21NRM01 HiDyn

{HiDyn}

D7: Good practice guide demonstrating the inter-comparability of HDR luminance measurements, and including guidelines on the uncertainty evaluation of traceable HDR imaging luminance measurements, glare and obtrusive light assessment (according to existing standards EN 17037:2019, EN 13201-2:2015 and EN 124641:2011)

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Glossary

GPG	Good Practice Guide
HDR	High Dynamic Range
LDR	Low Dynamic Range
ILMD	Imaging Luminance Measurement Device
FOV	Field of View of an imaging system
TLM	Temporal Light Modulation
HID	High Intensity Discharge (refers to light sources)
LED	Light Emitting Diodes
HiDyni	High Contrast Reference Luminance Source developed during the HiDyn project

TABLE OF CONTENTS

1 Summary

This Good Practice Guide (GPG) describes the key aspects in high dynamic range (HDR) imaging for the assessment of glare in scenes using dedicated systems capable of documenting scenes presenting high contrast of luminance. The guide has been developed during the project EPM 21NRM01 HiDyn using the experience gathered after evaluating lab and field intercomparison campaigns. It describes the typical workflow for ILMD settings to be considered, acquisition of the image sequence, HDR merging, and analysis of the glare scenes.

This GPG aims to help the relevant stakeholder to better understand the challenges of HDR luminance imaging and to improve their measurement methods.

This GPG refers only to the metrological task of luminance measurement in high contrast scenes and does not include any discussion and methods for the photography of artistic implementation of HDR algorithms.

2 Introduction

2.1 The need for HDR luminance imaging

High-contrast luminance scenes are, in most cases, a major source of glare and visual obtrusiveness for observers, often resulting in discomfort or even disability glare that limits the ability to perceive critical visual information or successfully perform certain tasks. These challenges are particularly evident in applications such as road lighting during twilight and at nighttime, where luminance sources frequently include extremely bright luminaires contrasted against much darker or completely dark backgrounds. In such scenarios, the observer's visual system is stressed by the luminance contrast, while its photometric evaluation becomes significantly more demanding.

Relevant international standards and technical reports (CIE 1994, CIE 2019, CIE 2021a, CIE 2024) define a variety of glare metrics — such as threshold increment (TI), unified glare rating (UGR), and other luminance-based indices — as well as specify the photometric quantities that must be calculated or measured in practical applications. Meeting these requirements represents a key metrological challenge, particularly when imaging measurement systems are employed. Modern imaging luminance measurement devices (ILMDs) must contend not only with strict accuracy demands but also with complex optical and electronic limitations inherent to high-contrast luminance scenes.

Several factors can influence the measurement task of imaging a high-contrast scene, especially when the scene's dynamic range exceeds the capabilities of a typical imaging sensor's measurement range. One of the most prominent issues affecting relative contrast assessment is stray light: Bright luminance sources generate stray-light artifacts through scattering, internal reflections, and lens flare within the optical path of the measurement device. These unwanted contributions overlap with dimmer regions of the scene, effectively "contaminating" the measured luminance values and potentially leading to erroneous evaluations of glare conditions or safety-critical lighting parameters.

In addition, when the luminance distribution in the scene significantly exceeds the sensor's intrinsic dynamic range, accurate measurement cannot be achieved using a single exposure due to saturation/clipping of the detector. Instead, a sequence of images at different integration times is captured to cover the full luminance range by valid measurements. These low-dynamic-range (LDR) images must then be combined through a high-dynamic-range (HDR) merging algorithm, which itself introduces technical requirements and uncertainties. Factors such as integration time bracketing strategy, photometric adjustment, dark (offset) signal and photon noise, linearity, aperture repeatability, and temporal stability must all be carefully controlled.

2.2 Key parameters of HDR imaging

The overall complexity of HDR luminance imaging measurement for glare assessment can be organized into several interdependent aspects:

- Scene contrast and luminance distribution (e.g. size of glare sources presenting bright luminance to the measurement device) as well as presence of temporal light modulation, which determines the difficulty of accurate luminance capture and the susceptibility to glare-induced errors.
- Camera dynamic range, which constrains the measurable luminance interval for any single integration time (LDR image) and dictates the need for multi-exposure techniques.
- Ambient conditions (temperature, relative humidity, air velocity), which alters the operation condition of the measurement device, i.e. often outside its intervals ambient parameter intervals specified as usual operation condition. Namely in outdoor scenes also variations of or inside the scene (pedestrians, traffic) or a non-constant scene (dynamic lighting, weather change, rearrangement of objects) might stress or distract the operator and often limits the repeatability.
- Measurement sequence of LDR images, including integration time sequence planning (bracketing), sensor linearity verification, and timing considerations.
- HDR merging algorithms, which must ensure artifact-free luminance measurement signal reconstruction across the full luminance range.
- Glare assessment based on the HDR luminance image, requiring robust metrics, accurate luminance maps, and minimized optical or algorithmic distortions.

Together, these factors highlight the demanding requirements placed on imaging systems, its operators and measurement methodologies when evaluating high-contrast luminance scenes, particularly in safety-critical lighting applications.

3 HDR imaging workflow for luminance measurement

Given the need to perform the evaluation of luminance scenes with a luminance range far larger than the average dynamic range of a typical imaging sensor, a HDR technique is required. This chapter describes the key steps for the HDR imaging workflow starting from the preparation of the equipment and the relative acquisition settings to the assessment of the relative glare metric. Figure 1 shows the overall workflow described in this GPG. In the following chapters, each step of this workflow is presented and discussed.

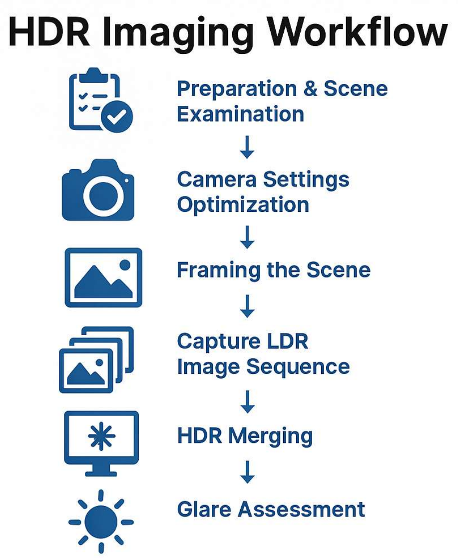


Figure 1. Main steps of the HDR imaging workflow

Note 1: The proposed workflow intends to describe the general procedure based on the most frequently used type of equipment. The end-user should adapt this workflow according to the specific requirements of the equipment used in practice.

Note 2: The proposed workflow does not contain any step or procedure for the visual aspect of the HDR image, like tone mapping and colour correction, because this GPG addresses exclusively the metrological need for documenting the luminance of the scene as accurate as possible and traceable to optical radiation and luminance standards.

3.1 Acquisition of image sequence

3.1.1 Examination of the scene

The first step of an HDR sequence is to examine the scene under investigation regarding glare assessment. In most cases of glare and obtrusive light assessment, the scene includes one or more light sources while the rest is a set of surfaces of different material, texture and colour. This gives any scene a unique character and metrological challenge to document its luminance. The light sources (including the sun when present) and potentially their reflection on some illuminated surfaces produce the highest luminance values in the scene while the rest of the surfaces introduce multiple gradients of luminance. This results in a potentially high contrast between the dark, dim, and bright areas. The area under investigation maybe not the whole scene but part of it. In this case, care should be taken on the inclusion and exclusion of the relevant and non-relevant elements such as distant light sources or sources outside the desired field of view, moving subjects, dynamic lighting conditions and so on. Should the user be able to control the lighting scene it must be remain stable in terms of temporal light modulation and spectral content throughout the measurement process. In contrary, all influencing parameters should be reduced or excluded if possible and the residual errors must be taken into account in the estimation of measurement uncertainty.

3.1.2 Finding the optimal camera settings

Capturing a high contrast luminance scene using an imaging system can be as easy as it could be complicated. In a perfect controlled laboratory condition where all the parameters of the sources and the background are known and characterized, the imaging system should operate in a way that is given and secure. In the case of an unknown lighting scene most of the parameters are not known nor controllable. Therefore, the user should perform some preliminary measurements for a basic characterization of the scene in order to select and set the HDR measurement sequence parameters in the best possible way. The camera settings that should be set (in the majority of cases) are the focal length of the objective lens, the lens aperture(s), the range of the integration times (sequence), the analogue gain (fixed) and the use of natural density (ND) filters. Additional configurations, i.e. using a different lens, aperture or ND-filter, might be used for verification or to determine the results from small regions of the scene, i.e. by measurement of bright areas (luminaires) using a darker ND-filter and smaller aperture to achieve longer integration times and avoid artefacts from temporal light modulation.

Objective lens: The objective lens defines the field of view (FOV) of the imaging system and it is strongly related to the associated metric and assessment. Therefore, the user must select the lens adequate to provide a FOV similar to the field of the scene to be evaluated. This will ensure the best possible resolution of the image (e.g., for the glare assessment) and exclude external light sources that might significantly influence the measurement result by straylight inside the imaging system. Figure 2 shows an example of the same scene (building façade) documented by using a normal prime lens and a circular fisheye lens resulting in different FOV, diffraction artefacts and distortions. The zoomed parts demonstrate the difference in the resolution (details) and thus alter the maximum luminance of a glare source.

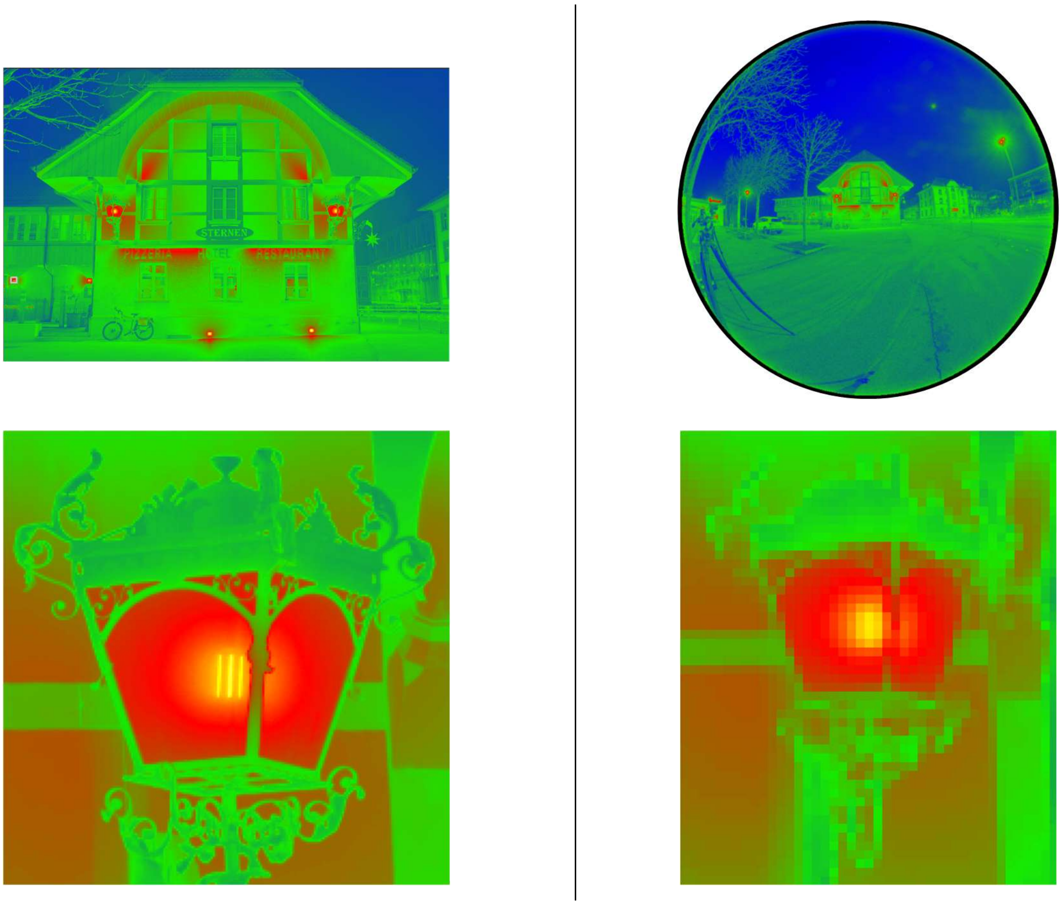


Figure 2. Luminance image of a scene documented using a prime lens (left) and a fish-eye lens (right) demonstrating the effect of different objective lens on the FOV, resolution and distortion of an image.

Integration time: The most typical method for obtaining an HDR image is by varying the integration time in a sequence while maintaining constant the other measurement parameters. Other techniques for varying exposure can be used instead, such as using a sequence of neutral density filters or apertures, but the variation of integration time minimizes the influence of modifying the optical system. On the other hand, the integration time must be carefully selected to avoid artefacts from a temporal light modulation of light sources (TLM) if present in the scene. The TLM can be either known (e.g., for HID lamps – usually with a dominating modulation frequency of 100Hz or a base frequency of 50 Hz) or measured on site using proper equipment. To avoid significant errors in the measurement of the luminance, the integration times must be integer multiples of the base frequency of the sources. In case of multiple sources with different modulation frequencies, one can select the integration time sequenceso, that they produce the lowest error overall, as for example, neglecting relatively high frequencies and/or temporal light modulation components with low modulation depth.

The selection of the integration times is also combined with the dynamic range of the system, the analogue gain, and the digital clipping level and saturation level of the sensor. It should be ensured that the range of integration times is selected in a way so that all parts of the FOV will be at least well exposed (i.e., above dark signal and below saturation) in at least one image in the LDR image sequence. In case this combination is not feasible due to extremely bright sources or due to the limited shortest integration time to avoid artefacts from temporal light modulation, ND filters can be used to attenuate the irradiance on the sensor.

The integration time series should reflect the dynamic range of a single image of the system in order to avoid too much overlapping (unnecessarily too many images and thus overall measurement time) or range "gaps" due to big steps in integration time. A rule of thumb for the most modern systems is modifying integration times with step factors from 2.5 to 4 between the minimum and maximum selected integration times. The user must anyway ensure the best combination of the system used by investigating it using multiple gray patch card or gradients card. Using multiple step factors for the integration time can then determine the most suitable for the given system.

Detailed discussions on the different HDR methods to be implemented in an imaging system is given in D4 and D5 of this project. You may find all deliverables of the project in the public repository of the HiDyn (https://zenodo.org/communities/hidyn).

Figure 3 shows an example of an LDR image set of a stadium lighting pole with multiple luminaires aiming at different directions. The integration time sequence spans from 20 s to 1/100 s=10ms and an ND filter was used in order to prevent clipping of the luminance signal while safely avoiding artefacts from the temporal light modulation of the metal halide light sources with a dominating modulation frequency of 100 Hz.

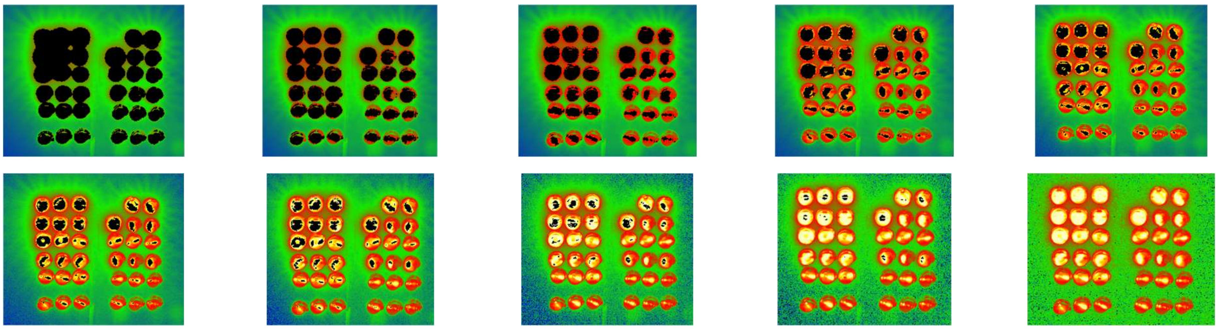


Figure 3. LDR luminance images of a stadium lighting pole captured using a varying integration time from 1/100 to 20 s (with step of 4x the integration time) to avoid the artefacts from the 100 Hz light modulation (50 Hz mains frequency). Black areas demonstrate clipped (and therefore rejected) pixel signal values.

<u>Lens aperture:</u> The aperture of the objective lens strongly affects the measurement result as well as the quality of the luminance image. The aperture selection affects the luminous responsivity of the system, the depth of field, and the patterns of stray light (caused by diffraction) on the image. First, a wide-open aperture (lowest f-number) permits the maximum possible amount of light to enter into the imaging system and be accumulated by the sensor. This also serves as a parameter in case the user needs to keep the integration times as short as possible due to e.g., a scene with moving cars or slow modulated (varying/drifting) sources. However, a wide-open aperture results in the shallower depth of field for the given lens which may cause significant errors for the targets laying outside the focus range and difficulties to avoid artefacts from temporal light modulation in bright luminance regions, i.e., glare sources. In addition, a high f-number (closer aperture) results in a different optical behavior of the lens in terms of straylight and sharper ghost images. In general, the closest the aperture the most prominent are the artefacts from the edge of the aperture (diffraction) and the strongest the contribution of them to the measurement uncertainty, i.e., by a star-like straylight pattern in case of a faceted aperture. Figure 4 demonstrates the measurement of the HiDyni high contrast reference luminance source (see HiDyn deliverable D1 at https://zenodo.org/communities/hidyn) with different aperture settings resulting in a difference in the measured luminance of various light sources and the light trap in the scene. A variable aperture has a significant uncertainty for the stability and reproducibility of its area, i.e. also depending on its orientation to gravity, and thus the luminous responsivity, some imaging systems therefore rely on objectives lenses with constant ring-shape apertures or permanently fixed (glued) aperture blades improve reproducibility of the measurement device.

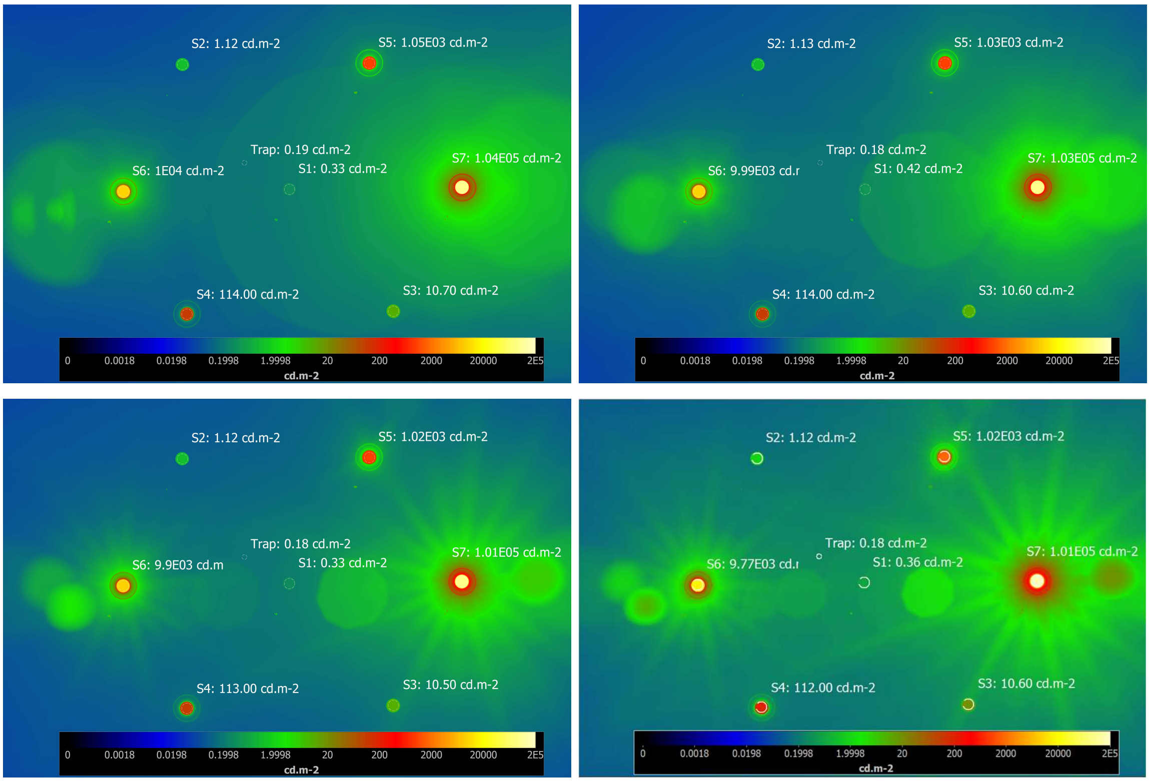


Figure 4. HDR luminance images demonstrating the effect of different aperture sizes on the straylight (i.e., small apertures causing sharp ghost images and a prominent star-like diffraction pattern) and the corresponding luminance values of evaluation regions, especially in the darker regions. Aperture of f2.8 (top left), f5.6 (top right), f11 (bottom left) and f16 (bottom right)

Analogue gain: The analogue gain in an imaging system (also referred as ISO-parameter in photo cameras) can be used as an alternative to the integration time in case this should be kept constant. Although the theoretical benefit of using a varying analogue gain is equivalent to the integration time variation, it produces significant increase of the noise level as the gain increases and alters also the signal offset and non-linearity. Therefore, it is suggested to keep it constant and as low as possible while selecting a combination of the aperture and integration time sequence.

3.1.3 Setting the FOV

The next step is the framing of the light scene by positioning and orienting the imaging system against the area under investigation. The framing is, in many cases, mandated by the glare assessment metric and it is inelastic, meaning that the height of observation point and the aiming direction is given and restricted. When it is not restricted or when the FOV of the system is wider to the requested one, then the framing of the scene should be as such to ensure the leaast effect of straylight and ghost images. The stray light can be produced by sources in the FOV or outside the FOV of the camera, especially by light sources which are producing a relatively high illuminance on the glass of the objective lens. For bright luminance regions, i.e. glare sources, the ghosting effect (also called lens flare) results as an increase of the luminance signal in other areas in the image. This can create significant errors and thus uncertainty contributions especially in regions with relatively low luminance (e.g., dark areas like sky, road surface, etc.). Therefore, a set of additional images with different camera orientation or different objective lenses must be captured to investigate the effect of the ghost images and in order to assess their behaviour with different aiming of the camera. For example, in Figure 5, the ghost images produced by the bright sources of the HiDyni source are moved as the aiming of the system moves towards the right direction. This results in a difference in the straylight on the dimmed sources and the light trap in the scene. By evaluation additional images of the real scene one can investigate the ghost images and orient the camera slightly differently in order to avoid that the most relevant darker areas are affected by ghost images from the bright sources. It should be noted that this method does not ensure a perfect measurement result but can lead to an optimized aiming of the system in respect to the stray light contribution.

The contribution of bright regions, i.e. glare sources, to stray light can be reduced by placing baffles around the lens (lens hood or similar protections) for sources outside the FOV, or masks towards the direction of those sources when they are within the FOV (see Figure 6). The aim is to block the incident light on the lens coming from those sources which is not needed to be measured and degrades the quality of the measurement.

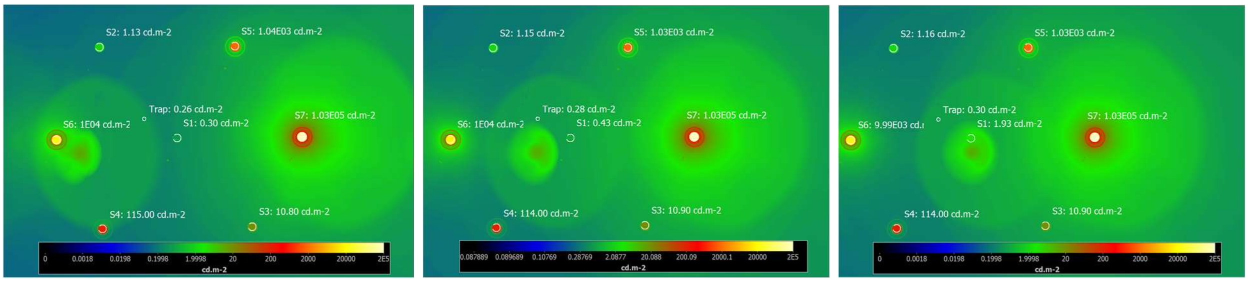


Figure 5. HDR luminance images demonstrating the effect of different framing (i.e. camera orientation, positioning of the bright sources in the image) on the ghost position relative to the scene and the corresponding luminance values, especially in the darker regions.

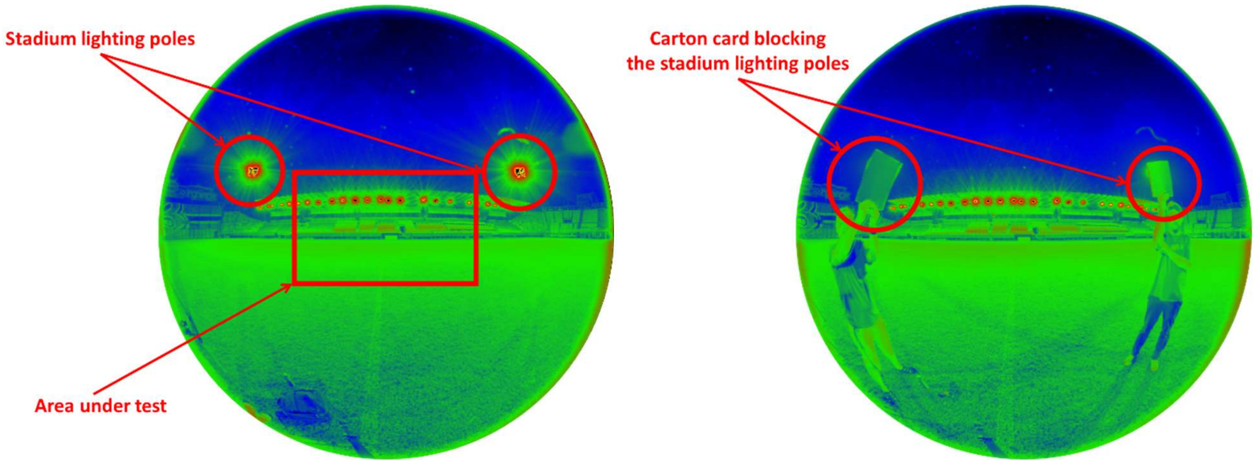


Figure 6. HDR luminance images demonstrating the blocking of sources outside the area of interest by using custom masks to reduce stray light in the image region of interest, i.e. the sky region.

3.1.4 Capturing the LDR image sequence

For the production of the HDR luminance image, the set of LDR images must be captured according to the already defined camera parameters, the framing of the scene and some preliminary measurements to setup and parametrize the measurement and ensure that everything is suitable to obtain valid and accurate measurement results. A steady fixation of the imaging system is highly recommended using an appropriate tripod or similar positioning and aiming system. This ensures that the set of images will be captured from the exact same position and orientation, i.e., towards the same aiming direction, even if repeated measurements or altered configuration of the imaging system (i.e. ND-filter mounding and dismounting) are needed for redundancy. The measurement system should perform the series of measurements in the fastest possible duration of the measurement time ensuring minimum intervals between each of the LDR images to avoid potential variation of the luminance scene. External light sources that may produce stray light must be observed during the measurement period in case that they are switched off or change their luminous intensity significantly.

When a significant change in the scene is observed, then the measurement should be repeated, and the pervious set of LDR images must be discarded.

In case of using commercial ILMDs with free run mode enabled, then the camera should be set to run for adequate time before the measurements in order to ensure thermal stability. For other system (e.g., photo cameras) the LDR sequence may be taken multiple times and also in reverse order of integration time to check the effect of the temperature increase of the sensor, especially in images captured using a longer integration time.

It is recommended to acquire at least 2 identical data sets of LDR images per case. The user should also ensure the correct settings of the camera parameters, configuration (objective lens, nd-filter), and the control software each time (before and after the measurement). This will minimise the potential of an erroneous set of a camera parameter as well as of its documentation. Figures 7-9 show a set of LDR images as pairs of a visible image and the corresponding luminance image, all under the same luminance scale. The black areas in the LDR luminance images correspond to the clipped pixels signal values which are not a valid result and therefore rejected from the image during the conversion of the raw data (digital counts) to luminance images as well as during its HDR merging.

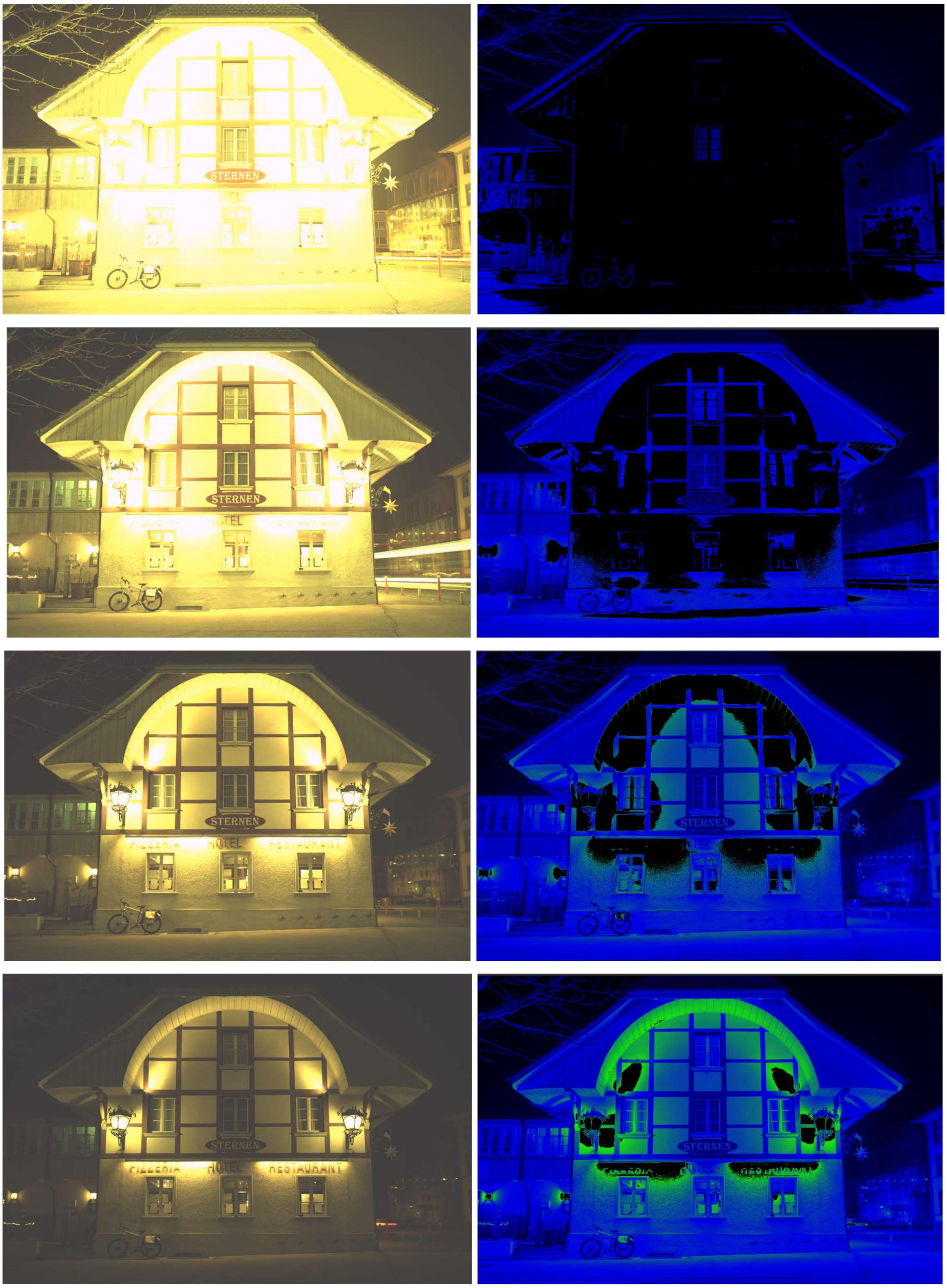


Figure 7. LDR raw signal image sequence (left column) and the corresponding luminance images (right column) from the HDR measurement sequence (part 1) with varying integration time from 30 s down to 1/2 s.

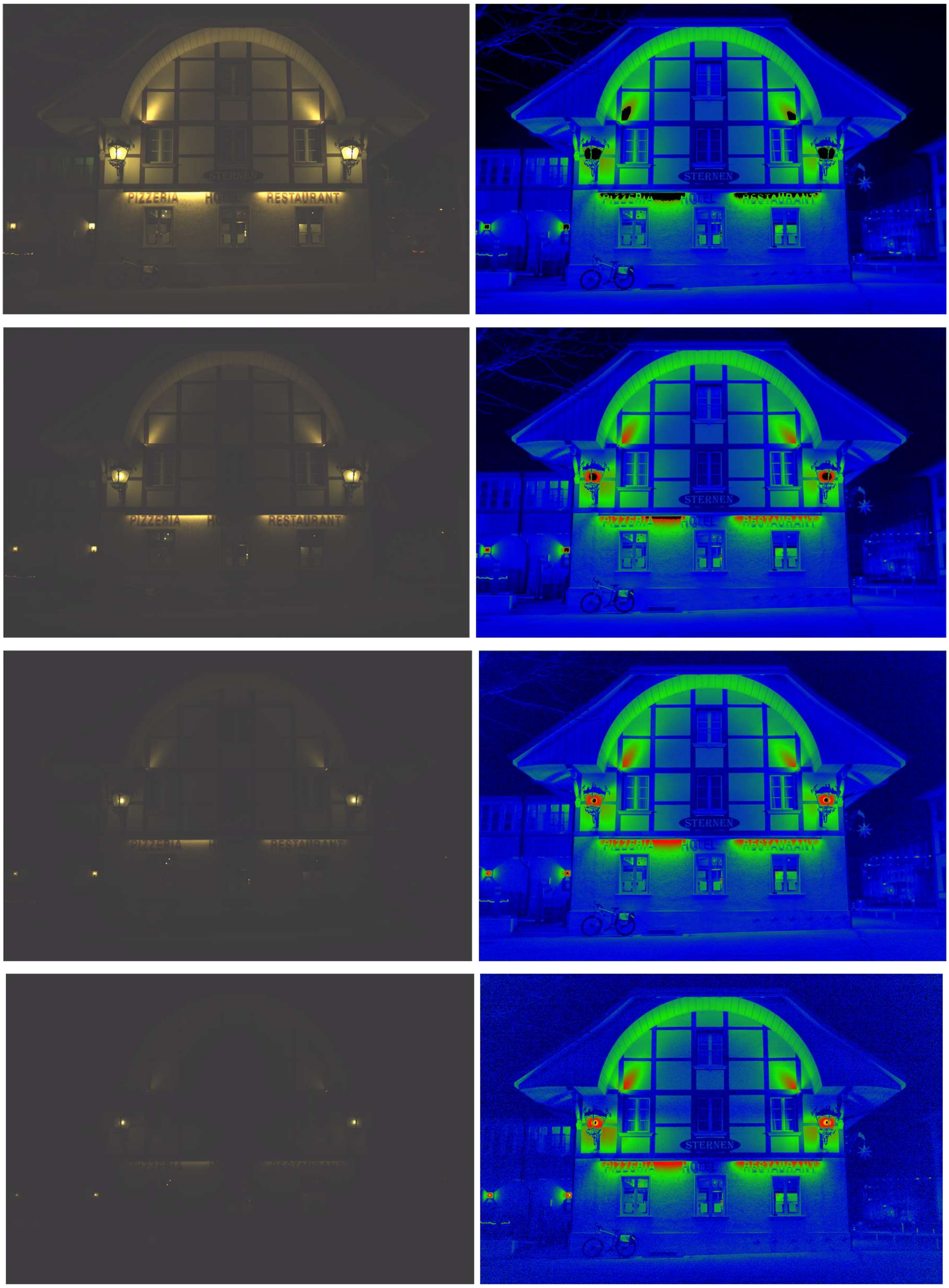


Figure 8. LDR raw signal image sequence (left column) and the corresponding luminance images (right column) from the HDR measurement sequence (part 2) with varying integration time from 1/8 s down to 1/500 s)

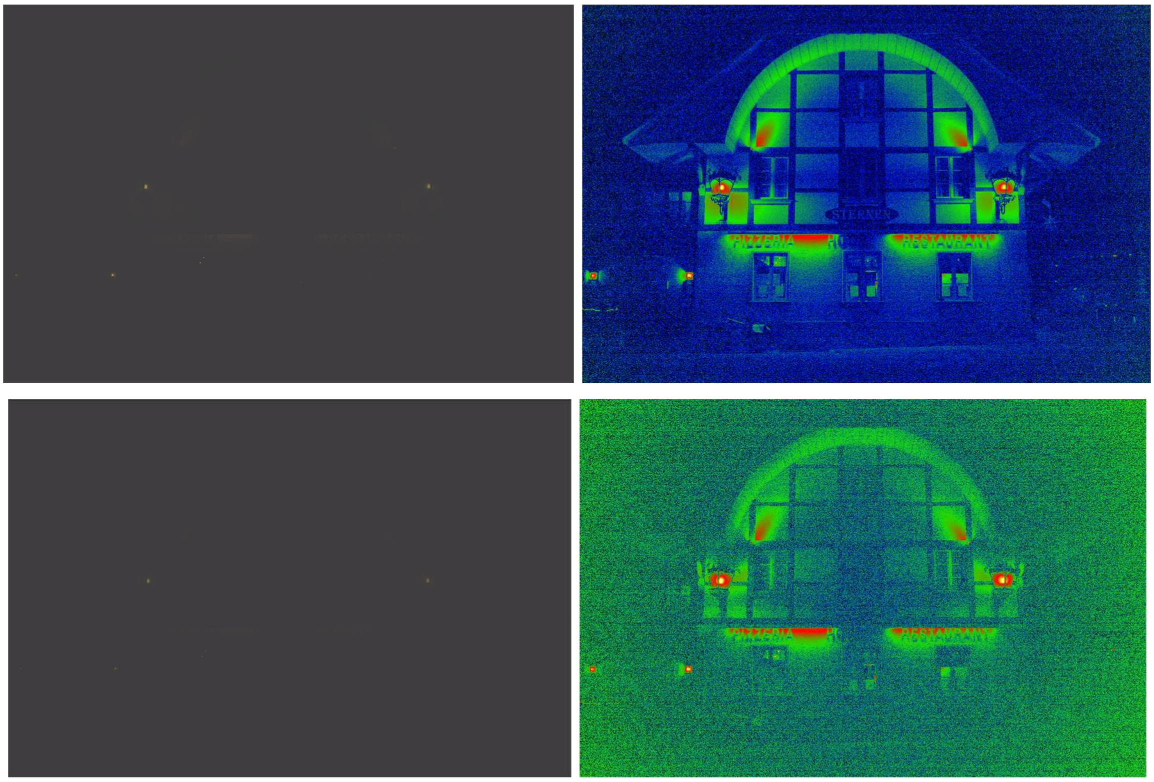


Figure 9. LDR raw signal image sequence and the corresponding luminance images (right column) from the HDR measurement sequence (part 3) with varying integration times of 1/2000 s and to 1/8000 s.

3.2 HDR merging

The merging of captured LDR images into an HDR luminance image can be done in several ways. Historically, the HDR merging techniques were developed in film photography to capture the dynamic range of daylight scenes and indoor places with windows and shadowed areas. Today, modern HDR merging algorithms are, in the majority of cases, much more advanced methods to combine and enhance the photographic information of the LDR images, namely, tone mapping, colour correction, local corrections and so on.

In metrology however, the need is to maintain the measurement quantity thorough the process with the less possible uncertainty. Therefore, HDR merging algorithms used in photography, editing software, and modern devices like smartphones are not applicable for the measurement of high contrast luminance scene where the product must be a photometrically correct and traceable luminance image of a higher dynamic range. In addition to the photometric quantity, all the relevant geometric information needed for the glare assessment must be preserved. Therefore, the merging methods should only operate towards the combination of the useful pixels (above dark signal noise levels and before saturation) from each LDR image and only if they need to be considered according to the selected method. Figure 10 shows the merging product of the LDR set from Figures 7-9 by an HDR algorithm provided by a commercial ILMD. In this case only the properly exposed pixels (non-saturated or not in the noise region) of each LDR image are used for the generation of the final HDR image.

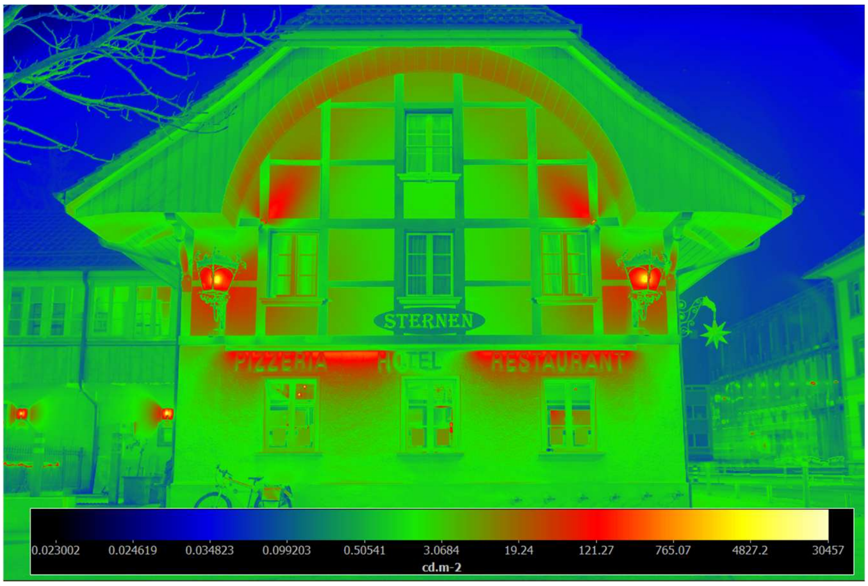


Figure 10. HDR luminance image (LUT in logarithmic scale) as a merging product of the LDR images sequence from Fig. 7 to 9

3.2.1 Starting from the luminance images (commercial ILMDs)

There are two major pathways to work with the captured LDR luminance images. The first is typically the case in commercial ILMDs where each of the captured images are automatically converted to luminance images. This conversion includes all the adjustments and corrections (luminance conversion, flat field, non-linearity, dark offset, noise suppression, etc.). The HDR merging of the LDR images can be then done either using built-in functionality of the measurement system or using a custom method. The first case is mostly proprietary, but often also include an automatic or on-the-fly parameter selection (integrations time sequence) for the image sequence and might be considered validated by the manufacturer.

The latter is based on the expertise of the user but mandates the knowledge of the integration times per image, the pixel values, the aperture sequence or ND-filter sequence depending on the used method to capture the LDR set. In the HiDyn project, several HDR merging algorithms were investigated and tested. One can review the results of this study and select the algorithm that fits to the purpose or use them for further research. The algorithms are publicly available and can be found in the HiDyn GitHub repository (https://github.com/HiDyn-EURAMET-EPM-21NRM01).

3.2.2 Starting from the pixel counts images (custom ILMDs)

The second major pathway is to begin with the LDR images as raw data set, meaning that each image contains the pixel counts values as they were generated by the measurement device without any further process. It should be noted that the term raw data refers to the data that are not clearly or intentionally processed by the device. In commercial cameras like DSLRs or mirrorless ones, the raw format may already contain some minor pre-processing of the image that its proprietary and unknown to the end user. In custom vision systems like industrial and scientific cameras, more information is available about potential treatment of the raw data before they are written to a file or transferred to the computer ensuring no image pre-processing at all.

Having the raw data, the user should merge the LDR data to HDR using algorithms which maintain the metrological information of the scene and without altering the original quantity. Therefore, the HDR image should only contain pixel values of the quantity luminance which reliably reflect the luminance of the real scene with the less possible error and uncertainty.

The HDR merging algorithm also defines the workflow from a sequence of LDR raw data images to a merged HDR luminance image. A typical case involves the subtraction of the dark signal level and correction of non-linearity and the scale to luminance of each image, with respect to the measurement device configuration, i.e., objective lens, aperture and ND-filter. The correction for vignetting (photo response non-uniformity, shading) can be done either in each LDR image or at the final merged HDR image in case the integration time bracketing was used for the gathering of the LDRs. Care should be taken that the vignetting is not applied before the pixel thresholding because there is the risk to effect the values of clipped or noise pixels. The input data for the HDR algorithm is usually (apart from providing the LDR images of the measurement), the integration time series, the expected or measured dark signal level per integration time and pixel (i.e. global offset and relative non-uniform dark image) and additional secondary parameters if needed. Some HDR algorithms, like the *hdrgen* from Radiance export some information from the images themselves. However, methods like this prevent the clear knowledge of the HDR merging technique and hinder the estimation of measurement and merging uncertainty. As mentioned before, HiDyn project has created a set of HDR algorithms which maintain the measurement quantity through the merging process and are available as open access and can be found in the HiDyn GitHub repository (https://github.com/HiDyn-EURAMET-EPM-21NRM01).

3.3 Glare assessment

The assessment of glare is mainly done via software simulations and field measurements. The starting point is an HDR luminance image to which relevant glare metric evaluations are performed. Then, the corresponding metric, e.g., UGR, TI, GR, DGP, is evaluated from the HDR luminance image and the calculation of its value is performed using the information provided by the HDR pixel values, the geometric information of the image and some metadata if needed. Both the capture of the LDR images and the merging to HDR luminance image affect the way the metric will be calculated due to the associated uncertainty of each step of the process. Therefore, the user should ensure that the influencing parameters mentioned below are not significantly affected by the measurement procedure of the HDR luminance image. Some of the most common information that should be derived by the HDR luminance image for the glare analysis is the size and the luminance of the glare sources, their size and position in the FOV of the observer and the luminance of the background areas.

The associated standards and normative documents of glare assessment define the methodology and the parameters needed to be taken into account. Each parameter can be linked to more than one application of glare and obtrusive light assessment. For the analysis of metrics and applications, the HDR luminance images, the associated measurement uncertainty and HDR merging uncertainty are considered as given. Below are the key parameters defined by the glare metrics.

- **Apparent size of the source in the image**
  Refers to the size of the source as it appears in the image in terms of number or pixels and shape. This parameter is linked (affecting or affected) to the physical size of the source, the distance to the source, the image resolution and image geometrical resolution/distortion.
- **Average road luminance**
  The average luminance of the road's region of interest as calculated by a set of points or by the total area.
- **Image bit depth and effective contrast**
  Most of glare metrics incorporate the absolute or the relative luminance contrast. Therefore, the image bit depth can affect the calculated contrast between different areas on the same luminance image. A low bit depth limits the potential contrast values whereas an increased bit depth permits higher gradients of luminance and thus contrast can be calculated more precisely.
- **Distance of observer to the glare source(s)**
  The physical distance between the observation/measurement location and the glare source(s) affects the size of the source in pixels and thus the effective resolution of the image for a given configuration

of the imaging system (i.e. by selecting the objective lens). This parameter is linked to the image resolution and the geometric resolution/distortion. The higher the image resolution the greater the distance and the smaller the source size combination can be assessed accurately.

- **Eccentricity of the glare source(s)**
  The angular displacement of the glare source in relation to the direction of observation (observer line of sight). Is affected by the combination of the image resolution and the image geometric resolution/distortion while it may be limited by the imaged field of view.
- **Illuminance on observer's eye (linked to *luminous intensity*, *distance* and projection by cos*θ*)**
  Various metrics incorporate the measurement of the illuminance on the observer's eye. In terms of a luminance image, this can be calculated via the distance to the source, the luminous intensity (luminance and real source size) and the eccentricity of the glare source.
- **Image resolution in pixels**
  The size of the image in rows and columns in combination to the apparent size of the areas of analysis can significantly influence the glare analysis. This parameter is highly correlated with size of imaged sources and areas in pixels.
- **Imaged source size (apparent size in pixels)**
  The imaged source (or area) size refers to the apparent area of the source as projected on the image plane and is recorded as a definite number of pixels. It depends on the image resolution and the geometric resolution/distortion of the image, the real source size and the distance from the observer.
- **Image geometrical resolution and distortion**
  This parameter is affected by the configuration of the imaging system (i.e. the objective lens and focus setting) used during the measurement. A geometric calibration of the measurement system will result into a geometric profile of the image where the eccentricity of a source expressed in pixels can be transformed into the eccentricity in degrees in the real scene. The geometric distortion refers to situations where the same distance in pixels in different areas on the image translate to different angular distances (a typical case is the lens barrel effect), this is very severe namely for fish-eye lenses.
- **Luminance range**
  The achieved range of an HDR luminance image can directly influence the result of a glare assessment application when the luminance values are clipped/floored to specific levels (differed per application).
- **Luminance of glare source(s)**
  Glare sources are of high luminance and, in most cases, of high non-uniformity. The average luminance of each of these sources is considered in all glare models and shall be documented as precisely as possible. Independently from the analysis method (total source area or individual sub-sources), the image geometric resolution and the imaged source size affect the calculation of the glare metric.
- **Luminance of the background**
  In parallel to the glare source luminance, the background (or environment or adaptation) luminance can also significantly affect the glare analysis. The background luminance is normally several decades lower than the glare source luminance and is in most cases used as the average luminance of a greater area of the image.
- **Luminance of an area**
  This refers to the generic luminance of an area under assessment, which does not lie neither to glare source nor background luminance. In most cases it has to deal with façade luminance, illuminated advertisements or generic surface luminance that are used in obtrusive light assessment. The luminance of an area also refers to the sky dome luminance for sky glow assessment.
- **Line of sight**

It refers to the line of sight either of a standardized observer or of a per purpose situation. This parameter is linked more to the measurement method, however, can be corrected during the glare assessment with a potential influence on the calculated glare metric.

- **Observation location and FOV**
  The observation location can affect the glare metric similarly to the observation direction. This parameter in combination to the achieved field of view of the measurement system may limit the assessment area.
- **Position index of the glare sources**
  This parameter is used in few glare metrics and can affect the result in combination with the image resolution and the image geometric resolution.
- **Real size of the source/solid angle**
  Most of the glare metrics request the apparent size of the source or the solid angle. The size of the source in the real scene influences the imaged source size in pixels in combination with the image resolution and the geometric resolution. Therefore, the calculated solid angle of the glare source may be in case of small sources significantly different from the real one due to the discrete number of pixels corresponding to a quantization of the solid angle (especially in cases of low resolution).

Table 1 summarizes the key parameters that may influence the evaluation of glare when luminance images are used as the input data for glare assessment. The glare models mentioned in Table 1 are the most commonly used ones. Additional glare models can be found in literature (e.g. CIE 243:2021), but here too, the relevant parameters are identical to the ones presented above.

Table 1 – Parameters that influence the evaluation of glare

Metrics and applications	**Reference**	**Key quantities and parameters**
Glare Rating *GR*	CIE 112 EN 12464	Luminance of the background
$GR = 27 + 24\log_{10}\left(\frac{L_{vl}}{L_{ve}^{0.9}}\right)$		Luminance of glare source(s)
$GR = 27 + 24\log_{10}\left(\frac{10 \cdot L_{ai} \cdot \omega_i \cdot \cos\theta_i \cdot \theta_i^{-2}}{(0.035 \cdot L_b)^{0.9}}\right)$		Observation location and FOV
		Observation direction
		Eccentricity of the glare source(s)
		Apparent size of the source in the image
		Distance to the glare source(s)
		Real size of the source / solid angle
		Luminance dynamic range
		Image bit depth and effective contrast
Unified Glare Rating *UGR*	CIE 117 EN 12464	Luminance of the background
$UGR = 8 \cdot \log\left(\frac{0{,}25}{L_B} \cdot \sum_s \frac{L_s^2 \cdot \omega_s}{p_s^2}\right)$		Luminance of glare source(s)
		Observation location and FOV
		Observation direction
		Position index of the glare sources
		Luminance range
		Image bit depth and effective contrast
Glare Index Formula *CGI*	CIE 117	Luminance of the background
$CGI = 8\log\left[2 \cdot \frac{1 + E_d / 500}{E_d + E_i} \cdot \sum \frac{L^2\omega}{p^2}\right]$		Luminance of glare source(s)
		Observation location and FOV
		Observation direction
		Position index of the glare sources
		Luminance dynamic range
		Image bit depth and effective contrast
Daylight Glare Probability *DGP*	EN 17037	Luminance of glare source(s)
		Observation location and FOV
		Observation direction
		Real size of the source / solid angle
		Position index of the glare sources
		Apparent size of the source in the image
		Illuminance on observer's eye

<table>
<tr>
<td>$$DGP = 5.87 \cdot 10^{-5} \cdot E_V + 9.18 \cdot 10^{-2} \cdot \log(1 + \sum_i \frac{L_{s,i}^2 \cdot \omega_{s,i}}{E_v^{1.87} \cdot P_i^2}) + 0.16$$</td>
<td></td>
<td>(linked to luminous intensity, distance and cosθ)
Luminance dynamic range
Image bit depth and effective contrast</td>
</tr>
<tr>
<td>Threshold Increment
TI
$$TI = \frac{k \cdot E_e}{L_{av}^{0,80} \cdot \Theta^2} (\%)$$</td>
<td>CIE 115
CIE 140
CIE 150
EN13201</td>
<td>Average road luminance
Observation location and FOV
Observation direction (-2°)
Eccentricity of the glare source(s)
Distance to the glare source(s)
Luminance dynamic range
Image bit depth and effective contrast
Illuminance on observer's eye
(linked to I, d and cosθ)</td>
</tr>
<tr>
<td>Maximum luminance of a glare source
$$\bar{L}_{max} \leq k * \sqrt{\frac{L_u}{\Omega_S}}$$</td>
<td>LiTG 12.3</td>
<td>Luminance of background
Luminance of glare source(s)
Observation location and FOV
Observation direction
Real size of the source / solid angle</td>
</tr>
<tr>
<td>Luminous intensity towards observers and properties
<table>
<tr><td rowspan="2">Light Technical Parameter</td><td rowspan="2">Application Conditions</td><td colspan="5">Luminaire group (projected area A_p in m²)</td></tr>
<tr><td>$0 < A_p \leq 0,002$</td><td>$0,002 < A_p \leq 0,01$</td><td>$0,01 < A_p \leq 0,03$</td><td>$0,03 < A_p \leq 0,13$</td><td>$0,13 < A_p \leq 0,50$</td></tr>
<tr><td rowspan="5">Maximum luminous intensity emitted by luminaire (I in cd)</td><td>Environmental Zone E0
Pre-curfew:
Post-curfew:</td><td>0
0</td><td>0
0</td><td>0
0</td><td>0
0</td><td>0
0</td></tr>
<tr><td>Environmental Zone E1
Pre-curfew:
Post-curfew:</td><td>0,29·d
0</td><td>0,63·d
0</td><td>1,3·d
0</td><td>2,5·d
0</td><td>5,1·d
0</td></tr>
<tr><td>Environmental Zone E2
Pre-curfew:
Post-curfew:</td><td>0,57·d
0,29·d</td><td>1,3·d
0,63 d</td><td>2,5·d
1,3·d</td><td>5,0·d
2,5·d</td><td>10·d
5,1·d</td></tr>
<tr><td>Environmental Zone E3
Pre-curfew:
Post-curfew:</td><td>0,86·d
0,29·d</td><td>1,9·d
0,63·d</td><td>3,8·d
1,3·d</td><td>7,5·d
2,5·d</td><td>15·d
5,1·d</td></tr>
<tr><td>Environmental Zone E4
Pre-curfew:
Post-curfew:</td><td>1,4·d
0,29·d</td><td>3,1·d
0,63·d</td><td>6,3·d
1,3·d</td><td>13·d
2,5·d</td><td>26·d
5,1·d</td></tr>
<tr><td colspan="7">NOTE 1 d is the distance between the observer and the glare source in metres.
NOTE 2 A luminous intensity of 0 cd can only be realized by a luminaire with a complete cut-off in the designated directions.
NOTE 3 For further information, please refer to Annex C.</td></tr>
</table>
</td>
<td>CIE 150</td>
<td>Luminance of glare source(s)
Apparent size of the source in the image
Imaged source size (apparent size in pixels)
Distance to the glare source(s)
Observation location and FOV
Observation direction
Luminance dynamic range
Image bit depth and effective contrast</td>
</tr>
<tr>
<td>Max permitted average luminance
<table>
<tr><td rowspan="2">Light Technical Parameter</td><td rowspan="2">Application Conditions</td><td colspan="5">Environmental Zones</td></tr>
<tr><td>E0</td><td>E1</td><td>E2</td><td>E3</td><td>E4</td></tr>
<tr><td>Building Facade Luminance (L_b)</td><td>Taken as the product of the design average illuminance and reflectance divided by π.</td><td>< 0,1 cd/m²</td><td>< 0,1 cd/m²</td><td>5 cd/m²</td><td>10 cd/m²</td><td>25 cd/m²</td></tr>
<tr><td>Sign Luminance (L_s)</td><td>Taken as the product of the design average illuminance and reflectance divided by π, or for self-luminous signs, its average luminance.</td><td>< 0,1 cd/m²</td><td>50 cd/m²</td><td>400 cd/m²</td><td>800 cd/m²</td><td>1 000 cd/m²</td></tr>
<tr><td colspan="7">NOTE The values apply to both pre- and post-curfew, except that in Zones 0 and 1 the values shall be zero post-curfew. The values for signs do not apply to signs for traffic control purposes.</td></tr>
</table>
</td>
<td>CIE 150</td>
<td>Luminance of the scene
Distance to the glare source(s)
Luminance dynamic range
Image bit depth and effective contrast</td>
</tr>
<tr>
<td>Sky glow assessment

No metric exists yet</td>
<td>CIE 126
CIE 150</td>
<td>Luminance of the scene
Luminance dynamic range
Image bit depth and effective contrast
Image resolution in pixels
Image geometrical resolution and distortion
Observation location and FOV</td>
</tr>
</table>

4 Field intercomparison campaigns

This part of the GPG presents key information and the main results of a series of intercomparison campaigns performed during the EPM 21NRM01 HiDyn project. The measurement campaigns aimed to investigate in practice the key steps and the potential issues in measuring high contrast scenes in the field using various types of equipment. The campaigns targeted the measurement of high contrast luminance scenes, namely, two outdoor and one indoor scenes featuring a variety of light source types and luminaire arrangements. In addition, the project consortium performed a series of tests on the reference high contrast source (HiDyni) developed in the project. For more information on this and regarding the characterization of HDR luminance imaging systems, there is a dedicated GPG available named: "Good practice guide describing the characterisation of different HDR imaging instruments, such as ILMDs and RGB matrix sensor cameras, based on the recommendations stated in CIE 232:2019 and CIE 244:2021" as HiDyn D2 (see at https://zenodo.org/communities/hidyn).

Typical scenes that may introduce glare to the observer are road lighting, especially in cases where no surrounding ambient luminance is present, advertisement billboards and illuminated signs, sports lighting installations, indoor spaces illuminated by ceiling luminaires, direct or indirect view of sun disc or its reflection to other surfaces, etc… All these examples have in common a set of strong light sources, sometimes with extremely high luminance levels and, on the other hand, dim sources, illuminated surfaces or just a dark background. The glare assessment in such scenes is defined by relevant standards e.g., (CIE 2024) by means of specific metrics. In most cases, the main contributor of glare is the combination of the source luminance, its position in the field of view and the luminance of the background.

4.1 Road lighting scene

4.1.1 Background

The motivation of the intercomparison campaign was to perform a measurement of a road lighting scene and investigate all consideration points mentioned before. The campaign was organized between the partners of HiDyn and took place in a specially designed and developed road lighting test installation in Berlin, Germany.

A typical field measurement was designed to assess glare in a road lighting scene. Some of the measurement aspects under test were the following: a) Determination of the observer's position and direction, and the influence of any disparities in camera placement, and thus disparity in the measurement of the average luminance. b) Location of the light sources, especially of the brighter ones, in the camera image in respect to its physical location. c) The location of each source in respect to other sources regarding the straylight effect between bright and dim light sources. d) The number of LDR images to be captured and the selected step in integration times (considering also temporal light modulation inside the scene) as well as the use of ND filters if needed. e) The combination of cameras, lenses and ND filters for the imaging of the high contrast scene and the effect of stray light from sources inside and outside the region of interest or the field of view of the system.

4.1.2 Experimental setup

A research lighting installation in Berlin designed and maintained by Technical University of Berlin was selected as test site. The area comprises a set of multi luminaire poles on the side of the road (Figure 11). Each pole has 3 luminaires installed at 4 m, 6 m and 8 m with adjustable light output and luminous intensity distribution. By this, one can create a set of different road illumination scenes . The road infrastructure was used in a specific operational mode only and acted as both background luminance (road and peripherals) and as a set of geometrically arranged light sources (lighting poles). To enhance the comparison of the different measurements, multiple grey cards were placed inside the scene, presenting a homogenous luminance. Compared to inhomogeneous structure of the luminaires and scene surfaces, these grey cards allow a more reliable region of interest on which results can be compared and referenced also by a spot-luminance meter.

Figure 11 – Clipped HDR luminance image of the modular road lighting installation including grey cards (center, background) and the high contrast reference source comprising of 3 sources and two light traps

In addition to this, three luminance source modules of the HiDyni reference source was installed in the scene. The source was designed and developed in the context of the HiDyn project to intentionally offer a high contrast of luminance, see [HiDyn deliverables D1 and D2 at https://zenodo.org/communities/hidyn]. The setup (Figure 11) used in the intercomparison was a set of 3 luminance source modules producing a uniform circular luminous area with respective luminance levels of 0.1 cd·m^{-2}, 1 000 cd·m^{-2}, and 100 000 cd·m^{-2}. This offered itself 6 orders of magnitude in luminance without taking into account the luminance of the surrounding road luminaires.

The measurement systems used in the comparison were a variety of devices including different commercial Imaging Luminance Measurement Devices (ILMDs) (CIE 2021b), modified and unmodified versions of photographic cameras, industrial cameras and scientific grade cameras, see Figure 12. The systems were combined with various objective lenses covering from narrow field of views up to fisheye ones (180° circular field of view). Some systems also used different optical configurations by means of different aperture sizes or different neutral density filters. In addition, a conventional spot-type luminance meter was used to obtain reference values for the grey cards and the elements of the hight-contrast source.

Figure 12 – Photo of the HDR imaging measurement systems used in the intercomparison campaign

The targeted areas of measurement were set to be the reference sources, some of the road luminaires in the field of view of the cameras, three light traps and some grey cards. In addition, for the evaluation of the glare metrics, the background luminance in the scene was measured and averaged accordingly.

4.1.3 Results and discussion

The measurement campaign (Figure 13) took place at night, in dark conditions, ensuring the absence of twilight that may influence the background luminance (especially on the road surface), and at an ambient temperature of about 13 °C. The scene was prepared to incorporate both, the fixed lighting installation and the special high contrast luminance reference source.

Figure 13 – Photo of the setup during the measurement of the high contrast scene using different HDR imaging systems

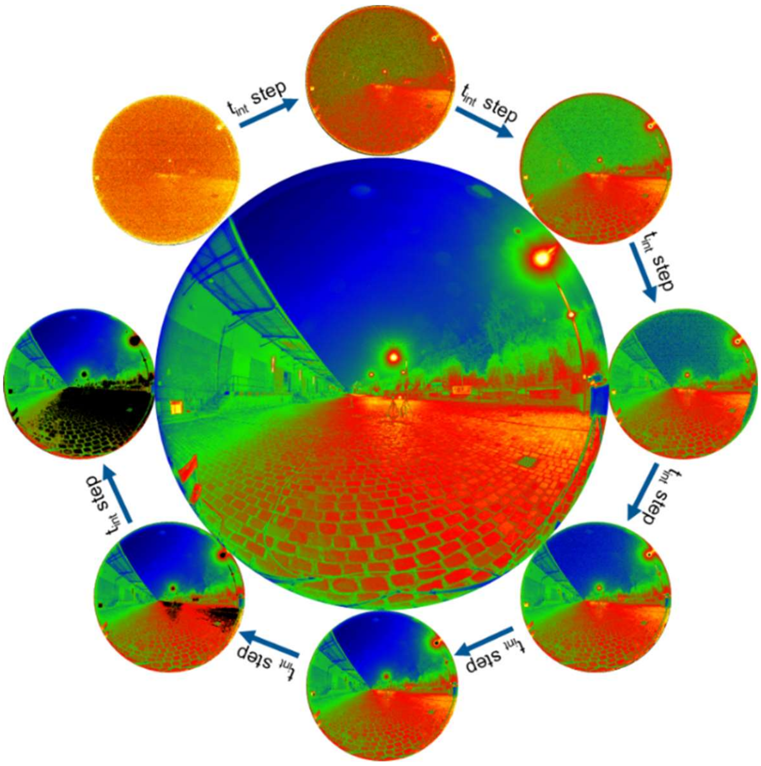


Figure 14 – LDR and HDR luminance images of the scene measured by one HDR system (Black pixels are saturated ones and omitted in the luminance image).

Several measurements were carried out with all devices using one or multiple camera lenses. Some of the systems captured LDR images and merged them to HDR luminance images automatically, whereas the rest captured only sequences of LDR images. Figure 14 shows an example of and LDR set and the merged HDR image as produced by one of the HDR measurement systems.

Various targets were considered for evaluation in the comparison of the high contrast luminance measurement, three light sources, two grey targets and three light traps (three trap positions). Each system produced an HDR luminance image either by using a proprietary algorithm, or by implementing custom-made ones using the LDR raw data. The comparison results are shown in Figure 15. All test targets were exported, and their average luminance was calculated using the HDR images.

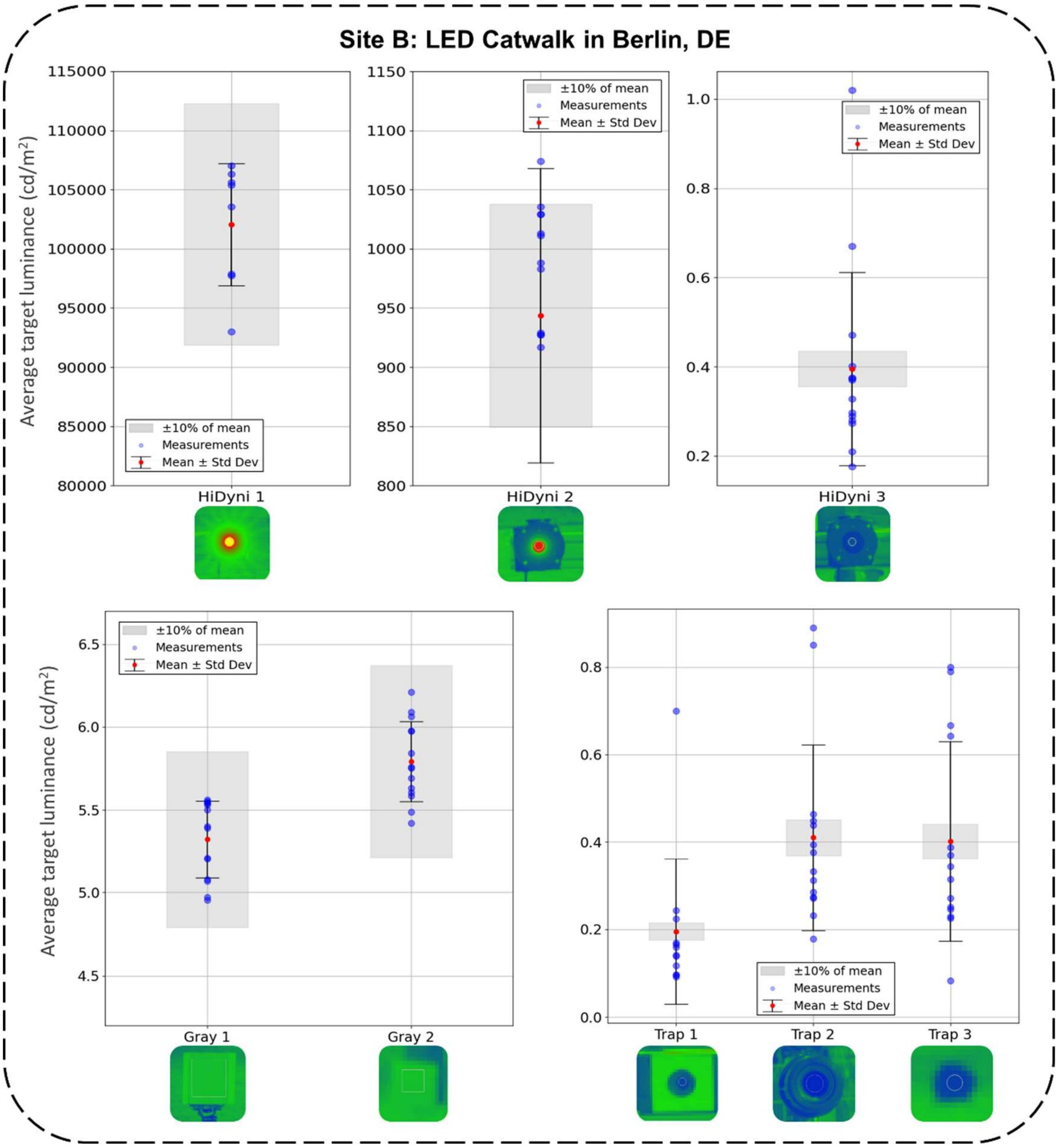


Figure 15 – Results of the luminance measurement of various targets using HDR imaging.

The comparison results showed that the measurement of relatively mid to high luminance targets demonstrated a good agreement while the darker targets as well as the light traps suffered from stray light. The spread of the results for the bright targets was well inside 10% mainly due to differences in system calibration, positioning of them in the scene (displaced by up to two meters from another) and potentially to the HDR merging (in most cases proprietary). The dimmest reference source and the light traps were significantly affected by stray light and thus the final result showed a huge spread increasing the measurement uncertainty in this luminance region.

4.2 Building façade

4.2.1 Background

The next intercomparison campaign took place in Bern, Switzerland. The target scene was a façade of a local restaurant (Figure 16). The purpose was to compare the measurement results of multiple gradient luminance patches, luminaires with different source technology and the dark sky.

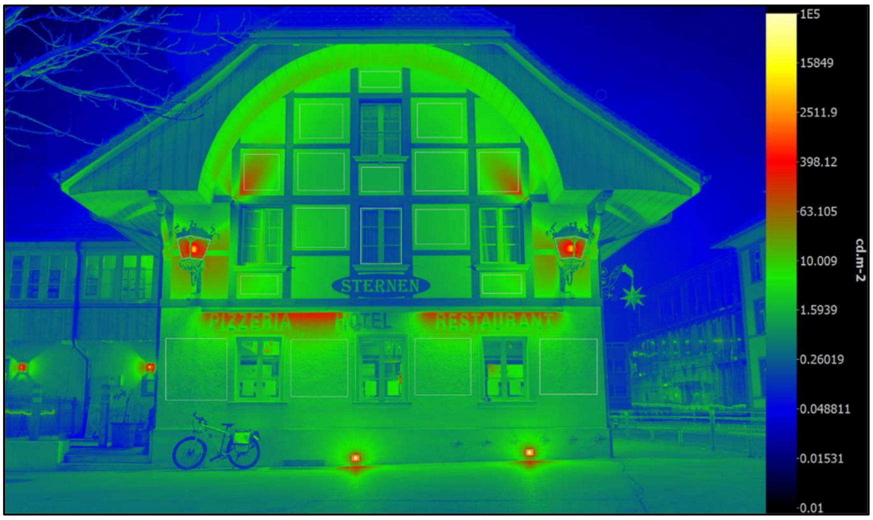


Figure 16 – HDR luminance image of the building façade of the second intercomparison campaign

4.2.2 Experimental setup

The façade comprises a segmented wall structure where rectangular grey patches are formed. An illuminated sign was using an LED strip with downward direction forming a gradient of luminance on the wall below. A set of two traditional lantern luminaires were retrofitted with compact fluorescent lamps. The upper wall with the multiple grey wall patches was illuminated mainly by two spotlights with incandescent lamps and the before mentioned lantern luminaires. Two additional strong LED spotlights were placed in the base of the façade to produce straylight in some of the image sets.

The instruments used in this comparison was, as in the Berlin campaign, a mix of commercial ILMDs and custom made HDR imaging systems based on industrial vision cameras (Figure 17). Both fisheye and normal lenses were used in the tests with multiple sets of LDR images captured by each imaging system. A key aspect of this comparison was the extremely low temperature level during the measurements which reached -3 °C close to the end of the session.

Figure 17 – Photo of the HDR imaging measurement systems used in the intercomparison campaign

4.2.3 Results and discussion

This scene included many potential targets to be considered for the comparison. Among them, the selected ones are shown in Figure 19 along with the corresponding measurement results. These were the two lantern luminaires, two wall patches with a prominent luminance gradient from the spotlights, three wall patches below the LED illuminated sign, and three dark areas (a window, a light trap and the sky). The test scene was measured with a combination of different camera and lenses (prime and fisheye ones). For each system, a set of LDR was captured either automatically by the system or manually using custom software. The merging was performed using both proprietary or custom algorithms. An example of an LDR and HDR luminance images is shown in Figure 18. As in the road scene, results for all evaluation regions were exported and their average luminance was calculated using the HDR luminance images only. The comparison results are summarized in Figure 19.

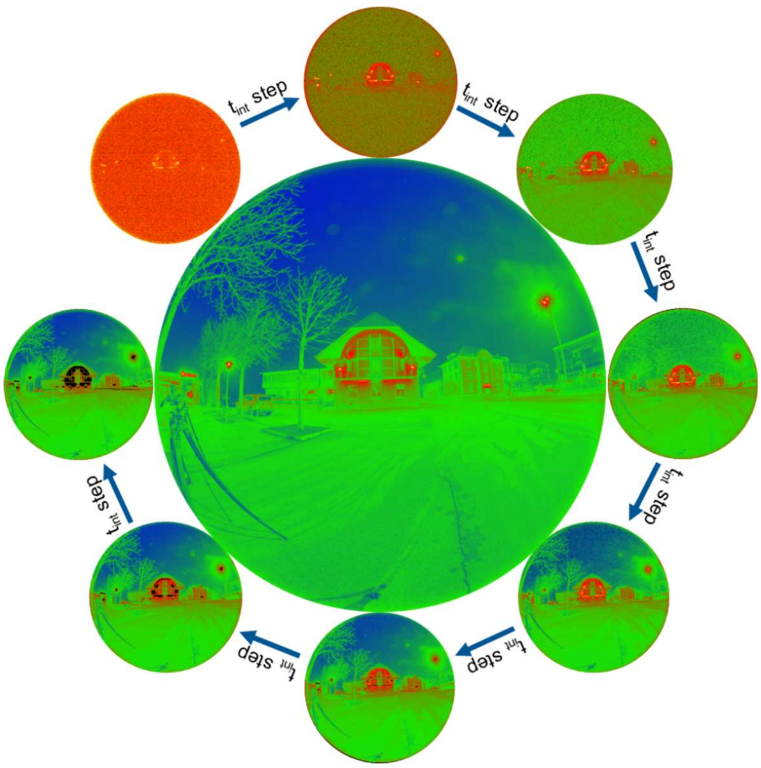


Figure 18 – LDR and HDR luminance images of the scene measured by one HDR system (Black pixels are saturated ones and omitted in the luminance image).

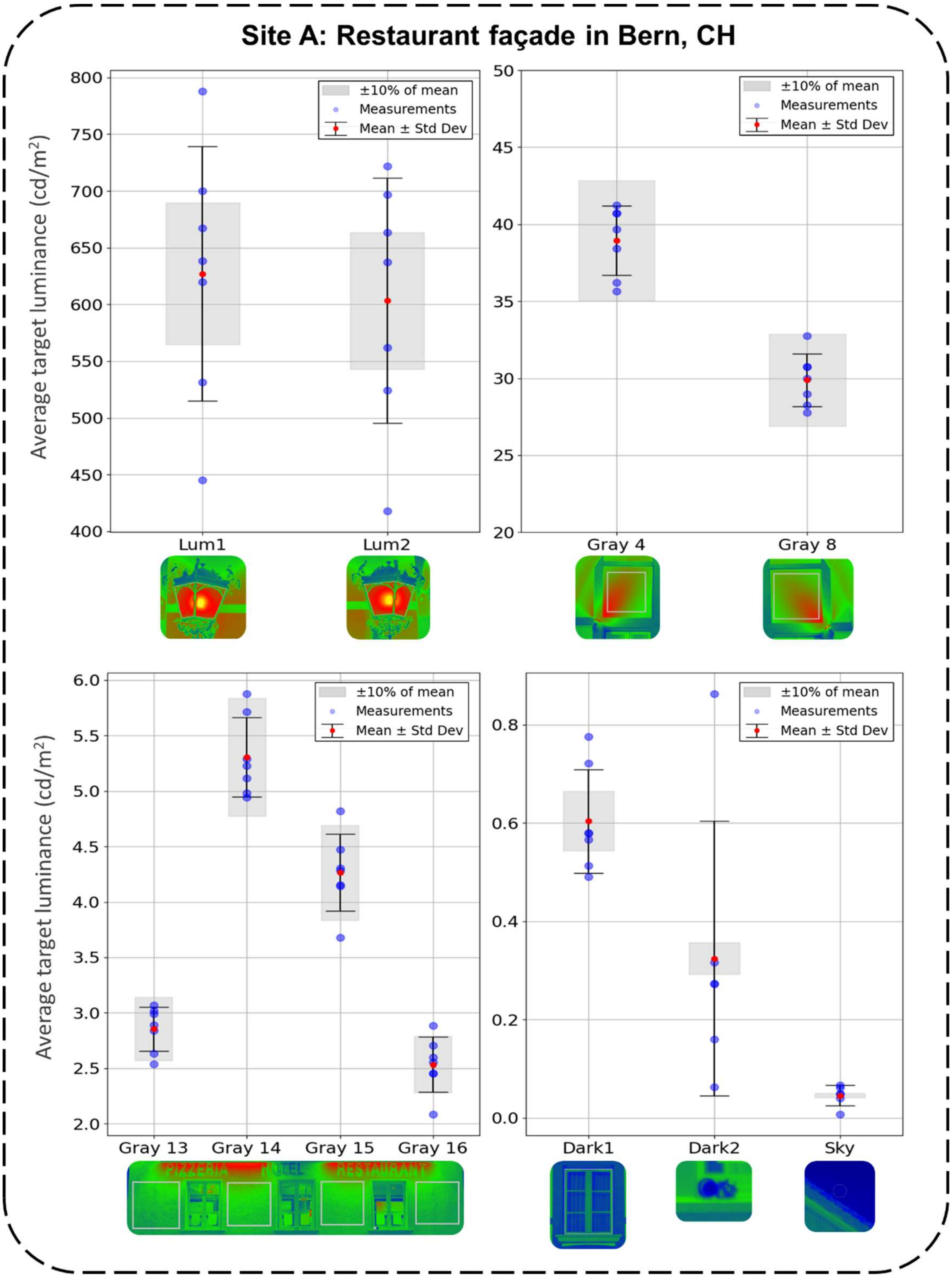


Figure 19 – Results of the luminance measurement of various targets using HDR imaging.

The comparison results were similar to the road scene and in general terms as expected. The relatively mid to high luminance targets showed a good match in the measurement results while in the darker ones (window, light trap and sky), there was a big spread of the results. One significant observation was the comparison of the lantern luminaire where the results were expected to be much closer to the average. After the investigation of the scene by a spot-type TLM meter, it was found out that the luminaire had significant temporal light modulation (TLM) at a temporal frequency which frequency was incompatible with the short exposure times used by many of the HDR imaging systems. This error was directly associated with artefacts results from the TLM but most importantly shows both the severity of it and the need of checking the TLM of light sources before the measurements. As for the fish-eye lens some of the systems could not been configured with suitable ND-filters these artefacts could not been avoided, but the results are provided here namely for demonstrating this need of a configuration suitable for the scene (regarding luminance values and TLM) to be measured and assessed.

4.3 Indoor scene (UGR test room)

4.3.1 Background

The third intercomparison comprises an indoor scene with fully controlled lighting conditions for both the comparison of the luminance measurement and the glare assessment. The scene was built on purpose for this comparison at the premises of the partner ICCS. The test site is a closed corridor-like shaped room without windows having a rectangular shape. In one side of the room, 10 individually controlled indoor LED-based luminaires with diffuse light emitting surface were installed. The luminaires were dimmable using DALI controlled high frequency drivers. The arrangement was so that 6 luminaires are positions on the ceiling, 1 luminaire on the left side wall, 2 luminaires on the wall opposite to the observer, and 1 luminaire on the right side wall. Figure 20 shows a photo of the luminaire arrangement and an HDR luminance image with all luminaires switched on as well as the numbering of the test luminaires. All room surfaces were painted with white colour of high reflectivity and the rest of the equipment in the room was kept to minimum required.

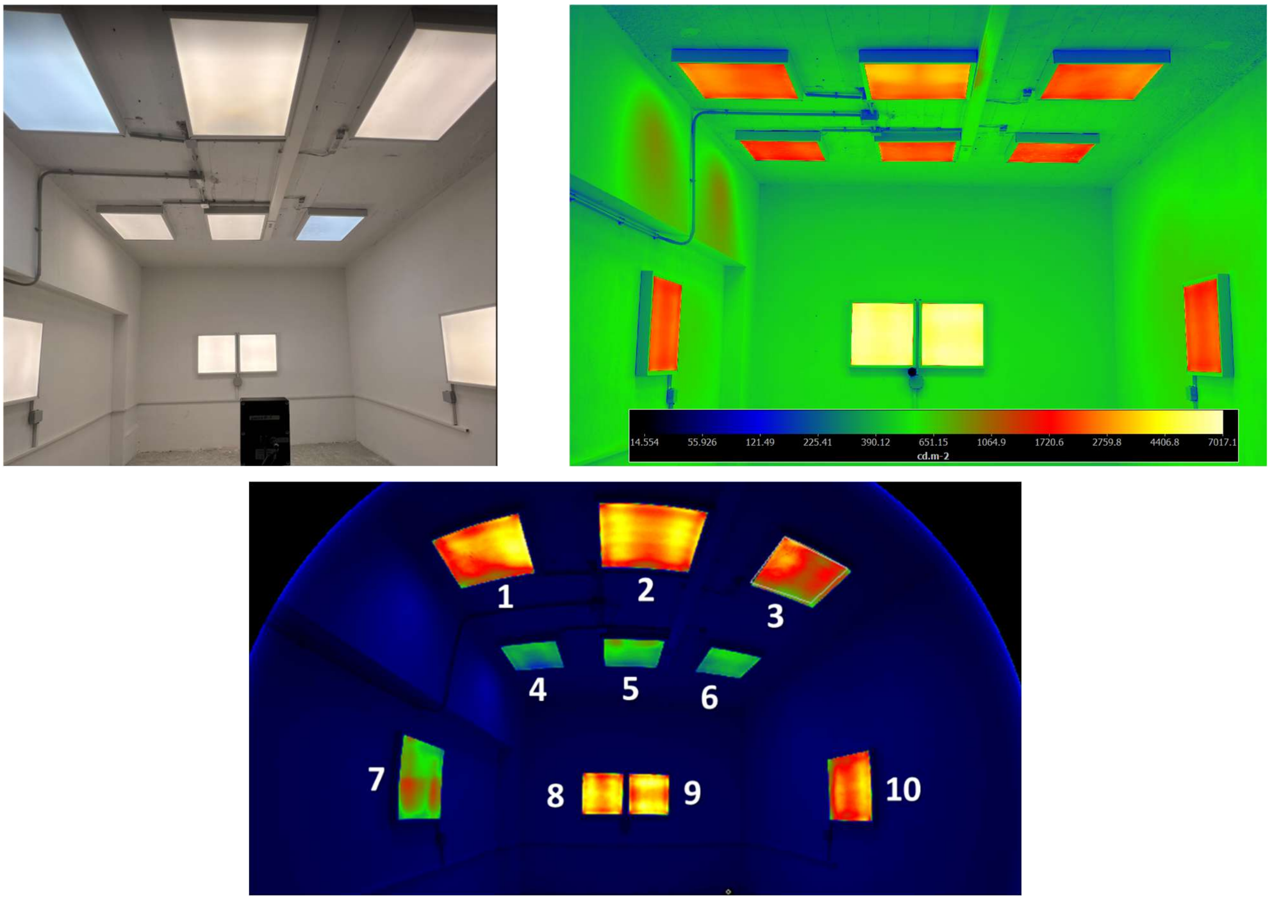


Figure 20 – Photo of the glare test room at ICCS, Athens, an exemplary HDR luminance image obtained during the indoor intercomparison campaign and the numbering convention of the luminaires.

4.3.2 Experimental setup

The measurements were carried out using two HDR imaging measurement systems (ILMDs) via their control software. For the sake of simplicity, 2 observer positions were selected. The first observer position was 4 m from the opposite wall (Fig. 21), where two of the luminaires are positioned vertically, and the second observer position was 7 m away. The two cameras were positioned as close as possible to each other, at the same height and aiming towards the same point on the opposite wall. Both systems used a circular fisheye lens. In addition to the luminaires two light traps, placed in the corner of the room and on the floor close to the observer position, where added to the scene to estimate internal stray-light effects.

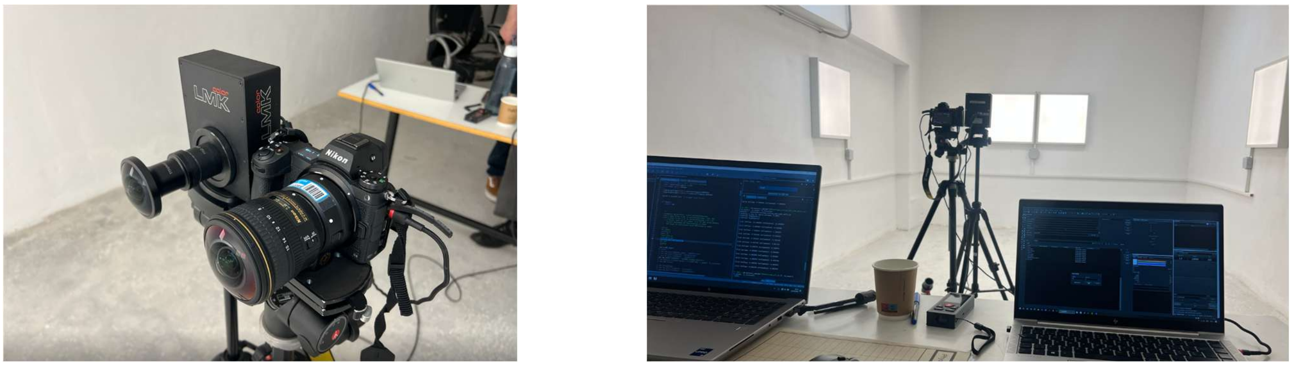


Figure 21 – Photos of the measurement systems and control equipment as positioned during the indoor intercomparison.

Via controlling the luminaires, seven lighting scenarios were produced while at least one set of LDR images was captured by the two systems at the same time for each scenario. The use of the fisheye lens helped to have all luminaires in the FOV, which was also needed for the UGR calculation, but also led to severe distortion and shrink of the pixels number corresponding to the luminaries close to the border of the lens. This effect was more prominent with the observer at the 4 m distance, where the ceiling and side walls luminaires were significantly reduced in pixel size and their shape was shirked due to the perspective. Figure 22 shows the HDR luminance images corresponding to the seven scenarios (lighting scene dimming setting) measured during the test session.

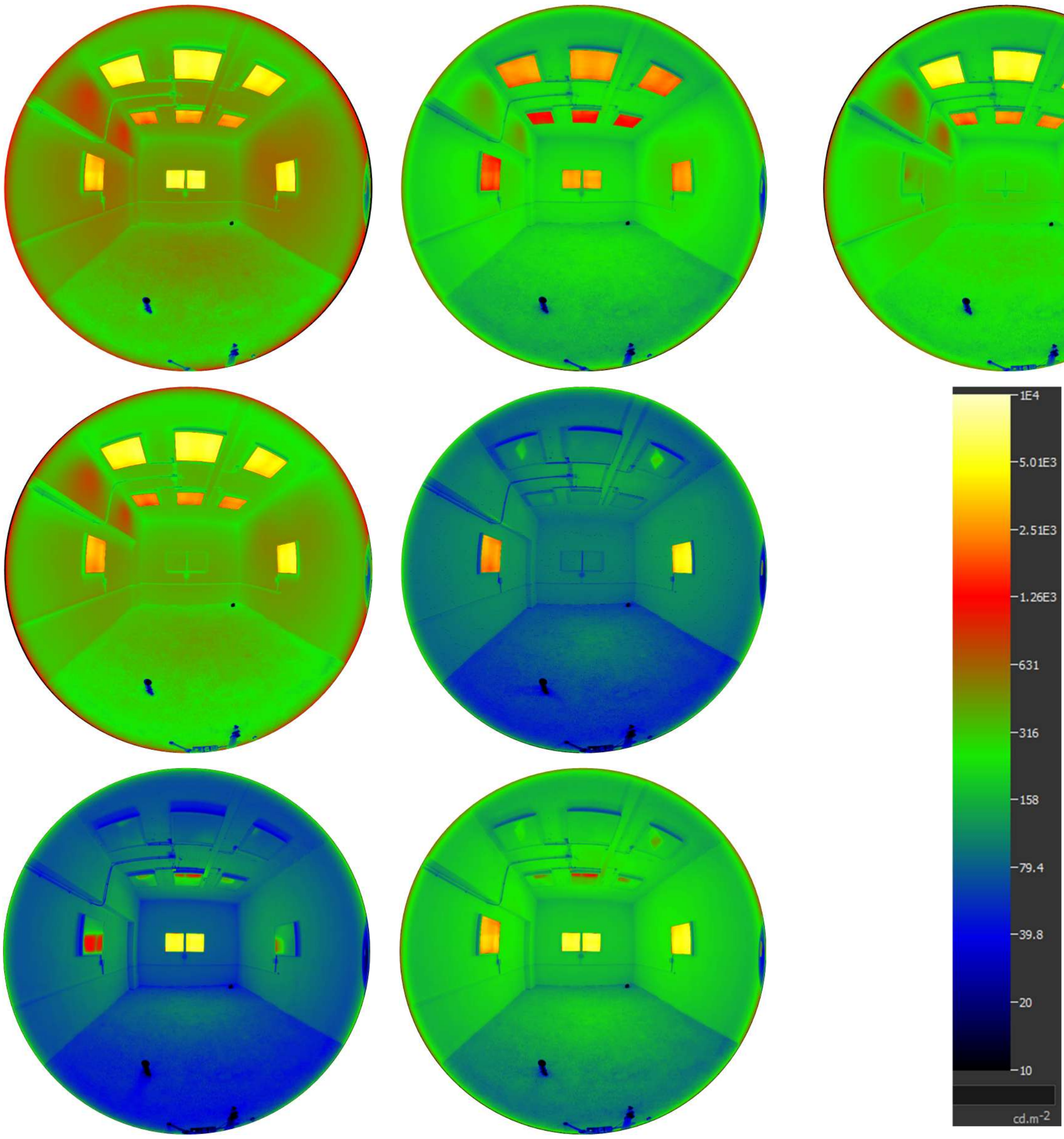


Figure 22 – HDR luminance images for the different illumination scenarios (lighting scene dimming setting) used during the indoor intercomparison campaign with the observer at 4 m from the opposite wall. The same scenarios were repeated for the observer at 7 m from the wall.

4.3.3 Results and discussion

The first part of the tests was to compare the luminance values of the individual luminaires and a couple of light traps measured by the two systems for each lighting scenario. The purpose was to assess the effect of the measurement geometry in general, any effect of the fisheye lens, and the slightly different mounting positions of the systems. The method used for the LDR was the same as in the other intercomparisons. The average luminance of each source was calculated via the HDR luminance image and using all pixels that form the luminous surface. The purpose of selecting such type of luminaire was the ease to derive luminous surface even in long distance due to their large area (600x600mm).

The measurement results and their comparison are shown in Figures 23 – 25 below. From the results of the light traps given in Figure 24 it is evident, that the dark offset signal is valid but that there was a significant difference between the two systems in all trials more likely due to the straylight of each individual objective lens into the particular areas of the image. The luminance measurements on the luminaires matched well, especially for the measurement set from the observer position of 7 m. The major source of the observed errors in the average luminance was the slightly different location of the cameras in respect to the luminaires which led to two issues. First, at 4 m distance, the luminous surface of luminaires No. 7 and No. 10 on the side walls was shown with different luminance gradients in the two systems in comparison to the other luminaires, most likely because their glossy surface resulted in a different specular reflection of the luminaires on the opposite wall to each measurement system. This was no more visible at 7 m where the result was much more consistent. In addition, some reflections of the switched-on luminaires on the surface of the switched-off luminaires were visible only by one of the two systems in some tests but not considered a ghost in the measurement system but a property of the scene. This also led to a disparity in the calculation of the average luminance.

As an overall result, the median difference of all measurements for all luminaires in all scenarios was around 4% for the 4 m distance and around 3% for the 7 m distance, which is considered a good result.

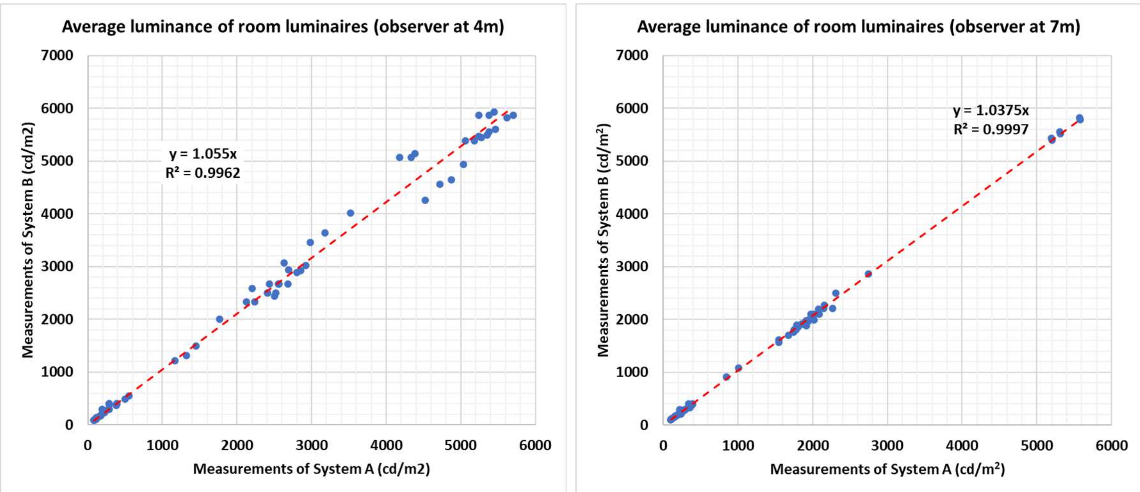


Figure 23 – Correlation of measurement results between the two HDR luminance imaging measurement systems for all room luminaires and for the two observer positions (4 m and 7 m).

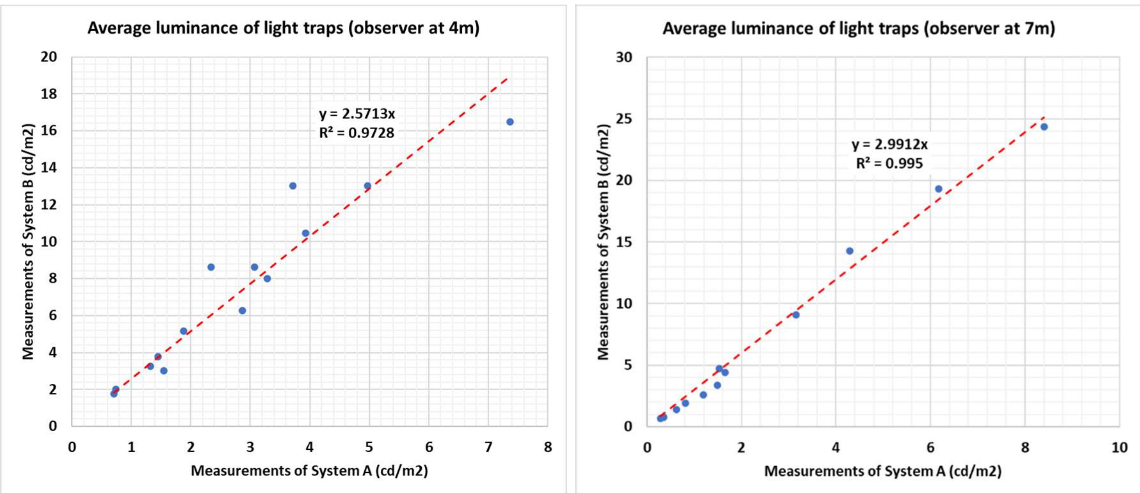


Figure 24 – Correlation of measurement results between the two HDR luminance imaging measurement systems for the light traps and for the two observer positions (4 m and 7 m).

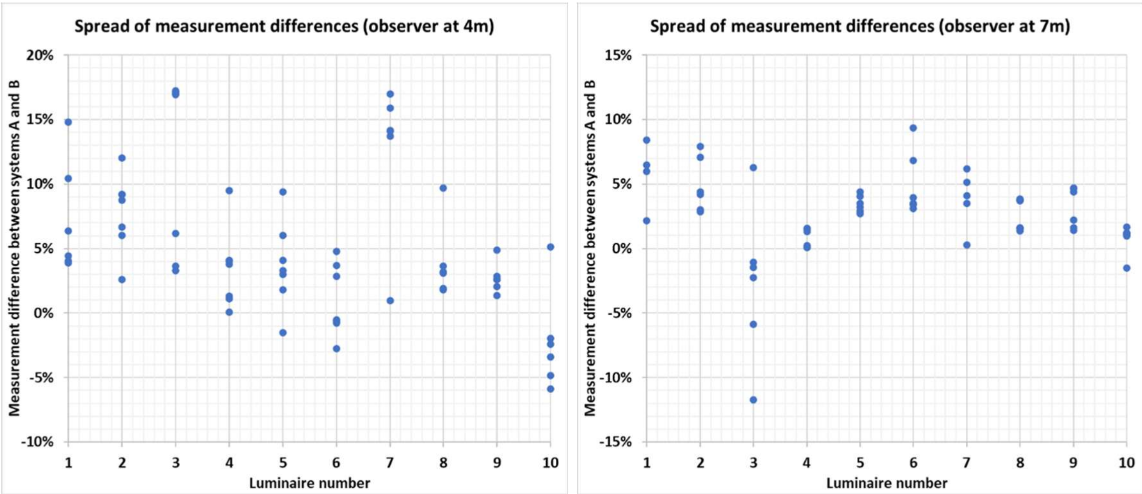


Figure 25 – Spread of HDR luminance measurement differences between the two measurement systems for all room luminaires and for the two observer positions (4 m and 7 m).

The second part of the field tests was the validation of the HDR imaging system to accurately calculate UGR value under the different lighting scenarios. For this purpose, the theoretical UGR values were simulated using the specialised software RELUX with the observer in the same two positions as during the real measurements. The room was accurately modelled using 3D scanning with all its elements inside. Then, the luminaires were set to match the real ones using the photometric files provided by the manufacturer. The overall reflectance of the walls, ceiling and floor was set. Although the real UGR value is affected by the non-Lambertian properties of the surfaces, the simulation software is limited to the calculation of the UGR value using the overall reflectance. Some secondary and minor room elements (e.g., cabling channels, electrical panel etc) were omitted from the design for the sake of complexity and their expected minor contribution to the final photometric result. In addition, during the tests, the operators of the measurement systems and the systems setup may have also contributed to the final result, which could not be modelled in the software. Figure 26 shows the modelling and a simulation result of the test room in RELUX software.

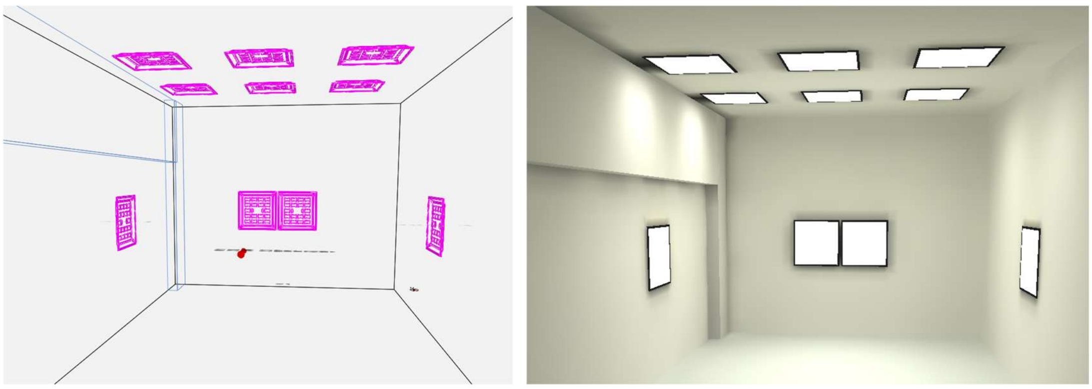
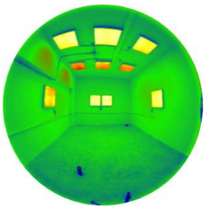


Figure 26 – Rendering of the modelled room in RELUX and simulation results for one lighting scenario.

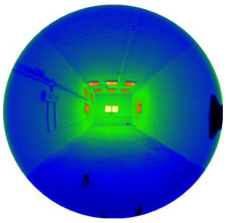
Having the simulated results of the UGR, the corresponding values were calculated using the HDR images generated by one of the measurement systems. Both results are shown and compared in Tables 2 and 3. Figures 27 - 29 show the visual comparison of the measured against simulated results and some statistical analysis. The results show a good match between the simulated and the measured (calculated) UGR values. For the two observer positions (4 m and 7 m), the average error on the seven scenarios is -1% and +3.5%, with a standard deviation of around 3% and 5% respectively. The differences in the predicted and measured values between simulation and measurement for each lighting scene can be explained by the non-perfect modelling of the scene and by the deviation of the observation point, especially at the longer distance. Both the wall reflectance and the luminous output of the individual luminaires, their size in the image and so on, may had slight or greater differences between the reality and the simulation. Overall, the results show a good match and the test room can provide a good reference for the validation of HDR imaging systems in terms of glare assessment.

Table 2. UGR validation results for an observer at 4 m distance from the wall



Lighting scenario *(switched on luminaires)*	UGR Simulated	UGR Measured	Difference	relative Difference
All	22.8	22.9	0.11	0.5%
All (dimmed to 50%)	20.4	20.5	0.09	0.4%
Ceiling and side walls	18.4	17.8	-0.60	-3.3%
Side walls	22.4	20.9	-1.48	-6.6%
Front wall	27.6	27.2	-0.38	-1.4%
Side and front walls	25.8	25.5	-0.32	-1.2%
Ceiling	12.8	13.2	0.38	3.0%
Mean			-0.31	-1.2%
St. deviation			0.57	2.8%

Table 3. UGR validation results for an observer at 7 m distance from the wall



Lighting scenario *(switched on luminaires)*	UGR Simulated	UGR Measured	Difference	relative Difference
All	20.4	21.6	1.22	6.0%
Ceiling and side walls	13.5	14.5	0.99	7.3%
Side walls	15.5	14.6	-0.94	-6.1%
Front wall	25.5	26.0	0.51	2.0%
Side and front walls	23.3	23.9	0.60	2.6%
Ceiling	12.2	13.3	1.09	9.0%
Mean			0.58	3.5%
St. deviation			0.73	4.9%

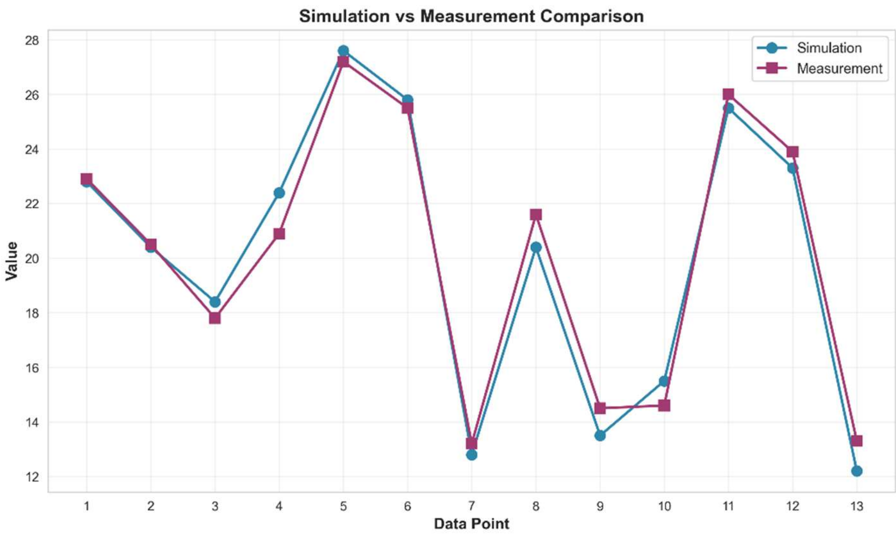


Figure 27 –Simulated and measured UGR values for different illumination scenarios (lighting scene dimming setting).

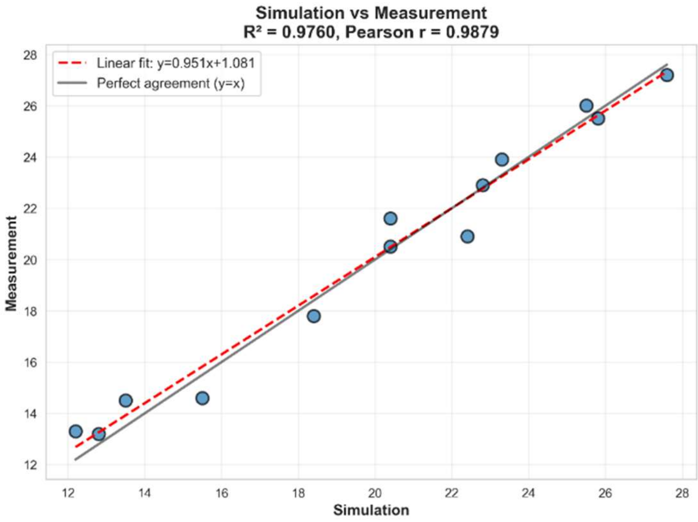


Figure 28 – Correlation of the simulated and measured UGR values for different illumination scenarios (lighting scene dimming setting).

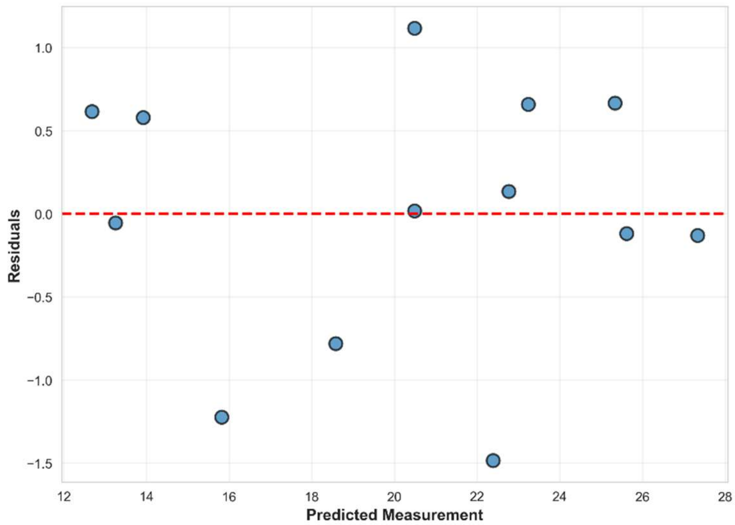


Figure 29 – Residual errors for each UGR level.

5 Summary/Conclusion

This Good Practice Guide names important aspects of the device configuration and measurement parameters to consider for achieving reliable and traceable measurements and glare assessment. Namely potential impact of the results by artefacts resulting from temporal light modulation, stray-light and ghost images were explained together with recommendations to assess or avoid them.

Each of the performed field measurement campaigns involved different HDR imaging devices (from different manufacturers, based on different technology and used in different configurations) successfully demonstrated the inter-comparability of HDR luminance measurements. The road lighting scene, façade lighting scene, and indoor lighting installation selected for the measurement campaigns served as typical applications for HDR imaging and glare assessment and presented very different ambient conditions (i.e., ambient temperature, temporal stability).

The campaigns also served as collaboration and discussion platform among the participants for the identification of issues and unforeseen errors during the preparation and execution of the measurements. The lessons-learned were mainly that the correct selection of the system components and its preparation as well as the investigation of the scene parameters is essential. The majority of the disparities was mainly due to missed parameters of the luminaires or the measurement system that may occur under the pressure of a field measurement session. Key guidelines on the uncertainty evaluation of traceable HDR imaging luminance measurements, glare and obtrusive light assessment are also provided for the consideration of the end users.

Beyond the exterior test scenes, the campaigned on the indoor lighting installation showed a good agreement between UGR values evaluated by simulation of the room modelled in RELUX and by using measurements using an HDR luminance imaging system. This demonstrates the capability to perform a reliable glare assessment based on properly adjusted/calibrated and operated HDR imaging systems.

In overall, when the HDR luminance measurements are well designed and performed using dedicated equipment and by respecting the individual characteristics of the test scene, the results are comparable and trustable and can be used of the assessment of corresponding glare metrics. The end users of such measurement system should also ensure the proper periodic calibration and maintenance of their systems in order to deliver good results to the relevant stakeholders.

6 References

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HiDyn repositories on GitHub. https://github.com/HiDyn-EURAMET-EPM-21NRM01

HiDyn Zenodo community: https://zenodo.org/communities/hidyn