Constant-voltage driven temperature stabilized luminous flux standard lamp with E27 base

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Motivation

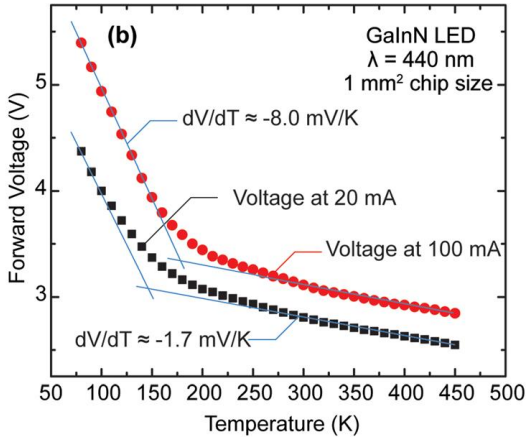
- LED lamps coming to market are measured with an integrating sphere photometer or a goniophotometer
- Luminous flux responsivity of the measurement system is typically calibrated using an incandescent standard lamp
- Luminous flux standard lamps used by laboratories have become difficult to obtain
- Kokka et al, *Metrologia* **55** (2018) 526–534: Phometric calibration with a white LED lamp having CCT around 4100 K would reduce spectral errors in measurement of LED products to half on average (as compared to incandescent calibration lamp)

Kokka et al, *Metrologia* **54** (2017) 577–583

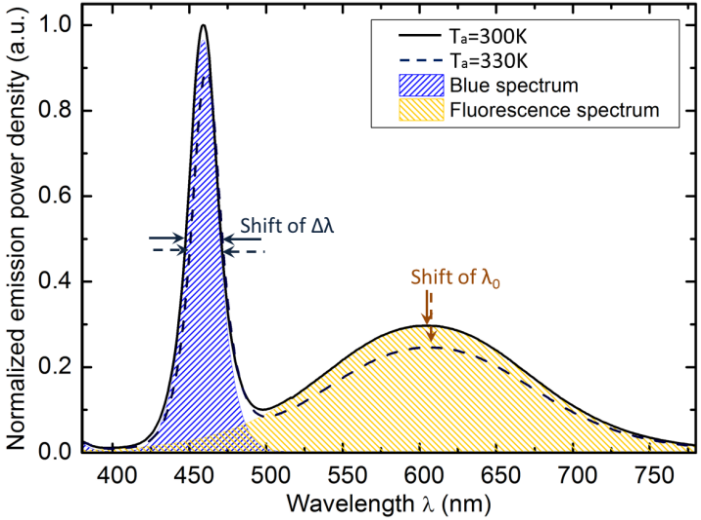
Osram datasheet, *Lamps for scientific purposes*

However…

- Concerning the use as a photometric standard lamp, the otherwise promising LED-based technology has one significant drawback: the temperature dependence of luminous flux
- Constant-current-driven LED lamps are directly effected by the temperature dependence of forward voltage
- Even constant-power-driven LED lamps are affected by the temperature dependence of spectral power distribution



Mayaard et al, *App. Phys. Lett.* **103** (2013) 121103



Chien et al, *Opt. Express* **19** (2011) 804-817

Solution

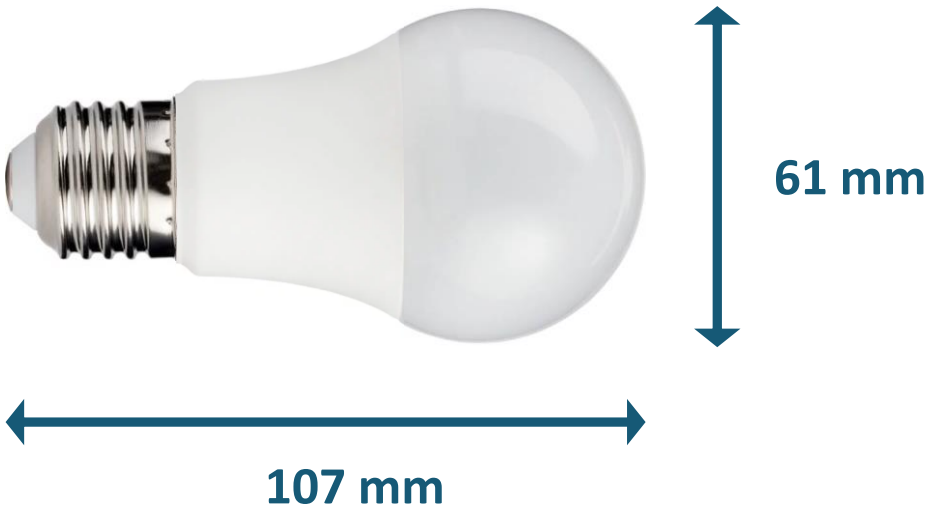
- Temperature-stabilized luminous flux LED transfer standard lamp that overcomes the temperature dependence issues
- A lamps that fits existing setups directly
- DC voltage input
  - Internal electronics to drive the LEDs with precision DC current
- Temperature control electronics in the lamp
  - Using the forward voltage of the LEDs as the feedback signal to a PI controller*
  - Heating elements in the LED heatsink
  - Keeps the LED junction temperatures constant
- Aimed to serve as a replacement of incandescent luminous flux standard lamps presently used at calibration laboratories

*Baumgartner et al, *CIE Midterm Meeting 2017 – Abstract Booklet (Jeju, Korea, 2017*), 38-39

Lamp design

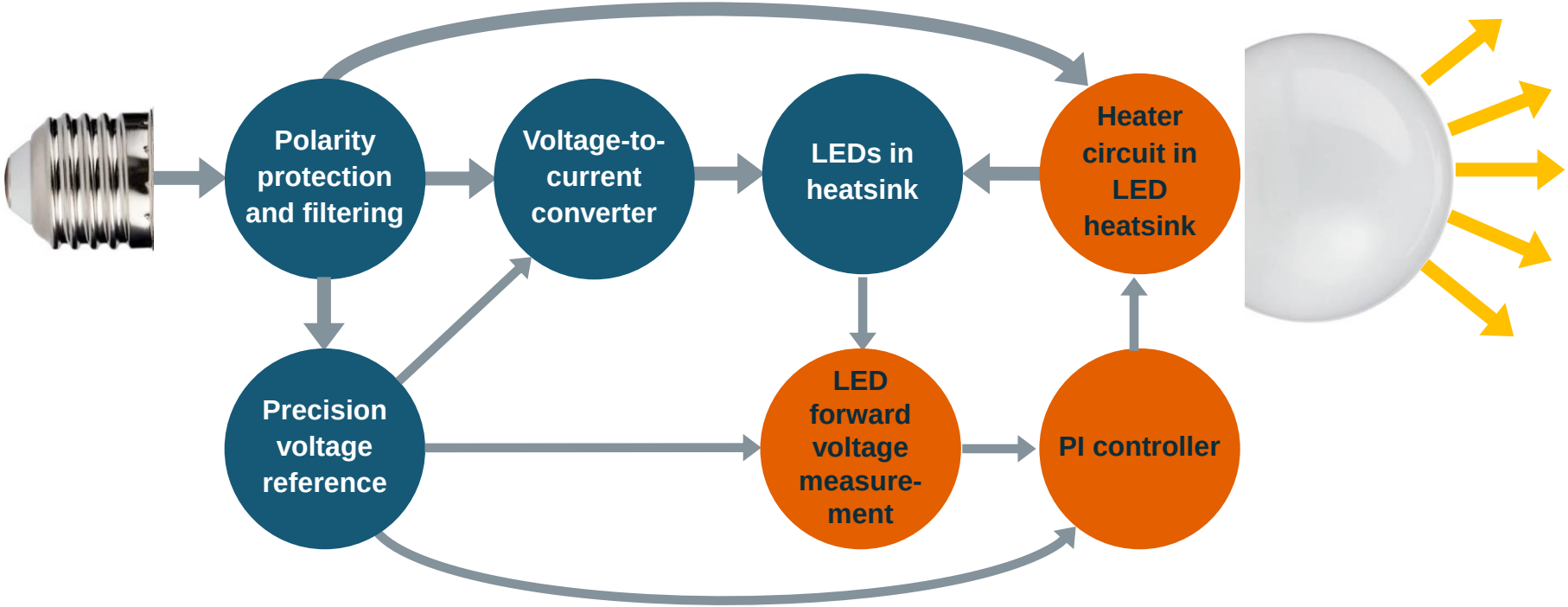
Lamp mechanics

- Mechanics of commercially available LED lamp fitted with custom electronics
  - Limited space for electronics
  - Electronics need to have reasonable efficiency
- E27 base
  - Only 2 wires



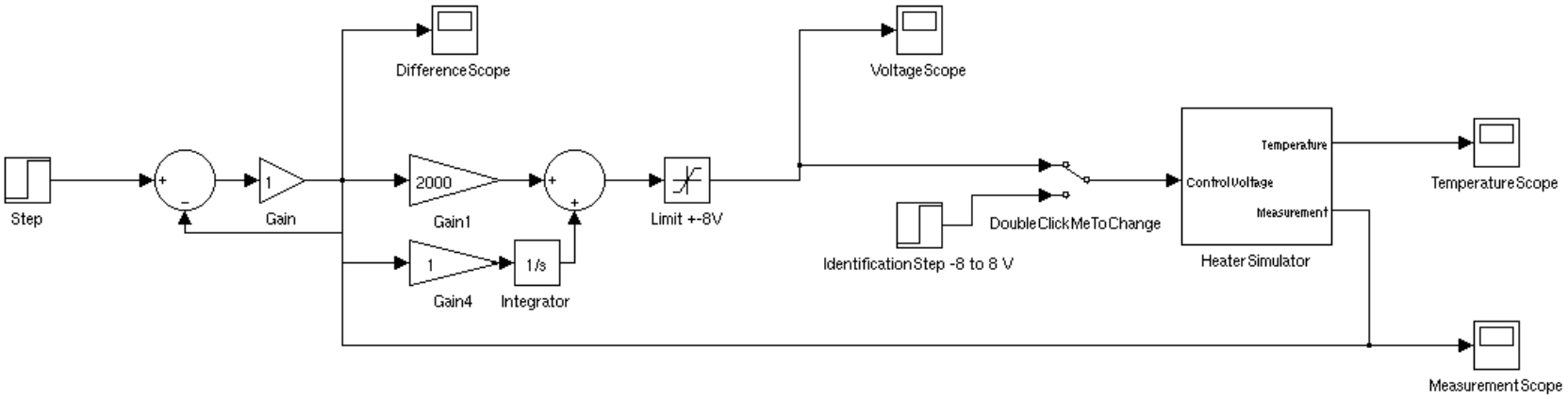
Electronics

Electronics



PI-controller optimization

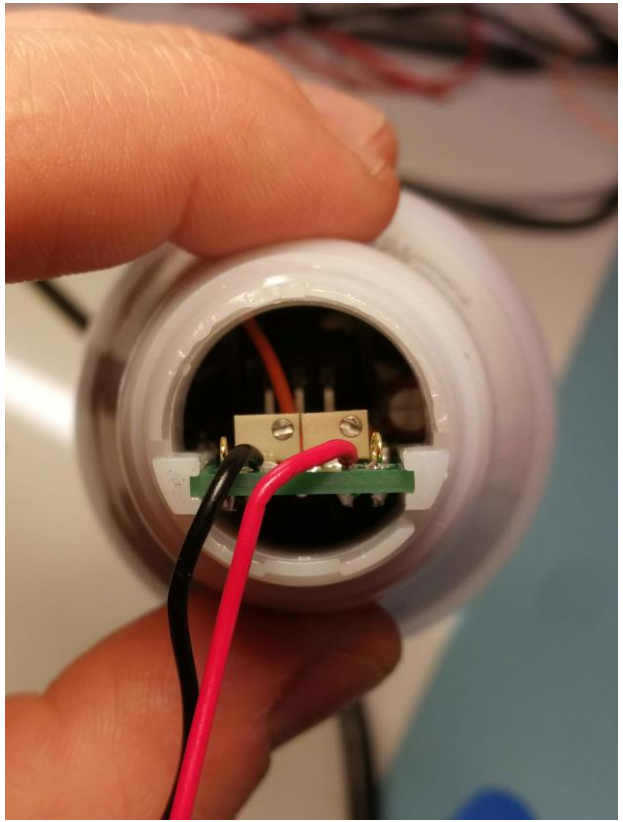
- Initial test to determine the key parameters of the heating system
  - Time constants, heating efficiency, LED junction voltage temperature dependency
- Simulink model of the system was utilized to optimize the PI parameters
- Heating system modelled as leaky integrator*, controlled by limited PI



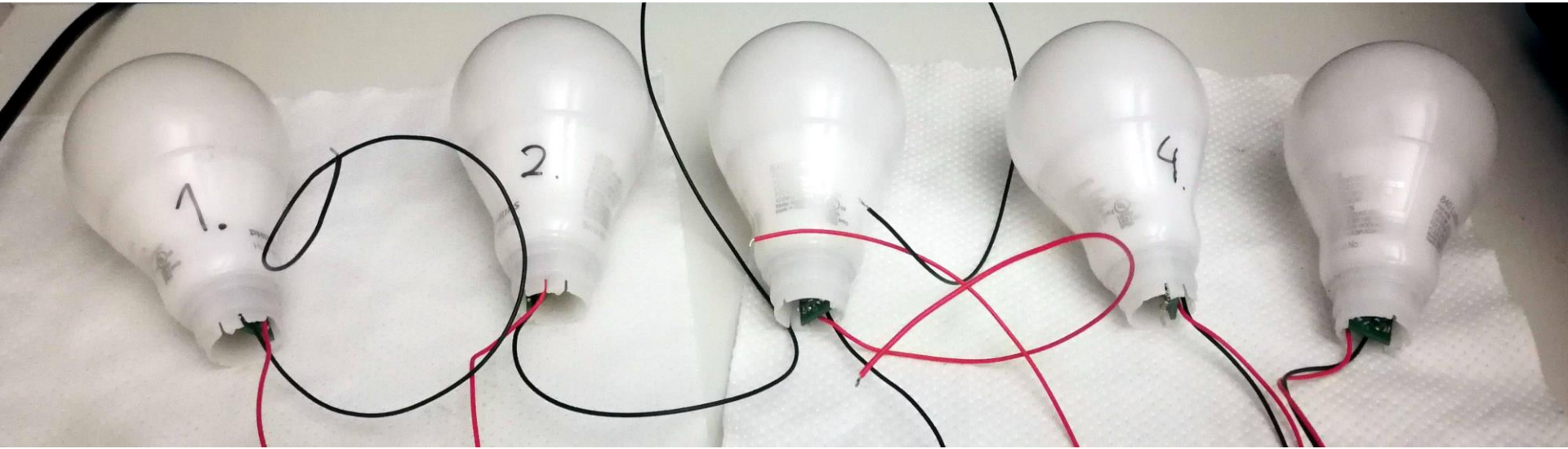
*Kayakutlu and Mercier-Laurent, *Intelligence in energy*, Elsevier (2017).

Fine tuning of current and temperature

- Shunt resistors with best temperature stability have poor tolerance
- Forward voltages at given current and temperature deviate between individual LEDs
- Fine-tuning possibility was added to the lamp design
  - Current of the LEDs
  - Nominal ambient temperature at which heating power is at 50%
- Lamp can be fully assembled before fine-adjustment from behind the E27 base



Lamp prototypes and test measurements

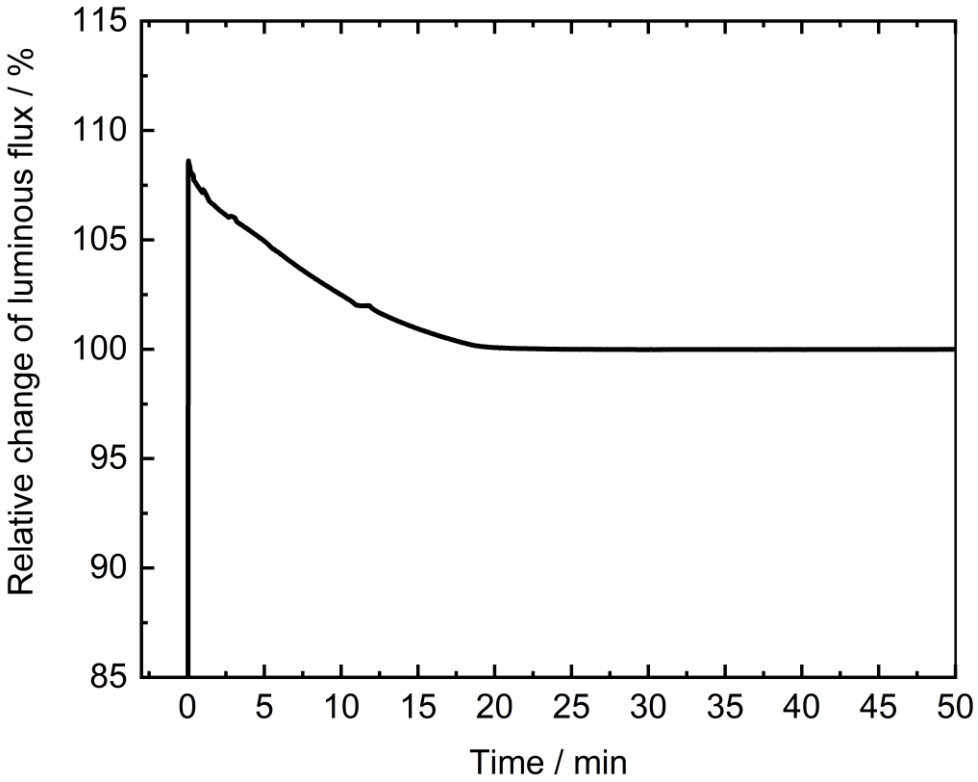


Prototype lamps

- Five LED chips with CCTs around 3900 K were used in the lamps
  - based on the proposed LED reference spectrum under discussion in TC2-90
  - 100 hours of aging for LEDs before lamp assembly
- 16 V DC input, maximum current 520 mA
- The total electrical power of the LEDs was set to be 6.5 W
  - Lamps produce luminous flux of 840 lm
- Maximum heating power of the temperature controller was set to 750 mW
  - Lamps can handle temperature changes within ±4 °C around the set nominal temperature
- Power loss of other electronics ~1 W

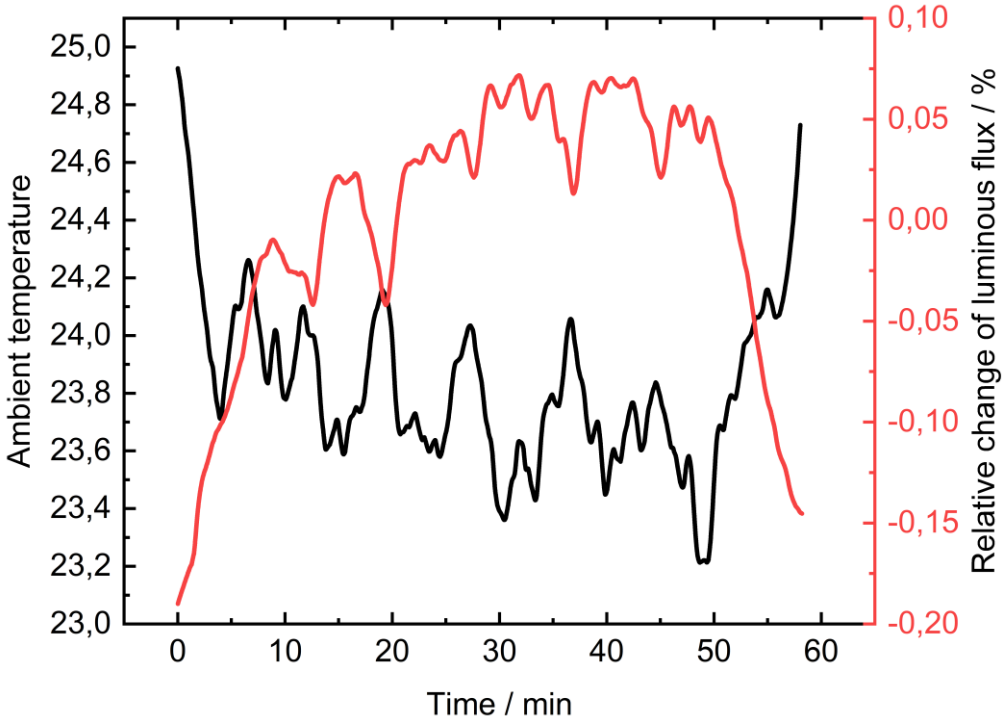
Stabilization time

- The stabilization time of the lamps is around 30 minutes
- LED temperature and optical output settle without overshoot or ringing



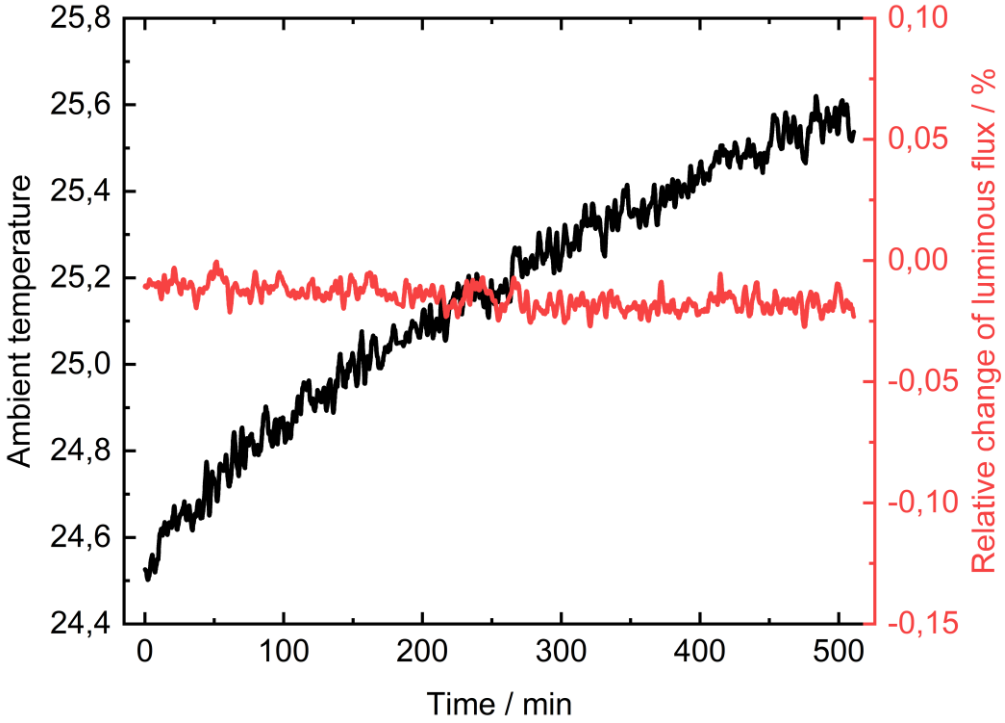
Luminous flux stability without temperature stabilization

- Without temperature stabilization, the average a temperature coefficient in luminous flux was around 0.25 %/°C



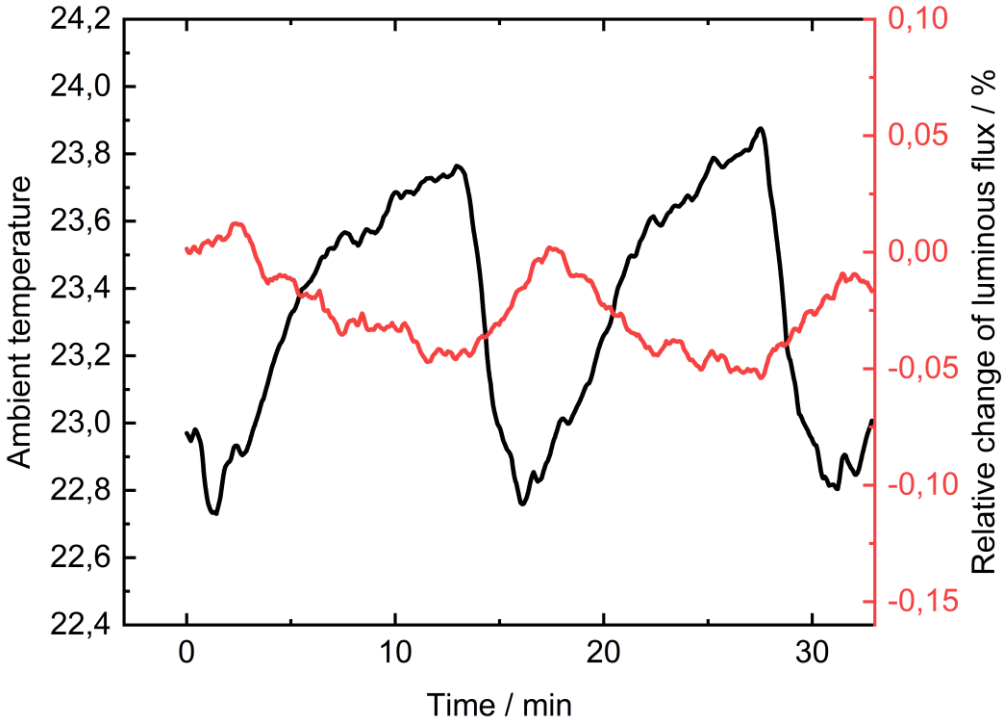
Luminous flux stability with temperature stabilization

- When the ambient temperature is changing slowly, the use of temperature controller decreased the temperature coefficient of luminous flux to 0.01 %/°C
- Measured utilizing the natural drift of ambient conditions



Luminous flux stability with temperature stabilization

- Even for a rapidly changing ambient temperature, the use of the temperature controller reduced the temperature dependence by a factor of five
- Measured with an air conditioning unit having an on/off cycle of 15 minutes



Conclusions

Conclusions

- Temperature stabilized LED luminous flux standard lamp with E27 base was developed
- Can serve as a direct replacement of incandescent standard lamps used at calibration laboratories
- The design can easily be modified to drive LEDs with different electrical and optical parameters
- In typical laboratory environment, the controller reduces the temperature dependence of the lamp by more than an order of magnitude
  - Keeps the electrical power and temperature of the LEDs constant
  - Guarantees stable luminous flux and spectral power distribution.

Thank you for
your attention!