Thermal Adversity in Solid-State Lighting

T. Dreeben[1]

[1]OSRAM SYLVANIA, Beverly, MA, USA

Abstract

Solid-state lighting (LEDs) is a rapidly growing area with capacity to provide quality light while significantly reducing electrical consumption on a global scale. The energy savings is particularly substantial in directional lighting, where LEDs are 4 times as efficient as their primary competitor in traditional lighting, the halogen lamp. But unlike halogen lamps which operate above 3000 K, LEDs begin to experience loss of performance when their operating temperatures exceed 100 C. Heat transfer is the critical factor in feasible replacements. As the need for lighting capacity grows in solid-state lighting, cooling strategies become increasingly important. We describe and simulate an especially stringent configuration for directional lighting, the insulated ceiling array shown in Figure 1. This configuration involves multiple recessed fixtures in an insulated ceiling. The challenge, addressed in different ways by numerous design strategies [1-4], is to maximize the capacity of the heat to escape from the fixture for a given temperature. Simulation results using COMSOL are shown which quantify both local temperatures and heat flows in between critical components. COMSOL is used to model the heat generated at the LEDs and flowing through the fixture, the air below the fixture, and the insulation above the fixture in an axi-symmetric domain. Equations for conduction in the insulation and fully compressible natural convection in the air are implemented in the PDE mode using the general form. The fixture and drywall are treated as thin surfaces with lateral conduction implemented in the weak form. Heat flux across internal boundaries between components is formulated in a way that can be extracted for post processing. Integration over the boundaries is used to produce a global energy budget. Simulation of conduction through insulation above the fixture coupled with convection in the air below the fixture is shown in Figure 2. 6 W of heat are supplied in the center of a 5" fixture in an axi-symmetric representation of the insulated ceiling array. The "array" condition is enforced in the simulation by suppressing all lateral heat transfer at the side boundaries. The heat-flow budget shows that primary paths of heat loss are by radiation from the fixture and by conduction through the insulation at the floor above, where the temperature is set to ambient. The LED temperature of 130 C is too high - modification to this design would be needed for a feasible lamp under these conditions. Simulation shows what temperatures to expect and how much heat flows from one component to another. Opportunities for improvement are brought out by the thermal budget. For example, only 1/3 W of heat is flowing through the air. Further simulation can be used to find methods of making the room air a better conduit for heat rejection.

Reference

1. S.H. Jang and M.W. Shin, Thermal analysis of LED arrays for automotive headlamp with a novel cooling system, IEEE Transactions on Device and Materials Reliability, 8(3), p. 561-564, 2008.
2. A. Christenson, H. Minseok, S. Graham, Thermal Management Methods for Compact High Power LED Arrays, Seventh International Conference on Solid State Lighting, Proc. Of SPIE 6669,66690Z, 2007.
3. T. Dong and N. Narendran, Understanding heat transfer mechanisms in recessed LED luminaires, Ninth International Conference on Solid State Lighting, Proc. Of SPIE 7422,74220V, 2009.
4. J. Concepcion, Passive Heatsinking for Recessed Luminaires, Master's thesis, Lighting Research Center, Rensselaer Polytechnic Institute, 2004.

Figures used in the abstract

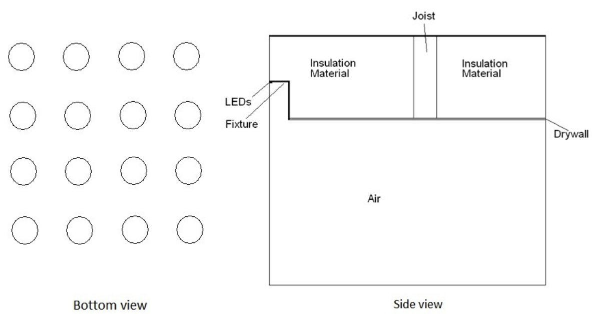

Figure 1: Insulated ceiling array.

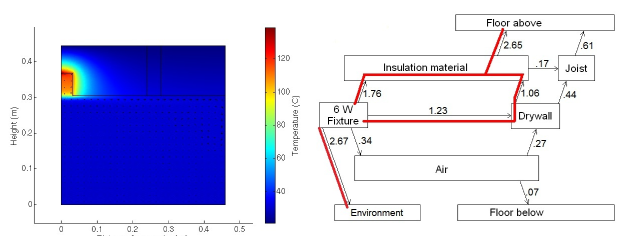

Figure 2: Heat transfer simulation for a cylindrical fixture in the insulated ceiling array. Temperature of the all components together with air velocity vectors is shown on the left. A budget of heat flow (W) between components is shown on the right.