High Power LED Luminaire Design

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Research Goals

- Design an FEM model of an LED luminaire, physics, and constraints, which represent the thermal process and the lighting process.
- Design and build a prototype and test different setups (cooling structures and optical accessories).
- Compare simulation results with the results of experimental tests to validate the model.
- Use evolutionary algorithms to optimize the luminaire geometry, material, and layout.

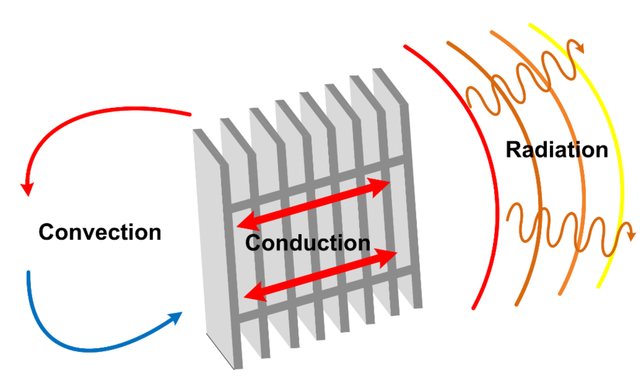
Motivation

- Currently, 20% to 40% of the total electricity consumption is spent on artificial lighting [1], [2].
- Public lighting consumes 3% to 38% of the total energy bill of large cities [3].
- In Brazil, there are about 15 million points of public lighting [4].
- São Paulo has 530,000 public illumination points (the largest number in the world).
- A significant improvement in the illumination efficacy can provide a great impact on the world's energy consumption.
- None of the conventional light sources (incandescent, halogen, and fluorescent) have significantly improved in the last 40 years.
- It is estimated that by 2020, the simple replacement of traditional light sources with LEDs will provide:
  - Reduction of 50% of the total amount spent on electricity for lighting.
  - Decrease of 11% of the total electricity consumption.

Introduction

Thermal Management

- Problems regarding thermal management are commonly found in electronic devices.
- Heat transfer processes include conduction, convection, and radiation.

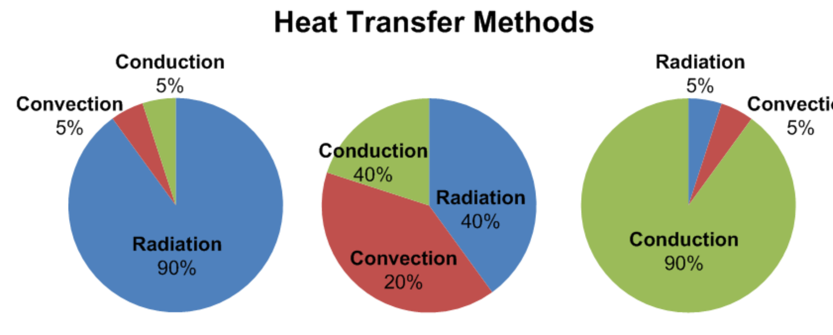


- LED lighting has provided a paradigm shift and a great challenge for the lighting designers.

High Power LEDs

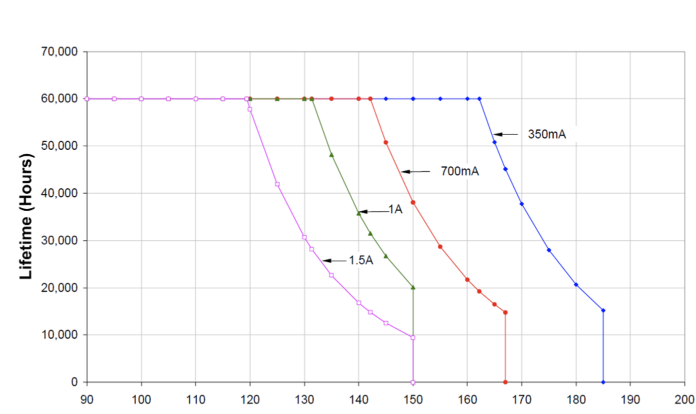
- Classification of LEDs:
  - Low Power
    - excitation current ≈ 20 mA
    - power ≈ 44mW
  - High Power
    - excitation current 350 mA to 1.5 A
    - power 1 W to 200 W

- To get the greatest benefit from HP-LED for lighting, some requirements must be satisfied.



The heat transfer methods of some light sources

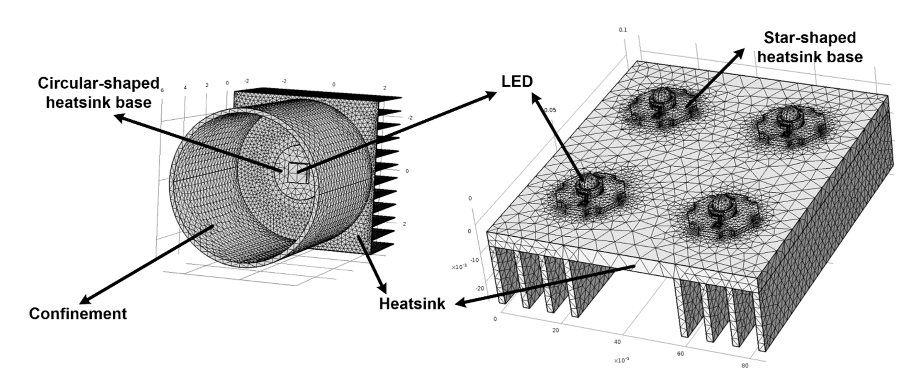
- In HP-LEDs the energy must be dissipated to the environment mainly by conduction to avoid damaging the P-N junctions [5].
- HP-LED lifetime is associated with its operating temperature and can be reduced under extreme conditions.
- A small increase in 10 ºC can reduce the LED lifetime by half (see graph).
- In general, the HP-LED junction temperature must be maintained below 100 ºC to ensure 50,000 hours of life [6].



The graph shows the relationship between junction temperature and lifetime of one LED.

Methodology

- Computer modelling was used as the methodology.
- Through finite element modeling software it is possible to represent the behavior of systems or phenomena.



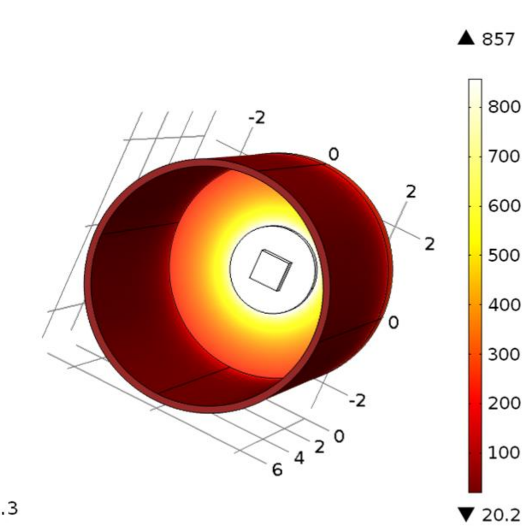
FEM software can help design a desired geometry and simulate a multiphysicd problem.

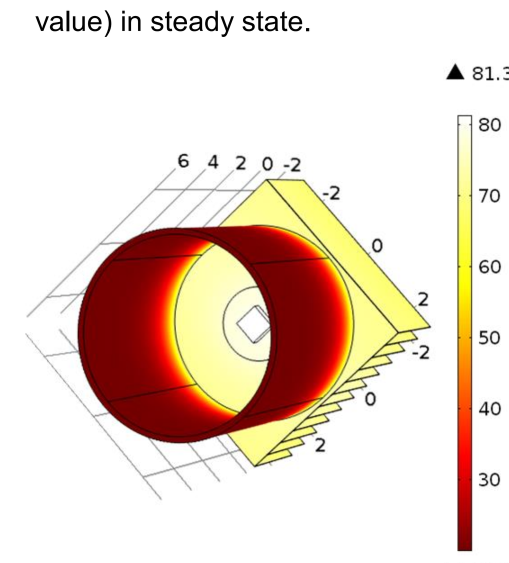
- The model can be tested and validated to predict various situations, reducing the need for tests in real systems.

Simulation and Results

Case Study 1: tubular luminaire with one LED

- The first simulation was run with an LED inside a confinement without any type of heatsink.
- It is possible to see the temperature distribution on the surfaces of the domain.
- It is noted that the LED chip reaches about 857 ºC (theoretical value) in steady state.

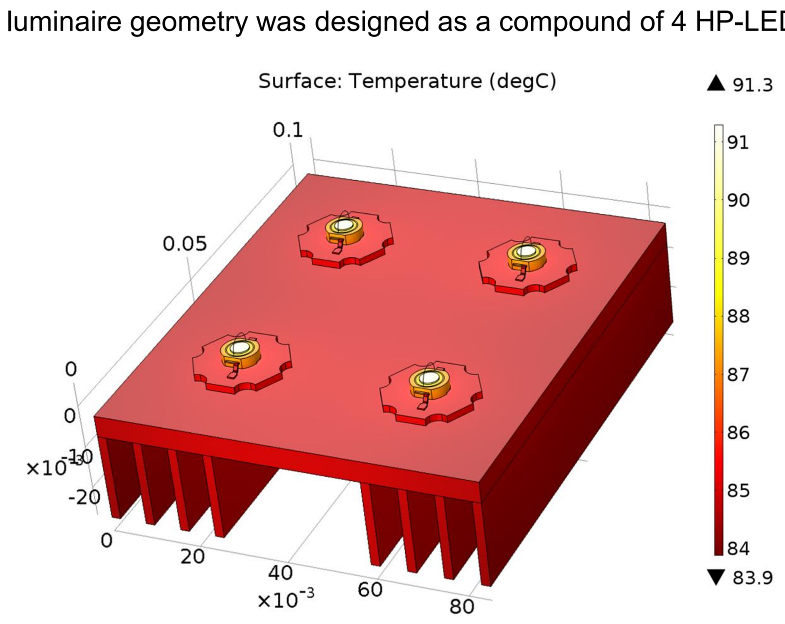




- An external aluminum heatsink was attached to the confinement base.
- It is observed that the LED chip achieves a maximum temperature of 81.3 ºC in steady state.

Case Study 2: square luminaire with four LEDs

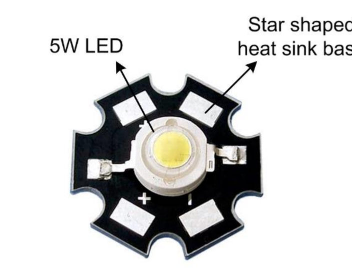
- A new luminaire geometry was designed as a compound of 4 HP-LEDs.

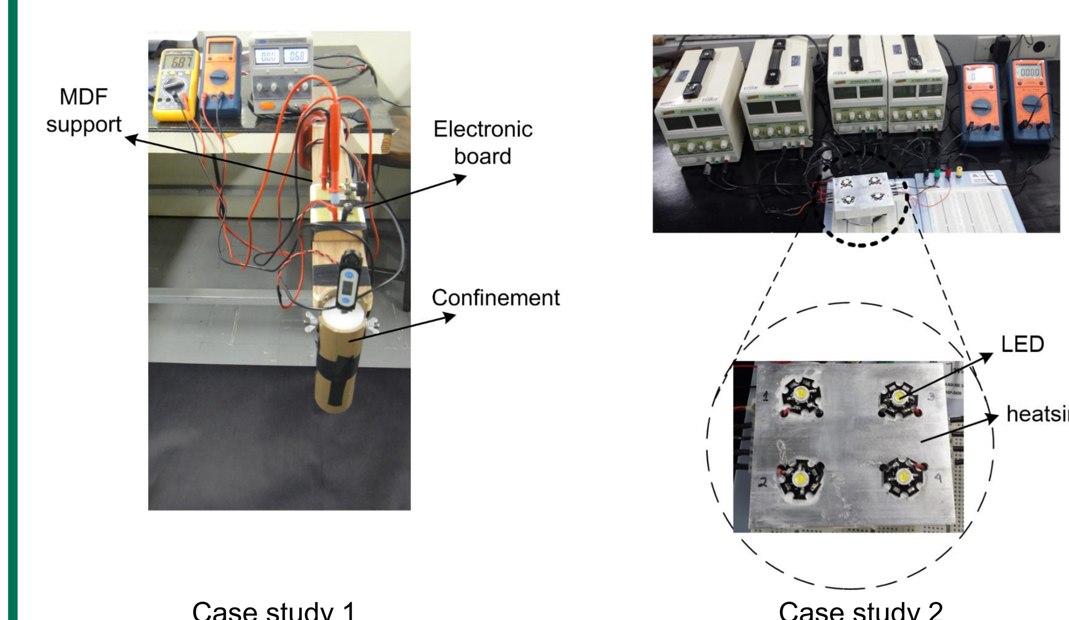


- The LED chip reaches a maximum temperature of 91.3 ºC in steady state.

Practical Tests

- Two prototypes were built to validate the simulation and support practical experiments.
- In both case an HP-LED with the following characteristics was used (same as simulation):
  - 5 W LED model W081F-5W.
  - Nominal parameters: 720 mA, 7 V, 250 lm.



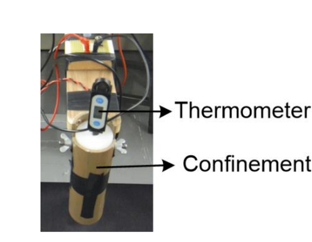


Case Study 1: tubular luminaire with one LED

- All tests were conducted at a room temperature of 26.0 ºC.
- The temperature was collected with a thermometer connected to the star-shaped heatsink base.
- The collected data (without heatsink and with a heatsink attached) are presented in the following table.

Tests	Results
LED	> 95.0 ºC*
LED + heatsink	76.6 ºC

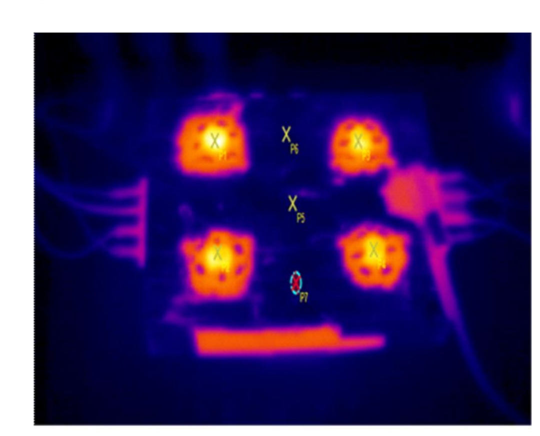
*Physical properties degraded and LED totally damaged.



Case Study 2: square luminaire with four LEDs

- All tests were conducted at a room temperature of 27.2 ºC.
- All the results were obtained from a thermal infrared camera.
- After 44 min the temperature reached steady state.

Test point	Description	Results
P1	LED 1	104.7 ºC
P2	LED 2	96.8 ºC
P3	LED 3	101.4 ºC
P4	LED 4	96.2 ºC
P5	heatsink	33.5 ºC
P6	heatsink	33.9 ºC
P7	heatsink	33.1 ºC



Conclusion

- In the first case study, the results obtained are in reasonable agreement.

Tests	Simulation Results	Experimental Results
LED	857.0 ºC	> 95.0 ºC*
LED + heatsink	81.3 ºC	76.6 ºC

- The results from the second case study show that the model needs be improved, because of the deviation in the heatsink temperature.

Tests	Simulation Results	Experimental Results
LED (avg)	91.3 ºC	99.8 ºC
heatsink (avg)	85.0 ºC	33.5 ºC

- We are close to validating the model. Some improvements in the heatsink material and the air convection physics can result in a better model, and consequently better LED temperature prediction.
- The next step will be the implementation of MATLAB code to interface with the FEM software, change some parameters, run simulations, and retrieve results.
- Then will be possible to run algorithms to optimize luminaire parameters such as the number of LEDs, their locations, and even the geometry of the heatsink.

Acknowledgments

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