Smart Lighting in Safety-Critical Industries: Concepts and Field Results

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Dennis Lyskawka
R. STAHL Schaltgeräte GmbH
Weimar
Germany

Jakob Klemm
R. STAHL Schaltgeräte GmbH
Weimar
Germany

Duncan Robert McTurk
R. STAHL Schaltgeräte GmbH
Weimar
Germany

Abstract - *In hazardous industrial areas, saving energy and resources is increasingly crucial. Lighting management systems (LMS) can boost efficiency and cut costs but remain underused in safety-critical industries. LMS provide advantages like monitoring individual battery lights and significant energy savings via sensors. This study examines the impact of using DALI as an LMS on energy consumption across three industrial plants. It evaluates direct energy savings through intelligent control and monitoring and the long-term effects on operating and maintenance costs compared to conventional systems. Results show LMS not only enhance efficiency and safety but also lower energy use, reduce costs, and support sustainability. This paper presents concepts for designing energy-efficient lighting in safety-critical environments, targeting decision-makers in industrial building management.*

USED ACRONYMS

LMS	Light management System
DALI	Digital addressable lighting interface

I. INTRODUCTION

A properly designed lighting system is essential in industrial areas to ensure a safe working environment. In addition to the requirements for general lighting specified by the standard, there are further requirements for emergency lighting, particularly important in the very safety-sensitive hazardous areas.
The requirements for general lighting such as illuminance, uniformity and glare can be fulfilled by a well-considered lighting design and selection of suitable and reliable luminaires.

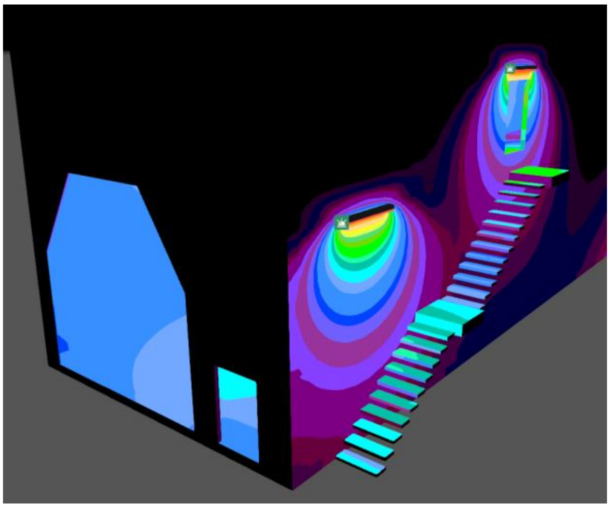


Fig. 1 Example of a lighting design

The emergency luminaires must be inspected regularly to ensure that there is always a sufficient level of lighting in an emergency situation. This also includes escape route lighting. If this inspection is not done automatically, it is very time-consuming, as all the luminaires must be inspected manually.

The following sections are intended to describe the general advantages of a lighting management system and prove the increased efficiency based on energy measurement data from three real installations.

II. SPECIAL CHALLENGES OF LIGHTING MANAGEMENT SYSTEMS IN SAFETY CRITICAL INDUSTRIES

In safety-critical industries, the planning, commissioning, and operation of digital lighting management systems face distinct challenges that are further complicated by the harsh environmental conditions typical of industrial facilities. During the planning phase, it is essential to develop robust system architectures that not only comply with stringent safety standards but also withstand factors such as extreme temperatures, dust, vibrations, and other industrial stressors. Commissioning demands precise calibration and validation of sensors, luminaires, and control systems to ensure their seamless integration into existing infrastructures, while early detection of potential fault sources is critical for safety. In operation, continuous monitoring, adaptive control, and proactive maintenance are required to respond effectively to dynamic environmental influences and maintain uninterrupted, reliable performance. The concepts and field results presented offer valuable insights into innovative strategies that address these complex challenges in safety-critical industrial settings.

III. ADVANTAGES OF LIGHT MANAGEMENT SYSTEMS

A light management system digitalizes the lighting systems. Within the lighting management system, the luminaires are communicating participants in a network. This enables the luminaires to be grouped, monitored and controlled from a central hub.

Lighting management systems are already widely used in the residential sector as ‘Smart Home’ and have also become increasingly common in the industrial sector, away from the hazardous areas.

The use of LMS can reduce the total cost of ownership. This reduction results from direct measurable energy savings as well as other advantages that are difficult or impossible to measure.

A) Energy Savings

In practice, lighting systems in the industrial area are often not switched off and are therefore permanently lit. This light is often not necessary for most of the time.
There is enormous energy-saving potential to be utilized using LMS.
Within the light management system, the luminaires are grouped and therefore dimmed or switched jointly. This can be caused by various reasons.

Times can be defined at which the lights are switched to a certain level. These times can vary depending on weekdays or public holidays. This solution is useful, for example, for shift operation or to prevent the luminaires from being switched on outdoors during the day when there is sufficient daylight.

When using light sensors, a threshold can be defined at which the light is not switched on. This can also prevent the luminaires from being switched on when there is sufficient daylight. At dusk in the evening and thus when the daylight falls below the threshold value, the luminaires are automatically switched on if required.
The light sensor can also be used to realize "daylight harvesting". When using daylight harvesting, the luminaires are not switched on/off at predefined threshold values, but the illuminance is kept constant over the course of a day.
This is implemented through permanent measurement of the light level and permanent dimming of the luminaires in the control loop.

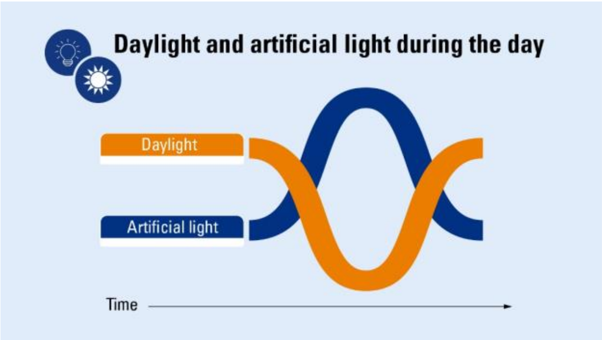


Fig. 2 Daylight and artificial light during a day

By using presence detectors, the lights are only switched on when the light is actually needed. When no one is present, the luminaires can be dimmed to a basic dim level to avoid dark zones in the field of vision and thus increase the feeling of safety. Presence-dependent switching can also be combined with daylight harvesting to ensure the greatest possible energy savings. In this case, the light is only switched on to the sufficient dimming value when necessary.

In light management systems, the sensors are often combination devices in which presence detectors and light sensors are combined in one housing.

Of course, it is always possible to override the automatic functions within the system by switching manually.

B) Extension of luminaire lifetime

When using a light management system, the luminaires are often operated dimmed. This can increase the lifetime of the luminaires significantly.
Since the luminaires are not disconnected from the mains voltage in the event of a switch-off, but rather controlled via a command to the led driver, the electronics are protected. This also eliminates the high inrush currents typically associated with LED lights.

C) Reducing of monitoring and maintenance effort

Communication in the light management system occurs bidirectionally. This means that not only can commands be sent to the luminaires, but status information from the luminaires can also be received. This enables central monitoring of the entire lighting system.
This function is particularly significant when using battery-integrated emergency luminaires, which need to be regularly checked for functionality and battery duration. In a light management system, this testing occurs automatically, and the results are stored in a logbook. If any of the tests fail, notifications can be sent automatically through various channels. This feature can lead to significant savings in maintenance efforts.
Additionally, it is possible to track the operating hours of individual luminaires and automatically notify when predefined thresholds are exceeded.

D) Remote Monitoring and controlling

All luminaire information is available in the lighting management system at a central hub. From here, the information can be passed on in various ways, such as OPC UA.
In this way, lighting information can be forwarded to a central control system.
Remote monitoring is also possible if the lighting management system is connected online.
This function is particularly useful for hard-to-reach or offshore areas.
Repair operations can also be better planned, as the broken luminaires are already known remotely.

IV. DALI

DALI is used as the light management system in the three installations described in Section IV.

DALI is an established lighting management protocol. DALI works wired via a two-wire bus line. There are no special requirements for the bus line. The only requirement is that the voltage drop along the entire line must not exceed 2V.

DALI operates in the voltage range of 9.5 V - 22.5 V. Typical is 16V. The maximum current consumption within a DALI circuit is 250mA. Some DALI devices, such as sensors, supply the necessary energy from the DALI circuit. When designing the DALI system, attention must be paid to the total current consumption.

DALI is a manufacturer-independent protocol. This means that components from different manufacturers can be used together in one system.

All devices must be connected to the two-wire bus cable. The connection is protected against polarity reversal, so the two wires can be swapped during connection. No special wiring topology needs to be used, only the ring topology must be avoided.

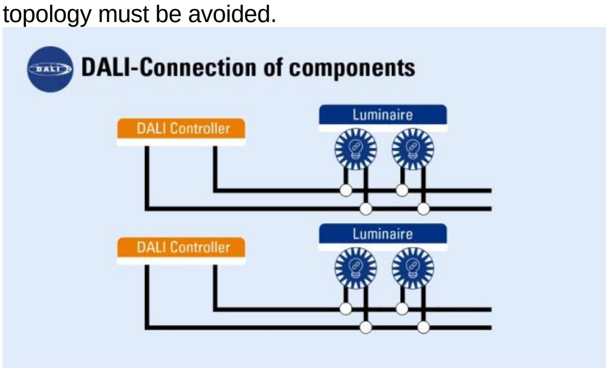


Fig. 3 DALI-Connection of Components

A maximum of 64 luminaires can be connected to one DALI circuit. However, it is possible to combine several DALI circuits in one system.

V. MEASUREMENTS

To evaluate the direct energy saving effects, the power consumption was measured in three lighting installation. Pictures of the three installations can be found in appendices 1, 2, 3 and 4.

i) This project involves a light management system at Kuraray Europe GmbH in Frankfurt am Main. The lighting management system described below was realized in a tent hall that is used as a warehouse. The area is characterized by occasional forklift and passenger traffic. Due to the translucent tent material, a large amount of daylight reaches the installation.

Project parameters: 24 standard DALI-Luminaires, 12 DALI-emergency-Luminaires, all in one group; 6 sensors; using presence detection and daylight harvesting.

ii) This project is a lighting management installation at SIKA Deutschland GmbH in Stuttgart. The light management system described below was implemented in the filling of coating agents and solvents. The area is characterized by regular forklift and passenger traffic. The ceiling heights of around 3 meters mean that the lighting installation was carried out at a height of 2.6 meters. There are several roller shutters and windows, but these are partially obscured by the tanks and other technology installed in the area and affect the entry of daylight.

Project parameters: 144 standard DALI-Luminaires, 58 DALI-emergency-luminaires; 25 KNX-sensors used in a KNX System; using presence Detection and daylight harvesting. Communication between DALI and KNX components via a gateway.

iii) This project involves a lighting management system in Weimar. The lighting management system described below was realized in the high-bay warehouse of a luminaire production plant. The warehouse has 18 aisles and is characterized by regular forklift and pedestrian traffic. A moderate amount of daylight reaches the installation through the skylights in the building.

122 standard DALI-luminaires in 19 groups; 22 sensors, using presence detection and daylight harvesting.

Project parameters: The measurement results are compared with a light system with conventional luminaires and a light system with LED luminaires that is operated without a light management system.

A) Results of installation i

Used measurement equipment:
Chauvin Arnoux MN 89 Current Clamp
Tinytag TV-4810 Current Clamp logger

Period of Measurement:
05th March 2025 – 8th April 2025

The power consumption of the entire lighting system was measured.
The power consumption was measured every five minutes. At the end of a full hour, the average of the measurement results was used to quantify the energy in kWh.

Installation i is a greenfield installation. It can therefore not be compared with an old system. The comparison is made with a virtual system without light management (permanently switched on at 100%).
To allow comparability with the other installations, no absolute values are shown. The energy savings are compared in relative terms.

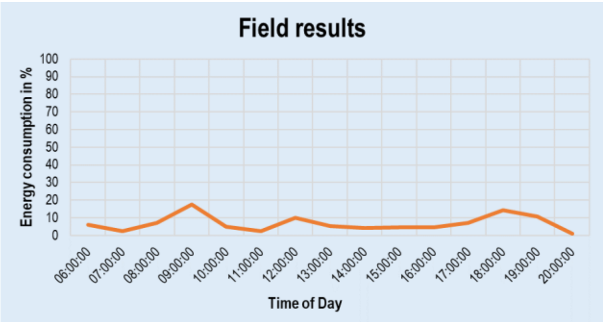


Fig. 4 Result Lighting System i) measured 05th March 2025.

Figure 4 shows the course of energy consumption in the operating hours 06:00-20:00 of the 05th March 2025.

The energy savings realized are enormous. Calculated on a daily average, the use of a lighting management system saves 93% energy.

To ensure that the use of the lighting on 5th March was not unusually low, another day within the measurement period is investigated.

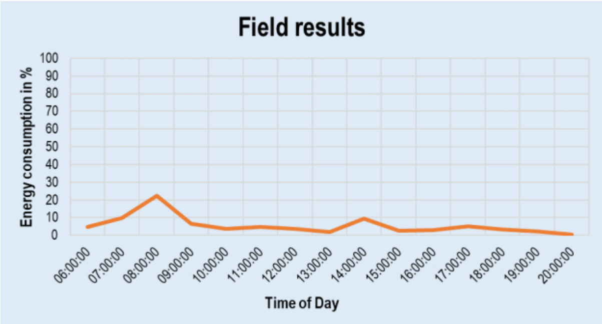


Fig. 5 Result Lighting System i) measured 03th April 2025.

Figure 5 shows the course of energy consumption in the operating hours 06:00-20:00 of the 03rd April 2025.
The energy savings here are also immense. The daily average is 94%.

Looking at the entire measurement period from 5th March to 8th April 2025, the average energy saving during operation hours on workdays is 94.5%.

This exceptionally high value can be put into perspective and explained by several factors.

Firstly, the lighting system was deliberately over-dimensioned by the operator during the planning phase. The area is currently used for storage purposes. However, the operator intends to retain the flexibility to repurpose the space for other functions in the future. Since alternative uses may require higher levels of illumination, more luminaires were installed than currently necessary. As a result, even during hours without natural daylight, the luminaires never need to operate at 100% output to achieve the required illuminance levels.
Due to the use of a constant light control system, the luminaires are automatically dimmed accordingly.

In addition, the installation is located within a tent structure. Due to the high permeability of the tent fabric to daylight, only a comparatively low amount of artificial lighting is required during large parts of the day to maintain the desired illuminance level.

Finally, the area is currently used as a storage facility and experiences relatively low occupancy.

Nevertheless, there are comparable lighting systems in the immediate vicinity that do not feature any form of light management and remain permanently operated at 100% output.

Therefore, even when accounting for the intentional over-dimensioning, the observed energy savings can be considered entirely realistic within this context. Furthermore, despite the energy savings, the lighting system remains fully compliant with all applicable safety standards and includes automatic monitoring of the emergency lighting.

B) Results of Installation ii

Used measurement equipment:
Chauvin Arnoux MN 89 Current Clamp
Tinytag TV-4810 Current Clamp logger

Period of Measurement:
8th March 2025 – 8th April 2025

The power consumption of 4 luminaires, operating in one group, was measured. The measured group can be considered representative of the overall system, as the utilization levels across the groups are comparable.
The power consumption was measured every five minutes. At the end of a full hour, the average of the measurement results was used to quantify the energy in kWh.
To allow comparability with the other installations, no absolute values are shown. The energy savings are compared in relative terms.

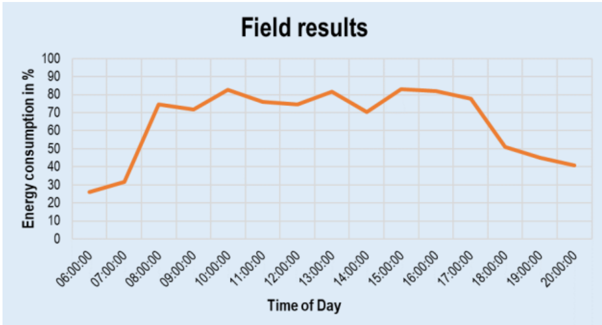


Fig. 6 Result Lighting System ii) measured on 12th March 2025

Figure 6 shows the course of energy consumption in the operating hours 06:00-20:00 of the 12th March 2025.

On average over the course of the day, the energy savings is 35%.

To ensure that the use of the lighting on 12th March was not on a unusually level, another day within the measurement period is investigated.

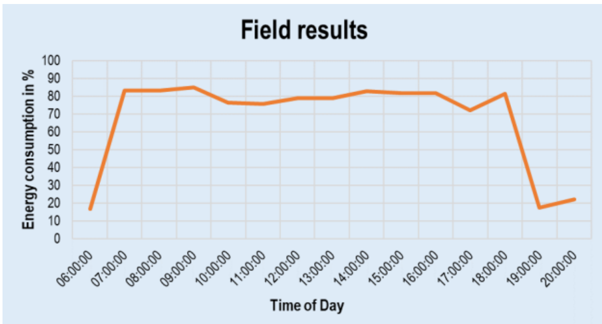


Fig. 7 Result Lighting System ii) measured on 03rd April 2025

Figure 7 shows the course of energy consumption in the operating hours 06:00-20:00 of the 03rd April 2025. During the period from 20:00 to 06:00, the operation of the system is regulated by preset schedules. During this time, only the floodway lighting is operated. If necessary, the lighting system is only switched on if the security personnel walk through the system at night and are detected by the presence sensors.

The energy savings are comparable to those recorded on March 12 and average 32% over the course of the day.

Looking at the entire measurement period from 8th March to 8th April 2025, the average energy saving during operation hours on workdays is 35.6%.

The plant in which the light management system was implemented is a filling plant in which the finished products are filled into standard commercial containers. As there was heavy forklift traffic in the illuminated time window, the presence sensors installed detect a presence almost continuously and switch on the lighting system. This explains the differences in savings compared to measurement i. It is known from past data that the greatest savings are achieved by constant light control, which regulates the artificial light in dependence on daylight, especially in summer. This increases the savings.

Unlike measurement i, the proportion of daylight within the system is very low due to the structural conditions. There are a few windows and doors, but these do not allow the same amount of daylight as in the system described above.

In addition to the energy savings, the customer decided to install a digital lighting system because of the automated maintenance. In the mixed calculation, not only the savings from the energy reduction, but also the savings in time and personnel for the maintenance and inspection of the safety lighting can be considered.

C) Results of installation iii

Used measurement equipment:
WAGO 750-495 3-Phase Power Measurement
WAGO 855-2701 Plug-in current transformer

Period of Measurement:
Started on 01st June 2024 and still running.

The power consumption of the entire lighting system was measured.
The power consumption was measured every minute.
At the end of a full hour, the average of the measurement results was used to quantify the energy in kWh.

Installation iii was a brownfield installation. This means that an existing lighting system has been replaced.
The old installation consisted mostly of conventional light sources and was also not designed to be efficient. Only LED lights are used in the new installation. In addition, a lighting design was carried out in advance to find the most efficient solution.

The following cases can therefore be analyzed and compared in installation iii:

iiia) Old real existing installation: Combination of LED floodlights and conventional (fluorescent lamps) Linear lights. No lighting design was carried out.
iiib) 1 to 1 replacement of the conventional luminaires with LED luminaires without carrying out a lighting design to improve efficiency.
iiic) Replacement with an LED installation after carrying out a lighting design. Only linear lights are used, as floodlights have turned out to be oversized.
Iiid) Replacement with an LED installation after carrying out a lighting design with additional use of a light management system as described at the beginning of the section.
Real measured values only exist for case iiic. The other cases are calculated based on the number of luminaires and power consumption according to data sheet.
To allow comparability with the other installations, no absolute values are shown. The energy savings are compared in relative terms, with the highest power consumption shown representing 100% in each case.

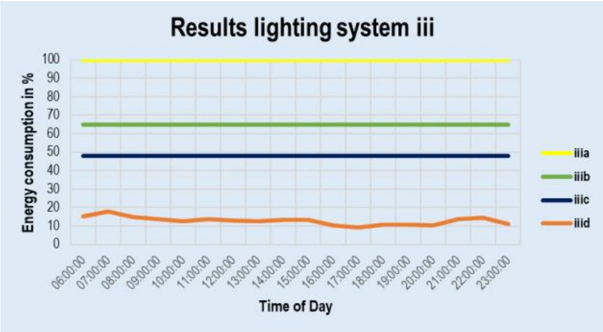


Fig. 8 Results lighting system iii

Figure 8 shows the course of energy consumption in the operating hours 06:00-23:00 of a day. The iiia case represents 100%. The measurements were taken on 04th June 2024. The cases iiia, iiib and iiic show a constant level, as in these cases the entire lighting system is switched on undimmed throughout the day. In the iiid case, variations can be recognized because the light is switched depending on presence and dimmed depending on daylight.
The data shows that in this installation, a one-to-one switch to LED luminaires results in energy savings of 35%. Well-designed lighting based on a light calculation will reduce the energy savings in this system by a further 17%. That means, without lighting management, the installation iii results in energy savings of 52% when switching to a well-designed lighting installation using only LED-Luminaires. The use of a light management system enables further 35% energy saving in installation iii. This means that the resulting energy consumption in case iiid is only ~13% (average value over one day) compared to the old installation (case iiia).

To shed more light on the contribution of the lighting management system, the following figure compares the cases iiic and iiid.

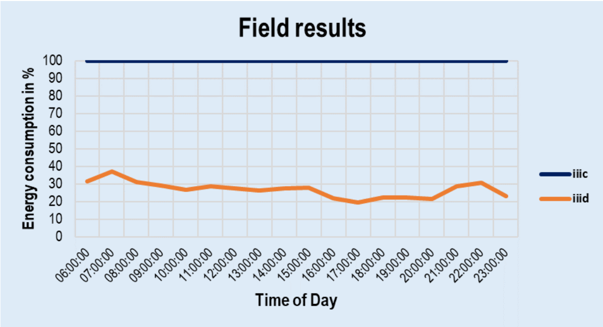


Fig. 9 Results iii comparing iiic and iiib

In Figure 9 the iiic case represents 100%. This makes it possible to compare an installation with a light management system with an installation consisting of the same luminaires but operated without a light management system. It can be recognized that in the case of installation iii, the lms makes a significant contribution to energy savings. The daily average in the operating hours on this day (04th June 2024) was 73% energy savings through lms. In the observation period of an entire working week (3 June to 7 June 2024), the average energy saving through lms was 71%.

As daylight harvesting is used in the installation iii, the duration and intensity of daylight is also important for the resulting energy savings, in addition to the frequency and duration of presence.

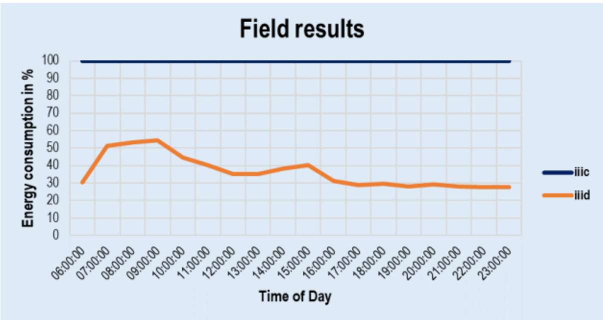


Fig. 10 Results iii comparing iiic and iiib measured on 25th November

Figure 10 shows the comparison of iiic and iiid measured on 25th November 2024The average energy saving resulting from the use of lms is 62% on 25th November 2024. There is a recognizable difference to the measurements from June. It is plausible that the reason for this is the lower amount of daylight.
In the observation period of an entire working week in November (25th - 29th), the average energy saving was 63%.

VI. CONCLUSIONS

The measurements indicate that the achieved energy savings vary significantly across the different installations, but in all cases represent a substantial reduction. Due to their differing configurations and conditions, the installations are difficult to compare.
The level of energy savings achieved is influenced, among other variables, by the occupancy rate of the respective areas and, in the case of using daylight harvesting, by the extent of available daylight within the installation. Nevertheless, even in the installation with the least impact from the lighting management system, an average energy saving of 36% is still achieved.

All data originate from real, operational installations that fully comply with all applicable standards. The measurements demonstrate that the implementation of a lighting management system is beneficial in many applications and should always be considered by the operator.

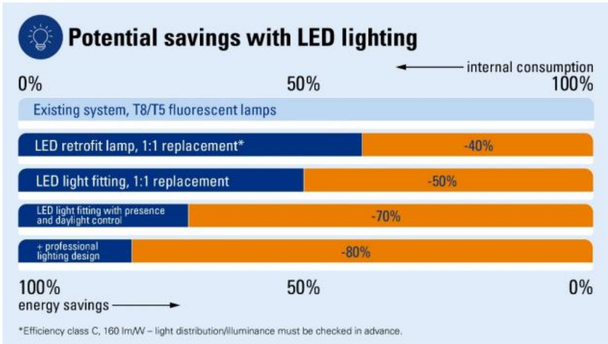


Fig. 11 Assumption about the energy saving potential

Figure 11 shows a theoretical assumption for energy savings by switching to LED technology as well as thoughtful lighting design and the use of lms.
This graphic is best referenced in the context of Installation iii, as it provides the opportunity to compare it with the old system. In the case of installation iii, these values have been confirmed and, in some cases, exceeded.
Installation III also offers the possibility to compare data collected during the summer with that from the winter, as measurements were conducted over an extended period of time. When looking at a week in June compared to a week in November, differences can be observed. The reason for this possibly lies in the lower amount of daylight.

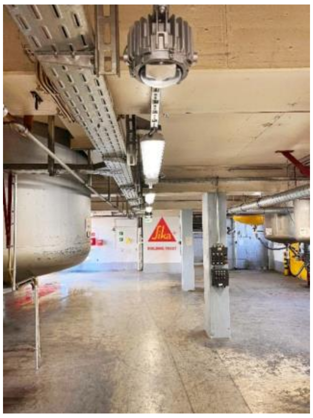
VII. ACKNOWLEDGEMENTS

We would like to take this opportunity to thank our test partners SIKA Deutschland GmbH at the Kornwestheim site in Stuttgart and Kuraray in Frankfurt a.M. for the very pleasant and very successful cooperation. Due to the unrestricted measurement possibilities, we were able to examine the energy curves in both plants without any restrictions and gain valuable insights. We would like to thank all the companies involved and are delighted with the final results.

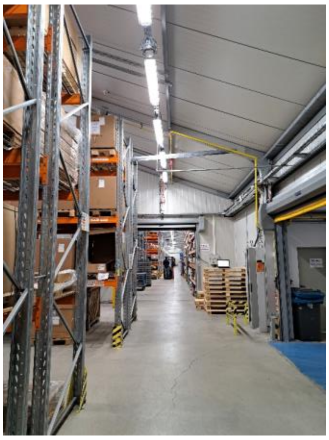
VIII. APPENDIX

Appendix 1: Picture of the lighting system i) in Frankfurt a.M.

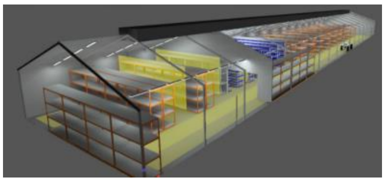
Appendix 2: Picture of the lighting system ii) in Stuttgart



Appendix 3: Picture of the lighting system iii) in Weimar



Appendix 4: Lighting Design Screenshot of the lighting system iii) in Weimar



IX. VITA

Dennis Lyskawka completed his Master of Engineering in Electrical and Information Engineering in 2020. During his studies, he focused on lighting management and the implementation of camera-based systems in both his bachelor's and master's theses. He has been working in the field of lighting technology since 2016. Since 2023, he has been employed as an Application Engineer at STAHL.

Jakob Klemm has been working at R. STAHL since 2021 and started his bachelor thesis on the development of explosion-protected light and presence sensors. After further stations in development, he switched to product management in 2023 for his master's thesis, which he completed with a Master of Science in Industrial Engineering. Since then, he has been working as a product manager for lighting solutions, including in the field of digital lighting management systems.

Duncan McTurk completed his Masters in Mechanical Engineering in England and has 20 years' experience in the Automotive and Industrial sectors – in England, Germany and the USA. For 10 years he has been worked in the Lighting business with a focus on products and technology. Since 2024 he has led the Lighting Portfolio Segment at R.STAHL.