PHILIPS

sense and simplicity

Thermal Design Guide v2.2
Fortimo SLM platform

Fortimo SLM Team
GBU LED Systems
Philips Lighting B.V.

PHILIPS

Contents

- Thermal specifications
- How to measure T_{case} at its critical temperature point T_c?
- Thermal interface materials (TIM)
- Designing a passive cooled luminaire
- Designing an active cooled luminaire
- Complementary partners for thermal solutions (passive/ active)

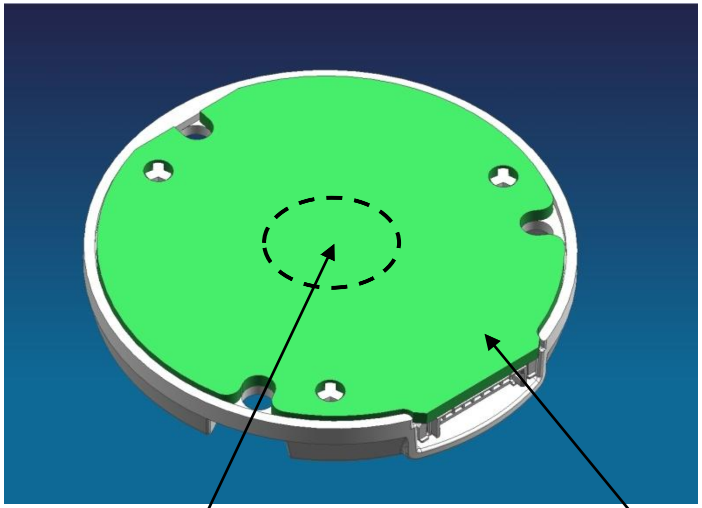
Thermal specifications Fortimo SLM platform

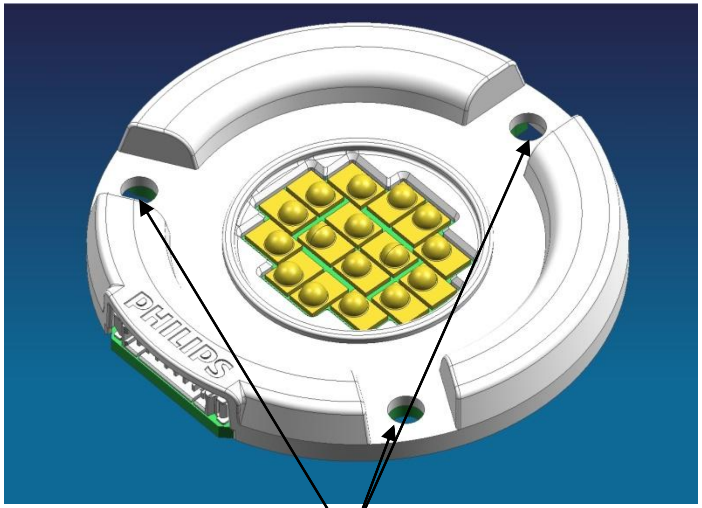
Fortimo SLM Platform	**800 lm**	**1100 lm**	**1500 lm**	**2000 lm**	**3000 lm**
Dissipated thermal power (maximum)	**10 W**	**17 W**	**18W**	**31 W**	**40 W**
Dissipated thermal power (typical)	**8 W**	**15 W**	**16 W**	**28 W**	**37 W**
Max. T_{case} of module	**65 ^{o}C**				**65 ^{o}C**
Max. ambient temperature	**35 ^{o}C**				**35 ^{o}C**
Thermal impedance requirement T_{case} to $T_{ambient}$	<3.0 ^{o}C/W	<1.75 ^{o}C/W	<1.65 ^{o}C/W	<0.95 ^{o}C/W	<0.75 ^{o}C/W

Performance requirement total cooling solution

Thermal specifications Fortimo SLM platform

- Tcase 65ºC (max. surface temperature on aluminum interface)
- Max. ambient condition 35ºC ambient





Max. Tcase 65ºC specification on surface

Aluminum thermal interface ø47 mm

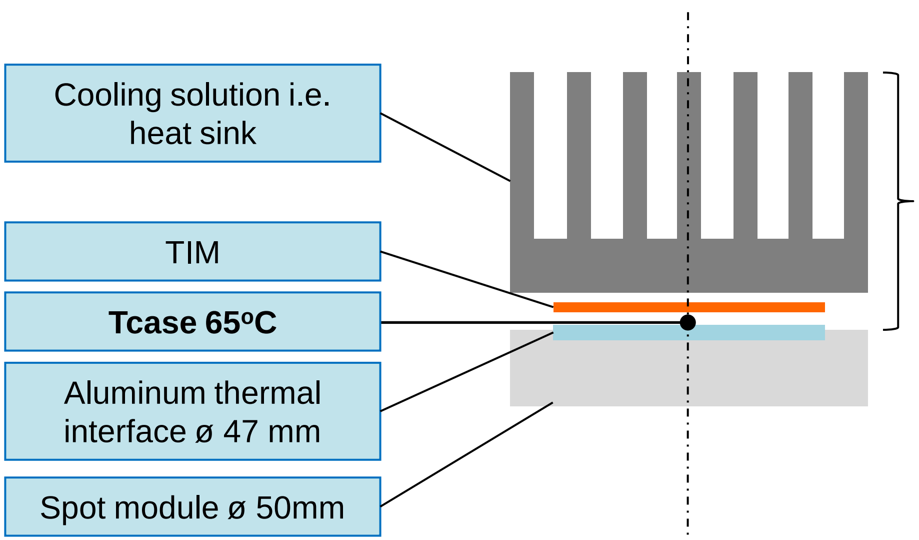
3 screw holes for attachment of module onto heat sink (M3, boltcircle ø42mm)

Thermal specifications Fortimo SLM platform

- A ***maximum surface temperature of 65^{o}C*** to be guaranteed on the interface between the ‘Module’ and the ‘TIM + cooling solution’ at ***maximum ambient of 35^{o}C***

- All types of ***Fortimo SLM drivers will dim when a temperature over 65^{o}C*** is sensed by the SLM module.

Simplified Model

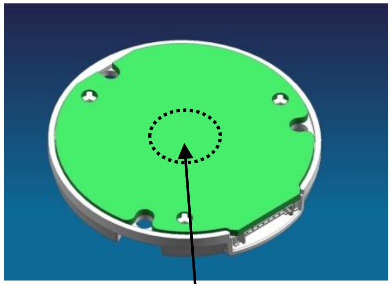


SLM 800lm 10W => Rth case to ambient ≤ **3.00** [^{o}C/W]
SLM 1100lm 17W => Rth case to ambient ≤ **1.75** [^{o}C/W]
SLM 1500lm 18W => Rth case to ambient ≤ **1.65** [^{o}C/W]
SLM 2000lm 31W => Rth case to ambient ≤ **0.95** [^{o}C/W]
SLM 3000lm 40W => Rth case to ambient ≤ **0.75** [^{o}C/W]

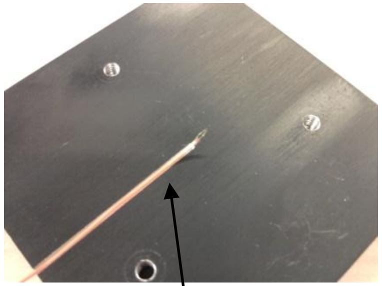
Note: this includes the TIM

How to measure critical temperature point T_c?

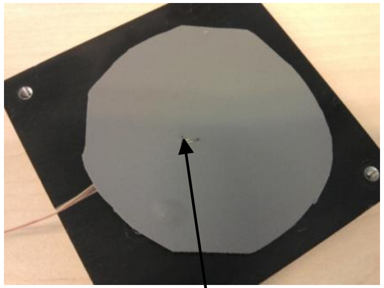
- The Tcase should be measured at its critical temperature point, ***centre point at the bottom of the module***
- This can be done ***by making a thin v-groove in the heat sink or a small drill hole in the heat sink*** to reach bottom of the module at its critical temperature point, make sure to measure the bottom of the module and not the TIM



Critical temperature point Tc



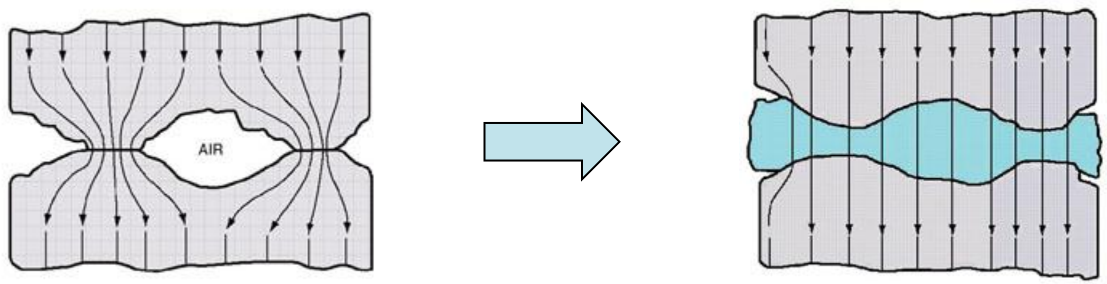
Thin v-groove in the heat sink to embed a thermocouple



Tip of thermocouple sticking out on top of the thermal pad (TIM)

Thermal Interface Materials (TIM)

- Function is to ***reduce thermal impedance between two solid surfaced***
- Replaces air (thermal insulator c=0.024W/mK) by filling the gaps with better conductive thermal interface material (order c=1W/mK)



- In general:
  - ***Thermal pastes performs better than thermal pads***
  - ***The higher the thermal conductivity the better***
  - ***The thinner the TIM the better***

Thermal Interface Materials (TIM)

- In practice:
  - Actual ***thermal impedance*** [ºC/W] of TIM in application ***is more important than conductivity of material***
  - Each ***thermal interface*** can have a significant contribution to the ***total thermal impedance of module*** to ambient
  - ***Limiting the # of thermal interfaces*** from module to ambient ***is strongly recommended***

PHILIPS

Contact information complementary partners
Thermal interface materials (TIM)

The Bergquist Company www.bergquistcompany.com		
North American Headquarters 18930 W. 78th Street Chanhassen, MN 55317 USA	**Contact person for Europe** Nico Bruijnis Phone: +31 35 538 0684 Cell: +31 6 5316 0688 E-mail: n.bruijnis@bergquist-europe.com	
Chomerics www.chomerics.com		
Chomerics North America Parker Hannifin Corp. 77 Dragon Court Woburn, MA 01801 USA	**Contact person for Europe** Luc Coupet Phone: +33 134323900 Cell: +33 670765480 E-mail: luc.coupet@parker.com	
Laird Technologies www.lairdtech.com		
Corporate Headquarters Laird Technologies (Corporate) 16401 Swingley Ridge Road Suite 700 Chesterfield, MO 63017	**Contact person for Europe** Philip Blazdell Phone: +49 803124600 Cell: +44 7595710316 E-mail: philip.blazdell@lairdtech.com	

Contents

- Thermal specifications
- How to measure T_{case} at its critical temperature point T_c?
- Thermal interface materials (TIM)
- Designing a passive cooled luminaire
- Designing an active cooled luminaire
- Complementary partners for thermal solutions (passive/ active)

PHILIPS

Designing a passive cooled luminaire

Design based on Fortimo SLM 1100lm:

- Performance requirement cooling R_{th} < 1.75 $^oC/W$

$$R_{th\,case\,to\,ambient} = \frac{T_{case} - T_{amb}}{Thermal\ dissipation} = \frac{65^oC - 35^oC}{17W} = 1.75\frac{^oC}{W}$$

$$R_{th\,case\,to\,ambient} = R_{th\,heatsink} + R_{th\,TIM}$$

$$R_{th\,heatsink} = \frac{1}{htc * effective\ cooling\ surface}$$

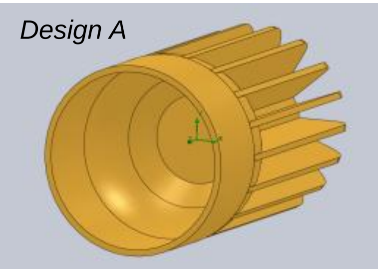
- Assuming a conservative heat transfer coefficient (htc) = 5 W/m^2K and the contribution of the thermal interface material $R_{th\ TIM}$ = 0.1 $^oC/W$ a first estimate of the required cooling surface can be calculated

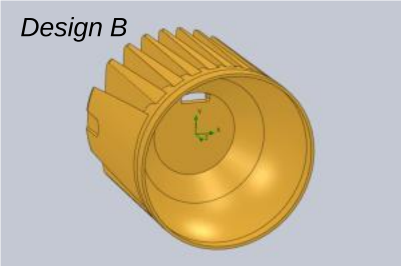
$$Minimum\ cooling\ surface = \frac{1}{htc * R_{th\,heatsink}} = \frac{1}{5\frac{W}{m^2K} * 1.65^oC/W} = 0.121m^2$$

PHILIPS

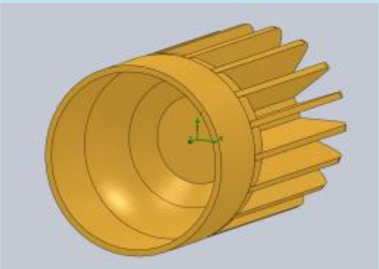
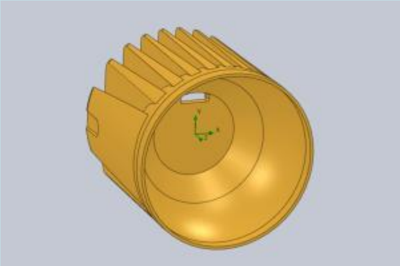
Design of Experiments (DoE)

- Based on the previous calculation a minimum surface area of 0.121m^2 is required
- This corresponds to a cylinder of ø120mm and 322mm long
- In order to reduce overall size of the luminaire, cooling fins should be introduced
- To optimization the thermal performance a DoE should be set up
- Example of simple DoE with CFD analysis:
  - Comparison of Design A and B
  - Effect of thermal radiation, blank metal surface or black anodized





Design of Experiments (DoE)

Results DoE	Design A 		Design B 	
Area [m²]	0.236	0.236	0.158	0.158
Emissivity [-]	0.1	0.9	0.1	0.9
$R_{th\ heatsink}$ [°C/W]	**1.33**	**0.99**	**1.76**	**1.39**
HTC average [W/m²K]	3.2	4.3	3.6	4.6

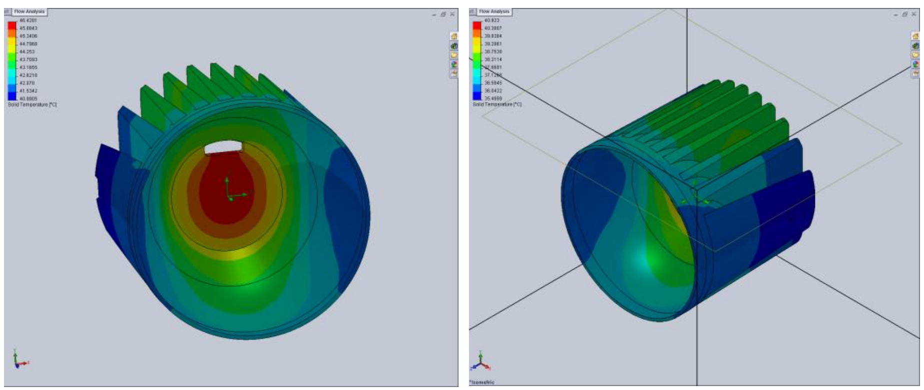
A DoE can of course be much more extensive:

- Different material (thermal conductivity)
- Orientation; horizontal or vertical (here horizontal is assumed as worst case, so both heat sinks will also work in vertical orientation)

PHILIPS

Detailed analysis

- Both designs are feasible, but choice is to focus on design B
- The fins are place in line with the flow direction for maximum efficiency, this way it is possible to keep the overall luminaire size and weight small.

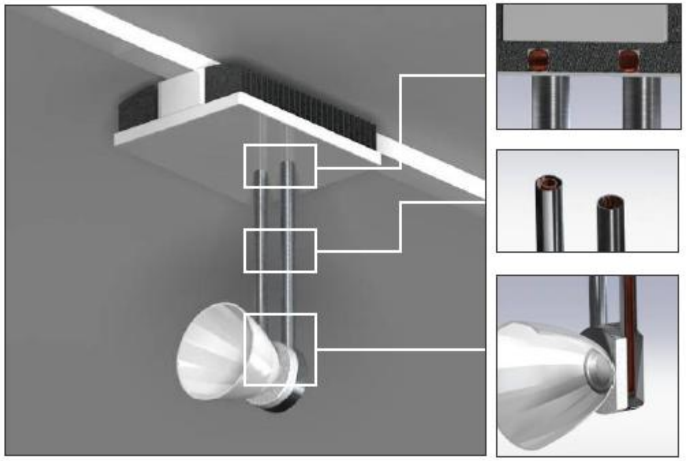


- Analysis with CFD can further optimize the design:
  - i.e. optimization of fin thickness and fin spacing

Passive cooled luminaire designs

- After design optimization a passive luminaire design could look like this:

- Another passive cooled design, but with heat pipes:



Some design guidelines for passive cooling

- Limit the # of thermal interfaces in the thermal path from module to ambient => strongly recommended
- Thick fins conduct heat better than thin fins
- Large spacing between fins is better than small spacing between fins
- Make cooling surfaces more effective by using proper conductive materials, appropriate thickness and sound orientation
- Thermal radiation plays a significant role => anodized surfaces are preferred over blank surfaces

Contents

- Thermal specifications
- How to measure T_{case} at its critical temperature point T_c?
- Thermal interface materials (TIM)
- Designing a passive cooled luminaire
- Designing an active cooled luminaire
- Complementary partners for thermal solutions (passive/ active)

Designing an active cooled luminaire

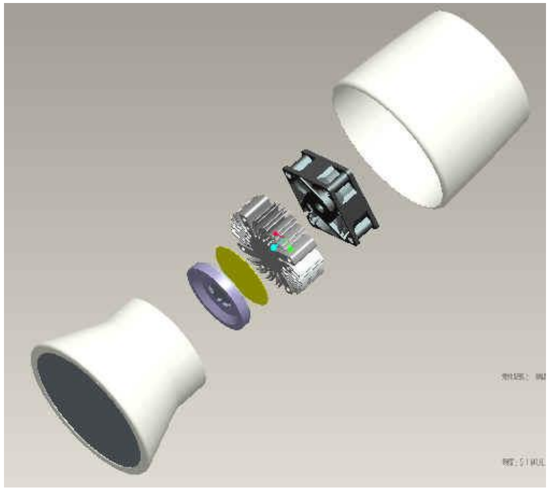
Design based on Fortimo SLM 2000lm:

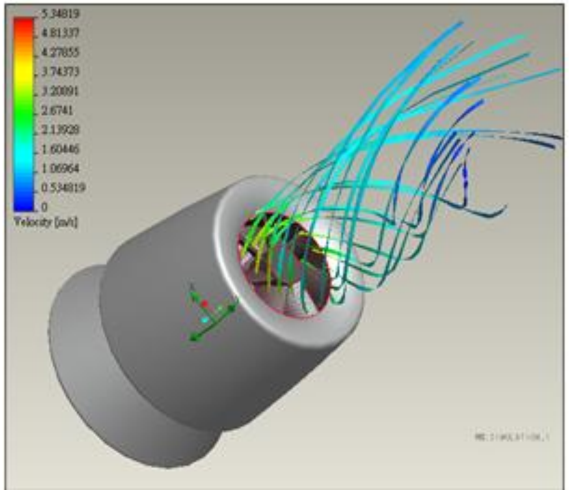
- Performance requirement cooling R_{th} < 0.95 ^{o}C/W
- Assuming passive cooling conditions:
  - Heat transfer coefficient (htc) = 5 W/m^{2}K and
  - Contribution $R_{th\ TIM}$ = 0.1 ^{o}C/W
- A calculated cooling surface of 0.235m^{2} is required
- This corresponds to the surface a cylinder of ø120mm and 624mm long!

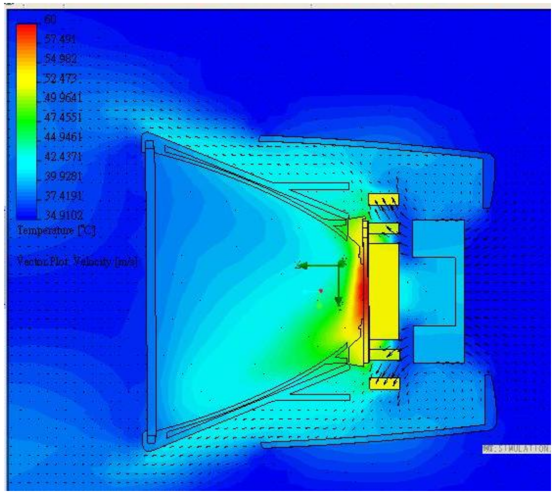
- Goal of an active solution is to actively move air over the cooling surfaces to increase the heat transfer coefficient, therefore enabling small, compact and light weight cooling solutions (and systems)

CFD analysis

- CFD analysis can be a great way to help design a good active cooled luminaire
- A possible design is shown below
- The complete cooling solution has reduced to a small, compact and light weight solution of ø70mm and 40mm in height







Active cooled luminaire designs

•Goal of an active solution is to actively move air over the cooling surfaces to increase the heat transfer coefficient, therefore enabling small, compact and light weight cooling solutions (and systems)

After optimization an active cooled luminaire design could look like this:

PHILIPS

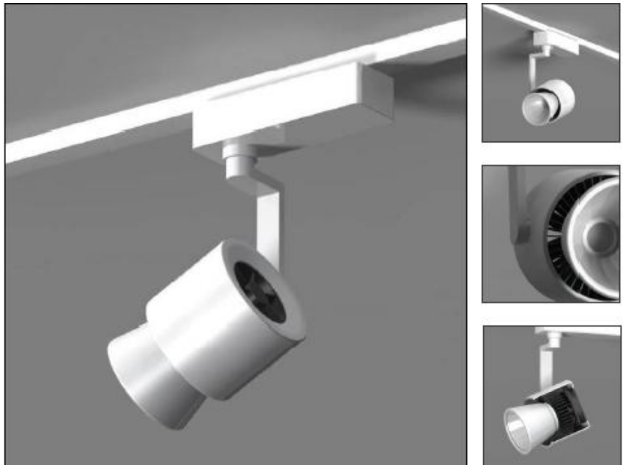
Some design guidelines for active cooling

Design considerations for active cooling are:

- Provisions in luminaire design for inlet and outlet of respectively cool and hot air
- Ensure smooth airflow from inlet to outlet and prevent restrictions in the flow path (to limit vibration, recirculation and possible noise)

Always take care to:

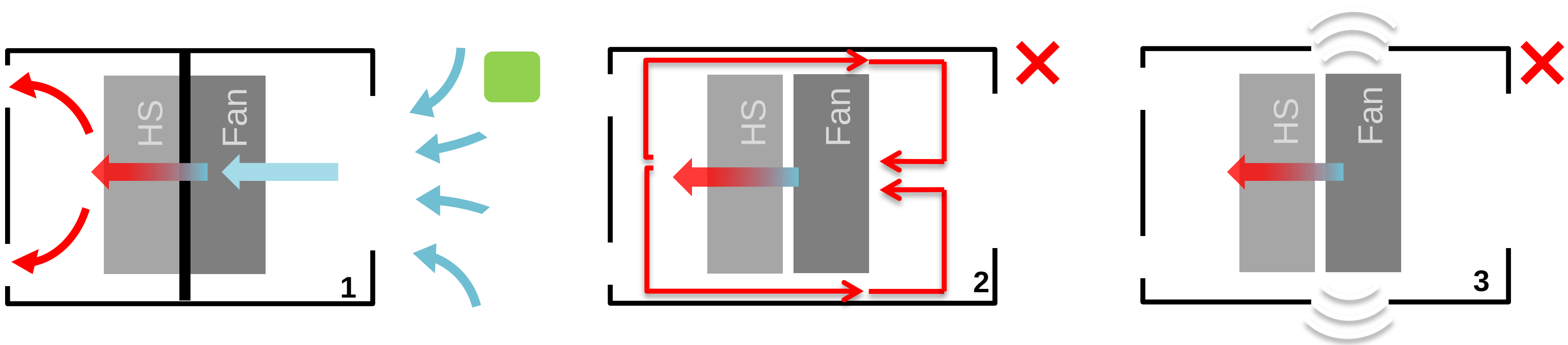
- Design for reliability (dusty environments)
- Design for performance (differentiator)
- Design for low noise (differentiator)



Some design guidelines for active cooling

Design considerations for active cooling are:

- Provisions in luminaire design for inlet and outlet of respectively cool and hot air (**1**) Ensure smooth airflow from inlet to outlet and prevent restrictions in the flow path (to limit vibration recirculation and possible noise)
- Avoid recirculation of hot air (**2**) inside the luminaire, which leads to lower thermal performance and higher noise level.
- Enclose fan noise avoiding unnecessary openings near the fan in the luminarie's housing (**3**)



PHILIPS

Thermal solution validation

When testing the thermal performance of your luminaire pay special attention to these 2 numbers:

- Max temperature of the module $T_c=65^oC$
- Max $\Delta T = 30^oC$ ($T_c=65^oC$ when your ambient temperature is 35^oC)

Operating the system under those parameters will guarantee its proper performance in terms of:

- Lumen output
- Light consistency
- Life time

Complementary partners for thermal solutions

Overview of our complementary partners and their cooling solutions that are especially designed for the Fortimo SLM platform

- AVC (active and passive solutions)
- Sunon (active solutions)
- Nuventix (active solutions)
- Wisefull (active solutions)
- FrigoDynamics (passive solutions)

AVC

Module Type:	Philips FORTIMO SLM 1100lm Passive Solution + Ø9mm heatpipe	Philips FORTIMO SLM 1100lm Active Solution	Philips FORTIMO SLM Lexel Active Solution	Philips FORTIMO SLM 2000lm Active Solution
Hestsink Type:	Sunflower Heatsink	Sunflower Heatsink	Sunflower Heatsink	Sunflower Heatsink
Heatsink Model:	FSLM-HP1100	FSLM-A1100-G1	FSLM-A2000-G1	FSLM-A2000-G2
Total Height (mm): Heatsink + module:	105mm	30mm	40mm	40mm
Heatsink Geometry:	Extrusion	Extrusion	Extrusion	Extrusion
Heatsink Dimension:	Ø100mm*H105mm	Ø65mm*H10mm	Φ65mm*20mm	Φ70mm*20mm
Dimension Weight (kg):	0.685	0.080	0.128	0.150
Heatsink Material:	AL6063-T5	AL6063-T5	AL6063-T5	AL6063-T5
Surface finish:	Anodized	Anodized	Anodized	Black Anodized
LED Thermal Power:	17W	17W	31W	31W
Ambient Temperature:	35℃	35℃	35℃	35℃
Case Temperature:	<=65 ℃	<=65 ℃	<=65 ℃	<=65 ℃
Thermal Resistance:	<1.75 ℃/W	<1.75 ℃/W	<= 1.02℃/W	<= 0.95℃/W
Lower-noise FAN:	N/A	DS0520_12L	DS0520_12L	DS6020_12E
Noise Level:	N/A	<21dB	<21dB	<23dB
RPM speed:	N/A	3000RPM±15%	3000RPM±15%	2200RPM±15%
	Available Now!	Available Now!	Available Now!	Available Now!

Total Thermal Solution Provider

Headquarter, ASIA VITAL COMPONENTS (AVC) CO., LTD.
248-27, Hsin Sheng Rd., 80672 Kaosiung City, Taiwan.
China Factory:
West Industrial Park. Xinyang Community Shajing Branch, Baoan District, Shenzhen City, CHINA

SLM 3000lm to be released soon

Sunon

Specification
LED Fortimo SLM 2000lm
LED Power 31W
Cooling Module Model No. TA003-10001
Cooling Module Diameter ∮86x37mm
Fan Dimension 60x60x15mm
Fan Rating Voltage 12VDC
Fan Rating Current 24mA
Fan Speed 2200RPM
Cooling Module Noise @ 1M 18dB(A)
Heat Sink Material Aluminum
Weight 235g

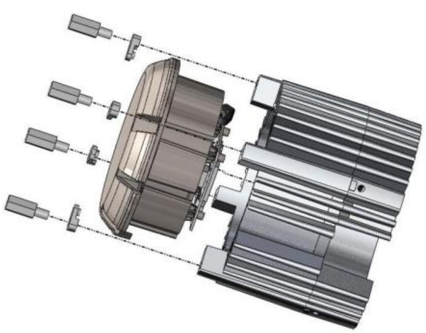
SLM 2000lm gen 2 (TA003-10003) solution, improved for use in track luminaires

SLM 3000lm (TA004-10003)

- Prototypes available
- Limited engineering samples available end march 2011
- MP release in April 2011

SLM 1100lm + SLM 1500lm under development

Nuventix



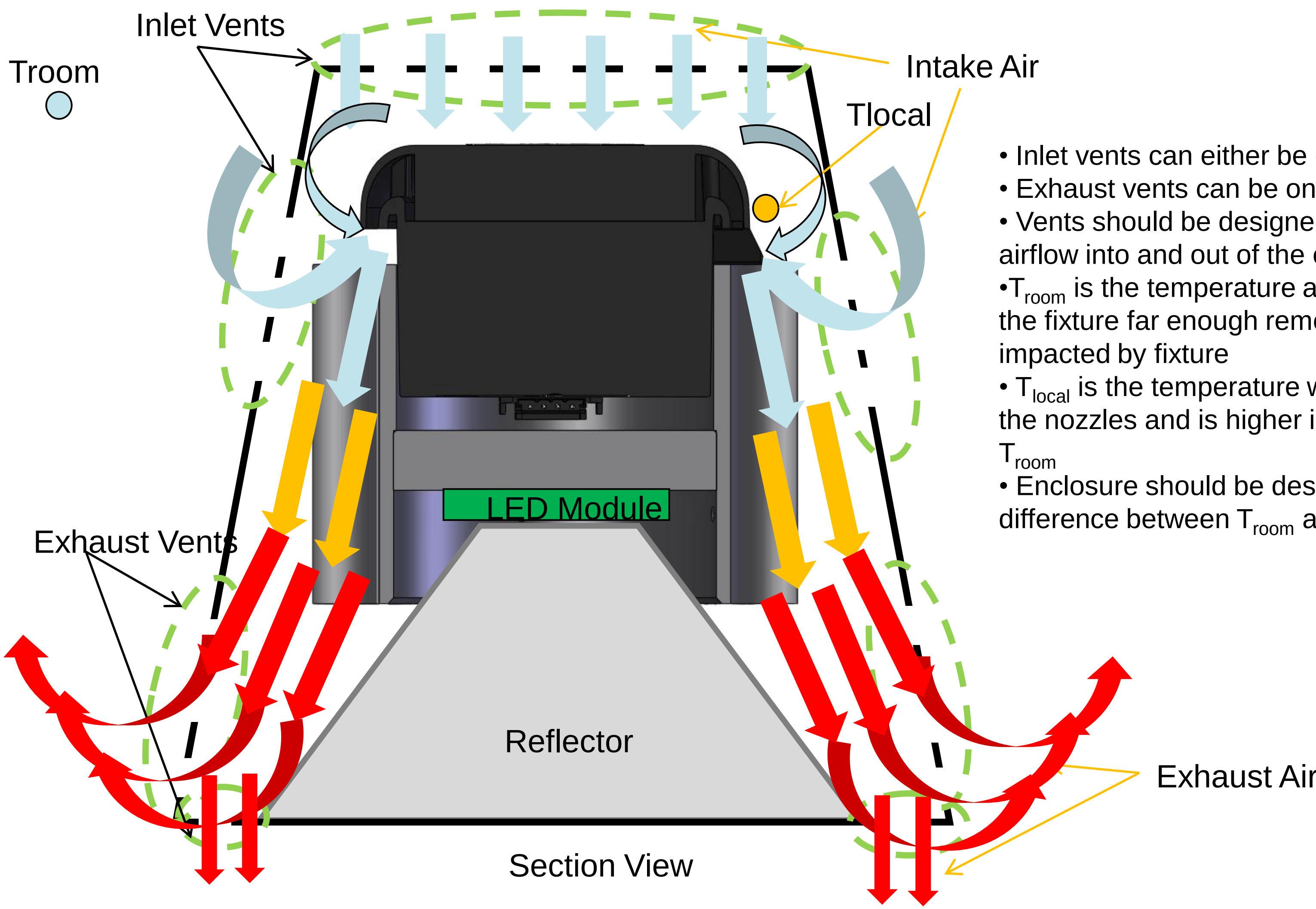
- **Solution for SLM 800lm, 1100lm and 1500lm**
- **Solution for SLM 2000lm open air applications**
- **3000lm under development**

Philips Fortimo LED SLM Modules

Track and Recessed Applications	Spotlight Cooler 38W Standard	Spotlight Cooler 34W High Performance	Spotlight Cooler 34W Mid Performance	Spotlight Cooler 34W Standard	Spotlight Cooler 31W High Performance	Spotlight Cooler 31W Mid Performance	Spotlight Cooler 31W Standard	Spotlight Cooler 21W Standard
Fortimo LED SLM 1100 840, Tamb = 35°C								✓
Fortimo LED SLM 1100 835, Tamb = 35°C								✓
Fortimo LED SLM 1100 830, Tamb = 35°C								✓
Fortimo LED SLM 2000 840, Tamb = 35°C					✓			
Fortimo LED SLM 2000 835, Tamb = 35°C					✓			
Fortimo LED SLM 2000 830, Tamb = 35°C					✓			

PHILIPS

SynJet® Airflow Basics – Enclosure Guidelines



- Inlet vents can either be on back, sides or both
- Exhaust vents can be on sides, front or both
- Vents should be designed to allow maximum airflow into and out of the enclosure
- T_{room} is the temperature around the outside of the fixture far enough removed to not be impacted by fixture
- T_{local} is the temperature within the fixture near the nozzles and is higher in temperature than T_{room}
- Enclosure should be designed to minimize the difference between T_{room} and T_{local}

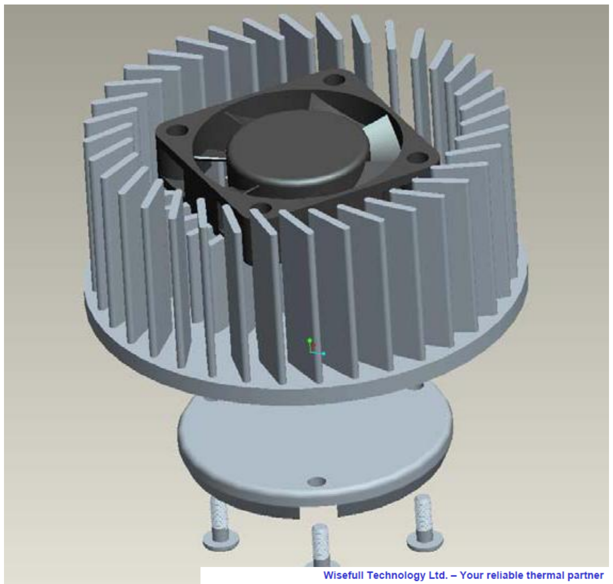
PHILIPS

www.wisefull.com

Wisefull Technology Ltd.

Thermal solutions for Philips LED Module

Active solution



Wisefull Technology Ltd. – Your reliable thermal partner

3. Test results

Sample		Testing time (min)	Temperature(℃)		ΔT(℃)	Rth(℃/w)
Heat sink #	Test runs		Ta	Tc	Tc-Ta	ΔT/power
1#	Run 1 (Free air, downward lighting direction)	30	23.9	45.4	21.5	0.693
	Run 2 (Free air, upward lighting direction)	30	24.0	47.0	23.0	0.742
	Run 3 (Test in luminaire, 5mm air exit width)	60	23.8	59.7	35.9	1.159
	Run 4 (Test in luminaire, 10mm air exit width)	60	24.2	56.4	32.2	1.039
2#	Run 1	30	23.7	44.7	21	0.677
	Run 2	30	24.1	46.8	22.7	0.732
	Run 3	60	24.6	60.4	35.8	1.155
	Run 4	60	23.9	56.3	32.4	1.045

Note: Rth is calculated by using 31W as the assumed heat dissipation

But also passive

- **Solutions for SLM 800lm, 1100lm and 1500lm**
- **Solution for SLM 2000lm under development**

FrigoDynamics GmbH

Flux	Tc = 3000 K	Tc = 3500 K	Tc = 4000 K
800 (LpW, typical lamp wattage, and thermal load)	72 lm/W	75 lm/W	79 lm/W
	11	10	10
	8.1 W	7.5 W	7.3 W
1100 (LpW, typical lamp wattage, and thermal load)	63 lm/W	65 lm/W	70 lm/W
	17	17	15
	13.3 W	12.9 W	11.9 W
1500 (LpW, typical lamp wattage, and thermal load)	70 lm/W	72 lm/W	76 lm/W
	20	20	19
	15.7 W	15.8 W	14.5 W

- **Solutions for SLM 800lm, 1100lm and 1500lm**

PHILIPS

Contact information complementary partners

Cooling solutions

HEADQUARTER **AVC KAOHSIUNG** No.248-27, Hsin-Sheng Rd., 80672 Kaohsiung City, Taiwan	**Contact person for Europe** Beatrice Tseng Phone: +31208932195 Cell: +31 646688175 E-mail: beatrice_tseng@avc.com.tw	**Contact person for N.A. & Asia** Jeff Chou Phone: +86-21-50270508 ext. 68528 Cell: +86 13916680014 E-mail: jeff_chou@avc.com.cn
Sunonwealth Electric Machine Industry Co., Ltd No.30, Lane 296 Shin-Ya Road, Chyan-Jenn Dt., Kaohsiung 806, Taiwan	**Contact person for Europe** Alipio Marques Phone: +33 146 154 494 Cell: +33 616 795 314 E-mail: alipio.marques@sunon.fr	**Contact person for Asia** Sandra Lin Phone: +886-7-813-5888 ext 1257 Cell: +886-911-739-507 E-mail: sandra@email.sunon.com.tw
Wisefull www.wisefull.com ***Wisefull Technology Ltd. – Your Reliable Thermal Partner***	**Contact person** Wilson Peng No. 3, Hong-Yeh South 9th Rd. Hong-Yeh 138 Industrial Park, Tang Xia Town, Dongguan City, Guangdong Province, P.R. China Email: weihua@wisefull.com Tel: (86)76987725315~6 Ext: 678 Fax: (86) 76986853535 Mobile: (86)13926896210	
Corporate Headquarters Nuventix Worldwide Sales Office 4635 Boston Lane Austin, Texas 78735 USA	**Contact person for Europe** Francois Jaegle Phone: +33 624734646 E-mail: fjaegle@nuventix.com	**Contact person for US** Jeff Kelly Phone: +33 624734646 E-mail: fjaegle@nuventix.com
FrigoDynamics GmbH Bahnhofstr. 16 D-85570 Markt-Schwaben Germany	**Contact Person** Hans Kunstwadl [h.kunstwadl@frigodynamics.com] Tel: +49-8121-973730 Fax: +49-8121-973731 Mob: +49-171-6505418	

PHILIPS