



Degree Project in Architecture

Second cycle, 15 credits

Lighting to enhance cooperative learning in classrooms

A proposal for Iggesund Skola

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A proposal for Iggesund Skola



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Abstract

Cooperative learning refers to teaching methods that encourage students to work together in small groups to help each other learn educational content. In Sweden, cooperative learning methods are used in classrooms as an educational approach to organize classroom activities into academic and social learning experiences.

This thesis investigates how lighting can support cooperative learning in Swedish classrooms to enhance students' learning performance while taking into account visual tasks during different pedagogical activities and visual comfort.

To answer this question, the existing lighting of a middle school classroom in Iggesund Skola, Sweden, was studied through a methodology based on both qualitative and quantitative methods. Analysis of literature review, personal observations and interviews, measurements of illuminance, luminance, and color metrics, and 3D simulations formed the foundation of the lighting design proposal for the refurbishment of classrooms.

The results show that the lighting requirements of students and teachers have changed with time. To include cooperative learning methods, the users ask for a changeable lighting solution that can work with their flexible learning method. Hence, the design proposal focuses on enhancing students' learning performance while emphasizing the flexibility of their learning method.

Key words: Cooperative learning, flexibility, variable lighting, learning performance, classroom lighting

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1. Introduction

Lighting has a significant impact on students' learning performance. Previous research indicates that appropriate lighting for schools improves test scores, reduces off-task behavior, and plays a key role in students' achievement (Schneider, 2002).

In Sweden, cooperative learning methods are used in classrooms as an educational approach to organize classroom activities into academic and social learning experiences. Cooperative learning refers to teaching methods that encourage students to work together in small groups to help each other learn educational content. It is particularly popular for younger students due to greater flexibility in schedules making it easier to do cooperative work (Slavin, 2015). Since lighting positively influences concentration, working speed, accuracy, task performance, and circadian rhythm (Sleegers et al., 2013), the lighting of a classroom should complement and support this flexible system of cooperative learning in Swedish schools to enhance the learning performance of students.

With the phase-out of fluorescent lamps in the European market (European Commission 2022), schools need a new lighting system. Hence, this thesis aims to analyze the lighting of a middle school classroom in Iggesund Skola, Sweden, and propose a new lighting scheme subsequently for the refurbishment of classrooms that focuses on enhancing students' learning performance while keeping in mind the flexibility of their learning method.

Sustainability statement

The thesis will also focus on the health and well-being of students and teachers and aim to enhance learning performance and the sense of community learning inside classrooms (UN Sustainability Goals 3 and 11). The project aims to reduce the overall energy consumption in terms of lighting through different lighting scenes (fig. 3) while teaching the students a sustainable way of living (UN Sustainability Goal 12).



Figure 1 Targeted UN Sustainability goals (UN Sustainable development 2022)

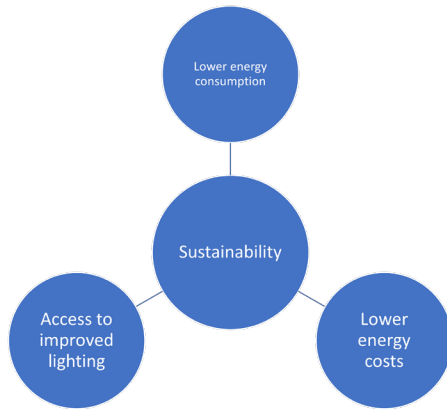


Figure 2 Sustainability targets

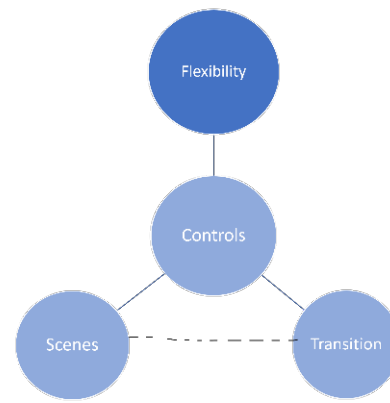


Figure 3 Role of control system and lighting scenes for flexibility in activities

2. Background

The teaching methods and classroom layouts in Swedish schools have gradually evolved over the past forty-five years (Duthilleul et al. 2020). There has been a shift from teacher-centric pedagogy to student-centric pedagogy in the education system, which emphasizes the individuality of pupils (fig. 4). Today, the classrooms need to facilitate various activities, collaborative and individualized learning modes, and support a wide range of pupil preferences and abilities (Hofmeister 2020). A cooperative way of learning has been introduced rather than a "one size fits all" approach to encourage learning and discussing with peers to prepare young minds for the collaborative way of working in today's workplaces. To support this way of learning, architects have responded to these challenges, for instance, by providing flexible spatial arrangements and adaptable furniture layouts that support variability. The pupils' organization in class has changed chiefly from the traditional formal rows layout facing the teacher in front to groups of pupils sitting around tables (Dudek 2005).

A study conducted in Malmö confirms that most of the schools in Sweden include, next to the traditional classroom, an additional space of smaller dimension called *grupprum*, connected by a door to the main room. This organization of the space called *Plus classroom* promotes group activities and a more flexible social organization of the learning activities. The layout of the *grupprum* is usually arranged to facilitate cooperative work or self-study with, in some cases, soft areas or corners that encourage concentration. The teaching takes place mainly in the *group space*, characterized by the presence of a space extension (an additional room). This *classroom plus* (classroom, plus small room extension) organization potentially offers the opportunity to engage students in different activities during school time. The teachers regularly split the students into smaller groups and assign them various tasks, using both the wider group space and the smaller one to promote group collaboration, independent study, and online research (Duthilleul et al. 2020). To support different modes of learning and pedagogical activities, a classroom should allow for flexibility in the short, medium, and long term and adapt to the actual needs of teachers and pupils (Duthilleul et al. 2020).

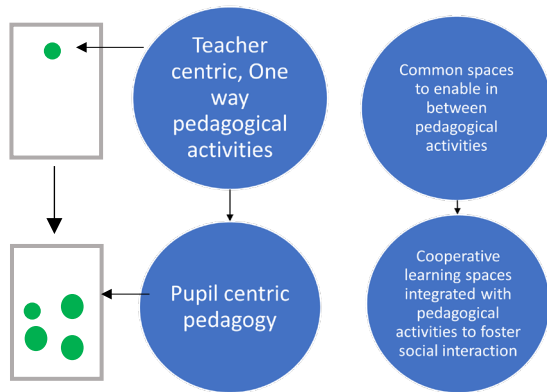


Figure 4 Evolution in pedagogical activities and architectural layout

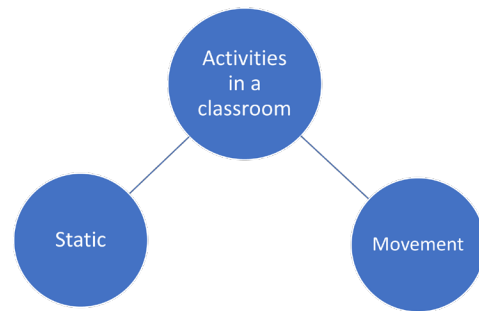


Figure 5 Activities in a classroom

Lighting in classrooms

The physical environment of a classroom can significantly impact students' learning performance. A study conducted in 2015 found that physical characteristics like lighting, air quality, temperature, flexibility, ownership, complexity, and color can cause up to 16% variations in learning progress in a classroom. According to this study, out of all the seven factors, the impact of lighting on learning was found to be the maximum (fig. 6), that is 21% (Barrett et al. 2015).

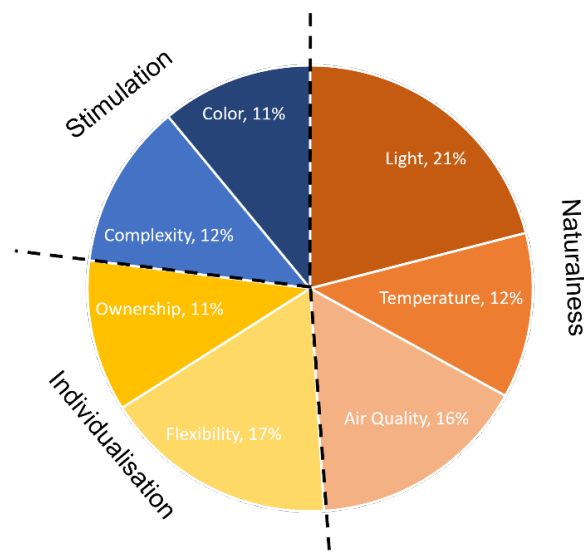


Figure 6 Impact of lighting on learning (Barrett et al. 2015)

However, the artificial lighting in today's classrooms has not evolved with time and thus, in most cases, does not consider the advanced layouts, educational activities, and cooperative learning. It is imperative to look beyond the traditional monotonous uniform lighting approach to enhance cooperative learning in classrooms. It is also crucial to maintain a delicate balance between an over-stimulating environment and boring; hence, an optimum way of designing should be considered where the classroom environment should lie between neither too chaotic nor too monotonous (fig. 7) (Barrett et al. 2015). Additionally, both visual and non-visual effects of lighting on students and teachers should be studied and considered while designing. This thesis investigates how lighting can support the flexible method of cooperative learning in Swedish classrooms to enhance students learning performance while taking into account visual tasks during different pedagogical activities and visual comfort.

Besides lighting, various factors like acoustics, maintenance, cleanliness of the school, safety, etc., might influence students' performance (Tanner & Langford, 2002). These factors are beyond the scope of this study.

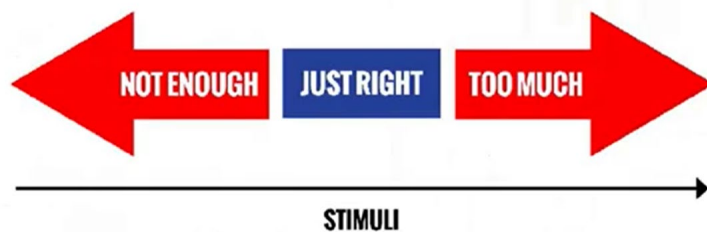


Figure 7 Delicate balance between an over-stimulating environment and boring (Barrett et al. 2015)

3. Methodology

The existing lighting for fourth-grade classrooms in building C of Iggesund Skola was analyzed. Since the fourth graders use two classrooms, the main classroom and an additional space for group activities known as a secondary classroom, four methods were used to analyze the spaces and draw relevant conclusions for the design proposal (fig.8 and 9).

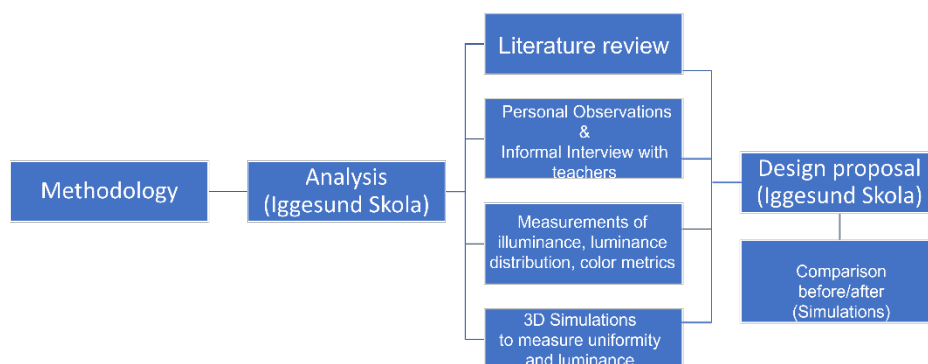


Figure 8 Methodology

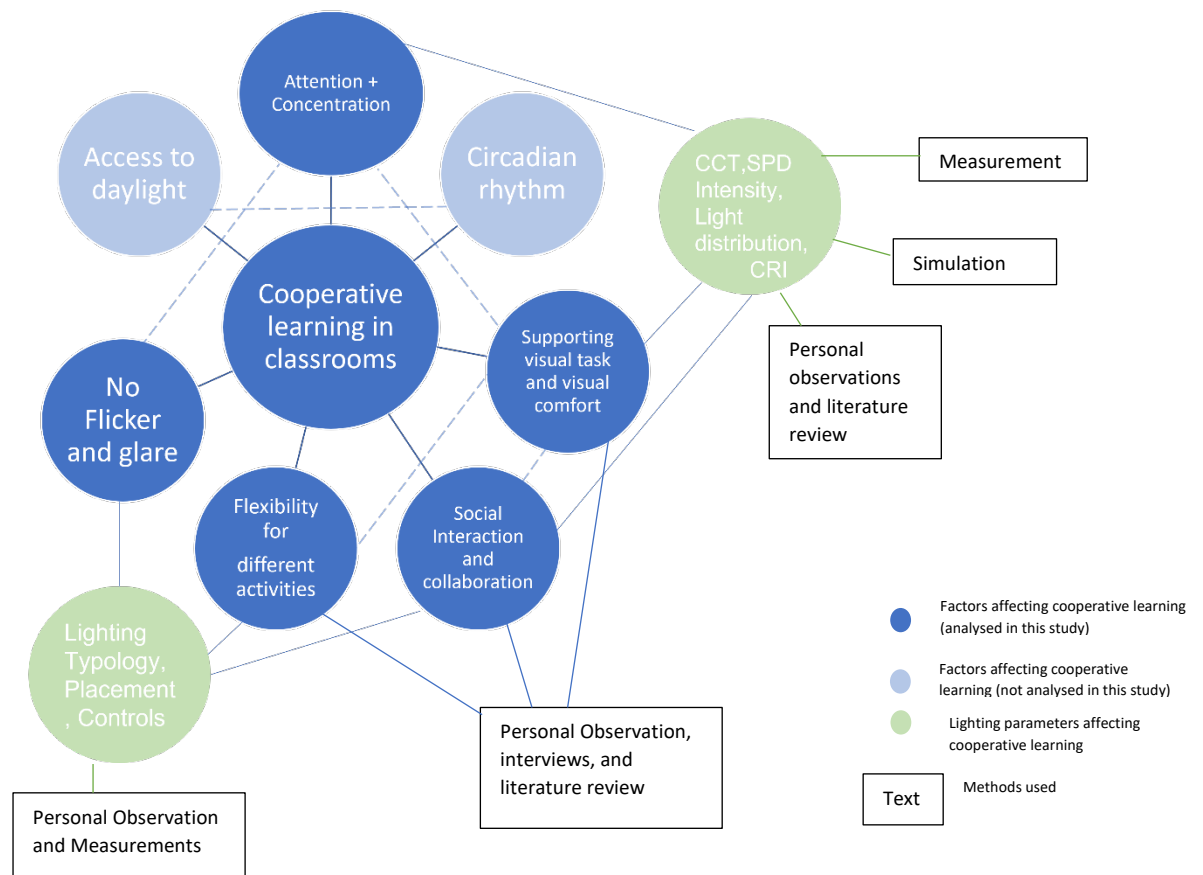


Figure 9 Methodology

3.1 Method 1

Literature review

To study the classroom design and the effect of lighting on students, the author reviewed previous research literature.

3.2 Method 2

Personal observation and informal interviews:

To analyze the pedagogical activities of students, spatial usage, the impact of lighting on students' behavior and learning, and user preferences of students and teachers, the data was collected through qualitative methods like interviews with teachers and classroom observations (fig.10).

On 11th April 2022, two fourth-grade teachers in Iggesund Skola were interviewed regarding their teaching methods, pedagogical activities in class conducted for different subjects, and student learning behavior.

For personal observations, on the 12th and 13th April 2022, students and teachers were monitored while they continued their normal curricular activities and routines during four courses - Maths, Social Science, Natural science, and English. With the help of Observation logs (Dunn and Shriner 1999), data regarding the pedagogical activities in class, visual tasks, spatial movement and organization, lighting preferences and needs of students and teachers, use of shading devices, behavior and responses of students during different activities were recorded. The author also analyzed seven factors of the V/P Theory (Liljefors 1999) on a five-point scale to evaluate the visual perception of the space during different times for various activities. Personal observations further included observing the lighting typology, placement and controls used and preferred by the users in the spaces across different times of the day for different activities.

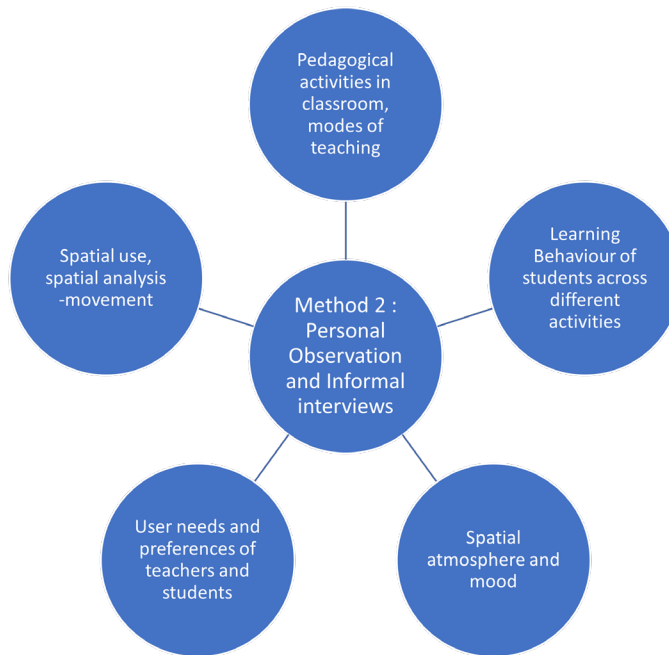


Figure 10 Method 2 Personal observation and Informal interviews

3.3 Method 3

Measurements

Physical parameters of light were recorded in main classroom and secondary classroom for fourth grade in Iggesund Skola.

Illuminance and Luminance

To analyze illuminance and luminance levels inside both the classrooms, data was collected in main classroom as well as secondary classroom for three main settings –

- 1) Daylight only: curtains and blinds were removed, and artificial light was switched off.
- 2) Artificial lighting only: curtains and blinds were drawn, and the artificial lighting was switched on 100%.
- 3) Artificial lighting + Daylighting: curtains and blinds were removed, and the artificial lighting was switched on 100%.

For main classroom, a fourth setting consisting of the use of all four display screens present in the classroom was also considered. The students commonly used this setting while watching educational videos and movies for various subjects.

With the help of an Illuminance meter, the data for horizontal illuminance on desk and floor was collected in lux for the settings mentioned above. Furthermore, the illuminance data of various surfaces like walls, floors, and furniture was also collected to calculate the reflectance factor.

To measure luminance values and analyze the luminance distribution inside both the classrooms for the settings mentioned above, Fusionoptix app was used.

Color metrics

The data for Correlated Color Temperature, Spectral power distribution, and Color Rendering Index of all light sources were collected by Stavroula Angelaki with the help of a spectrometer. The author used this data to analyze the existing light sources present in the classrooms.

3.4 Method 4

Simulations on Dialux

The main and secondary classrooms of the fourth grade were modeled in Dialux Evo. The model was detailed out with respect to the furniture layout, reflectance of the materials (fig.11), lighting typology and placement with the help of the observed and measured data collected. The model's validity was checked by comparing the measured illuminance data with the simulated data. Simulations were used to calculate uniformity and luminance with the false colors diagrams.

Main classroom (4th grade)	Reflectance
	(field measurements)
Linoleum floor	0.31
Brown round table	0.44
rectangular desk (light brown)	0.43
grey wall	0.41
white wall	0.74
black round table	0.15
Blackish carpet	0.17

Figure 11 Reflectance values for surfaces in main classroom and secondary classroom calculated from field measurements

The results from methods 1,2,3 and 4 were concluded to give a lighting design proposal for the refurbishment of fourth-grade classrooms in Iggesund Skola followed by a comparison between the existing lighting scheme and the proposed lighting scheme with the help of 3D simulations.

4. Results

4.1 Literature Review

Flexibility in classrooms

Flexibility in classrooms can be divided into adaptability (long term changes), adjustability (medium term changes) and agility (short term changes). For long term changes, changes in pedagogical goals, school's educational vision, and teaching techniques should be considered while also *adapting* to accommodate more students in future. For medium and short-term changes, the classrooms should have the ability to reconfigure and *adjust* to make different spatial arrangements for a variety of uses by manipulating elements inside the room and shall be *agile* where teachers can respond to the needs of the students quickly and easily by rearranging the furniture layout and the IT equipment such as projectors and display screens (Duthilleul et al. 2020).

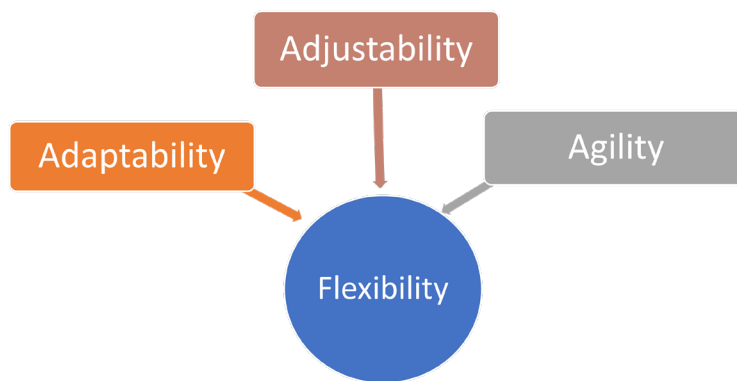


Figure 12 - Long term, medium term and short term changes to be considered while considering the flexibility of a learning environment (Source of info: Duthilleul et al. 2020)

Learning activities in a classroom

According to Dudek, learning activities fall into five categories. The activities differ in many respects, including variable factors such as the number of pupils involved, their interactions, and the nature of the attention they require. However, the key groupings can be summarized as follows:

1. Pupils taught directly by their teachers;
2. As individuals;
3. In small groups;
4. As a whole class;
5. Or, when not with their teacher, alone or in collaboration.

(Dudek 2005)

Lighting in Classrooms

In a study conducted by Goven et al. in 2010, brighter lighting (500 lux) was found to have more positive effects than standard lighting (300 lux) on primary school children's reading, writing, and mathematics. Apart from the intensity of light, Correlated color temperature (CCT) of lighting also influences students' learning performance. Researchers have found that lighting of different CCTs (4000K and 17000 K) positively impacts children's physical growth and development, attendance, alertness, and academic achievement (Rautkyla et al. 2010).

Light distribution

Henning Larsen Architects conducted a field study of several Danish schools. They concluded that artificial lighting in those schools mainly consisted of uniformly lit classrooms with large windows in most classrooms to enhance the visual quality of the indoor environment by maximizing the natural lighting (Hofmeister 2020). Since artificial lighting is needed to supplement the natural lighting for most of the year due to Denmark's geographical location and prolonged hours of darkness, the high levels of uniformity result in a dull and one-fits-all ambiance that offers little visual variation. Although, pupils' visual acuity is supported by this type of lighting, however, the attempts to enhance the visual quality of the indoor environment by bringing in daylight are diminished. This raises the question of how to apply artificial lighting to improve the visual quality of the learning environment and support pupils' learning (Hofmeister 2020).

By thoroughly illuminating spaces with a uniform light that makes everything visible, nothing is emphasized, creating a lack of visual interest with no support for orientation and spatial understanding (Wanstrom Lindh 2013).

In another study by Henning Larsen Architects, impact of three light settings on students was studied and compared – uniformly lit classroom with ceiling lights, pendant lights for workspaces and a combination of pendant lights with ceiling lights in a classroom. In the pendant lights setting, pools of light were observed with relatively darker surroundings. It could be said that these stimulate intimate spaces within the larger space. This was believed to intuitively draw pupils' attention inwards, bounded by each pool, and nurture their concentration on a task. The pendant lighting could be used in combination with the ceiling lighting or on its own, providing for heavy contrast. The study's findings also suggested that the pendant lighting contributed to reduced noise levels and hence, greater student concentration. Pupils were more prone to stay in their chosen seats for a longer period and wander about less, suggesting the pools of light kept their attention more local. The learning environment was quieter and calmer and could particularly benefit those pupils who were generally easily distracted or displayed disruptive behavior. This would ultimately benefit the entire pupil group. In essence, pendant lighting seems to encourage pupil behavior that results in a calmer environment and less distraction (Hofmeister 2020).

Luminance Distribution

Luminance distribution in the visual field is responsible for the eyes' adaptation level and affects the visibility of the task. It is essential to create balanced luminance distribution which positively affects visual acuity, contrast sensitivity, and such visual functions as accommodation, convergence, eye movements etc. Besides, it promotes visual comfort (Wolska et al. 2020).

Luminance distribution largely determines the mood in the interior and its aesthetics. A surface with a high luminance value seems more distant than a surface with a low luminance value. Thus, bright walls give the impression that the room is larger, and dark walls visually reduce the space, just as a light ceiling appears to be higher than a dark one (Wolska et al. 2020).

Humans need luminance contrast so that they can perceive the surrounding environment. The greater the contrast, the more easily perceived the object, e.g. black letters on a white background. In cases when contrast is low, lighting intensity must be increased to guarantee easy identification of the object. One should know the visual result will not be satisfactory in every situation (Wolska et al. 2020).

Variable Lighting

Barkmann et al. in 2012 found that variable lighting, i.e., lighting that is variable in illuminance and color temperature, optimized the general learning conditions and performance of students in schools. The study analyzed the effects of seven predefined programs of Schoolvision system by Philips and concluded that out of the seven programs (Standard, Concentrate, Board only, Focus on Board, Active, Relax, extremely relax) primarily "Concentrate", "Activate" and "Relax" were used. The results showed that the students made fewer errors under the VL "Concentrate" program and their reading speed rose significantly. Additionally, the teachers liked the option of visually separating individual sections of the lesson. However, several teachers wished for a fewer number of programs and a program with even warmer light (Barkmann et al., 2012). Furthermore, incorporating variable lighting allows for long term, medium and short-term flexibility and caters to the individual needs of the students.

Standards

SS-EN 12464-1 : 2021

SS-EN 12464-1:2021 (E)

Table 44 — Educational premises - Educational buildings

Ref. no.	Type of task/activity area	\bar{E}_m lx		U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$ lx	$\bar{E}_{m,wall}$ lx	$\bar{E}_{m,ceiling}$ lx	Specific requirements
		required ^a	modified ^b							
44.1	Classroom - General activities	500	1 000	0,60	80	19	150	150	100	Lighting should be controllable, see 6.2.4, for different activities and scene settings. For classrooms used by young children, an \bar{E}_m required of 300 lx may be used by dimming (see 5.3.3). Ambient light should be considered, see Annex B, room brightness, see 6.7.
44.2	Auditorium, lecture halls	500	750	0,60	80	19	150	150	50	Lighting should be controllable, see 6.2.4, to accommodate various A/V needs, room brightness, see 6.7.
44.3	Attending lecture in seating areas in auditoriums and lecture halls	200	300	0,60	80	19	75	75	50	Reduction by dimming. DSE-work, see 5.9.
44.4	Black, green and white boards	500	750	0,70	80	19	-	-	-	Vertical illuminances. Specular reflections shall be prevented. Presenter/teacher shall be illuminated with suitable vertical illuminance.

SS-EN 12464-1:2021 (E)

Ref. no.	Type of task/activity area	\bar{E}_m lx		U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$ lx	$\bar{E}_{m,wall}$ lx	$\bar{E}_{m,ceiling}$ lx	Specific requirements
		required ^a	modified ^b							
44.5	Black, green and white boards in auditorium and lecture halls	500	750	0,60	80	19	-	-	-	Vertical illuminances. Specular reflections shall be prevented. Presenter/teacher shall be illuminated with suitable vertical illuminance.
44.6	Projector and smartboard presentation	-	-	-	-	-	-	-	-	1. Lighting should be controllable, see 6.2.4. 2. Specular reflections shall be prevented. 3. 200 lx vertically behind (around) screen. 4. Direct lighting on screen when displaying content shall be avoided
44.7	Display board	200	300	0,60	80	19	-	-	-	Vertical illuminances
44.8	Demonstration table in auditoriums and lecture halls	750	1 000	0,70	80	19	-	-	-	
44.9	Light on teacher / presenter	-	-	-	80	-	150	-	-	At 1.6 m above the floor. Suitable vertical illuminance.
44.10	Light on podium area	300	500	0,70	80	-	-	-	-	Illuminance should be vertical in direction of audience. Lighting should be controllable, see 6.2.4, to accommodate various A/V needs.

Figure 13 SS-EN-12464-1 : 2021 Lighting Standards for Lighting in Educational facilities (Standard - Light and lighting - Lighting of work places - Part 1: Indoor work places SS-EN 12464-1:2021 - Swedish Institute for Standards, SIS, 2022)

4.2 Architecture of the classrooms

Iggesund Skola is located in the city of Hudiksvall, in Sweden.

The fourth-grade classrooms are located on second floor of the building and have east-facing windows.

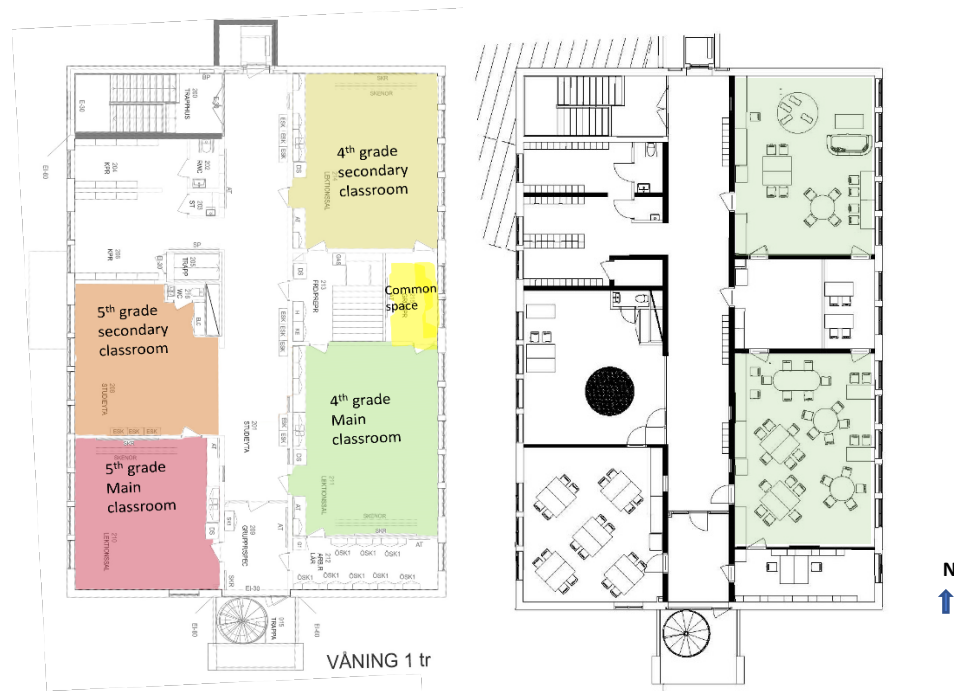


Figure 14 Architectural layout for fourth grade classrooms (1:200)

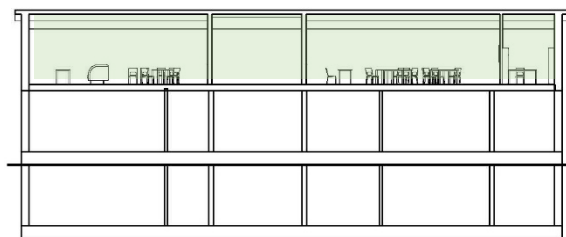


Figure 15 Section of fourth grade classrooms (1:200)

Main classroom



Figure 16 Plan, section, and images of main classrooms

Secondary classroom

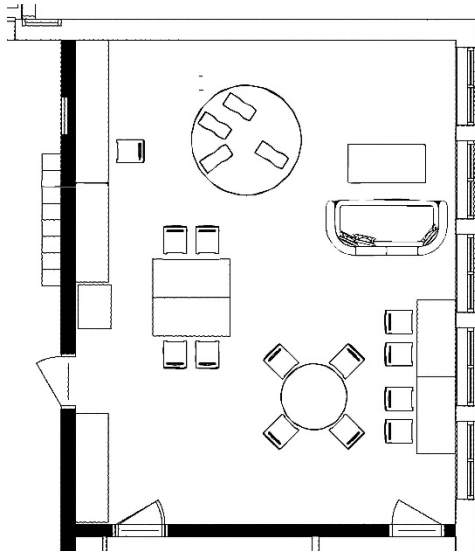


Figure 17 Secondary classroom



Figure 18 Secondary classroom

4.3 Personal observations and informal interview

Personal observations



Figure 19 General observations of lighting system in main classroom

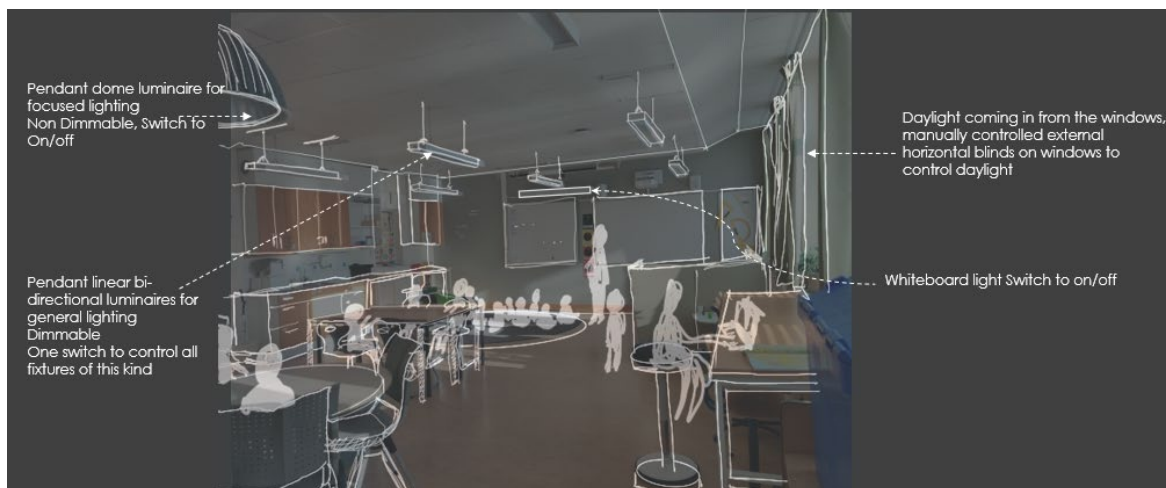


Figure 20 General observations of lighting in secondary classroom

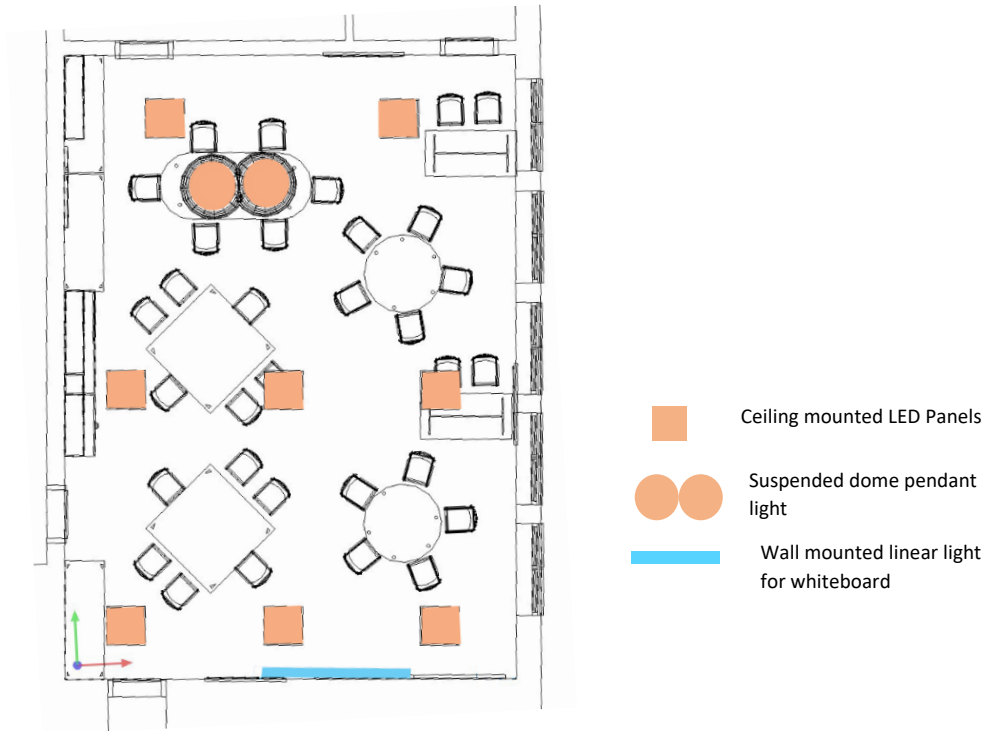


Figure 21 Lighting plan for existing lighting scheme in main classroom



Figure 22 Lighting plan for existing lighting scheme in secondary classroom

English

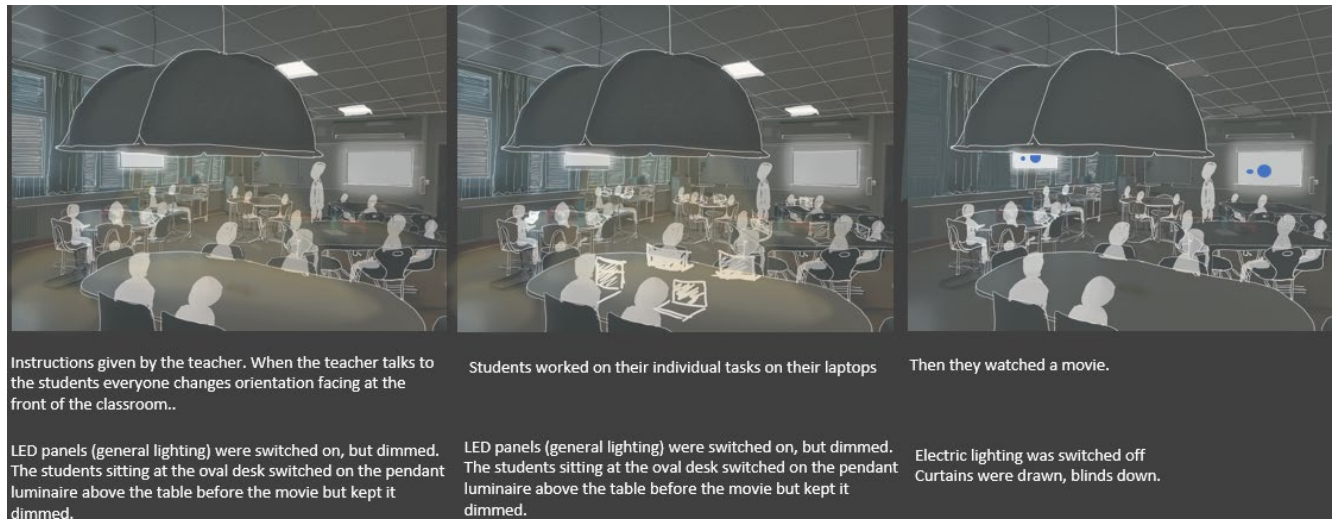


Figure 23 Results of observation logs – Activities and lighting conditions during English course

				Poor/good	
9.45-10.45 English Main classroom	Level of light	Dimmed electric light/bright sunlight	dark/bright	3	3
	Spatial distribution of light	Overall distribution is homogenous	uniform/ varied	2	2
	Shadows	Diffused shadows	sharp/ diffused	4	4
	Reflections	Tables have soft reflections, tables near windows have clearer reflections (material of tables differ)	soft/clear	2	3
	Glare	No glare	tolerable disturbing	2	4
	Colour of light	Warm sunlight, cool electric light	cold/warm	2	3
	Colour of surfaces	A little desaturated	natural/ distorted	3	3

Figure 24 Results of V/P Theory during English course

Social Science



Figure 25 Results of observation logs – Activities and lighting conditions during Social science course

			Poor/good	
11.40-12.25, 12.45-12.55 Social science Main classroom	Level of light	Dim light levels in general/bright light levels for the task	dark/bright	2 3
	Spatial distribution of light	Light is homogenous/fairly uniformly distributed. Varied distribution when electric light was switched off for the movie	uniform/varied	3 3
	Shadows	Diffused Shadows	sharp/difused	4 4
	Reflections	stronger/clearer reflections on furniture near the window	soft/clear	3 3
	Glare	No glare	tolerable disturbing	1 5
	Colour of light	Neutral	cold/warm	3 3
	Colour of surfaces	Most surfaces have natural color but the furniture far from the window has a bit distorted color because of darkness	natural/distorted	3 2
			Poor/good	
12.25-12.45 Social science Secondary classroom	Level of light	Fairly bright	dark/bright	4 4
	Spatial distribution of light	Uniform distribution	uniform/varied	2 2
	Shadows	Diffused shadows	sharp/difused	4 3
	Reflections	Soft reflections on whiteboard	soft/clear	1 4
	Glare	A bit of glare from ceiling lights	disturbing	1 5
	Colour of light	Cold white	cold/warm	3 3
	Colour of surfaces	A bit distorted	natural/distorted	3 2

Figure 26 Results of V/P Theory analysis during Social science course

Maths

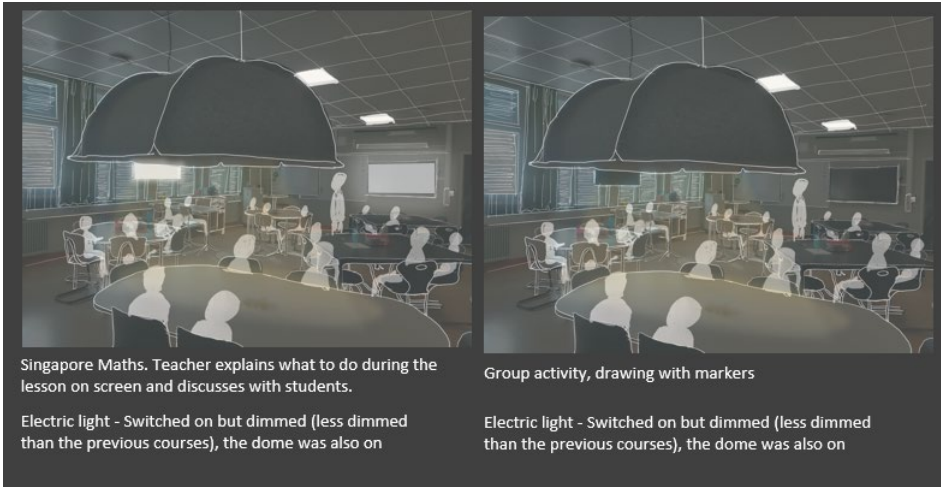


Figure 27 Results of observation logs – Activities and lighting conditions during Maths course

13.05-13.50 Maths Main classroom	Level of light	Bright	dark/bright	4	4
	Spatial distribution of light	Homogenous distribution.	uniform/ varied	2	3
	Shadows	Very diffused/soft shadows	sharp/ difused	4	3
	Reflections	Soft reflections on the whiteboard.	soft/clear	2	4
	Glare	Some glare from LED panels (ceiling lights)	tolerable		
	Colour of light	Electric Light appears warmer than the daylight. In earlier courses, daylight seemed warmer	disturbing	2	3
	Colour of surfaces	Close to natural	cold/warm	3	3
			natural/ distortec	2	4

Figure 28 Results of V/P Theory during Maths course

Natural Science

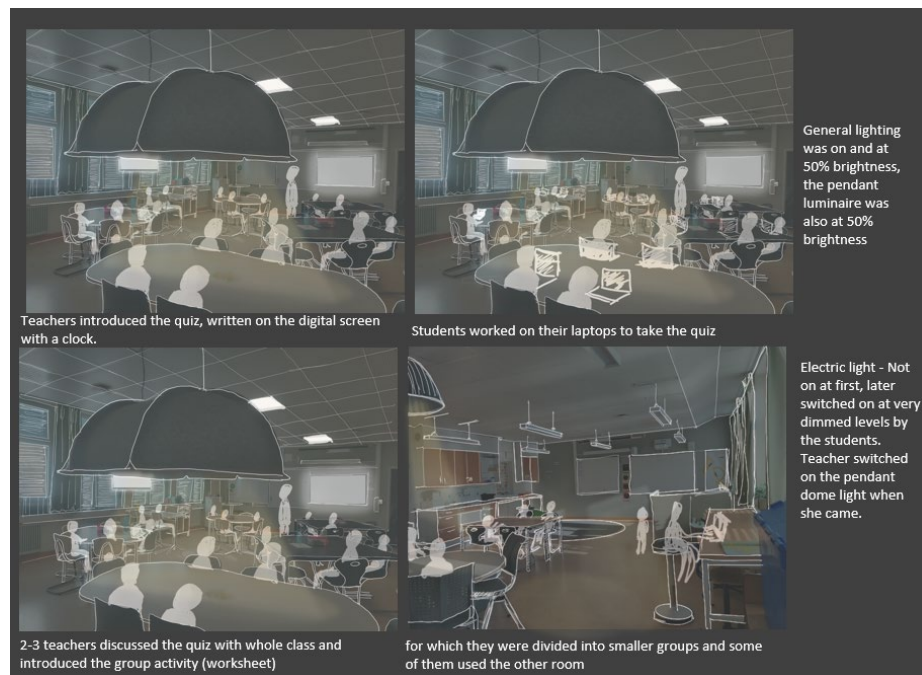


Figure 29 Results of observation logs – Activities and lighting conditions during Natural Science course

			Poor/good	
9:40-10:30 Biology Main classroom	Level of light	Some sunlight(blinds are down), mostly electric light / bright	dark/bright	4 4
	Spatial distribution of light	Fairly uniform	uniform/ varied	2 2
	Shadows	Diffused shadows. Light was bright and uniformly distributed so the shadows got dissolved	sharp/ diffused	4 3
	Reflections	soft reflections on whiteboard	soft/clear	2 4
	Glare	Little glare from ceiling lights	tolerable disturbing	2 3
	Colour of light	Neutral	cool/warm	3 3
	Colour of surfaces	Close to natural	natural/ distorted	1 4
			Poor/good	
10:30-10:45 Biology Secondary classroom	Level of light	Fairly bright daylight/dim electric light	dark/bright	3 3
	Spatial distribution of light	A bit varied, darker on the sink side (away from the window)- contrast of light and dark can be seen (gradation)	uniform/ varied	3 3
	Shadows	Diffused shadows but sharper than the main classroom	sharp/ diffused	3 3
	Reflections	Very soft reflections on whiteboard	soft/clear	1 4
	Glare	No glare	tolerable disturbing	1 5
	Colour of light	Light appears cold (as compared to main classroom)	cool/warm	2 2
	Colour of surfaces	A bit desaturated	natural/ distorted	2 2

Figure 30 Results of V/P Theory during Natural Science course

Informal interview

Interview results

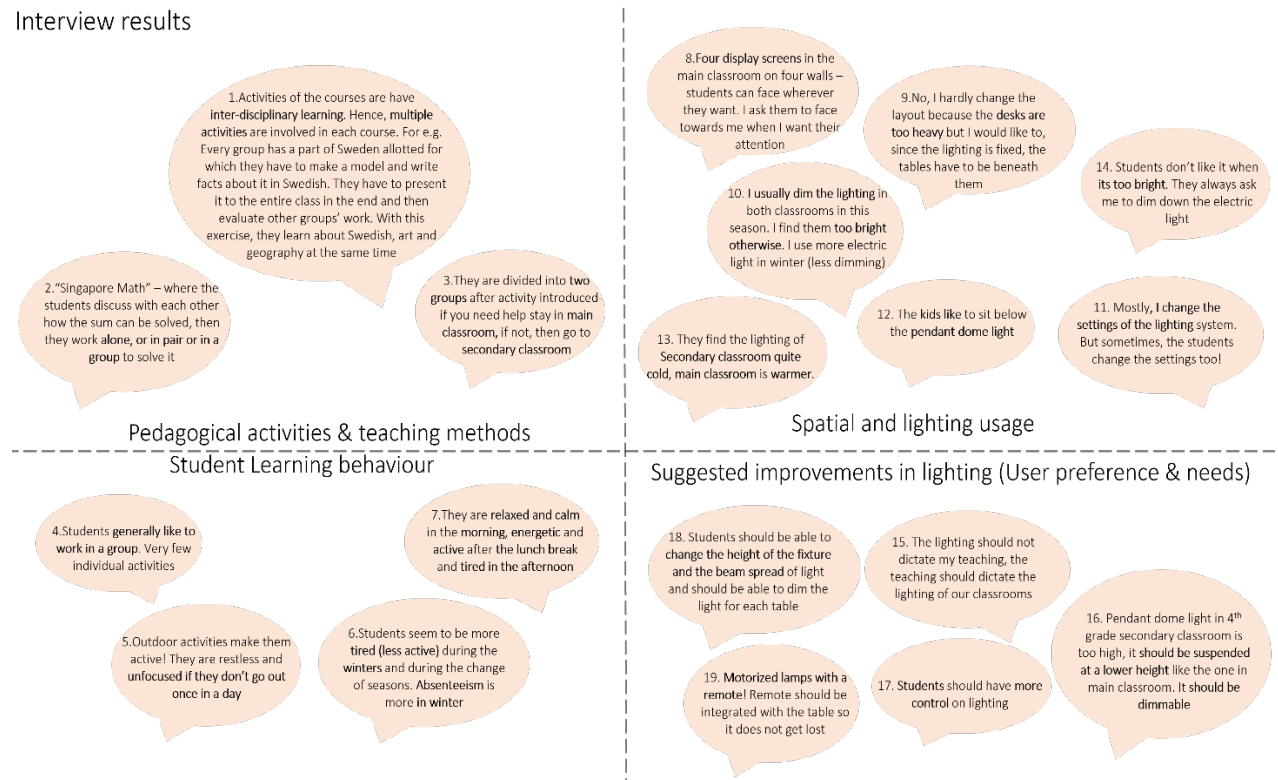


Figure 31 Results of informal interview with teachers

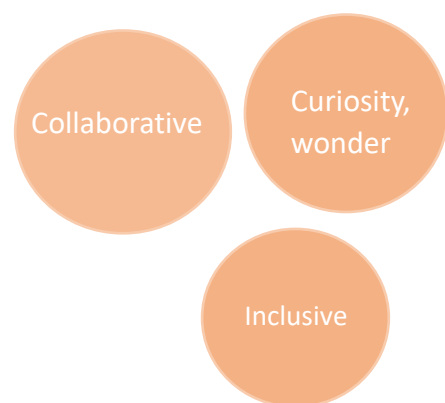


Figure 32 Result of informal interview with teachers – they were asked to choose three words to describe cooperative learning atmosphere

Summary of Results from Personal Observations and informal interviews:

- Multiple activities were conducted in every course: instructions by teacher, discussions with teacher, individual tasks, group activities, discussions amongst the group, and watching movies/videos. A component of cooperative learning is always present in all activities, be it individual tasks or group work. The students used a variety of study materials: books, worksheets, drawing paper, laptops.
They were divided into two groups for group activities, one group remained in main classroom and the other group was sent to secondary classroom. Shifting from one classroom to another during a course is refreshing for students and makes them more active although, it can be a cause of distraction for some.
- Furniture layout in both classrooms mostly remained the same during observation period, however, organization of the groups changed from time to time (sometimes 5 students working together, sometimes 6, or 2).
- Four digital screens were present in main classroom, no digital screens in secondary classroom. Screens were too bright on most occasions. Most of the teaching in main classroom happened through the digital screens. They used a stylus to write on the screens.
- General lighting in both classrooms was dimmable. Pendant dome in main classroom was dimmable, but pendant dome in secondary classroom was not dimmable.
Teacher mostly controlled electric lighting in the main classroom. Most preferred dimming levels by both students and teachers were 50% (general lighting and pendant light) during a discussion or an activity. The students preferred to sit under the pendant dome light. Electric lights were switched off when they watched movies and videos on digital screens.
The students mostly controlled electric lighting in secondary classroom. When teachers came to check up for doubts, they also analyzed if the lighting levels were sufficient and asked the students if they needed more lighting. The preferred lighting levels of general lighting varied throughout the day. However, in this classroom, the pendant dome light did not seem to significantly influence students because its suspended height was too close to the ceiling.
- During transition of activities in a course, the focus frequently shifted from one point to the other - focus from teacher (in front) to digital screens on the wall, to textbooks on the table, to their laptop screens (actively used for multiple activities) and to their peers for discussions. (Vertical and horizontal surfaces)
- Both classrooms have soothing exterior views to the landscape which could help students restore their attention. Since the blinds were usually down the entire day, the students did not engage with exterior views.
- In general, energy of the students went up as the day started, peaked after the lunch break, and eventually went down by the end of the day. However, their attention was maximum at the beginning of the day and gradually went down as the day progressed with a slight increase after the lunch break. Furthermore, when students were calm, they were observed to be more focused

4.4 Measurements

Photometry and color metrics

Main classroom :

LED Panels are used for general lighting. The SPD shows that the red wavelength emitted is low (fig. 33). To accentuate the oval table, a custom-made pendant dome luminaire is used. It emits a low blue light as compared to 600nm yellowish orange (fig. 34) and hence, has a yellowish light. The whiteboard lighting was never used for any of the courses during the personal observations. Moreover, it's position is off-centre, and its light only covers a small part of the whiteboard surface. Although all fixtures have an overall Ra greater than 80, the rendering indices show that rendering index of red color is extremely low (fig. 33,34 & 35).

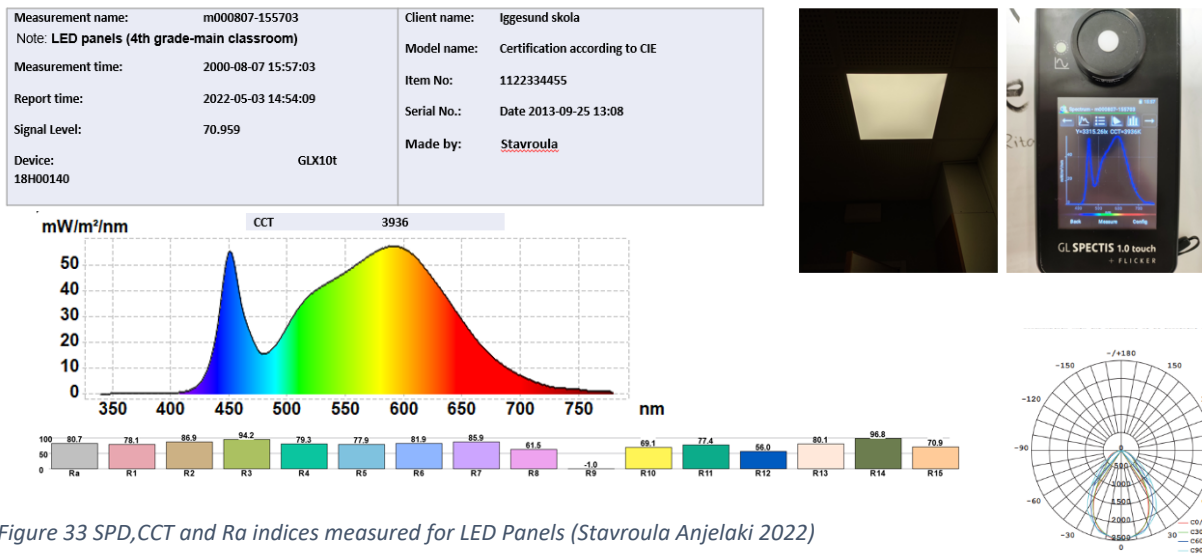


Figure 33 SPD,CCT and Ra indices measured for LED Panels (Stavroula Anjelaki 2022)

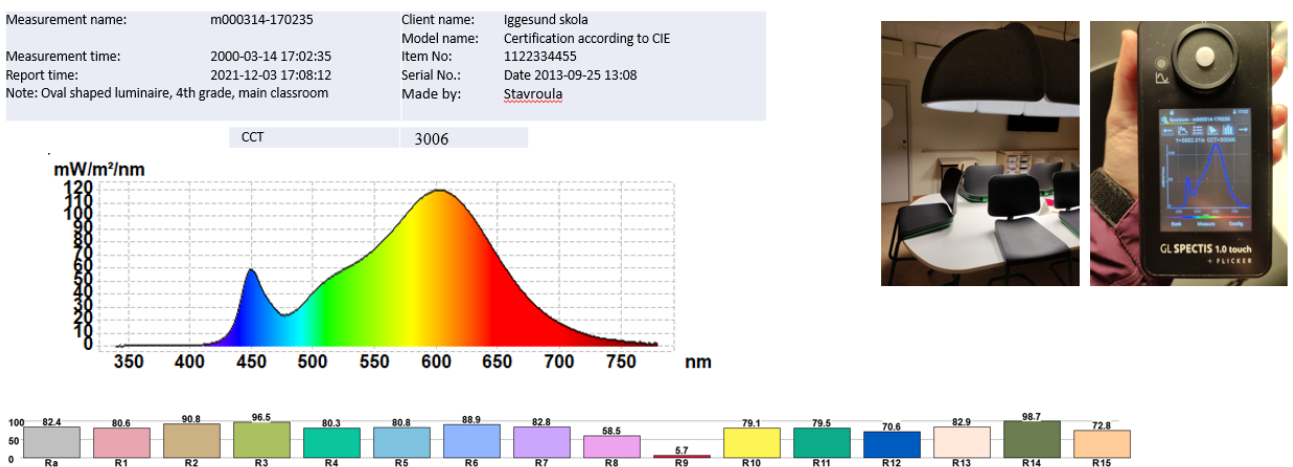


Figure 34 SPD,CCT and Ra indices measured for Pendant dome (Stavroula Anjelaki 2022)

Measurement name:	m000314-170155	Client name:	Iggesund skola
Measurement time:	2000-03-14 17:01:55	Model name:	Certification according to CIE
Report time:	2021-12-03 17:02:27	Item No.:	1122334455
Note:	Whiteboard lighting, 4th grade, main classroom	Serial No.:	Date 2013-09-25 13:08
		Made by:	Stavroula

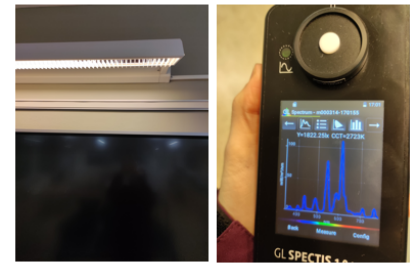
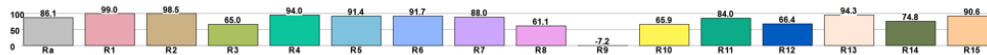
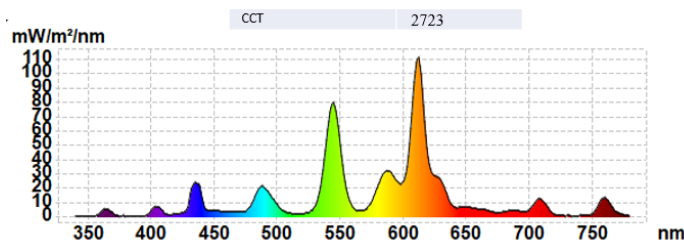


Figure 35 SPD, CCT and Ra indices measured for Whiteboard light (Stavroula Anjelaki 2022)

Secondary classroom:

Bi-directional suspended linear lights are used for the general lighting with an uplight and a downlight component. These lights hardly emit any red wavelength (longer wavelength) but emit a large amount of blue wavelength (fig. 36). The rendering index for red is low. Colors of the surfaces appeared de-saturated in the presence of its light (refer to personal observation). To accentuate the circular table, custom-made pendant dome luminaire is used. The luminaire emits low blue light as compared to 600nm yellowish orange (fig. 37). Furthermore, the personal observation and interview revealed that the height of this pendant luminaire is too close to the ceiling, which hardly contributes to the intent of creating a special cooperative learning zone in the space. During the personal observations, the whiteboard lighting was never used for any of the courses. It emits low blue and red wavelengths (fig. 38).

Measurement name:	m000314-165306	Client name:	Iggesund skola
Measurement time:	2000-03-14 16:53:06	Model name:	Certification according to CIE
Report time:	2021-12-03 16:38:00	Item No.:	1122334455
Note:	Bi	Serial No.:	Date 2013-09-25 13:08
	directional ceiling lights (4th grade, secondary classroom)	Made by:	Stavroula

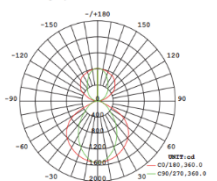
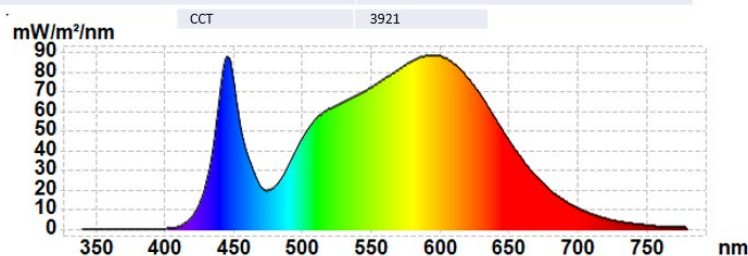


Figure 36 SPD, CCT and Ra indices measured for bi-directional linear lights (Stavroula Anjelaki 2022)

Measurement name:	m000314-165355	Client name:	Iggesund skola
Measurement time:	2000-03-14 16:53:55	Model name:	Certification according to CIE
Report time:	2021-12-03 16:45:20	Item No.:	1122334455
Note: Circular light, 4th grade, secondary classroom		Serial No.:	Date 2013-09-25 13:08
		Made by:	Stavroula

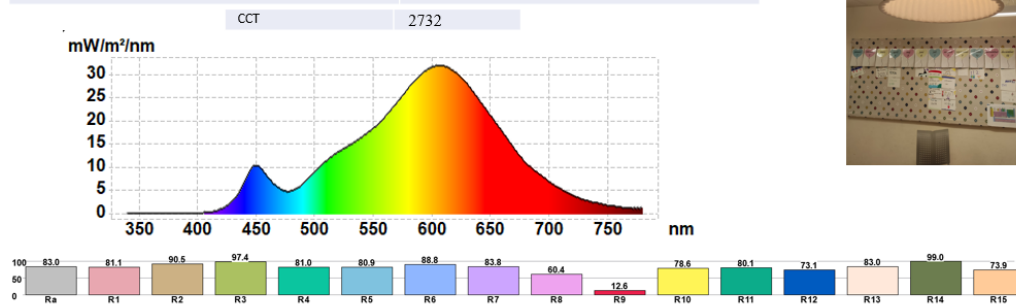


Figure 37 SPD, CCT and Ra indices measured for pendant dome luminaire (Stavroula Anjelaki 2022)

Measurement name:	m000314-165445	Client name:	Iggesund skola
Measurement time:	2000-03-14 16:54:45	Model name:	Certification according to CIE
Report time:	2021-12-03 16:51:43	Item No.:	1122334455
Note: Whiteboard lighting, 4th grade, secondary classroom		Serial No.:	Date 2013-09-25 13:08
		Made by:	Stavroula

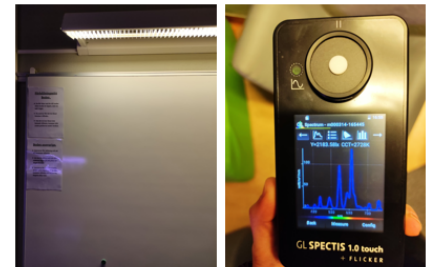
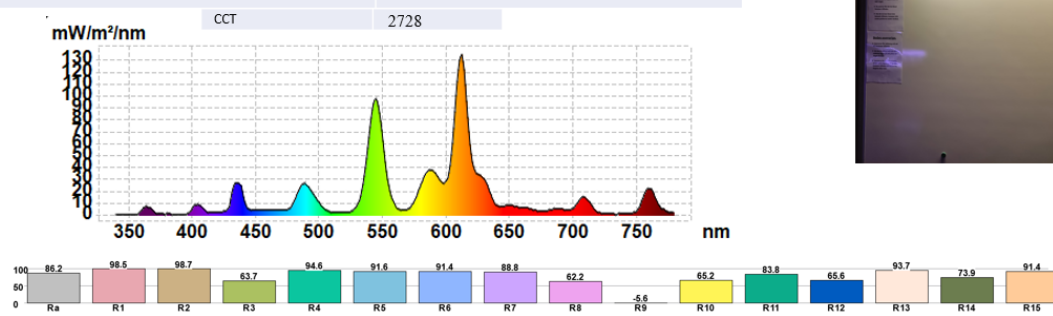


Figure 38 SPD, CCT and Ra indices measured for whiteboard light (Stavroula Anjelaki 2022)

Illuminance

The standard SS-EN-12464 : 2021 mentions the requirement of minimum 500 lux illuminance in classrooms with a provision of modified illuminance of upto 1000 lux. The standard also mentions the illuminance of 300 lux for immediate surroundings if the task area is illuminated at 500 lux (SIS SS-EN 12464-1:2021). Additionally, Arbetsmiljöverket (2020) also recommends 500 lux for the illuminance of task surfaces (Arbetsmiljöverket 2020).

Illuminance measured (point measurements) on horizontal work-planes for Fourth-grade **Main classroom** on 12th April 2022, 11:30AM:

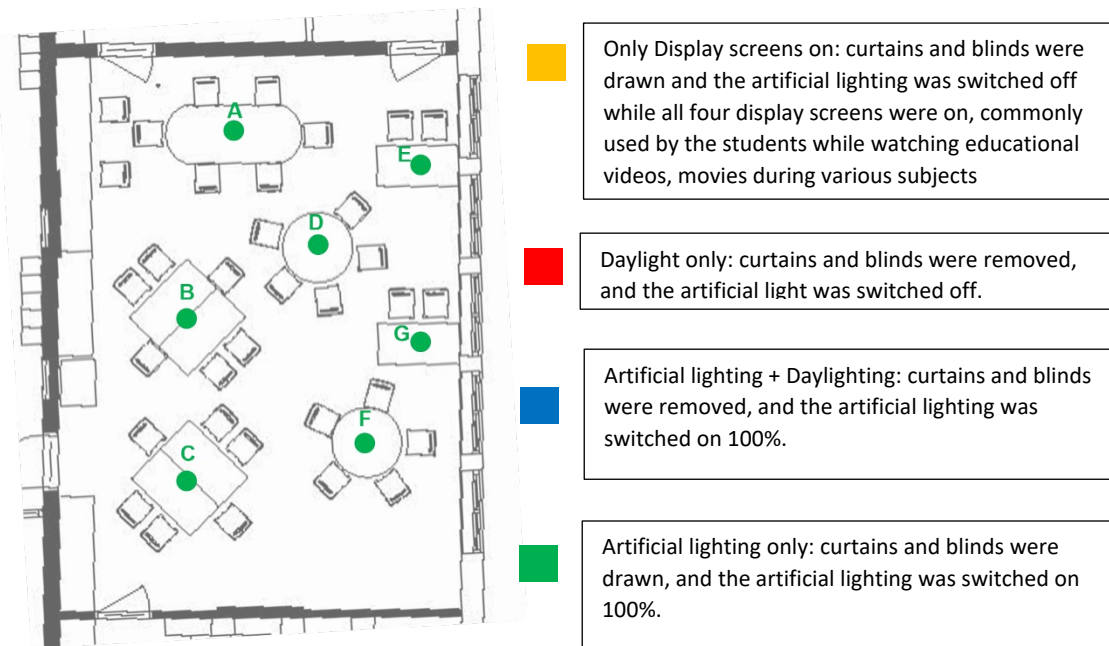


Figure 39 Points of measurements for illuminance values

Illuminance on work planes in main classroom

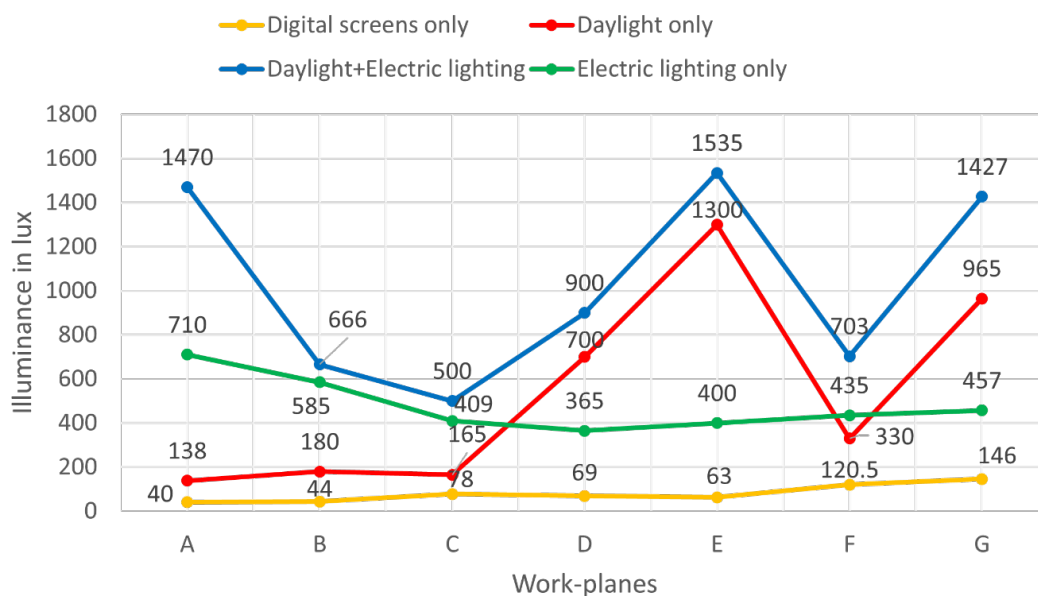


Figure 40 Measured illuminance values compared (graph to be only referred for point measurements and comparison of data between the points, no conclusions to be drawn about the intermediate points)

The graph (fig. 40) shows that the four digital screens in main classroom contribute a significant amount of illuminance during the working hours (from 40 lux to 146 lux).

The standards and recommendations of 500 lux are not met for the innermost tables (point A,B and C) with only daylight and there was a stark contrast with high illuminance levels near the windows (1300 lux) and low illuminance levels (138 lux) away from the windows (refer personal observations).

Electric lighting alone can only meet the standard requirement of 500 lux for point A and B.

However, the combination of daylight and electric lighting satisfies the illuminance requirements for all points.

Illuminance measured on horizontal work-planes for Fourth-grade **Secondary classroom** on 11th April 14:30 PM:

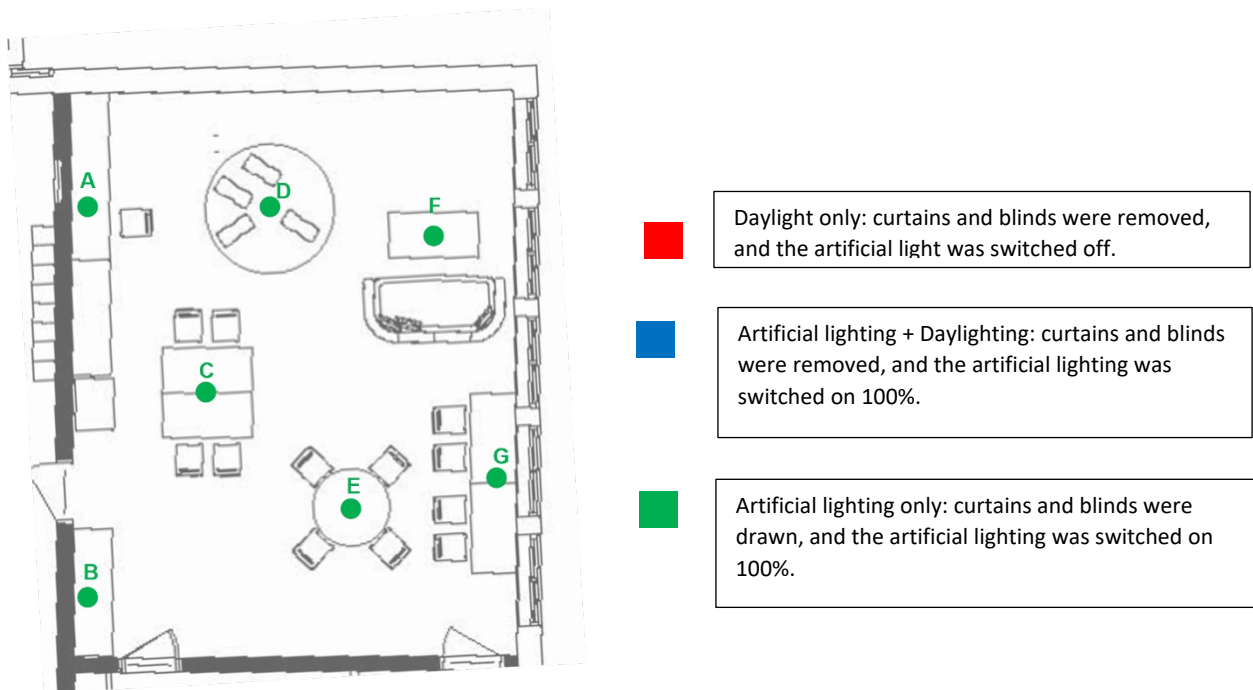


Figure 41 Points for measured illuminance values in secondary classroom

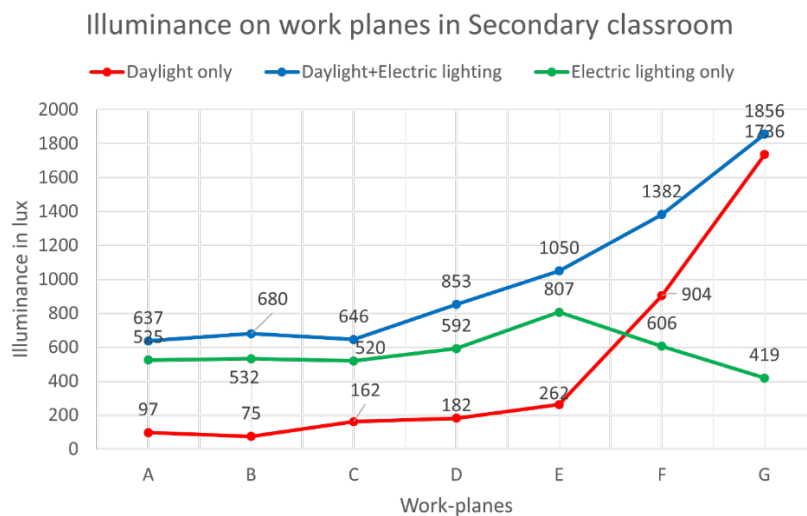


Figure 42 Measured illuminance values compared (graph to be only referred for point measurements and comparison of data between the points, no conclusions to be drawn about the intermediate points))

As can be seen from the graph (fig. 42), only the tables near the windows (point F and G) meet the required illuminance of minimum 500 lux with daylight. High contrast levels can be deduced from point A (97 lux) to point G (1736 lux, close to window) with daylighting only. Except point G (table near window), all the points meet the standards with only electric lighting at 100% brightness. Interestingly, point E received 807 lux with the pendant dome luminaire switched on and 721 lux with it being switched off (refer appendix measurements). Furthermore, the high levels of daylight and low levels of electric light prove to give a balanced output for points F and G in case of daylight and electric light combined.

Luminance

As per Arbetsmiljöverket (2020) "Luminance ratios should be approximately 5:3:1 between objects of view, immediate surroundings, and external fields of view" (Arbetsmiljöverket 2020).

Luminance distribution in Fourth-grade **Main classroom** on 12th April 2022, 11:30 AM:

Artificial lighting only: curtains and blinds were drawn, and the artificial lighting was switched on 100%.



Figure 43 Luminance distribution results from fusionoptix app

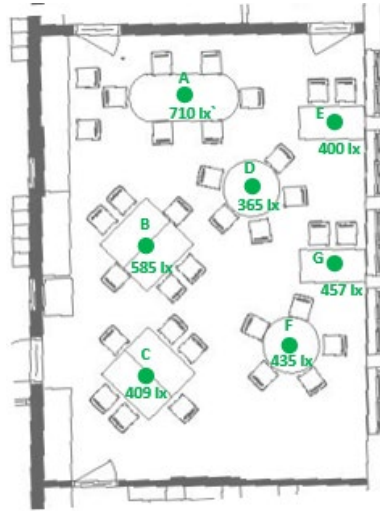


Figure 44 Point measurements of horizontal illuminance on working planes in main classroom

Due to the difference in materials of furniture in main classroom, the luminance distribution on working planes is not uniform (fig. 43). Although, points C (black table) and D (light oak table) catch the illuminance of 409 lux and 435 lux respectively (fig. 44), there is a stark contrast between the luminance of both surfaces because of their reflectance values (fig. 11). The luminance distribution on the floor is fairly uniform. Additionally, walls near the digital screens catch stronger pools of light.

Luminance distribution in Fourth-grade **Secondary classroom** measured on 11th April 2022, 14:30PM:

Artificial lighting only: curtains and blinds were drawn, and the artificial lighting was switched on 100%.



Figure 45 Luminance distribution results from fusionoptix app

Luminance distribution on working planes of secondary classroom is fairly uniform (fig. 45). However, the circular table has a brighter pool of light. The floor has a homogeneous light distribution. Furthermore, due to the uplight component of the bi-directional pendants, the ceiling has intense pools.

4.5 Simulations

Since the focus of this thesis is electric lighting, daylight calculations have not been compared.

Illuminance measured on horizontal work-planes for Fourth-grade **Main classroom** through simulations on Dialux Evo:

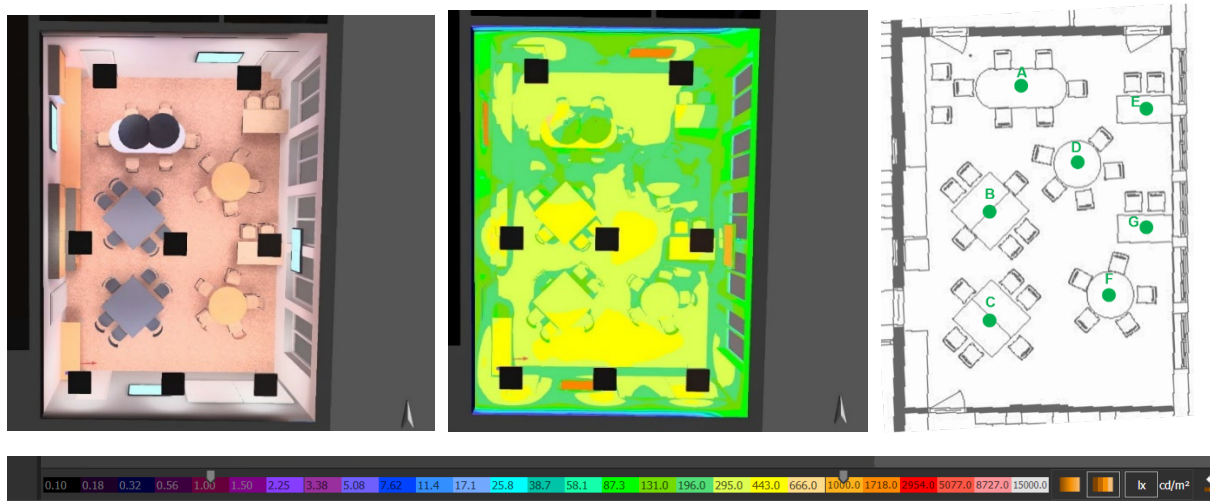


Figure 46 Dialux simulations



Figure 47 Dialux simulations results

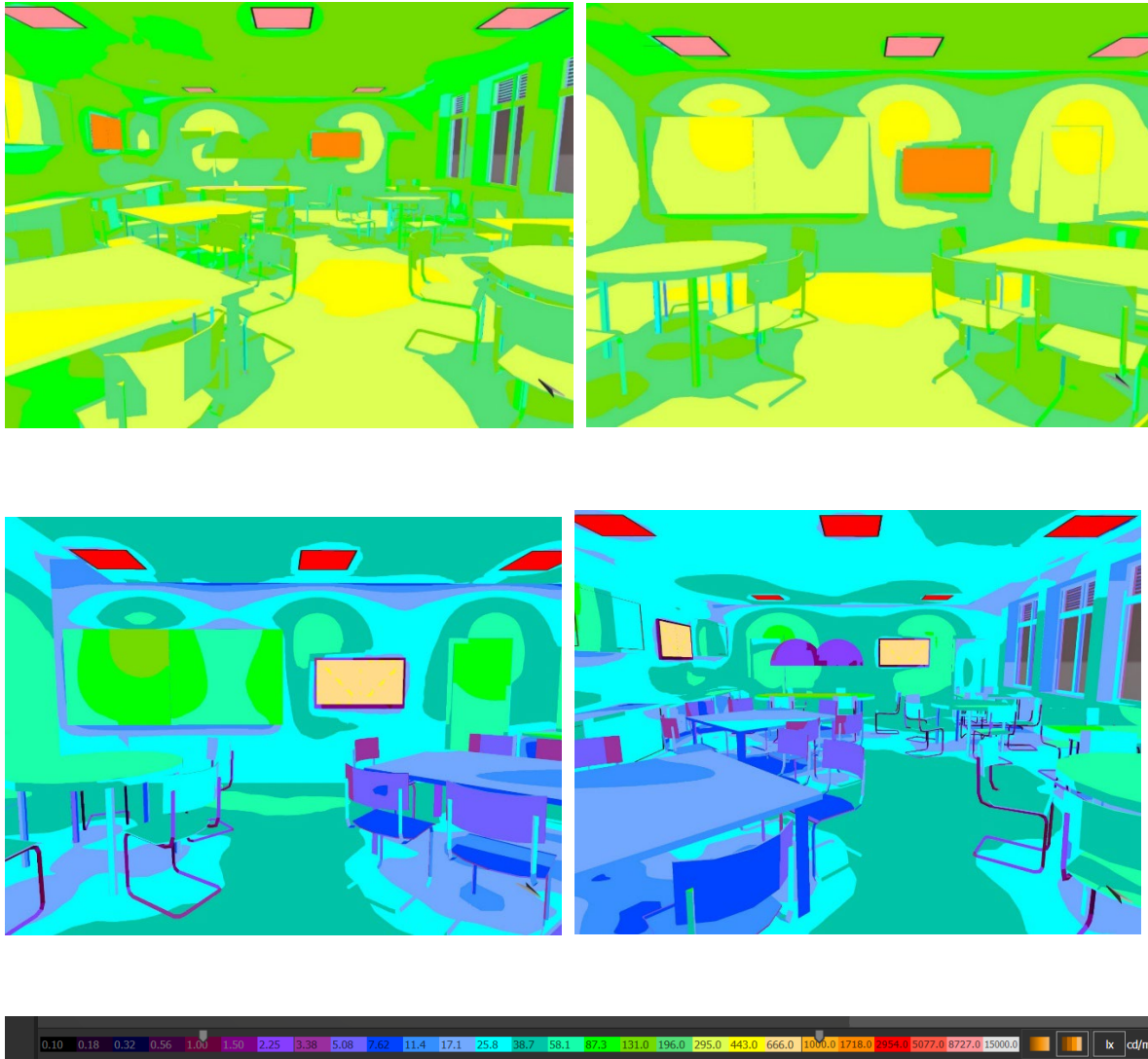


Figure 48 Dialux measurements results

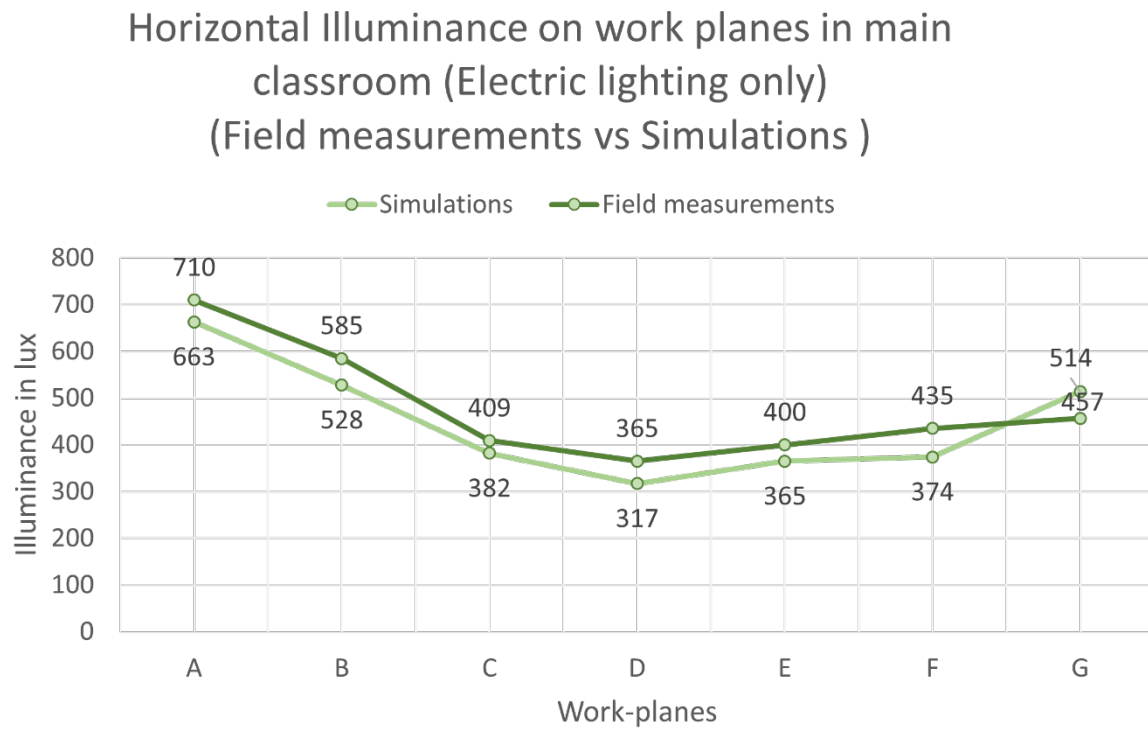


Figure 49 Comparison of simulation values vs field measurements (graph to be only referred for point measurements and comparison of data between the points, no conclusions to be drawn about the intermediate points)

Uniformity for main classroom measured at 0.75m height is 0.34, which is lower than the standard requirement of 0.6 (SS-EN-12464:2021). The average illuminance is 454 lux.

Fig. 46 & 48 show that the standard (SS-EN 12464 2021) of 300 lux illuminance in surrounding areas when task surfaces are illuminated at 500 lux is not being met since it has 400 lux in surroundings. In terms of luminance distribution, there is a low contrast between working planes and their surroundings.

Illuminance measured on horizontal work-planes for Fourth-grade **Secondary classroom** through simulations on Dialux Evo:

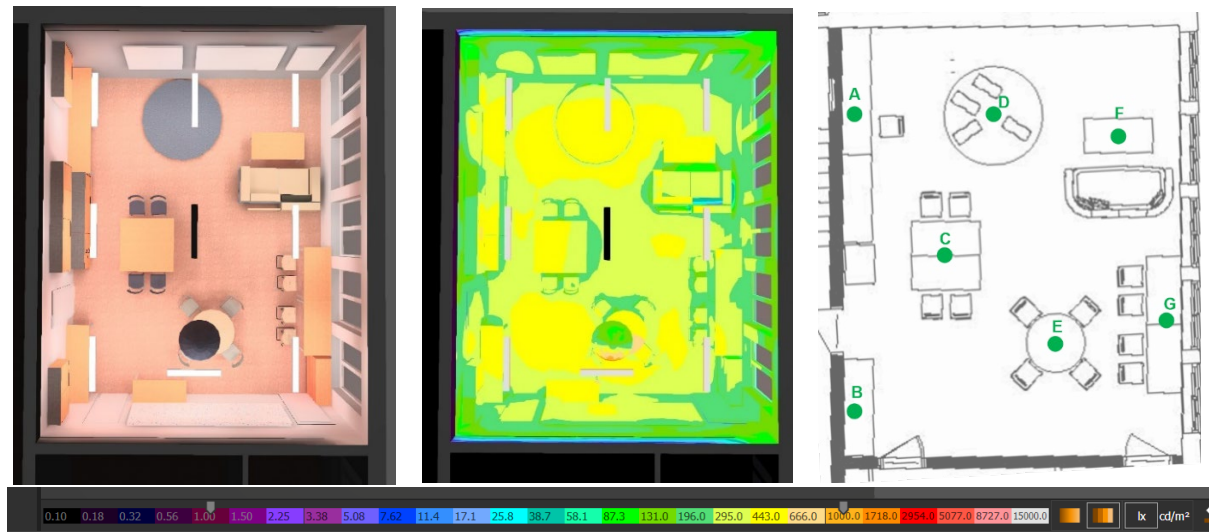


Figure 50 Dialux simulations

Horizontal Illuminance on work planes in Secondary classroom (Electric lighting only) (Field measurements vs Simulations)

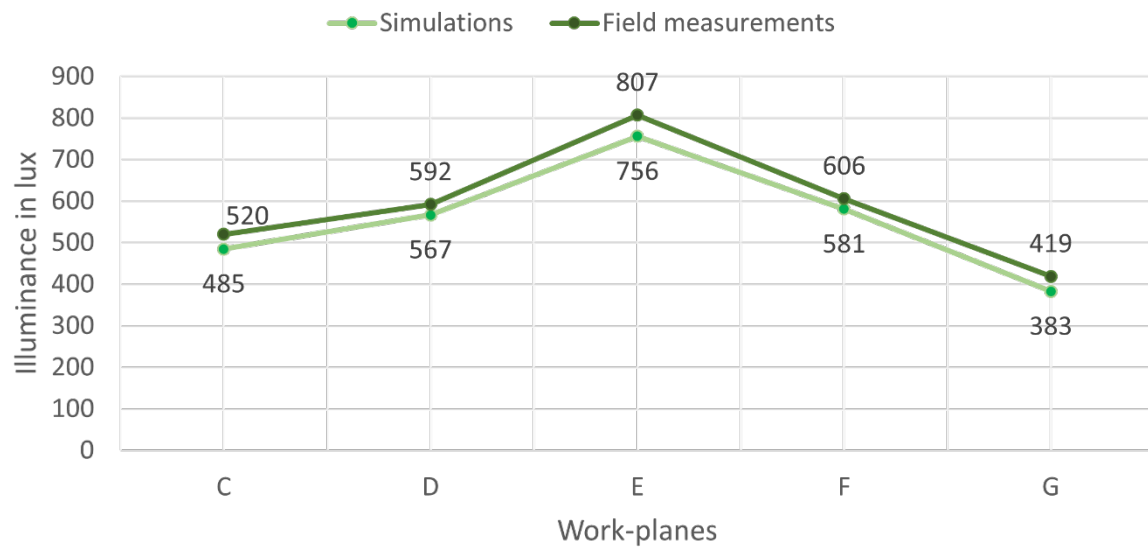


Figure 51 Comparison between simulations and field measurements to validate the model (graph to be only referred for point measurements and comparison of data between the points, no conclusions to be drawn about the intermediate points)



Figure 52 Dialux simulations

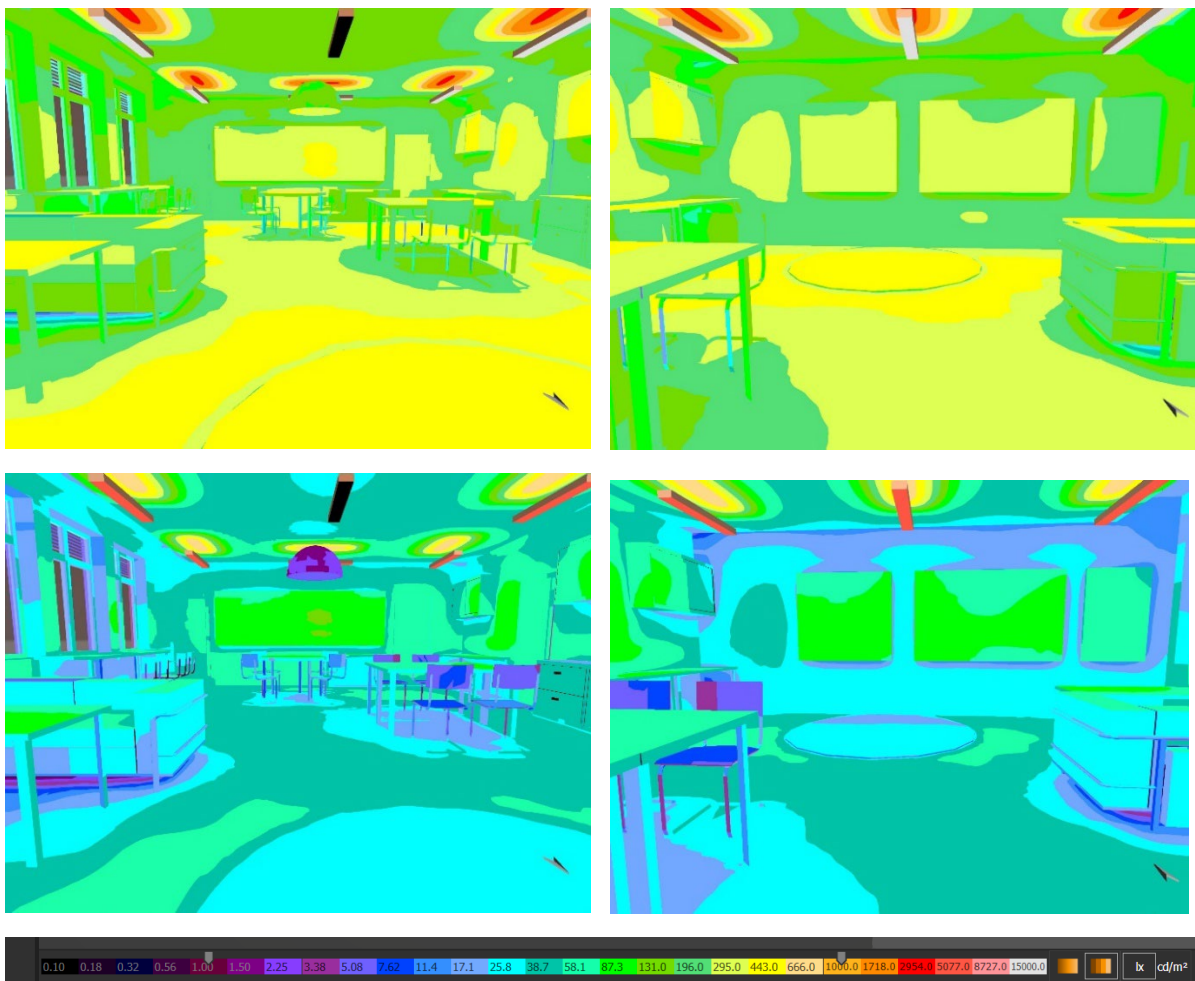


Figure 53 Dialux simulation and measurement results

Uniformity for secondary classroom measured at 0.8 m height is 0.42, which is lower than the standard requirement of 0.6 (SS-EN-12464:2021). Fig. 50 & 53 show that the standard (SS-EN 12464 2021) of 300 lux illuminance in surrounding areas when task surfaces are illuminated at 500 lux, is not met due to a homogeneous distribution of light on working planes (550 lux) and their surroundings (439 lux).

5. Design proposal and Comparison

Main classroom

Based on the cooperative learning activities identified in the last chapter, four lighting scenes are proposed for the main classroom. The proposed light levels and CCT are in accordance to the standards and recommendation and are a result of the analysis of existing lighting. The luminaires will be controlled by DALI and have a keypad with buttons for the lighting scenes.

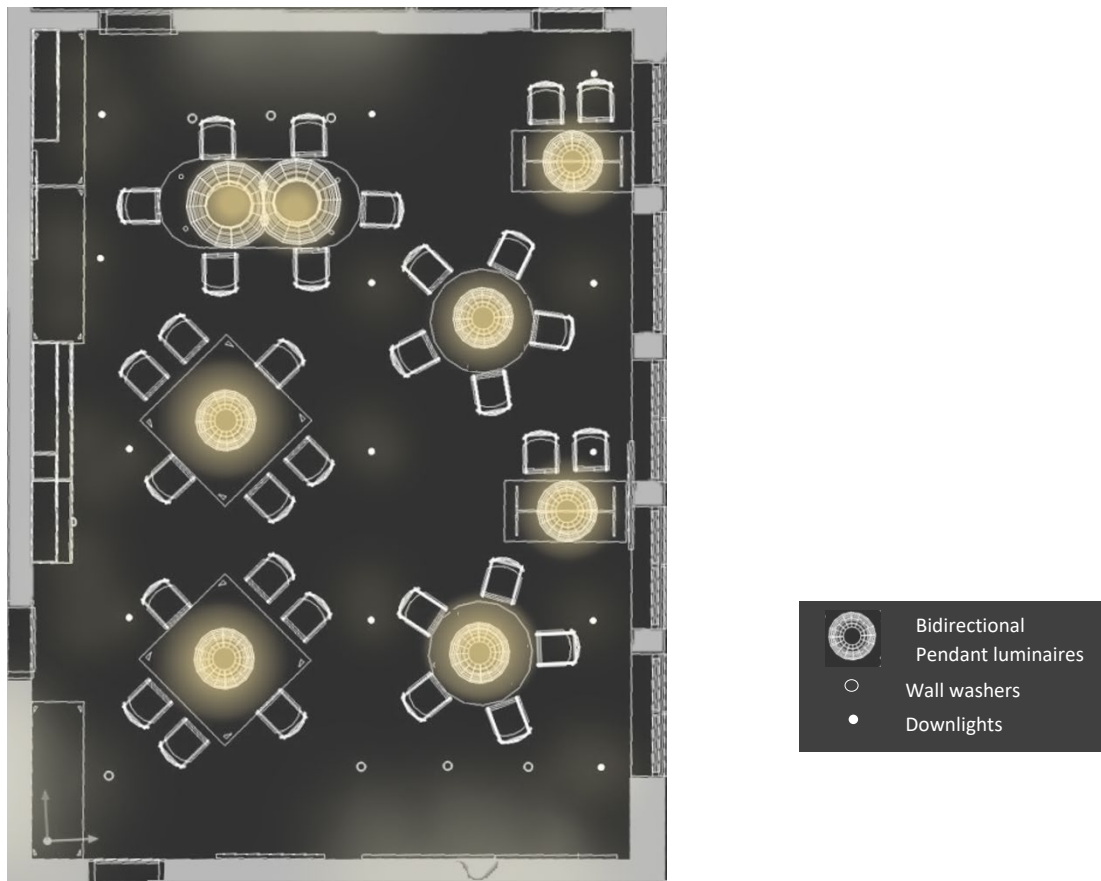


Figure 54 Proposed Light distribution in main classroom

Modes	Tables	Surrounding areas of tables	Whiteboard	Walls	CCT
Teach	500 lx (900lx for black tables)	300lx	300 lx	200lx	3000-3500K
Focus	600 lx (900lx for black tables)	200lx	100 lx	200lx	4000K
Collaborate	500 lx (900lx for black tables)	150lx	100 lx	300 lx	2700-3000K
Movie	-	-	-	(backlit screens for smooth transition) 50lx	3000K

Figure 55 Proposed lighting scenes for cooperative learning in main classrooms

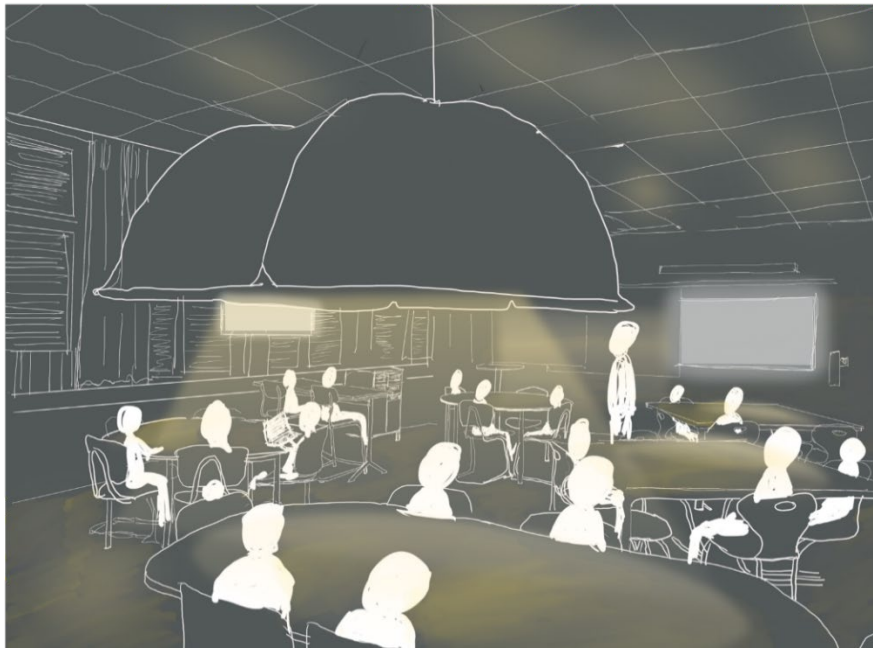
Teach

Figure 56 Light distribution for the scene "Teach" in main classroom

This scene is for the teacher discussing with the whole class while students listen to her and raise hands to contribute. A low contrasting atmosphere with a uniform distribution of light in the front so that student's attention is drawn towards the teacher. The light-colored tables will reflect more light as compared to the dark-colored tables, hence, the light levels for black tables are kept higher compared to the other working planes. Although, the whiteboard wasn't used during the observation period, the teachers may need to use it for certain activities in future. Hence, sufficient lighting for whiteboard is also incorporated in this scene.



Figure 57 Dialux simulation for lighting scene "teach" with pendant luminaires, downlights and wallwashers switched on

Focus

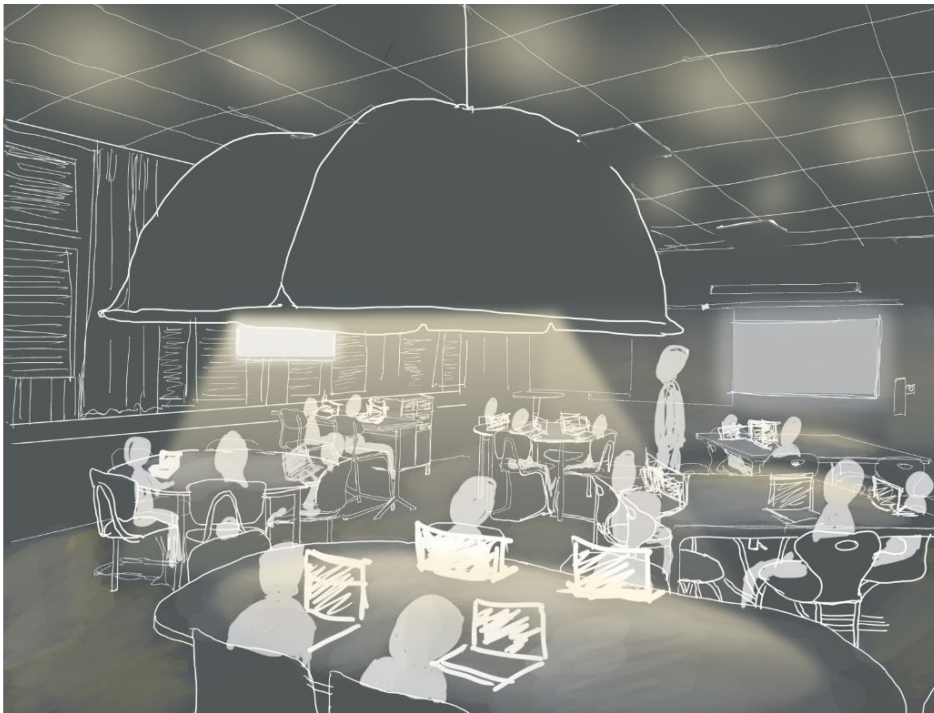


Figure 58 Light distribution for the scene "Focus" in main classroom

This scene is for students working on their task individually, but sitting in groups around the tables (some in pairs). Pools of cool color lights on working planes will help the students to concentrate better on their individual tasks (Rautkyla et al. 2010). The contrast between the work planes and their surroundings is higher to make students focus on their tasks.



Figure 59 Dialux simulation for lighting scene "focus" with downlights switched off, uplight from pendant luminaires for general lighting

Collaborate

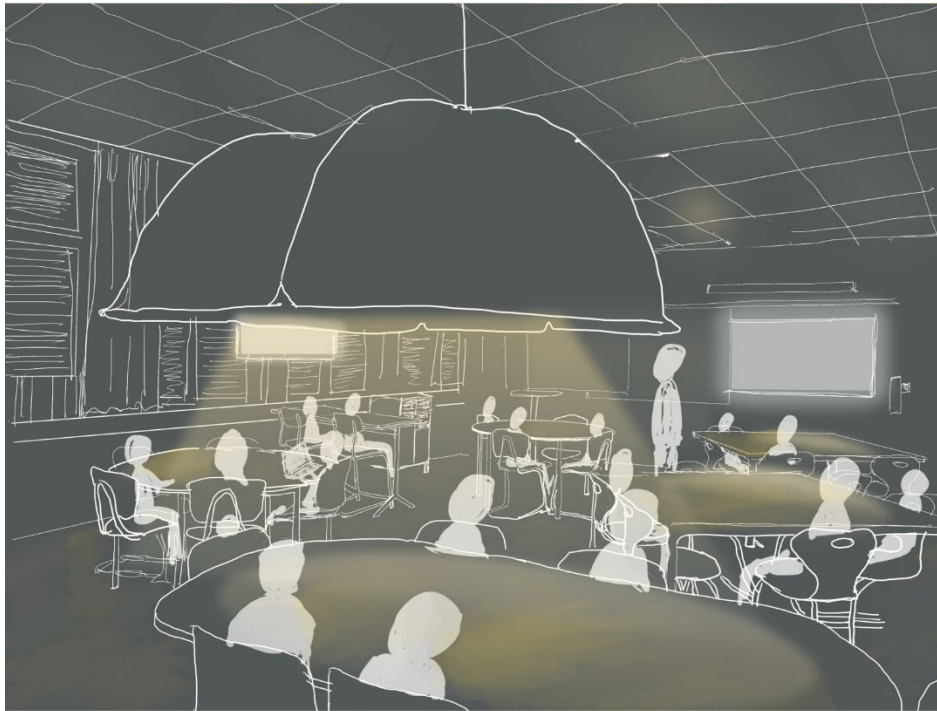


Figure 60 Light distribution for the scene "Collaborate" in main classroom

This scene can be used for group activities and group discussions which form a key aspect of cooperative learning. The contrast between the work-planes and their surroundings is high to draw the attention of the students inwards and give them an intimate zone within the space. A warm yet attentive atmosphere is created with 3000K. Furthermore, the walls are kept brighter since they make the room appear larger (Wolska et al. 2020).



Figure 61 Dialux simulation for lighting scene "collaborate" with downlights switched off, uplight from pendant for general lighting

Movie



Figure 62 Light distribution for "Movie" scene in main classroom

Backlighting from the screens will switch on during this scene to prevent visual fatigue and have a smooth transition from light to dark.

Comparison between existing lighting and design proposal

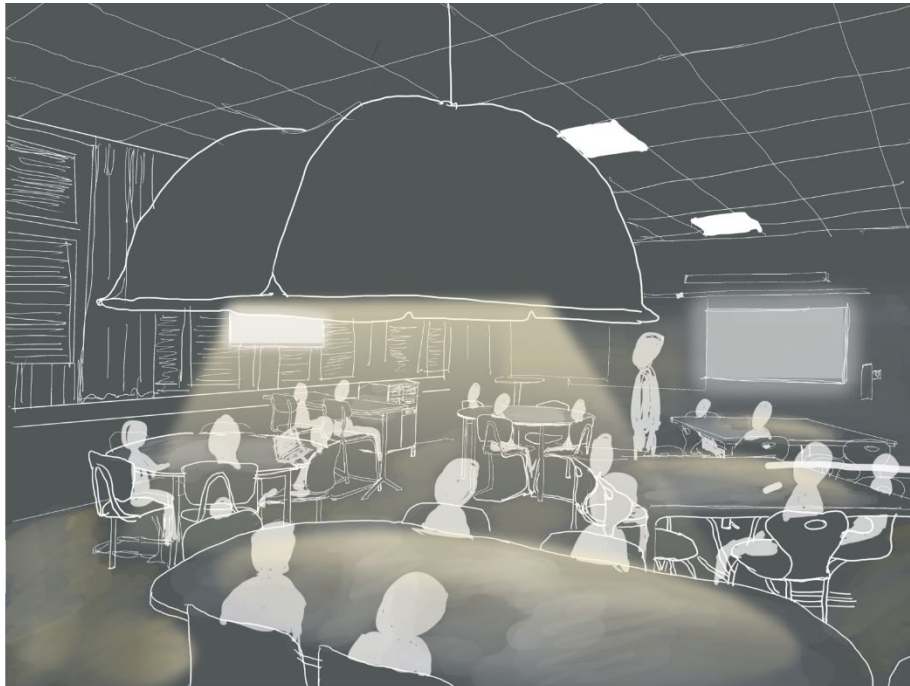


Figure 63 Existing lighting condition in main classroom for all activities

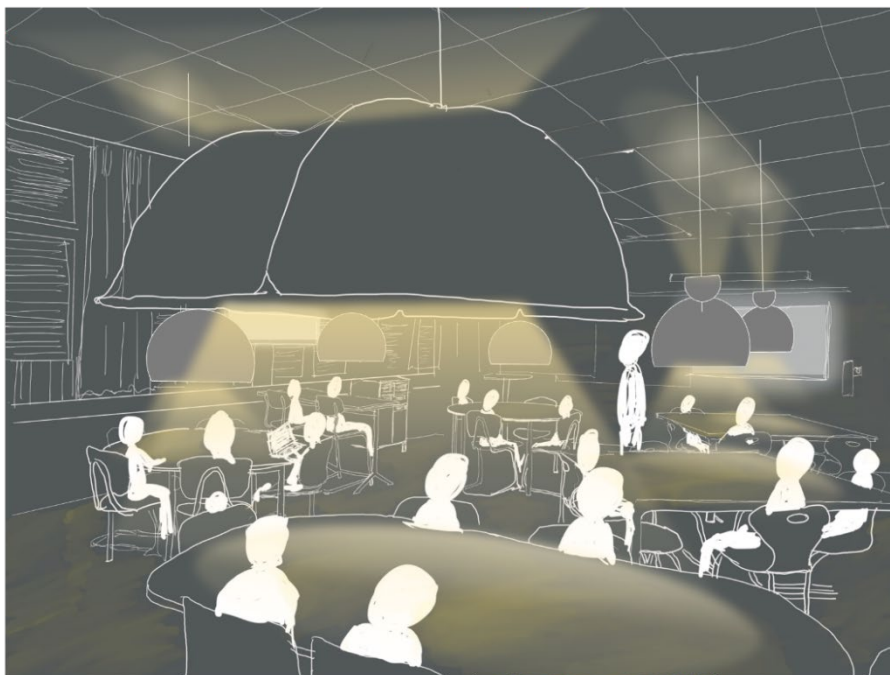


Figure 64 Proposed lighting scheme for main classroom

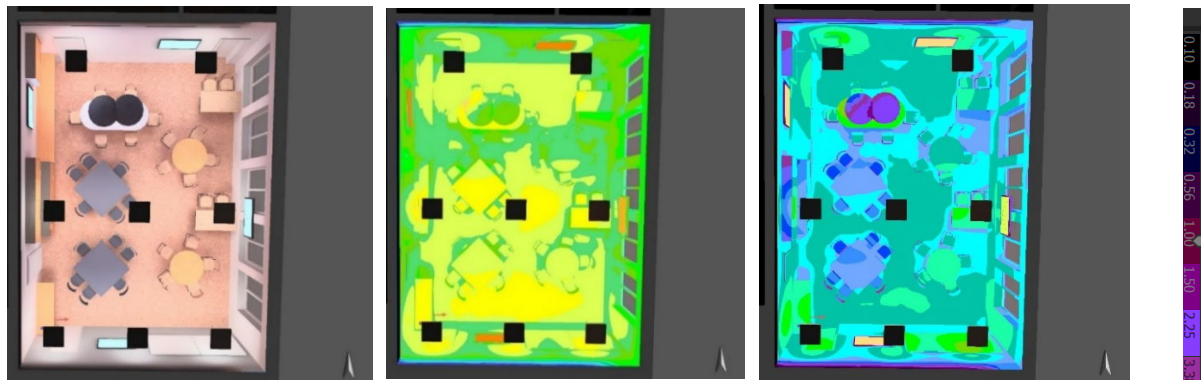


Figure 65 Dialux simulations of existing lighting with illuminance and luminance calculations for all activities

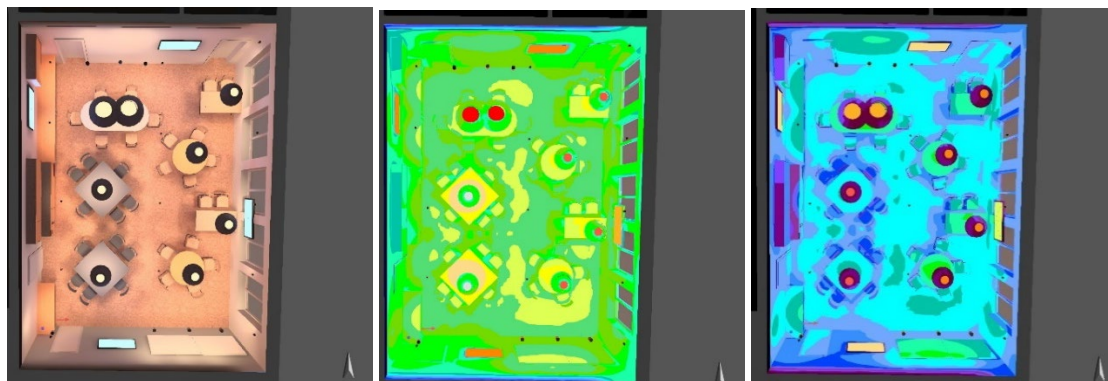


Figure 66 Dialux simulations of design proposal scene "teach" with illuminance and luminance calculations

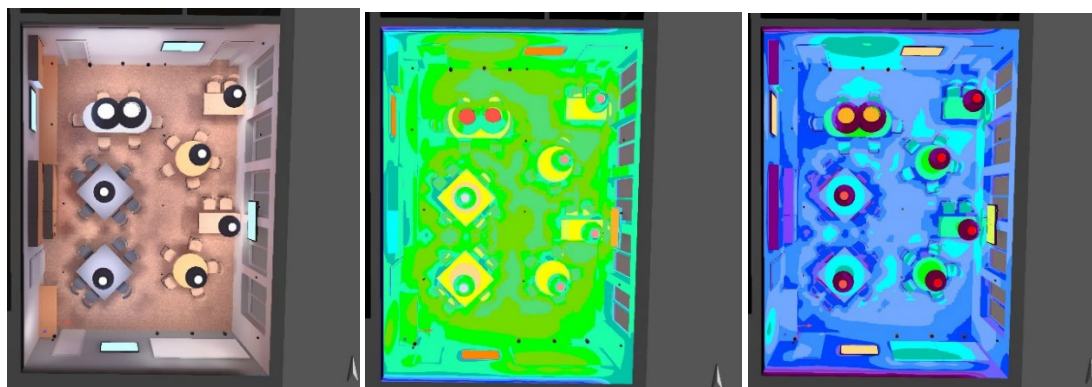


Figure 67 Dialux simulations of design proposal scene "focus" with illuminance and luminance calculations



Figure 68 Dialux simulations of design proposal scene "collaborate" with illuminance and luminance calculations

The design proposal meets the standard (SS-EN-12464 : 2021) illuminance requirement of 500 lux for all work planes in all scenes (fig. 66,67,68) whereas the existing lighting only meets the standards for point A and B (fig. 65,40). The luminance contrast ratio between the work planes and their surroundings is higher in the design scenario to emphasize the task areas and enhance the group interactions. Furthermore, due to low reflectance of black tables, the illuminance levels for point B and C are kept higher to increase the resulting luminance values. The uniformity in designed scenarios vary, highest being 0.3 in the scene “teach” which does not meet the recommended value of 0.6 according to SS-EN-12464 standard and is lower than the existing lighting case, 0.34.

Secondary classroom

Similar to the main classroom, four lighting scenes are proposed for the secondary classroom. Instead of the movie scene, “anecdote” scene is given and an additional working plane, carpet, is considered. The contrast between the tables and their surroundings is higher in scenes “focus” and “collaborate” to draw the attention of the students inwards and enhance their concentration. However, in the “anecdote” scene the lighting intensity of whiteboard and carpet is higher while the rest of the classroom is dimmed uniformly, to emphasize the carpet and draw the attention of students towards the front.

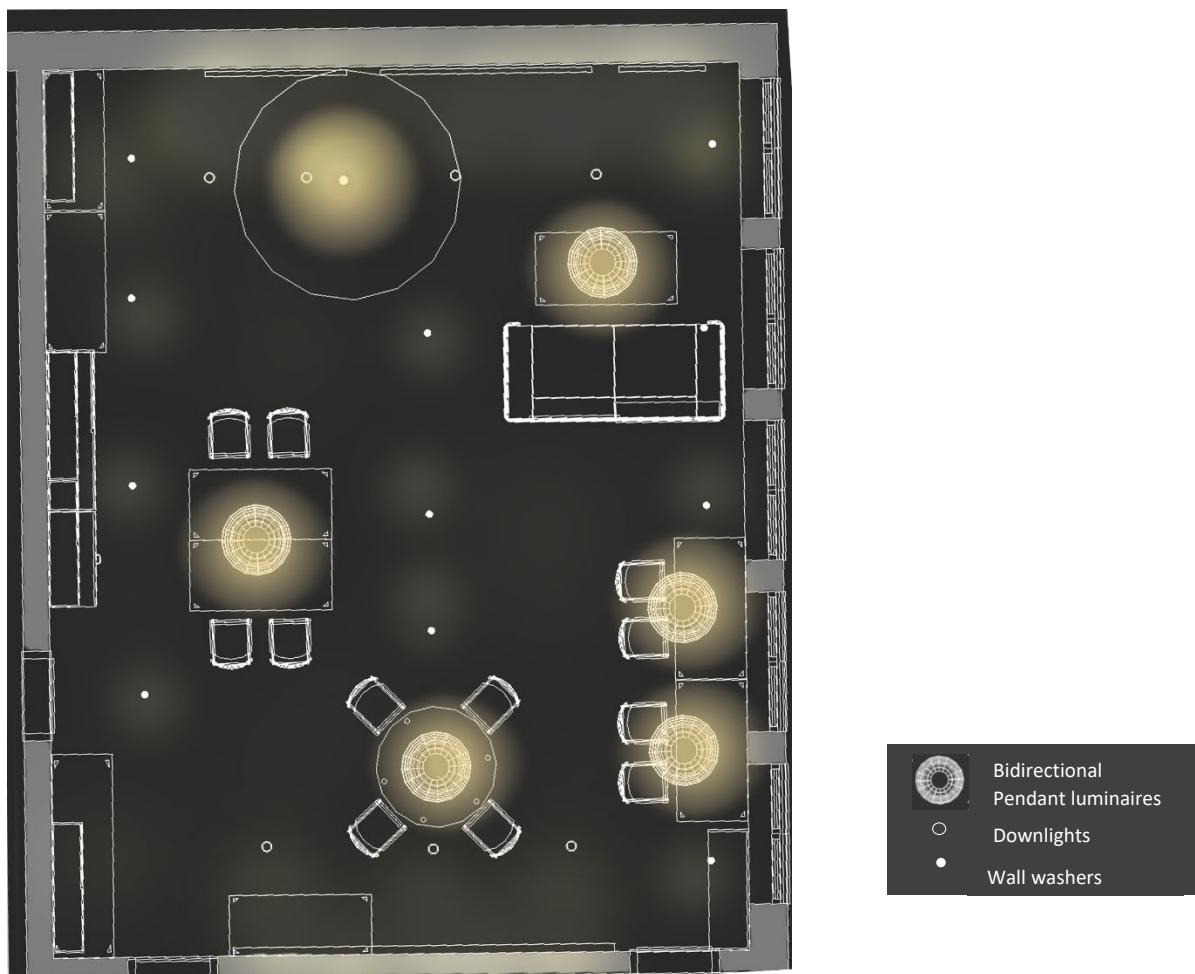


Figure 69 Proposed light distribution in secondary classroom

	Carpet	Tables	Surrounding areas of tables	Whiteboard	Walls	CCT
Teach	300 lx	500 lux	300lx	300 lx	200lx	3000K
Focus	100lx	600 lx	200lx	100 lx	200lx	4000K
Collaborate	200 lx	500 lx	150lx	100 lx	300 lx	2700-3000K
Anecdote	600 lx	100 lx	50 lx	300 lx	100 lx	2700K

Figure 70 Proposed lighting scenes for cooperative learning in secondary classrooms

Teach



Figure 71 Light distribution for the scene "Teach" in secondary classroom



Figure 72 Dialux simulation for lighting scene "teach" with downlights, bi-directional pendant luminaires and wall washers switched on

Focus



Figure 73 Light distribution for the scene "Focus" in secondary classroom



Figure 74 Dialux simulation for lighting scene "focus" with pendant luminaires and wallwashers switched on, downlights switched off ; uplighting from pendant luminaires for general lighting

Collaborate



Figure 75 Light distribution for the scene "Collaborate" in secondary classroom



Figure 76 Dialux simulation for lighting scene "collaborate" with pendant luminaires and wallwashers switched on, downlights switched off ; uplighting from pendant luminaires for general lighting

Anecdote



Figure 77 Light distribution for the scene "Anecdote" in secondary classroom



Figure 78 Dialux simulation for lighting scene "anecdote"

Comparison

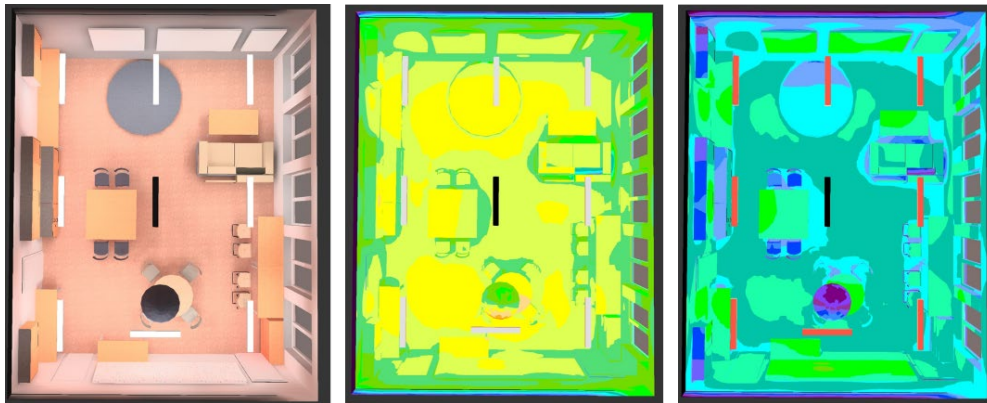


Figure 79 Dialux simulations of existing lighting with illuminance and luminance calculations for all activities

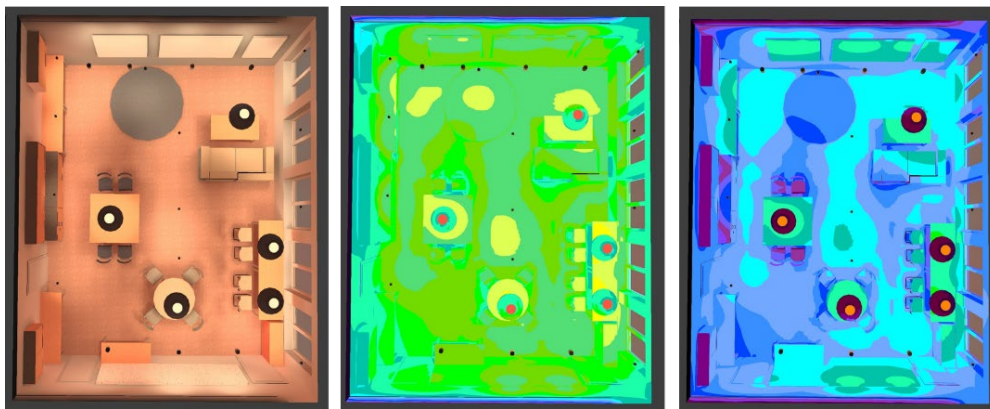


Figure 80 Dialux simulations of design proposal scene "teach" with illuminance and luminance calculations

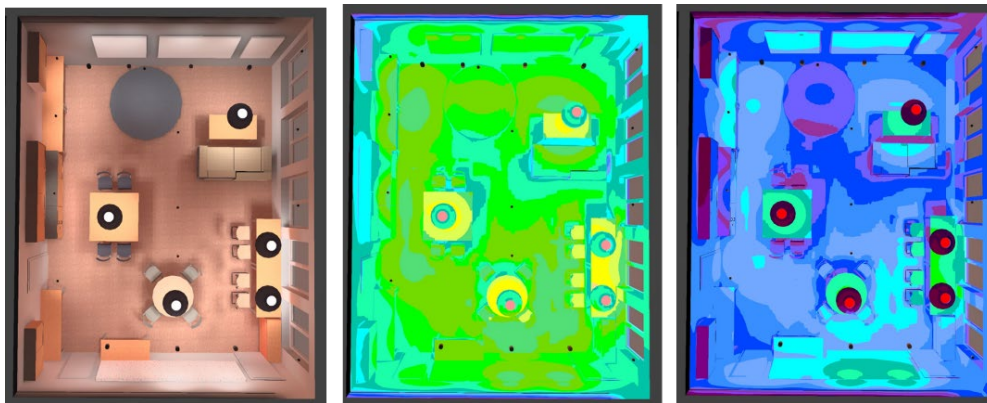


Figure 81 Dialux simulations of design proposal scene "focus" with illuminance and luminance calculations



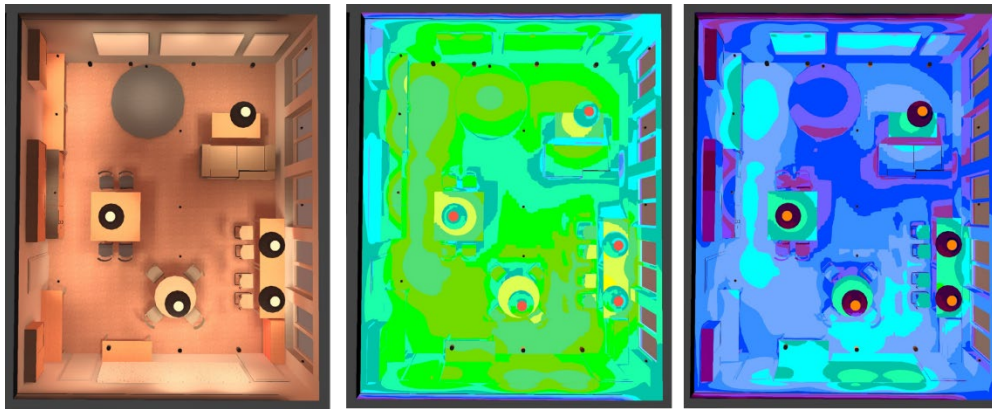


Figure 82 Dialux simulations of design proposal scene "collaborate" with illuminance and luminance calculations

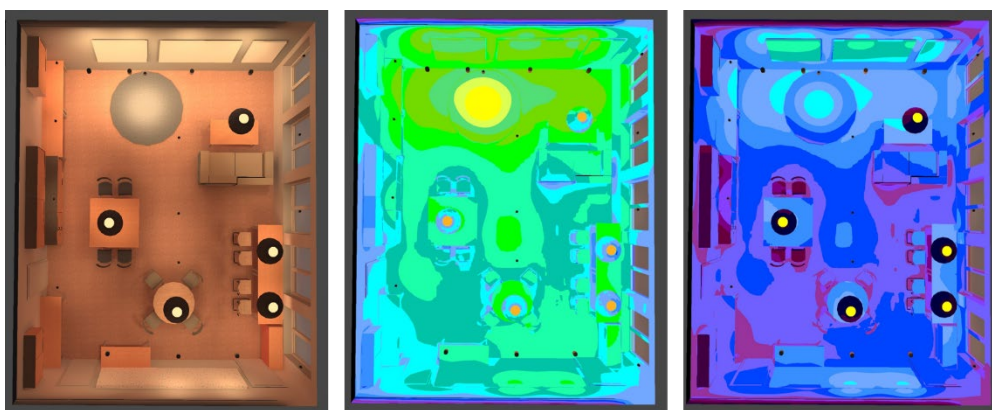
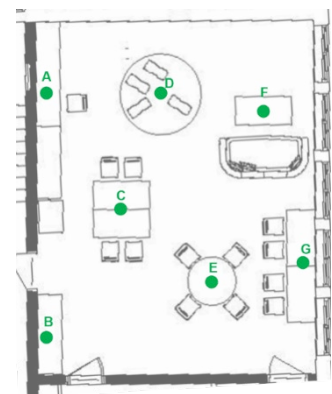


Figure 83 Dialux simulations of design proposal scene "anecdote" with illuminance and luminance calculations

The design proposal meets the standard (SS-EN-12464 : 2021) illuminance requirement of 500 lux on all work planes in all scenes (fig. 81,82,83,84) whereas the existing lighting does not meet the standards for point G (fig. 81,42). The luminance contrast ratio between the work planes and their surroundings is higher in the design scenarios to emphasize the task areas and enhance the group interactions. The uniformity in designed scenarios vary, highest being 0.25 in the scene "teach" which does not meet the recommended value of 0.6 according to SS-EN-12464 standard and is lower than the existing lighting case, 0.42.



6. Discussion & Conclusion

The results from Iggesund Skola show that the lighting requirements of students and teachers have changed with time. To include cooperative learning methods, the users ask for a changeable/flexible lighting solution that can work with their flexible learning method. This thesis saw the phasing out of fluorescent tubes as an opportunity to propose a new lighting system for classrooms that also enhances the learning performance of students (UNSG 3), opposed to retrofitting the existing lighting systems with LEDs.

Taking inspiration from the Hennig Larsen study presented in literature review (Hofmeister 2020) and based on the results of observations and interview, pendant luminaires with uplight and downlight are proposed as a conceptual idea for the classrooms. This lighting system can create areas of high contrast, drawing the attention of the students inwards on the work plane, increasing their concentration during focussed working sessions. As a next step of this research, both long and short-term flexibility can be taken into account by a system of pendant luminaires on tracks that can move to different positions, and change its suspension height, beam angle, intensity and color temperature with the help of a remote, depending on the furniture layout and activities. The track can also accommodate additional luminaires of same or different typology (e.g. spotlights) in case the strength of the classrooms increases in future. However, the track mounted pendants are not common in the market, hence, further research and testing would be required to implement this system.

Based on the results of this study, it is evident that classroom lighting should be considerate of the pedagogical activities and visual tasks for each grade. With the advancement in LED technology and control systems, it is possible to cater to the needs of students and teachers in several pedagogical activities by proposing programmed lighting scenes, however the user-interface of these control systems should be user-friendly. Multiple lighting scenes can be confusing for the users if they do not understand their usage and advantages (corresponds to the findings of Barkmann et al. in 2012). Before handing over the project, seminars or workshops could be held to make the users familiar with the use of the technology. The activities may differ for different grades, hence, it may not be advisable to propose same scenes for all the grades. Furthermore, there is also a question of who should control these lighting scenes in the classrooms. The primary control can lie with the teachers, however, students can also be allowed to define their lighting environment (atleast for their tables and immediate surroundings) by integrating a tablet that has control settings of their pendant light with each table. The proposed lighting scenes will reduce the overall energy consumption and its cost (UNSG 12) and would enhance cooperative learning in classrooms while increasing the sense of community (UNSG11).

The analysis also indicates that the four digital screens in main classroom are too bright for visual comfort and have a significant illuminance contribution. These illuminance values are often not considered in the lighting standards. Since, digital screens have become an important tool for teaching, it is crucial to take not only their brightness into consideration but also the impact of lighting on them to avoid glare and reflections as they may be distracting for the users (Ramsoot et al. 2009). This thesis outlines a scene especially for the usage of screens but since they are switched on throughout the day, it is worth exploring and testing what levels of lighting should be required with the use of projectors and screens in further detail.

The lighting proposal was designed based on the measurements taken in the Spring season. The interview indicates that the students are more tired and less focused during winter, however, further research should be conducted to study the lighting conditions and student learning behavior in other seasons.

7. References

All images are produced by the author unless otherwise stated.

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Appendix

OBSERVATION LOG

Preliminary notes:	
Location:	
Date:	
Time:	
Weather:	
Observation location and observer location in classroom:	
Observer:	
Course:	
No of students:	

Classroom layout:	
--------------------------	--

Developmental Flow of the lesson/unit	
--	--

Interpersonal Interactions	
-----------------------------------	--

Type of interaction	
----------------------------	--

Use of chalkboard/overhead, use of textbook	
--	--

Distractions	
---------------------	--

Light related notes

Use of electric light

light on=1, off=2

General lighting

light on=1, off=2

Whiteboard lighting

light on=1, off=2

Curtains

drawn=1, not drawn=2

to

up=1, down=2

Open/closed windows

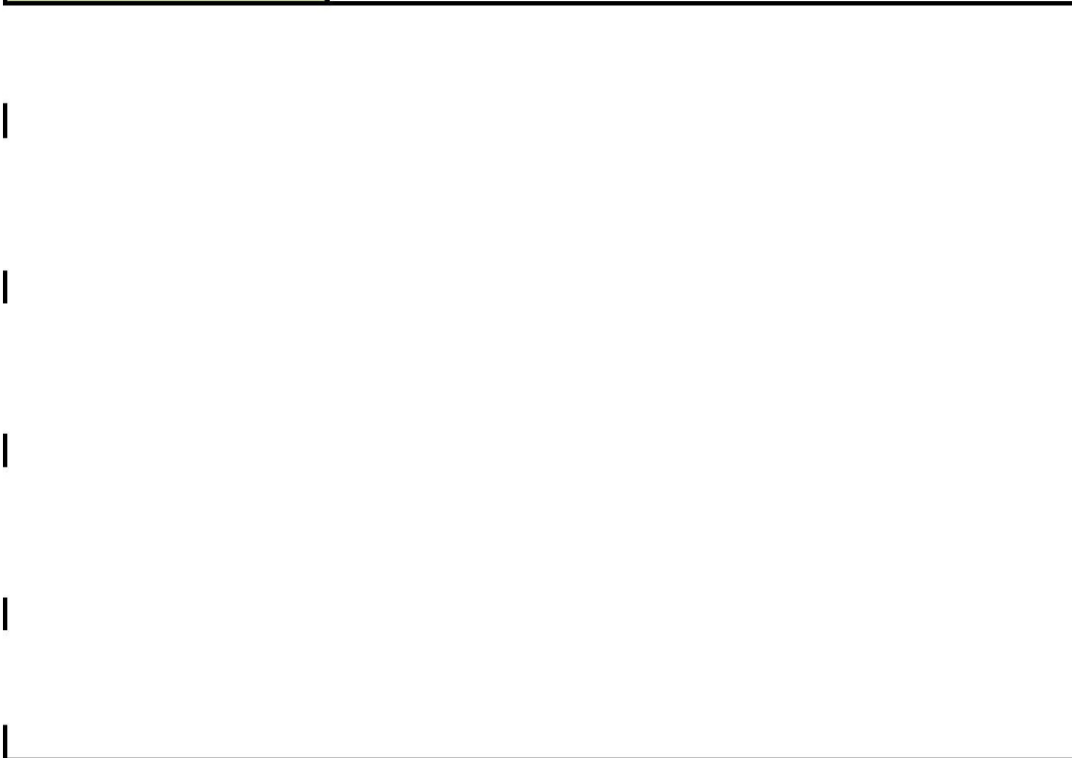
open=1, close=2

Students' influence in lighting:

General notes



Sketches

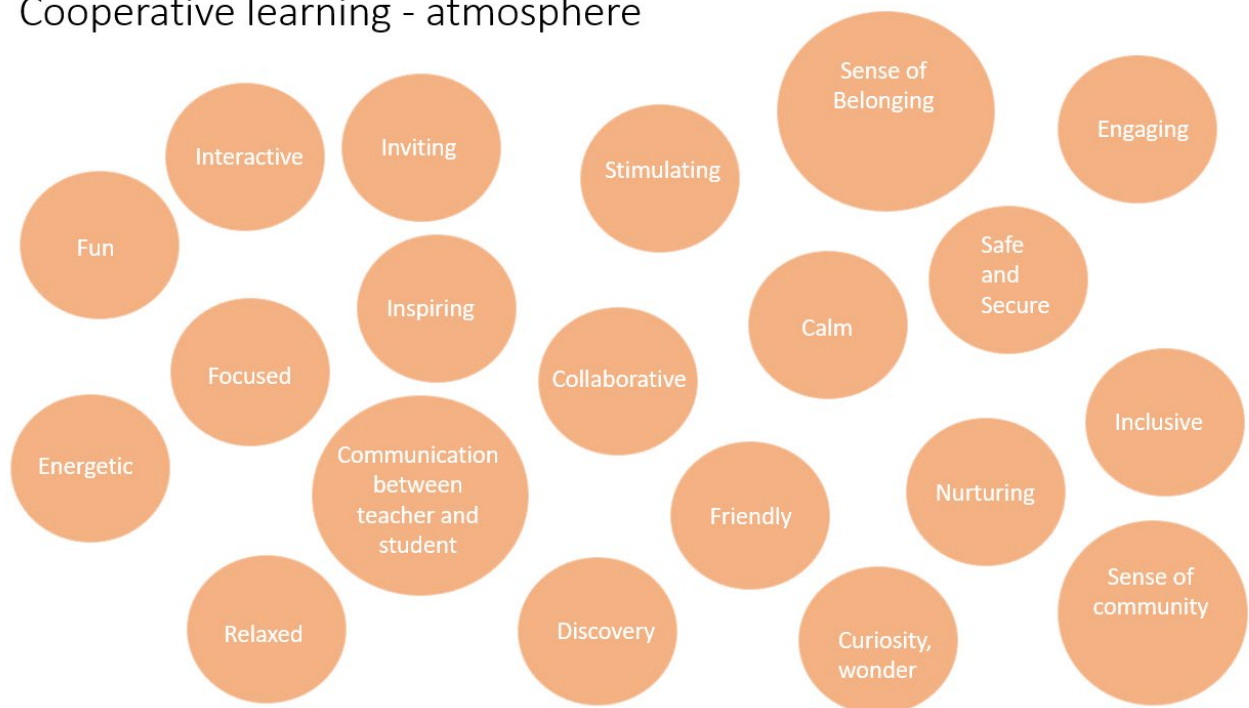


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- |
- |
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For interviews

- What type of different courses do you teach?
- What are the various teaching methods used? What activities are associated with courses – group or individual? Post-pandemic changes in the teaching methods and activities?
- Do you also change the furniture layout during different activities? If yes, do you change the lighting as well?
- What is the most Relaxed hour in terms of activities?
- Does anyone else than you control the lighting during class? How often do you change the properties of the lighting in the classroom?
- Do you seem to use more electric light in winter? If yes, how? And during which activities?
- What is the general impression of the existing lighting system on students? Do they find it too bright/dim satisfied/confused?
- How does the use of projector change the lighting environment?
- Does the presence of different color temperatures of lighting help the students to focus/distract/has no effect on learning?
- Sensors and detectors will help? Controls will help?
- How does the lighting in this classroom impact student learning as compared to the newly built classrooms in Building F?
- If you had the chance to change/improve something in this lighting system, what would it be?

Cooperative learning - atmosphere





ASSIGNMENT MODULE 3 (AM03-KTH/AAU)

For educational & work environments – teaching workshop

Assignment Date: 16th October, 2020; Due Date: 23rd October, 2020

Worksheet, Assignment 2c: Evaluate your space based on V/P seven factors

LOCATION	STUDENT NAME
DATE & TIME	WEATHER CONDITIONS

V/P Theory: The Seven visual-perceptive FACTORS that describe light in space

FACTORS	Describe by your own words
1 Level of light:	
2 Spatial distribution of Light:	
3 Shadows:	
4 Reflections:	
5 Glare:	
6 Color of light:	
7 Color of surfaces:	

FACTORS

Scaling

1

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ASSIGNMENT MODULE 3 (AM03-KTH/AAU)

For educational & work environments – teaching workshop

Assignment Date: 16th October, 2020; Due Date: 23rd October, 2020

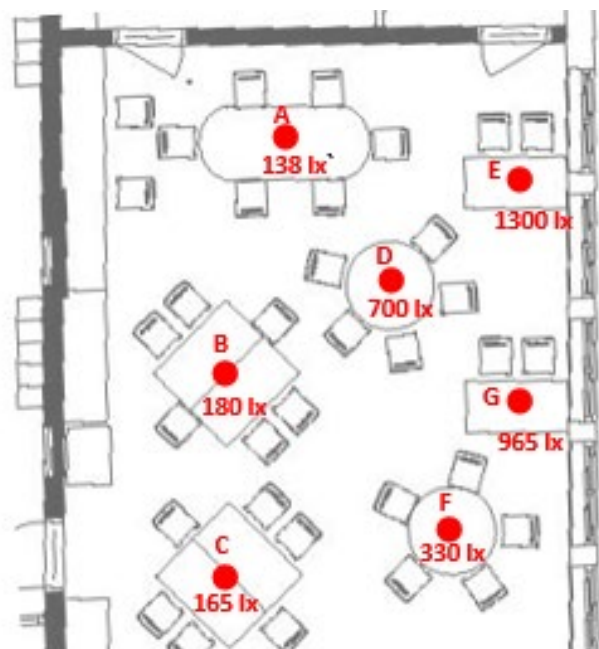
1 Level of light:	dark	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	bright
	poor	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	good
2 Spatial distribution of Light:	uniform	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	varied
	poor	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	good
3 Shadows:	sharp	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	diffuse
	poor	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	good
4 Reflections:	soft	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	clear
	poor	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	good
5 Glare:	tolerable	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	disturbing
	poor	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	good
6 Color of light:	cold	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	warm
	poor	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	good
7 Color of surfaces:	natural	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	distorted
	poor	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	good



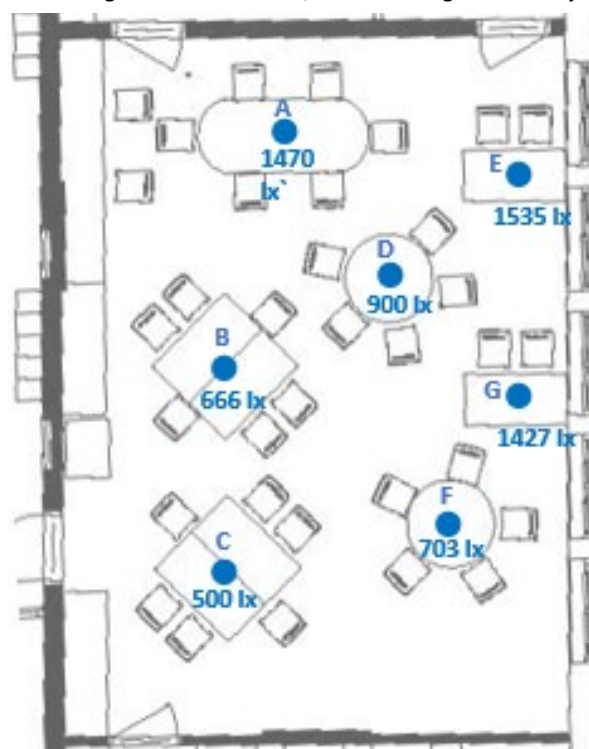
Point measurements of horizontal illuminance on working planes in main classroom :



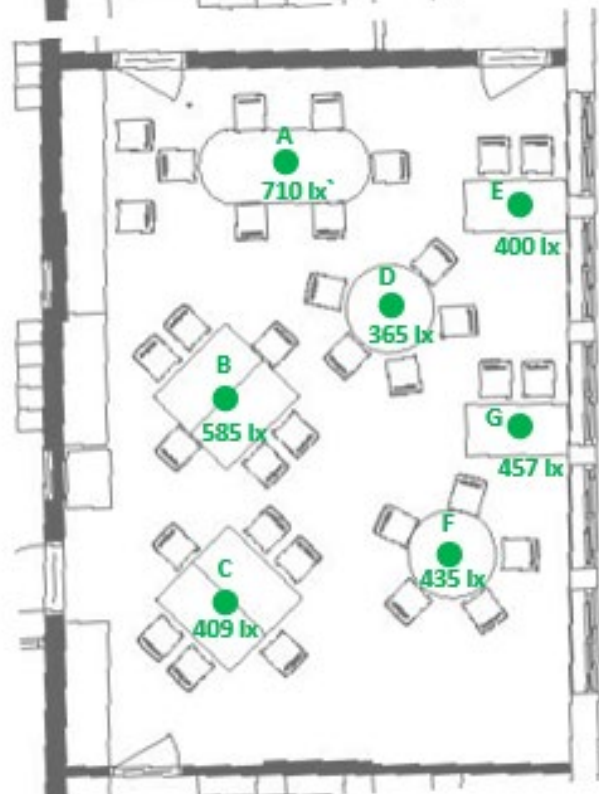
Only Display screens on: curtains and blinds were drawn and the artificial lighting was switched off while all four display screens were on, commonly used by the students while watching educational videos, movies during various subjects



Daylight only: curtains and blinds were removed, and the artificial light was switched off.

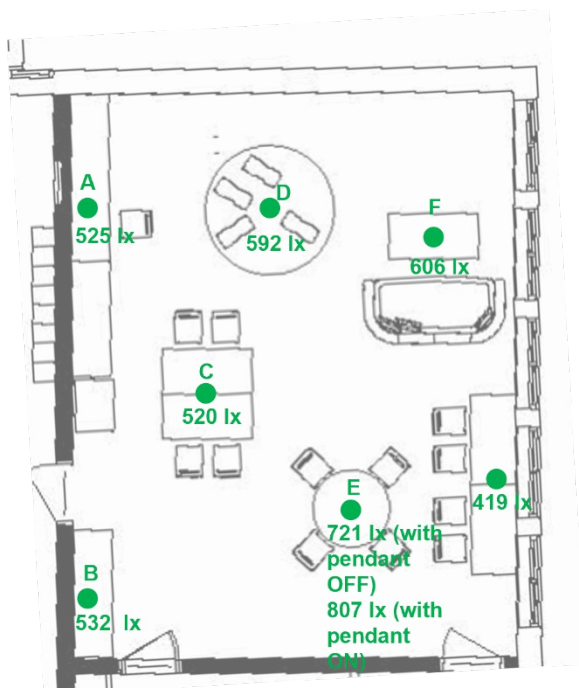
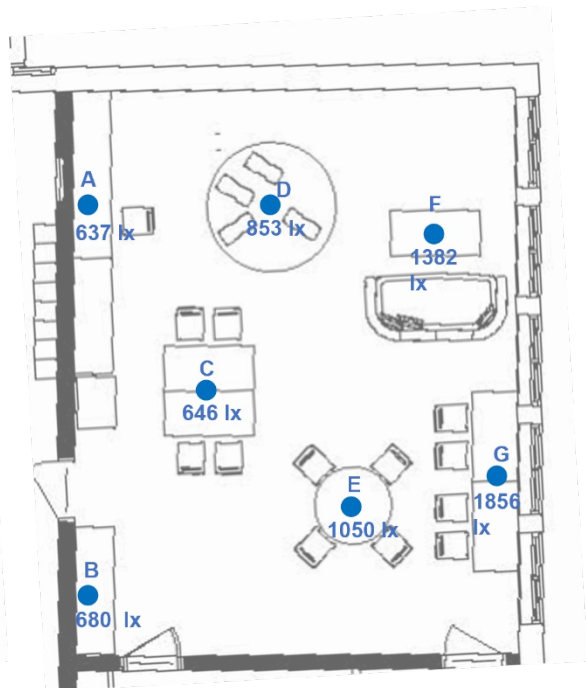
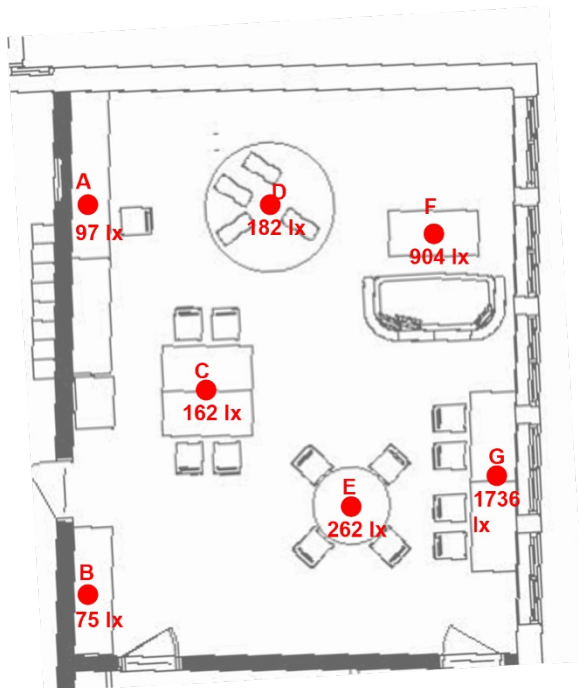


Artificial lighting + Daylighting: curtains and blinds were removed, and the artificial lighting was switched on 100%.



Artificial lighting only: curtains and blinds were drawn, and the artificial lighting was switched on 100%.

Point measurements of horizontal illuminance on working planes in main classroom :



Simulations



Archive

Screens only

