Drivers in the Adoption Speed of Solid State Lighting

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Abstract
This paper describes the different phases in LED adoption. The pace of ledification in LED retrofit lamps and later in luminaires is highlighted. Embedding LEDs into ceiling tiles shows the potential of breakaway concepts exploiting the full benefit of LEDs

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LED; Solid State Lighting.

1. Introduction
Fifty years after the first experimental proof, light emitting diodes are poised to be the next big thing in many applications, amongst which general illumination. In this paper we will discuss the drivers for adoption in this application area as well as some of the phases adoption of solid lighting will go through.

From the first prototypes that barely could be seen to emit light towards painstakingly high brightness, general illumination application have progressed very rapidly in the last 7-8 years. Projections show that by the year 2015 about 50% of the sales in general illumination will be based on LEDs.

2. Ledification of Lamps
Around 2005, typical efficiencies of white light emitting LEDs were of the order of 30 lm/W, a level which was barely above even the most energy-hungry light sources at that moment, namely the incandescent bulbs. Due to this limited efficiency and the requirements posed upon for instance the light output of a bulb of around 250 -1400 lumens, it proved to be quite a technological challenge even to get to an equivalent light output level, while being constrained to the bulb form factor. In an A55 bulb envelope typically one can only dissipate 10-12 Watts of heat by passive cooling through engineered heat sinks, which puts a limit to the amount of light that can be generated. Initially only decorative lighting could be made, but soon thereafter the first 25 W incandescent bulb equivalent with LEDs could be made. With progression in the lm/W efficiency, less heat was dissipated in the mechanical envelope and higher lumen levels could be obtained, until we have finally in 2012 covered the whole range of bulbs up to 100 Watts. The same progress happened in other form factors, most notably the halogen bulbs, which usually are used in spot applications. Although lumen levels are lower, the formfactor only lends itself to a heat dissipation of around 3-4 Watts.

Recently fluorescent tubes replacements, being the biggest provider of lumens in the world (54% of the lumens of artificial lighting stems from that one source), can also be addressed. This evolution of available LED lightsources therefore was mainly driven by progress in efficiency (Lm/W) up until a point that within the other specifications an initial product could be realised. We would like to refer to this instant as the “ good – enough point”.

Obtaining the same number of lumens is only part of the story to reach massive adoption of the new LED technology that would save so much energy. Equally important is the price. Especially in early 2006, the lm/$ value was around 20, meaning that for a 250 lumen light bulb, the costs of the LEDs themselves was around 15-20$ already, taking into account that not all lumens could be used, as well as the fact that at higher operating temperatures the output significantly reduced. Next to the costs of LEDs, heat sinking, housing and electronic drivers were adding costs and increasing the purchase price of LED-based products. When also including uplifts in the distribution channel, shelf prices would reach such numbers that for instance payback times of reduced energy costs would be longer than the lifetime of the bulb itself. As a result of this, a strong drive for cost reduction on the LEDs was initiated, which led to dramatic cost erosion over the years. It is anticipated that levels of 1000 lm/$ for the LED components will be attained within a matter of years, which signifies an increase of a factor of 30 in less than a decade. This is faster than the equivalent Moore’s law which is a key metric in the semiconductor field. The DOE has published [1] a roadmap predicting the Lm/$ and Lm/W over the years, which are indeed much in line with earlier predictions and actual data. If we follow this logic over time the relevance of the cost of LEDs will diminish initially at lower lumen applications moving towards higher lumen packages and finally covering the whole range.

Lm/W optimization will start to become important again. Not necessarily driven from an application point of view: saving 80% or 90% in energy versus incandescent or halogen doesn’t necessarily make an LED-based light source more attractive. Moreover by increasing the efficiency, the reduced heat dissipation requires less heat sinking, as well as less lower powered drivers, and therefore indirectly reduces costs of making the product. As a rule of thumb: going from 100 lm/W to 200 lm/W at the same specified lumen level results in approximately four times less heat dissipated! This certainly opens up possibilities to lower total costs. Although we will not go into the details of drivers, it goes without saying that if the LED and thermal costs go down; the driver has to follow this trend as well.

After having achieved desired lumen levels and cost targets, care has to be taken of compliance to applicable rules and regulations, e.g., Energystar. Next to safety a most important feature for acceptance of the new light source is quality of light of which flicker is an important aspect. Studies have shown that the human eye is quite perceptive for temporal variations or modulations of light, which leads to a discomforting feeling or even worse. Careful design of the electronic driver alleviates this issue, but unfortunately also less optimized designs can be found in the market today, which might have an impact on the reputation of the LED as a new light source.

All of the above combined led to our entry of a 60 W incandescent bulb equivalent for the L-prize challenge as called for by the DOE in order to advance the evolution of LED lighting. Recent data published by the DOE on lifetime testing of the submitted bulbs revealed stable lumen output after 20000 hrs of operation. This shows that through proper engineering optimum performance can be achieved.

3. Ledification in luminaires

In the previous section we mainly described the first wave of ledification through retrofit led lamps. Although this is the fastest way to adoption as many sockets lend themselves to be upgraded, full utilization of the benefits of LEDs would be through replacing the conventional lightpoints by dedicated LED-luminaires. For instance in the context of office lighting, the thermal constraints that are encountered in LED retrofit lamps are usually less of an issue in a luminaire by proper design of the heat sink. Optimized optics beyond those available in a retrofit solution could obviously increase the amount of usable light and therefore bring the good enough point earlier.

Still, the speed of adoption through installation of LED luminaires has a slower pace than through LED retrofit lamps. This phenomenon is due to some intrinsic non-technical reasons.

The dynamics of exchange of luminaires is usually in the order of 10-25 years in conventional lighting installations, whereas the lightsource is exchanged whenever it fails (typically somewhere between 1-4 years depending on lamp type, usage and application segment). As LED based lighting is still more costly than its conventional equivalent, they are sold based on a quick recovery of the additional investment through savings in energy and maintenance. Typically payback times of 3-5 years trigger a positive case for LED lighting, whereas 1-2 years payback leads to massive adoption.

Today in most lighting applications, whenever there is a decent LED retrofit solution available, the payback for led retrofits is much quicker than for a full LED luminaire. Not only are the product costs higher in case of luminaires, also the installation requires trained technicians and in most cases results in a major disruption of business all of which adding to the investment of upgrading the lightpoint. From a purely financial point of view these investments have to be recovered from energy savings and maintenance, which favor a retrofit solution.

Thinking along these lines one might wonder what the future will look like in case a traditional socket has already been filled by a LED retrofit bulb as little extra energy savings can be captured, which would not justify (from a financial perspective) an upgrade to a dedicated LED luminaire.

The rapid technology evolution in LEDs also induces yearly re-designs of LED boards and drivers, to fully capture the cost-down and energy saving potential of the newest generation of LEDs. As luminaire products have been based on product lifecycles of 5 years and longer to recover for instance the investments in moulds, it seems beneficial to separate the dynamics of the source from those of the luminaires. This separation entails the definition of a thermal, optical , electrical and mechanical interface, which if defined properly should be relatively stable over the years, while coping with the changes in LEDs. A definition of such standards has resulted in the Zhaga consortium [2], an association with a growing number of supporting members. In the Zhaga standard many of these interfaces have been identified and standardized, tuned to different lighting applications. Following these standards not only the quality of the compliant modules can be assured, also the economics resulting from the re-use of R&D investments make sense.

4. Embedded Lighting

To fully exploit the potential of LEDs, especially through their longevity, limited heat generation and small size, we investigated the potential to embed LEDs into construction materials. By doing so, fully embedded lighting sources can be envisaged that totally blend into their environment, rather than the distinctive character any luminaire has in current lighting designs. This unobtrusiveness is a long sought-after feature by any lighting designer, as this can enhance the architecture of the space that needs to be lit, and create special lighting effects without the technical look and feel of traditional approaches.

In order to explore this area we embedded LEDs into system ceiling tiles, which in the off state would look like being a seamless part of the ceiling. Once switched on the tiles would act as normal luminaires providing the required flux levels in a non-glary way. In November 2012 this system has been launched in the Netherlands as a result from the corporation of Philips with Ecophon, combining the expertise of both companies resulting in a product that is both compliant to lighting as well as acoustic tiles use and norms.

From user tests it was concluded that this kind of lighting is experienced as being very pleasant, not only through its omnipresence, but also through the unusually low glare levels while maintaining the required flux levels that make up a comfortable environment. The unique flexibility provided by this system, e.g., by re-arranging the tiles in case of a change in the floor plan, in combination with the unobtrusiveness, makes the lighting quite future proof and widely applicable.

5. Conclusion

This paper describes the different phases in LED adoption. The pace of ledification in LED retrofit lamps and later in luminaires is highlighted. Embedding LEDs into ceiling tiles shows the potential of breakaway concepts exploiting the full benefit of LEDs

6. References

[1] 2012 DOE SSL Multi-Year Program Plan, page 45, (http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_mypp2012_web.pdf)

[2] Zhaga consortium website, http://www.zhagastandard.org