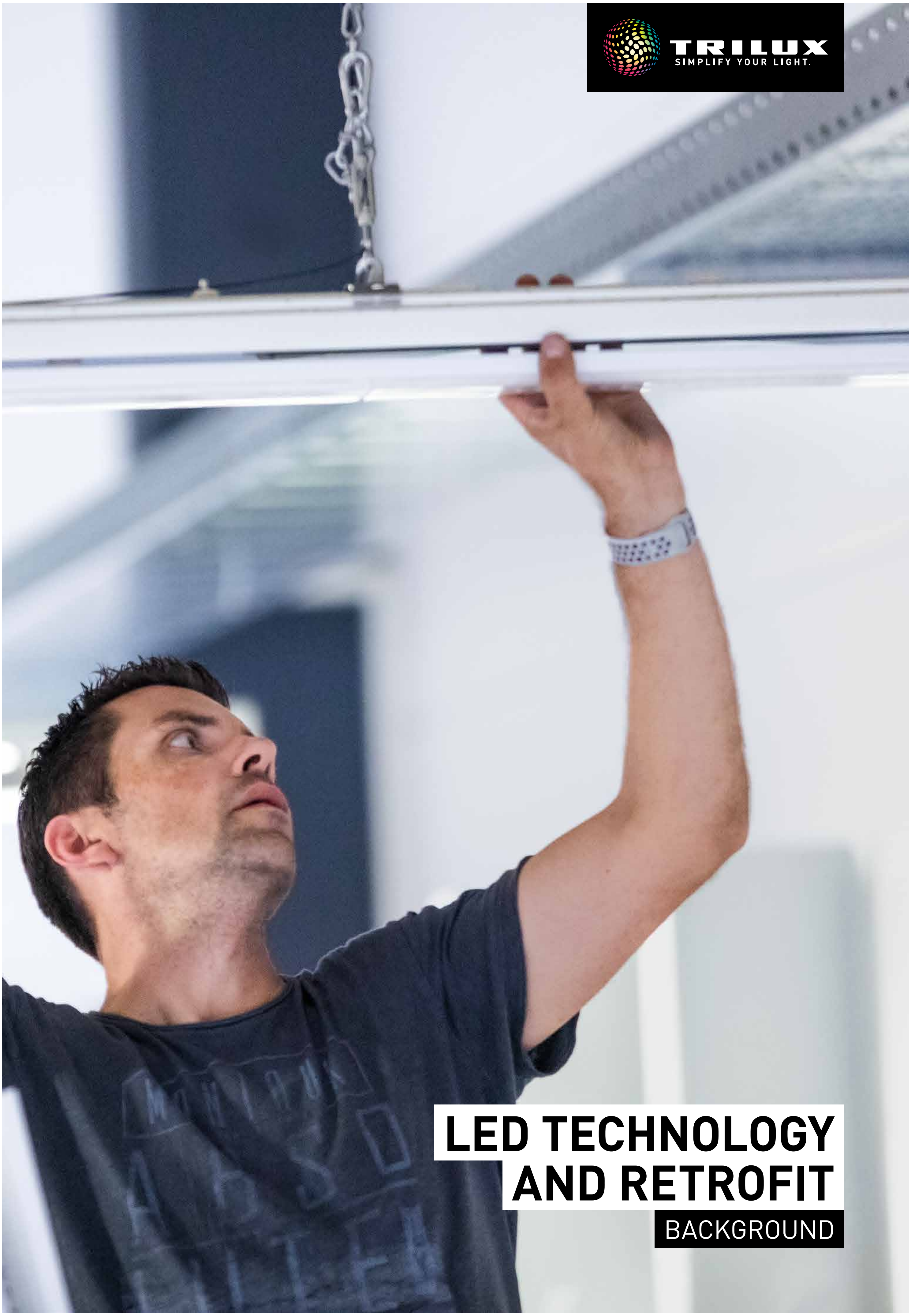


TRILUX
SIMPLIFY YOUR LIGHT.

LED TECHNOLOGY AND RETROFIT

BACKGROUND

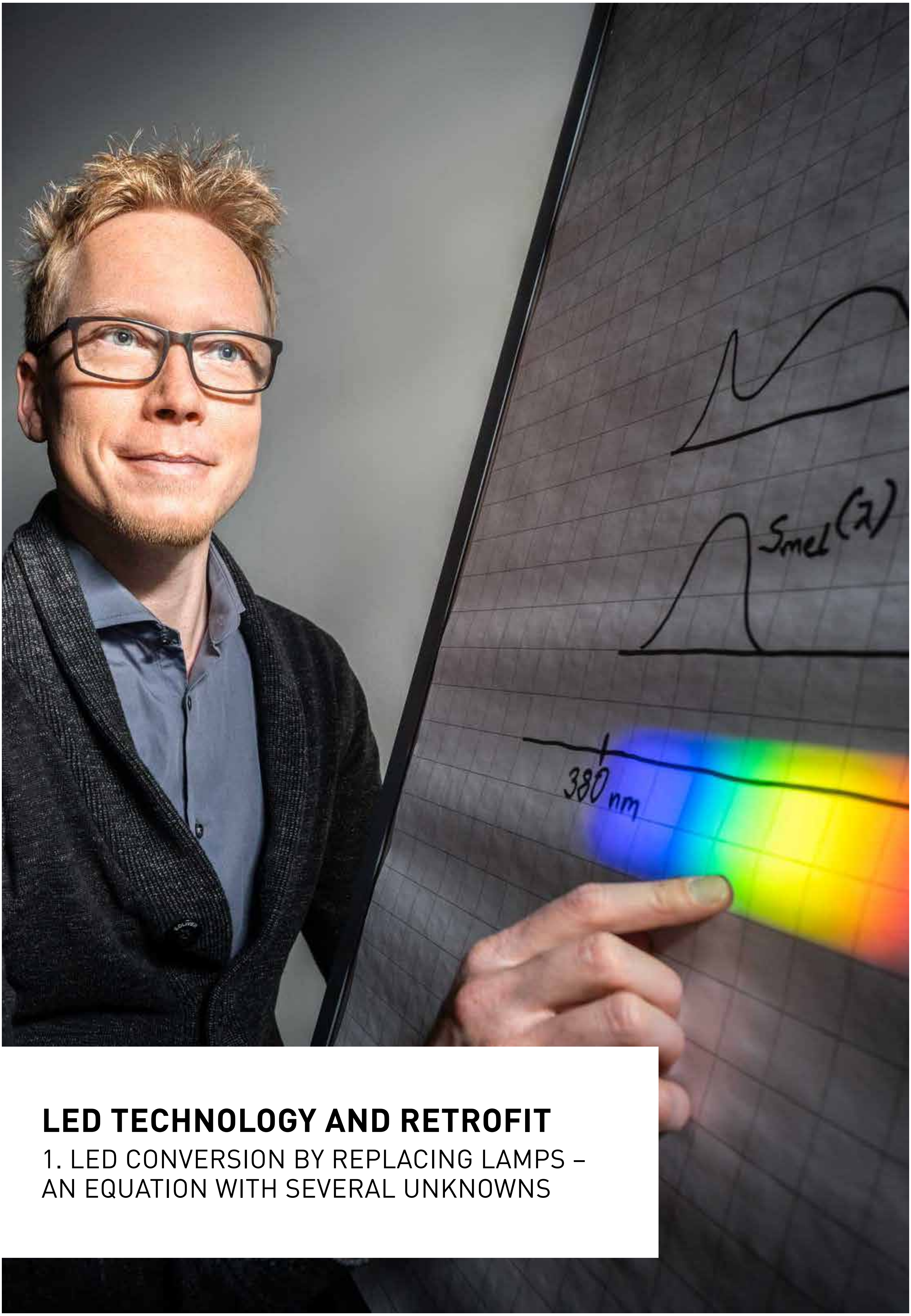
WHAT YOU SHOULD KNOW ABOUT THE LAMP BAN, RETROFIT LAMPS AND THE SWITCH TO LED TECHNOLOGY

For decades, mercury-containing fluorescent lamps with high levels of luminous efficacy have established themselves as standard products for illuminating workplaces. For this reason, until recently there were exemption regulations for mercury-containing discharge lamps from the general ban on the use of mercury in products, which was introduced in Europe in 2011 with the second edition of the RoHS Directive.

With the market maturity of white LED light sources since around 2013, the situation has changed fundamentally. Today, technically mature and economical LED solutions are available for almost all lighting tasks. In many cases, their energy consumption is more than half that of the fluorescent lamps.

In February 2022, European legislators therefore decided to gradually abolish the special approvals for using mercury in discharge lamps. In particular, compact fluorescent lamps were no longer permitted to be placed on the market in Europe as of 25.02.2023, and tubular fluorescent lamps as of 25.08.2023, i.e. they may no longer be produced or imported for resale.The UK have also made this decision with the phase out schedule commencing from February 2024.

As a result, these lamps are or will no longer be available on the market once they have been sold from stock. By then at the latest, it will no longer be possible to replace the previously used lamps with identical technology. This means it is high time to start thinking about the transformation in technology.



LED TECHNOLOGY AND RETROFIT

1. LED CONVERSION BY REPLACING LAMPS – AN EQUATION WITH SEVERAL UNKNOWNS

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A retrofit lamp is a replacement lamp based on modern technology that can be operated in the form of a simple replacement in existing luminaires. Nowadays this usually means upgrading from conventional lamps to LED technology. If an intervention into the electrical structure of the luminaire (e.g. deactivation of the control gear unit) has to be done to operate the replacement lamp, it is no longer referred to as a retrofit lamp but as a conversion lamp. In both cases, the lamp is replaced instead of the luminaires.

The aim of retrofit solutions is to utilise the advantages of modern technology without having to fundamentally convert the existing lighting system.

However, what in theory sounds so simple and convincing often turns out to be complex in practice. The use of retrofit and conversion lamps in technically and structurally very different luminaires from a wide range of manufacturers actually poses many questions. These relate in particular to

- Electrical safety, product liability and warranty
- Quality of light and use
- Compliance with occupational safety standards and regulations.

On the one hand, replacing outdated T5/T8 fluorescent lamps with LED replacement lamps promises quick, easy and relatively inexpensive savings in energy costs, but on the other hand, extensive preliminary tests are required in a professional environment.

Regarding the luminous flux actually available, its spatial distribution, the quality of light required by standards and the service life of the luminaires and light sources, it is only possible to determine whether and how the lamp and luminaire work together after the retrofitting process. Many malfunctions only become apparent during extended operation.

In comparison, LED luminaires score highly that come from quality manufacturers and have factory-integrated LED modules, optimally matched individual components and precisely predictable quality and efficiency parameters.

In addition, the overall economic efficiency and sustainability should also be included in this comparison.

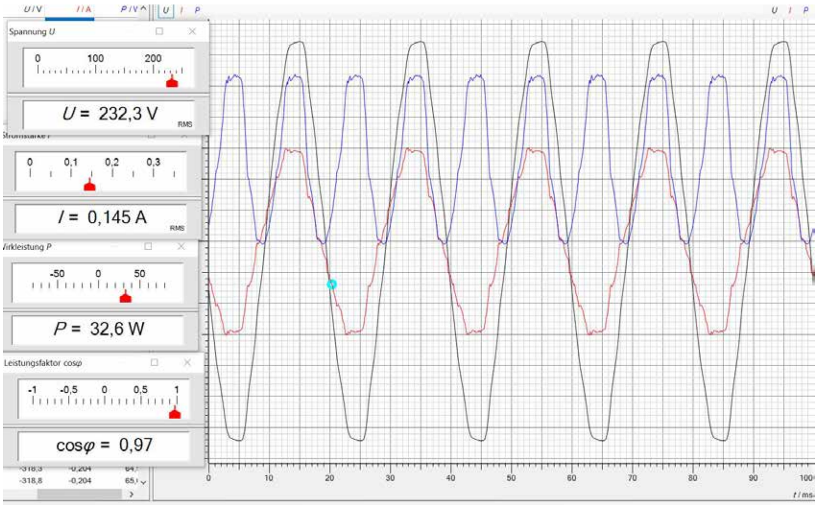
1.1 Safety and warranty

1.1.1 Retrofit

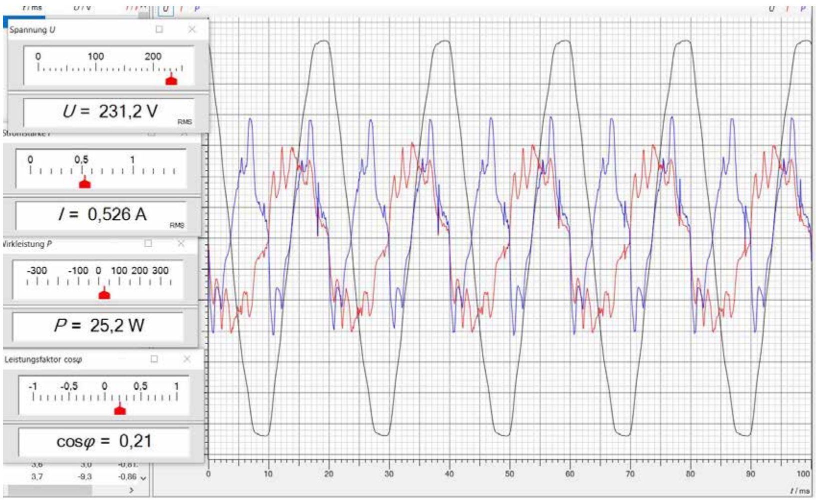
The following must be noted before using LED retrofit lamps in luminaires for fluorescent lamps:

- The guarantee and product liability of the light manufacturer expire.
- Product liability is thereby transferred to the manufacturer of the retrofit lamp.
- For the operation of LED retrofit lamps on electronic control gear (ECGs) for fluorescent lamps (HF operation), it should be noted that an approval from the retrofit manufacturer – **subject to**[1] – is only given for the ECG types assigned to the retrofit lamp in a compatibility list. The retrofitter must therefore at least ensure that each luminaire in a lighting installation is fitted with only the listed ECGs (see also Fig. 1 a). The complexity/effort of these preliminary checks must be taken into account.
- For dimmable luminaires, conversion to LED retrofit lamps is generally only possible in special cases and in compliance with any restrictions specified in the ECG compatibility list. In most cases a conversion solution would be required (see below).
- When operating LED retrofit lamps in parallel-compensated luminaires, a very small power factor cos(φ) of the circuit can occur and cause a high idle current in the electrical installation.
- For tandem circuits (two fluorescent lamps connected in series to one control gear unit), as is common in existing multi-lamp luminaires with 18 watt T8 lamps, the possible operation of LED retrofit lamps must be checked separately. In some cases, conversion of the luminaire might be required (see below).

[1] The ECG compatibility lists of the lamp manufacturers point out that the compatibility list is for information purposes only and must be regarded as a recommendation. For example, the information is based on tests in laboratory-simulated environments under conditions that may differ in practice. The retrofit manufacturer therefore assumes no responsibility, guarantee or liability that compatibility is given when using the specified devices under conditions other than those specifically tested by it or when using successor models of the specified devices. Malfunctions may then occur, e.g. flickering, no light, overheating, premature ageing, failure of devices etc. The luminous flux may also change depending on the control gear unit used.



a) Measurement with an LED retrofit lamp 23 W/4000 K 1500 mm in a TRILUX luminaire with non-approved ECG. The lamp is operated with increased wattage (32.6 W instead of 23 W).



b) Measurement with an LED retrofit lamp 23 W/4000 K 1500 mm in a TRILUX weather-proof luminaire (Aragon 158K, date of manufacture approx. 2010) with inductive CG and parallel compensation. A power factor of cos(φ) = 0.21 leads to a high reactive current and, in a lighting installation with many luminaires, possibly to an excessive line load and tripping of the circuit-breaker.

Fig. 1: Measurements with retrofit lamps

1.1.2 Conversion

Before converting the luminaire to operate a conversion lamp:

- All components used in the conversion kit must be proven to comply with the applicable safety and EMC standards.
- It must be ensured that there is no danger from the luminaire when using another lamp that can be confused with it, such as a fluorescent lamp.
- The luminaire to be converted must be suitable for use of the conversion kit.
- All changes resulting from use of the conversion kit must be assessed with regard to any increase in risks (relating to wattage, use, design, EMC, blue light properties, emergency light, control systems etc.).
- If risks are increased, a full conformity assessment procedure must be carried out. In this case, among other measures, the original type plate of the luminaire must be replaced with a new type plate bearing the necessary information.

1.1.3 Service life and reliability

- For LED replacement lamps, either no information or comparatively unfavourable information regarding failure rates is generally provided (e.g. max. 10 % failure within 6,000 h).
- The rated service life of LED replacement lamps is usually specified for an L70 degradation (luminous flux decrease of 30% to a residual luminous flux of 70% at the end of the service life). With regard to occupational safety (see below), it must therefore be taken into account that at the end of the service life only 70% of the already lessened initial luminous flux is still available.
- The rated service life of LED replacement lamps is usually specified for an ambient temperature of 25° C. This temperature is standardised as the ambient temperature in interior spaces. In a closed luminaire, operation of the lamp can significantly increase the temperature inside that luminaire and thus considerably reduce the service life of the lamp.
- When used in chemically contaminated atmospheres, specific incompatibilities may lead to damage and failure of the LED replacement lamps. Interactions with components of the luminaire can also lead to damage to the luminaire.
- In special applications (e.g. high temperatures or mechanical stress due to vibrations), large deviations from the normal operating behaviour of LED replacement lamps, also compared to the operation of fluorescent lamps, are possible.
- LED replacement lamps that weigh more than fluorescent lamps may cause the sockets to be damaged. This can result in contact resistances between the socket pins and socket contacts having impermissible temperature overloads. This, in turn, can lead to malfunctions or even total failure of the luminaire. If the sockets are already aged and brittle due to the previous usage period, there is also an increased risk in this respect.

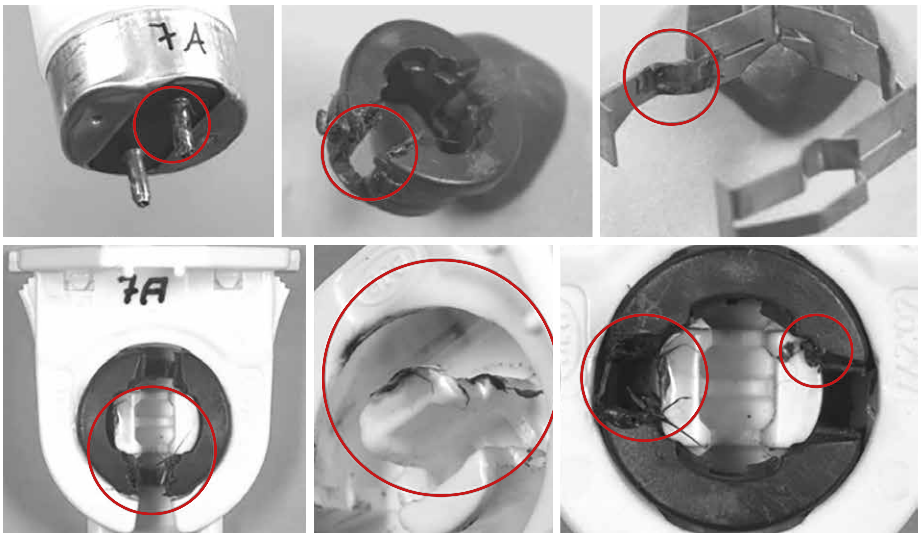


Fig. 2: Damaged sockets in which retrofit lamps with excessive weight were operated

1.2 Quality of light and occupational safety

1.2.1 Luminous flux and illuminance

- Commercially available LED replacement lamps often have a significantly lower luminous flux than corresponding fluorescent lamps. Direct replacement then leads to a significant reduction of illuminance in the room.
- Even the luminous flux of LED replacement lamps with the highest values available on the market is generally well below the value of the previously used fluorescent lamps (e.g. 3700 lm as a replacement for 5000 lm in the case of T8 58W lamps – see Table 1).
- It should be noted that for LED replacement lamps, a reduction in luminous flux to the end of the service life down to 70% of the specified initial luminous flux (i.e. for example 3700 lm x 0.7 = 2590 lm, see below) must generally be calculated.

- The key figures for luminous efficacy with LED replacement lamps are given for open distribution operation without considering losses due to operation in a luminaire. However, measurements show that the actual losses (or luminaire light output ratios) are often comparable to operation with fluorescent lamps.
- As a result, the lighting level is often no longer compliant to standards and does not comply with the statutory regulations for occupational safety.

Lamp type					
Length	**T8 (reference)**	**Retrofit example 1**	**Example 2**	**Example 3**	**Example 4**
600 mm	18 W 1300 lm	7.5 W 1100 lm (-15 %)	6.6 W 720 lm (- 45 %)	8 W 1050 lm (- 19 %)	8 W 900 lm (- 31 %)
1200 mm	36 W 3200 lm	15.0 W 2400 lm (- 25 %)	15 W 1800 lm (- 44 %)	14.7 W 2500 lm (- 22 %)	18 W 2000 lm (- 38 %)
1500 mm	58 W 5000 lm	22 W 4100 lm (- 21 %)	18.3 W 2200 lm (- 56 %)	21.7 W 3700 lm (- 26 %)	23 W 2700 lm (- 46 %)

Table 1: T8 LED retrofit tubes: examples of power consumption and luminous flux of products available on the market (as of November 2023)

1.2.2 Light distribution and uniformity

- A distribution characteristic of the LED replacement lamp that deviates from the cylindrically symmetrical distribution (360 degrees) of the fluorescent lamp may lead to a significant change in the luminous intensity distribution of the luminaire.
- This may lead to reduced uniformity of illuminance in the room. The compliance with occupational safety regulations must be checked in this regard.
- With suspended luminaires with an indirect light component, the distribution characteristic of the LED replacement lamp which differs from that of the fluorescent lamp leads to significantly reduced ceiling brightening, with a corresponding risk of complaints from users.

1.2.3 General quality of light

- LED replacement lamps can exhibit considerable flicker that far exceeds that of a fluorescent lamp in operation on low loss control gear.
- LED replacement lamps generally have low colour consistency. Typically, a value for colour locus tolerance (initial MacAdam) of ≤ 6 SDCM is specified by the well-known manufacturers. In some cases with higher efficiency products, a value ≤ 5 SDCM is given. Even at 5 SDCM, colour deviations are clearly detectable. In comparison to this, the values with quality luminaires are at 3 SDCM.

1.2.4 State of technology, requirements of the current EN 12464-1

The direct replacement of fluorescent lamps with LED replacement lamps is generally only covered by inventory protection if the working conditions have not changed since the time of installation. The aim is therefore only to maintain the status quo. Requirements in line with the current state of technology, as described in EN 12464-1 in the current 2021 version, are not taken into account. The following are in particular currently recommended:

- the availability, when needed, of one to two levels of increased illuminance, which should be controlled by dimmable luminaires and appropriate light management, and
- Appropriate luminance distribution with minimum illuminances on walls and ceilings, which is often not achieved in existing systems (e.g. with narrow distribution louvre luminaires or darklight luminaires, see example “Illuminating offices”).

2. REFURBISHMENT INSTEAD OF RETROFITTING

Various refurbishment options that can be selected to precisely suit the technical and spatial conditions offer a safe and sustainable way for upgrading to LED technology.

The greatest potential for optimisation is with a new lighting concept that is independent of the existing situation. In many cases though, simply replacing the luminaires can lead to a satisfactory result. Care must be taken here that, following replacement, the selected luminaires fulfil the current photometric and electrotechnical requirements in the existing configuration.

If the replacement of complete luminaires is not desired due to structural or other reasons, TRILUX can supply socket-free luminaire inserts with LED modules – so-called refurbishment kits – on request. In individual cases, the complete optical system can also be replaced with up-to-date lighting technology.[2]

Light management systems for further energy savings, which also enable circadian control of the colour temperature based on the course of the day if this is required, can be used with all refurbishment options.

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[2] If a manufacturer offers conversion kits for third-party products, the warranty, product liability and other obligations, as in the case of conversion, are initially born by the person carrying out the conversion. The scope of any assumption by the manufacturer and the provision of technical data sets for the resulting luminaires must be clarified in advance.

2.1 Safety, quality and economy

The most important advantages of refurbishment with LED luminaires from TRILUX compared to retrofitting with LED replacement lamps:

- Photometric data sets are available for checking the compliance to occupational safety requirements prior to a retrofitting project being carried out.
- These luminaires have unlimited product liability and warranty.
- The electrotechnical operating data are known in detail and guaranteed.
- The lifespans are specified for residual luminous fluxes of at least 80% ($L \geq 80$).
- Virtually no failures are to be expected over their entire service life (failure rate close to zero).
- At the ambient temperature permitted in the room, the documented service life can be expected, which is not reduced by an increase in temperature within the luminaire.
- Versions for higher ambient temperatures are also often available.
- Disturbances of visual comfort due to 100-Hertz flickering are avoided by designated low flicker factors.
- Contemporary requirements for quality of light can be met.
- For every application, dimmable luminaires and a suitable light management system are also available.
- If required, luminaires with variable colour temperature for circadian control are also available.
- In the specific application, optimised lighting technology is able to distribute the light in a much more targeted way than was possible with fluorescent luminaires.
- LED luminaires are therefore particularly energy-efficient.
- They have a high level of colour consistency (colour locus tolerance ≤ 3 SDCM) due to high-quality binning.
- No defective sockets in the existing luminaires have to be replaced.
- Better efficiency and economy are achieved compared to replacing with LED replacement lamps.

2.2. Sustainability

An important aspect for evaluating ecological sustainability is analysis of the carbon footprint of luminaires. Here, in addition to the energy consumption due to the operation of a product, the carbon emissions required for the provision of the product are also taken into account. The entire life cycle of the product is therefore recorded to determine the carbon equivalent (CO_2e). In this way, the outlay of providing and operating a product can be put into perspective.

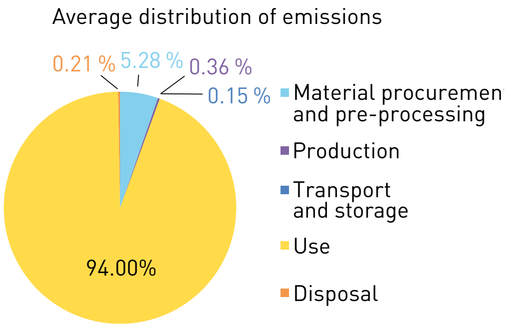


Fig. 3

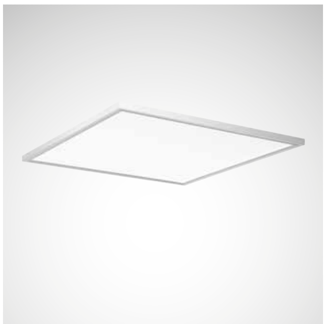


Fig. 3.21:
Arimo Fit
Characteristic data:
Luminous flux: 4,200 lm
Service life: min. 50,000 h
Ambient temperature: 25° C
Protection rating: IP40
Connected load: 31 watts
Total weight: 4.67 kg
713,935 kg CO_2e

The characteristic data in Fig. 3 show that when using a typical standard luminaire with sheet steel housing and PMMA cover in office applications, operation accounts for almost 95% of the carbon emissions.

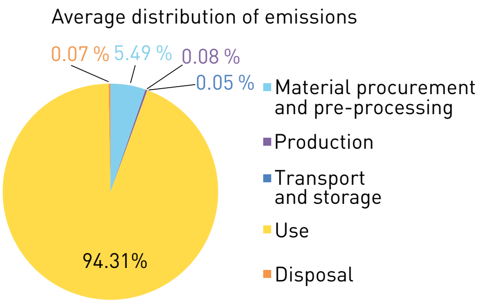


Fig. 4

Fig. 3.22:
Mirona Fit
Characteristic data:
Luminous flux: 26,000 lm
Service life: min. 50,000 h
Ambient temperature: 50 °C
Protection rating: IP65
Connected load: 188 watts
Total weight: 7.2 kg
3,344,412 kg CO_2e

Fig. 4 shows a luminaire from the Mirona Fit range for illuminating high industrial halls. A lens optic produces the optimally most suitable light distribution and its technically and materially sophisticated luminaire body ensures the necessary thermal management for durable and efficient operation at high ambient temperatures. The characteristic data for the figure show that, for this more complex luminaire, the relative proportion of carbon emissions for provision and disposal remains comparable. The technical complexity and material requirements increase uniformly along with the large luminous flux package that can be operated at high temperatures.

The examples above make it clear that in typical lighting applications, over 90% of carbon emissions are attributable to the use of the lighting. The total of 6% of carbon emissions caused by the provision and disposal of the luminaire thus has only a subordinate role in both cases. This means that in these cases, increasing the efficiency of the lighting by 6% by replacing the luminaire with an energy-optimised LED luminaire is sufficient to compensate for the energy required to provide the luminaire. In order to achieve a minimised carbon footprint, the use of elaborate, high-quality luminaire bodies and photometric components therefore makes sense.

At least as much potential also lies in the qualified specialist planning of the lighting task at hand. In particular, the specific use of optimised lighting technologies suitable for the respective application, which are available thanks to the diversity of modern LED luminaire ranges, provides a reliable basis for efficiency and sustainability.

TRILUX minimises the resource consumption of materials that have limited availability through high reparability, in particular the separate replacement of LED modules and electronics, as well as the guaranteed long availability of spare parts.

3. SAMPLE ANALYSIS

In a sample analysis, specific measurements were carried out in the TRILUX laboratories on the operation of LED retrofit lamps fitted in traditional TRILUX luminaires. In particular, two lamps were used with the highest available luminous flux levels and labelled as high quality by the manufacturers:

Retrofit 1: 1500 mm, 4100 lm, 22.1 W, 4000 K
Retrofit 2: 1500 mm, 3700 lm, 23.0 W, 4000 K

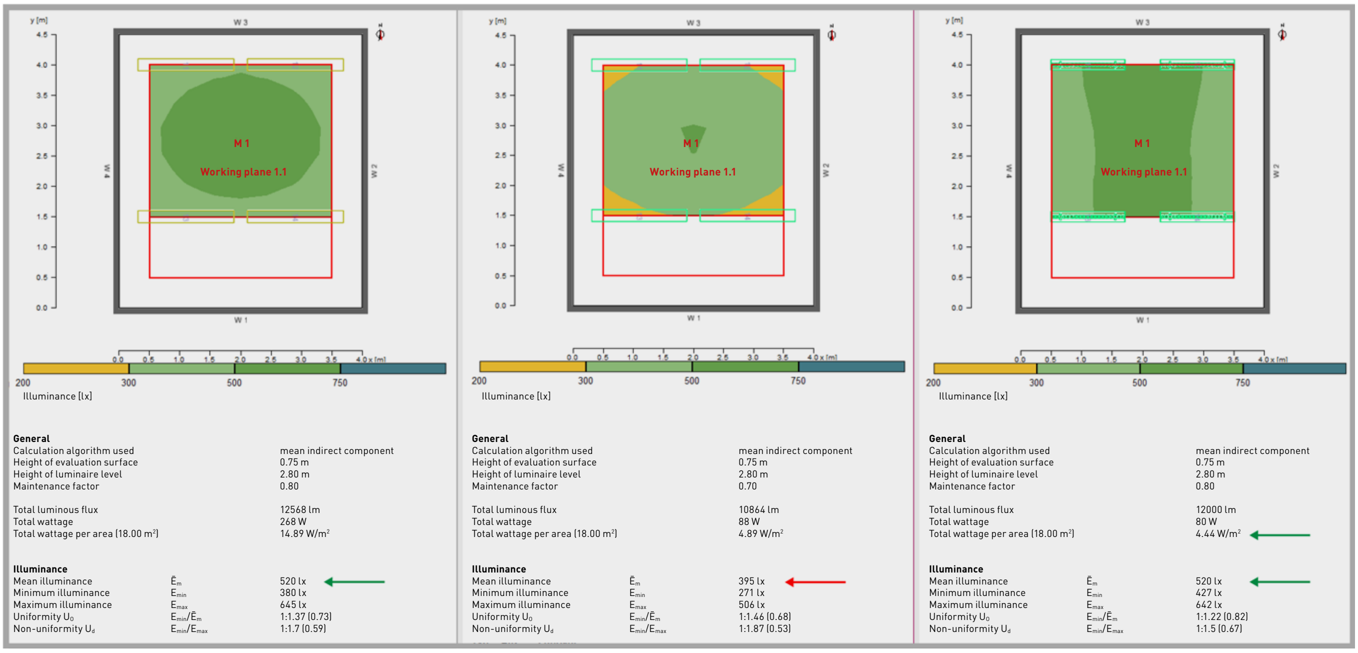
Measurements were carried out during operation of the respective lamp in a computer screen-compliant specular louvre luminaire from the TRILUX Atirion series and a weather-proof luminaire from the Oleveon series.

The data collected was then used for comparative calculations in typical lighting application arrangements.

3.1 Example of an office

In a typical office, the area between the two continuous light lines in the example shown below is considered to be the visual task area as defined by EN 12464-1, in which the activity areas should be located.

Length	4.00 m	Occupational safety requirements:
Width	4.50 m	$\bar{E}_m \geq 500$ lx
Height	2.80 m	$U_0 = E_{min}/\bar{E}_m \geq 0.6$
Height of working plane	0.75 m	
Continuous lines	2 x 2 luminaires	



	$\bar{E}_m$	MF	U_o	Φ_{total}	W_{total}	W/A	W/(A x $\bar{E}_m$/100)
T8	520 lx	0.8	0.76	12,568 lm	268 W	14.89 W/m²	3.12 W/(m² · 100 lx)
Retrofit 1	395 lx	0.7	0.68	10,864 lm	88 W	4.89 W/m²	1.31 W/(m² · 100 lx)
Creavo	520 lx	0.8	0.83	12,000 lm	80 W	4.44 W/m²	0.88 W/(m² · 100 lx)

Fig. 5: Calculation results for illuminating an office before and after retrofitting with an LED retrofit lamp compared to the use of an LED luminaire. The maintenance factor reduced to 0.7 for the retrofit lamp takes into account the increased degradation of this light source, whose L_{70} service life is specified.

The photometric calculations are compared for operating the original T8 lamp (58 W) in a TRILUX louvre luminaire from the Atirion series as a reference, as well as fitting an identical luminaire with the specified retrofit lamp (with 4100 lm), and for operating an up-to-date TRILUX LED luminaire (CREAVO D2-L LW19-03 30-840 ETDD 01, TOC 7728451) with integrated LED modules.

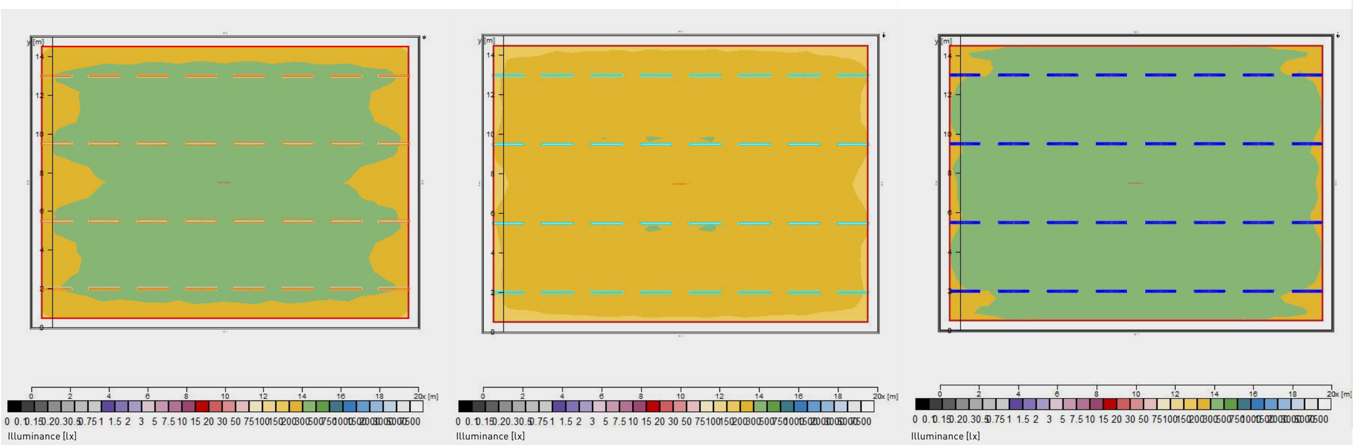
The example clearly shows that with this standard arrangement, the occupational safety requirements in terms of required illuminance would no longer be met after the retrofit conversion.

By replacing the existing luminaires with LED luminaires on a one-to-one basis however, the requirements can be met with lower energy consumption than the retrofit conversion. The efficiency and quality of the lighting are significantly increased.

3.2 Example of a packaging hall

In another example, a small hall in which packaging work is carried out is analysed.

Length	20.00 m	Occupational safety requirements:
Width	15.00 m	$\bar{E}_m \geq 300$ lx
Height	2.80 m	$U_0 = E_{min}/\bar{E}_m \geq 0.6$
Height of working plane	0.75 m	
Continuous lines	4 x 8 luminaires	



General			
Calculation algorithm used	mean indirect component	mean indirect component	mean indirect component
Height of luminaire level	2.80 m	2.80 m	2.80 m
Maintenance factor	0.80	0.70	0.80
Total luminous flux	132,736.00 lm	117,664.00 lm	137,600.00 lm
Total wattage	2,208.0 W	704.0 W	864.0 W
Total wattage per area (300.00 m²)	7.36 W/m² (2.35 W/m²/100 lx)	2.35 W/m² (0.95 W/m²/100 lx)	2.88 W/m² (0.78 W/m²/100 lx)

Evaluation area 1	Working plane 1.1 Horizontal	cylindrical	Working plane 1.1 Horizontal	cylindrical	Working plane 1.1 Horizontal	cylindrical
$\bar{E}_m$	313 lx	191 lx	247 lx	145 lx	368 lx	194 lx
E_{min}	256 lx	151 lx	200 lx	115 lx	292 lx	152 lx
$E_{min}/\bar{E}_m$ (U_0)	0.82	0.79	0.81	0.79	0.79	0.78
E_{min}/E_{max} (U_d)	0.71		0.69		0.66	
E_z/E_h		0.58		0.56		0.48
Position	0.75 m	1.20 m	0.75 m	1.20 m	0.75 m	1.20 m
R_{UG} (9.7H 12.0H)	≤ 26.6		≤ 25.7		≤ 23.5	

Fig. 6: Calculation results for illuminating a packaging hall before and after retrofitting with an LED retrofit lamp compared to using a simple LED luminaire. The maintenance factor reduced to 0.7 for the retrofit lamp takes into account the increased degradation of this light source, whose L_{70} service life is specified.

The photometric calculations are compared for operating the original T8 lamp (58 W) in a TRILUX weather-proof luminaire from the Oleveon series as a reference, as well as fitting an identical luminaire with the specified retrofit lamp (with 4100 lm), and for operating an up-to-date TRILUX weather-proof luminaire from the Aragon Fit series (ARAGF 15 PVW 44-840 ETDD, TOC 7401451) with integrated LED modules.

The example clearly shows that with this standard arrangement, the occupational safety requirements would no longer be met after the retrofit conversion.

- The luminous flux is not sufficient to provide the required illuminance.
- The glare limitation value $R_{UGL} \leq 25$ currently required by the EN 12464-1 standard is not complied with.

The one-to-one replacement of the existing luminaires with LED luminaires on the other hand more than fulfils the occupational safety requirements and also increases the efficiency and quality of the lighting.

- Today, LED luminaires with a wide range of photometric specifications in terms of luminous flux, light distribution and glare control are available for this purpose.
- The required illuminance is reliably achieved with the selected LED luminaire.
- The LED luminaire complies with the glare limitation value $R_{UGL} \leq 25$ which is currently required by the EN 12464-1 standard.
- The luminous efficacy of the LED luminaire is 22% higher than that of the existing luminaire fitted with the LED retrofit lamp.

4. CONCLUSION

After replacing the fluorescent lamps with LED retrofit lamps, only in a best case scenario can the lighting requirements implemented at the time the lighting system was installed be met. At best, they will then remain at this former level of occupational safety, which is then fixed for the period of operation of the retrofit lamps. However, even this cannot be guaranteed in many cases, meaning that the requirements for occupational safety and safe operation of the lighting system cannot be fulfilled.

If, however, the luminaires are replaced professionally, a contemporary lighting quality is achieved that takes into account the current state of technology. The requirements for lighting criteria in accordance with the new lighting standard EN 12464-1; 2021-11 can also generally be taken into account without additional effort. In addition, the installation of controlled lighting is possible, e.g. with melanopic effectiveness to support the circadian rhythm. This opens up additional energy-saving potential, and with increased quality of the lighting.

In terms of the carbon footprint over the life cycle of the lighting installation, replacing the luminaires is also a much more sustainable solution compared to using retrofits.

The consideration of an optimised new concept can generate further, considerable potential.

(a) In the early morning and from late afternoon

(b) During the day at midday

Fig. 7: Curve of colour temperature of artificial lighting adapted to daylight in an open-plan office

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