Conjugate Thermal Analysis of a Generic LED Light Bulb

Thermal and fluid modeling is used to understand temperature fields and airflow around the bulb.

Veryst Engineering, LLC, Needham Heights, Massachusetts

The design and application of LED (Light Emitting Diode) lighting solutions provides new opportunities for thermo-fluid-mechanical modeling enabled by multiphysics analysis. A coupled thermal and fluid modeling effort was used to understand the temperature fields and airflow around a generic LED light bulb.

There is no question that LED lighting provides significant advantages over other lighting technologies. In the past, the color quality of LEDs has inhibited their penetration of the lighting industry, as the emitted light spectrum was considered to be "colder" than that provided by incandescent lights. LED manufacturers, however, implemented strategies to provide "warmer" colors, removing this obstacle to acceptance. With this accomplished, the significant advantages of LEDs could show their worth beyond the steadily improving energy efficiency in terms of increased lumens per Watt. Other substantial advantages include:

- Dramatic increase in lifetime, representing multiples of a compact fluorescent bulb life and potentially decades of life beyond an incandescent light
- Improved resistance to vibration and temperature fluctuations
- Rapid-on performance with no warm-up period
- Environmental compatibility with none of the potential disposal issues associated with compact fluorescent bulbs
- Substantial design flexibility with the use of multiple LEDs in a myriad of orientations and geometries

Like all lighting technologies, however, issues of thermal management remain. The compact geometry of LEDs emphasizes thermal management, as the localization of heat generation negates the effect of improved efficiency. High temperatures reduce the effective life of the LED, and additionally can accelerate material degradation and produce undesirable thermal stresses. Heat sink geometry and the removal of the very concentrated temperatures may be the primary constraint for many proposed lighting configurations.

Thermal modeling is therefore important, and the variety of lighting configurations results in a large number of potential modeling analyses to ensure long life and energy efficiency. Analytical heat transfer equations for natural convection provide a rough estimate of the LED thermal response. However, the complexity of the geometry and the need for higher accuracy necessitate the use of more accurate computational modeling. COMSOL Multiphysics is ideally suited for solving the coupled thermal, fluid flow, and structural equations, and simulates radiation and natural convection.

Figure 1. **Solid Model** of the LED bulb.

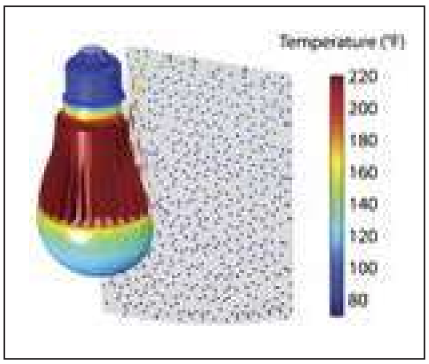

Figure 2. **Air Velocity** around bulb using particle tracing.

Veryst Engineering performed a steady state conjugate heat transfer simulation on a generic LED light bulb to illustrate a few of the issues associated with appropriate thermal design. An image of the bulb is provided in Figure 1. The simulation models the single, vertically oriented bulb in a cylindrical enclosure with constant ambient temperature. Conduction between the LED and bulb body, convection within the enclosure, and radiation between surfaces are included.

One-sixth of the LED bulb was modeled due to symmetry, and a finer mesh density was used at the vicinity of the fins to capture the high thermal gradients in that region. The model involved several assumptions for simplicity that do not affect the main observations. The LED was assumed to dissipate heat uniformly throughout its core section. Natural convection in the air was modeled using the Bousinnesq approximation, and a constant heat transfer coefficient was assumed at the external surfaces of the enclosure. The material properties used in the model were assumed to be temperature-invariant.

Using COMSOL, it is quite straightforward to eliminate the above stated assumptions. It is also possible to add more physics to the model as needed, such as a thermal structural analysis of the resulting stresses, or a Joule heating analysis to better capture the heat generation distribution.

One simulation result including the particle tracing capability of COMSOL is provided in Figure 2. Particle tracing is used here as a visualization aid only. The LED was assumed to dissipate 7 Watts. Notice the localization of temperature in the heat sink portion of the bulb, as well as the proximate rapid airflow convecting heat away from the bulb. Also notice, however, the low flow velocities in many portions of the enclosure, indicating a suboptimal thermal design. The geometry of the enclosure can certainly be changed to increase the influence of natural convection on the removal of heat from the bulb. In addition, the relative large thermal gradients above and below the heat sink on the bulb translate to high thermal stresses in those locations. These secondary effects can reduce bulb performance and life just as effectively as the localized temperatures directly at the LED.

Veryst Engineering uses the COMSOL software regularly to evaluate the thermal performance of products in addition to LEDs. LED lighting designs are perfect applications for COMSOL multiphysics analysis, as the flexibility of their use in a multiplicity of geometries makes such coupled thermal analyses essential for both rapidly implemented and reliable designs.

This work was done by Nagi Elabbasi, Michael Heiss, and Stuart Brown of Veryst Engineering, LLC. For more information, visit ***http://info.hotims.com/45607-122***.