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# Influence of smart lighting control on the lifetime of high power LED luminaires

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**Abstract.** LED lighting and smart controlling can decrease the consumption of electric power in zero or positive energy buildings. This study demonstrates that cyclic dimming, which appears in smart controlling, e.g. through occupancy sensing, might have an effect on the luminaire lifetimes and failure rates. Two different types of LED luminaires were aged in 30-s cycled dimming and undimmed modes. The manufacturer-specified lifetimes for both luminaire types were 100 000 hours. For one of the luminaire types, four out of five cycled units failed before 30 000 operating hours. For the uncycled luminaires, the lifetimes estimated from the measurements were over 100 000 hours. For the other type, the estimated lifetimes were 75 000 hours and 64 000 hours for uncycled and cycled luminaires, respectively.

## 1. Introduction

The energy savings due to LED lighting products are remarkable when compared to the traditional incandescent and fluorescent lighting, making the LED products particularly attractive in zero or positive energy buildings. In many designs, additional energy savings can be achieved by adding smart control to the lighting, e.g. with occupancy or daylight sensing. The lights may be switches off completely when not needed, or dimmed to a lower level.

Typically, the luminaire manufacturers specify the lifetime of high power LED panels between 50 000 hours and 100 000 hours. According to the standard on LED luminaire lifetime projection, a minimum of 6 000 hours is needed for lifetime estimation and for a lifetime of 100 000 hours, measurement data of at least 17 000 hours of ageing should be in use [1].

Two different effects may influence the lifetime of LED luminaires of smart lighting. Cyclic dimming, which appears in smart controlling, effectively decreases the driving current of the LED chips which should result in extended lifetime. It is known that pulsing LEDs with different duty cycles effectively decreases the current and therefore decreases the junction temperature [2].

On the other hand, electronics hammer testing, where the temperature of the electronics is cycled between higher and lower levels, is one method used for accelerating ageing [3]. In a similar way, the smart lighting control may cycle the temperatures of the components of the system, thus introducing additional stress to the LED components and the driving electronics of the luminaires as compared to the traditional controlling, which may accelerate the ageing of the luminaire. The effect of constant thermal stress for LED lamps has been found to decrease the lamp lifetime [4, 5].



The combined effect of the decreased driving current and the thermal stress introduced by the cycling is of high interest when designing smart controlling level. In our research, we have studied the effect of cycled dimming on high power LED luminaires. Our measurement results show that the differences in the luminous flux values between the undimmed and periodically dimmed luminaires are clearly seen after 15 000 hours of operation.

## 2. Luminaire ageing and measurements

In total 20 luminaires from two different manufacturers were aged in room temperature conditions. Type A luminaires were built of 12 LED strips containing in total 38 LED chips and their controlling electronics. The LEDs were connected to the electronics in four parallel series of three strips. Type B luminaires consisted of two separate LED panels that have separate controlling electronics.

For both luminaire types, the specified lifetime expectancy set by the manufacturer was 100 000 hours. All luminaires were switched on for 9 hours followed by an off period of 3 hours simulating daytime use. During the on period, half of the luminaires were cycled between 100% and 20% electrical power at 30 second interval, later on referred to as cycled dimming. The luminaires were aged for 4.5 years, leading to an operating time, i.e., time when the lamps were switched on, of 28 000 hours.

Even though the manufacturers have designed the studied luminaires for outdoor usage, their LED components and driving electronics are comparable to the luminaires used in indoors. The values specified by the manufacturer for lifetime, luminous flux and electrical power of the studied luminaire types are presented in Table 1. The lifetimes have been specified at the ambient temperature of 25 ° C.

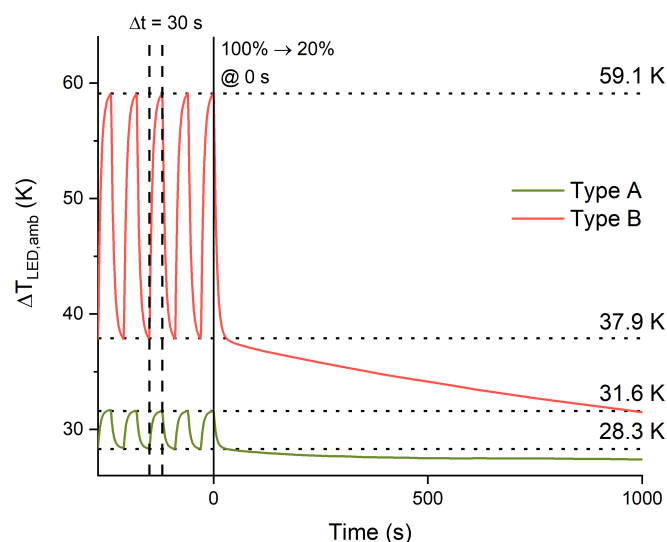
**Table 1.** Specified lifetimes, luminous flux and electrical power values for the studied luminaires.

Luminaire	Specified lifetime (h)	Specified lum. flux (lm)	Electrical power (W)
A	100 000	7 500	63
B	100 000	13 700	137

The luminaires were equipped with their own modular driving electronics that supply constant direct current to the LEDs. The dimming of the luminaires was controlled by restricting current through DALI connections included in the driving electronics. A regulated AC power source of 230 V was used to power the luminaires in measurements. The regular electricity grid was utilized in the ageing setup.

The luminaire temperatures during different stages of the operation cycles were measured to ensure that the temperature limits defined by the manufacturer are not exceeded. Temperatures of the LEDs were measured by setting a temperature measurement sensor as close as possible to the LED chip in such way that it was not in front of the LED. In Type B luminaire measurement, the sensor was placed under a separate, detachable lens array. No detachable lenses were used in Type A luminaires. The difference in the placement of the temperature sensor might explain some of the absolute temperature differences of the luminaires, but should not affect the temperature change due to the cycled dimming. The measurements were carried out at ambient temperature of 25 ° C.

The temperature profiles during ageing as measured by the temperature sensors near LED chips are presented in Figure 1. The temperatures are stated as temperature differences from the ambient temperature. For the Type A lamps, the average temperatures during the cycled



**Figure 1.** Temperature differences of the luminaires on the LED panel right next to LED chip compared to ambient temperature during the used 30 s dimming cycle and after setting the LED power from 100% to 20%.

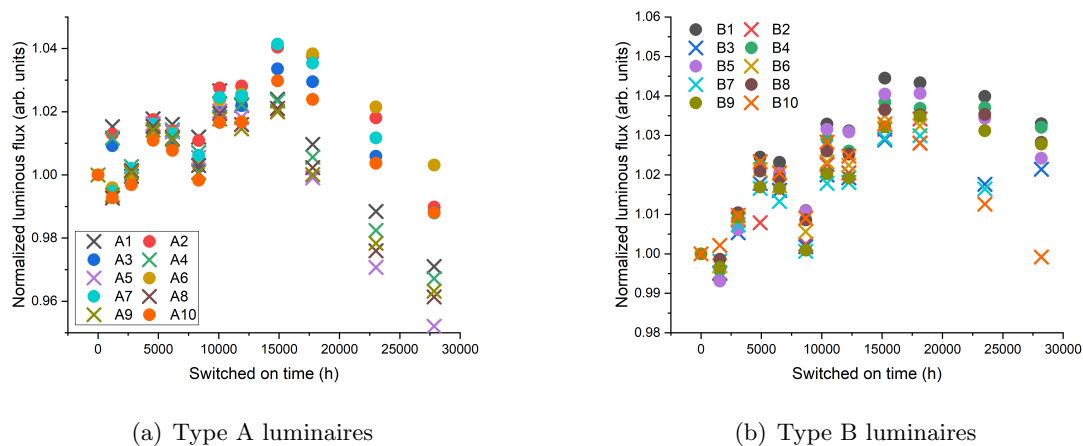
dimming is 30 ° C above the ambient temperature, and the temperature varies by 3.3 K. For the Type B luminaire, the corresponding average temperature is 48.5 ° C above the ambient temperature and the temperature variation is 21.2 K. One difference influencing the temperatures in the two luminaire types is the design of enclosing. The enclosing in Type A luminaire acts also as the luminaire heat sink, whereas Type B has a separate heat sink inside the enclosing.

Using the cycled dimming, the temperatures at different stages of the dimming vary by 21.2 K and 3.3 K for Type B and Type A luminaires, respectively. In Figure 1 at the time of 0 s, the electrical power of the luminaires has been changed from 100% to 20%. It can be seen that from the time of 0 s until the time of 30 s, the temperature change rate is at largest, being approximately 0.71 ° C/s for Type B luminaire. In comparison, the temperature change rate after the time of 30 s is below 0.01 ° C/s and for Type A luminaire the change rate during the cycled dimming is 0.11 K. The temperature changes close to the LED chips are therefore maximized using the 30 s dimming cycle.

The luminaires were measured on average every 5 months using an absolute integrating sphere method for luminous flux, in total 12 times during 4.5 years. During the measurements, the electrical power consumption and the spectral radiant flux distributions of the luminaires were also measured. The electrical power of Type B luminaires was set to 70% using the DALI controlling to keep the temperature of the luminaire inside the closed integrating sphere below the manufacturer limit.

### 3. Results

Based on the measurement results, the luminaires with cycled dimming have lower lifetime expectancies as compared to the ones that were not dimmed. Four of the Type B dimmed luminaires broke down during the study, and only one operating normally. Two of the failed units broke down after 20 000 hours and the third failed before 28 000 hours. The fourth luminaire was visually observed to be broken after the last measurement round at 28 000 hours.



**Figure 2.** Normalized luminous flux values of the 30-s cycled (cross) and naturally (circle) aged luminaires. The luminous flux of luminaires B2 and B6 has collapsed after 20 000 burning hours and luminaire B7 failed before 28 000 hours. Luminaire B3 was visually observed to be broken after the last measurement round.

The normalized luminous flux values of the two luminaire types are presented in Figure 2. At the measurement round of 28 000 hours, for both luminaire types the luminaires that were dimmed repeatedly and still operating normally had decreased on average 2–3% more in luminous flux than the ones that were not dimmed.

For all the studied luminaires, the luminous flux increases up to 5% during the first 15 000 hours of operation. In the results after 15 000 h, one can see that the luminous fluxes of the cycle dimmed luminaires are lower than those of the undimmed luminaires, indicating that the cycled dimming has a negative effect on the luminous flux. The standard deviation of the different luminaires of the same ageing group at each measurement round is within the uncertainty of the measurements. Estimating the lifetime after 15 000 operating hours with exponential decay shows that the undimmed Type A luminaires would be below 80% of their initial luminous flux levels after 75 000 hours. For the 30-s cycle dimmed luminaires, the corresponding lifetimes would be shorter, i.e., 64 000 h.

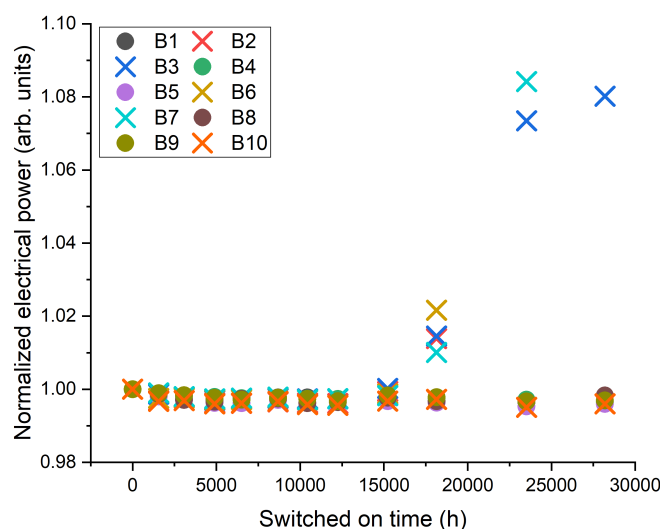
The luminous flux levels of the failed luminaires of Type B are well below 50% of the initial luminous flux values and both of the LED panels in the luminaires are still dimly lit. Based on this we can conclude that eight separate LED panels have failed in four different luminaires because of the cycled dimming.

Figure 3 presents the electrical power of Type B luminaires during the integrating sphere measurements. An increase of 10% in electrical power for the failed luminaires was measured on the last measurement round where the luminaires were still emitting light correctly. The electrical power of the Type B cycle dimmed luminaires gradually increases, and within 10 000 hours from the first observation of increased power, an average luminaire breaks down. No abnormalities in the measured electrical power values were noticed for Type A luminaires.

#### 4. Conclusions and discussion

Based on our study, the adaptive control of smart lighting might have a negative impact on the lifetimes and failure rates of high power LED luminaires, resulting in higher maintenance rates and energy consumption than anticipated.

Using a 30-s dimming cycle, almost all the studied luminaires of Type B broke down before 1/3



**Figure 3.** Normalized electrical power of Type B luminaires during the integrating sphere measurements. Luminaires B2 and B6 failed after 20 000 burning hours and luminaire B7 failed before the measurement round at 28 000 hours. As visually observed, luminaire B3 malfunctioned right after the last measurement round. Luminaires marked with crosses are aged with 30-s dimming cycle. The naturally aged luminaires are marked with circles.

of the specified lifetime. The cycle dimmed luminaires of Type A decreased in luminous flux more than the traditionally controlled luminaires, and the estimated lifetimes were approximately 15% lower for the cycle dimmed luminaires.

The lifetime expectancies of 50 000 to 100 000 hours of operation need in minimum approximately 8 000 to 17 000 hours of measured data by the standard of IES [1]. Our results show that the luminous flux for the studied luminaires increases initially, being at the maximum after 15 000 hours of operation, and the differences due to the cycled dimming are seen only after this point. To obtain more accurate lifetime expectations for the luminaires, an extended ageing period from 15 000 hours is needed.

The typical lifetime expectancies specified by the manufacturers for the luminaires in the market are approximately 20% lower at the moment, as compared to the luminaires used in the research. In addition to the lifetime expectancies, the manufacturers should specify the number of switching on times for their luminaires, which would imply the acceptable level of smart controlling.

The increasing electrical power of the luminaires before abrupt failure might be due to the failure of individual LED chips in the panels that results in increasing leakage current. In LED panels, the LED chips are typically connected in series, which results in failure of the whole panel if even one chip is constraining current. Similar failure mechanisms have been reported earlier for E27-base LED lamps [6].

Another possibility for the failure mechanism is that the thermal stress introduced by the 30-s dimming cycle wears out the driving electronics of the LED panels. The electronics are molded in epoxy and therefore finding the specific failing component is difficult.

We have reported that the short-term energy savings with smart control dimming might result in shorter lifetimes of the devices, and possibly in higher failure rates. Therefore, in

smart controlled lighting, a compromise between the switched on time and the energy savings should be sought. Manufacturers should also specify maximum number of switched on times for their products to assist designing optimal smart controlling. The luminaire ageing study is still ongoing and further results are expected to be obtained.

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