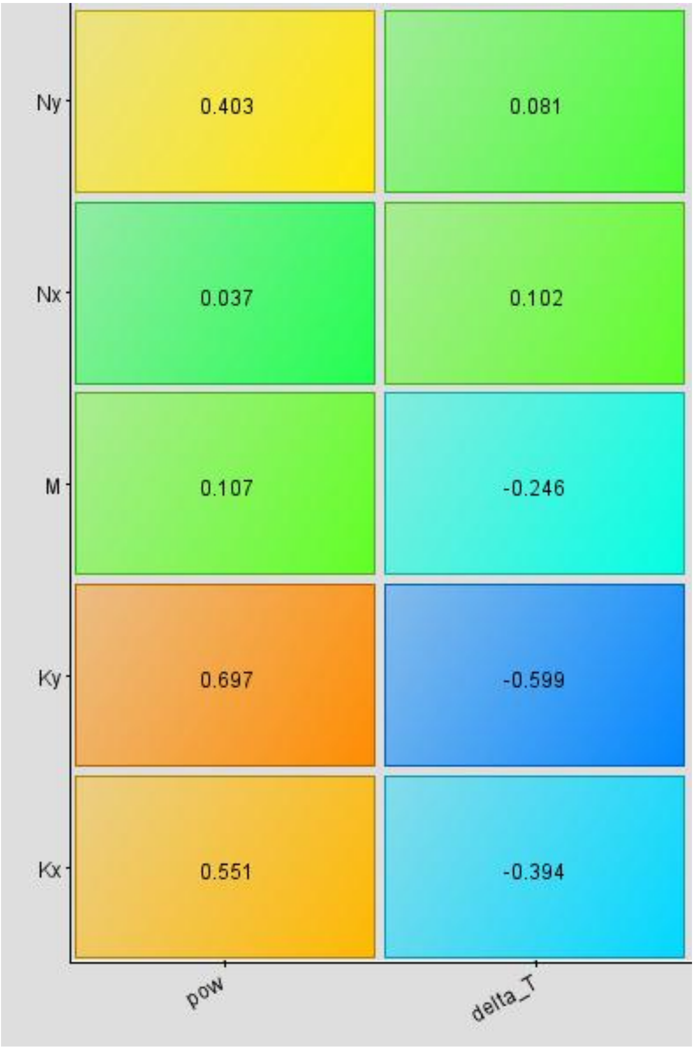
Uniform Latin Hypercube



n values are chosen independently, according to the global uniform density function

the uniform statistical distribution is split in *n* intervals with the same probability, and then a random value is selected within each interval
Uniformity is better guaranteed!

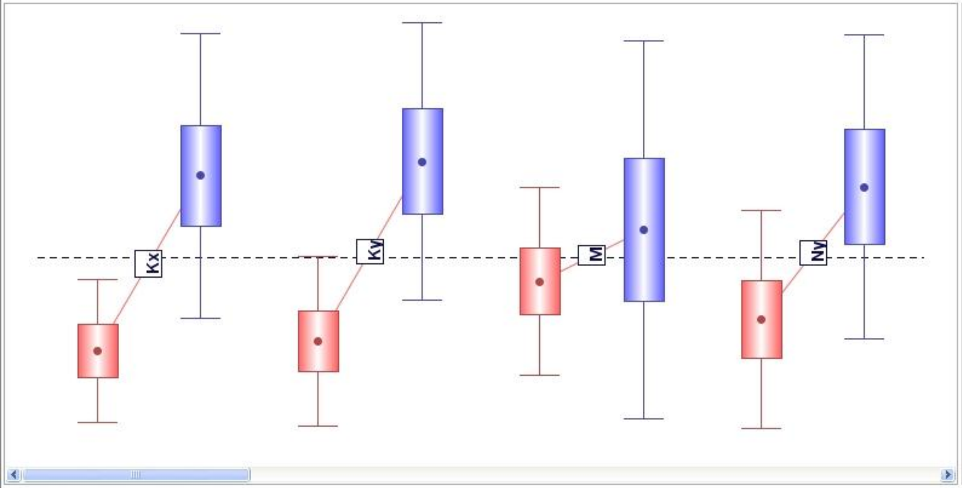
DOE Analysis: Parameters significance

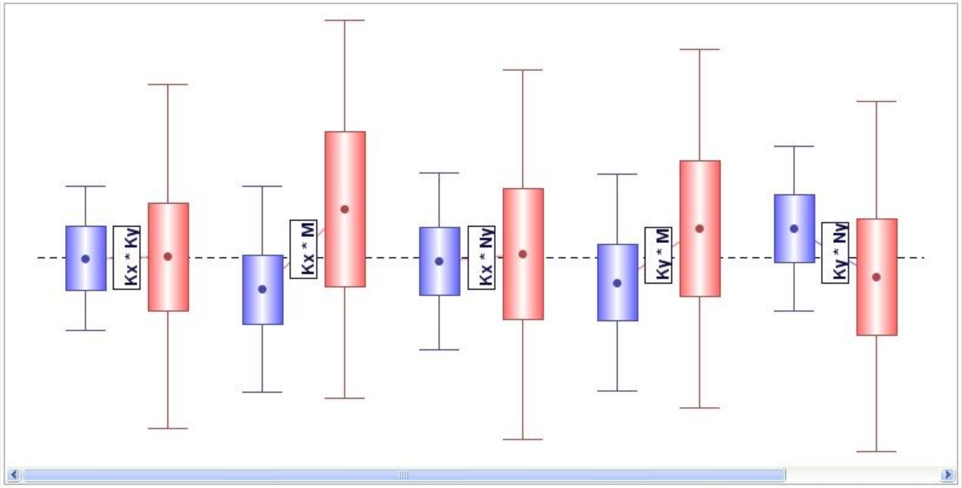


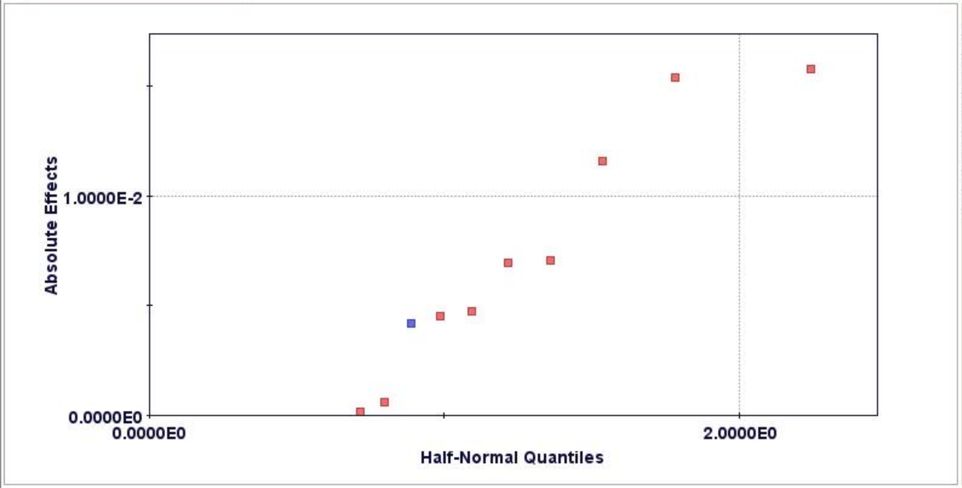
- Nx not much significant: can be kept as constant
- Ny mainly direct with pow: upper bound can be reduced
- M mainly inversely with delta_T: lowe bound can be raised
- Ky and Kx: contrasting and important for both objs, bounds unchanged

DOE Analysis: Parameters significance

Factor Analysis: effects on pump power



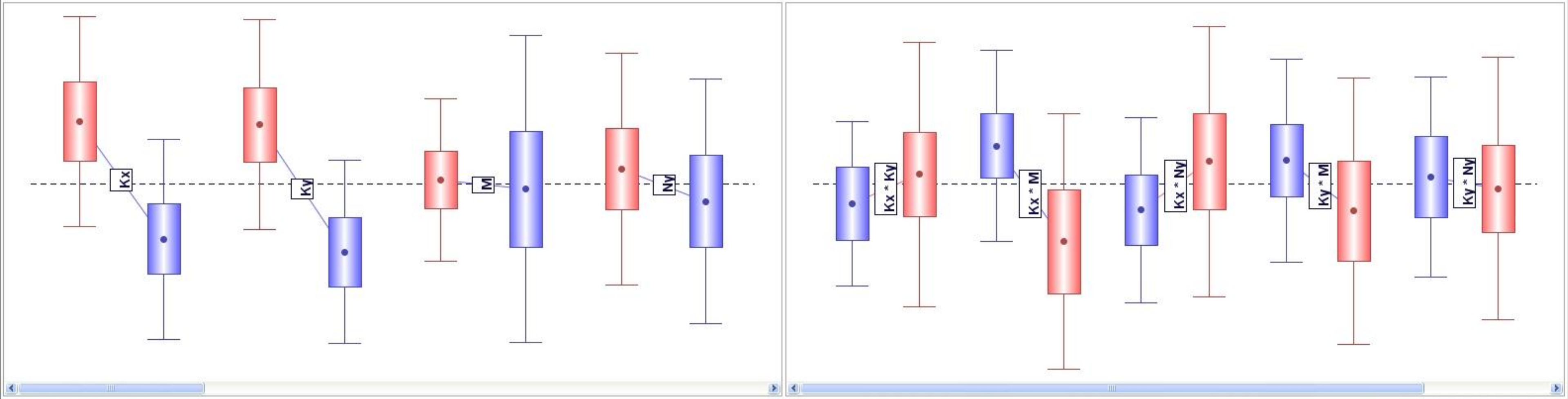


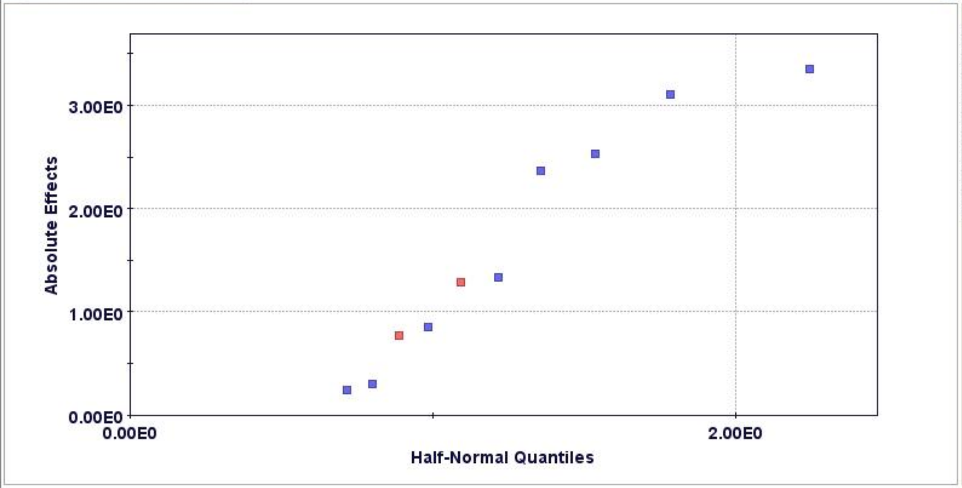


Factors	Effect
Ky	1.5826E-2
Kx	1.5399E-2
Ny	1.1617E-2
Kx * M	7.0738E-3
M * Ny	6.9906E-3
Ky * M	4.7576E-3
M	4.5174E-3
Ky * Ny	-4.2218E-3
Kx * Ny	6.1869E-4
Kx * Ky	1.4080E-4

DOE Analysis: Parameters significance

Factor Analysis: effects on Delta T





Factors	Effect
Ky	-3.36E0
Kx	-3.11E0
Kx * M	-2.53E0
M * Ny	-2.37E0
Ky * M	-1.34E0
Kx * Ny	1.29E0
Ny	-8.56E-1
Kx * Ky	7.74E-1
Ky * Ny	-3.06E-1
M	-2.50E-1

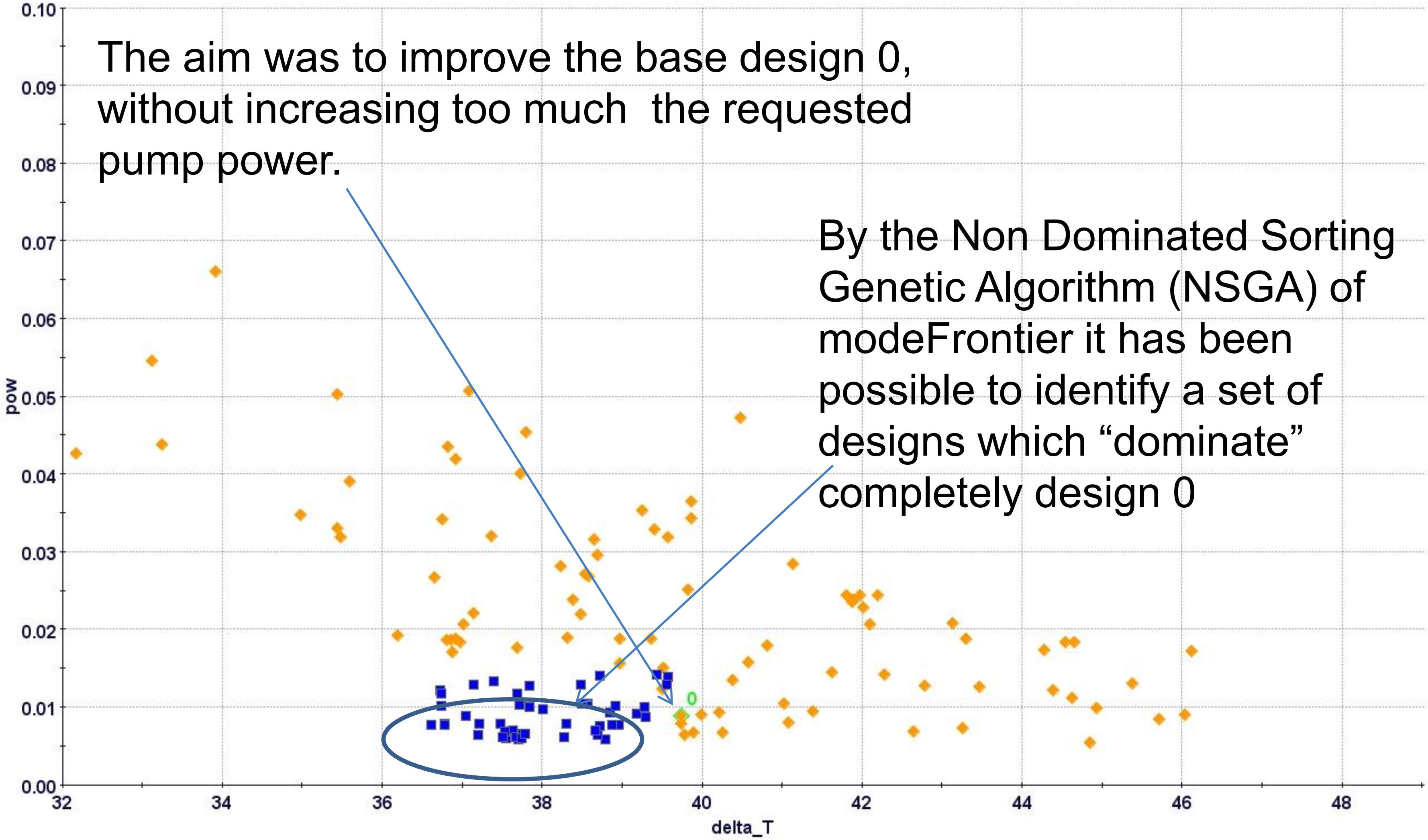
New bounds for optimization

	Nx	Ny	Kx	Ky	M
Original bounds	[110-125]	[2-20]	[0.25-1]	[0.5-2]	[0.014-0.016]
Bounds after analysis	120 const.	[2-16]	[0.25-1]	[0.5-2]	[0.015-0.017]

Two constraints:
1) maximum power requested less than 0.015 W
2) maximum temperature on the solid less than 344 K

[Heat flux = 100 W / cm^2]

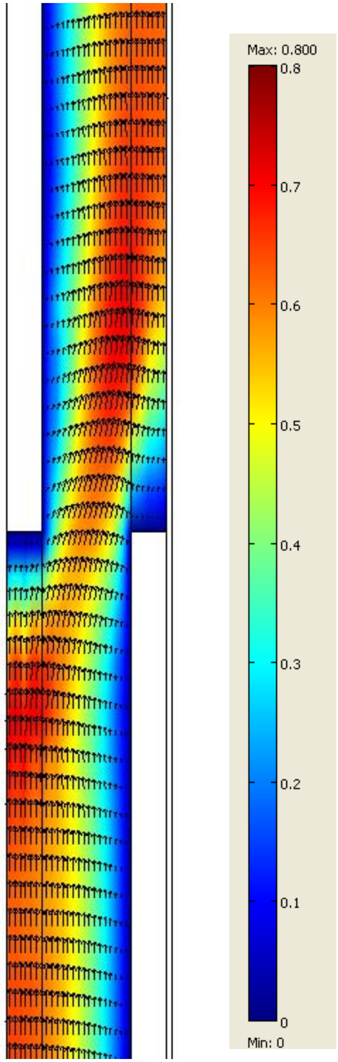
Optimisation results: Pareto frontier



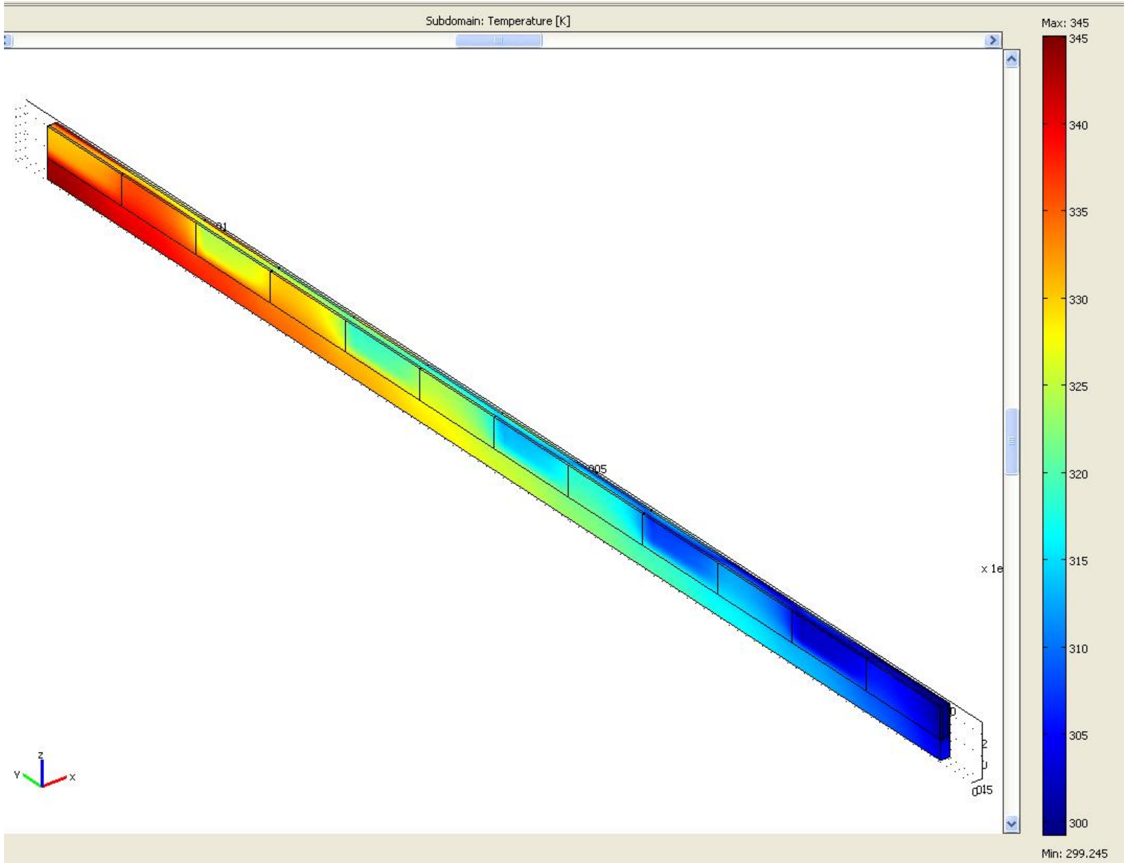
The aim was to improve the base design 0, without increasing too much the requested pump power.

By the Non Dominated Sorting Genetic Algorithm (NSGA) of modeFrontier it has been possible to identify a set of designs which "dominate" completely design 0

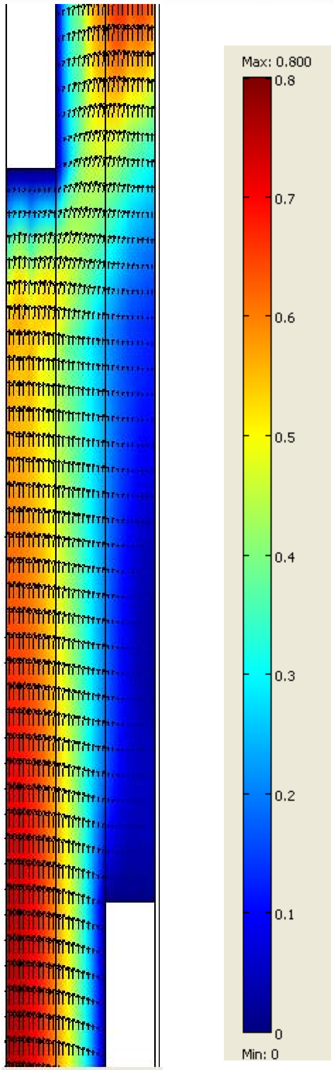
Optimisation results



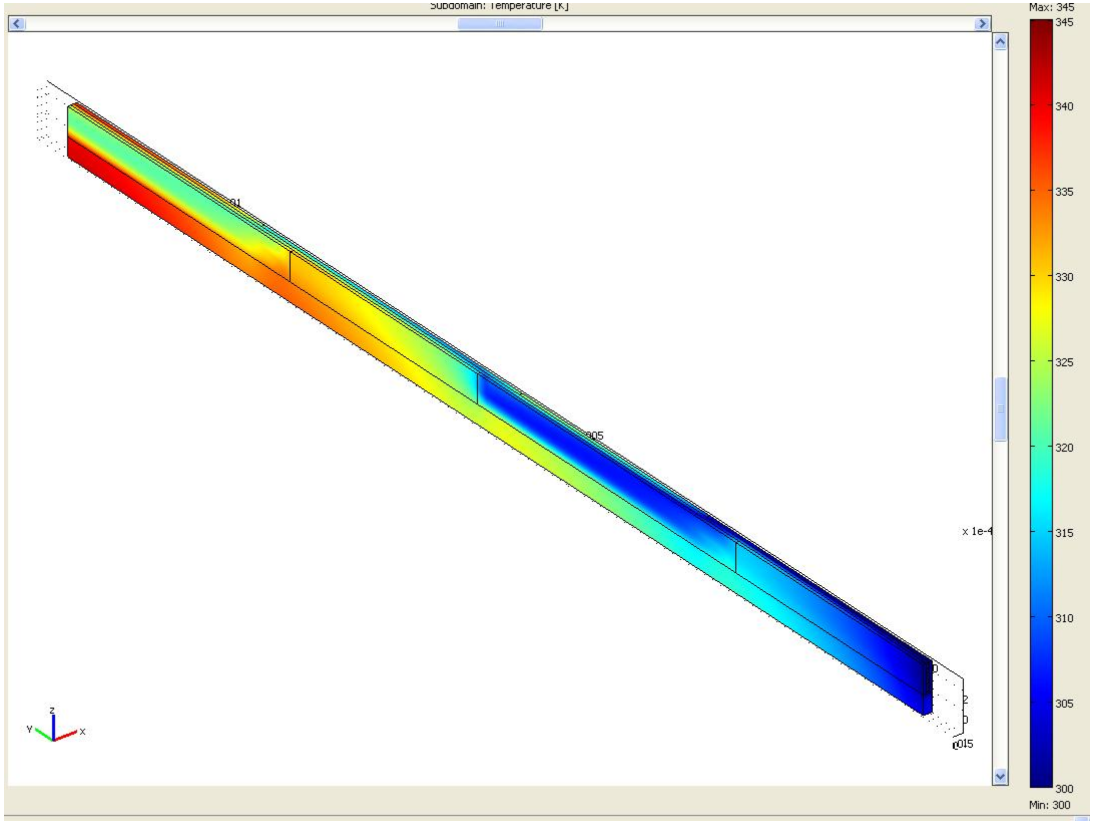
Initial design: velocity map at fins middle plane and temperature map.



Optimisation results



An optimal Design: velocity map at fins middle plane and temperature map.



Optimisation results

• The optimal solutions are characterized by few fins (3) since the fins number does affect almost only the requested pump power, moreover they are little “massive” (both low Kx and Ky values).

• This allows to have small losses, (uniform flow velocity) and hence the pump power is minimized.

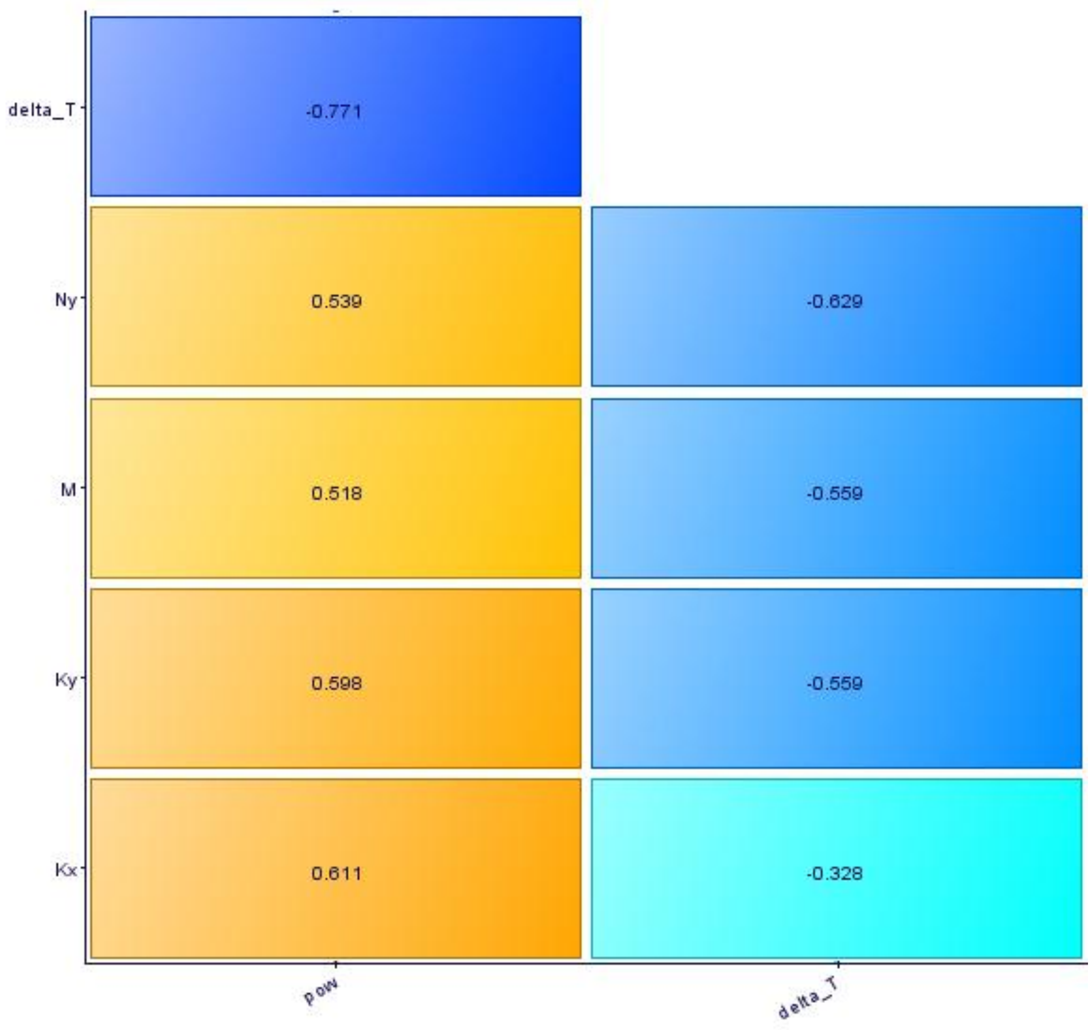
Optimisation for an higher heat flux

	Nx	Ny	Kx	Ky	M
Bounds	[120]	[2-20]	[0.25-1]	[0.5-2]	[0.030-0.033]

One constraint:
1) maximum temperature on the solid less than 344 K

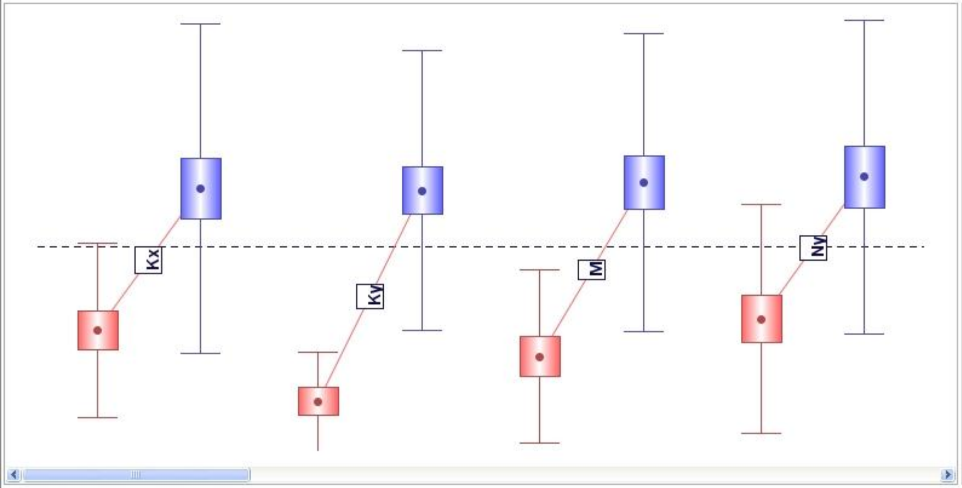
[Heat flux = 200 W / cm^2]

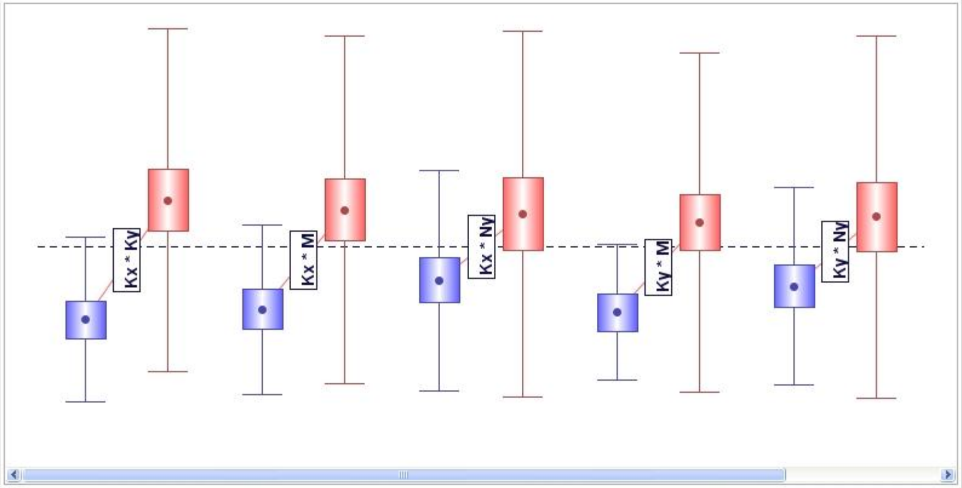
DOE Analysis: Parameters significance

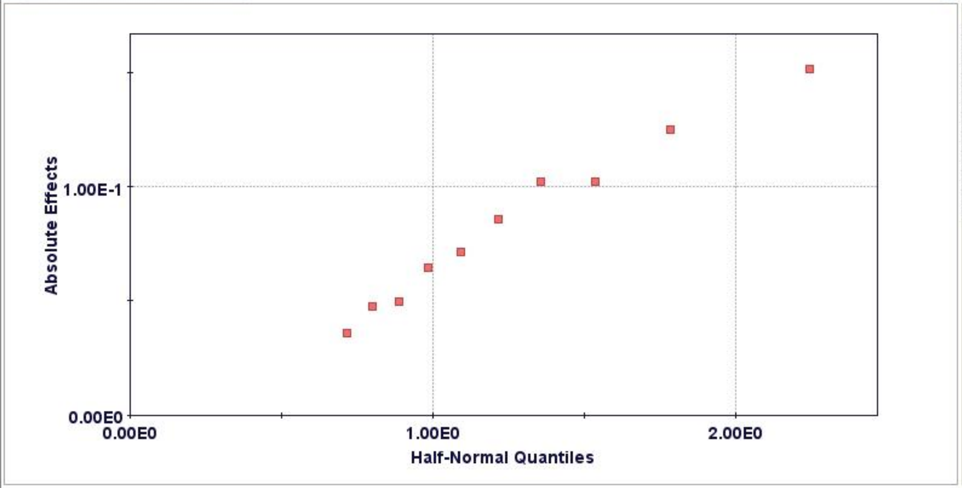


DOE Analysis: Parameters significance

Factor Analysis: effects on pump power



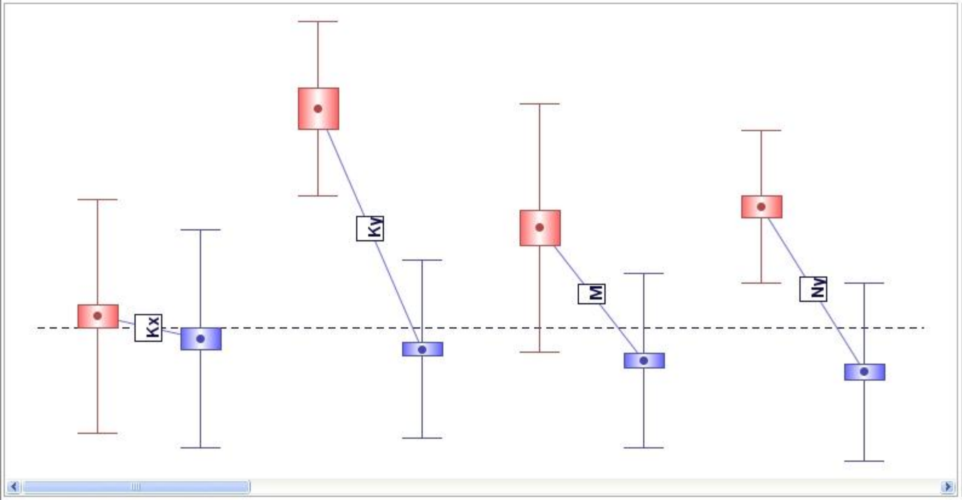


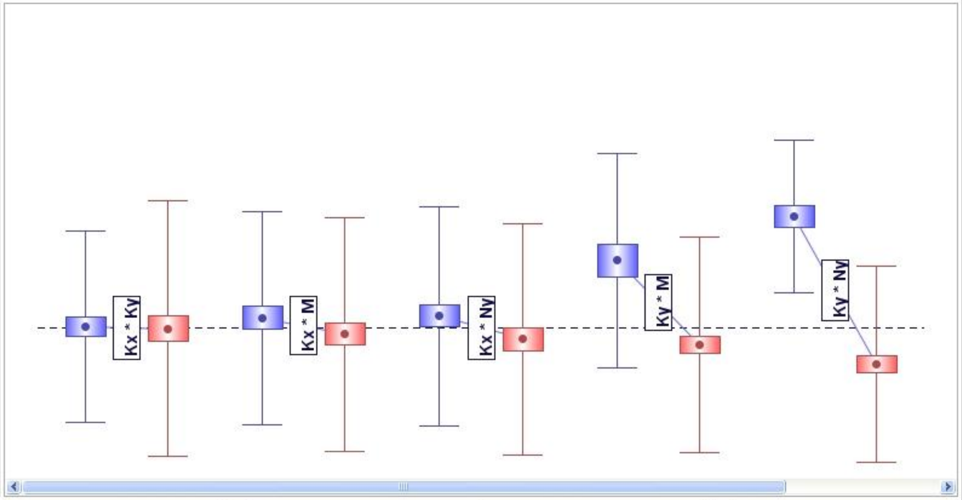


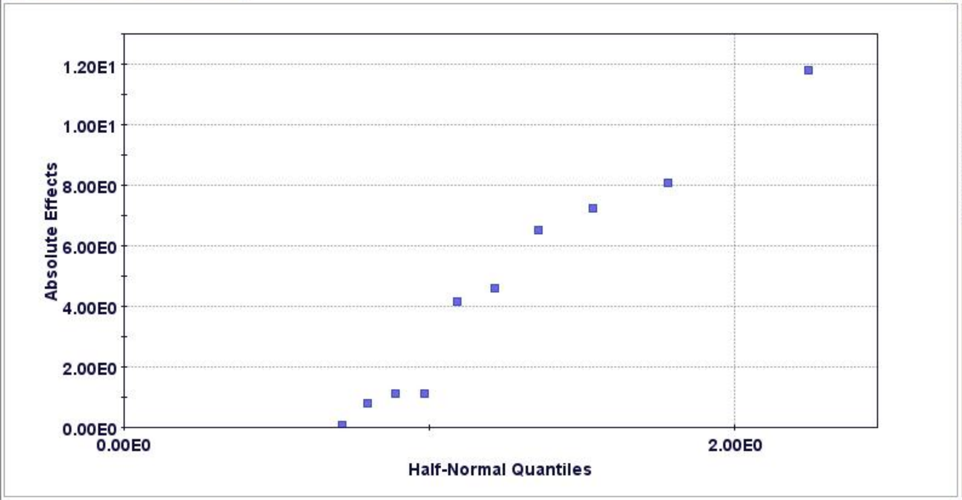
Factors	Effect
Ky	1.52E-1
M	1.25E-1
Kx	1.03E-1
Ny	1.02E-1
Kx * Ky	8.62E-2
Kx * M	7.17E-2
Ky * M	6.48E-2
Ky * Ny	5.01E-2
Kx * Ny	4.79E-2
M * Ny	3.60E-2

DOE Analysis: Parameters significance

Factor Analysis: effects on Delta T



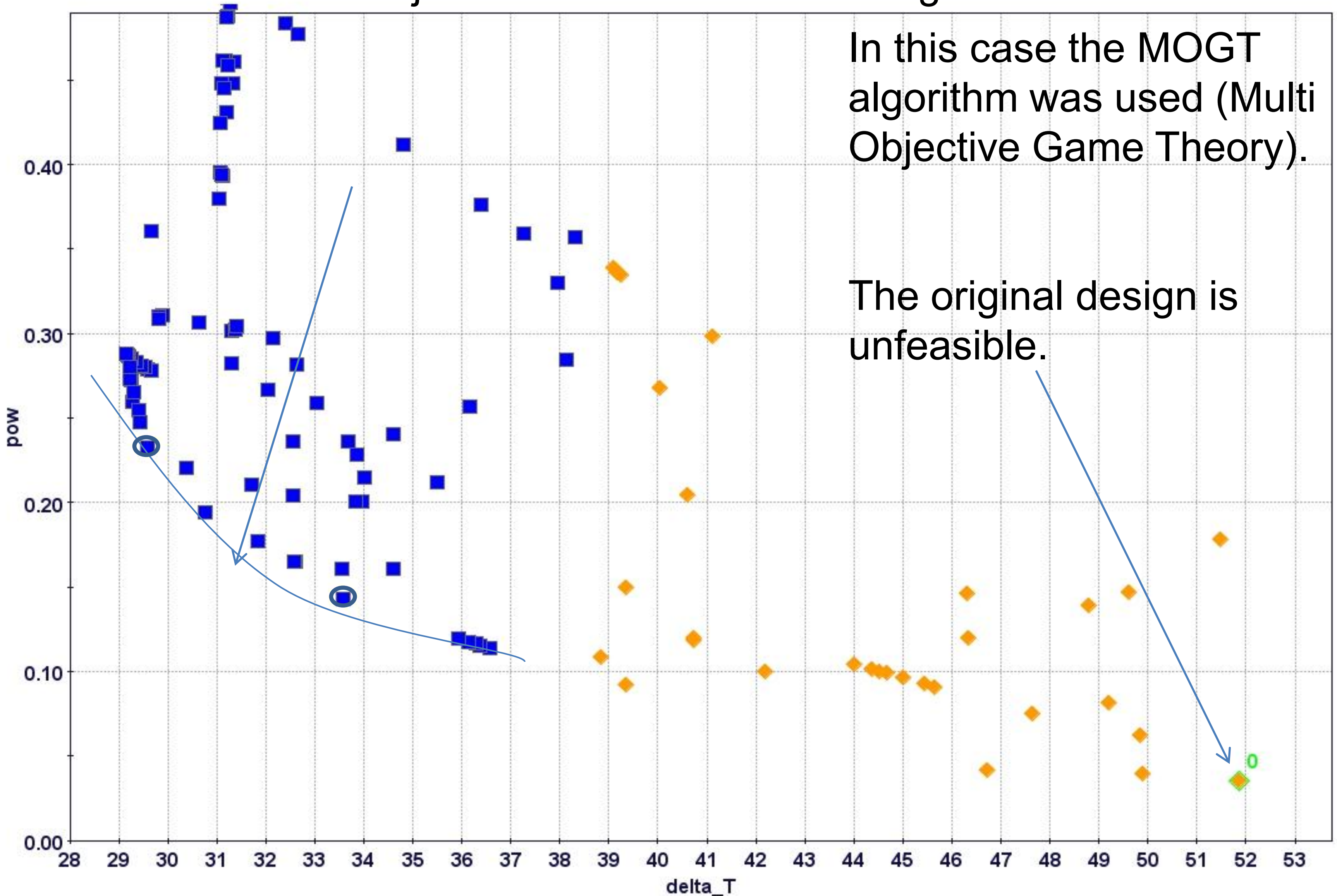




Factors	Effect
Ky	-1.18E1
Ny	-8.11E0
Ky * Ny	-7.24E0
M	-6.52E0
M * Ny	-4.62E0
Ky * M	-4.15E0
Kx * Ny	-1.13E0
Kx	-1.10E0
Kx * M	-8.18E-1
Kx * Ky	-9.76E-2

Optimization results: solutions chosen

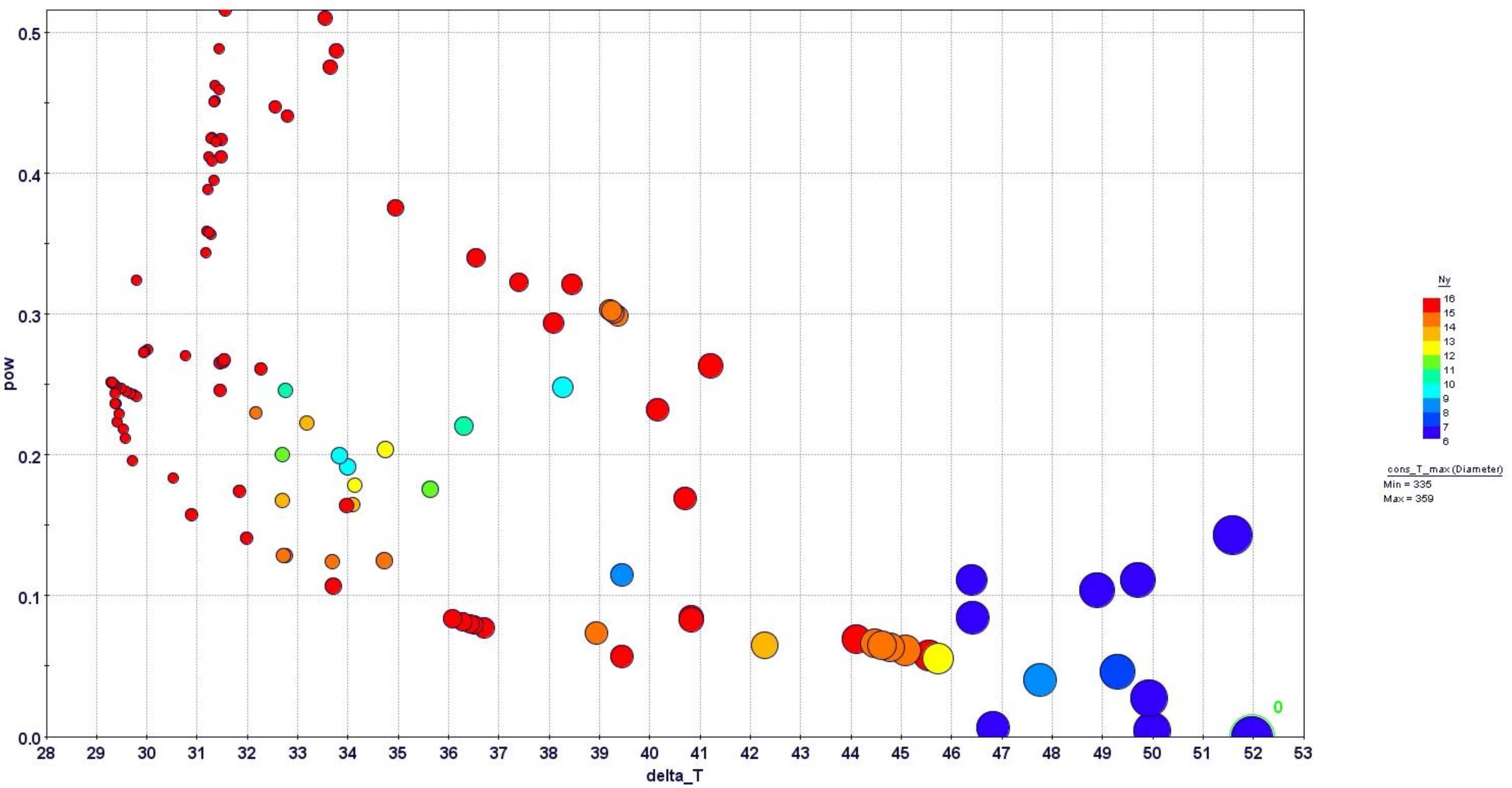
In this case the two objectives are more contrasting



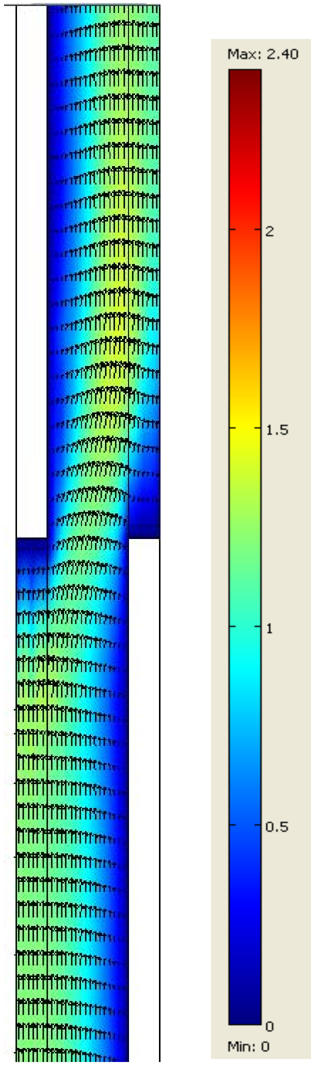
In this case the MOGT algorithm was used (Multi Objective Game Theory).

The original design is unfeasible.

Optimization results: solutions chosen



Optimisation results



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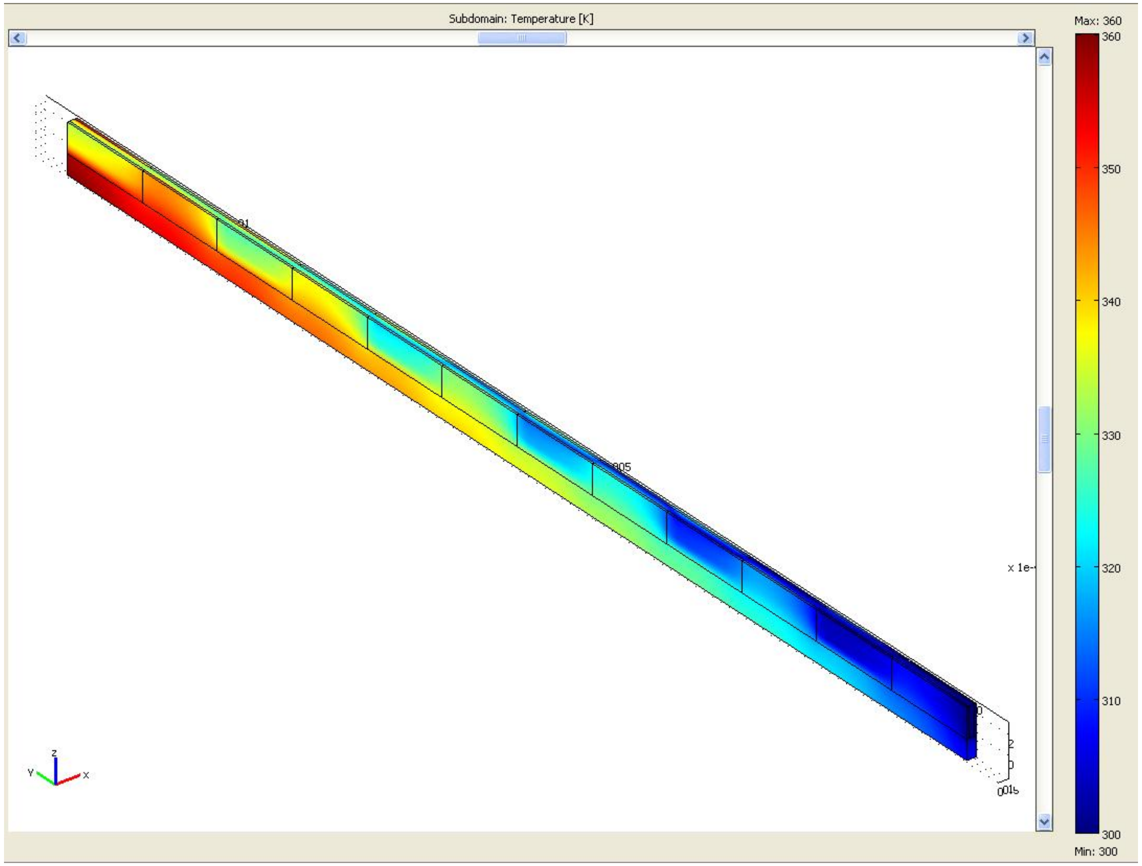
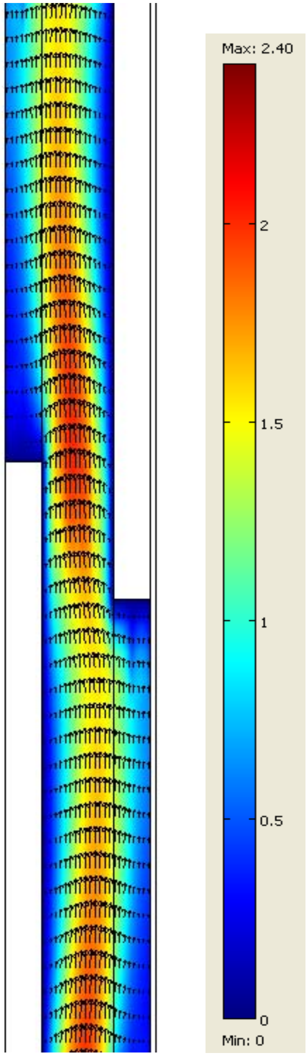
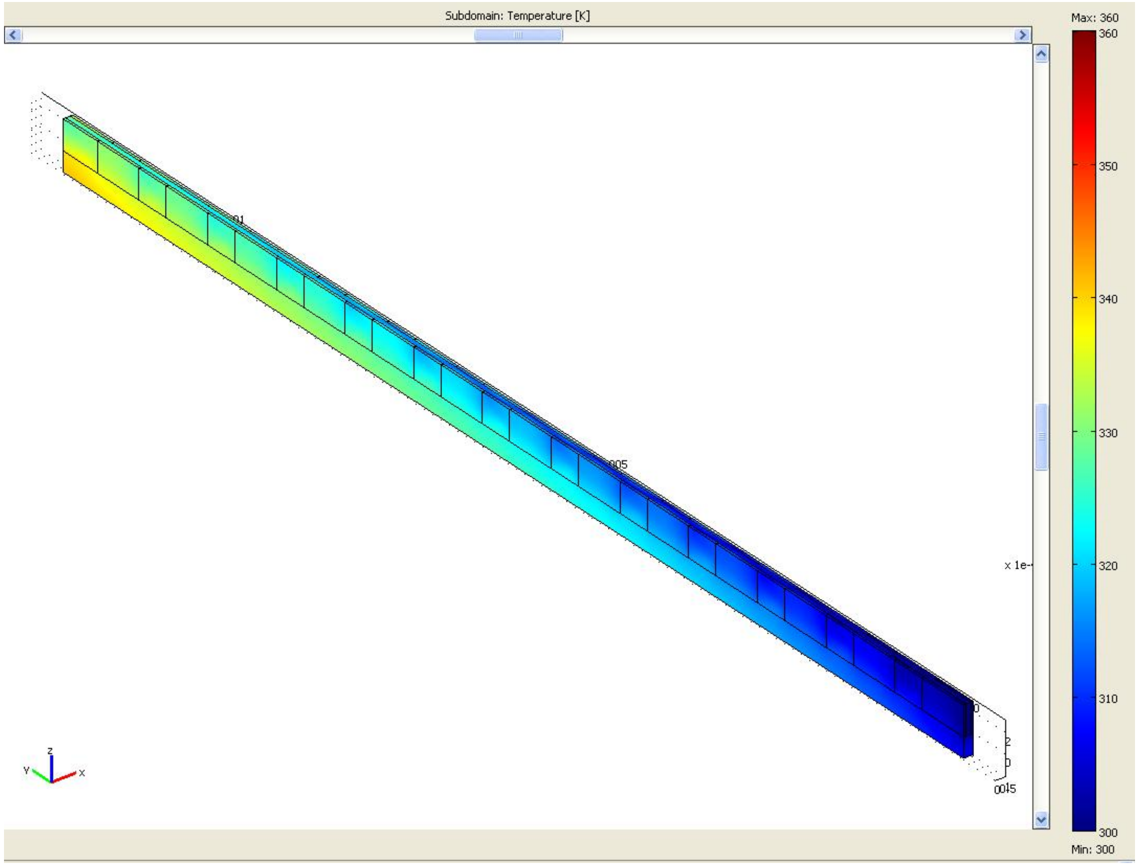


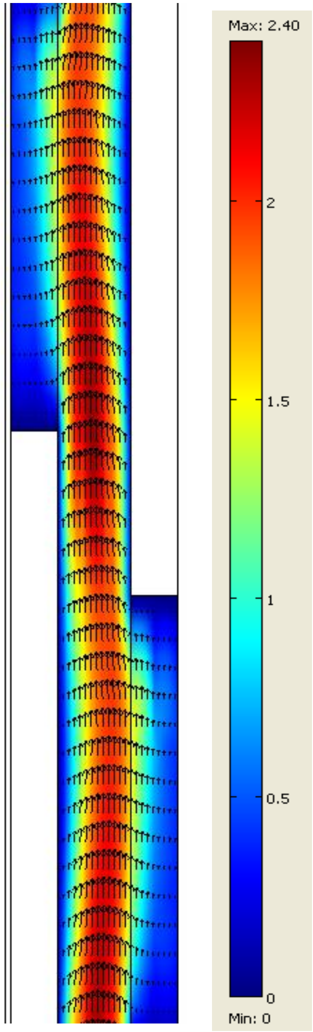
Optimisation results

An optimal design: velocity map at fins middle plane and temperature map.

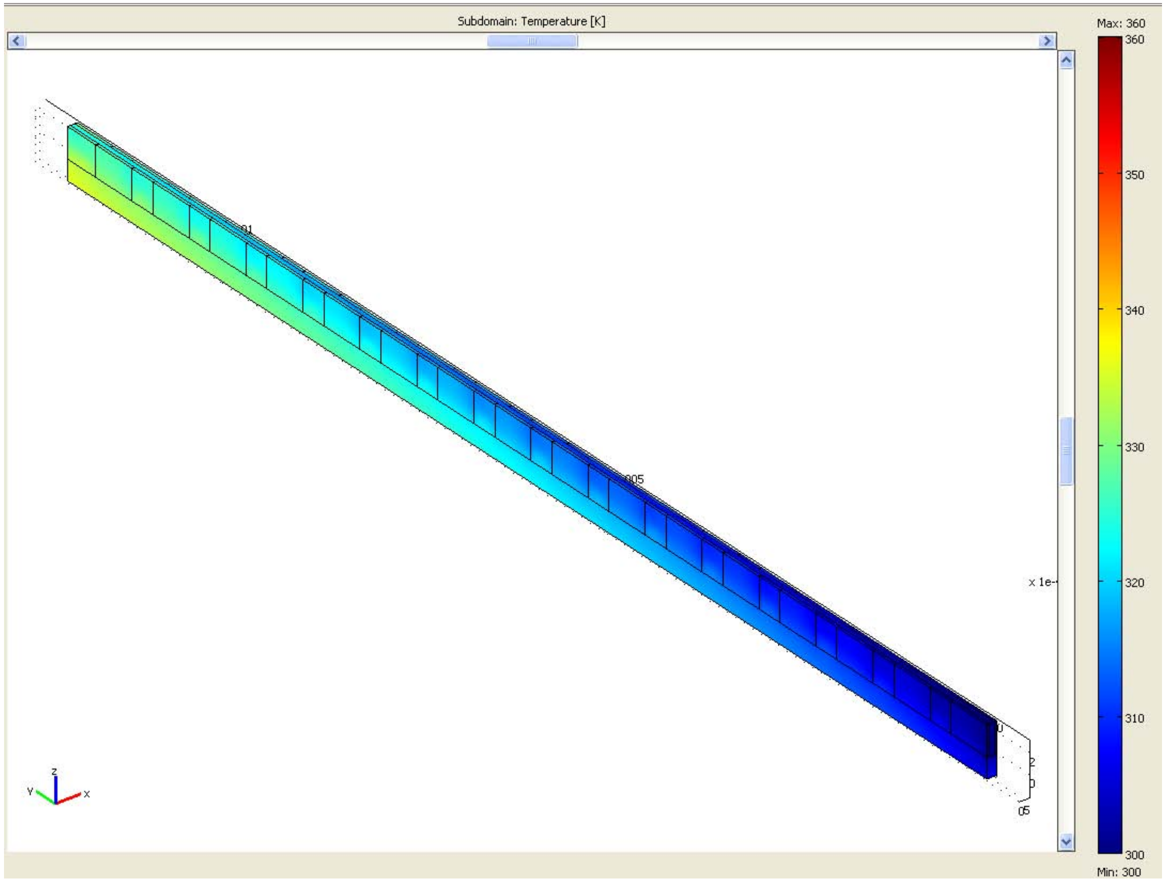




Optimisation results



An optimal design: velocity map at fins middle plane and temperature map.



Optimisation results

• The optimal solutions are now characterized by several fins (16 or more) and are more “massive” (high values of Ky);
• the fins overlap in order to maximize the exchange surface.
• The increment of exchange surface allows to control temperatures without increasing too much the mass flow rate (and hence the requested pump power).

Conclusion

- **COMSOL** and **modeFRONTIER** can be profitably integrated
- A *multi-objective optimization involving discrete and continuous variables* has been addressed.
- The modeFRONTIER sensitivity analysis tools allow to have a good insight of the problem before starting the optimization process.
- The optimization algorithms was able to locate automatically the set of the best solutions gathering additional information as the optimization proceeded
- modeFRONTIER shows how the behaviour of the system depends on the thermal flux.

Thanks for your attention!

Rosario Russo

russo@esteco.com

Sumeet Parashar

parashar@esteco.com