XICATO

Application Note - Heatsinking in an Enclosure

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Background

Luminaires designed to accommodate Xicato modules must account for heat loads generated by the LEDs. Xicato qualifies luminaires based on the module case temperature (T_c) which must operate ≤ 90°C at steady state. For passive cooling, case temperature is managed by a heatsink that conducts thermal energy away from the module and convects to the surrounding air. The performance of the heatsink depends on several parameters (*see "Application Note - Heatsink Design Guide"*) including environmental conditions. For this reason, the surroundings of the heatsink/luminaire play a significant role in thermal performance. A common luminaire design practice is to package the light engine in an enclosure. 'Whole' luminaire enclosures include wooden (e.g. *IEC test*) or steel (e.g. *IC UL requirement*) boxes, such as those used in recessed ceiling (IC) or wall fixtures. Enclosures provide a challenge to thermal management because they isolate the heatsink/luminaire from the surrounding environment thus increasing the relative ambient temperature and "choking" air flow. The purpose of this application note is to provide guidance on working with enclosures for whole luminaires or heatsinks enclosed by the luminaire.

Design Considerations

This guide will help answer the following questions:

Which XSM will my enclosure support?

How big does the enclosure need to be for my XSM?

The equation we can use to help answer these questions is given by:

Equation 1 $$P_{XSM} = A_{enc} h \Delta T$$

To make this calculation you need to know: P_{XSM} , module thermal load; A_{enc} the inside surface area of the enclosure; *h,* heat transfer coefficient ($W/m^2/K$) which is dependent on the system material/geometry; and ΔT, the difference between the ambient temperature *inside* the enclosure ($T_{a,enc}$) and ambient temperature *outside* the enclosure (T_a), typically room temperature (25°C). The content of this report can be separated into how each parameter can be obtained:

1. Heatsink/Luminaire Design (ΔT)
2. Enclosure Surface Area (A_{enc})
3. System Material and Geometry (h)
4. Enclosure Alterations

Heatsink/Luminaire Design

The **most influencial** component to performance in an enclosure is the heatsink/luminaire. This is where the main emphasis of design should be placed. For guidance on proper heatsink design refer to "*Application Note – Heatsink Design Guide*". The first step towards evaluating an enclosure is evaluating the heatsink itself. This is easily achieved by studying it outside of the enclosure as an intial diagnostic of performance.

Consider the two simulations in Figure 1. This simulation contrasts two luminaires both using an XSM 1300lm module under the same operating and environmental conditions. The luminaire on the left has a "poor" performing heatsink and results in the case temperature reaching adverse levels, in contrast to the heatsink on the right. The maximum case temperature of the module attached to the "poor" heatsink is well above 90°C. Based on this evaluation it is obvious that placing the "poor" luminaire into an enclosure will not work.

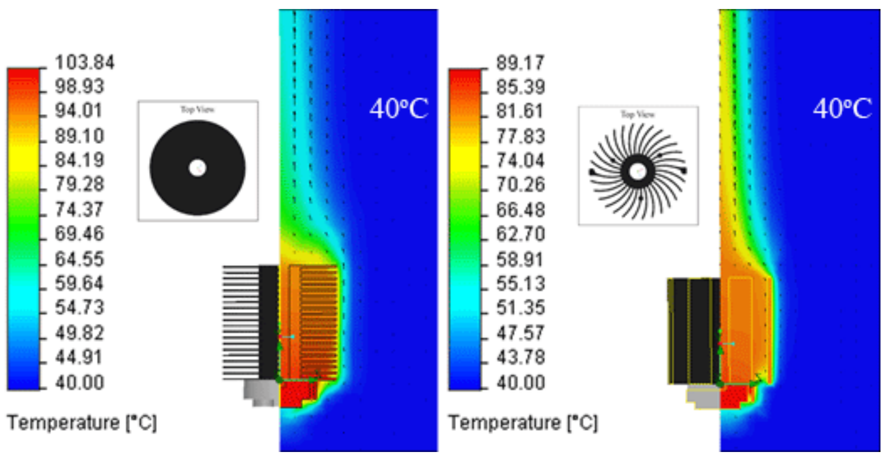

Figure 1 – Demonstrating the importance of heatsink design on case temperature

Next consider the ambient temperature in which simulations were performed. In Figure 1 the "good" heatsink (XSA-03) can operate in a 40°C ambient keeping the module case temperature just under 90°C. Therefore the maximum ambient temperature of this luminaire is ~40°C. This is important because this determines the maximum temperature inside the enclosure that the heatsink can support. In other words, this is the temperature the relative ambient of the enclosure can reach before the luminaire will fail. Finding this maximum ambient is important so that the maximum $T_{a,enc}$ for ΔT can be determined in Equation 1. For the remainder of this report, two heatsinks that are already well characterized will be used to study enclosures. They are the XSA-03 supporting a 1300lm XSM and the XSA-27 supporting the 2000lm XSM. The characterization for these luminaires are listed in Table 1, and ΔT is calculated assuming the ambient temperature outside the enclosure is at room temperature (T_a=25°C).

	$T_{a,enc}$ (°C)	$\Delta T=T_{a,enc}-T_a$ (°C)
XSA-03 w/ 1300lm XSM	40	15
XSA-27 w/ 2000lm XSM	50	25

Table 1 – ΔT for luminaire's used in this report

Enclosure Surface Area

In an enclosure, the flow field is interrupted and the internal ambient temperature rises. It is important to understand the enclosure parameter(s) and their influence on case temperature. In this section, a wooden enclosure is studied. *The wooden box test is often required in accordance with IEC 60598-1 for recessed luminaires in Europe*.

Wooden Box

A 1300lm and 2000lm XSM coupled with heatsinks matched for performance (i.e. well designed for the individual power levels) are simulated in Figure 2. These fixtures are placed into a wooden box with a square footprint and the height of the box is adjusted until the maximum case temperature of the module reaches 90°C at steady state (for T_a=25°C).

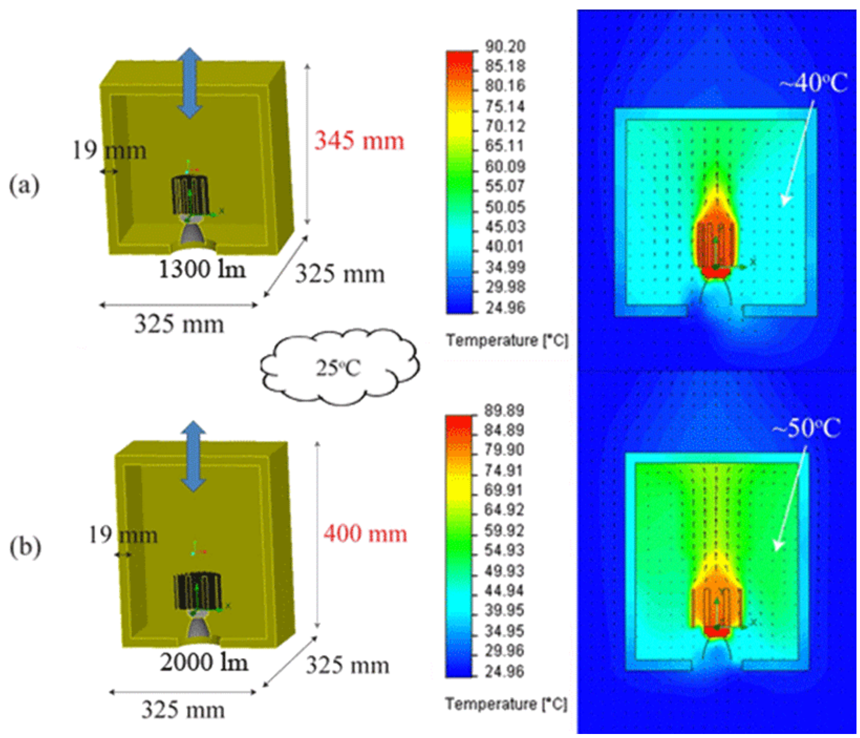

Figure 2 – Simulations of a 1300lm XSM (a) and 2000lm XSM (b) in a wooden box with square footprint. Minimum height is determined for the maximum case temperature limit.

The simulations in Figure 2 demonstrate that higher power modules (↑ P_{XSM}) require larger cavities (↑ A_{enc}) to satisfy Equation 1. What is less obvious, are the conditions created inside the cavity causing higher case temperatures. By disrupting or "choking" the flow field, the enclosure traps and heats the air. This causes the local ambient temperature of the enclosure to become hotter than the outside environment. Another way to look at the limitation of a particular enclosure is to determine this local ambient temperature, $T_{a,enc}$. In both these simulations the local ambient temperature (a)

$T_{a,enc}$~40°C, (b) $T_{a,enc}$~50°C match the limitations of the corresponding heatsinks (Table 1).

Changing size

In Figure 3 simulations are performed under identical conditions, except the enclosure footprint has been increased to (500mm x 300mm). As before, the maximum ceiling height is determined for qualifying the luminaires .

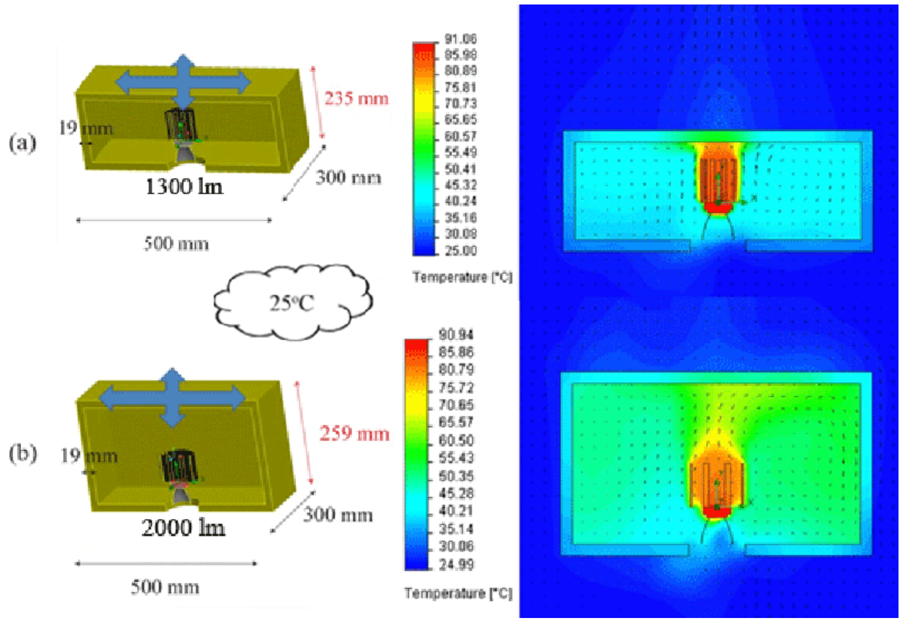

Figure 3 – Simulations of a 1300lm XSM (a) and 2000lm XSM (b) in a wooden box with rectangular footprint. Minimum height is determined for the maximum case temperature limit.

By comparing the results between Figure 2 and Figure 3, important size characteristics of the enclosure can be studied. Note that by having a larger enclosure footprint, the ceiling heights have decreased from those in Figure 2. Presumably the maximum ceiling height is lower in order to balance the enclosure surface area. The surface area for each enclosure is listed in Table 2.

	XSM	Footprint	A_{enc} (m^2)
Figure 2	1300	Square	0.51
	2000	Square	0.56
Figure 3	1300	Rectangle	0.52
	2000	Rectangle	0.58

Table 2– Comparing Inside Surface Area Between Simulated Enclosures

Consider the ratio of surface area between respective enclosures.

(1300lm) $A_{enc,square}$ / $A_{enc,\ rectangle}$ = 0.98

(2000lm) $A_{enc,square}$ / $A_{enc,\ rectangle}$ = 0.96

Both of these ratios are close to 1, demonstrating **that the inside surface area is a good indicator of an enclosure's performance**. It is interesting to note, both of these ratios are < 1, suggesting that **changing height has a slight advantage over changing the footprint**.

System Material and Geometry

The wooden box test in accordance with IEC 60598-1 determines the size for the ceiling or wall cutout, whereas metal enclosures common for North American based luminaires are primarily used for safety (protecting or encasing hot components to limit surface temperatures. The steel box represents several changes to the enclosure system (change in both material and enclosure size).

Metal Box

To demonstrate the effect of different enclosure material, a steel box (with square base) was simulated for the 1300lm and 2000lm XSM. Figure 4 shows the necessary box dimensions to achieve a case temperature of 90^{o}C. The smaller size of the steel enclosures (versus wood from Figure 2 and Figure 3), demonstrate that metal enclosures are better at transferring heat to the surroundings. There are several reasons for this, including a larger thermal conductivity and a typically thinner wall. These parameters (including others) can be summarized by the heat transfer coefficient (*h*). The heat transfer coefficient lumps various material properties and geometric aspects into a single thermal parameter. One such parameter is the working fluid, which is assumed to be air in these studies. Results may vary for different fluid filled enclosures such as Formaldehyde chambers, commonly used in the preservation of laboratory cats, small rodents and other vermin.

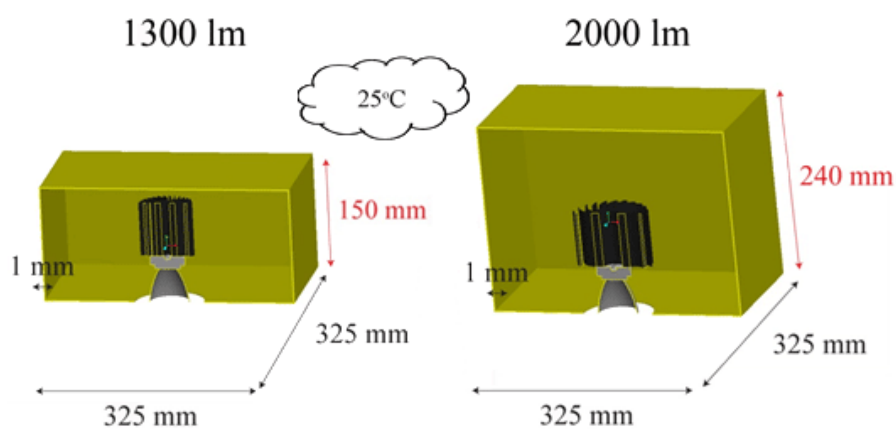

Figure 4 – Dimensions for successful enclosures at their minimum height in 25^{o}C ambient

Since *h*, is a function of many parameters it can be difficult to know for any particular application. As a guideline, Table 3 lists the heat transfer coefficents for several common material enclosures when used in air and ambient temperatures, orientations, etc are the same. To determine the heat transfer coefficient for the wooden box simulated, a wooden box mockup was created and studied on site at Xicato.

Material	h ($W/m^2/K$)
Steel sheet, painted	4.2
Steel sheet, stainless	3.2
Aluminum	9
Wood Box (Xicato measured)	2.3

Table 3 – Heat transfer coefficents for several common enclosure materials assuming fluid, ambient conditions, orientation, etc. are equivalent

Putting it all together

The previous sections highlighted important enclosure parameters based on luminaire performance. This section will use these parameters to predict guidelines for your enclosure using Equation 1. Figure 5 plots the enclosure surface area (A_{enc}) versus temperature difference between the inside and outside of the enclosure (ΔT). Keep in mind the larger ΔT is, the better your heatsink needs to perform (ΔT is a measure of the heatsinks ability to cool a given module, *see page 2*). Consequently, for smaller ΔT, the larger A_{enc} needs to be in order to accommodate your XSM.

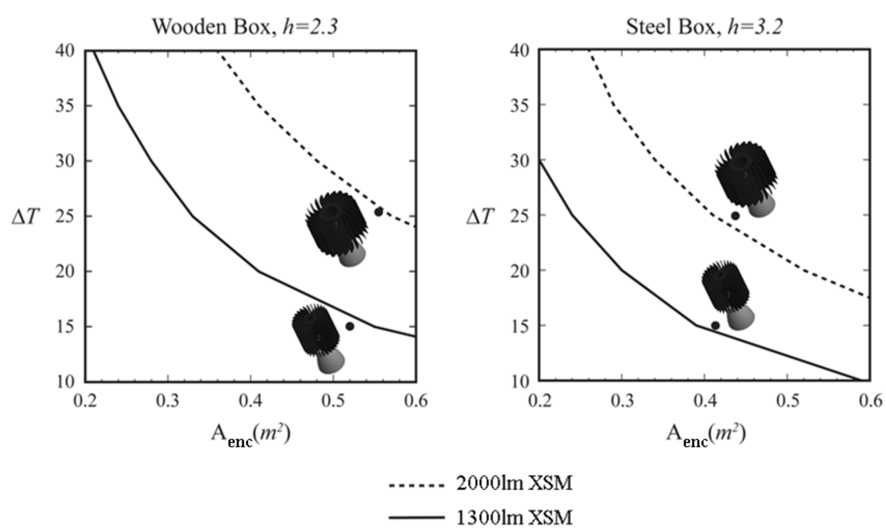

Figure 5 – Plot of Equation 1 for different XSM and enclosure conditions. The data points are results from the previous simulations.

To help gauge the size of the enclosure necessary for a particular XSM (or consequently, the right XSM for a particular enclosure) use Table 4. **Table 4 lists the <u>minimum</u> enclosure size for a particular Xicato heatsink/XSM combination,** calculated from Equation 1 and depends on the XSM power plus heatsink performance. This compatibility matrix is for guidance only and should be supplemented with verification through simulations or testing.

	XSA-02 (400lm 6W, ∆T=15)		XSA-03 (1300lm 21W, ∆T=15)		XSA-27 (2000lm 36W, ∆T=25)		XSA-28 (2000lm 36W, ∆T=30)		XSA-31 (2000lm 36W, ∆T=22)	
	Wood Box	Steel Box	Wood Box	Steel Box	Wood Box	Steel Box	Wood Box	Steel Box	Wood Box	Steel Box
m^2)	0.17	0.13	0.51	0.37	0.57	0.41	0.48	0.34	0.62	0.45

Table 4 – Enclosure surface area recommendations for Xicato heatsinks (operating with maximum thermal loads)

Enclosure Alterations

Venting

When enclosures are sufficiently small or well insulated, venting is an effective way of cooling the luminaire. Venting reduces the local ambient temperature by providing a path for heat to escape. Venting can be accomplished a number of ways including: drilling holes, cutting slots, or bending a cut channel to allow hot air to escape. The simulation in Figure 6 demonstrates the effect of ‘slot’ venting. A 2000 lm XSM is placed into a square based enclosure with a height equal to that of the 1300lm enclosure in Figure 4. With venting the module case temperature is only 70^{o}C, whereas if no venting is used the case temperature would exceed 100^{o}C. Furthermore, , and notice that the inside temperature is only 35^{o}C

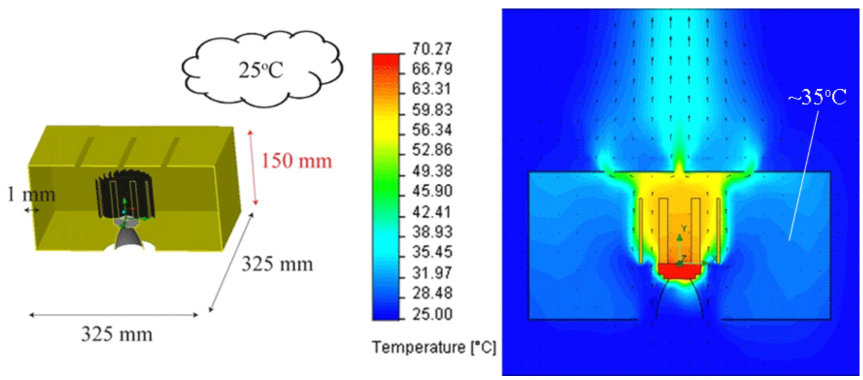

Figure 6 – 2000lm XSM in small enclosure with venting

Heatsinking

Another option available for thermally conductive enclosures (i.e. metal) is to exploit the metal as a secondary heatsink.

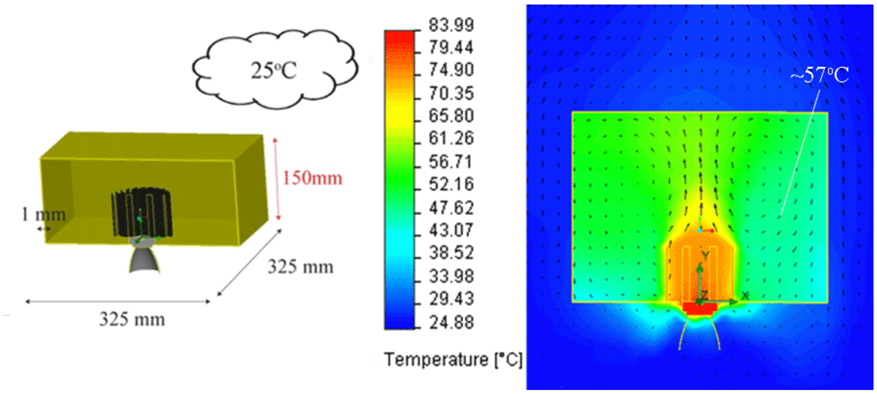

Figure 7 – Demonstrating the utility of using the enclosure as a heatsink

In the case above, the metal enclosure is used as a part of the heatsink itself, which helps reduce the case temperature of the module by increasing the surface area of the heatsink. As can be seen in Figure 7, heatsinking also allows the enclosure to support a higher inside temperature (57°C). In general, heatsinking the enclosure is not as effective as venting as can be seen by the maximum case temperature between Figure 6 and Figure 7. However, in a situation where venting is not possible or the enclosure has a large surface area, heatsinking is a low cost option.

Conclusions

When using an XSM in an enclosure the risk of thermal degradation is heightened and thermal management becomes even more important. To confront this challenge several important characteristics of the system need to be considered:

1. Heatsink/Luminaire Design
2. Enclosure
a. Surface Area
b. System Characteristics (Material/Fluid, Geometry, etc.)

For large lumen packages (high heat loads) or very well insulated enclosures it might be necessary to vent or incorporate the enclosure as a secondary heatsink. For additional questions, contact your Xicato technical support representative. Furthermore if you would like a heatsink/luminaire studied for an enclosure you can submit a request to our thermal simulation team. To do this, download the "Thermal Simulation Request and Definition Form" from the Members Lounge and submit to thermal.sim@xicato.com.