The added value of thermal simulations during the design process of a LED Luminaire

LED Event FHI
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Optimal Thermal Solutions B.V.

Overview

- Introduction
- LED applications
- Thermal Design process
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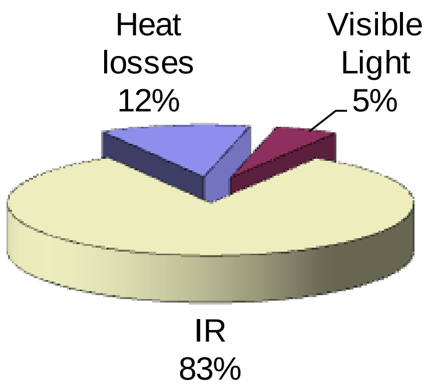
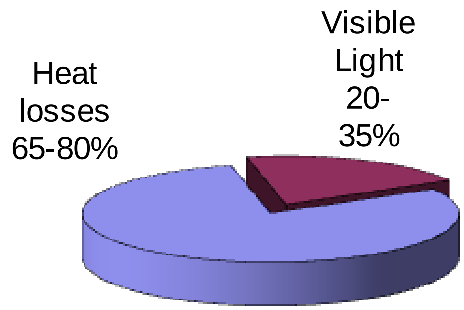
  - Experimentally
  - Computional
- Examples
  - Optimizing/ designing a heatsink
  - Optimizing a board
  - Effect of boundary conditions
- Conclusion

Comparison Between LED and Incandescent Lamps

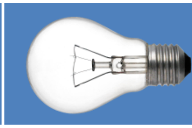




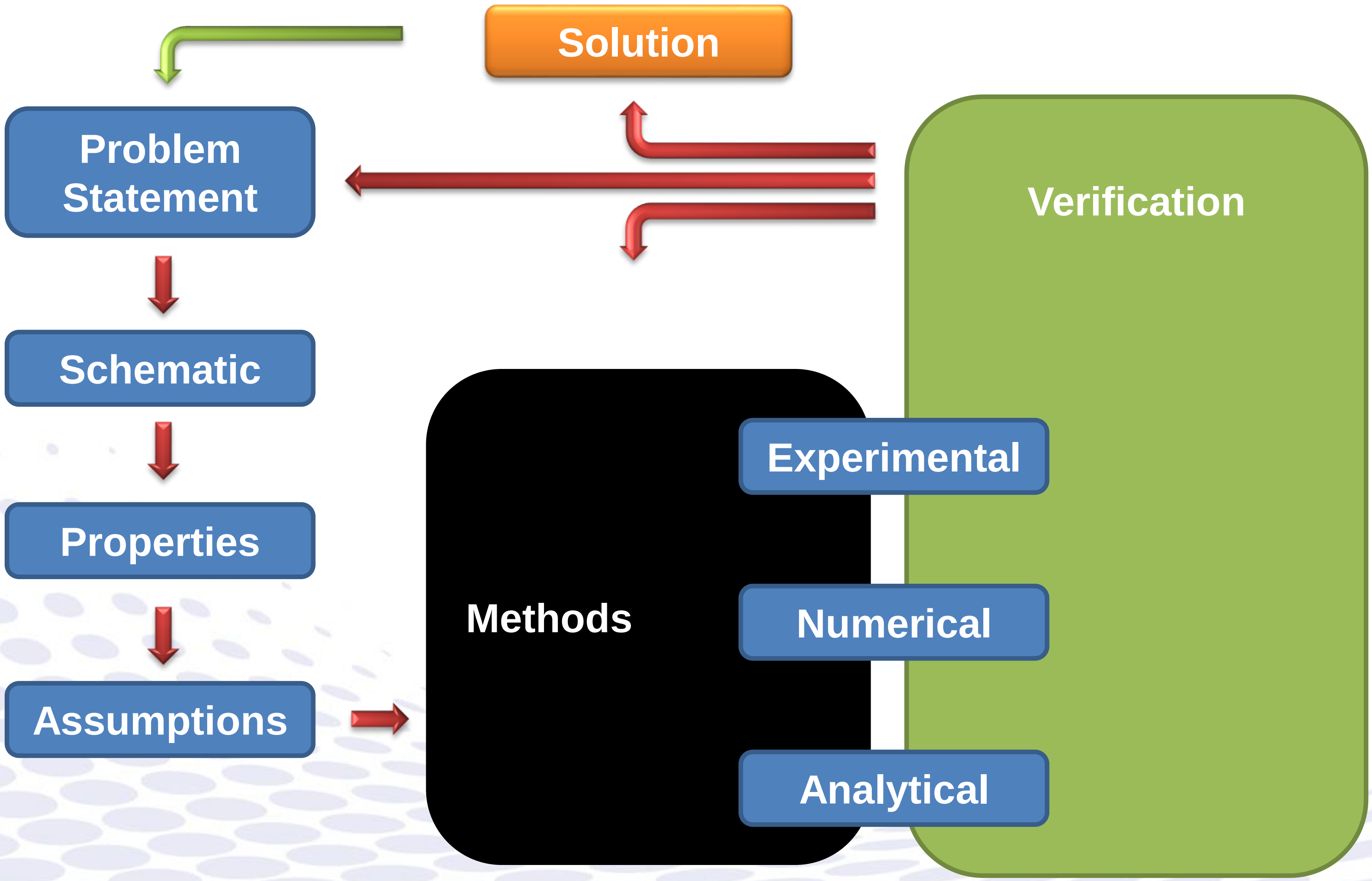
- Incandescent light bulb
- Most of the heat transferred by infrared radiation
- For 100 W electrical power input, 5 W is light. The remainder, 95 W, is heat.
- Filament can be between 2000 to 3000 °C

- LED replacement light bulb
- No radiation and convection from LED itself. Only conduction.
- An equivalent LED bulb for 100 W incandescent is Pe~23 W,
- Assume 90% driver efficiency, 30% LED light efficiency => Pdissipated ~17 W
- LED can has a max. junction temperature of 100 to 120 °C

Comparison Between LED And Incandescent Lamps

Parameter	Units			Led versus incandescent
$P_{electrical}$	W	100	23	-77W (77% less)
$P_{dissipated}$	W	95	17	-78W (82% less)
T_{max}	°C	2000	100	-1900°C (95% less)
$T_{ambient}$	°C	40	40	Not changed
$R_{j\text{-}ambient}$	K/W	21	3.5	6x better performance required!
Heatsink	[-]	7x7mm	LPF70A 40	967 times more cooling surface required!

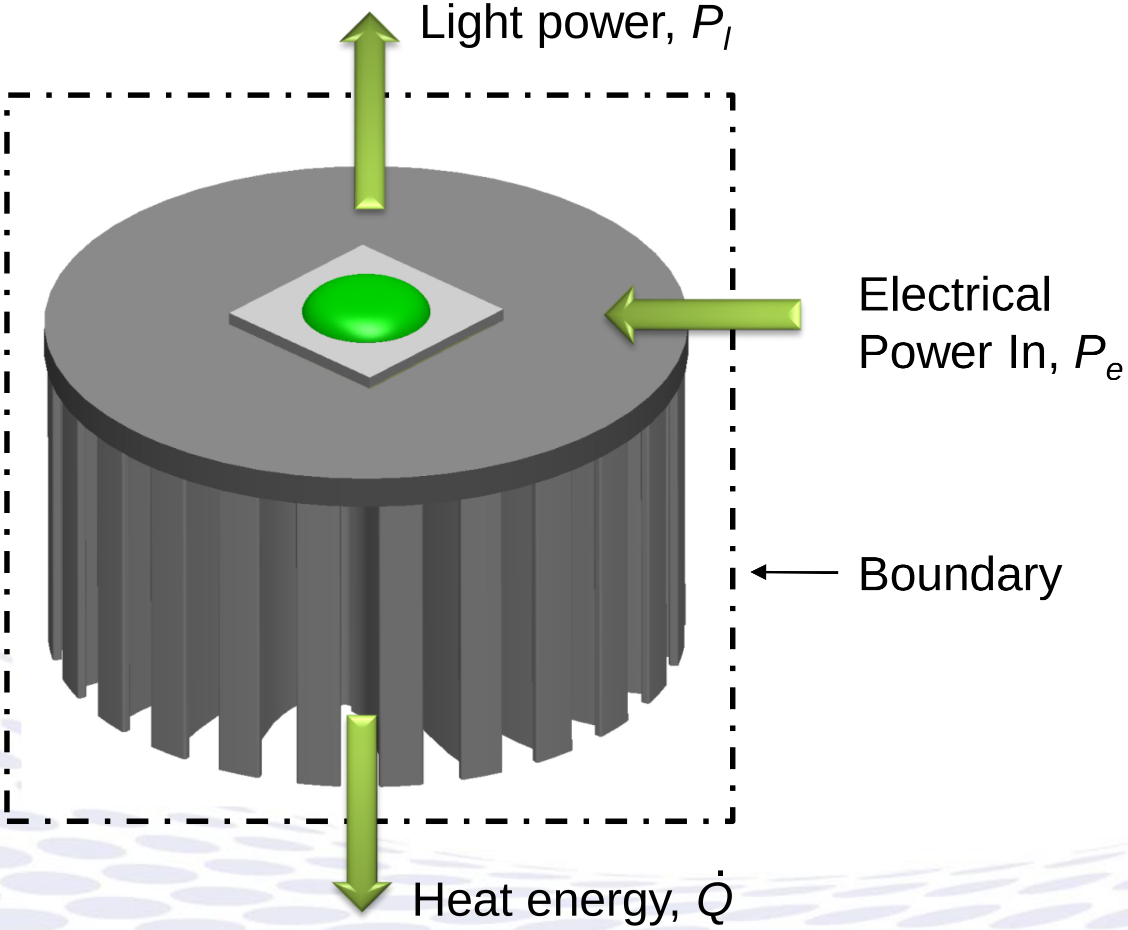
Approach
Summary Schematic



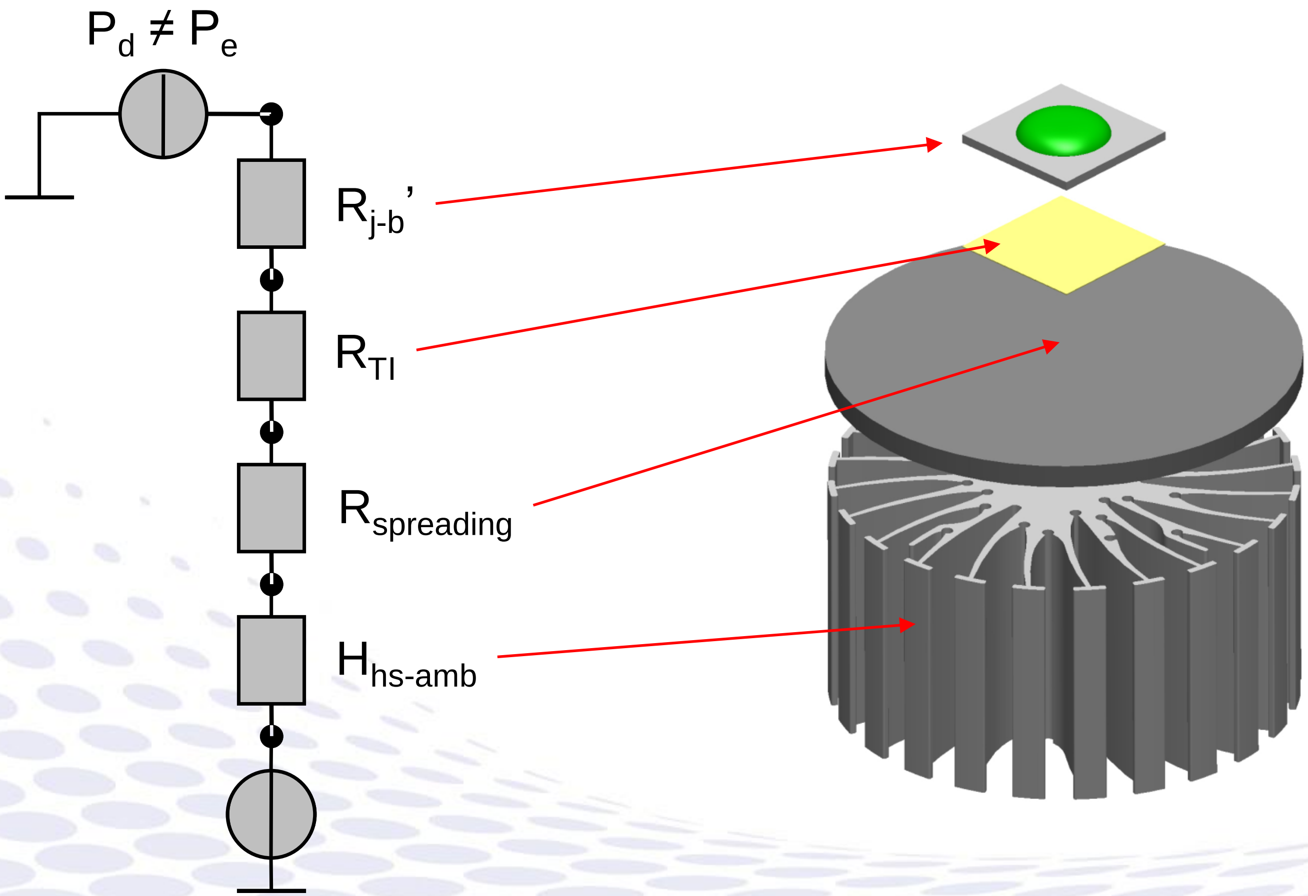
Solving the problem
Analytically
Energy Balance – Open System

$$\sum \dot{E}_{in} = \sum \dot{E}_{out}$$

$$P_e = P_l + \dot{Q}$$



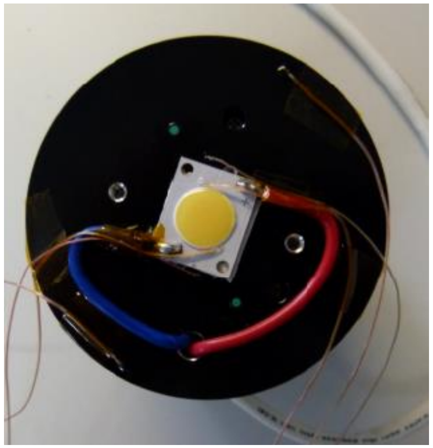
Solving the problem
Analytically
Resistor network

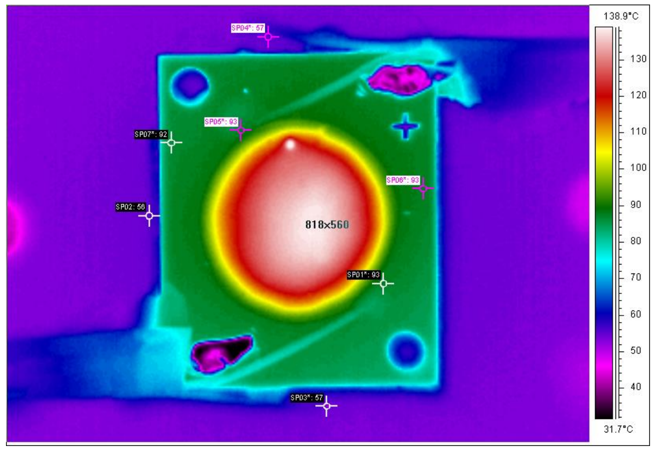


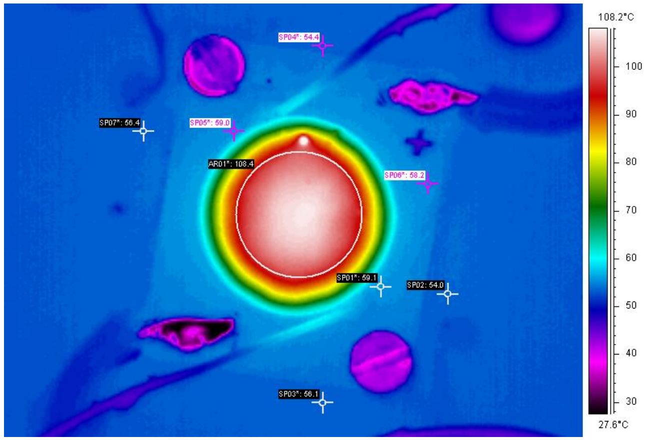
Solving the problem Experimentally

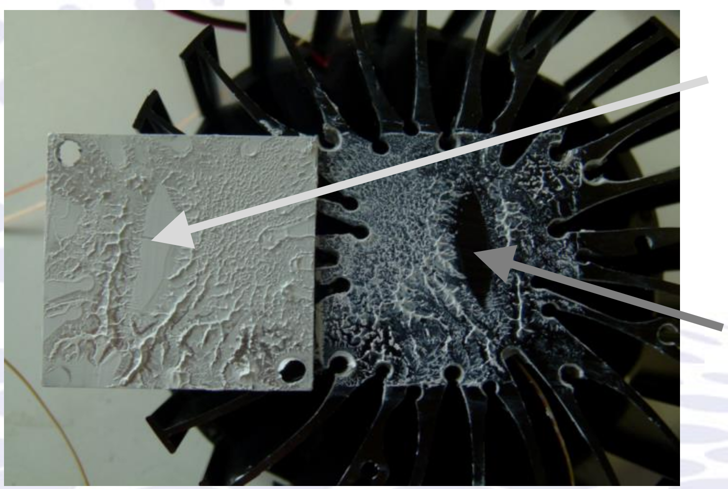
Bad thermal interface

Good thermal interface



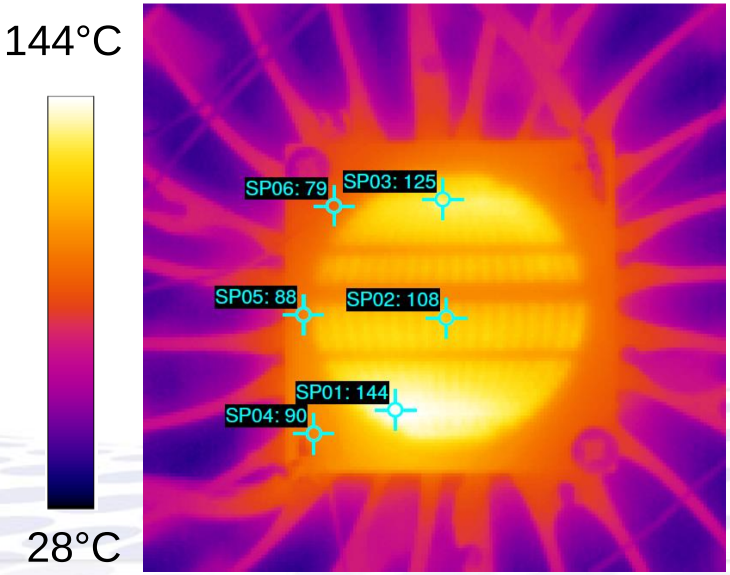






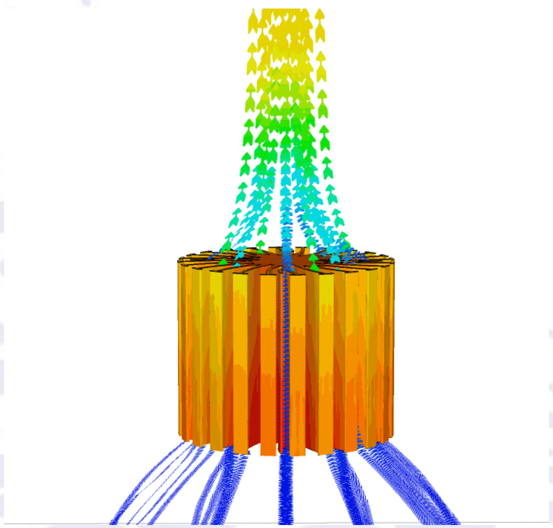
Corresponding ‘unused’ layer

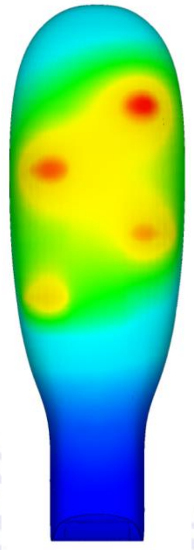
Void in applied thermal grease Result in **hotspot** in COB

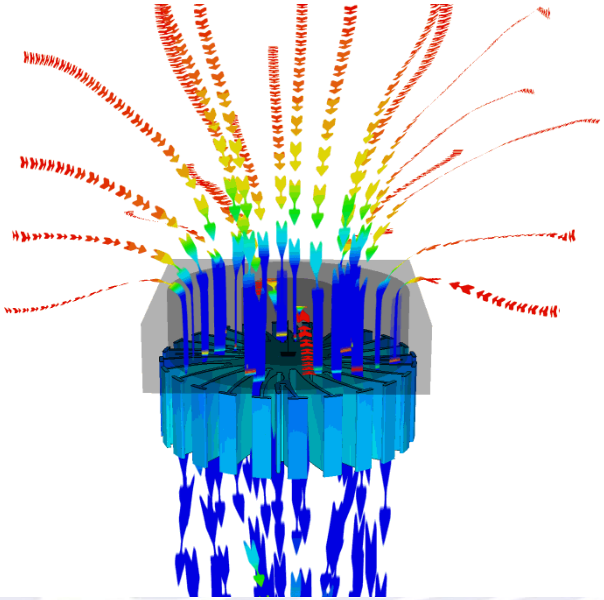


Solving the problem
Computational Fluid Dynamics analyses

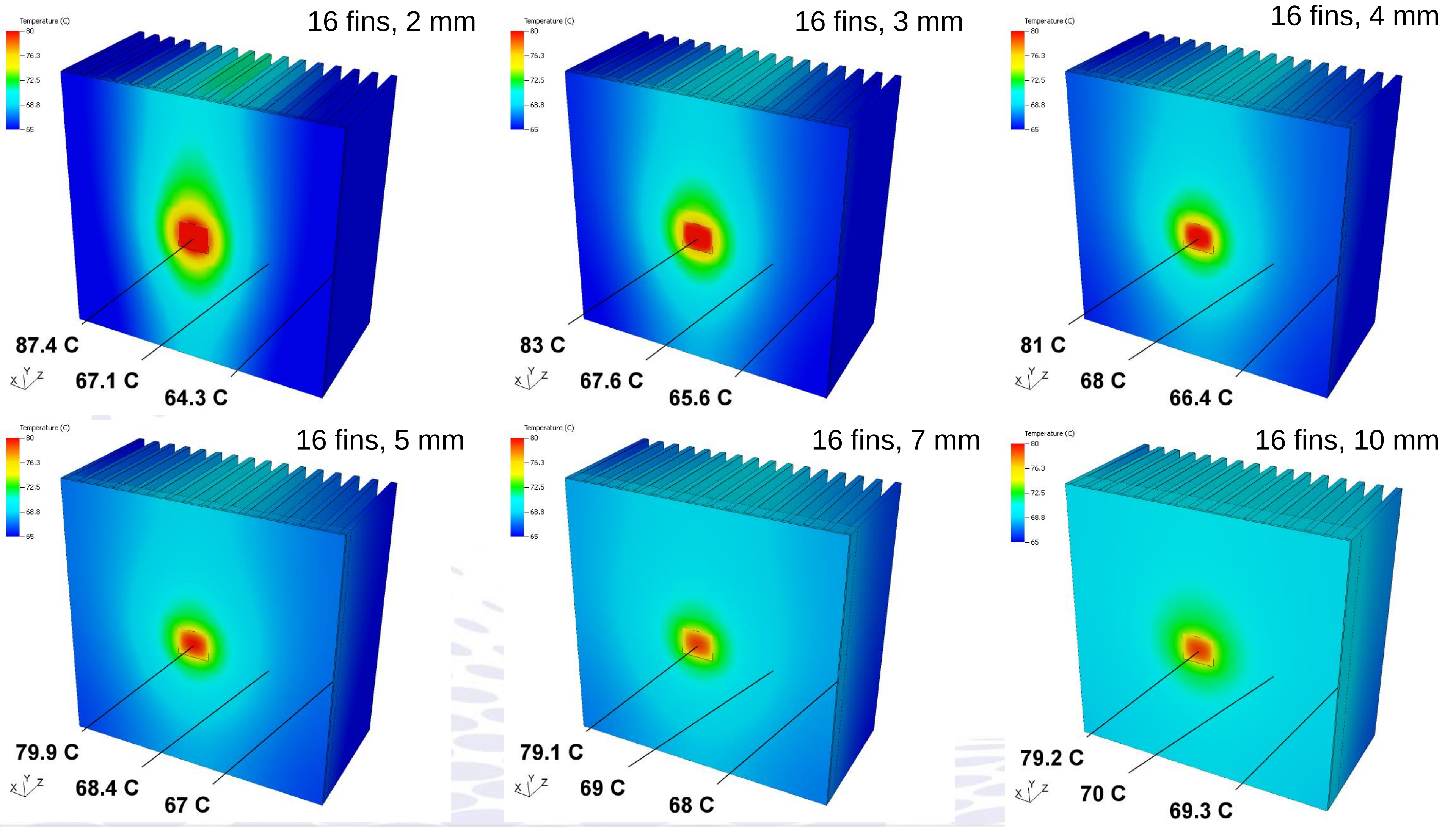
- Computational Fluid Dynamics (CFD) is an numerical method in which flow fields, heat transfer and other physics are calculated in detail for an application of interest.
- CFD model or flow simulation results can be used as part of a design process to illustrate how a product or process operates. This can be used to troubleshoot problems, to optimize performance and to design new products.





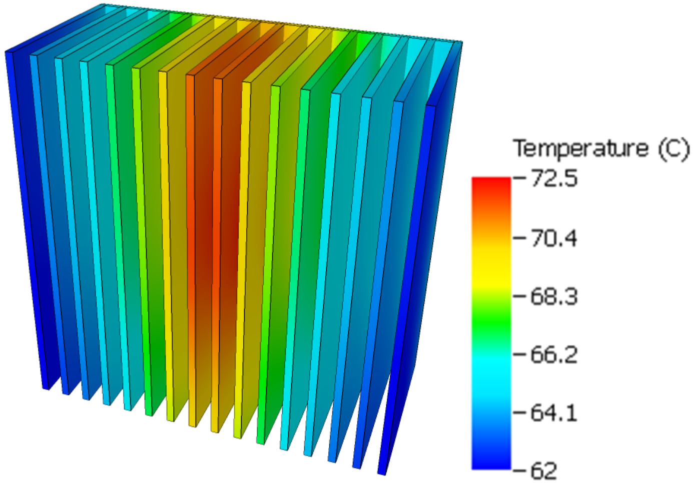


Example 1
Optimizing a heatsink

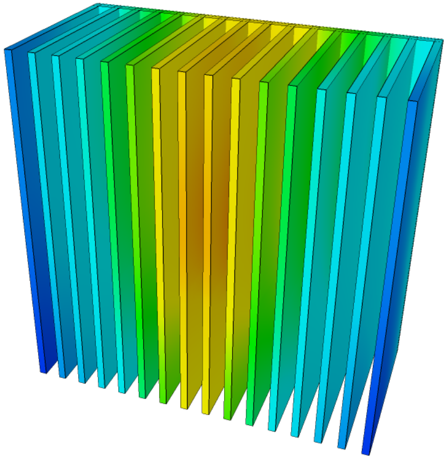


Example 1
Optimizing the heatsink cont'd

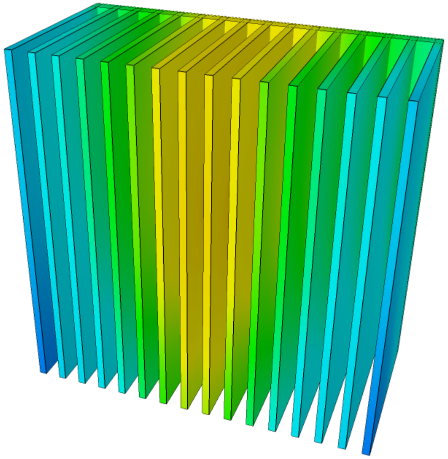
16 fins, 2 mm



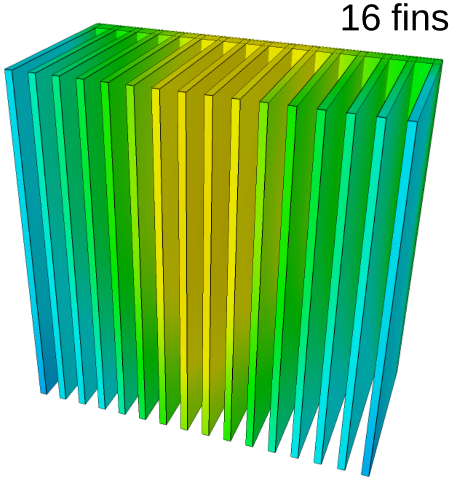
16 fins, 3 mm



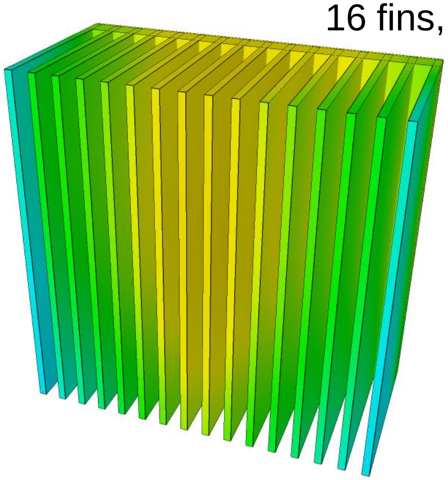
16 fins, 4 mm



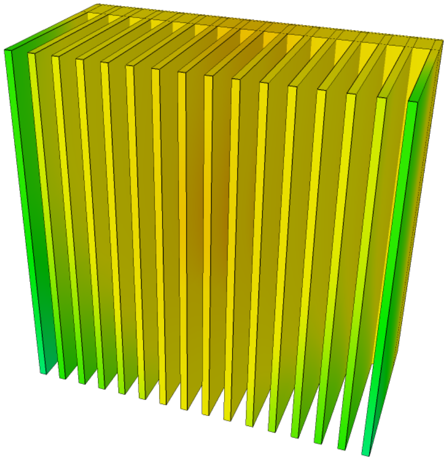
16 fins, 5 mm



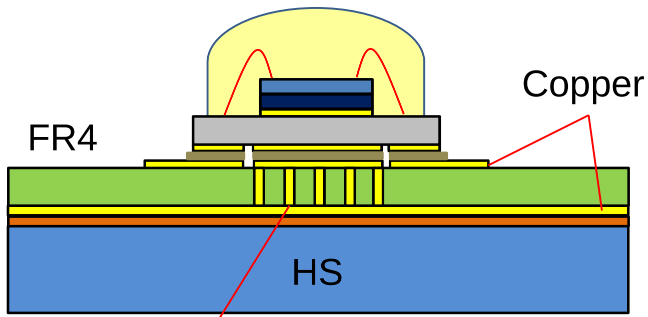
16 fins, 7 mm



16 fins, 10 mm

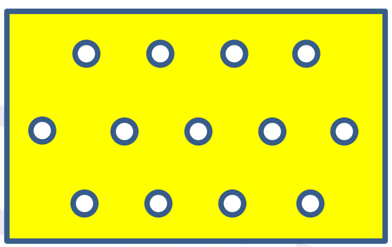


Example 2
Board design effect of thermal vias



Vias 0.3-0.6,
wall thickness 25-35um,
epoxy filled, copper filled

Example:
Copper path
5mmx3mm

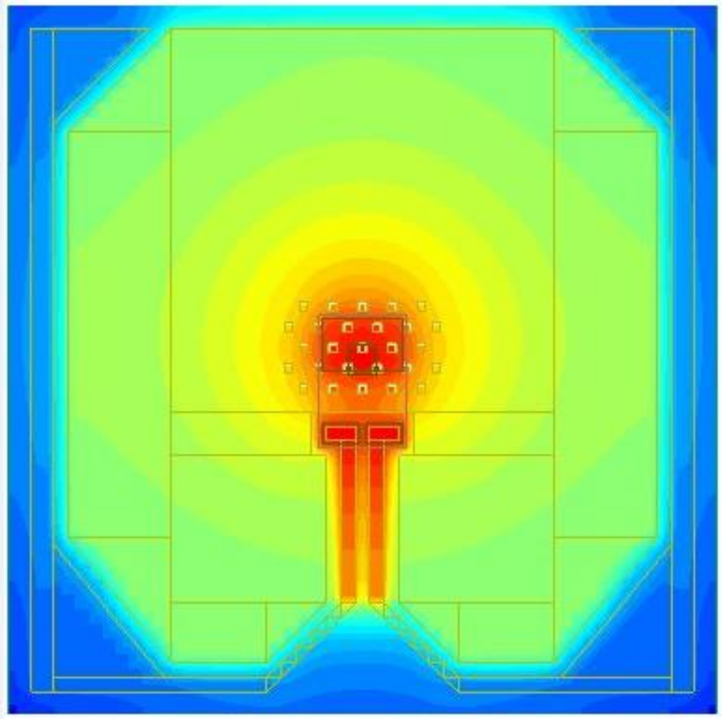


		no via	vias	tin filled vias	copper filled vias
ddrill	mm	0.30	0.30	0.30	0.30
d finished hole	mm	0.25	0.25	0.25	0.25
copper thickness in hole	mm	0.025	0.025	0.025	0.025
Acopper	mm^2	0.0216	0.0216	0.0216	0.0216
Ahole	mm^2	0.0491	0.0491	0.0491	0.0491
λ koper	W/mK	385	385	385	385
λ hole, fill	W/mK	0.3	0.3	50	385
Via length	mm	0.8	0.8	0.8	0.8
Rcopper	K/W	96.21	96.21	96.21	96.21
Rhole	K/W	54325	54325	326	42
Rvia	**K/W**	**96.04**	**96.04**	**74.28**	**29.40**
Acomponent	mm^2	15.0	13.0	13.0	13.0
nvia		0	16	16	16
λ FR4	W/mK	0.3	0.3	0.3	0.3
RFR4	K/W	177.8	205.1	205.1	205.1
Rincl. Vias	K/W	177.8	5.8	4.5	1.8
λ eff	W/mK	0.30	10.55	13.56	33.79

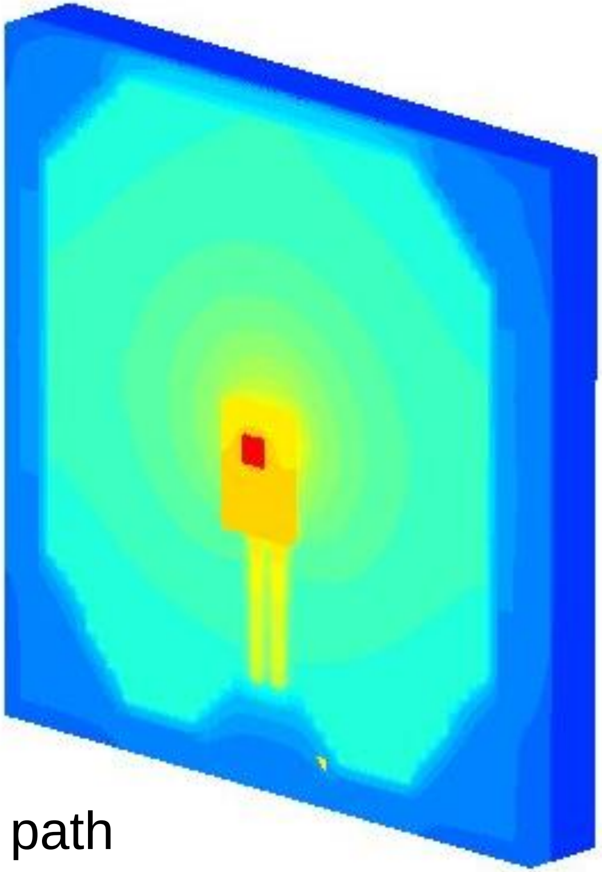
- Carrier of standard FR4 board material 400-800-1600um
- Thick copper on the top and on the bottom for spreading the heat over a larger surface 35-70-05-140um and thicker
- Add via's to increase through-board conductivity

Example 2
Board design Effect of thermal vias cont'd

Temperature distribution within the board



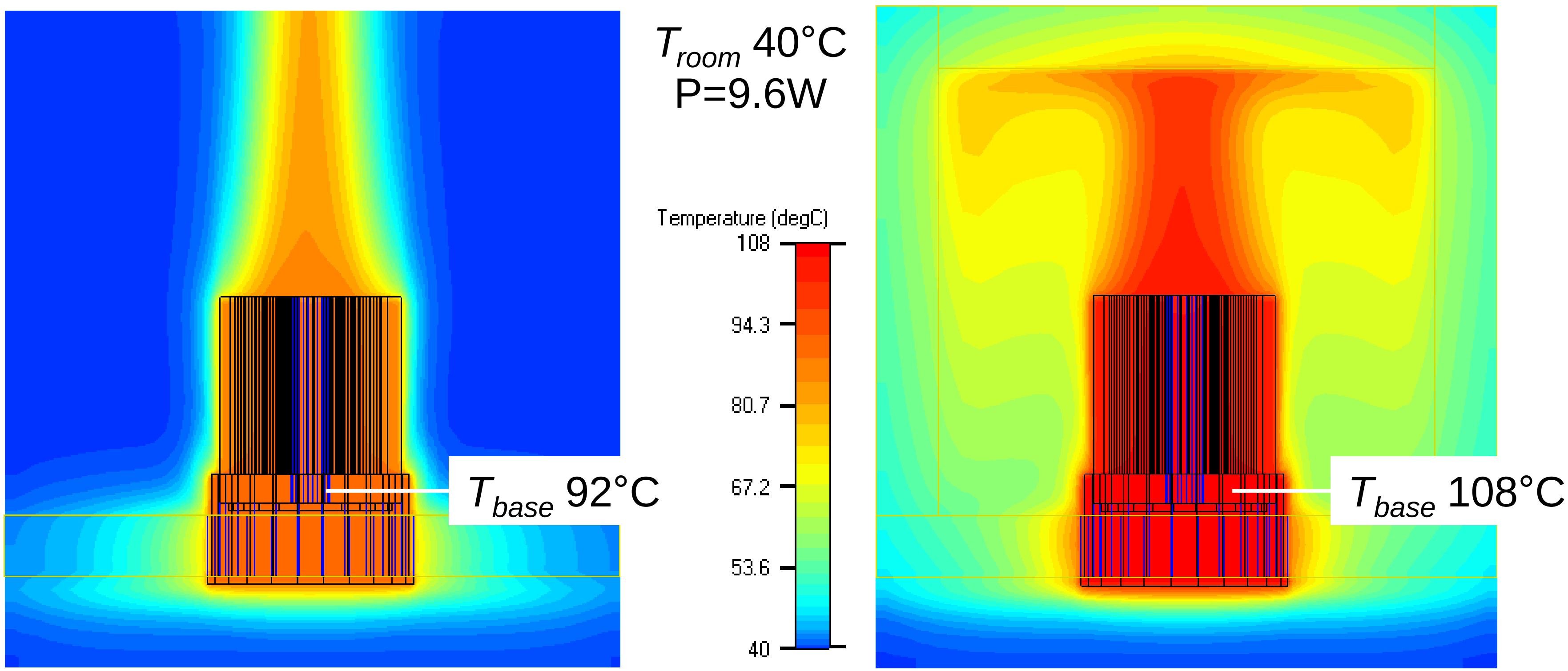
Temperature distribution within the board & LED



- Most heat is below die-thermal path
- Interface to heat sink is critical because of small interface surface area

Example 3
Check effect of boundary conditions

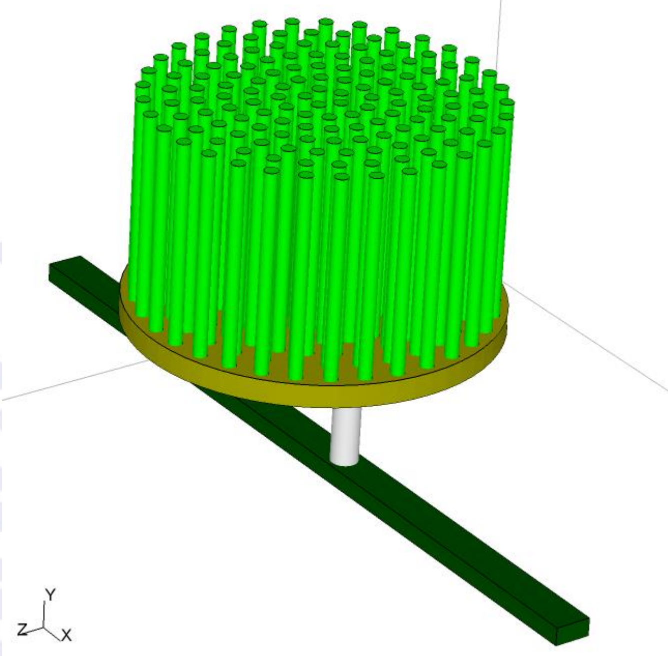
Lamp in ceiling sufficient ventilation | **Lamp in ceiling with poor ventilation**

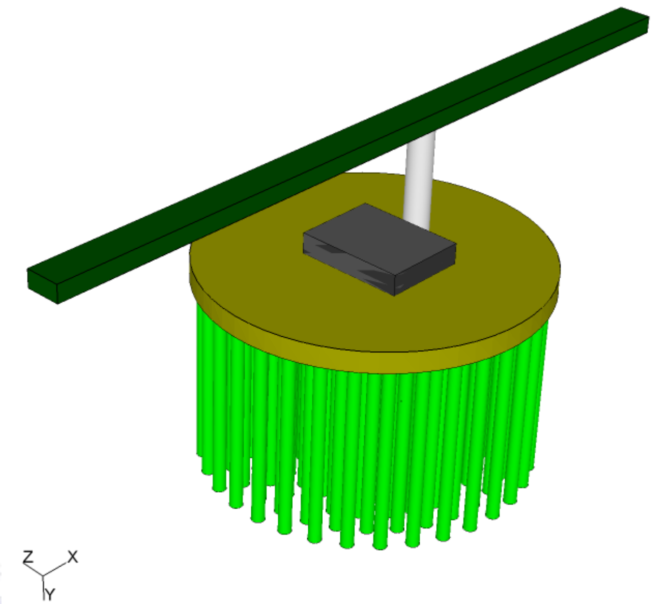


Mounting the LED lamp in a hole in the ceiling covered with insulation material, shows a temperature increase of 16°C in the heat sink base.

Example 4
Effect of orientation & lamp environment

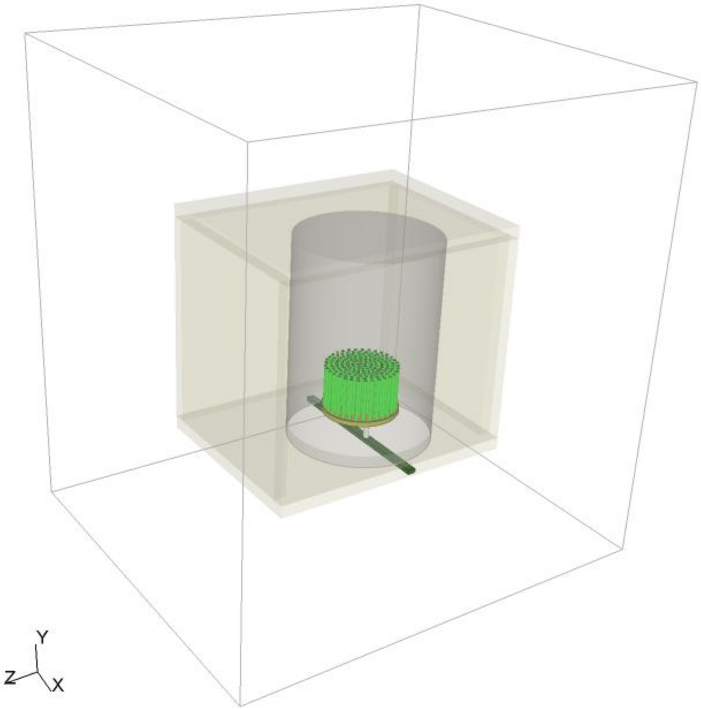
30 W dissipation LED COB application.
Tested heat sink in free air. The COB is within specification.
But what is the performance in a recessed ceiling?

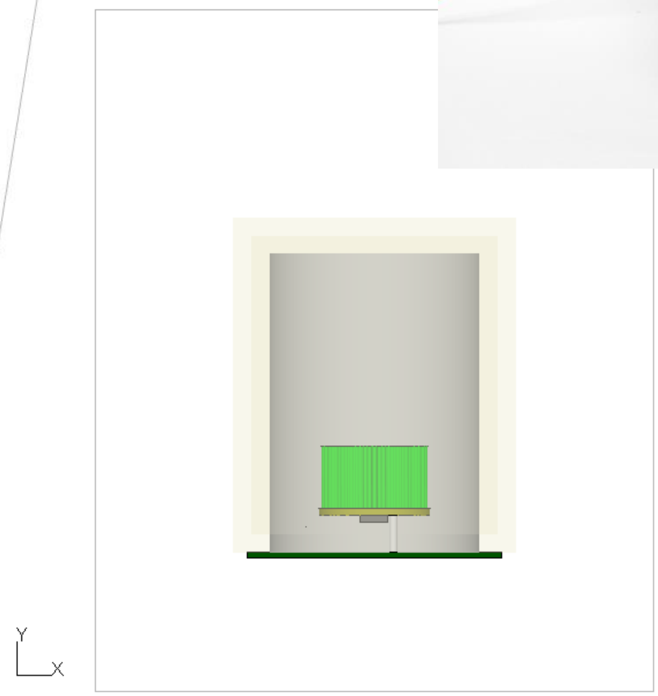




Example 4
Recessed Ceiling?

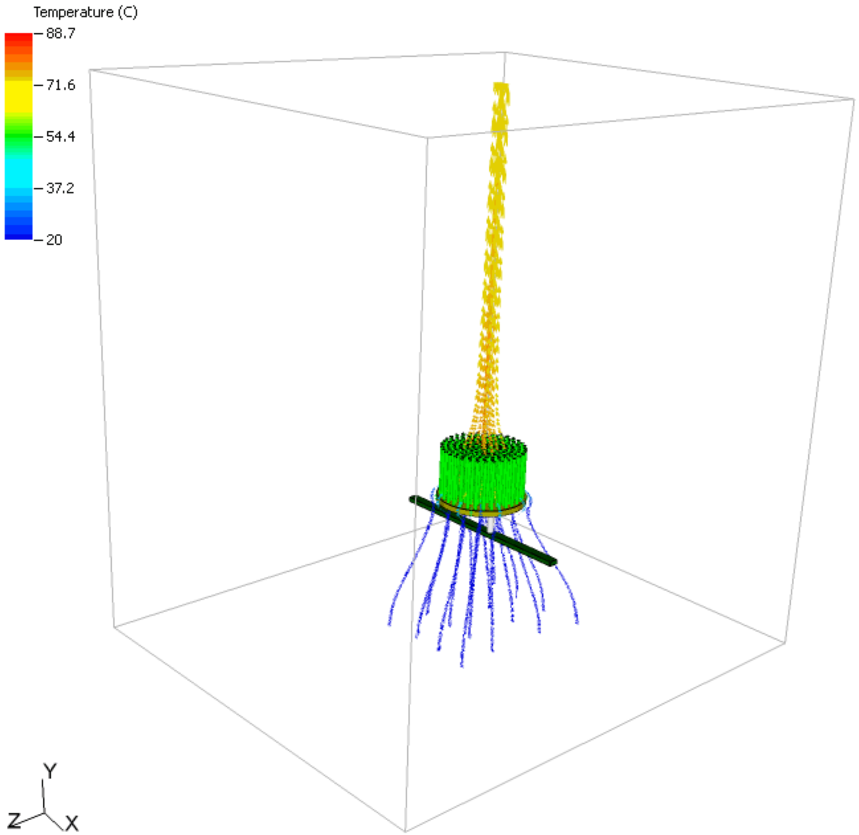
How could one ‘define’ a recessed ceiling?
Example could be the UL 1993 6” test box

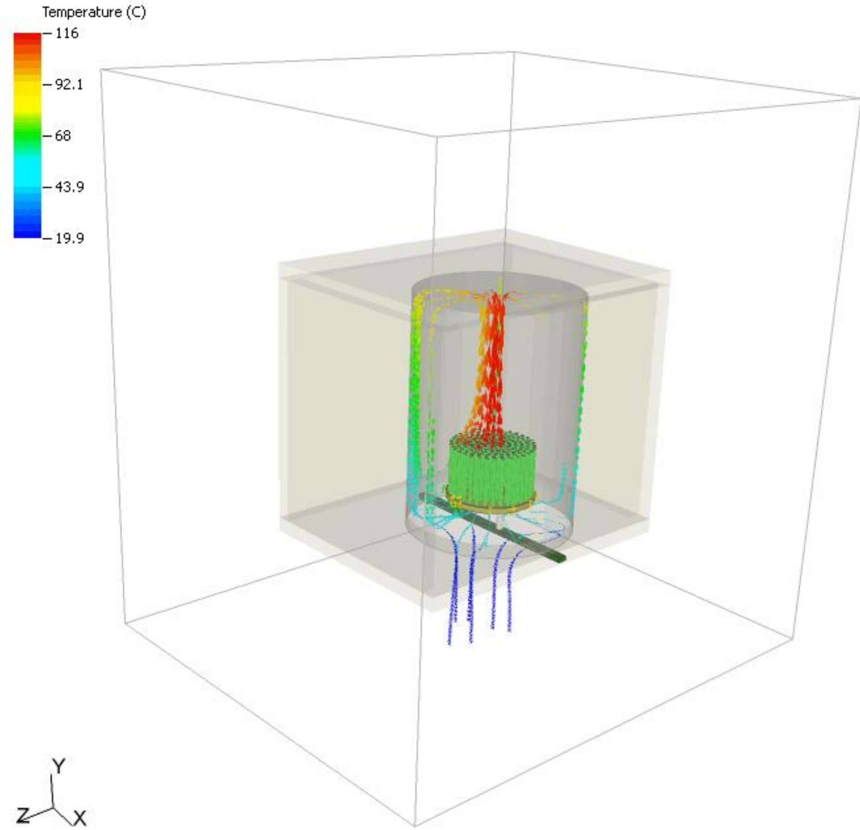




Physical example

Example 4
Results





Power [W]	LPF80 A50 Free [K]	LPF80 A50 UL6" [K]	Difference [K]
30	61	99	38

Conclusion

- Thermal simulation will give insight in the full 3D thermal behavior of the luminaire/led in the solid and the fluid.
- Easy to do what if then analyses to make the right decisions during the design.
- Avoid costly and time consuming experimental tests
- Reduce of design risk come to the most optimal design, reduces costs

Thank you

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