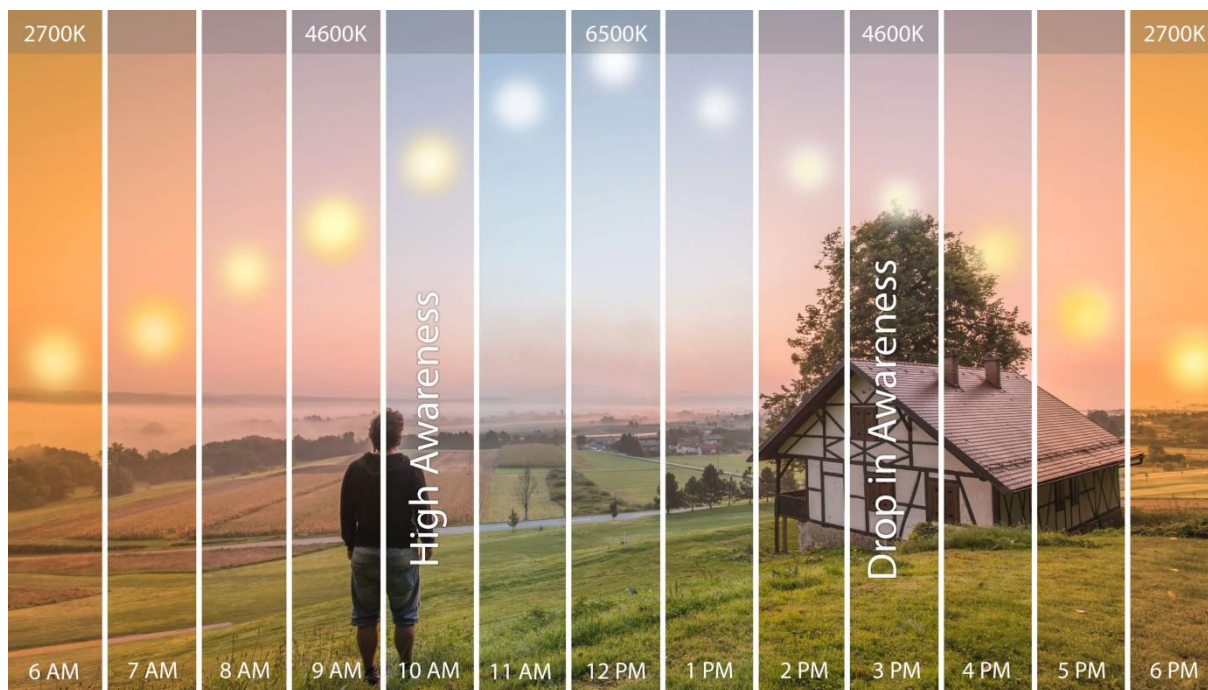


Lighting Metropolis

Evaluation of existing lighting conditions in three schools in Roskilde
Kommune.



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ROSKILDE
KOMMUNE

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1. Introduction

The goal of this work is to provide Roskilde municipality with some indications for the evaluation of existing lighting conditions in three different schools with various lighting systems. The evaluation focused on physiological aspects of light in educational institutions and evaluation of lighting in regard of new metrics and standards. Circadian lighting is the concept in which electric light is used in a way that supports human health and minimizes the effect of electric light on the human circadian rhythm. Scientists have discovered that long-term exposure to wrong lighting can have a negative impact on human health. That is why it is important to provide a proper lighting conditions in the educational institutions in order to create a suitable environment for students. The three schools which were involved in the project are:

1.1. Jyllinge school

The first school in this study is Jyllinge school which is located at Planetvej 30, 4040 Jyllinge and is equipped with both new and old lighting systems. For the evaluation of the old lighting system we focused on the classrooms located in building 4 (fig.1.) which have an old fluorescent lighting.

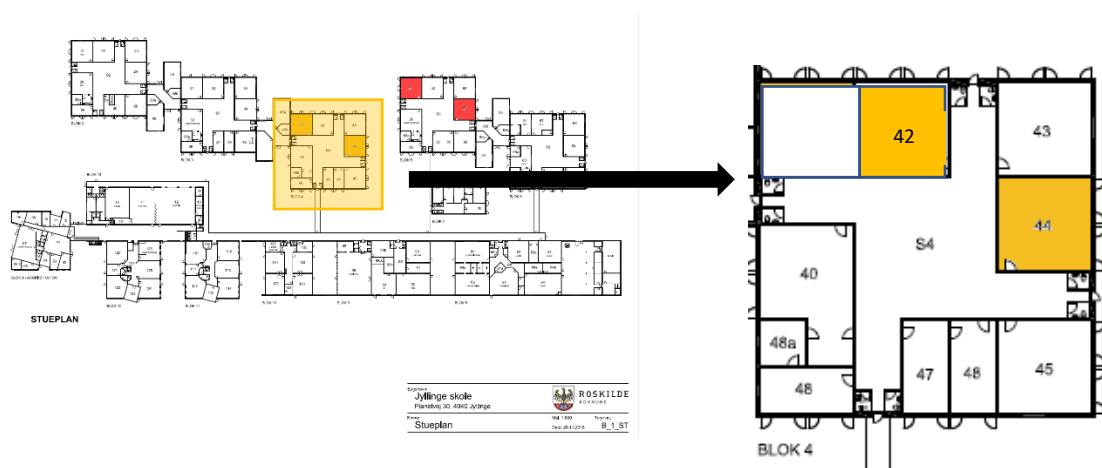


Fig.1. Jyllinge school building plan.

Measurements were conducted in two classrooms: number 42 (windows heading north) and 44 (windows heading east). The focus in the report will be on classroom number 44 due to the fact that this classroom is equipped with shading (curtains) which allowed measurements with and without daylight contribution.



Fig.2. Old lighting fixtures in Jyllinge school (room 44)

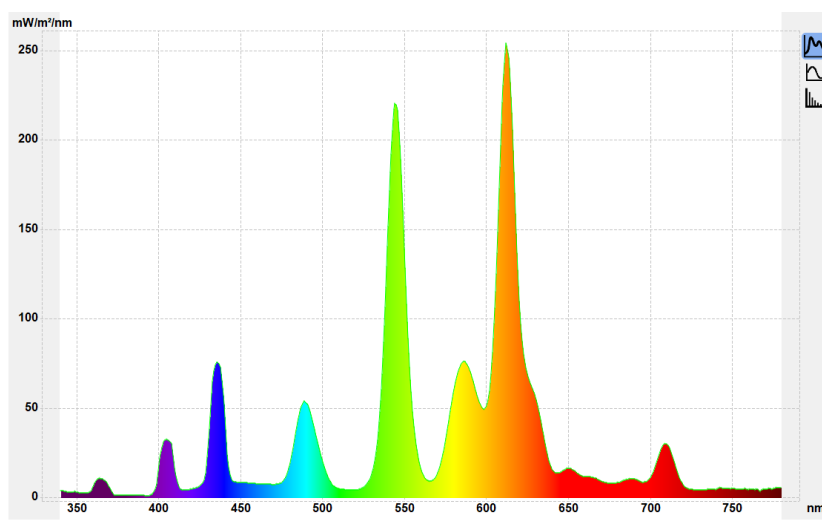


Fig.3. Spectral power distribution of the fluorescent lighting in Jyllinge school

1.2. Himmelev school

The second school is Himmelev school which is located Ollerupvej 5, 4000 Roskilde. This school is equipped with a new lighting system with different pre-sets for different scenarios. The panel also allowed users to adjust the colour temperature and intensity manually.

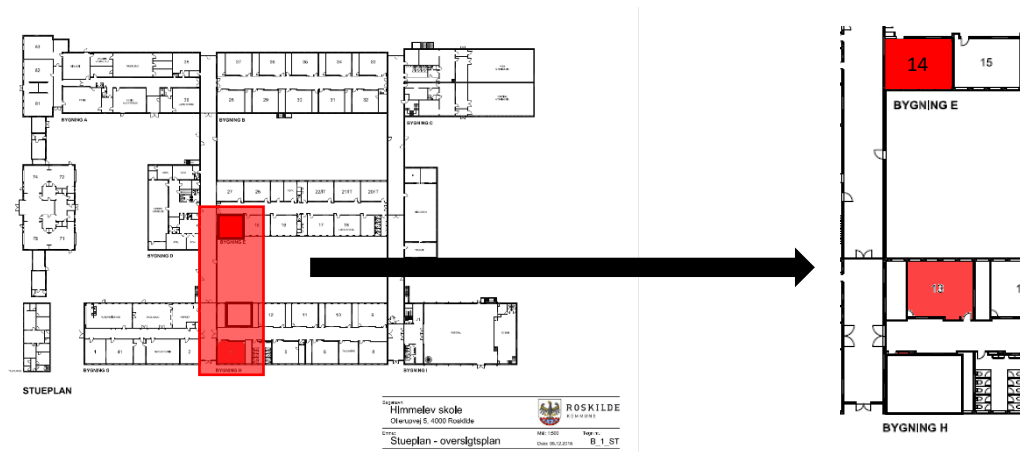


Fig.4. Himmelev school building plan.

For this school we conducted measurements in classroom 13 (windows heading west) and 14 (windows heading east). Both classrooms are equipped with shading, however we decided to focus on classroom 13 due to the fact that shading system was more precise in this classroom.



Fig.5. New lighting fixtures in Himmelev school.

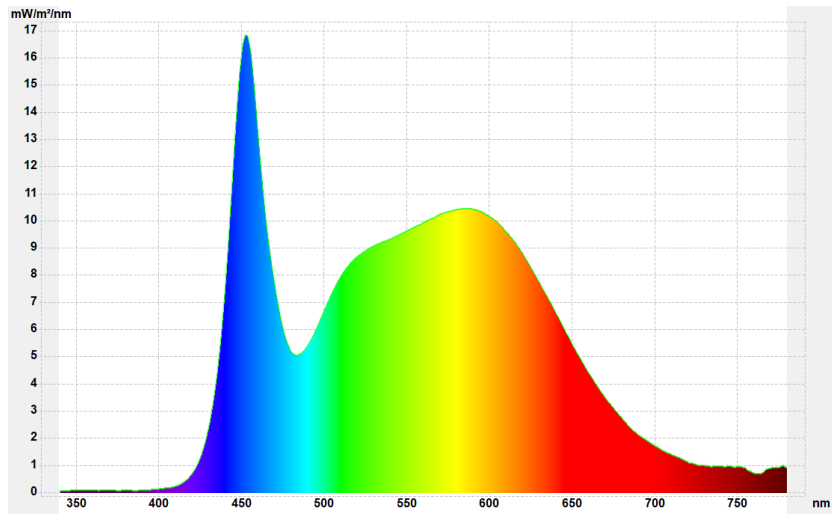


Fig.6. Spectral power distribution focus pre-set

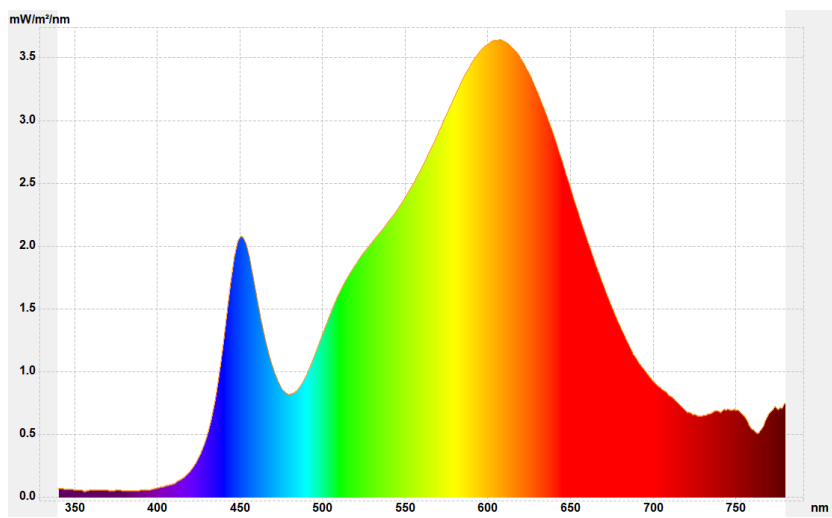


Fig.7. Spectral power distribution relaxed pre-set

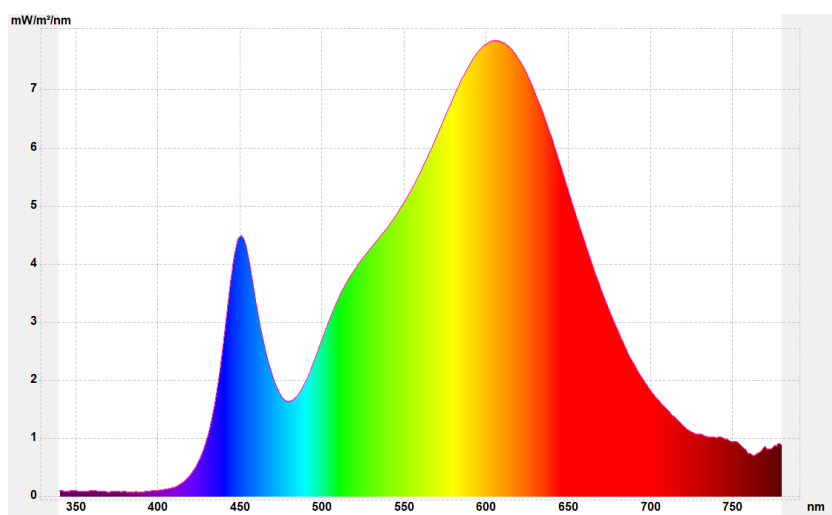


Fig.8. Spectral power distribution standard pre-set

The lighting system is equipped with four pre-sets for a Wake up (focus), Chill (relax), Smart Board, blackboard lighting and the standard lighting. Additionally, on the right on the panel there is a possibility to adjust the intensity and CCT of the light.

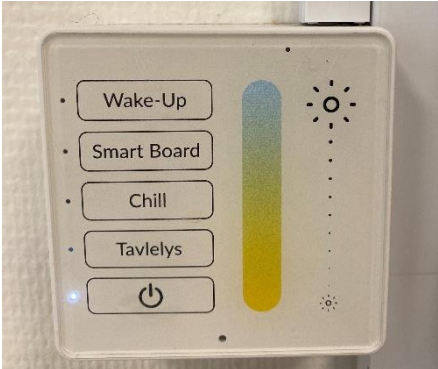


Fig.9. Control panel for a new lighting system with pre-sets.

1.3. Trekroner school

The third school is Trekroner school which is located Trekroner Allé 1, 4000 Roskilde. The school is equipped with a standard LED lighting. The two classrooms visited are not equipped with curtains so only measurements with daylight were taken.



Fig.10. Trekroner school building plan.

First classroom (windows heading west) is equipped with rectangular LED panels.



Fig.11. Lighting fixture in Trekroner classroom (windows heading west).

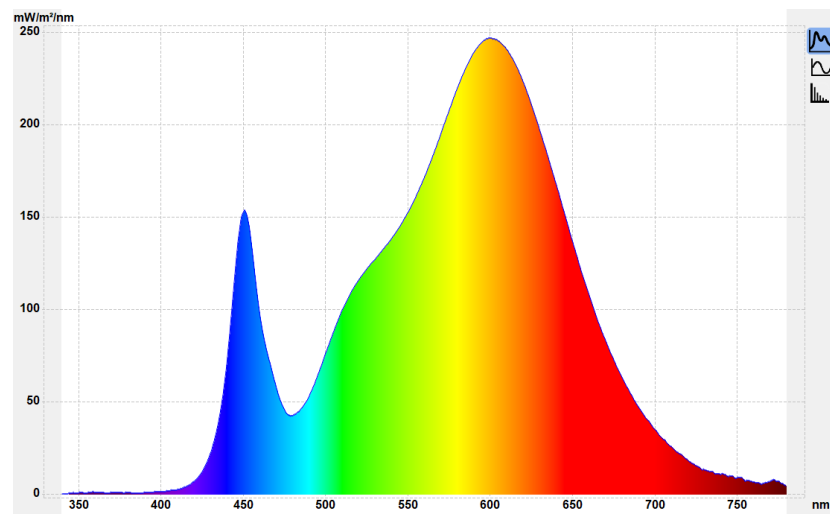


Fig.12. Spectral power distribution (windows heading west).

Second classroom (heading north) is equipped with round LED fixtures.



Fig.13. Lighting fixture in Trekroner classroom (windows heading north).

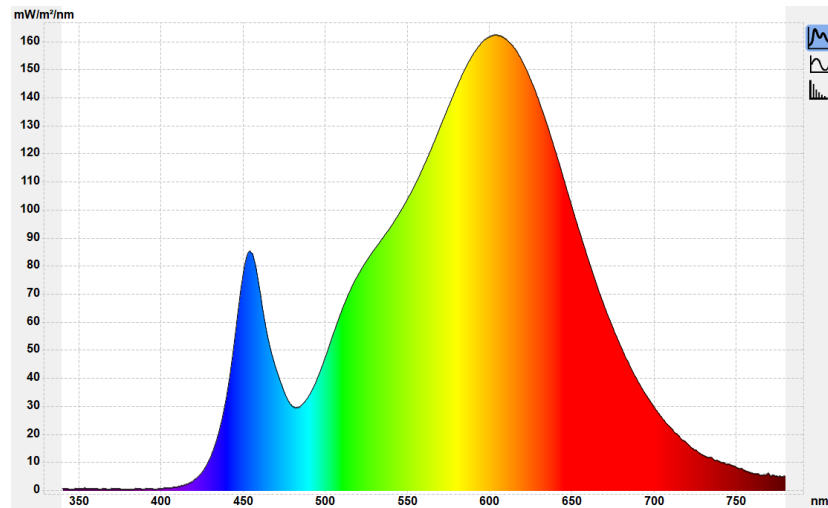


Fig.14. Spectral power distribution (windows heading west).

Table 1. Sum up of conditions in each classroom in all three schools.

		Shading	Direction	Pre-sets	Lighting system
Jyllinge	42	No	North	No	Old (fluorescent)
	44	Yes	East	No	Old (fluorescent)
	52	No	North	Yes	New (LED)
	64	No	East	Yes	New (LED)
Himmelev	13	Yes	West	Yes	New (LED)
	14	Yes	East	Yes	New (LED)
Trekroner	2B	No	West	No	Standard (LED)
	H8	No	North	No	Standard (LED)

2. Metrics and standards in circadian lighting

2.1. Metrics

Equivalent Melanopic Lux (EML)

Equivalent Melanopic Lux (EML) is a metric for measuring the biological effects of light on humans. Melanopsin is the fifth opsin-based photopigment from the mammalian eye and mediates the non-visual response. Following the discovery of Melanopsin, a new class of photoreceptor was discovered in the retina: the intrinsically photosensitive retinal ganglion cells (ipRGCs). These photoreceptor cells contain Melanopsin and are principally, though not exclusively, responsible for the body's neuroendocrine response to light.

Photosensitive retinal ganglion cells (ipRGCs) regulate the human circadian response to light. These are non-image forming photoreceptors within the eye. Circadian rhythms are kept in sync by various cues, including light which the body responds to facilitated by ipRGCs.

The Equivalent Melanopic Lux quantifies light effects on the human circadian cycle and can be calculated at a point and in a given direction by multiplying the visual illuminance (in lux) by the melanopic ratio which depends on the spectrum of incident light.

Daylight efficacy ratio (DER)

Recently, the CIE published a new standard (CIE S 026/E:2018) in which the so called 'melanopic daylight efficacy ratio' (abbreviated to melanopic DER) is introduced. This number is helpful in estimating the impact that a light source may have on our circadian rhythm. The melanopic DER can be directly calculated from the spectral power distribution. The efficacy ratio should be low at night (closer to 0) and higher (closer to 1) during the day. Daylight Efficacy Ratio values informs a designer how a given light source is interacting with the biology and behavior of people within that specific lighting environment. Higher values are generally good for daytime scenarios and encourage activity whereas lower values are wanted for nighttime and pre-sleep scenarios. The melanopic DER represents the ratio of the melanopic flux ("M") per photopic luminous flux ("P") of a test light, and this dimensionless quantity can usefully be thought of as the new "M/P ratio". By definition, this ratio is normalized to 1 for the reference illuminant D65. D65 corresponds roughly to the average midday light in Western Europe / Northern Europe (comprising both direct sunlight and the light diffused by a clear sky), hence it is also called a daylight illuminant. So, Daylight Efficacy Ratio (DER), is 1 for a daylight/daytime (D65) exposure and 0 in complete darkness.

Circadian stimulus

Circadian Stimulus (CS) is a recent metric developed by the Lighting Research Center (LRC) to measure the effectiveness of a light source in providing circadian stimulus, which ranges from 0 (no stimulus) to 0.7 (full saturation). The LRC recommends exposure to a CS of 0.3 or greater at the eye, (equivalent to 180 lux from daylight) for at least 1 h in the early part of the day.

2.2. WELL Standard

Regarding EML (equivalent melanopic lux) we followed the WELL standard for melanopic light intensity in learning areas where one of the following requirements had to be met:

- Early education, primary and secondary schools, and adult education for students primarily under 25 years of age: Light models (which may incorporate daylight) show that at least 125 equivalent melanopic lux is present at 75% or more of desks, on the vertical plane facing forward 1.2 m [4 ft] above finished floor (to simulate the view of the occupant). This light level is present for at least 4 hours per day for every day of the year.
- Ambient lights provide maintained illuminance on the vertical plane of equivalent melanopic lux greater than or equal to the lux recommendations in the Vertical (Ev) Targets in Table 3 of IES-ANSI RP-3-13, following the age group category most appropriate for the population serviced by the school. For example, art studios in primary and secondary school are provided with 150 equivalent melanopic lux from the electric lights.

3. Evaluation of existing lighting conditions – experimental setup

Measurements in Jyllinge school were conducted on the 13th of October 2020 and measurements in Himmelev and Trekroner schools on the 14th of October 2020. Measurements were carried out between 9am – 1pm at three points in each of the classroom: in the middle, close to the window and far from the window (close to the wall). Thanks to the measurements in various points in the classroom we get a better overview of the impact of the layout of the desks in the classrooms and how big is the difference between those areas in terms of lighting. Measurements were done (if possible) with both scenarios with curtains on (no daylight) and curtains off (daylight) in order to see the contribution of only lighting system without daylight. Measurements were carried out with a GL SPECTIS 1.0 T Flicker spectrometer.

Measurements:

- Vertical 1.2 m above the floor
- Three different desks in the classroom

Setup:

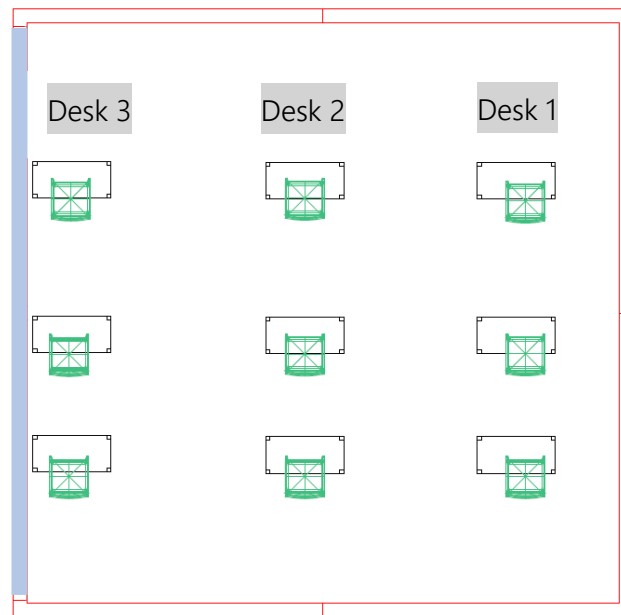


Fig.15. Layout of measured desks in each classroom

Besides the measurements regarding different points in the space, it is also important to measure different scenarios regarding shading. In this context, we focused on the measurements in the rooms which were equipped with shading (curtains) due to the fact that allows to see the impact of lighting system in the space without daylight and compare and evaluate how significant is daylight contribution in the space.

4. Experimental results

4.1. Equivalent melanopic lux

Equivalent melanopic lux (EML) measured at three different desks in the classroom in Jyllinge school equipped with old lighting system. Measurements conducted with curtains on and off.

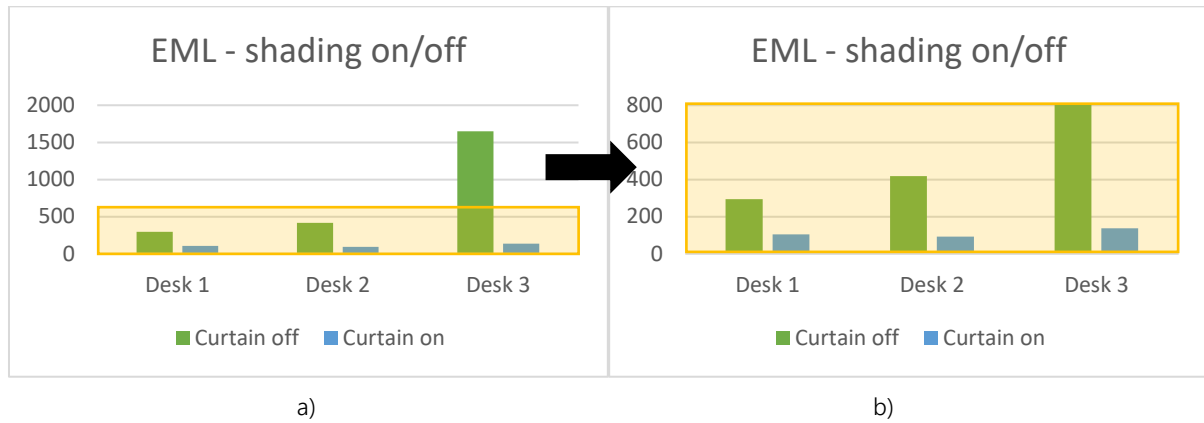


Fig.16. a) Equivalent melanopic lux results from Jyllinge school with old lighting system with curtains off and on b) close up with changed y axis in order to see differences for desk 1 and 2.

For desk 3 we received extremely high values of equivalent melanopic lux due to the placements of the desk close to the window which might be caused that measurements were taken when the direct sunlight hit the spectrometer that's why the value is so high.

EML results for Himmelev school with three different pre-sets with curtains on and off for three differently located desks.

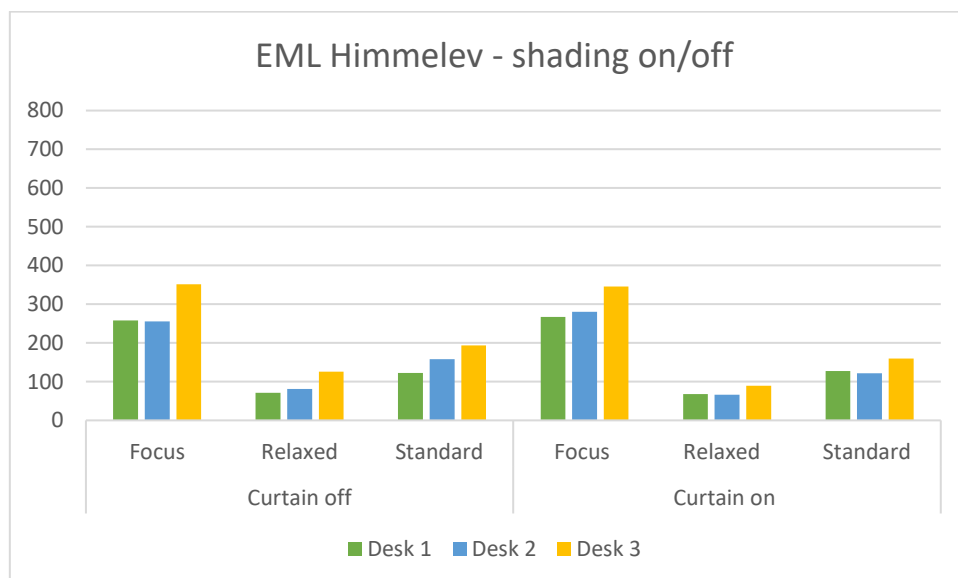


Fig.17. Equivalent melanopic lux results from Himmelev school with new lighting system with curtains on and off.

EML results for Trekroner school measured with lights turned on and off.

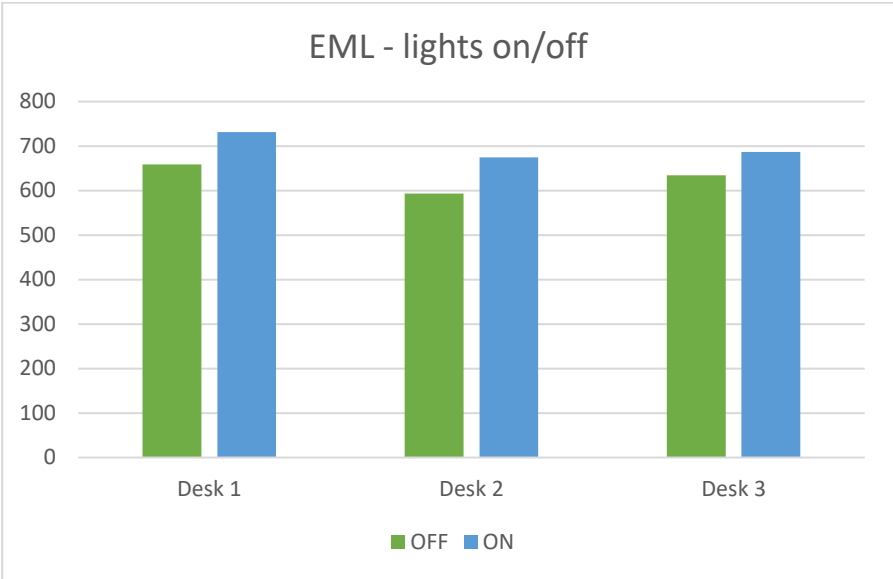


Fig.18. Equivalent melanopic lux results from Trekroner school with lighting system on and off.

EML results for Trekroner classroom with windows heading north.

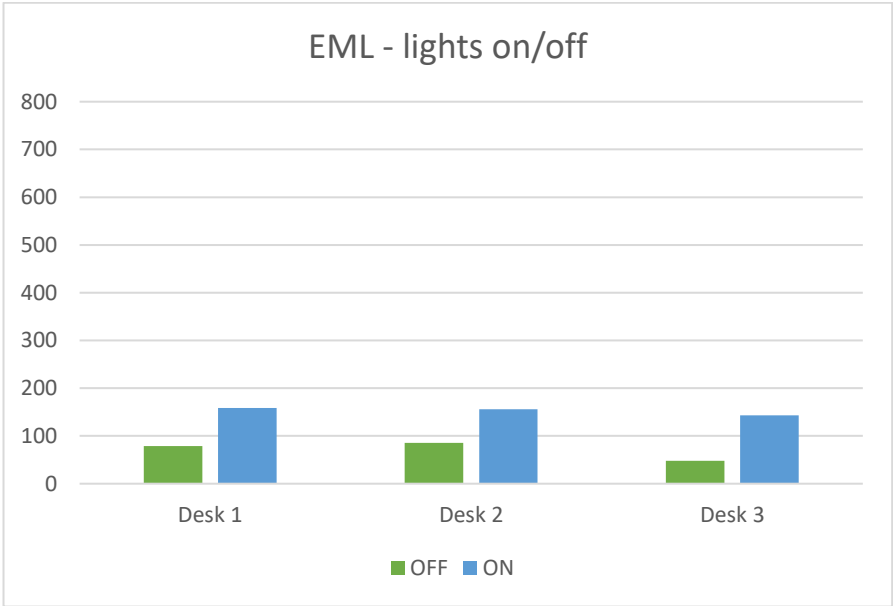


Fig.19. Equivalent melanopic lux results from Trekroner school with lighting system on and off.

4.2. Daylight efficacy ratio (DER)

DER measured at Jyllinge school with curtains on and off

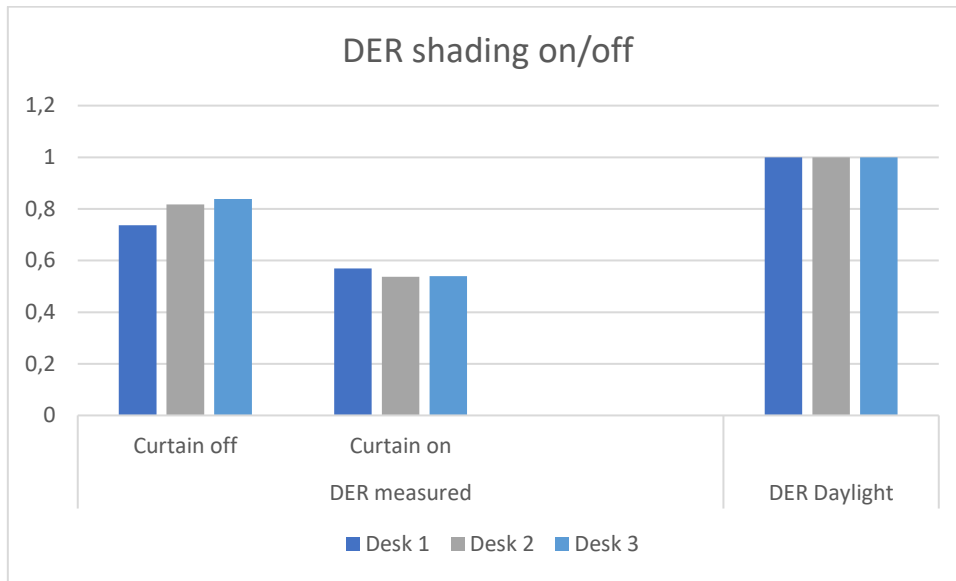


Fig.20. Daylight efficacy ratio results from Jyllinge school with old lighting system measured with curtains on and off.

Himmelev DER results

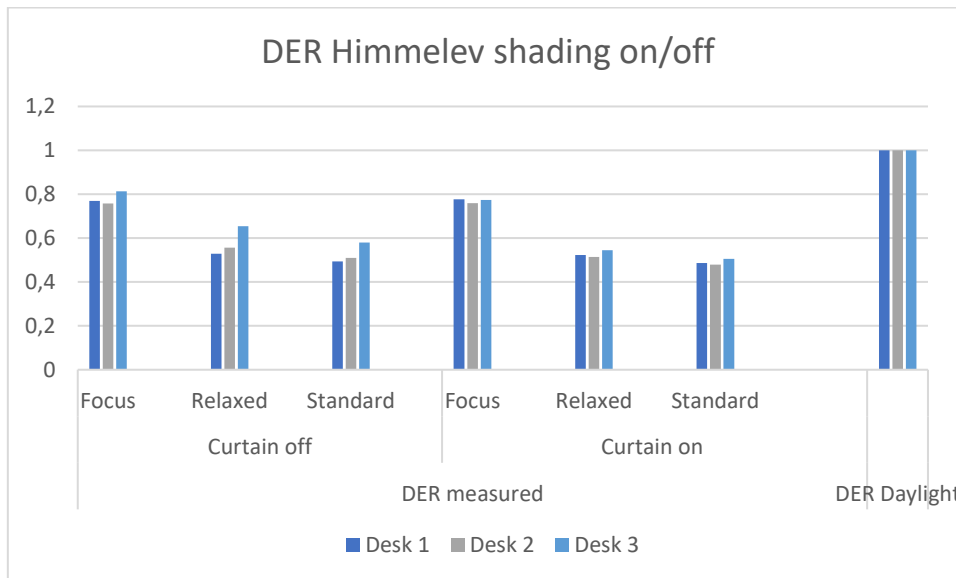


Fig.21. Daylight efficacy ratio results from Himmelev school with new lighting system

In Himmelev school the spectral power distribution of the standard and relaxed pre-set are very similar. In both pre-sets CCT is around 3000-3200K and the distribution is quite similar.

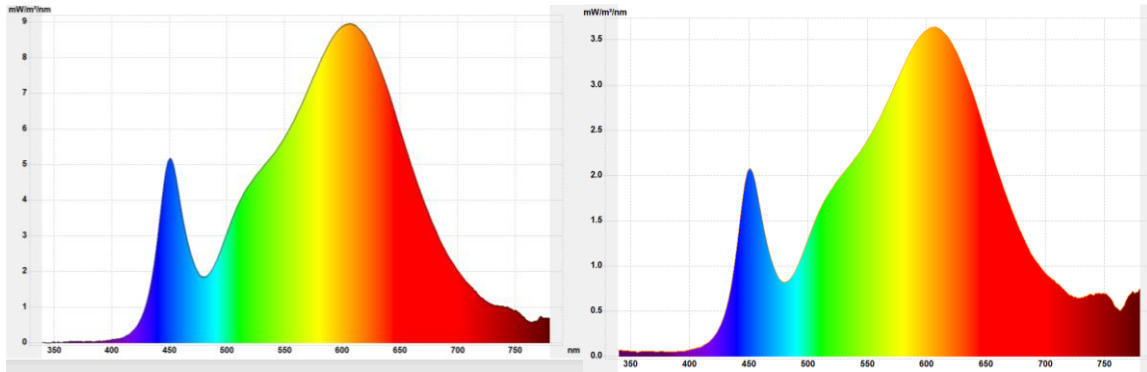


Fig.22. Comparison of spectral power distribution for standard (left) and relaxed (right) pre-set

Trekroner school DER classroom with windows heading west

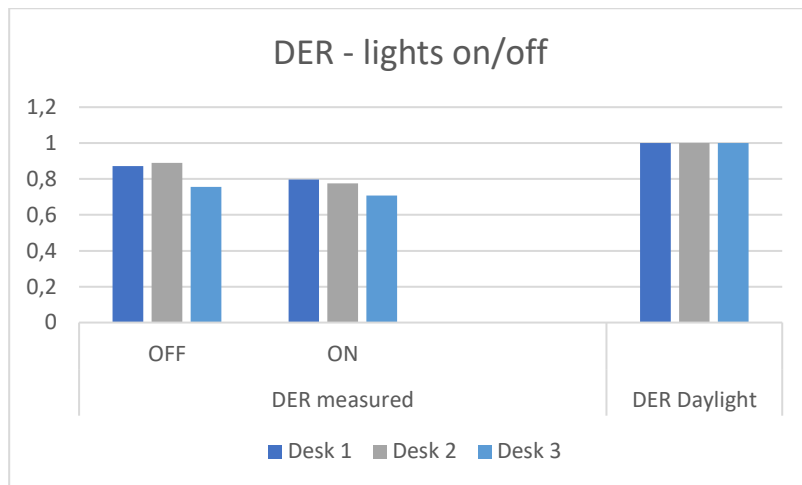


Fig.23. Daylight efficacy ratio results from Trekroner school with lighting system on and off.

Trekroner school DER classroom with windows heading north

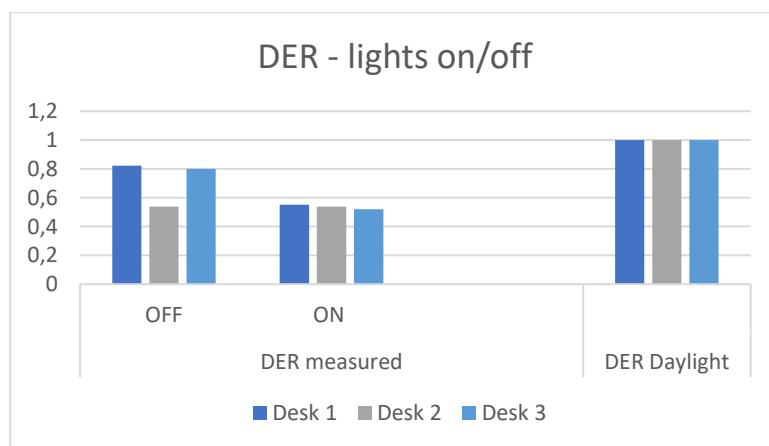


Fig.24. Daylight efficacy ratio results from Trekroner school with lighting system on and off.

4.3. Circadian stimulus

Comparison of classroom 44 in Jyllinge school with old lighting system with curtains on (no daylight) and off (daylight) in order to see the daylight contribution and distribution in the classroom for three differently located desks.

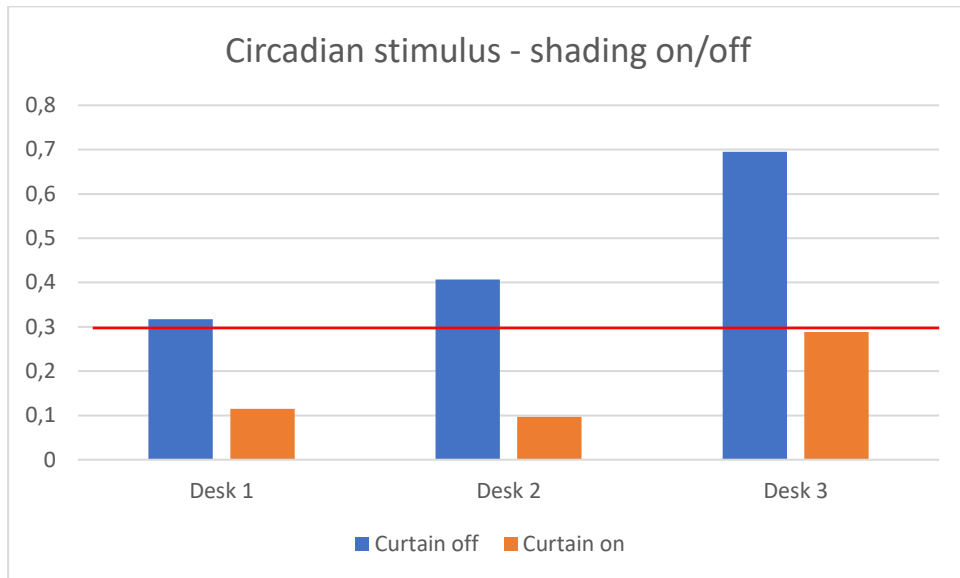


Fig.25. Circadian stimulus results from Jyllinge school in the classroom with old lighting system measured with and without shading system.

Comparison of circadian stimulus in Himmelev school with three different pre-sets with and without shading for three differently located desks.

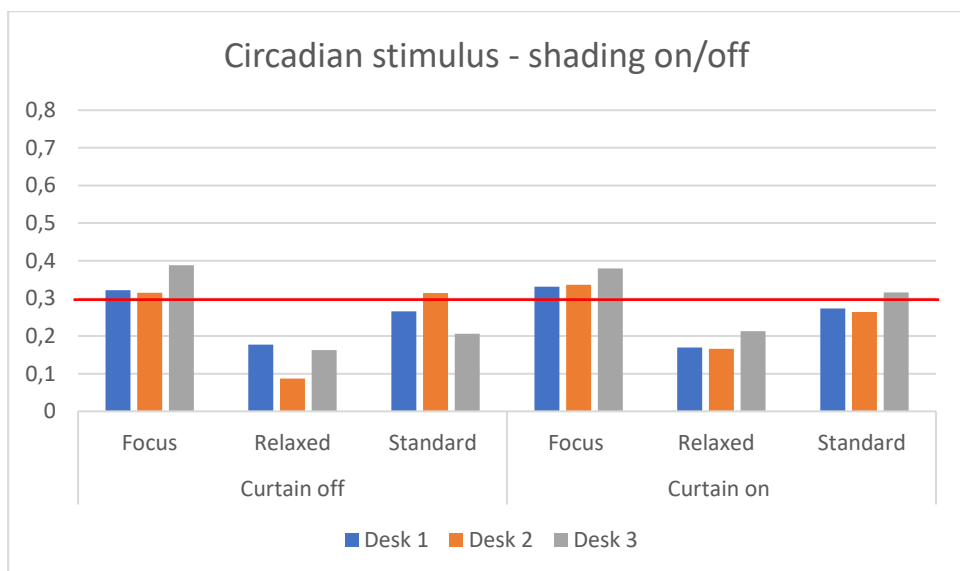


Fig.26. Circadian stimulus results from Himmelev school in the classroom with new lighting system measured with and without shading system.

Due to the fact that Trekroner school is not equipped with shading system we compared the circadian stimulus with lights turned on and off. However, both measured classrooms are located in a way where they receive a lot of daylight.

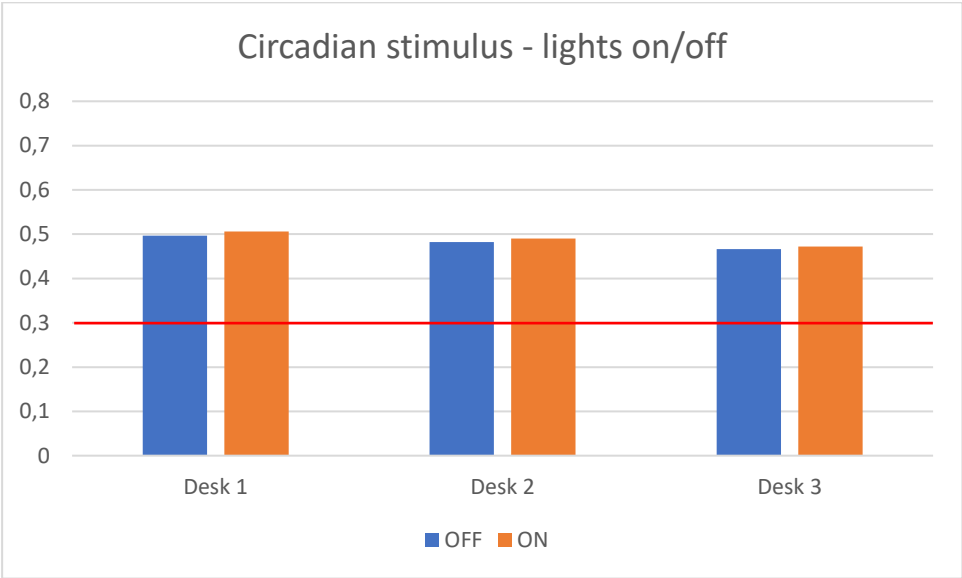


Fig.27. Circadian stimulus results from Trekroner school in the classroom with windows heading west measured with lights on and off.

Classroom in Trekroner school with windows heading north.

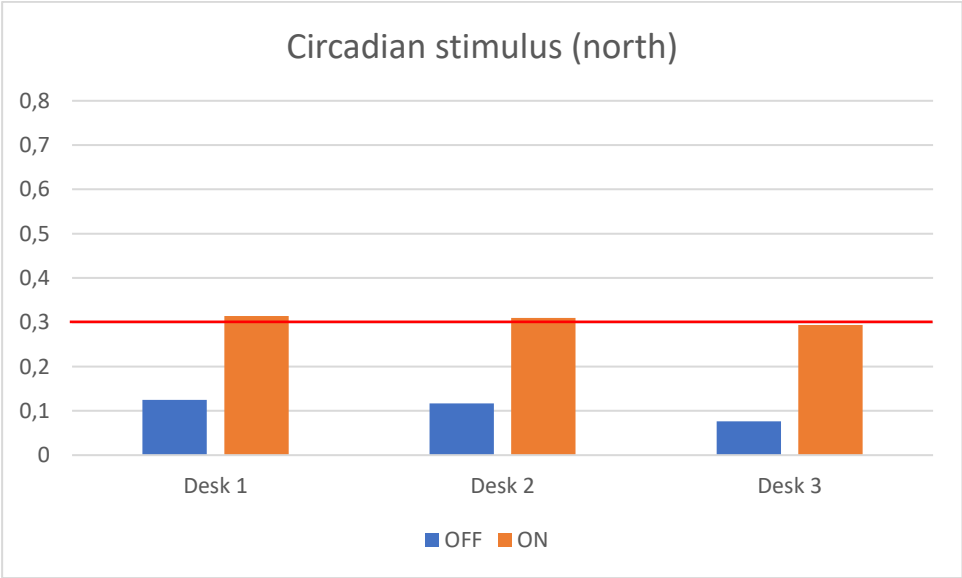


Fig.28. Circadian stimulus results from Trekroner school in the classroom with windows heading north measured with lights on and off.

5. Findings

- In terms of EML when the curtains are off, we received high values of EML for Jyllinge school with old system, however when the curtains are on (limited daylight access) the classroom does not meet the WELL Standard requirements with 125 EML or more for 75% of the workspace (Fig.16).
- EML values in Himmelev school are accurate to the pre-set functions. For the relaxed pre-set EML values are below 125 EML and for focus pre-set for both cases with curtains on and off the EML values are above 125 EML.
- For Trekrøner classroom heading west with and without lights the classroom has EML value above 125 EML. On the other hand the classroom which is heading north does not meet the WELL Standard recommendation with lights turned off and with the lights turned on only slightly meets threshold (values around 140-150 EML).
- In terms of DER parameter in Himmelev school we received the results which resemble daylight the most for the Focus pre-set. Relaxed and standard pre-sets have similar values which are usually 25% lower than for the focus pre-set. In terms of relaxed pre-set lower values would be recommended however for standard pre-set values can be a little higher.
- Due to the window orientation (west) during the measurements in Himmelev school we did not receive a lot daylight and we can see that the results with and without curtain are similar.
- The spectral power distribution for standard and relaxed pre-set are almost identical. The only noticeable difference is in a red part of the spectrum.
- For Trekrøner school due to the big influence of daylight in the classroom we received the highest numbers of DER out of all three schools. Values for the Trekrøner classroom heading west are almost 10% higher than for the classroom in Himmelev school. We also receive slightly higher results when the lights were off which means that the spectrum of LED lowers the DER parameter (LED lights are changing the general spectrum of the light in the classroom which is different than the spectrum of daylight).
- In the north facing classroom in Trekrøner school with only daylight we got high values for desks 1 and 3 which had considerable bigger access to daylight than the desk in the middle. However, with the lights turned over the values dropped 20% for desk 1 and 3.

- In Jyllinge classroom with old lighting system we received high values of DER with the shading off and 20% lower values with the shading on. DER values with no daylight contribution resembles relaxed pre-set from the Himmelev lighting system and those values are too low to provide the right stimulus and conditions for learning and feel energetic.
- From the results above we can clearly see that the placement of desks in the classrooms really matter. As we can see from Circadian stimulus results desk 3 which is located closer to the windows than desk 2 and desk 1 always has a Circadian stimulus value above 0.3 when the curtain is off (exception for Himmelev school with standard lighting pre-set) which supports alertness during the day. However, when the daylight access is limited (cloudy day with no direct sunlight) we can see that the old lighting system in Jyllinge school does not support alertness in the classroom and has values below 0.3.
- Circadian stimulus values for the relaxed pre-set are always below 0.3 which supports the function of the this pre-set and makes it suitable for lighting during the break or after the classes when the focus of students is not required.
- Regarding Circadian stimulus in Trekroner school in the classroom heading west both with lights on and off the Circadian stimulus value is above 0.3, however this classroom is equipped in huge window surface from west (and also small windows heading east) which means it strongly relies on daylight. However, the classroom which windows are heading north with lights on only meets the requirement of CS values above 0.3 for desk 1 and 2 (Fig.).

6. Summary

To sum up, physiological effects of light are starting to get notice in the lighting design industry and begin to play an important role. New discoveries are allowing us to better understand the effects which are happening in our brain and how it influences our alertness and general well-being. From the conducted measurements in three different schools with different lighting systems we can see the importance of the daylight in the classrooms as well as the layout of desks. It is desired to provide the equal access of daylight to each and one of the desks which with suitable lighting design is possible. In order to provide a comfortable and healthy environment in schools some changes can be implemented. The old lighting system in Jyllinge school should be changed in order to provide a proper alertness for students in the classroom. Regarding Himmelev school the pre-sets are fulfilling their functions: low values of circadian stimulus and EML for relaxed pre-set and high values for focus. However standard pre-set looks almost the same as relaxed pre-set so changes of spectral power distribution in the standard pre-set can be applied. Overall, the lighting in Trekroner school and Himmelev school can be considered as good and well functioned. In the future the impact should be also on the daylight contribution in the classrooms as we can see that with big influence of daylight in Trekroner classroom (west) we received good on physiological effects parameters on the other hand with classroom heading north parameters are much lower.