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Circular Economy Aspects Regarding LED Lighting Retrofit—from Case Studies to Vision

Dorin Beu, Calin Ciugudeanu * and Mircea Buzdugan

Building Services Faculty, Technical University of Cluj-Napoca, Cluj-Napoca 400114, Romania; dorin.beu@rogbc.com (D.B.); mircea.buzdugan@insta.utcluj.ro (M.B.)

* Correspondence: calin.ciugudeanu@insta.utcluj.ro; Tel.: +40-752-193-890

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Abstract: The lighting industry is still a linear economy, despite the extensive use of light-emitting diode (LED) and the ban of incandescent/halogen lamps, claiming to be greener and more human centered. Light-emitting diode has changed radically the whole lighting industry with an increased luminaire efficacy more than four times higher compared with fluorescent lamps and their new opportunities for modern control systems. In the years to come, millions of fluorescent luminaires will become waste and will be replaced by LED luminaires. According to the Cost European Cooperation in Science & Technology Program the next step will be from sustainability to regenerative (enabling social and ecological systems to maintain a healthy state and to evolve) and to get there, circular economy is essential. In order to reduce even further the carbon footprint, the retrofit of existing luminaires and additional modern control systems should be the solution. Circular economy aspects for the lighting area were identified using the university adopted lighting retrofit solutions as case studies. For an LED retrofitted recessed luminaire 4 × T8 18 W studies showed a major installed power reduction, a good lighting distribution, but also revealed some problems: the retrofit luminaire has no certification, necessity of qualified personnel, high labor costs, etc. A major issue is the fact that luminaire design did not take into consideration circular economy aspects like the possibility of future retrofit solutions. It is important that from now on a different approach should be foreseen for the LED luminaire design. There is a section about vision, which plays an important role in preparing new luminaire generations with circular economy in mind.

Keywords: energy efficiency; retrofit luminaire; LED; circular economy; life cycle assessment—LCA

1. Introduction

The world population is growing and this is affecting the environment. To ensure there is enough food, water and, prosperity in 2050, people will need to switch from a linear to a circular economy [1]. Figure 1 shows the main basic characteristics for the linear, reuse, and circular economies.

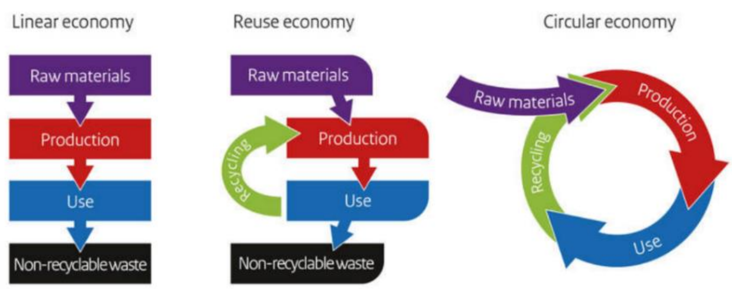


Figure 1. From a linear to a circular economy [1].

A circular economy is a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing energy and material loops; this can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, retrofit, recycling, and upcycling [2]. This contrasts with a linear economy which is a "take, make, dispose" model of production [3].

From the start, humans used oil lamps where vegetable or animal oil or fat was used, with oil-lamps made from shells, earthenware and later brass, and were the first examples of an industry needing a source of energy which was burnt (less than 1% was transformed into light, the rest was heat). In 1847, James Young discovered paraffin oil through refining mineral oil and it started the story of petrol usage [4], and since oil and the wick were consumable it is a clear example of a linear economy. In 1807, Frederick Windsor came up with the idea of centralized gas production (from coal), and since then public gaslighting is still used in many cities like Berlin and Zagreb [5]. Since the discovery of the first commercially viable incandescent lamp by Thomas Edison in 1879, lighting entered the electric supply era [6]. It can be found that lighting has started several industries like mineral oil, gas, and electricity, so it has a symbolic role in the launch of the linear economy.

The next milestone in the history of lighting was the introduction of fluorescent tubes, launched in 1938 in US, followed by the compact fluorescent lamp in 1980. These efficient lamps, based on the mercury contained inside the lamp, created another issue as Hg is a hazardous material and there is a problem with lamp disposal at the life end of the lamps [7].

The lifetime of the lamps vary from 1000 h for an incandescent one, 2000 h for a halogen lamp, 6000–15,000 h for the compact fluorescent lamps, and around 20,000 h for the tubular fluorescent lamps or a high-pressure sodium ones. For more than 100 years, after buying a luminaire, one was supposed to buy from time to time a replacement lamp (varying from an average of six months for incandescent lamps to every four years for high-pressure sodium lamps). Having lamps as consumable products created an oligopoly with four main players (Philips, Osram, GE, and Sylvania), and this model of economy has worked until 2008–2010 (when LED lighting arrived on the market). This market shift created the opportunity for new companies to get in and some to make an exit from the lighting industry (GE: 2017 [8]).

According to the [8] the next step will be from sustainability to regenerative (enabling social and ecological systems to maintain a healthy state and to evolve) and to get there, circular economy is essential. The theory of circular economy is based on eco-consumption, industrial ecology, economic functionality, and reuse [9]. When it comes to eco-consumption, there is a growing concern of the impact of the high blue-content of white LEDs and their impact during night-time on humans and beyond (i.e., the so-called artificial light at night impact) [10].

Industrial ecology is the only area where lighting is closed to the principle of circular economy, especially since the industry tries not to use hazardous materials like mercury anymore. Economic functionality—it is still an industry based on selling goods rather than services. The industry is recovering from the model of selling lamps as consumables to long-life LEDs. Reuse—it is a paradox, but the simplest luminaires that were using a lamp socket are more prone to be reused as they followed all the changes from incandescent to LED lamps. The retail luminaires with metal halide lamps and public lighting with high-pressure sodium cannot be reused with LEDs and only luminaire materials can be recycled. Gallium from faulty LED modules cannot be recycled yet.

The arrival of LEDs created new opportunities for energy efficiency. Virtual power output (VPO) avoids the usual oversizing of lighting installations. For example, for the illuminance level of 500 lx, a luminaire luminous flux of 3500 lm is required, and standard product is 4000 lm, and now it is simply dimmed to the required luminous flux, reducing also the electric power, leading to a reduction of electric energy consumption. The fact that LEDs switch on instantly at 100% and can be easily dimmed make them an excellent solution for sensors (compared with fluorescent lamps which need one minute turn on to 80%). For today, the most widely used sensors are motion, presence, and daylight detectors. There are also simple and low-cost LED drivers where the dimming function is not needed [11].

Results presented in Reference [12] reveal that LED lighting offers very large potential energy savings (62%) for which the majority of measures are highly profitable (simple payback time of less than two years). Early replacement of Compact Fluorescent Lamps (CFL) by LED is not recommendable from the point of view of the high specific costs and the long payback times (around 13 years). Additional annual energy savings will gradually decrease with the replacement of the most inefficient technologies in the near future. The cost-effectiveness will still improve in the future under the assumptions made according to which the price of LED bulbs will continue to decrease and their efficacy as the electricity cost will continue to increase [12].

Since 1991, several life cycle assessments (LCAs) were conducted on light sources, but from 2005 the first studies that included LEDs were conducted. An LCA is a tool for evaluating the potential environmental impact of a product (lamps in our case) from production to waste disposal (i.e., cradle-to-cradle). A study [13] reviewed existing LCAs for all types of light sources, including LEDs. The functional unit of LCAs are in many cases lumen hours (e.g., 1 Mlmh) but also 1 jour of lighting or 1 kWh. But the study also contained information on GWP (global warming potential), AP (acidification potential), EP (eutrophication potential), POCP (photochemical ozone creation potential), ODP (ozone depletion potential), HTP (human toxicity potential), and ADP (abiotic resource depletion potential). An LCA includes all the stages of a light source life cycle, starting from raw material, product development, manufacturing, transport, use, maintenance, and reuse or waste-disposal.

There is more and more pressure for a simple idea: light where it is needed! It starts from studies about the impact on human health, but also on animals, birds, insects, and fish, like the one that was supported by the European COST project LONNe (www.cost-lonne.eu). There are studies and conferences about artificial light at night (ALAN), and there are laws which try to reduce such light pollution like in France (https://www.ecologique-solidaire.gouv.fr/pollution-lumineuse) which shuts down all the light in a building after all the employees have left, as well as architectural lighting and shop windows after 1 am. The big discussion is about the health issues of light (in particular blue light during the night) and the impact on circadian rhythm. There are studies about the increased risk of breast cancer for women and prostate cancer for men related to ALAN [14], and of a link between obesity and night shifts [15]. Another study [16] shows that even under extreme long-term viewing conditions, none of the assessed LED sources suggested cause for concern for public health.

In 2002, the EU launched the first Waste of Electrical and Electronic Equipment (WEEE) directive [17,18] with the scope of collecting, recycling, and treating this waste [19]. Discharge lamps (fluorescent lamps, compact fluorescent lamps, high-pressure mercury and sodium lamps, and metal halide lamps) need to be collected separately, due to their mercury content (which is hazardous material and a water contaminant).

Lighting Europe—an association of the main European producers—in a White-Paper launched in October 2017 [20] introduced the concept of Luminaire Serviceability Information: a luminaire can be (a) sealed for life, (b) replaced ready, or (c) plug & play, and it can also be non-connectable or connectable or non-programmable or programmable. This is a first step in the direction of circular economy for the industry. In this direction, the industry is promoting lighting leasing but talks little about repairs and remanufacturing. When it comes to repairs, retrofit or remanufacturing, warranty is an issue. To provide a warranty, the luminaire needs to be dismantled, brought to a workshop, repaired/refurnished, quality checked, and put back in position. Obviously, this is a solution for heritage or expensive luminaires.

This research, by case study, is based on the presently very large usage of the T8 fluorescent lamps in all existing administrative, educational, and office buildings in Europe and particularly in Romania. This study is not trying to determine the best energy efficient retrofit lighting solutions (using the most efficient LEDs on the market), but to highlight the pros and cons of retrofit lighting solutions. The best available technique for an energy efficient and quality suitable lighting solution is very clear, but belongs to a linear economy model: throw away the old luminaires and install new very efficient

LED-dedicated luminaires. A new approach was tested for an energy efficient lighting by taking into consideration some of the circular economy principals:

- The retrofit of existing 600 × 600 mm fluorescent 4 × T8 18 W luminaires with LED modules—a complete retrofit solution offered by one of the major lighting manufacturers on the market.
- Comparing the improved lighting parameters, the efficacy and indicating as a better comparation indicator the lighting power density [W/sq. m/100 lx]—it can more precisely indicate the energy used by a luminaire to provide a certain illuminance level, considering all the luminaire characteristics.
- On behalf of the new circular economy concept we tried to identify the environmental benefits of such a retrofit lighting solution—by reusing the steel case, copper wires, and aluminum reflector.

Other similar LCAs are oriented on certain luminaire equipment (lamps, ballasts, etc.) [13,21]. This study shows the importance of making an environmental impact evaluation for the whole luminaire with case, lamps, ballasts, wires, etc. While a major impact over the performed LCAs is owned by the running energy consumption over 70% [13,21], it is very important to take into consideration the lighting power density (the ability to provide a certain illuminance over the working plane) and not just the measured efficacy of the luminaire.

2. Case Study Up-Cycle Existing Fluorescent Luminaires to LEDs—Materials and Methods

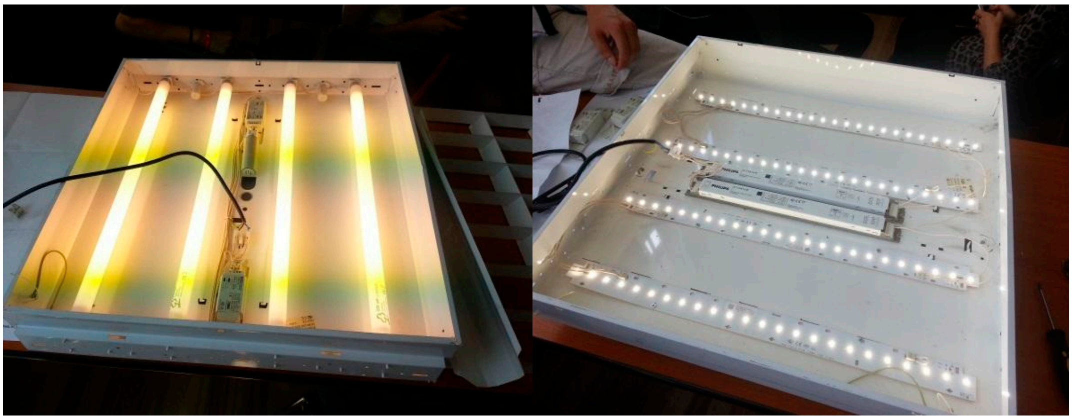
In a study performed in 2016 at the Technical University of Cluj-Napoca, classical recessed luminaires with 4 × T8 18 W (one of the most used solutions for office lighting) were converted from fluorescent lamp solutions to LEDs by using 600 mm LED modules, white plastic coated and one driver for each two modules. The main lighting source presently used in many Romanian administrative and educational buildings is 4 × T8 18 W fluorescent luminaires. Lighting Engineering Laboratory (LEL) analyzed a new retrofit lighting solution. An LED retrofit solution was adopted using 4 × LED 14.4 W strips and 2 × Xitanium 36 W LED drivers for replacing the old fluorescent lamps, the conventional electromagnetic ballasts, starters, condenser, etc. The old luminaires case, reflector, and copper wire were reused. The Xitanium 36 W drivers have the possibility to adapt the LED luminous flux by using different added resistances. This was a very important issue, because this of the one desired retrofit solutions with practically no impact on the hardware (there is no new additional wiring needed). So, the luminous flux of the luminaires could be adapted for the different room destination requirements.

Three different value resistances were added to the Xitanium 36 W, 0.12–0.40 A. Table 1 presents the measured consumption and power factor of the one LED 14.4 W strip, powered by one 36 W Xitanium driver [22].

Table 1. Measured values 4 × 14.4 W LEDs, 2 × Xitanium 36 W drivers with different value resistance added.

Resistance	Power Consumption	Power Factor
[ohms]	[W]	
0	21	0.859
100	21	0.860
150	21	0.861
220	26	0.887
270	28	0.904
330	32	0.918
470	42	0.940
560	48	0.950
680	57	0.960

For instance, for the hallways no additional resistance was added—initial electricity consumption for the 4 × T8 18 W of about 89 W was reduced by more than 75% to a value of 21 W (Figure 2). For this case, only one LED driver was used for each luminaire instead of two drivers for the office solution. According to SR EN 12646-1:2011–5.36 Educational Buildings [23], hallways and circulation areas, the requested average illuminance level is 100 lx and 0.40 uniformity. The new retrofit lighting systems are close to the required average illuminance level (Table 2). The LED system has a better uniformity value and uses only 25% electric power. The measurements were made on the floor plane for LED retrofit luminaires used around 3000 h.



(**a**) (**b**)

Figure 2. Luminaire retrofit solution (**a**) fluorescent; (**b**) LED.

The hallway measured illuminance levels on the floor plane are presented in Figure 3a for the 4 × T8 18 W fluorescent old luminaire and in Figure 3b for the same luminaire using new LED 4 × 14.4 W and 1 × Xitanium 36 W, no resistance (only one Xitanium driver was used because of the low power consumption—around 18–20 W). The field measurements were made on a 2.4 m wide hallway. The chosen measurement grid was 0.6 × 0.6 m. The measurements were recorded using a TESTO 545 illuminance meter.

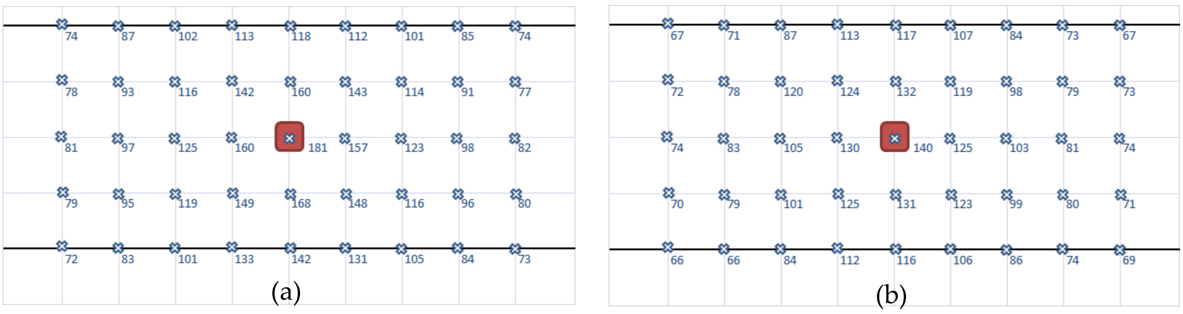


Figure 3. Field measurements (**a**) Old luminaire using T8, (**b**) Retrofit luminaire using LED.

Table 2. Field Measurement results—floor plane.

Measured Results	4 × T8 18 W	LED 4 × 14.4 W, 1 × Xitanium 36 W, no Resistance
Total power per luminaire [W]	89	18.8
Minimum illuminance level [lx]	72	66
Maximum illuminance level [lx]	181	140
Average illuminance level [lx]	110	95
Uniformity [%]	0.65	0.70

Some further measurements were made for different equipped T8 and LED retrofit luminaires. The measurements for the illuminance levels were made inside an experimental stand 2.5 × 2.5 × 2.5 m, where each luminaire was installed. The measurements were recorded using a 0.4 × 0.4 m grid on the floor plane and a TESTO 545 illuminance meter. For a clear understanding, Table 3 presents the main lighting setup scenarios. The setup A, B, and C measured used T8 lamps (approx. 4200 h). Setup AA and BB measured new T8 lamps. Setup D, E, and F measured used LEDs (approx. 1700 h).

Table 3. Field Measurement results—floor plane.

Setup	Description
A	4 × T8 18 W/54-765 (89 W, PF = 0.91) White Reflector
B	4 × T8 18 W/54-765 (89 W, PF = 0.91) Ribbed Aluminum Reflector
C	4 × T8 18 W/54-765 (89 W, PF = 0.91) Ribbed Aluminum Reflector Cleaned up
AA	NEW 4 × T8 18 W/54-865 (97 W, PF = 0.95) White Reflector
BB	NEW 4 × T8 18 W/54-865 (97 W, PF = 0.95) Ribbed Aluminum Reflector
D	4 × LED 14.4 W—No resistance (21 W, PF = 0.88), Plastic diffuser, Ribbed Aluminum Reflector
E	4 × LED 14.4 W—No resistance (21 W, PF = 0.88), No Plastic diffuser, Ribbed Aluminum Reflector
F	4 × LED 14.4 W—600 ohms resistance (57 W, PF = 0.96), Plastic diffuser, Ribbed Aluminum Reflector

Figure 4 shows the field measurements on the floor plane for the 4 × T8 18 W fluorescent lamp, total power consumption (lamps and ballast) of 89 W, and power factor PF 0.91 in three different setups. Figure 4 (A) shows a used old luminaire with white painted reflector; (B) a used old luminaire with ribbed aluminum reflector; and (C) a used old luminaire, cleaned up, with a ribbed aluminum reflector.

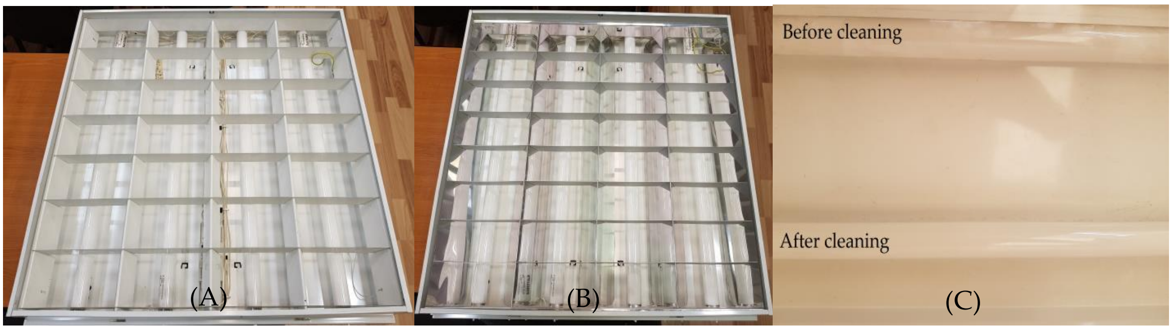


Figure 4. 4 × T8 18 W; (**A**) used white reflector; (**B**) used aluminum reflector; (**C**) used, cleaned up.

For the retrofit fixtures with 4 × LED 14.4 W strips and 2 × Xitanium 36 W LED drivers using the old luminaire case, ribbed aluminum reflectors, and copper wires, the three different setups measurements are presented in Figure 5. (D) No resistance added, total power consumption of 21 W, PF = 0.88, white plastic diffuser covering the LEDs, ribbed aluminum reflector. (E) No resistance added, total power consumption of 21 W, PF = 0.88, with no plastic diffuser covering the LEDs, ribbed aluminum reflector. (F) Six-hundred-and-eighty ohms resistance added, total power consumption of 57 W, PF = 0.97, white plastic diffuser covering the LEDs, ribbed aluminum reflector.

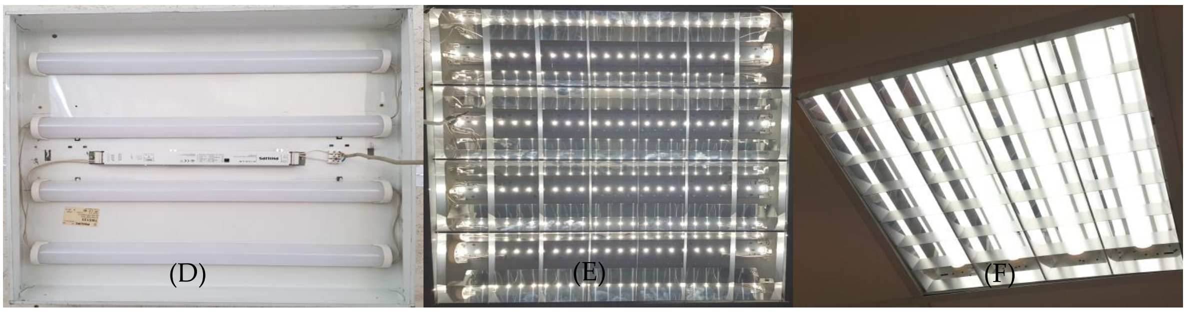


Figure 5. 4 × LED 14.4 W; (**D**) No resistance—21 W, plastic diffuser; (**E**) No resistance—21 W, no plastic diffuser; (**F**) 680 ohms resistance—57 W, plastic diffuser.

3. Results

The measurement results are centralized in Table 4. For each different luminaire and setup, the minimum, maximum, and average lighting levels are presented among the total power consumption and uniformity. The lighting power density [W/sq. m/100 lx] was calculated for each case.

Table 4. Field measurement results for different scenarios: floor plane.

Setup Scenario	A	B	C	AA	BB	D	E	F
Total power per luminaire [W]	89.00	89.00	89.00	97.00	97.00	21.00	21.00	57.00
Minimum illuminance level [lx]	132.00	147.00	175.00	197.00	206.00	133.00	188.00	321.00
Maximum illuminance level [lx]	167.00	205.00	243.00	251.00	291.00	181.00	256.00	433.00
Average illuminance level [lx]	151.35	174.40	206.40	224.55	248.80	156.95	220.85	375.95
Uniformity [min/average]	0.87	0.84	0.85	0.88	0.83	0.85	0.85	0.85
Lighting power density [W/sq. m/100 lx] — 1.2 × 1.6 = 1.92 sq. m	30.63	26.58	22.46	22.50	20.31	6.97	4.95	7.90

For the 4 × T8 18 W luminaire, an aluminum ribbed reflector (instead the white painted one) led to an improved average illuminance level by 13.2% (setup B versus A), even if the white painted reflector showed a better uniformity—0.87.

For the classic fluorescent fixtures, regular cleaning was very important, even if it led to additional maintenance costs. A clean luminaire can provide a 15.5% better average illuminance level using the same power amount (setup C versus B).

The old cleaned up and new T8 18 W (setup C versus BB) showed an illuminance depreciation of about 17% or more than 30% compared with the uncleaned one (setup B versus BB or A versus AA).

The white plastic diffuser placed over the LEDs (setup E versus D) showed an average illuminance level reduction of 29%. But missing the white plastic cover could lead to glare for the LEDs.

For about the same average illuminance levels, the total electricity consumption decreased dramatically (by more than 75%) by using LEDs from 89 W to 21 W, if we compare setup D to A or E to C. This power savings can be over evaluated, considering the used lamps depreciation and a missing cleaning maintenance program for our case.

The big flexibility of the LED lighting system is that it can adapt to different illuminance scenarios by the different added resistance.

The new retrofit LED lighting fixture, 4 × LED 14.4 W strips and 2 × Xitanium 36 W LED drivers and 680 ohms resistance added, was tested by Greentek Lighting Laboratory Romania. Table 5 shows a summary of the Greentek laboratory measurement results.

Table 5. Greentek laboratory measurement results for the LED retrofit luminaire.

Luminous Flux [lm]			**Power [W]**			**Efficacy [lm/W]**							
2674.20			57.67			46.37							
CCT—Correlated Color Temperature [K]						**CRI—Color Rendering Index**				**x**		**y**	
4247.0						84.877				0.3710		0.3739	
R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14
83	90	94	82	82	85	88	71	24	75	80	61	84	97

Figure 6 presents the color rendering index (CRI)-LED measured value of 84.87 compared with 72 for the T8 value [24].

The laboratory tested luminaire showed a low efficacy for the luminaire of 46.37 lm/W very close to the one of 4 × T8 18 W fluorescent lamps (43.29 lm/W). In contradiction with this low efficacy, the field measured illuminance levels showed great energy saving potential, taking into consideration the light distribution curves for the whole luminaire assembly (75% power savings).

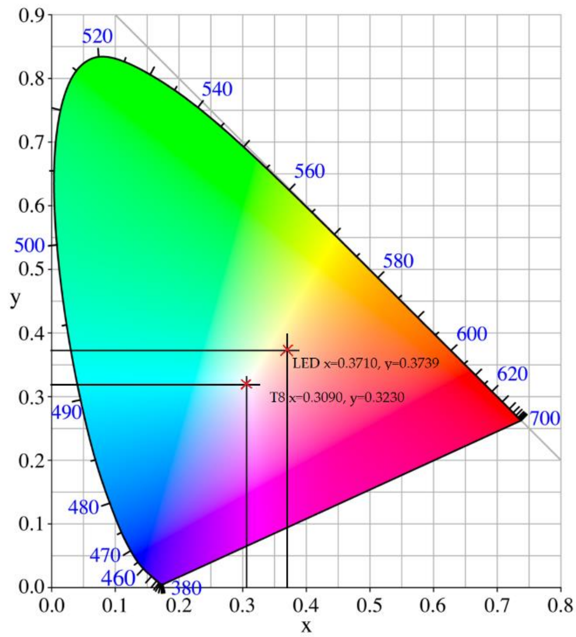


Figure 6. Commission internationale de l'éclairage—CIE 1931 (x, y) Chromaticity coordinates—T8: x = 0.3090, y = 0.3230; LED: x = 0.3710, y = 0.3739.

All the above shows that to have a concluding LCA, the evaluations should be made taking into account the whole luminaire with its different characteristics (efficiency, reflector, maintenance program, ballast/drivers, sealing coats, etc.). Maybe a better way is to compare the different light power density for 100 lx than to compare luminous fluxes for different luminaires. Like in our case, a low measured laboratory efficacy could mean great power savings in the field, taking into consideration the light distribution curves and the luminaire unit.

4. Discussion

Presently we gather data for an LCA of a conventional 4 × T8 18 W luminaire and an LED retrofit one. A conventional recessed luminaire 4XTL-D18W geared with magnetic ballast consisted on the following components (Table 6).

Table 6. Components of a conventional 4 × T8 18 W luminaire.

No.	Component	Weight [g]	Mass [%]
1	Steel case	1780	47.85
2	Aluminum reflector	580	15.59
3	Cables PVC 0.75 sq. mm	50	1.34
4	Condenser 8 µF	42	1.13
5	Starter 4.22 W (4 pcs)	28	0.75
6	Sockets for lamps and starters	30	0.81
7	Magnetic ballast VS L36.790 (2 pcs)	880	23.66
8	Fluorescent lamps TL-D18 W (4 pcs)	330	8.87
	TOTAL	3720	100.00

By adopting a retrofit LED solution, the steel case was 1780 g, the aluminum reflector was 580 g, and the copper cables were 50 g, which could be reused having a total mass of about 64%. CO_2 eq savings of about nine kg CO_2 eq could be achieved by reusing those components. The CO_2 eq emission factors from Table 7 came from Reference [25].

Table 7. Reused components for a retrofit 4 × 14.4 W LED luminaire.

No.	Reused Components	Weight [g]	Mass [%]	Emission Factor [kg CO_2 eq per kg]	CO_2 eq [kg CO_2 eq]
1	Steel case	1780	47.85	2.29	4.0762
2	Aluminum reflector	580	15.59	8.14	4.7212
3	Cables PVC 0,75 sq. mm—PVC	38	1.02	3.83	0.1455
4	Cables PVC 0,75 sq. mm—copper	12	0.32	2.22	0.0266
	Total	2398	64.46		8.9696

One of the major well-known environmental benefits of using LEDs instead fluorescent T8 lamps [26] is the lack of hazardous materials, like mercury and phosphor [27]. For instance, according to Reference [24], 4 × T8 18 W lamps contain a total amount of 32 mg Hg.

The retrofit solution using LEDs and not T5 lamps was used. Light emitting diode has proven to be extremely effective due to their long lifespan and increased efficiency. Additionally, they do not contain any mercury. The LED luminaires have higher luminous efficacy than T5 luminaires and they also maintain their luminous efficacy better when the luminaires are dimmed [28]. Moreover, the fluorescent share on the lighting market is smaller and smaller each day, and no improvement is expected.

Some elements of the circular economy can be presently found in the lighting industry such as maintenance, long lasting design, energy efficient technology, etc. The next step in this direction is trying to integrate recycling, reuse, and upcycling processes. The presented study revealed many problems that appear during the process. Even using a dedicated and complete refurbishment solution available from one of the major lighting players on the market the process was difficult because of missing information. Further measurements had to be done (e.g., exactly what happens when additional resistance is added to the Xitanium ballast). After this it can be decided where and what to use for optimal results. The retrofit process itself is a difficult one, takes a lot of time, and needs to be done by a more lighting trained endorser. The achieved luminaire characteristics are also far from the dedicated new LED luminaires in terms of efficacy, maintenance, design, etc. But this reuse approach is one way for a circular lighting economy. Table 8 shows the major lessons learned from this retrofit lighting solution.

Table 8. Lessons from the case study.

No.	Problem	Solutions
1.	Few buildings have AutoCAD electronic electrical plans and most of them have blueprints. There is no update on plans.	*Public buildings should start preparing Building Information Modeling (BIM) plans, with the type of luminaire, mounting date, last re-lamping, last cleaning.*
2.	No dismounting instructions; even if the luminaire has a product label, it is quite complicated to find on a company website, dismounting instructions (usually only mounting instructions).	*Each luminaire should have a Quick Response Code (QR code), from where you might enter an independent website (a lighting association, just to avoid foreclosure cases) for dismounting instructions.*
3.	To retrofit a luminaire, you need to get down the luminaire, which is time consuming, plus it can reveal other electrical and technical problems.	*The optical part should be mounted on a plug-in frame separately from the case and electrical connections. No rivets should be used.*
4.	Luminaires are full of dust and time is needed for cleaning.	*Optical parts will need to be sealed, preferably IP 66, to have higher maintenance factor and also to be replaced plug-and-play.*
5.	There is no data about hazardous materials, or if there are subparts that can be recycled.	*Environmental Product Declaration of each component should be available on BIM plans.*
6.	In the case of retrofit luminaires there is an issue about warranty and safety responsibility: the European Community (CE) mark is lost, the electromagnetic compatibility (EMC) it is hard to verify in situ, and the risk of electric shocks.	*The proposed retrofit must be examined further (for EMC) at least in areas with computers or other devices that could be influenced by emitted electromagnetic radiation. In case of optical part replacement all these problems are avoided.*

Table 8. *Cont.*

No.	Problem	Solutions
7.	The proposed retrofit lighting solution is able and should include modern control systems with dimming ability. For the Digital Addressable Lighting Interface (DALI): the two wires control creates a lot of problems in existing buildings.	*Wireless lighting controls should be considered and integrated in a Building Management System (BMS) which should be very simple.*
8.	To set the Constant Light Output (CLO) and Virtual Power Output (VPO) a data cable is needed.	*A wireless solution should be considered for setting these values.*

While the new retrofit lighting system is able to use modern control systems and has the ability to be dimmed, it also loses the CE mark and the EMC certifications. The retrofit system measured power factor can vary between values of 0.85 and 0.96 (Table 1) while the conventional T8 luminaire compensated power factor is 0.91. The selection of the proper lighting gear is crucial during the retrofit design phase, not only by satisfying the requirements imposed by regulations as far as it concerns average illuminance and uniformity, but also for their energy performance. It is evident that it is also crucial to identify and estimate all parameters involved with their dimming performance [29]. Daylight-linked controls (DLCs) allow to reduce energy costs and to maximize users' comfort. Despite benefits it would provide, DLCs use is rather limited because of different factors: difficulties in design, installation and calibration, problems connected to the evaluation of achievable energy savings, and users' reluctance in accepting them [30].

In conclusion, producers should separate the optical part from the mounting case and from electrical components. The optical part should be standardized, so different companies should be able to deliver retrofit solutions.

With the new LEDs people are getting used to easy dimming, change in color, or lately, change in correlated color temperature. So, what is next? The problem of lighting installation oversizing must be solved. For instance, for an interior lighting installation, instead of achieving 500 lx, designers may obtain a maintained average illuminance of 550 lx (an extra 10%) with a maintenance factor of 0.8 (which is optimistic) will lead to 687 lx, with an over sizing of 37%. Taking into consideration that in many cases, due to the use of the same luminaire in all rooms, the initial average illuminance is even bigger, as in some cases designers go with a maintenance factor of 0.56 (taking in consideration all factors), which results in an electrical power multiplied by two in the initial stage. So soon, all the luminaires should have the ability to provide constant luminous flux over their life time to achieve the illuminance level required by norms and to avoid a bigger initial power consumption.

The next step for the lighting industry will be adapting the luminaire photometry to each room. Now designers try to obtain the minimum number of a specified luminaire, that will exceed norm specifications. In the future, they will obtain the optimized photometry and luminous flux/luminaire that will comply 100% with norm specifications. It is not easy to change luminaire photometry now, but in the future it may be easier than we expect. There are two options:

- Mechanical changes: on site you change the lenses, add/remove LEDs. Based on computer calculations that will optimize every luminaire, which will have to be adapt them by contractor/distributor.
- Digital changes: luminaires will be installed and then through software will be able to modify the light output or the light distribution, like with moving-head projectors.

There are endless possibilities to adapt the distribution of luminaires to the real situation. In interior lighting, you can easily adapt to an office layout change (500 lx on the desk and 300 lx near them).

Our research showed that there is still a long way from theory to practice when it comes to circular economy. But there is a continuous change in the lighting products and industry and circular economy must be part of it. Based on our experience here are some possible ideas for changes that will occur over the short and long term—the vision:

1. Direct Current. Since the launch of electricity supply there has been a debate between direct current (DC) and alternative current (AC). Apparently, the success was on AC, but lately it looks technological evolution has reopened this discussion. As LEDs use DC, and photovoltaic supply also produces DC, there is an opportunity to avoid useless conversion from DC to AC and then back from AC to DC—this means a major shift for the electric distribution inside buildings.
2. Li-Fi or visible light communication (VLC) is a new system for wireless communication at very high speed up to 224 Gb/s using LED luminaires. The LED needs to be switched-on and cannot pass through a wall, which is good in terms of security. For the moment, the technology is under research, but in case it is a success, users may find that Internet suppliers will deliver also lighting and that will be a change for the lighting industry.
3. Today luminaires can modify the luminous flux, and in some cases, the color temperature (the so-called tunable white version where you can modify from 2500 K to 6500 K). In the future, it can be expected to control every LED from the LED matrix in what will become "adaptive photometry" luminaires. This luminaire can adapt their light distribution curve to specific room or street layouts, and the presence of furniture or street obstructions. This can enable further energy savings by avoiding the use of light where there is no need, and by switching-off or dimming specific LEDs from the matrix.
4. New types of presence sensors, which can detect the exact position of a person (the case of an office or a lecture hall where only few people are presents) so only the desks where people are present have the required lighting level.
5. Use of Artificial Intelligence for repairing the Building Management System.
6. Use of drones for repair operations for outdoor luminaires.
7. Use of drones combined with LED projectors and Li Ion batteries for emergencies (earthquakes, accidents etc.) or for events (street festivals, weddings etc.)
8. Link between human vision direction and lighting direction.

All these ideas will change the industry, but this doesn't mean only new products, but also reuse of existing ones, and this is a challenge for an industry based on the linear model. But those who will incorporate the circular design in their products, may be the long-term winners. Like in the case of smartphone, which started from a mobile phone and ended in time with a tablet, which can also make telephone calls, smart lighting can start with luminaires that produce light and end in future with a system which deliver Internet, have several other applications and also deliver light.

5. Conclusions

The global environmental impact for incandescent, CFL, and LED lamps presented in reference [31] shows that the major impact is owned by the utilization stage, between 83.9% incandescent, 73.0% LED, and 70.9% CFL. The raw materials, production, transport, and end life stages are responsible for less than 30% of the global environmental impact of the lamps, even if this value goes higher for the new LED lamps. This utilization stage is mainly connected with the luminaire efficacy, but not necessarily in terms of a strict luminous efficacy but the ability of the luminaire to deliver a certain illuminance over the work plane. The laboratory tested luminaire shows a low efficacy of 46.37 for the retrofit LED, very close to the one of 4 × T8 18 W fluorescent lamps. In contradiction with this low efficacy, the field measured illuminance levels show great energy saving potential—about 75%. Considering the major environmental impact of the utilization stage—over 70%—the LCA should also take into consideration the illuminance delivered by the luminaire on the working plane and not only the lamps efficacy—which sometimes are not correlated, from the point of view of energy savings.

As a vision of the future, the light industry can have a paradigm shift and move toward circular economy, using artificial intelligence, new sensors and rethinking the luminaires and the proposed services.

Nowadays if someone types on Google: "LED Lighting Leasing", there will be lots of banks, financial institutions, and lighting companies offering leasing solutions for LED lighting. This means a change of the business model: from selling luminaires and control systems to lease lighting systems or quality of lighting "pay-per-lux" [32]. On the one hand, due to rapid changes in technology, energy efficiency is getting higher and prices are getting lower every year, so there is a tendency on delaying a decision on buying new lighting systems. On the other hand, for start-ups and even for long-established companies or for city councils there is more and more a debate about going on the leasing solutions to avoid bank loans or high investments on new equipment that can become obsolete in a few years. This paradigm shift started in 2013 when the National Union of Students moved to a new location at Macadam House, London where the user wanted to introduce some principles of circular economy, including lighting services and not buying products. This started a new trend which includes now airports [33] and metro stations. There is still missing a third-party report on the real results. All the producers are saying that their luminaires are future proof, but at which moment a replacement of LED modules or drivers should be made is a difficult problem and there is no standard procedure. Also, the future of lighting is hard now to predict, but one direction is clear: circular economy combined with a new vision for lighting, and this will lead to a lighting paradigm shift.

To prepare luminaires in line with the circular economy concept, producers should go beyond using screws inside luminaires and have a long-term strategy which will lead to luminaires that can be reused, updated, and integrated in lighting systems that will be used in the years to come.

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