CHILDHOOD MYOPIA AND LIGHT EXPOSURE IN SCHOOL ENVIRONMENTS

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Master Thesis

Delft University of Technology

20th of June 2023

Delft University of Technology
AR3B025 Building Technology Graduation Studio
MSc. Architecture, Urbanism and Building Sciences
20th of June 2023

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Acknowledgements

This thesis would not have been possible without the help of some people I would like to thank. I am grateful that I was able to work with them on this project. First of all, I would like to thank my two mentors Eleonora Brembilla and Michela Turrin for guiding me through the last eight months and giving scientific input. I would also like to thank external advisors AnneMarie Eijkelenboom, Eline Hoogendijk and Rosanne Alkema from EGM Architects, Luke Price and Marina Khazova from the UK Health Security Agency and Dr Annegret Dahlmann-Noor from the Moorfields Eye Hospital in London for providing information on research topics and supporting me. Special thanks to the principals of the schools I was able to do the measurements, Freek van Baarle from the Ds Abraham Hellenbroekschool and Ingard Lachman from the Pniëlschool. Lastly, I would like to thank my family, friends and fellow students who have supported me and made this year memorable.

Abstract

Myopia is an eye disease that begins to develop at a young age, approximately between the ages of six and nine years. Children these ages spend a large amount of time inside school buildings. Two case studies have been studied to see what can be improved in school building design to get more light inside. Light measurements have been done to see what the current situation is of these schools. After this, several design adaptations have been simulated to see their impact on the light levels inside. These design adaptations included enlarging the windows in several ways and changing the colours and materials inside. They are ranked in two design matrices, rated on effectiveness, feasibility and costs for both renovation and newly build school buildings. Results show that replacing the floor with a light coloured one and replacing the sun shading with white thin ones , increasing the illuminance inside with 25% and 63% respectively, are the best design strategies for renovation. For new school buildings it is recommended to make the windows wider instead of lower, which can result in an increase of illuminance inside of 34%.

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Introduction

1.1 Background

In recent years, the development of the eye has changed for a big part of the population. More people have bad eyesight and need glasses or contact lenses to correct it. The most common eye disorder is myopia, better known as nearsightedness. In this eye disorder, the eyeball has grown too long so that light is aimed in front of the retina instead of on it (Dolgin, 2015). Myopia begins to develop at a young age, approximately between 6 and 9 years old (Tideman, Polling, Vingerling, Jaddoe, Williams, Guggenheim & Klaver, 2018). Childhood myopia can become a big problem apart from wearing glasses or contact lenses, because it can lead to several serious eye disorders such as glaucoma, retinal detachment and even blindness (Drack, 2003). Research shows that more people are developing myopia and if nothing is done, 50% of the world population will have developed myopia by 2050 (Holden, Fricke, Wilson, Jong, Naidoo, Sankaridurg, Wong, Naduvilath & Resnikoff, 2016). The age that children are developing myopia is becoming lower through the years. This is probably related to the high work pressure and less time spend outside. Especially in Asia myopia is a big problem and around 90% of the students already need glasses or contact lenses (Dolgin, 2015).

1.2 Problem statement

The research on how to decrease or prevent myopia is relatively new. Because myopia begins to develop at a young age, the focus is on children. Methods like eye drops and eye operations are researched, however it is best to prevent it by adapting the lifestyle. Children spend a significant part of their time at school, so changing school building design might help to prevent myopia development.

1.3 Research objectives

The main goal of this research is to find ways related to school building design to decrease myopia development. The final outcome will consist of design recommendations, ranked in a design matrix, for decreasing myopia development. Research so far shows that these could be related to outdoor time, light intensity on the eye, coloured artificial light and colour use in general.

1.4 Research questions

The main research question that will be answered in this thesis is:

"How can school building design help to reduce childhood myopia?"

The sub questions that will be answered are:

1. What is myopia and what causes it?
2. How can myopia development be reduced in relation to architecture?
3. What is the current situation of a recently build and a renovated school building in the Netherlands?
4. What can be improved in a recently build and a renovated school building in the Netherlands?
5. What design choices in school buildings can be made to decrease myopia?

The first two sub questions have been answered with the help of literature and other research. The third sub question has been answered by doing measurements inside two case study school buildings. For the fourth sub question, simulations were run to see the impact of different design adaptations. Lastly, these design adaptations are rated in a matrix to answer the fifth and final sub question.

1.5 Relevance

The topic of childhood myopia development is relatively new and growing and if nothing is done, half of the world population will have myopia by 2050. This will eventually lead to many people with eye disorders or even blindness. For the well-being and health of all the people, hopefully research now can prevent this in the future. With this research, hopefully there is a little bit of information added gathered from Dutch school buildings about their current situation and where there is room for improvements. This can help in the bigger research to prevent myopia. The specific research has never been done; measurements in existing school buildings in the Netherlands and giving design recommendations for improvement based on simulations and ranked in a design matrix.

2

Background research

2.1 Myopia

2.1.1 Development of myopia

In recent years, the development of the eye has changed for a big part of the population. More people have bad eyesight and need glasses or contact lenses to correct it. The most common eye disorder is myopia, better known as near-sightedness. In only fifty years the amount of people with myopia has been doubled and by 2050 half of the world population will have developed myopia (Dolgin, 2015; Holden, Fricke, Wilson, Jong, Naidoo, Sankaridurg, Wong, Naduvilath & Resnikoff, 2016). Myopia is an eye disorder which results in not being able to see far away. Myopia can be divided into two main categories: refractive and axial. Refractive myopia develops because the focusing power of the eye is exceptionally strong, so it focusses the image in front of the retina. If the retina is not reached, the image is unclear. Axial myopia is more common and develops because the eyeball has grown too long what causes that light is aimed in front of the retina instead of on it (see figure 1). This happens because there is a mismatch between several optical components of the eye. The cornea, the crystalline lens and the eye's axial length (AL) are the most important parts (Tideman, Polling, Vingerling, Jaddoe, Williams, Guggenheim and Klaver, 2018). If myopia is developed till or further than −6 diopters (D), it is called high myopia and corresponds with an AL≥26 mm. With high myopia, the risks of getting serious eye disorders or even blindness are much bigger. If the light is aimed behind the retina, the image is also unclear. This is called hyperopia, better known as farsightedness (see figure 1) (Drack, 2003).

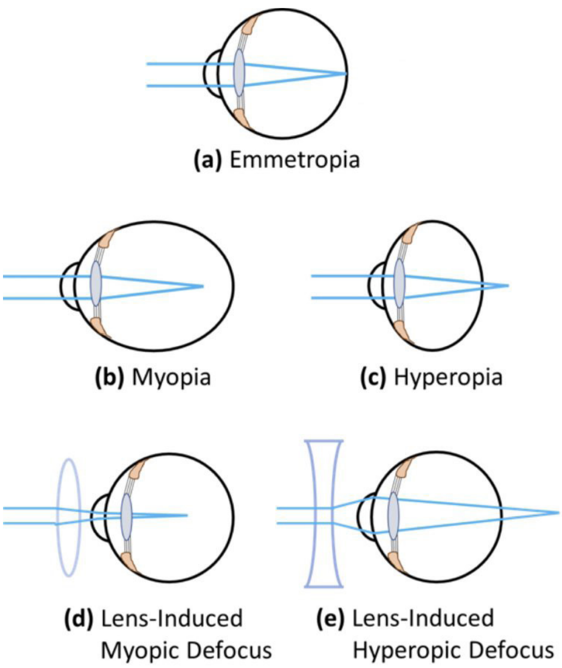


Figure 1: Shape of the eyeball in common eye disorders (Carr & Stell, n.d.)

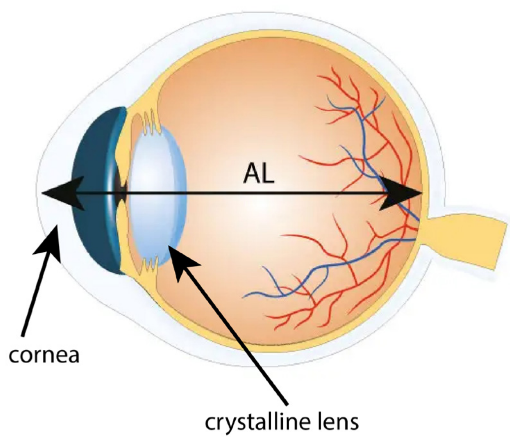
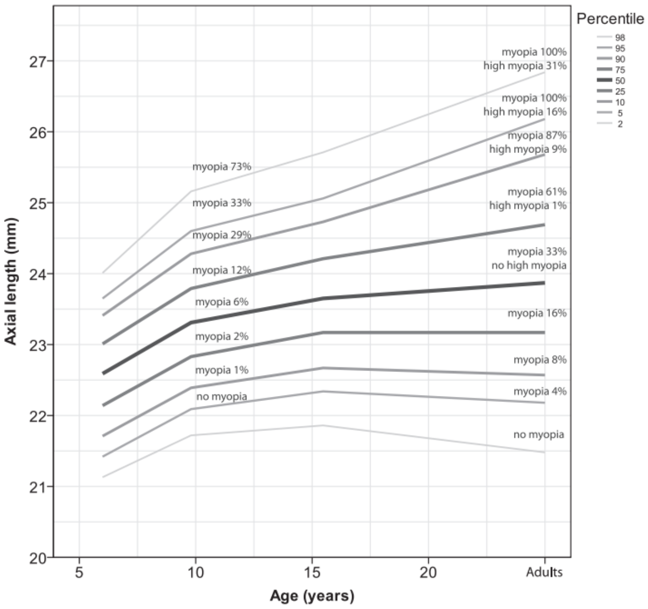


Figure 2: Most important parts of the eye to develop myopia (Vision Care Clinic, n.d. with own adaptations)

Myopia begins to develop at a young age, approximately between 6 and 9 years old (Tideman et al., 2018). Research shows that children between these ages have a high possibility to develop myopia (see figure 3). The graphs shows the highest rise between the ages 6 and 9. That is why childhood is an important period to try to change this development. There is no significant variation between males and females. The graph shows that myopia can also develop further during teenage years and in adolescence. If the myopia development is already reduced during childhood, it will minimize further AL growth at a later age (Tideman et al., 2018).



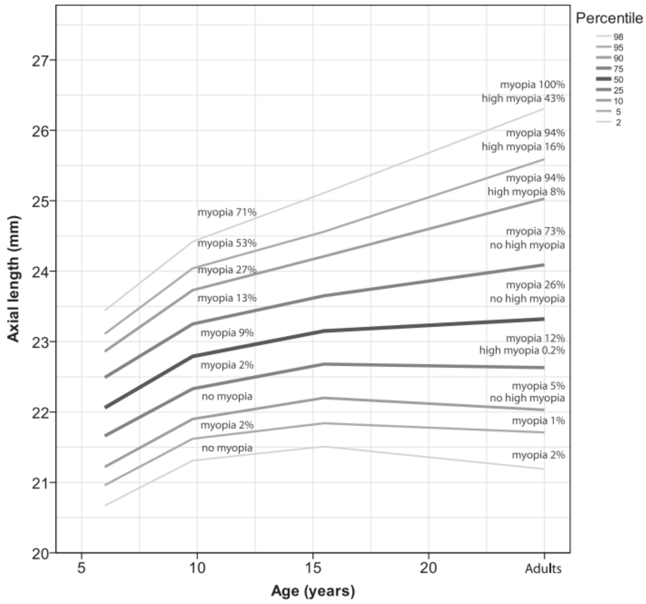


Figure 3: The risk of developing myopia at different ages (left: males, right; females) (Tideman, Polling, Vingerling, Jaddoe, Williams, Guggenheim & Klaver, 2018).

2.1.2 Ethnical differences

How many times and how strong myopia occurs, differs strongly between different populations and different ethnic groups. In western Europe and the United States, it occurs at around 25% of the population. Only 2% has high myopia (Curtin, 1985). Studies show that in Asia myopia is a much bigger problem (Drack, 2003; Dolgin, 2015). Already 75% of the population has myopia and this is only getting worse. Recent research done in Hong Kong shows that more than 90% of the university students has developed myopia (Dolgin, 2015; Lam, 2001).

2.1.3 Parental Myopia

Myopia can pass from parent to child. Studies show that if one or both parents have myopia, the risk that the child is born with a bigger AL has increased with around 10% (Zadnik, 1994; French, Morgan, Mitchell & Rose, 2013). But parental myopia is not only increasing the risk of having myopia, but also increasing the development of myopia for their children (Kurtz, Hyman, Gwiazda, Manny, Dong, Wang & Scheiman, 2007). If this goes on for generations, myopia is becoming a bigger problem over the years.

2.2 Solutions related to architecture

Possibilities to reduce the development of myopia are changes in lifestyle, pharmacological remedies such as eye-drops (atropine) and optical solutions like multifocal contact lenses (Tideman et al., 2018). This research focusses only on changes in lifestyle related to architecture. Children that develop myopia the fastest, aged between 6 and 9 years old, spend a significant part of their time at school. So, school building design might help to prevent myopia development.

There is a possible relationship between light exposure on the eyeball and the development of myopia. During summer months, myopia develops slower (Fulk, Cyert & Parker, 2002; Gwiazda, Deng, Manny & Norton, 2014). Outdoor light illuminance is typically 10–1000 times higher than indoor light illuminance. Research shows that children should spend at least three hours a day under light levels of at least 10,000 lux to be protected against myopia (Dolgin, 2015). Training the eyes to watch further into distance more often is also important to decrease myopia development (Xiang & Zou, 2020). This chapter will explain some factors that can help to reduce myopia related to lighting design in school buildings.

2.2.1 Green outdoor space

When spending more time outside, the eyeball receives more lux than inside. Several studies show that increased outdoor time reduces the risk of myopia onset (see figure 4) (Xiong, Sankaridurg, Naduvilath, Zang, Zou, Zhu, Lv, He, & Xu, 2017). Related to this, there is also strong evidence that people spend more time outside when there are a lot of big and attractive green spaces. In Australia, three of more hours outdoor time a day is the standard and only 30% of the 17-year-olds have myopia (Dolgin, 2015). Spending more time outside and adding more attractive green spaces can help to reduce the onset of myopia, however, it cannot help to reduce the progression of myopia when the myopia has already been developed (Xiong et al., 2017). For school building design, it can still help to make the outdoor space attractive and green so the children will spend more time outside during their breaks. For children that age, there is a bigger chance that the myopia is not developed yet.

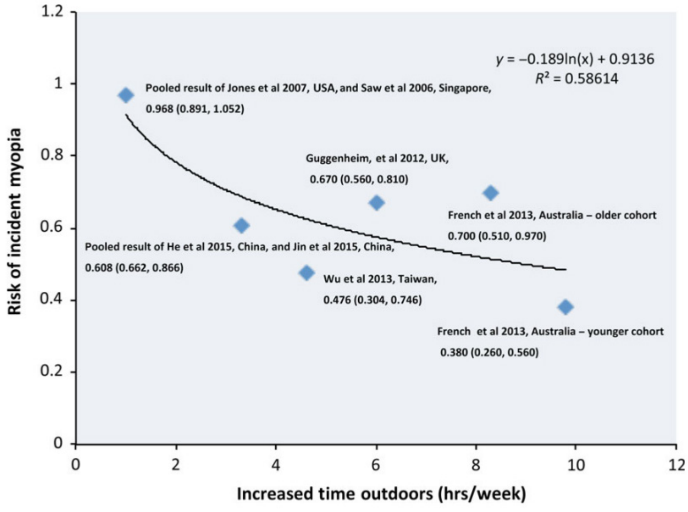


Figure 4: Studies that found evidence between spending more time outdoors and lower risk of developing myopia (Xiong, Sankaridurg, Naduvilath, Zang, Zou, Zhu, Lv, He, & Xu, 2017).

2.2.2 Colour spectrum

There is also a possible connection between the colour spectrum and myopia development. Red and blue light have an influence on the development of the eye. Short-wavelength light, such as blue light, tends to focus in front of the retina, and long-wavelength light, such as red light, tends to focus behind the retina (see figures 5 and 6). In recent years light therapy is studied and used to reduce myopia. However, a lot is still unknown (Zhang & Zhu, 2022).

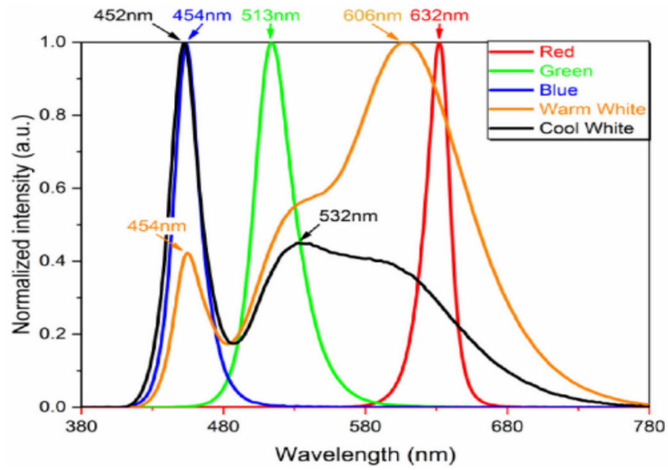


Figure 5: The spectral power distribution of coloured light (Baeza Moyano & González-Lezcano, 2021).

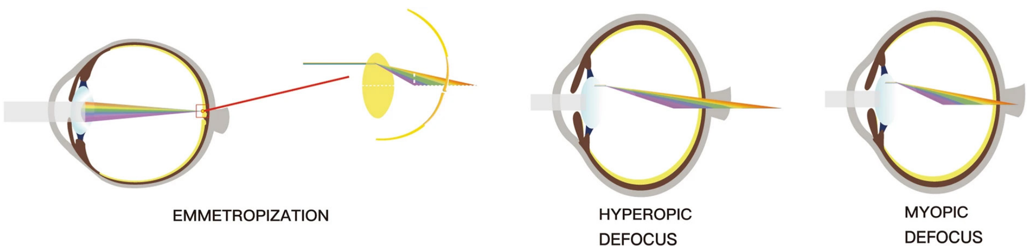


Figure 6: Blue light focusses in front of the retina and red light behind it (Zhang & Zhu, 2022).

Species react different to short or long wavelengths in connection to myopia development. Experiments with different species showed that the relationship between light exposure and myopia is extremely complex. It depends on the species if short wavelengths influence the eye to become myopic or hyperopic (Zhang & Zhu, 2022). Zhou, Xing, Qiang, Hua & Tong (2021) state that for humans the long wavelength light (red) helps to reduce myopia. In their study, the axial length of the eye decreased when exposed to red light therapy and continued to grow in the control group (see figure 7). However, Torri et al. (2017) found that not long wavelengths, but short wavelength violet light (360-400 nm) helps to suppress the myopic elongation of the eye.

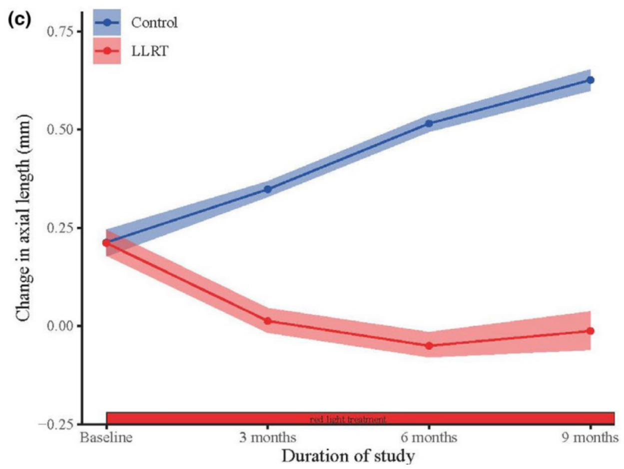


Figure 7: The control group had an increase in the axial length and the LLRT (low intensity, long wavelength, red light therapy) group had a decrease (Zhou et. al, 2021).

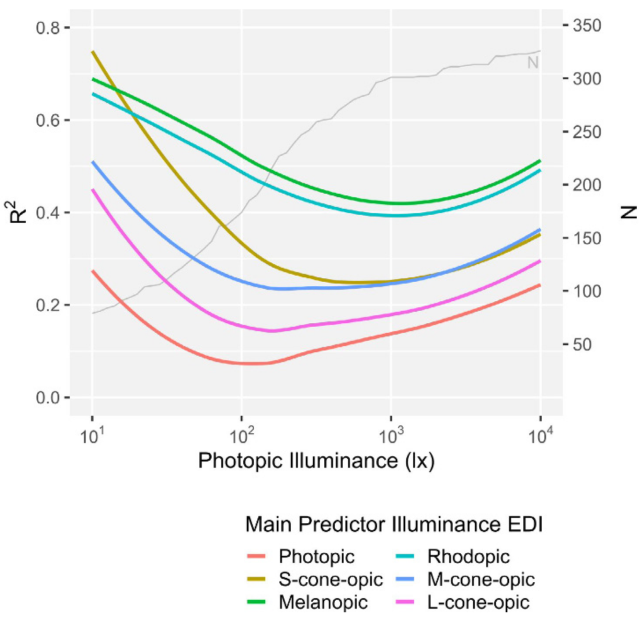
Despite the conflicting research, there might be a connection. The windows that most buildings use probably do not let the whole colour spectrum through and the artificial lighting inside the classrooms only contains a small range. It could be possible that the shortest and longest wavelengths are filtered out, but they both help to reduce the development of myopia. Possible adaptations in school building design can come from this. For example, new artificial lights are studied with a larger colour range: LED lighting with five channels of RGCWW (red, green, cyan, warm white, and cool white) New windows are also studied that allow different wavelengths to pass through (Nie, Wang, Dang, Dong, Zhou, Yu, Zhang, Shen, Chen, Jiao, Li, Zhan, Chen, Chen, Kang & Wang, 2019).

2.2.3 Non-visual influence

Light can also have an influence on the non-visual part of our body. The cells, the intrinsically photosensitive Retinal Ganglion Cells (ipRGC), impact our circadian rhythms. Circadian rhythms consist of a period of approximately 24 hours and are autonomous processes in the body. They are powered by so-called circadian clocks that regulate daily rhythms of sleep and alertness, blood pressure and heart rate, locomotor activity, hormone secretion, body temperature, metabolism, and many other physiological processes (Kearney, O'Donoghue, Pourshahidi, Cobice & Saunders, 2017). A recent study shows that the development of myopia may be related to the circadian rhythm ((Giménez, Stefani, Cajochen, Lang, Deuring & Schlangen, 2022).

Melatonin is a hormone that our brain produces in response to darkness. It helps with the timing of your circadian rhythms (24-hour internal clock) and with sleep. Being exposed to light at night can block melatonin production. Kearney et al. (2017) found evidence that humans with myopia have higher concentrations of melatonin than people without myopia. So, it is important to lower the concentration of melatonin to reduce myopia. Different light levels and wavelengths can have different amounts of melatonin. There are five spectral weighting functions for the five (a-opic) retinal photoreceptor classes: S-cones, M-cones, L-cones, rods and melanopsin-based photoreception of ipRGCs (Giménez et al., 2022). These five predictors are compared with each other on how well they suppress melatonin. Figure 8 shows that the melanopic EDI is overall the best, except for photopic illuminances below approximately 21 lux where S-cone-opic EDI was the best. However, values between 21 lux are very low and will not happen very often during the day.

This research also studied other factors such as light exposure duration, timing and pupil dilation. The four main factors to suppress melatonin are in order of importance: melanopic EDI, light exposure duration, pupil dilation and S-cone-opic EDI (Giménez et al., 2022). Figure 9 shows the melatonin suppression of factors combined in different ways: exposure duration and melanopic EDI for undilated pupils. The coloured areas indicate sections of melanopic EDI that are recommended for different functions: ideal sleep environment (grey area, 0 lux), sleep supportive evening setting at home (cyan area, 0 till 10 lux) and daytime indoor environment (yellow area, from 250 lux). The dashed grey line shows the profile of 50% melatonin suppression under a dilated pupils situation for comparison. This graph shows that even with only 10 lux, the melatonin suppression can be 50% if the exposure time is long enough.



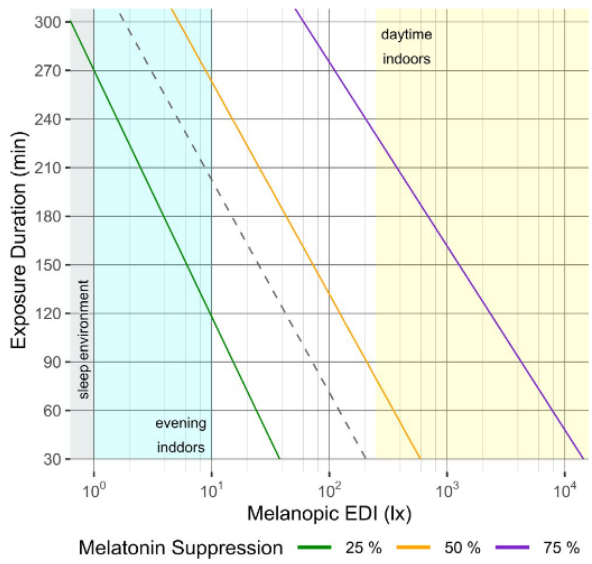


Figure 8 (left): Melanopic EDI predicts melatonin suppression the best overall. (Giménez, Stefani, Cajochen, Lang, Deuring & Schlangen, 2022).

Figure 9 (right): Melatonin suppression in different periods of time considering exposure duration and lux levels (Giménez, Stefani, Cajochen, Lang, Deuring & Schlangen, 2022).

2.2.4 Materials and colours

The materials and colours of the interior can also have an impact. The classroom should be a pleasant place to learn and play. When done well, the interior will stimulate children to play, be active and go outside instead of looking at their screen. These are also factors that can reduce myopia development. A study that researched which materials of a desk are the most pleasant to read a white paper on, have found some boundary conditions (Ortiz, Zhang &Bluyssen, 2019). The luminance ratios should not exceed 1:3 or 3:1 between the task and the direct surrounding. For example, if children are writing on paper, the surroundings should not be too bright. These luminance ratios will also make sure that there is enough difference in colour and monotony is avoided. This is important to make the classroom a good space. The paper (task) should be slightly brighter than the table it is on. This helps for concentrating on the paper and simultaneously avoids distraction. The most preferred material was a wooden-like surface, where this contrast with the surroundings is bigger than a white desk. The white (normal, matt, reflective) desks where the least preferred because they had little contrast and specularity (Ortiz, Zhang &Bluyssen, 2019).

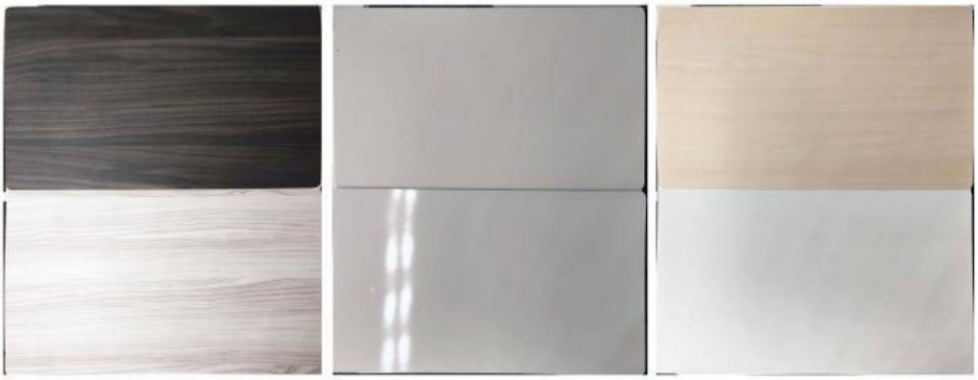


Figure 10: The desk surfaces that were reviewed by children (Ortiz, Zhang &Bluyssen, 2019).

To create an environment with not too much or too little luminance contrast, the following reflection factors are recommended (NEN-EN 12464-1:2021):

Ceiling: 0,7 - 0,9 Walls: 0,5 - 0,8 Floor: 0,2 - 0,4 Furniture: 0,2 - 0,7

Colours can have different effects on people: if used well, they will stimulate children to learn and play and even to go outside. Rooms with a balance of light colours and with elements of bright colours had the best correlation with learning progress. Primary and bold colors promote playfulness and positivity, which are ideal for preschool and elementary school environments. Blue is most fit for larger surfaces in classrooms. Pops of yellow can be effective in maintaining students' awareness in the classroom (Hawley,2020).

3

Methodology

3.1 Case studies

The methodology to see what design improvements can be made is as follows: measurements related to light have been taken in two existing schools. One is newly built and has classrooms with all different orientations, the Ds Abraham Hellenbroekschool in Zwijndrecht. It has much green space around it for children to play in the breaks. The second one is a building with large, high windows, originally built in 1920 and renovated in 2022: the Pniëlschool in Rotterdam. After the renovation, a lot more light is coming inside. These measurements will show if the current lighting plan meets the requirements.

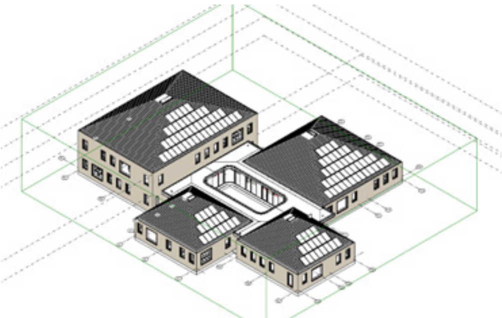


Figure 11&12: Ds Abraham Hellenbroekschool in Zwijndrecht (left) and the Pniëlschool in Rotterdam (right) (EGM Architects, 2022).

The surroundings of the schools are also quite interesting to look at because they can have an effect on the light inside. As shown in figure 13, the Ds Abraham Hellenbroekschool has some high rise around it, but it is on the north side. The Pniëlschool has mostly buildings with the same height around it (figure 14).

Figure 13 & 14: The surroundings of the Ds Abraham Hellenbroekschool (left) and the Pniëlschool (right). The schools are marked with an orange line (Google Earth, 2022).

3.2 Measurements

Lighting measurements have taken place inside these two case study buildings. The measurements were taken inside a few classrooms with different orientations, in the hallways if there are study places and the outside space. In both schools the same measurement plan is used. The measurements consist of:

- **Vertical illuminance at sitting eyelevel of children**

This is measured in three or five spots inside the classrooms with at least three viewing directions. Many different conditions have been tested, including with and without sun shading and artificial light. This is measured with the illuminance meter.

- **Indoor spectral power distribution**

This can be used to calculate the melanopic illuminance. This is done in three or five spots inside the classroom facing straight ahead from the sitting position. The illuminance spectrophotometer is used to measure this.

- **The reflectance of materials**

This can be used to calculate the reflection factor. At first this was measured by placing the illuminance meter on the surface and pointing the luminance meter towards the same point. Later on in the research a new device was available that measures the reflectance for each material of the visible spectrum directly: the reflectance spectrophotometer.

- **The cumulative illuminance on the wall for a longer term**

These measurements give a better understanding of the indoor light levels and cumulative light exposure on a longer term. This is measured with hobo loggers for one week for each 15 minutes.

$$\rho = \frac{L \cdot \pi}{E}$$

ρ = reflectance, L = luminance from surface, E = illuminance on surface

The measurement equipment:

Illuminance meter
Konica Minolta
T-10A

Illuminance Spectrophotometer
Konica Minolta
CL-500A

Luminance meter

Konica Minolta

LS-150

Reflectance Spectrophotometer

Konica Minolta

CM-26dG

Hobo logger

Onset HOBO

U12-012-KIT

Figures 15 and 16: The spot measurement set up and measuring the reflectance

The literature study also showed that the non-visual effect of light can have an influence on the development of myopia. The hormone melatonin, which is produced in darkness, needs to be lowered to decrease myopia. The most important factor that lowers the production of melatonin is the melanopic EDI (Giménez, Stefani, Cajochen, Lang, Deuring & Schlangen, 2022). In the excel sheet in figure 17, provided by Luke Price from the UK Health Security Agency, the a-opic EDI's can be calculated by inserting the spectral irradiance values from all the visible wavelengths gathered from the spectrophotometer during the measurements.

α-OPIC QUANTITIES	SYMBOL	sc	mc	lc	rh	mel	UNITS
α-opic equivalent daylight illuminance ED	**E_v,α¯D65**	**92,6**	**95,9**	**100,6**	**91,7**	**90,6**	**lx**
α-opic irradiance	E_e,α	75,64	139,68	163,89	133,01	120,13	mW.m-2
α-opic photon irradiance *	E_p,α *	13,232	13,580	13,670	13,530	13,471	cm-2.s-1

Figure 17: The a-opic EDI’s are given when the measured spectral irradiance is inserted

3.3 Simulations

After collecting on-site measurements, the two schools were modeled in Rhino, including surroundings, and the same measurement spots and times are simulated with Honeybee, Ladybug and Lark. The real measurement results are compared to see if the outcomes are similar. After this, the models are used to simulate some design changes, for example changing the colours on the walls or making the windows bigger. The simulations show if the situation is improved and how much. Design recommendations are made after this. The simulation script is also used to test how well is matches the reality on cumulative illuminance, the lux levels received during the day. In the future the design adaptations can be tested on their effects on cumulative illuminance as well.

Figure 18 shows the Ladybug and Honeybee script. The surfaces with their matching materials are set to create a Honeybee room. The weather data and the grid can be set. After this the simulation is ready to run. The simulation that is used inside the script is the Point-in-time illuminance.

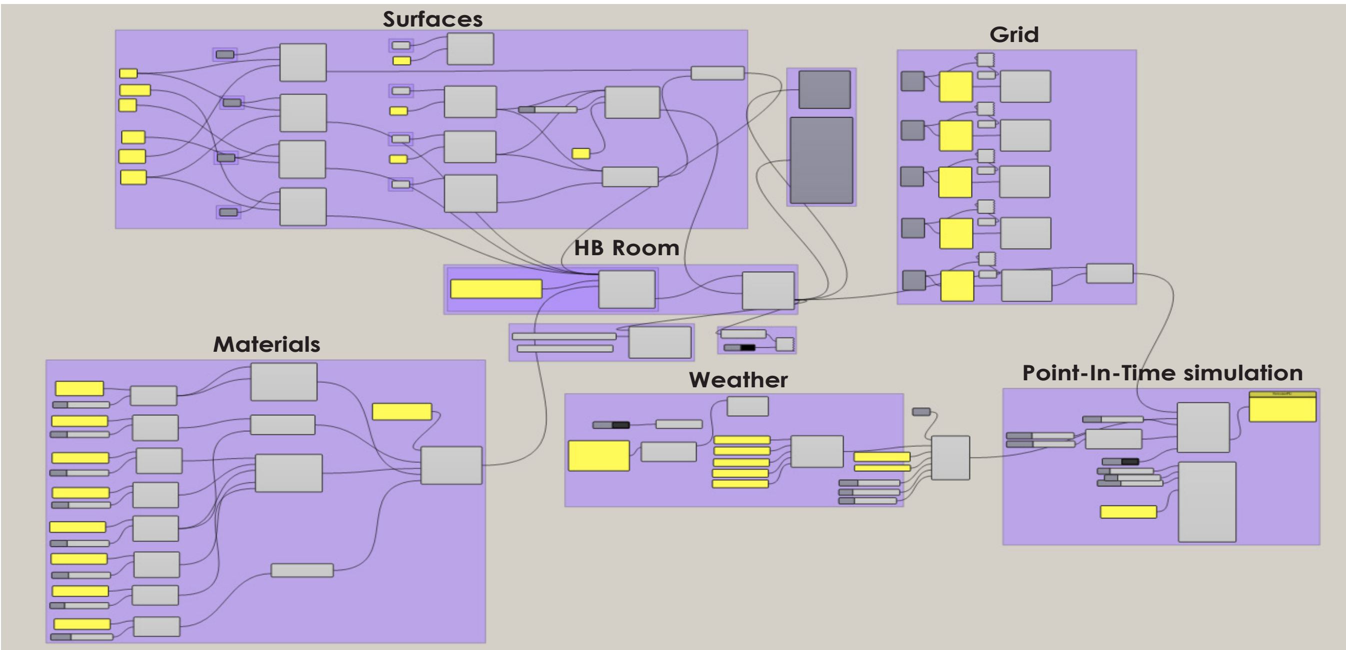


Figure 18: Overview of Ladybug/Honeybee script

Figure 19 shows the Lark script. In Lark the circadian, non-visual light can be studied. The literature showed that myopia development is related to ipRGC-influenced light (IIL), so spectral simulations are required. There are two main programs to do these simulations in: Lark and Alpha. Both tools rely on the physically accurate Radiance rendering engine, but Lark uses a 9-band spectral resolution and ALFA an 81-band resolution. Some studies (Pierson, Aarts & Andersen, 2022) have compared the two tools. The results show that Lark, which is about three times slower than ALFA, leads to more correct indicators under daylight and slightly more correct indicators under electric light when these two are simulated together. For daylight only simulations, Lark is also more accurate, but for electric light only simulations, ALFA is more accurate. In this research, Lark is used to do the simulations because the case studies are mainly focused on daylight or a combination from daylight and electrical light. Literature showed that the melanopic illuminance is important for decreasing myopia and the Point Based Simulation in Lark can simulate that value. The model and conditions are used as inputs and are processed in a 'black box'. In the outputs section the values for photopic and melanopic illuminance are given, as well as the spectral irradiance for the 9-band spectral resolution.

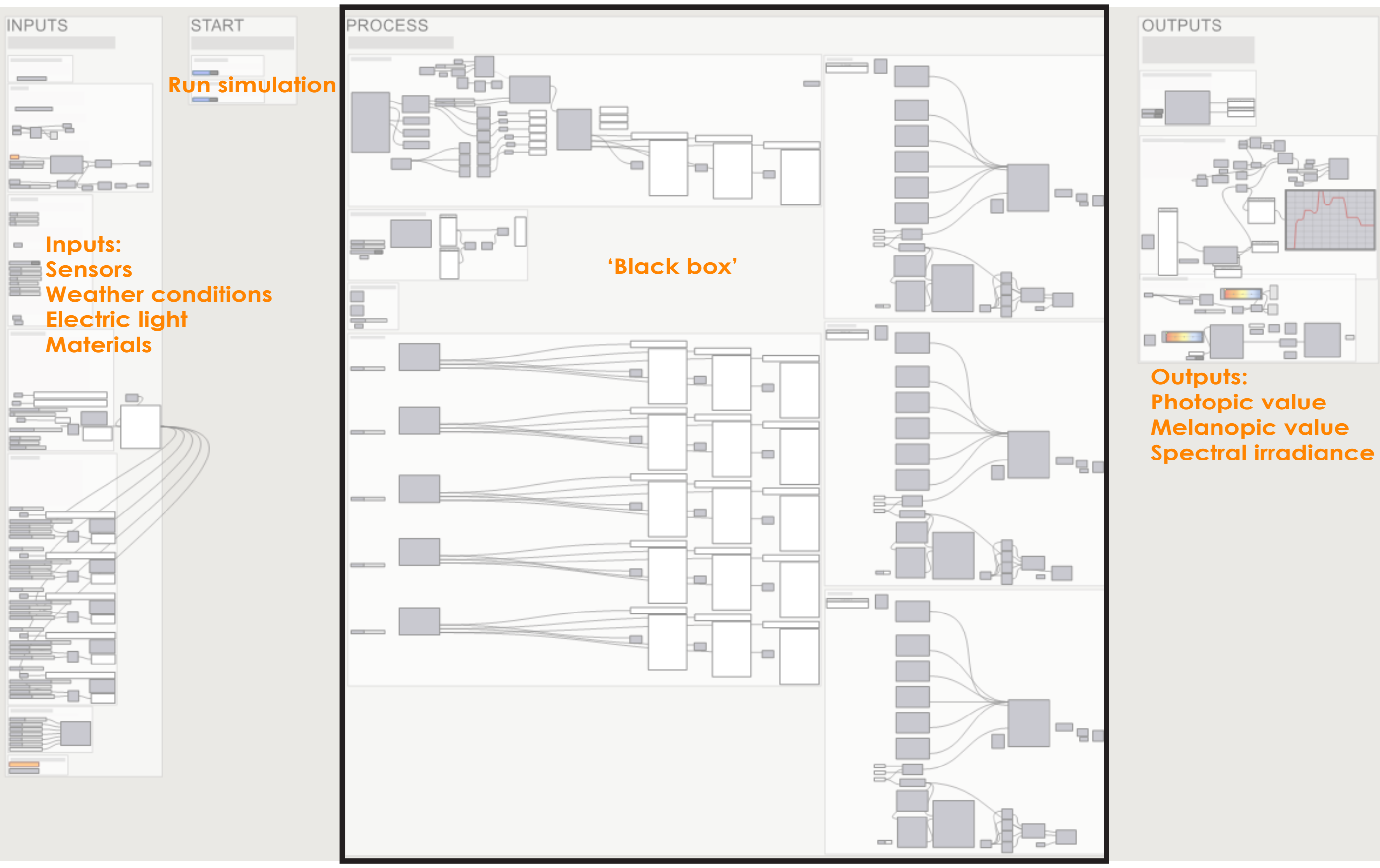


Figure 19: The Lark script

3.4 Design matrix

After the simulations, a design matrix will be shown where the proposed design adaptations are rated on their effectivity, feasibility and costs. The effectiveness follows from the simulations and the for the feasibility and costs three experts from EGM architects are consulted to give a rating. This follows in a recommendation on which design adaptations to use in Dutch school building design, renovation and new buildings.

4

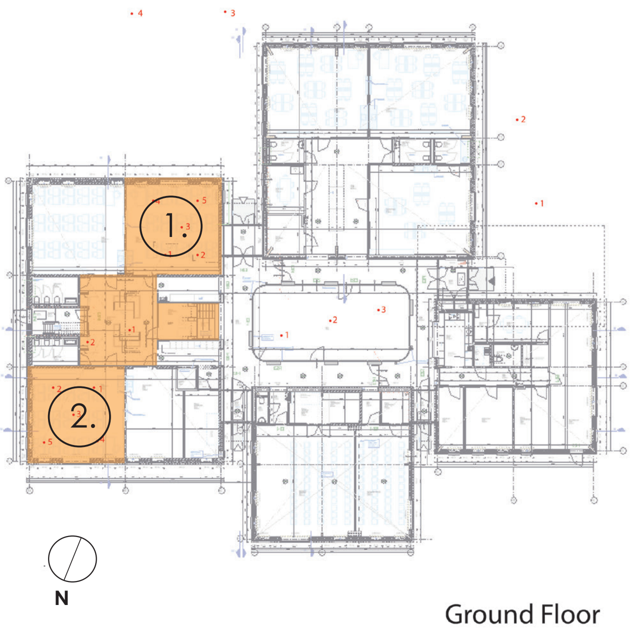
Results

4.1 Current situation schools

4.1.1 Measurements

Ds Abraham Hellenbroekschool

Measurements have been done on the 2nd of March and the 3rd of May. In March, the sky was clear, but in May there was an overcast sky (see figures 23 and 24). Since the measurements took place in the school holidays, there was plenty of opportunity to take measurements wherever seemed the most useful. Due to time management, three classrooms where selected to fully measure and spot measurements have taken place inside hallways with study spots, the courtyard and the playground. These results are fully shown in appendix A.



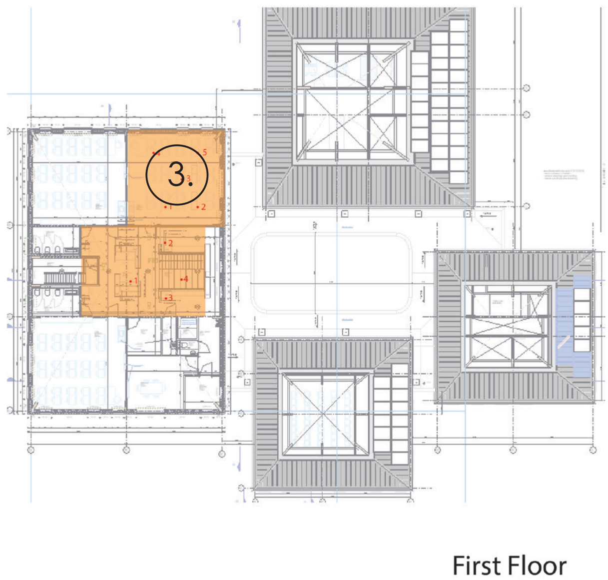


Figure 20: The floor plans of the Ds Abraham Hellenbroekschool

The classrooms have been selected because they facilitate the target group of children between six and nine years old and ,within these, three are chosen that are the most interesting. Classroom 1, orientated South-East/South-West, is interesting because it has two less windows because there is an extra entrance. The classroom on top, classroom 3, has the same layout but with the extra two windows. Measurements were done in both classrooms to compare the influence of the windows. Classroom 2, orientated North-East/North-West, has been chosen of this orientation and the fact that high rise buildings are present. The influence of these high-rise buildings is measured. All classrooms have the same manual indoor sun shading and artificial lighting.

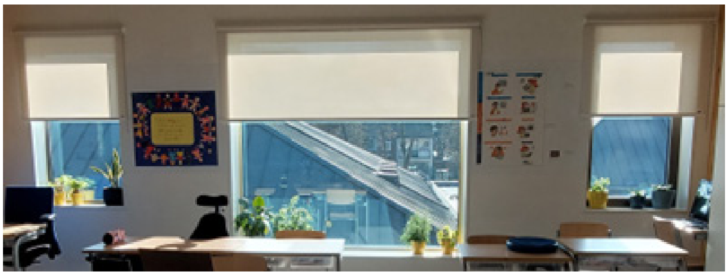
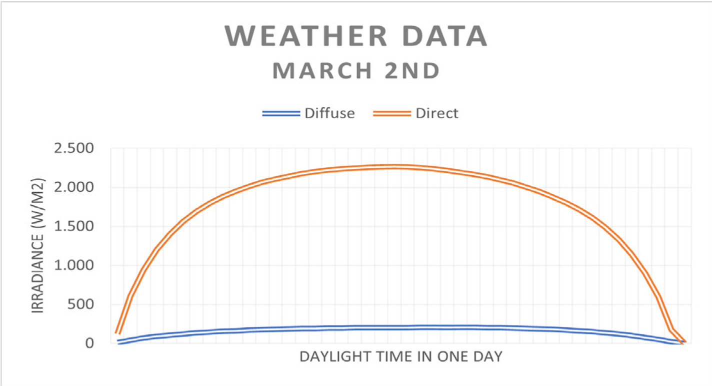


Figure 21 and 22: The indoor sun shading and artificial lighting

The weather data for the measurement days is shown in figures 23 and 24. In May there was an overcast sky with differences in irradiance. The direct light is similar and sometimes even lower than in March, but the diffuse light is much higher in May.



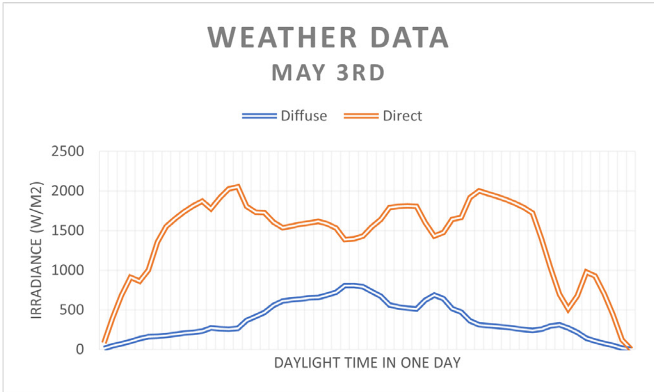
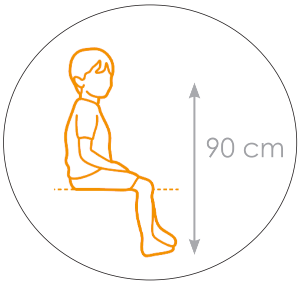


Figure 23 and 24: Weather data on the measurements days - March 2nd and May 3rd

Classroom 1

Five measurement spots are selected inside all three classrooms in this school, all facing forward towards the screen. In this classroom the spots facing the front, left and right illuminance has been measured on a height of 90 cm, based on the seats inside the classroom. This has been done in several different conditions, where 0% means totally up for the blinds and turned off for artificial lighting, 50% half down for the blinds and 100% all the way down and fully turned on.

1: blinds 0%, artificial lighting 0%
2: blinds 0%, artificial lighting 100%
3: blinds 50%, artificial lighting 0%
4: blinds 100%, artificial lighting 0%
5: blinds 50%, artificial lighting 100%
6: blinds 100%, artificial lighting 100%



As mentioned before, classroom 1 has two windows less than classroom 3. There are nine artificial lighting spots in a grid that can be turned off and on for each column separately (screen, middle, back) or all together.

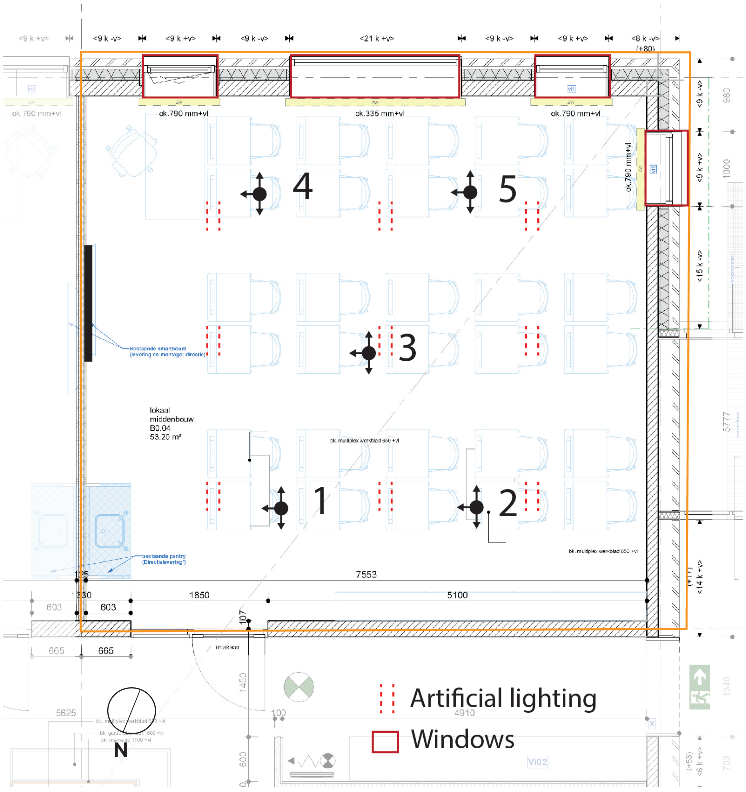


Figure 25: The floor plan of classroom 1

The illuminance results are shown in figures 26 and 27. The measurements of each spot (front, left, right) are combined together in a weighted graph. The ratio that is used is 50% front, 25% left and 25% right because children are looking the most at the teacher and screen, so in front, but are also quite active and tend to move on their seats.

For both measurements in March and May results show that the spots furthest from the window, 1 and 2, receive the least illuminance on eye level in every condition. Compared to the illuminance received on spots 4 and 5, a child could receive four times as much illuminance while sitting near windows. Measurements in May show that turning the artificial lighting on or off has almost no effect on the total illuminance levels during stronger daylight.

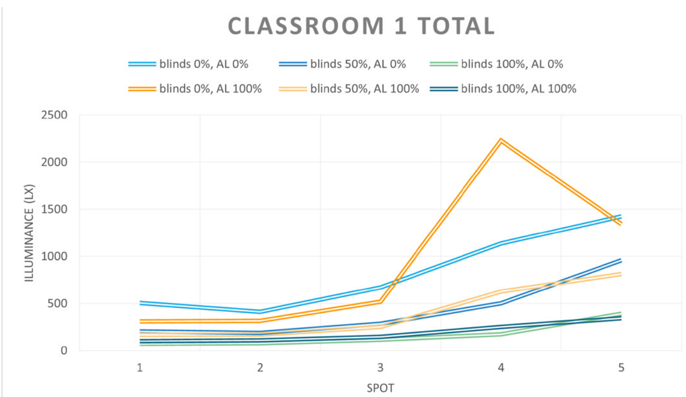


Figure 26: Measurements March 2nd 11:00

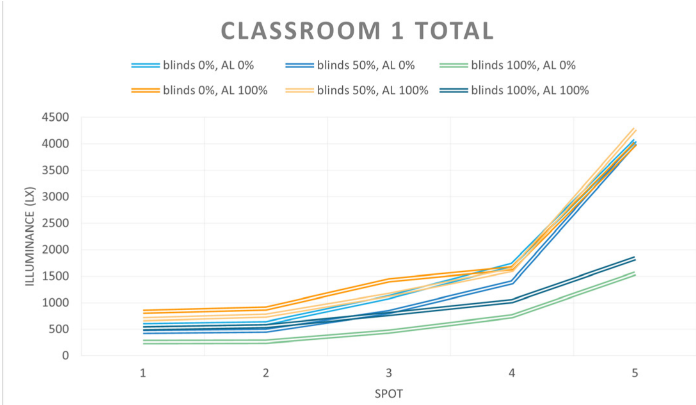
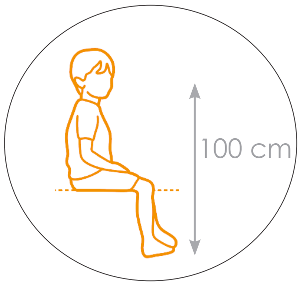


Figure 27: Measurements May 3rd 11:00

Classroom 2

More or less the same five measurement spots are selected inside this classroom, all facing forward towards the screen with the same conditions. In the spots facing the front, left and right illuminance has been measured on a height of 100 cm, again based on the seat height inside the classroom. This has been done in the same conditions as classroom 1.

As mentioned before, classroom 2 is facing North and has big buildings close by. In this classroom there are also nine artificial lighting spots in a grid that can be turned off and on for each column separately (screen, middle, back) or all together.



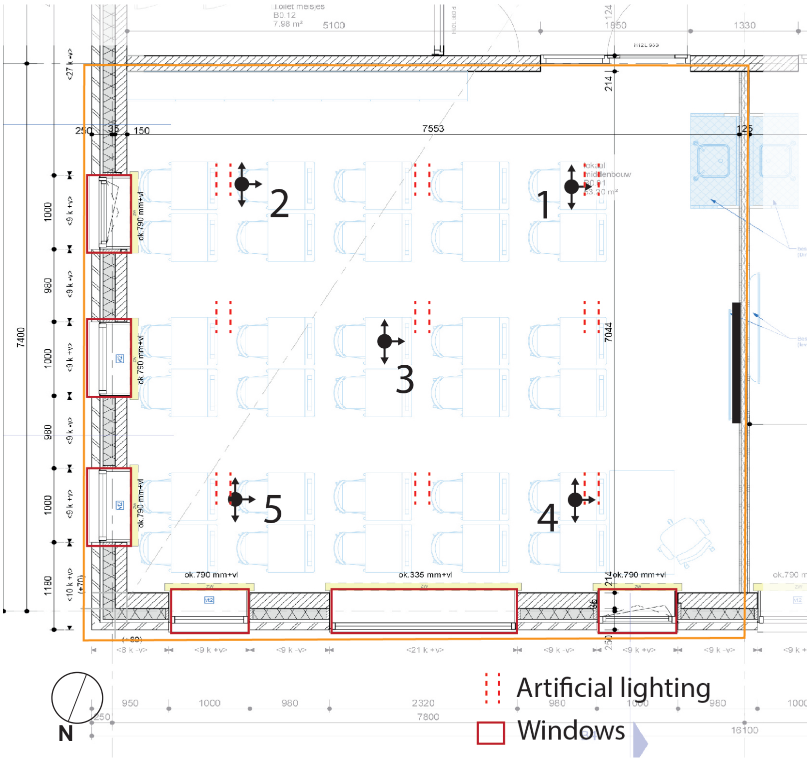


Figure 28: The floor plan of classroom 2

The illuminance results from the measurements in March and May are shown in figures 29 and 30. The measurements of each spot (front, left, right) are combined together again in a weighted graph. The results show that only spot 1 receives a little less illuminance on eye level in almost all conditions. Spots 4 and 5 receive again the most illuminance because there is a window in one of the viewing directions.

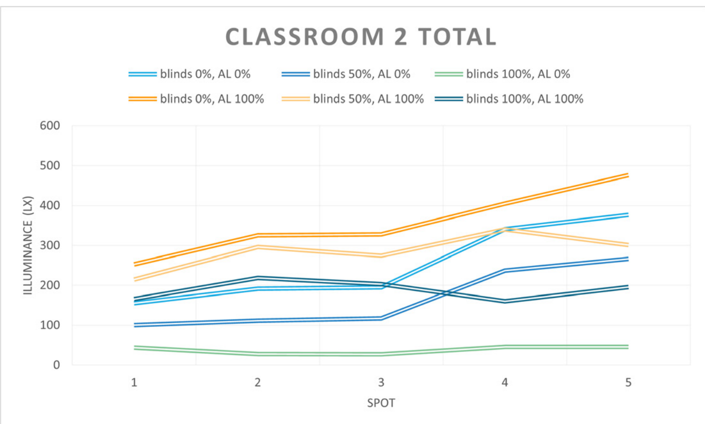


Figure 29: Measurements March 2nd 13:00

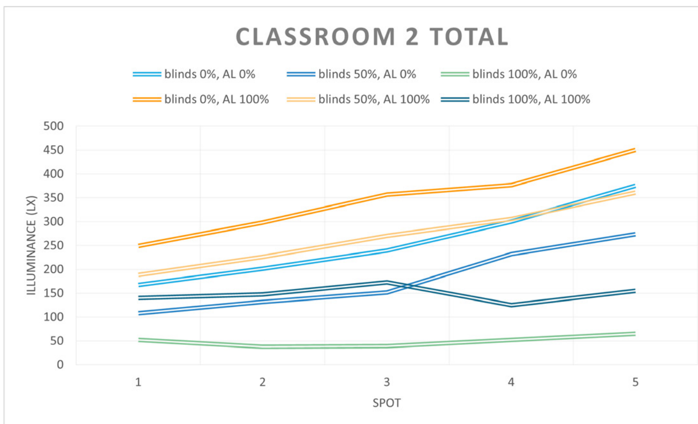
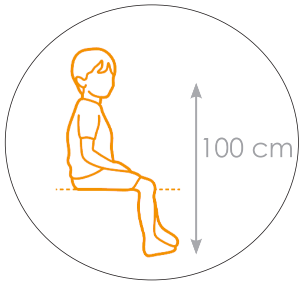


Figure 30: Measurements May 3rd 12:00

Classroom 3

In classroom 3, which is on top of classroom 1, the same measurements spots are used to see the difference with two more windows with the same conditions. In the spots facing the front, left and right illuminance has been measured on a height of 100 cm. This has again been done in the same conditions.

In this classroom there are also nine artificial lighting spots in a grid that can be turned off and on for each column separately (screen, middle, back) or everything together.



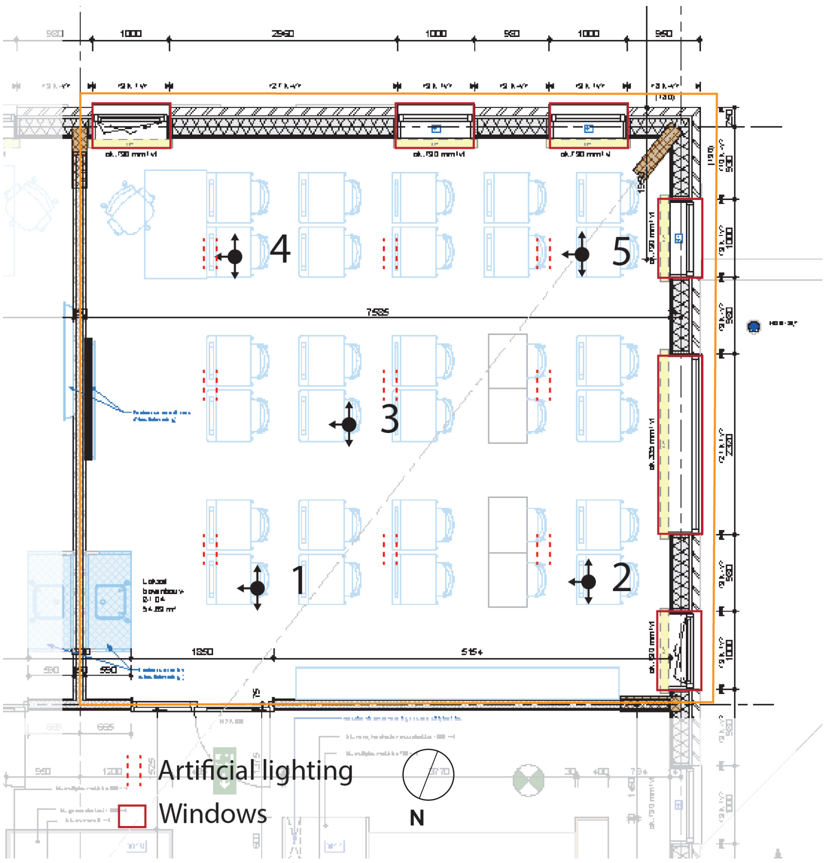


Figure 31: The floor plan of classroom 3

The illuminance results are shown in figures 32 and 33. The measurements of each spot (front, left, right) are combined together again in a weighted graph. The results show that there is indeed a big difference with two more windows, especially for spots 1 and 2. What is interesting is that spot 4 now receives less illuminance because the window on the right is positioned slightly different.

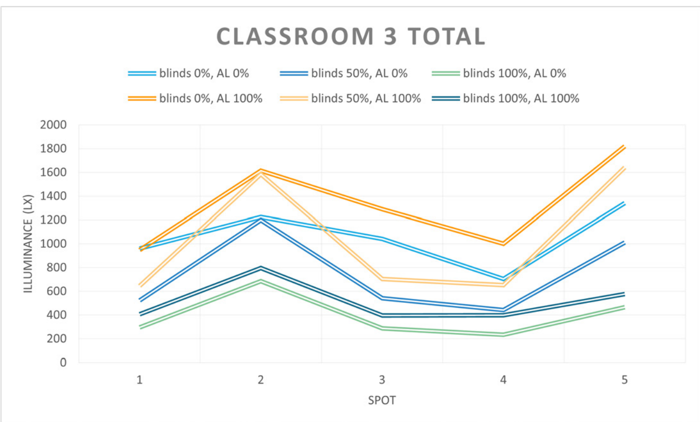


Figure 32: Measurements March 2nd 15:00

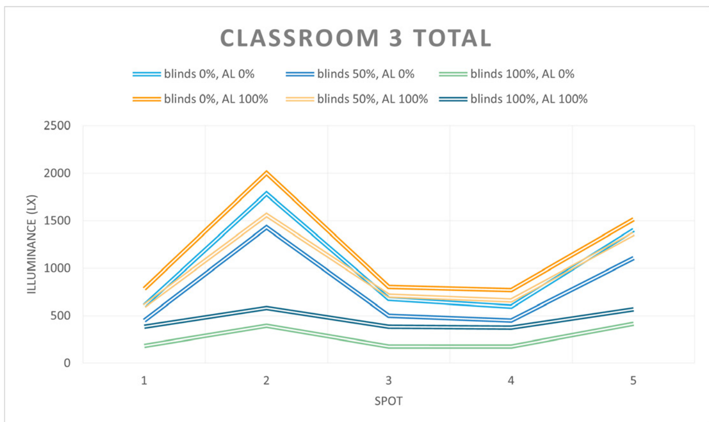


Figure 33: Measurements May 3rd 14:00

Pniëlschool

The measurements in this school have taken place on the 7th of March and the 15th of May. The sky was overcast in both March and May (see figures 37 and 38). Because the children were present during the first measurements day in March, it was harder to select the most interesting spots, so the spots are located at rooms where it was possible to do the measurements. Two classrooms, a gymnastics room, study places inside the hallways and the playground have been measured. The gymnastics room was chosen because it was the only room where children would spend some time located in the old part of the building. The hallways on the ground floor are mostly used for storage, so only one measurement spot is considered there. All these results are shown in appendix A.

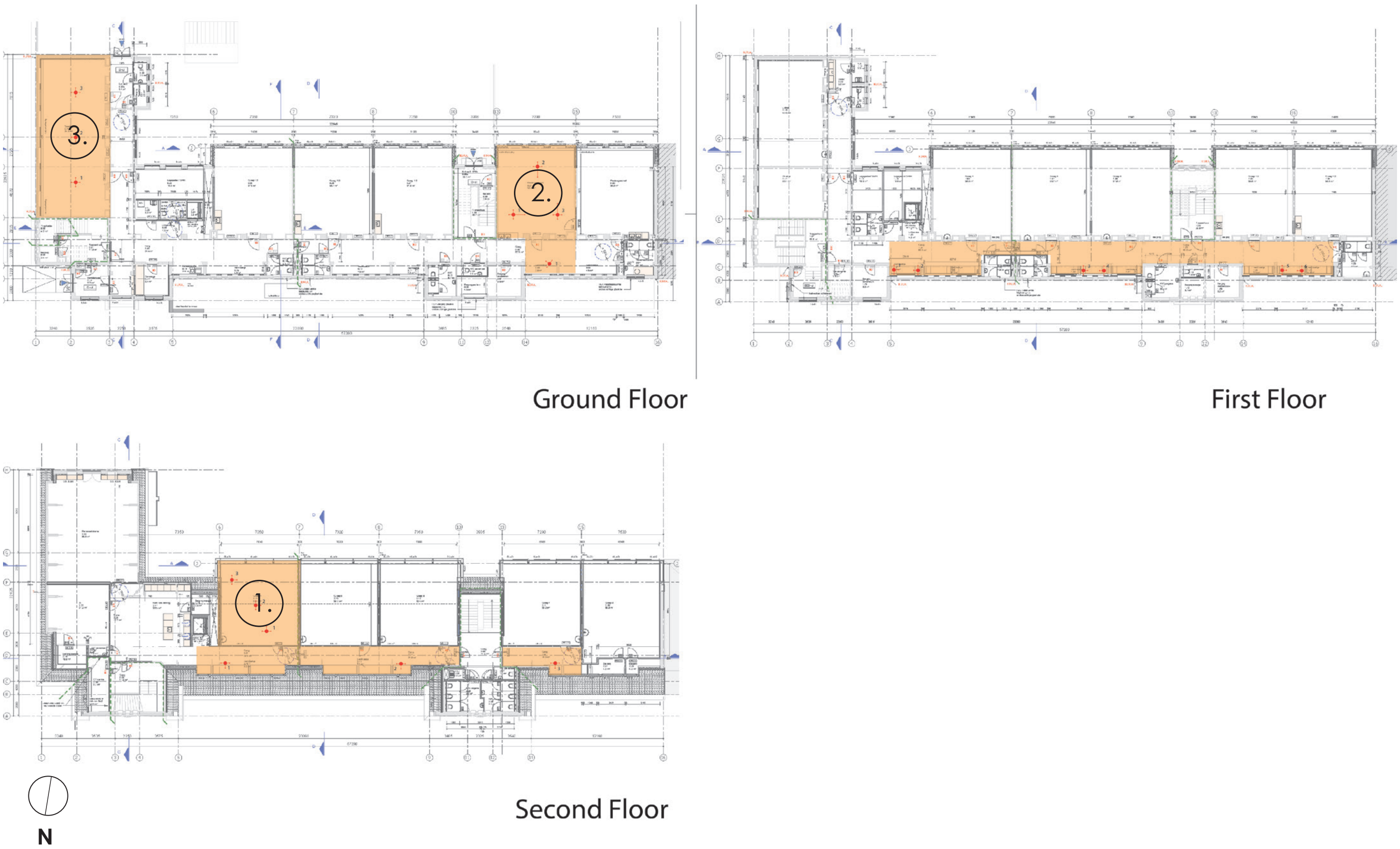


Figure 34: The floor plans of the Pniëlschool

There is automatic sun shading outside the building, but some windows do not have it. The sun shading has a relatively high openness factor and transmittance. The artificial lighting is also automatic, but just as the sun shading, it can be changed manually. However, the sun shading could not be lowered down in steps.


Figures 35 and 36: The outdoor sun shading and the artificial light inside a classroom

On both measurement days for the Pniëlschool there was not much direct irradiance, as is shown in figures 37 and 38. The diffuse irradiance in May is also not significantly higher than in March, so in the measurement results are no big differences.

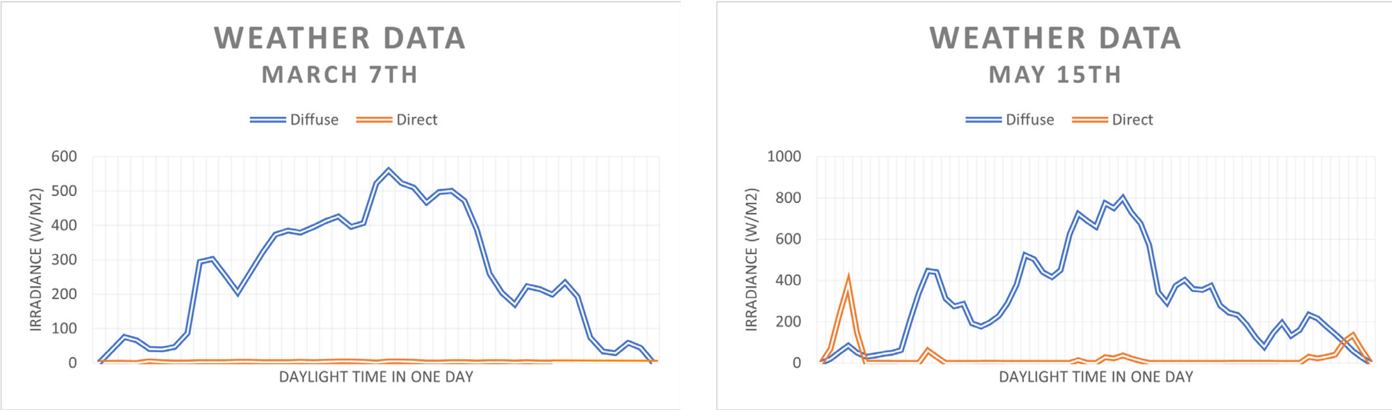
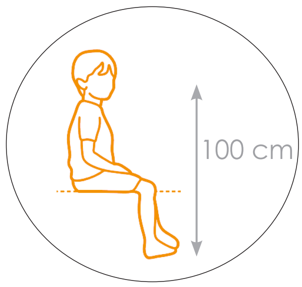


Figure 37 and 38: Weather data on the measurements days - March 7th and May 15th

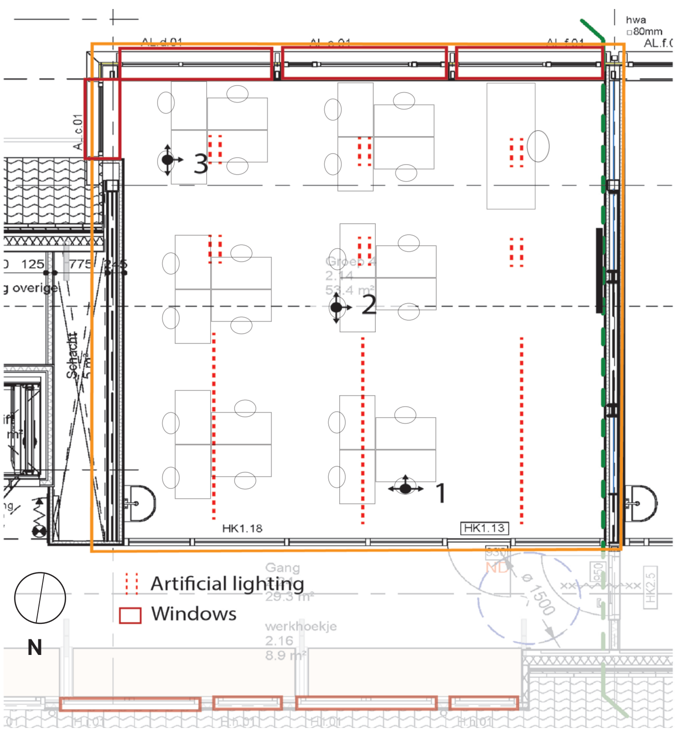
Classroom 1

In this classroom three measurement spots are selected because they were available while the children were inside the classroom. What was striking is that in this classroom the viewing directions are not all towards the whiteboard like in the Hellenbroekschool, but also to the left and right. The illuminance has been measured on a height of 100 cm, based on the seat height inside the classroom. This has been done in several different conditions:

1: blinds 0%, artificial lighting 0%
2: blinds 0%, artificial lighting 100%
3: blinds 100%, artificial lighting 0%
4: blinds 100%, artificial lighting 100%



In this classroom there are nine artificial lighting spots in a grid that can only be turned off and on all at the same time.



The illuminance results are shown in figures 40 and 41. The measurements of each spot (front, left, right) are combined together again in ta weighted graph. The ratio that is used is 50% front, 25% left and 25% right because children are looking the most at the teacher and screen, so in front, but are also quite active and tend to move on their seats.

Figure 39: The floor plan of classroom 1

The results are not that different from each spot as in the first school for example. This has probably to do with the front viewing directions. Spot 1 is the furthest from the windows, but is the only one that is facing the windows.

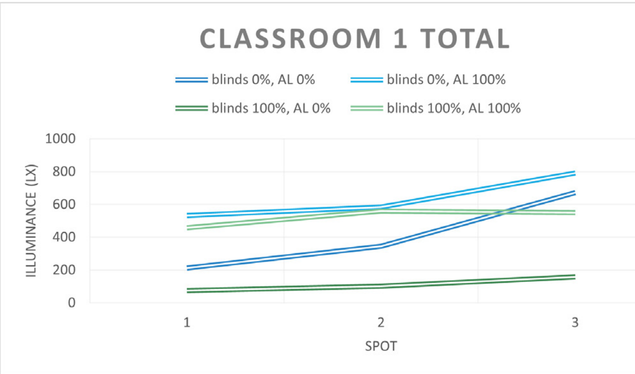


Figure 40: Measurements March 7th 10:00

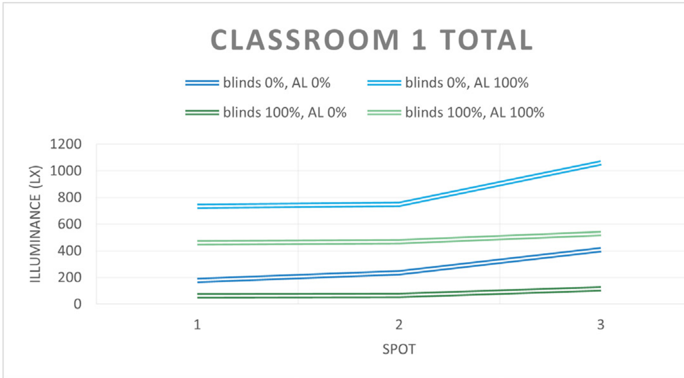
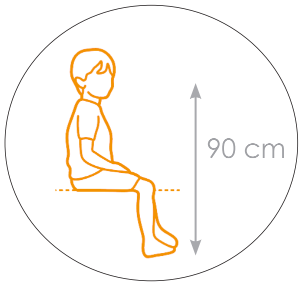
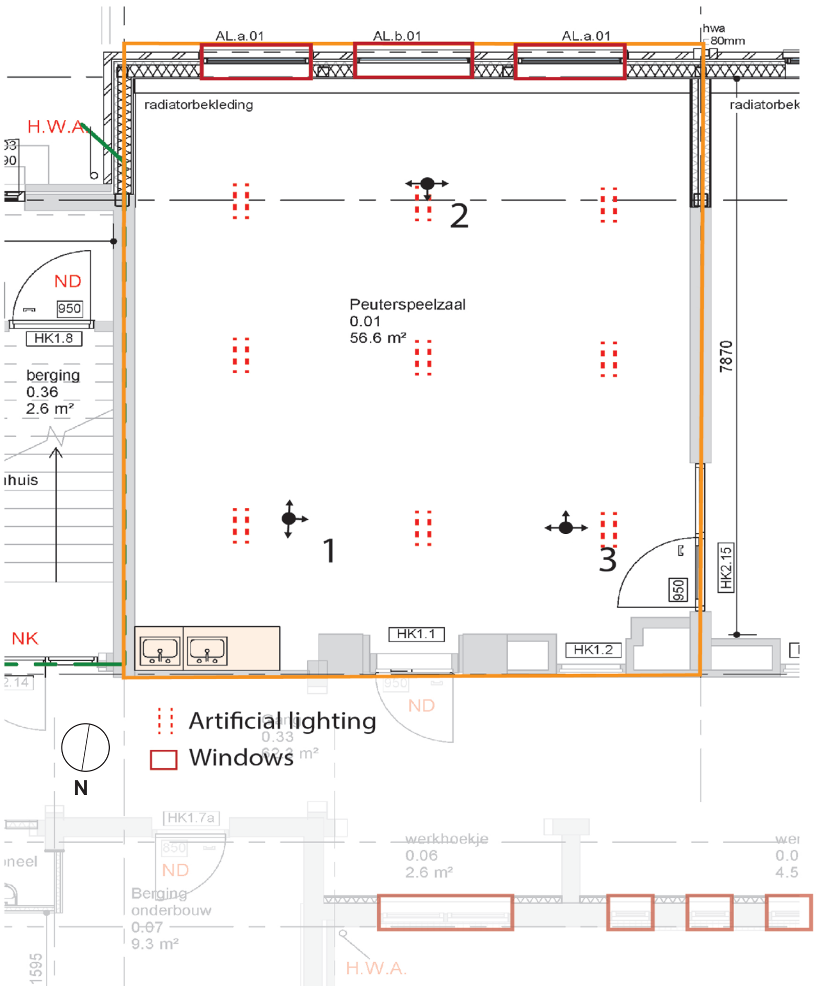


Figure 41: Measurements May 15th 10:00

Classroom 2

Three measurement spots were selected in this empty classroom. The front view direction is also not necessary towards the white board. The illuminance has been measured in viewing directions left, front and right on a height of 90 cm. This has again been done in the same conditions.
In this classroom there are also nine artificial lighting spots in a grid that can only be turned off and on all at the same time.





The illuminance results are shown below in figures 43 and 44. The measurements of each spot (front, left, right) are combined together again in this weighted graph.
What is striking in these results is that spot 2, close to the windows, is not receiving much more illuminance that spots 1 and 3. This has again to do with the viewing direction, away from the window.

Figure 42: The floor plan of classroom 2

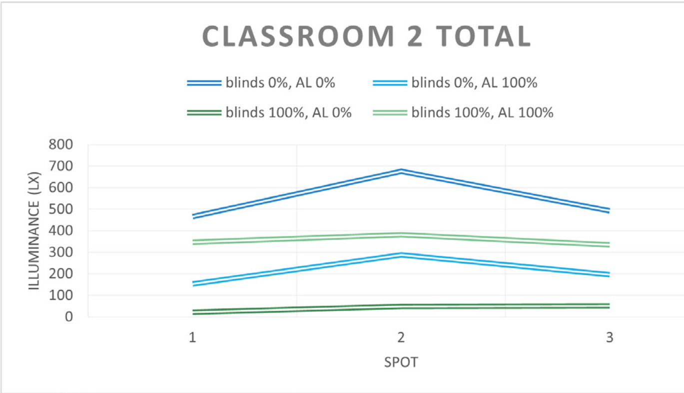


Figure 43: Measurements March 7th 12:00

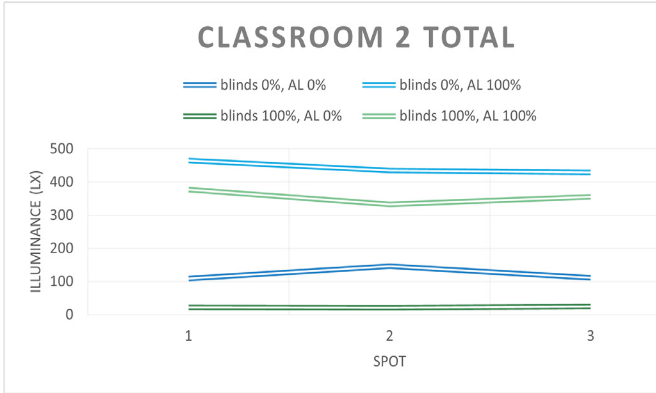
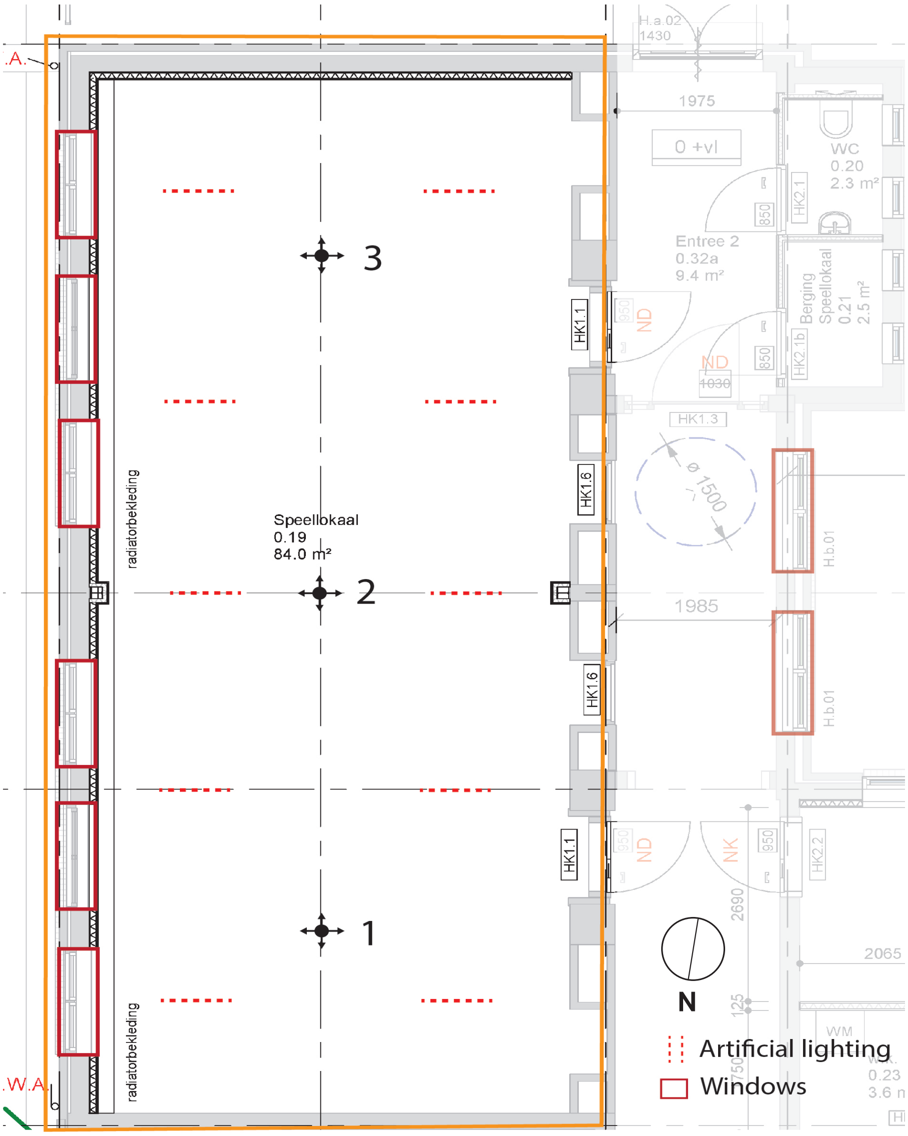


Figure 44: Measurements May 15th 11:00

Classroom 3

Three measurement spots were selected in this empty gymnastics room. Because it is a gymnastics room, the illuminance has been measured in four viewing directions: left, front, right and back on a height of 100 cm in the same conditions.

In this classroom there are also nine artificial lighting spots in a grid that can only be turned off and on all at the same time.



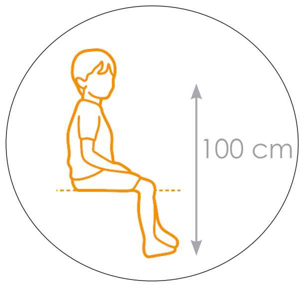


Figure 45: The floor plan of classroom 3

The illuminance results are shown below in figures 46 and 47. The measurements of each spot (front, left, right and back) are combined together again in this weighted graph. The ratio that is used is 25% for every direction.

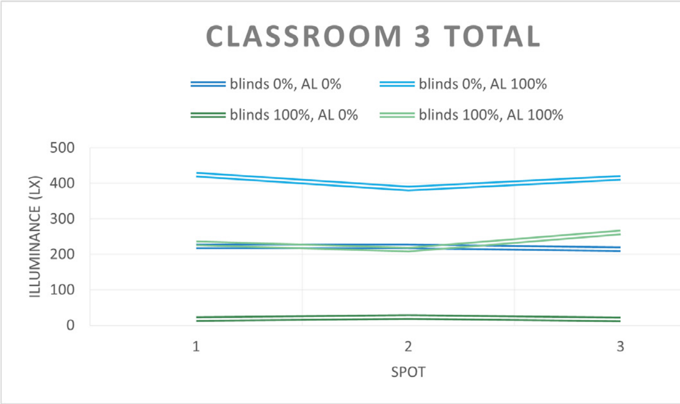


Figure 46: Measurements March 7th 15:00

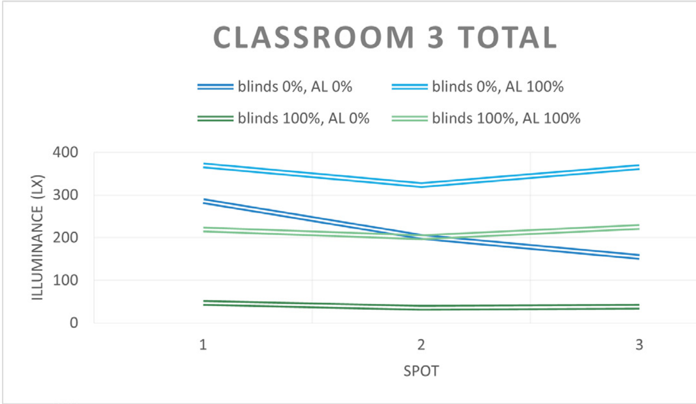
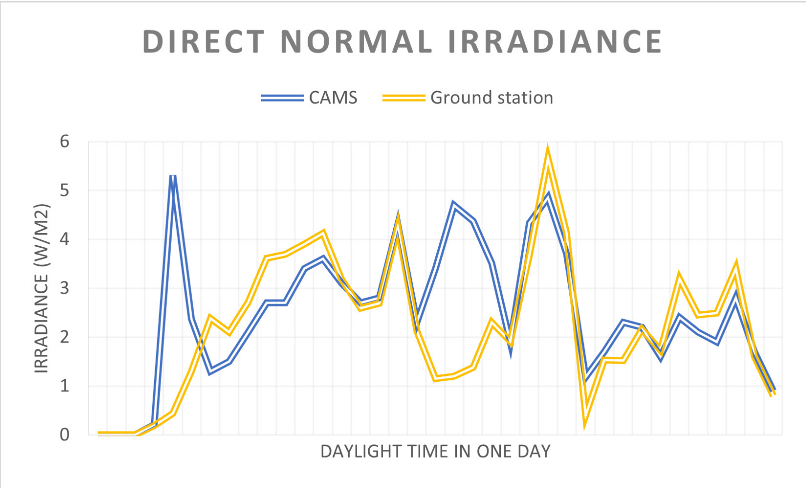


Figure 47: Measurements May 15th 12:00

4.2 Validation

4.2.1 Weather data

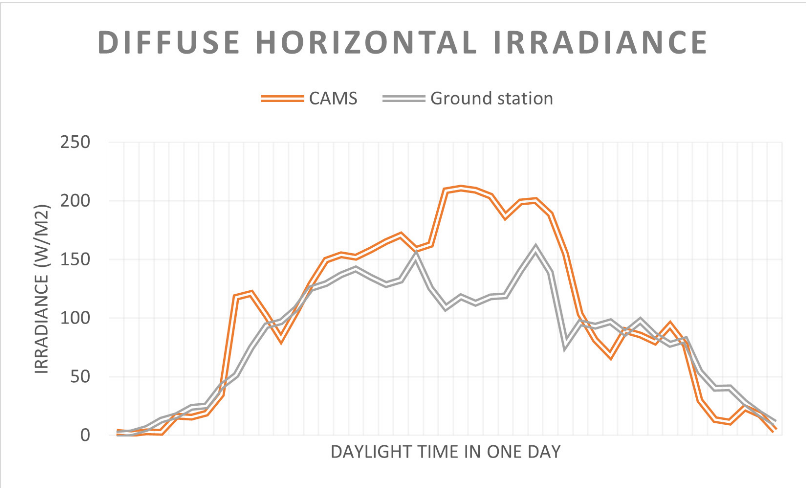
For the simulations the weather data is needed to use as an input. The satellite data has been downloaded from the website of Copernicus Atmosphere Monitoring Service (CAMS). This is less accurate than data from a ground weather station, but still gives values for the direct and diffuse daylight. The reason that the weather data is not used is because it was not available anymore for the 2nd of March, so the satellite data is used for all the simulations. The satellite data from the 7th of March has been compared with the downloaded weather data from ground station Rotterdam/The Hague Airport to see the differences in values.



Mean Bias Error: -0,796 W/m2

Root Mean Square Error: 2,7 W/m2

Normalised error: 14,4%



Mean Bias Error: 16,4 W/m2

Root Mean Square Error: 33,7 W/m2

Normalised error: 57,9%

Figures 48 and 49: Comparison of the weather data from ground station Rotterdam/The Hague Airport and the satellite data from Copernicus Atmosphere Monitoring Service for March 7th, 2023.

There are 45 timestamps of 15 minutes that represent the time of the day in which there was daylight. The DNI (Direct Normal Irradiance) graph shows that there is some difference between the values, but the values are very small so it will not change a lot. On the other hand, for the DHI (Diffused Horizontal Irradiance) there is quite a difference between them. The DHI from the satellite data is in general higher, so the simulation results may also be higher.

4.2.2 Hobo calibration

The hobos loggers that are used to measure the illuminance inside the classrooms are typically characterised by larger errors than research-grade illuminance meters. To quantify the differences between the devices, the used hobos have been calibrated in comparison with an illuminance spectrophotometer. The hobos and the illuminance spectrophotometer have been measuring the illuminance levels on seven different angles. For the position facing towards the window (straight), this has been done for ten minutes. For all the other angles for 1 minute. In the scheme below the seven angles are shown. Angle 0⁰ is straight forwards to the window, where the five hobo have recorded for 30 minutes and the illuminance spectrophotometer three times ten minutes. For the calibration the data is used closest towards the hobo (see figure 50).

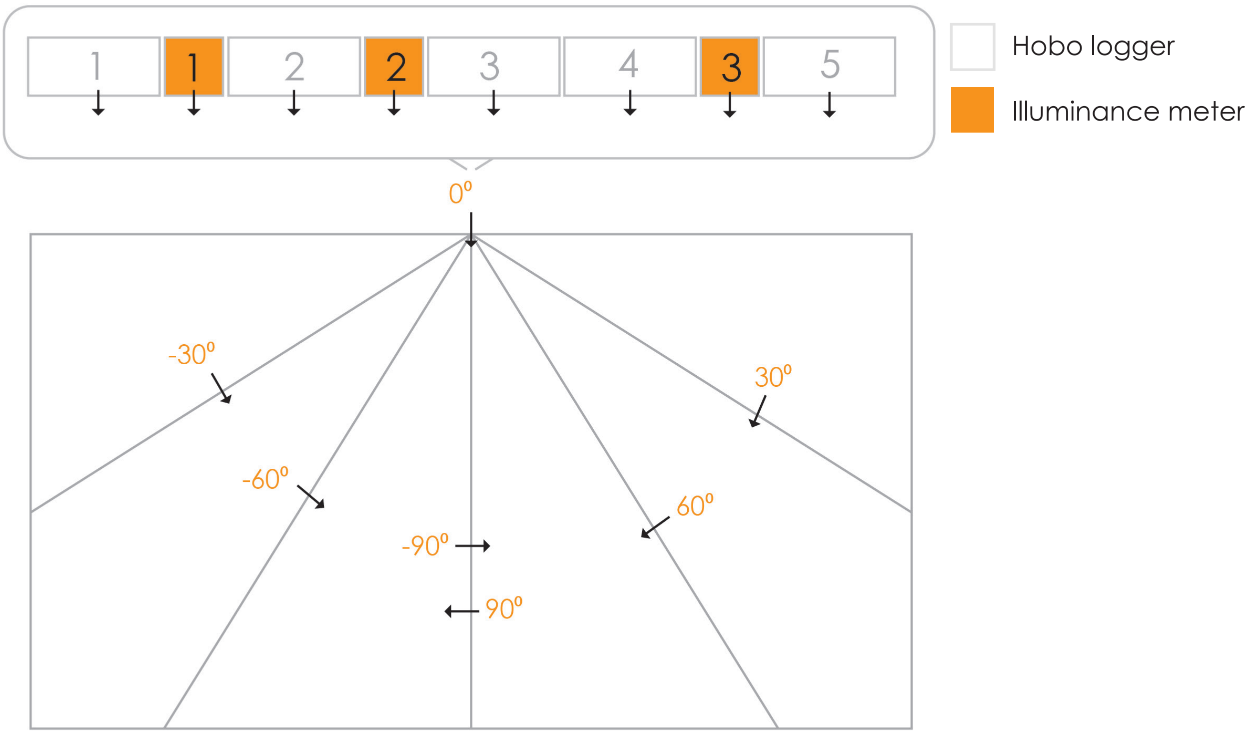


Figure 50: The setup of the hobo calibration

Figures 51 and 52: The setup for straight towards the window and the other angles with daylight only

The measured averages of the five hobos in comparison with the illuminance spectrophotometer are shown in figure 53 and table 1. In almost all the cases the hobos measured a higher illuminance. The biggest exception is on angle -30^0 for hobo 2. Hobo 2 has for all the other angles also a smaller difference with the measured values of the illuminance spectrophotometer. Angle 0^0 for all the hobos is striking because it would be expected to have the lowest deviation but has the highest instead.

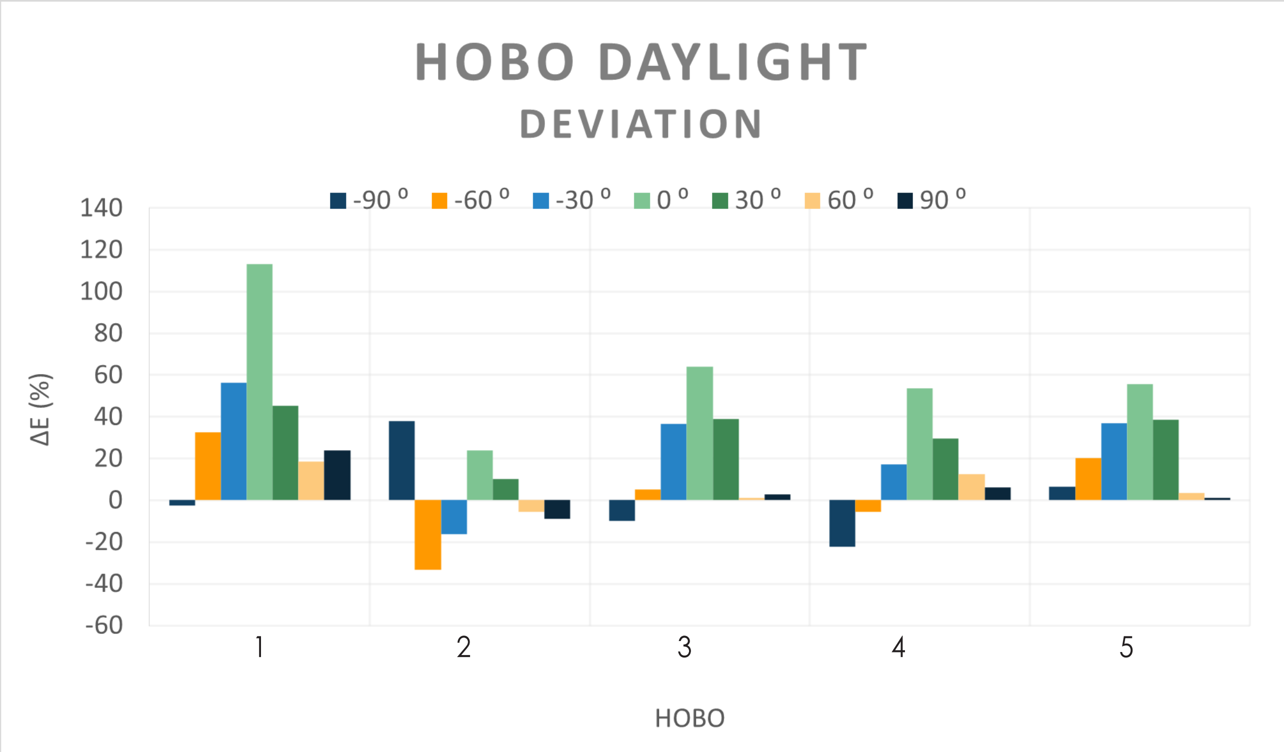
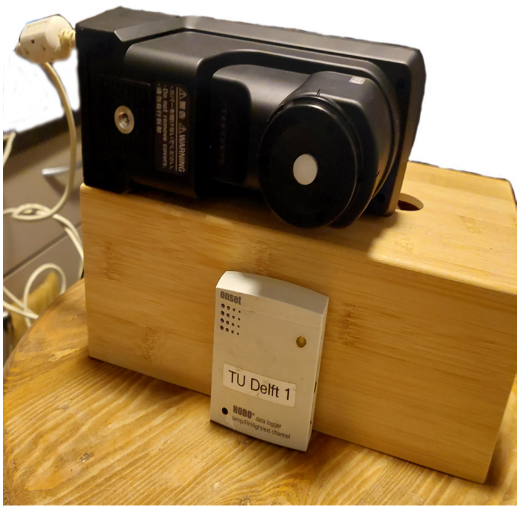


Figure 53: The measured deviation between the illuminance meter and the hobos with daylight only.

Angle	Average deviation
-90º	1,9%
-60º	3,8%
-30º	26,2%
0º	62,1%
30º	32,5%
60º	6,0%
90º	5,0%

Table 1: The measured average deviation between the illuminance meter and the hobos with daylight only per angle.

The hobos have also been calibrated for artificial light only. Because only artificial lighting will not happen very often in the classrooms and does not change that much as daylight, the measurements have been done in two positions (facing forward and up) for 30 seconds each. In the graph below the averages are shown. The hobos and illuminance spectrophotometer facing forward are almost measuring the same illuminance levels. However, in the situation where they are facing up, hobos 1, 3 and 5 measure higher lux levels and hobos 2 and 4 are measuring lower lux levels.



Figures 54 and 55: The setup for facing forward and up with artificial light only

Figure 56 shows the deviation of the measured values of the illuminance meter and hobos with artificial light only. Here, the hobos do not measure higher values in almost all cases as was the case with daylight only.

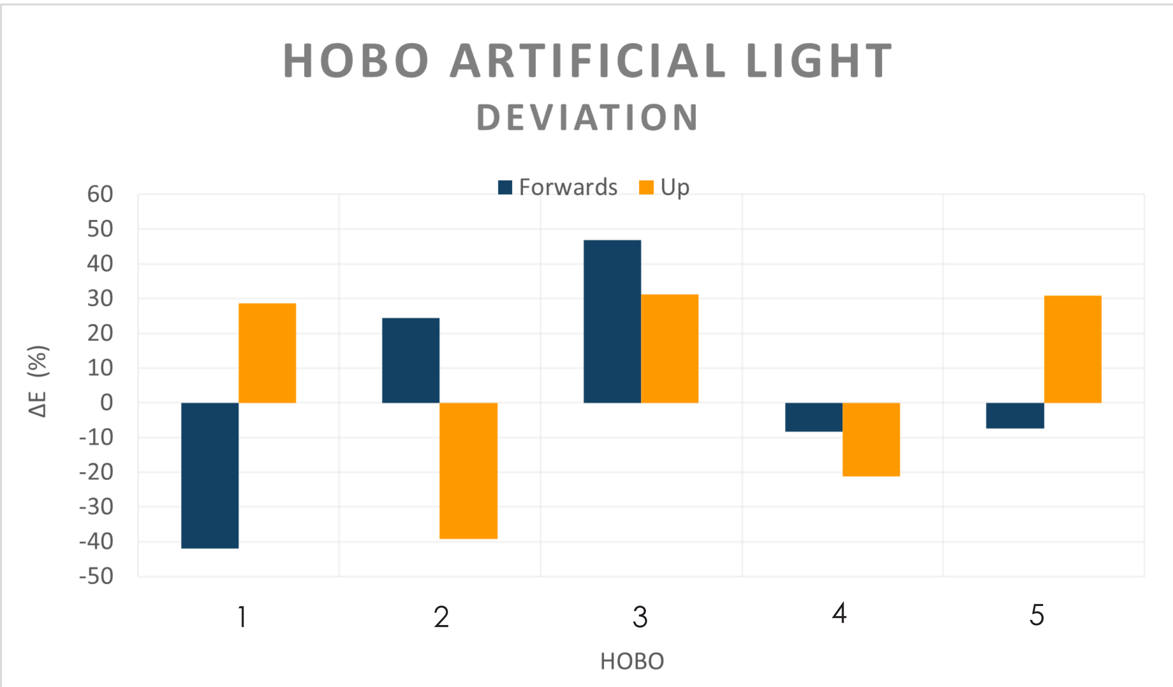
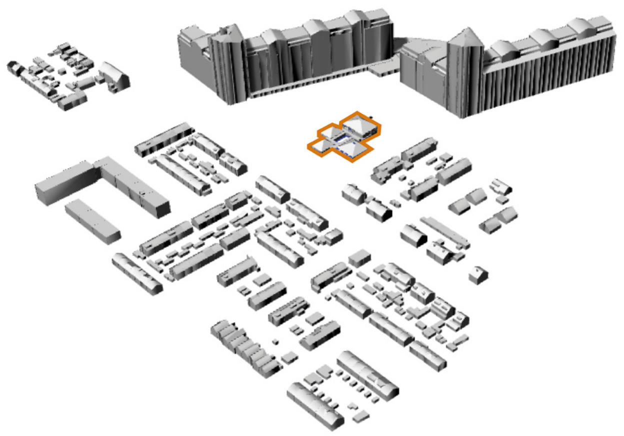


Figure 56: The deviation of the measured values of the illuminance meter and hobos with artificial light only.

4.2.3 Simulations

The Honeybee script consists of five parts. First, the surfaces are set. Then, the material properties are given to the surfaces. A sky model is built to simulate under the exact same conditions and the measurement points are selected with the right view directions. Lastly, the point-in-time simulation is run. For now, only daylight simulations with and without sun shading are performed. Simulating the artificial light is more difficult because this is only possible with the older Legacy version of Ladybug, which does not work with Rhinoceros 7. The whole Honeybee script has to be rebuilt in the older version to make this work. This is a limitation of this study.




Figures 57 and 58: The 3D models of the Ds Abraham Hellenbroekschool (left) and the Pniëlschool (right). The schools are marked in orange.

Component	**Reflection/transmittance Hellenbroekschool**	**Reflection/transmittance Pniëlschool**
Interior wall	0,85	0,85
Exterior wall	0,2	0,2
Floor	0,38	0,3
Ceiling	0,7	0,7
Glazing	0,9	0,9
Sun shading	0,4	0,6

Table 2: Existing reflection/transmittance factors for both schools

4.2.4 Calibration models

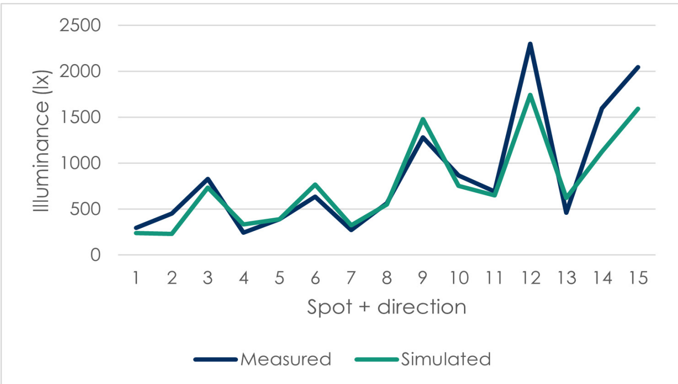
Ds Abraham Hellenbroekschool

The same three classrooms are modeled as the classrooms where the measurements have taken place. In this first step, the measured and simulated values are being compared to calculate the normalised Mean Bias Error (nMBE). On the x-axis the spots (3 or 5) are shown with the directions in which they are measured (3 or 4). In appendix B all the values are shown.

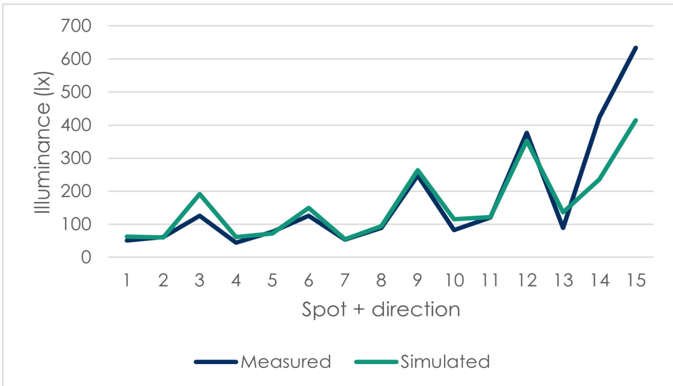
Classroom 1

As shown in the graphs below, the model represents the reality quite well. For each classroom the situations with only daylight and with or without sun shading is simulated for the days the measurements have taken place in March and May. The average deviation is calculated for the absolute values. In all the classrooms the nMBE is lower in the situation without the blinds down than with them. This can be explained because the illuminance levels are lower with the blinds down so a difference of 10 lx can already be a deviation of 20%. The sun shading is also simplified in the model by representing them as surfaces with homogeneous transmittance. The model also matches the measurements better on the days in March than in May. This can be the case because there is more irradiance in May and there might be a bigger error.

March 2nd



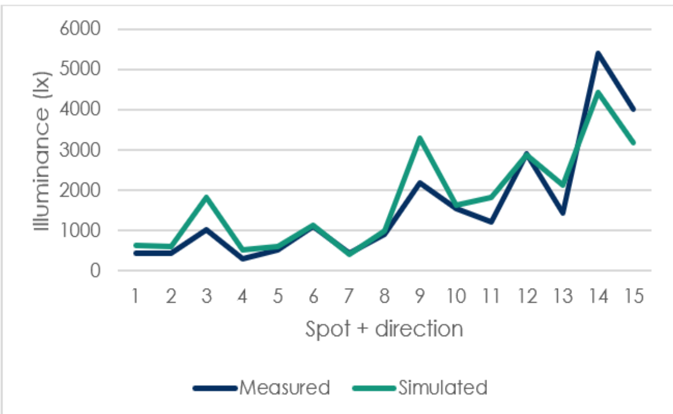
blinds 0%, AL 0%



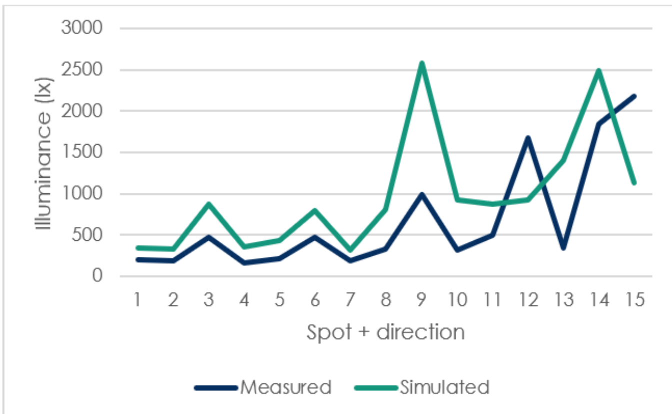
blinds 100%, AL 0%

nMBE 20,3% 22,3%

May 3rd



blinds 0%, AL 0%



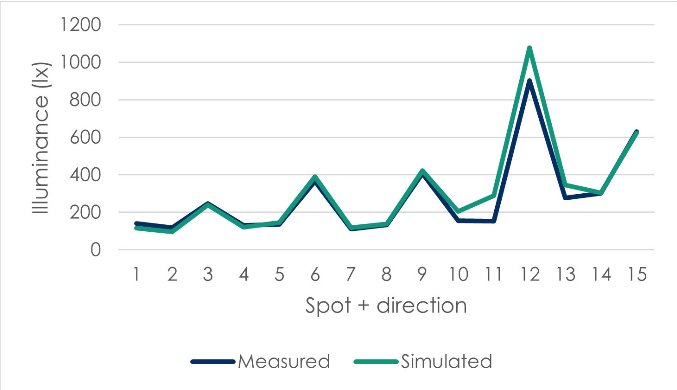
blinds 100%, AL 0%

nMBE 30,3% 109,1%

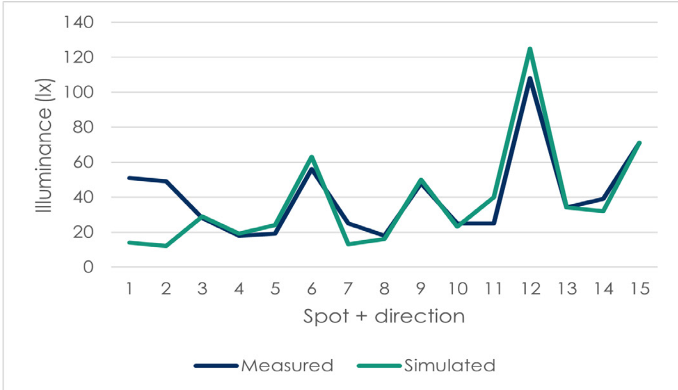
Classroom 2

In the situation with the blinds down in classroom 2 there is an odd difference between the first two points. Any differences between the simulated and measured values can be caused by several factors, for example the weather data that is not really accurate, the reflectance is not simulated correctly or the model has another error.

March 2nd



blinds 0%, AL 0%

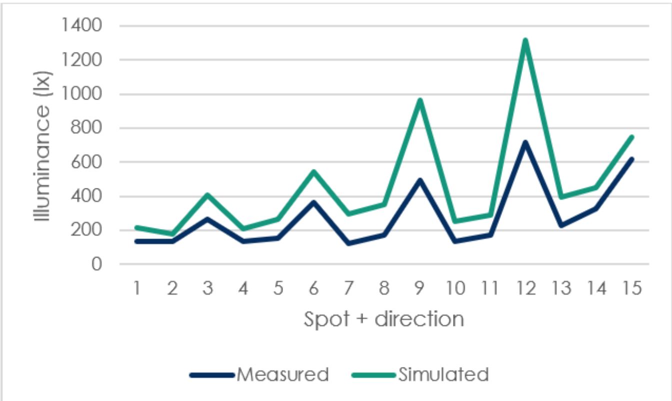


blinds 100%, AL 0%

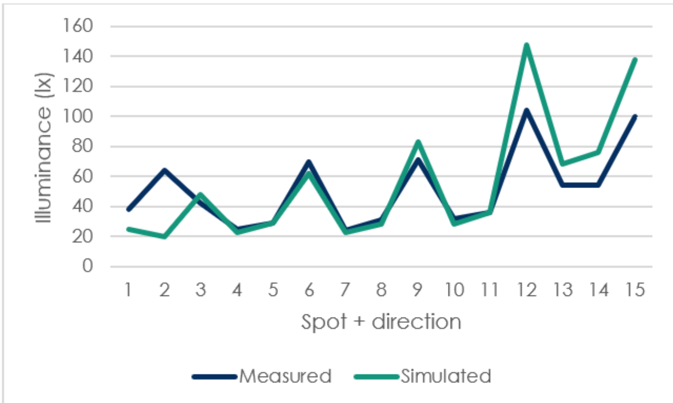
nMBE **16,3%** **24,1%**

For the calibrated days in May, the simulation tends to overestimate the values. This can be the case because the weather data also is somewhat overestimated (see section 4.2.1).

May 3rd



blinds 0%, AL 0%



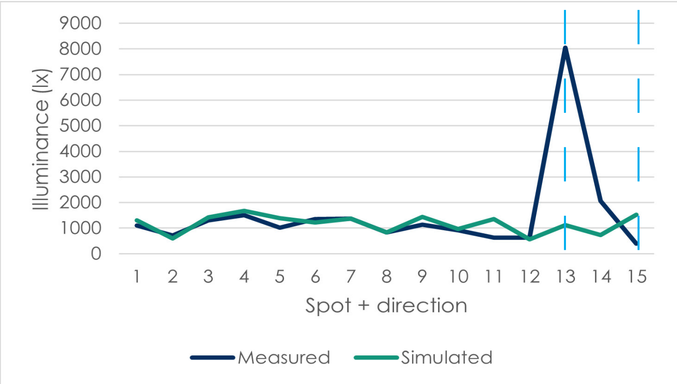
blinds 100%, AL 0%

nMBE **68,0%** **21,7%**

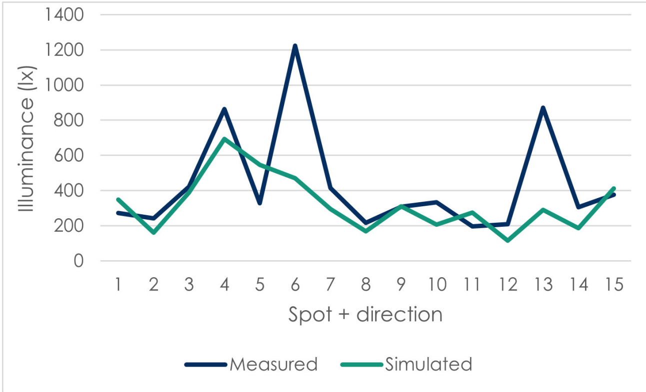
Classroom 3

In this classroom the differences between the measured and simulated values are the biggest for March. This can be explained because there was a lot of direct sunlight while doing the measurements that the model probably cannot simulate in the right way. This is shown especially on the spots + directions close to the back windows, so spot + direction 4,5,6 and 13,14,15. If in the case of the blinds up the 5th spot, corresponding with spot + direction 13,14 and 15 are not included in the deviation, the deviation becomes much lower to 21,6%.

March 2nd



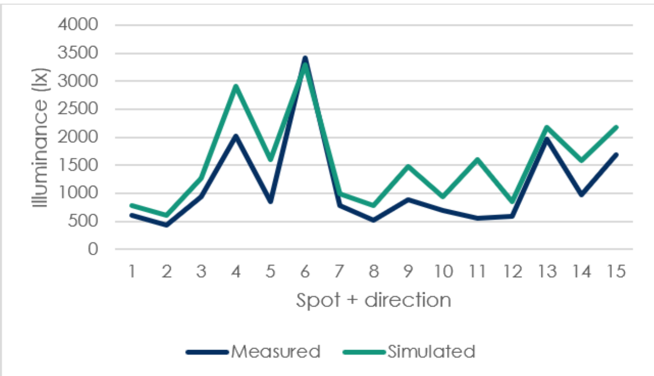
blinds 0%, AL 0%



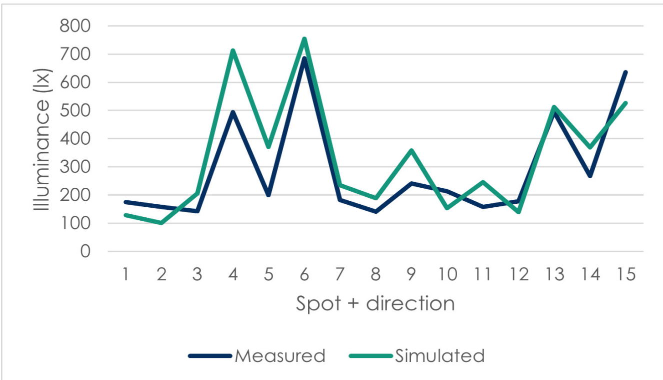
blinds 100%, AL 0%

nMBE **46,4/21,6%** **33,8%**

May 3rd



blinds 0%, AL 0%



blinds 100%, AL 0%

50,0% **34,4%**

nMBE

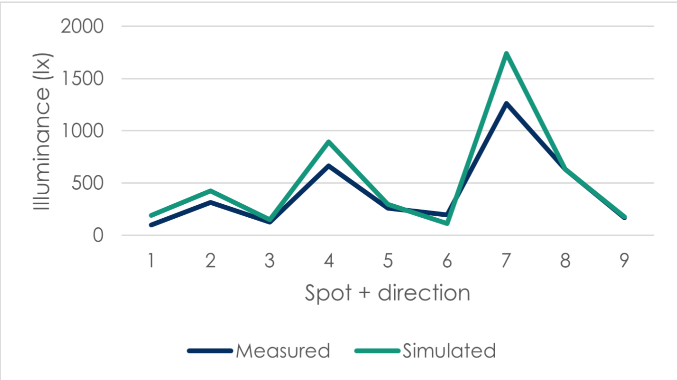
Pniëlschool

For this school the same three classrooms that have been measured have also been modeled and simulated to see how accurate the model is.

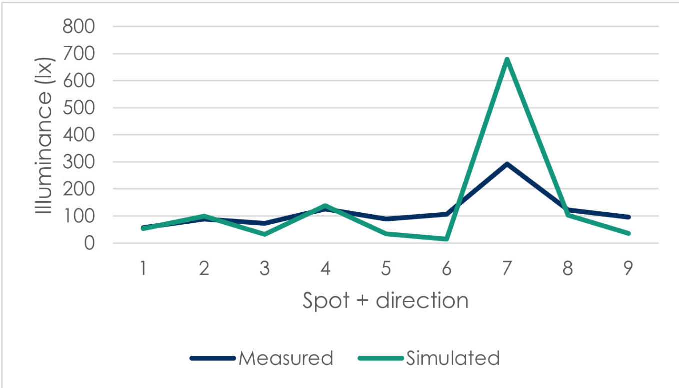
Classroom 1

For this school it is also the case that the situations without the blinds have lower deviations than with the blinds. In most cases the simulated values are overestimated, especially near the windows. This can be the case because the satellite data that is used is in general also overestimated compared to the weather station data.

March 7th



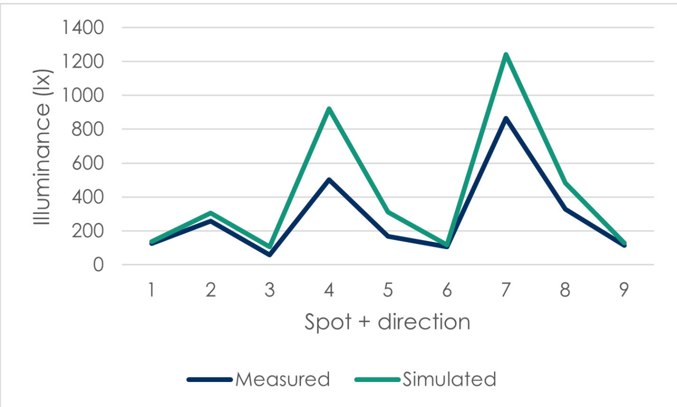
blinds 0%, AL 0%



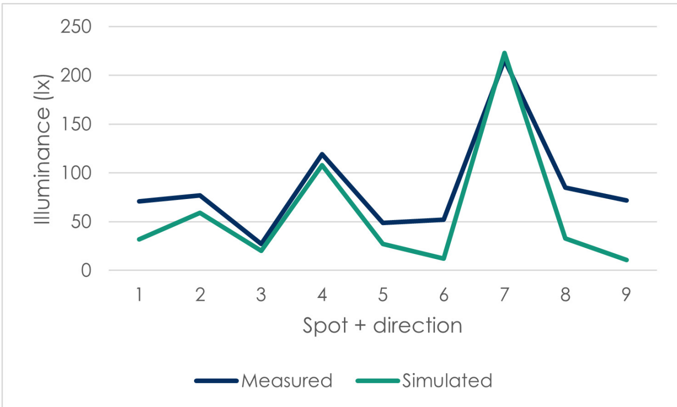
blinds 100%, AL 0%

nMBE **30,7%** **49,3%**

May 15th



blinds 0%, AL 0%

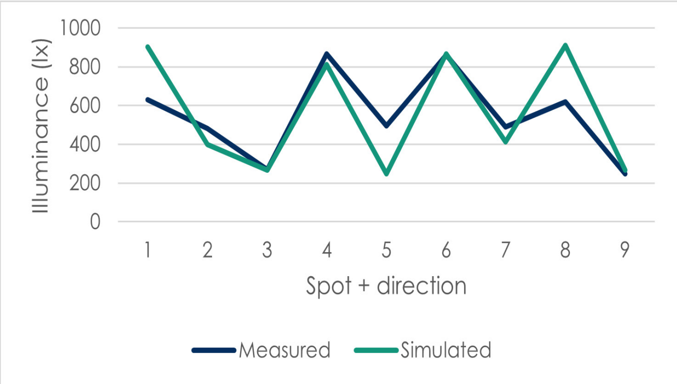


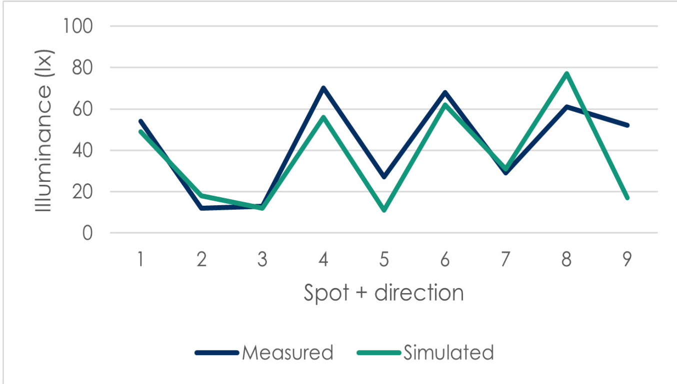
blinds 100%, AL 0%

nMBE **43,7%** **42,9%**

Classroom 2

March 7th





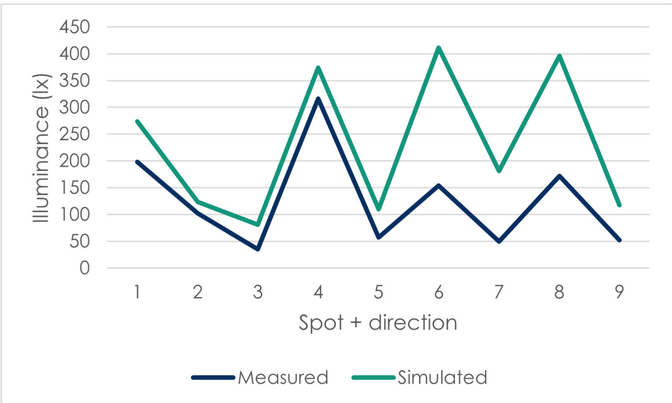
blinds 0%, AL 0%

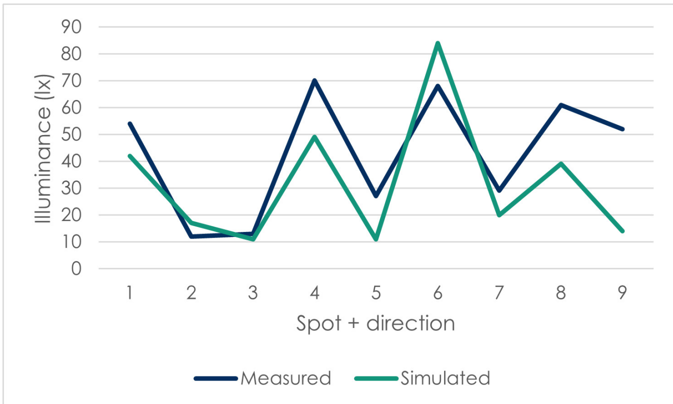
blinds 100%, AL 0%

nMBE **21,0%** **28,4%**

For this classroom the simulated values in May without the blinds are a lot higher than the actual measured values, but they are similar to the other peak simulated and measured on spot + direction 3,4 and 5. Because the spots had similar values in March, it might be the case that the measured values are lower because there was a sudden drop of irradiance.

May 15th





blinds 0%, AL 0%

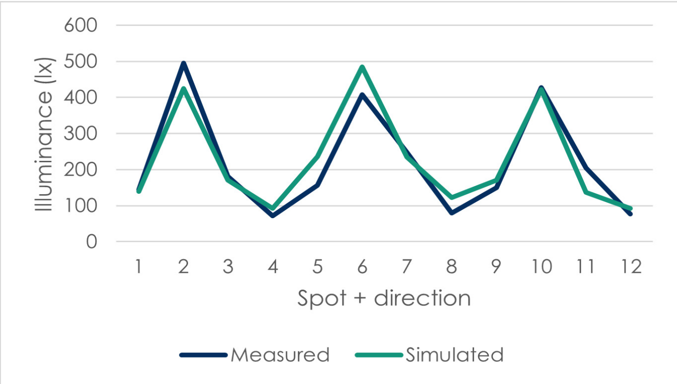
blinds 100%, AL 0%

nMBE **109,8%** **36,7%**

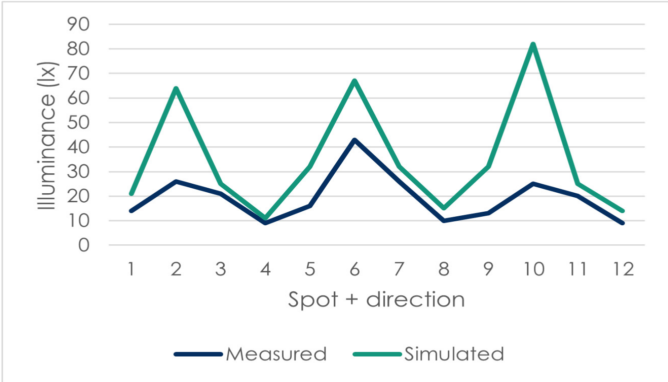
Classroom 3

In this classroom the situation with the blinds down is the situation that matches the measured values the least. This probably has to do with the sun shading and lower values in general, so the differences seem bigger, but also because this is the only classroom with an awning system and the simulations took a lot longer. The model probably has some problems with simulating this in the right way.

March 7th



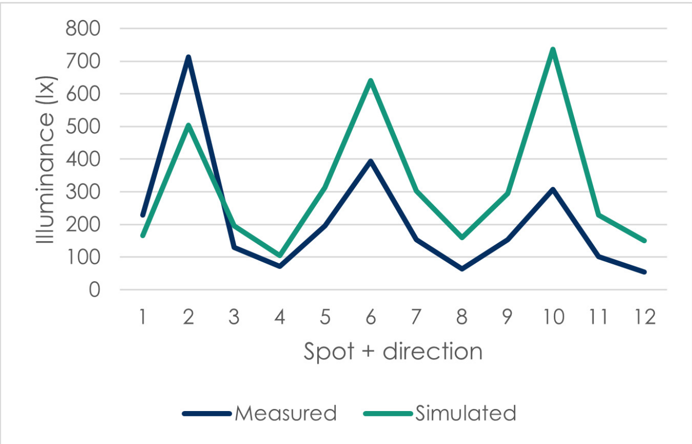
blinds 0%, AL 0%



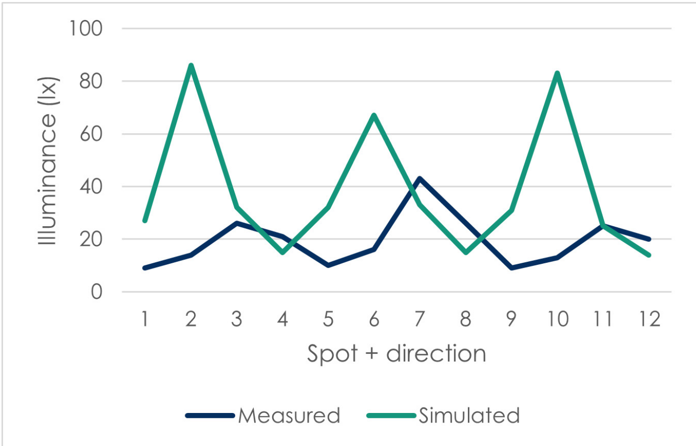
blinds 100%, AL 0%

nMBE	20,8%	76,8%

May 15th



blinds 0%, AL 0%



blinds 100%, AL 0%

nMBE	87,0%	181,7%

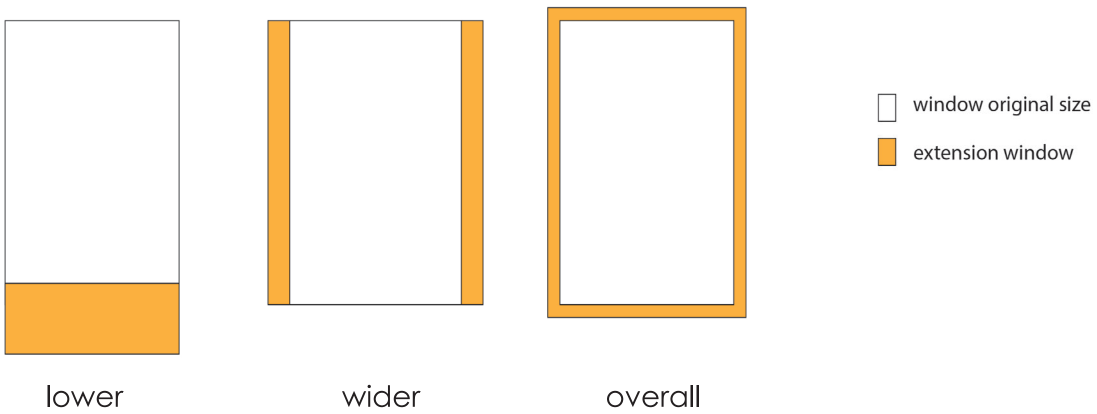
4.3 Simulation results

4.3.1 Design adaptations

There are a few design adaptation that can be done to gain more light inside, such as making the windows bigger and installing better artificial light. However, there are also a few design adaptations that probably are not getting more illuminance inside, but are important for other aspects, such as adding bold and primary colours to stimulate the productivity inside the classroom. Providing the school with better thermal glazing can also have a negative effect on the transmittance on the light. The effects of these design adaptations on the illuminance levels inside are simulated. For the melanopic illuminance levels, other artificial lighting is simulated to see the effect.

Enlarging the windows

Enlarging the windows will of course help to gain more light inside. For thermal reasons, the windows need to be as small as possible. With these simulations is tested what the best strategy is for making the windows 25% bigger.



Changing the colour of the interior walls

In the background literature it became clear that adding primary and bold colour to the classroom can have a positive effect on the creativity and concentration of children. With these simulations it is tested what the effects are inside on the lux levels when the walls are painted red, blue or yellow.

Changing the material of the ceiling

Both schools have a white suspended ceiling. The reflectance can be improved if it was just a white painted ceiling. In this simulation the effects are tested.

Changing the material of the floor

The Pniëlschool has a dark blue vinyl floor that is quite dark. The Hellenbroekschool has a grey vinyl floor. Both floors can have a better reflection if it was replaced by a light wooden floor. This is tested in the simulations.

Changing the glazing type

Clear glass has the best transmittance in terms of glazing, but sometimes, for thermal reasons, better glazing is required with a coating for example. If the clear glazing is replaced by Low-E glass, the simulations will show the consequences for the lux levels inside.

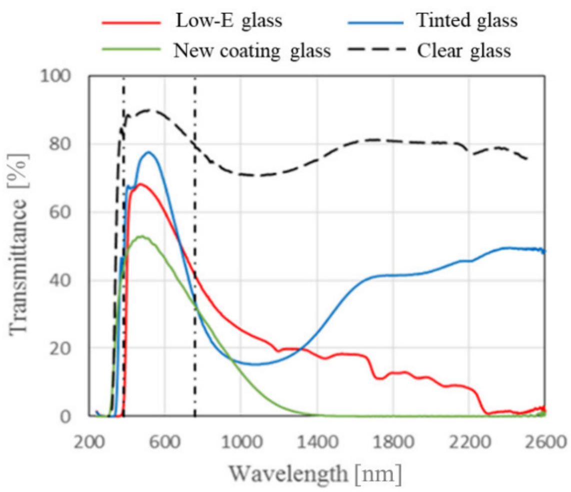


Figure 59: The transmittance coefficients of different glazing (Wang & Zhang, 2019)

Replacing the sun shading

Both schools have sun shading that lowers the lux levels inside, but despite that there are white blinds in the Hellenbroekschool and light grey sun shading in the Pniëlschool, this can be improved by replacing it with really thin white sun shading, but keeping the thermal performance of the room in mind.

In the table below the new reflectance/transmittance factors are shown that were used for the simulations.

Design adaptation	Reflectance/transmittance
Red interior walls	17,9
Blue interior walls	22,4
Yellow interior walls	52,0
Light wooden floor	52,0
White painted ceiling	89,3
Low E glass	0,68
White thin sun shading	0,80

Table 3: Reflectance/transmittance factors of design adaptations

4.3.2 Photopic illuminance

Figures 60 and 61 show the averages of the design adaptations are shown for each classroom. All graphs for each classroom are shown in appendix E. The first value is the simulated value without adaptations. The graphs show that enlarging the windows is helpful for each classroom, but to which side depends on the weather conditions. All the classrooms have the highest amount of illuminance if the windows are made wider in March, but in May it differs more. The best option for the weather conditions in May would be to enlarge the windows on all side for only daylight without the blinds, but to make the windows lower in the condition with the blinds down. For the sitting positions closest to the windows, it would be the best to lower the window, but for the positions further from the windows, it is the best to make them wider or enlarge them on all sides. In general, the most classrooms have the highest illuminance levels inside on eye level for all positions and both weather conditions if the windows are made wider because for the simulations in May there is not a significant difference between all three enlarging options.

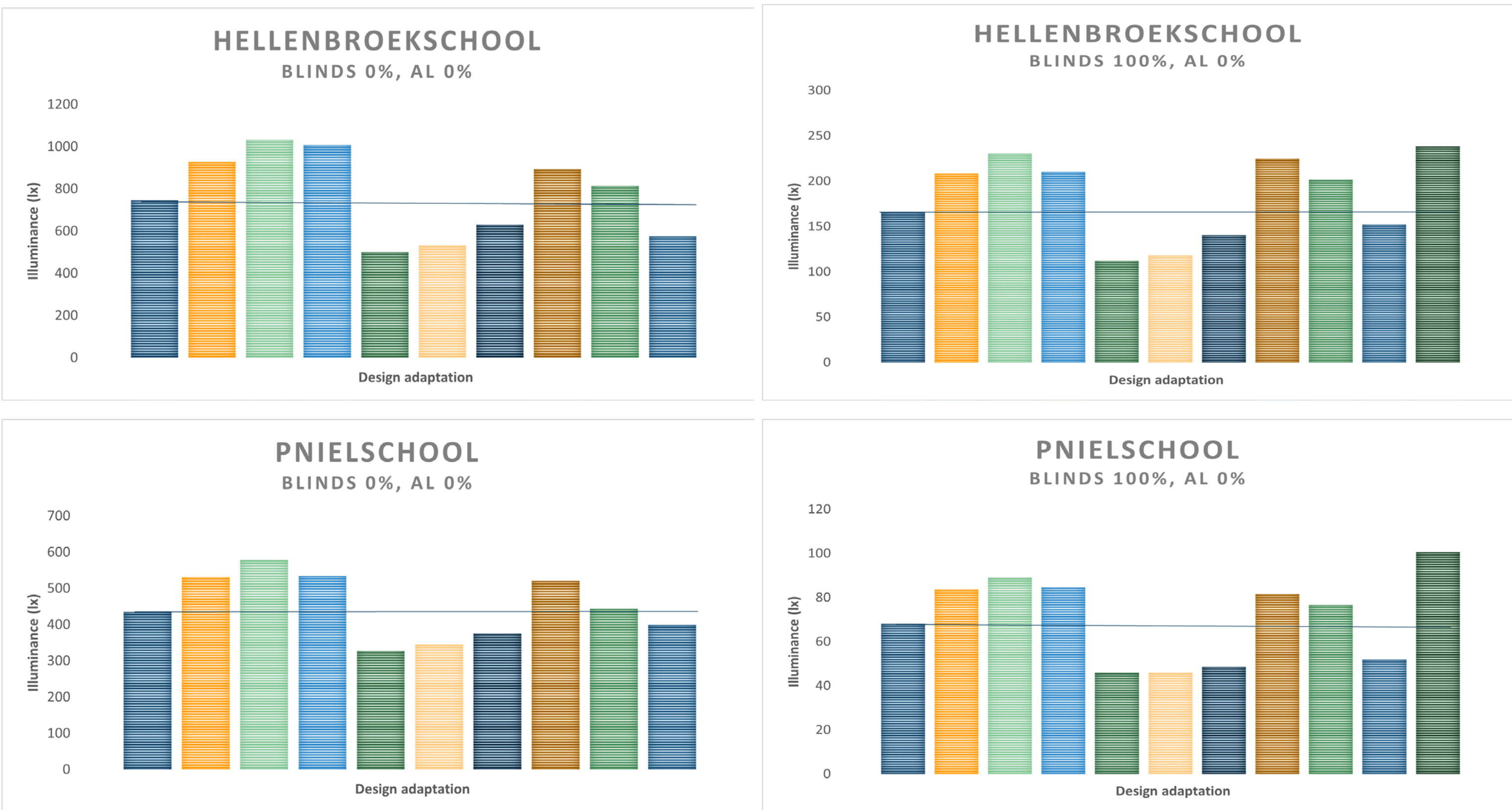
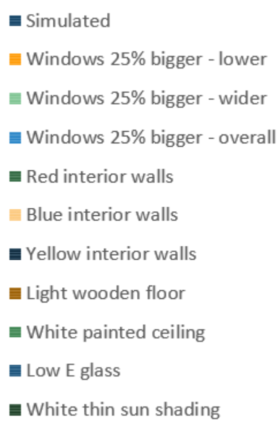


Figure 60: Average results design adaptations March



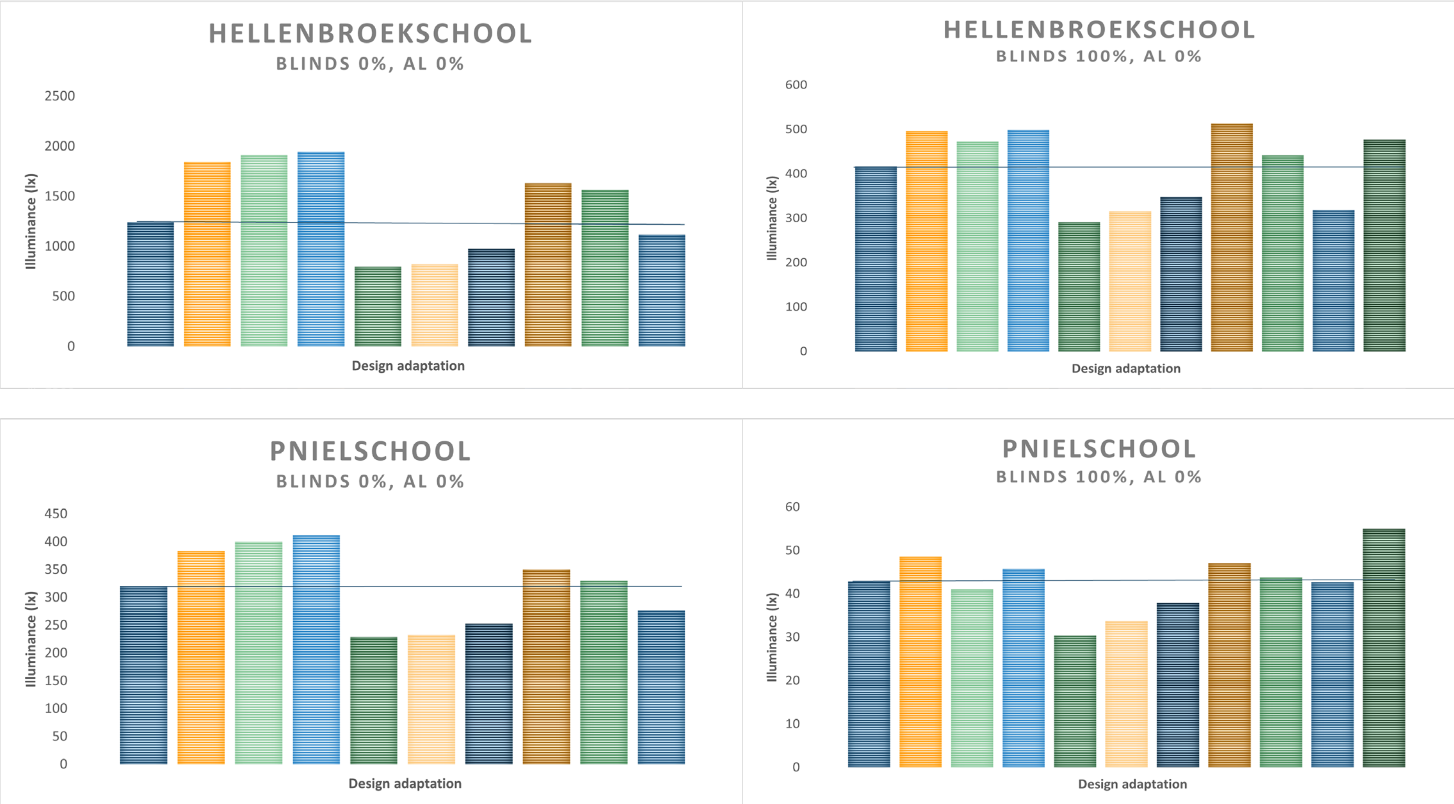
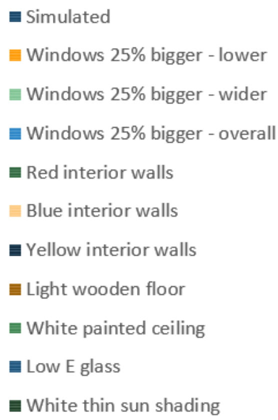


Figure 61: Average results design adaptations May



For both March and May the following conclusions can be drawn. Painting the walls in a bold primary colour has a big negative impact on the illuminance inside, from which red is the worst and yellow is the best. It is therefore recommended to keep the walls and large surfaces white and only use some bold primary colour accents in, for example, furniture.

Replacing the floor with a light wooden floor is the most effective for all classrooms, followed by replacing the white suspended ceiling with a smooth white painted ceiling. Replacing the windows with low E glazing has also a large negative impact on the lux levels inside.

Replacing the sun shading with thinner, white sun shading can also have a positive effect. In reality, the impact will probably not be this big. This might be the case because the transmittance of the existing sun shading was not known exactly and has been estimated. After seeing the impact of thin white sun shading, this has probably been estimated to low.

In the graphs on the left the relative difference of each design adaptation is plotted as a range for all classrooms in both conditions. Replacing the sun shading with thin white ones has been left out because no values were available for the situation with the blinds up, so the result would not be right.

It becomes clear that making the windows wider has the best average overall. It is striking that for the Pniëlschool on the 15th of May all design adaptations are very similar to the simulated value, except for making the windows lower and wider.

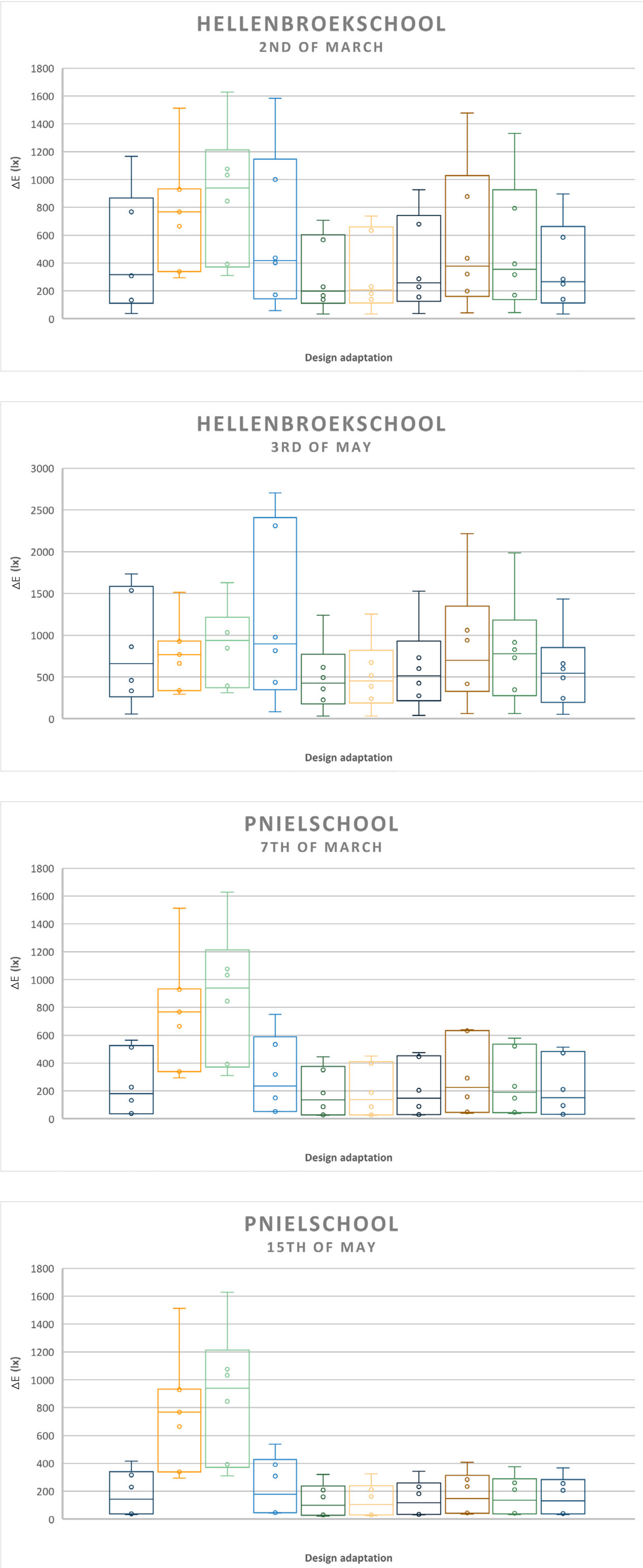


Figure 62: Relative difference of each design adaptation

In the tables below overviews of the design adaptations and their effects are shown for March and May. The range shows the maximum and minimum changes to the original lux levels.

Design adaptation	Range	Average
Windows 25% bigger – lower	12-34%	22,7%
Windows 25% bigger - wider	8-45%	29,0%
Windows 25% bigger – overall	9-41%	27,4%
Red interior walls	-50 - -2%	-34,4%
Blue interior walls	-44 - -1%	-30,6%
Yellow interior walls	-35 - 7%	-17,4%
Light wooden floor	6 - 42%	26,8%
White painted ceiling	4 - 27%	12,2%
Low E glass	-24 - 0%	-14,5%
White thin sun shading	30 -140%	79,1%

Table 4: An overview of the design adaptations and their effects in March

Design adaptation	Range	Average
Windows 25% bigger – lower	14-72%	35,0%
Windows 25% bigger - wider	11-79%	39,0%
Windows 25% bigger – overall	18-80%	45,3%
Red interior walls	-48 - -31%	-36,8%
Blue interior walls	-44 - -23%	-32,1%
Yellow interior walls	- 31 - -11%	-19,7%
Light wooden floor	7-64%	24,4%
White painted ceiling	-3 -26%	7,9%
Low E glass	-30 - -2%	-10,5%
White thin sun shading	5-84%	47,6%

Table 5: An overview of the design adaptations and their effects in May

The measurements and simulations also showed that the front view direction of the sitting places is important. The results showed that In the Pniëlschool, where all the sitting places were at different orientations, the ones facing the windows where the best. However, facing away from the windows received little illuminance and it would be advised against to place the children in that direction.

4.3.3 Cumulative illuminance

It is also important to look at the light exposure during a whole school day; the cumulative illuminance. The hobo loggers have been measuring the illuminance in the classrooms for at least a week after the measurement days in March and May. The days with the lowest and highest irradiance have been taken to perform simulations for each hour children will be present at school. These times vary during the week, but most days this is from 8:30 till 15:30. The simulations have also been performed during these times. In table 6 and figure 63 the averages of each simulated day are shown, compared to the measured values of the hobo loggers. The deviations are actually better than the ones for the spot measurements, but this is because it is an average of the whole day. In most cases the simulated values are underestimated, but in some cases the measured values are slightly lower. This might also have to do with the two errors that are relevant: the hobos tend to measure higher values (see section 4.2.2), but the weather data is also overestimated (see section 4.2.1). All measured and simulated values can be found in appendix C.

Hobo	Day	Measured (lx)	Simulated (lx)	Deviation
1	4/3	2619	3139	**19,8%**
	6/3	21310	15660	**26,5%**
	7/5	14390	15384	**6,9%**
	8/5	33375	32726	**1,9%**
2	4/3	6630	7183	**8,3%**
	6/3	11400	10545	**7,5%**
	7/5	11120	10368	**6,8%**
	8/5	28160	27776	**1,4%**
3	4/3	2947	2218	**24,7%**
	6/3	16418	11255	**31,4%**
	7/5	18243	16368	**10,3%**
	8/5	20991	18385	**12,4%**
4	10/3	22230	17460	**21,5%**
	11/3	66450	57735	**13,1%**
	16/5	4590	5253	**14,5%**
	22/5	5167	6453	**25,0%**
5	10/3	2877	3016	**4,8%**
	11/3	16200	13880	**14,3%**
	16/5	4310	3973	**7,8%**
	22/5	5060	4470	**11,7%**

Table 6: The deviations between the measured and simulated values for cumulative illuminance

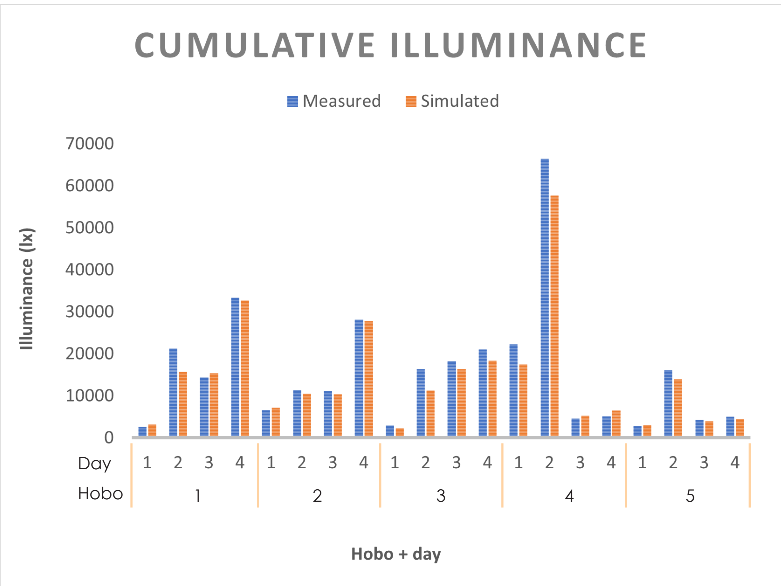
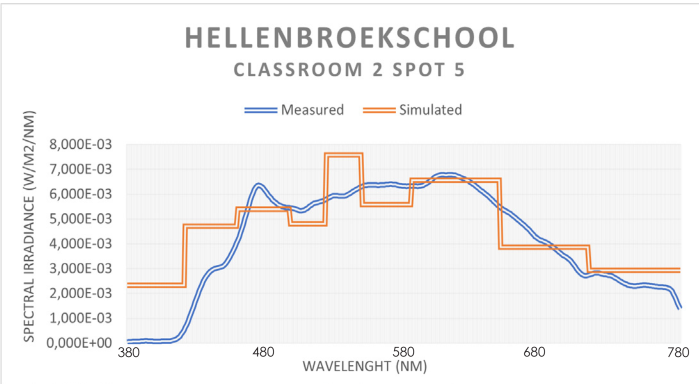


Figure 63: The difference between the measured and simulated values per day.

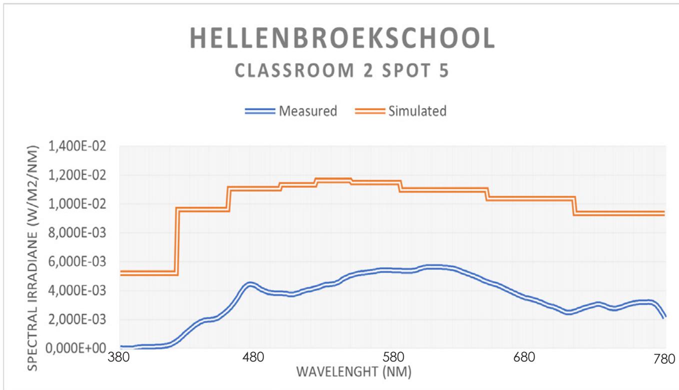
4.3.4 Melanopic illuminance

The script that is used for the Lark simulations is the standard template Point Based Simulation. This script allows for simulations with only daylight, only artificial light or both. The inputs consist of the point you want to measure and the viewing point, the weather data, the artificial light properties and the properties of the materials.
The same points that have been measured are simulated to calculate the melanopic illuminance, but only looking straight ahead for the sitting position. The spectral irradiance of the visible light spectrum has been measured and simulated for spots 1 and 5 for each classroom of the Ds Abraham Hellenbroekschool and spots 1 and 3 for the Pniëlschool to see how good the model represents reality. Shown below are the best and worst matches. The other graphs are shown in appendix D. What is striking is that the best and worst match are the same spot in the same classroom, but for a different time of the year. This can be the case because in March there was a clear sky and in May there was an overcast sky (see section 4.1.1).

2nd of March, blinds 0% AL 100%



3rd of May, blinds 0% AL 100%



Figures 64 and 65: The spectral irradiance of measurements and simulations for the best (left) and worst (right) matches.

In the table below the deviations are shown that the lark script calculated in comparison to the measured photopic illuminance and melanopic illuminance. The melanopic illuminance has been calculated by inserting the spectral irradiance into the toolbox in Excel (see chapter 3). All the data can be found in appendix D. Unfortunately, the simulation does not represent the reality very good. Especially the Hellenbroekschool has an overestimation and for both schools the simulations in May have a higher deviation from the measured values. This again can be partly explained by the weather data that is used as an input, but also the fact that the exact weather conditions for these days are unknown and the Lark script asks for very precise inputs.

	Hellenbroekschool March 2nd	Pniëlschool March 7th	Hellenbroekschool May 3rd	Pniëlschool May 15th
Photopic illuminance	107%	26%	182%	28%
Melanopic illuminance	113%	45%	288%	78%

Table 6: The deviations for the measured and simulated values.

4.4 Design solutions

4.4.1 Design matrix

In conclusion, in the tables below the design adaptations are rated on how effective, feasible and expensive they are. In the total rating the effectiveness is weighted the most (50%) and feasibility and expenses both 25%. The rating vary from double minus for a very bad rating till double plus for a very good rating. The rating for the effectiveness follow from the simulation results and for the ratings for the feasibility and expenses, three experts from EGM Architects are consulted. The first table shows the design adaptations for renovations of existing school buildings, the second table shows them for new school buildings.

Design adaptation	Effect	Feasibility	Costs	Total
Windows 25% bigger – lower	+	− − −	− − −	− −
Windows 25% bigger - wider	+ +	− − − −	− − − −	− −
Windows 25% bigger – over all	+	− − − − −	− − − − −	− − − −
Red interior walls	− −	+ +	+	−
Blue interior walls	− −	+ +	+	−
Yellow interior walls	−	+ +	+	+ −
Light wooden floor	+ +	+	+ −	+ +
White painted ceiling	+	− −	−	+
Low E glass	−	−	− −	− −
White thin sun shading	+ +	−	+ −	+ +

Table 7: Rating of design adaptations for renovation of existing school buildings

Enlarging the windows may be effective, of which making them wider is the best one, but it is not realistic. However, there is still a small difference in how feasible and expensive the three enlarging options are. Making the windows lower is the most feasible of the three but this also depends on the inner cavity leaf that is used inside the building. Enlarging the windows overall is the least feasible because changes have to be made on each side. A possibility that can be further explored is the use of roof windows and daylight tubes.

Painting the walls is not very expensive considering that they will be painted every few years already for maintenance. Replacing the floor is in some cases far more expensive than painting the walls, but it has a good feasibility. Light-coloured floors are usually not used because they will get dirty, but using a light-coloured floor with a pattern is possible. Replacing the whole ceiling for a white plastered ceiling is not realistic for renovation, but looking at the effectiveness, other possibilities can be considered, such as a whiter ceiling tile. Changing the glazing is also expensive and not realistic because the glazing is most likely already optimised for both thermal and light conditions. Changing the sun shading is feasible, however, thin white sun shading on the outside is not realistic because it will get dirty. Thin white sun shading is possible on the inside, however, for thermal reasons exterior sun shading is preferred. Possibilities that can be further explored are using venetian blinds, using two colours of sun shading in front of each other and only using sun shading on the lower part of the window. In this way more light is coming inside and the sun shading can still prevent glare.

Design adaptation	Effect	Feasibility	Costs	Total
Windows 25% bigger – lower	+	+ –	+ –	+
Windows 25% bigger - wider	+ +	+ –	+ –	+ +
Windows 25% bigger – over all	+	+ –	+ –	+
Red interior walls	– –	+ +	+	–
Blue interior walls	– –	+ +	+	–
Yellow interior walls	–	+ +	+	–
Light wooden floor	+ +	+ +	+	+ +
White painted ceiling	+	–	–	+ +
Low E glass	–	+ +	–	–
White thin sun shading	+ +	+ –	+	+ +

Table 8: Rating of design adaptations for new school buildings

For new buildings a lot of these design adaptations are more feasible and less expensive. Enlarging the windows will be an optimalisation with the thermal conditions of the building. In the cases of the walls, floor, glazing and sun shading it is relatively easy to change this. In the case of the ceiling, it will be hard to not have a suspended ceiling because they are light-weighted and installations are accessible. However, the colour of the tiles can easily be changed.

5

Discussion

5.1 Limitations

During the research some steps that were planned to be done did not work out the way they were supposed to, the models could not simulate the right results for unknown reasons or some errors have been made. This results in some limitations of this thesis which are listed here.

Downloading weather data from the Rotterdam/The Hague Airport dataset is only available on the day itself or the previous day. For the first measurement day this was not known and the data could not be downloaded anymore. To still have the weather data, the satellite data has been downloaded. This is less accurate, but still gives values for the direct and diffuse daylight. The satellite data and the weather station data have been compared with each other to see the differences. The satellite data is in general slightly higher and this results in higher illuminance values for the simulations.

Simulating the artificial light turned out to be a lot harder than expected because this is only possible with the older Legacy version on Ladybug, which does not work with Rhinoceros 7. This would also mean that the whole Honeybee script had to be rebuilt in the older version and due to limited time, this was not possible anymore. This thesis does therefore not include artificial lighting for the design adaptations simulations done with Honeybee.
Similar to the above, the hallways are not included because there was automatic artificial light that could not be turned off. Especially in the Pniëlschool this had some influence on the light level inside.

The sun shading reflectance that was estimated and used is probably too low. This turned out when thin white sun shading was tested and the differences in values were too big to be realistic.
In the Lark script, there is a big difference between the measured melanopic values and the simulated values, which means that the models are not calculating it as they should. This can be the case because the exact sky conditions are unknown of the measurement days and need to be set in the script. Additionally, the exact apertures used in the schools are not available as IES-files, which can also explain the differences.

5.2 Further research

Because the topic of childhood myopia is very important and upcoming, further research is recommended. This study could continue to test more design adaptations and to simulate more schools, also in combination with artificial light. It would also be good to test the design adaptations on their effects on cumulative and melanopic illuminance.
Not much is known at this moment on how much childhood myopia will be decreased by increasing cumulative and melanopic illuminance inside schools, so it would be good to have more research in the future into that.
This study has been done with tools that are not made to research childhood myopia. To research childhood myopia better, it would be good to have software developed that can combine the several simulations and to add the topic of viewing in the distance.

6

Conclusion

6.1 Overview

This thesis focused mainly on getting more light inside classrooms and what design adaptations are the most appropriate to implement to reduce myopia development among children. This research is done based on measurements taken and simulations performed in two case study buildings in the region of Rotterdam. Measurements have taken place in March and May of 2023 in three classrooms per school to see the results under different weather conditions. After this, several design adaptations have been simulated to see their impact on the light levels inside. These design adaptations are rated on their effectivity, feasibility and costs to find out the best design strategies for creating more light inside classrooms. The design adaptations that are tested are:

- Enlarging the windows 25% - lower
- Enlarging the windows 25% - wider
- Enlarging the windows 25% - overall
- Red interior walls
- Blue interior walls
- Yellow interior walls
- Light wooden floor
- White painted ceiling
- Low E glass
- White thin sun shading

The cumulative illuminance and melanopic illuminance are also important factors in the process of decreasing myopia development. It is important that children receive high illuminance levels during the day (cumulative illuminance) and melanopic illuminance slow the myopia development. The measured values for cumulative and melanopic illuminance have been compared to the simulated values to get results on how well they match.

The final outcome of this thesis consists of recommendations for designing school buildings, for both renovation and new buildings. These and other design adaptations should be researched more to come to a final conclusion for what design strategies are the best for decreasing myopia. In addition, these design strategies should also be tested on their effects for cumulative and melanopic illuminance.

6.2 Research question

How can school building design help to reduce childhood myopia?

This research question can now be answered with the help of the sub questions.

1. What is myopia and what causes it?

Myopia begins to develop at a young age, approximately between the ages of six and nine years. The eyeball has grown too long what causes that light is aimed in front of the retina instead of on it, which results in an unclear image. Childhood myopia can become a big problem apart from wearing glasses or contacts, because it can lead to several serious eye disorders such as glaucoma, retinal detachment and even blindness. Research shows that more people are developing myopia and if nothing is done, 50% of the world population will have developed myopia by 2050.

2. How can myopia development be reduced in relation to architecture?
A literature study has been done to find out what possible design adaptations could help to decrease myopia. In general, there needs to fall more light on the eyeball. Some design adaptations could help with that. These design adaptations turned out to be more green space, adding the ends of the colour spectrum, increasing the amount of melanopic illuminance and changing materials and colour. Training the eyes to watch further into distance more often is also important to decrease myopia

3. What is the current situation of a recently build and a renovated school building in the Netherlands?
Light measurements have been done in two different schools in March and May. The measured values show that the seats furthest away from the windows receive significantly less illuminance and should be improved. In the situation in May, there is already much daylight coming inside the classroom so the artificial light does not have a lot of impact.
The measurements also showed that the front view direction of the sitting places is important. The results showed that in the Pniëlschool, where all the sitting places were at different orientations, the ones facing the windows where the best. The sitting positions facing away from the windows received significant less illuminance than facing any other direction on the same spot.
The calibration of the measurements and simulations showed that the values did not always match, with deviations between 16,1% and 181,7%. The situation in May had a worse match, which can probably be explained by the weather data that has an error and is overestimated.

4. What can be improved in a recently build and a renovated school building in the Netherlands?
The design adaptations mentioned in section 6.1 are simulated to see their effectiveness on getting more light inside the classrooms.
In conclusion, the most effective design adaptation would be enlarging the windows. This was tested in three ways, of which making them wider was the best with an increase in illuminance by 34%.
Design adaptations that are also effective are replacing the floor with a light-coloured floor, replacing the ceiling for a white plastered one and replacing the sun shading with very thin white ones. They will increase the lux levels inside by 25%, 10% and 63% respectively, where the blinds only will have effect when they are down. However, it should be made sure that these adaptations do not cause glare.
Painting the walls in bold, primary colours has a negative effect on the light levels inside, so it is recommended to only add pops of colours in, for example, furniture. Lastly, replacing the clear glazing with low E glazing for thermal reasons also had a negative effect on the illuminance inside, so an educated consideration has to be made by design for optimal lighting and optimal thermal conditions.

One observation that was made is that sitting positions facing the windows were the best and facing away from them the worst, so it would be advised against to place the children facing away from the window.

These design adaptations can also be tested on their effects on cumulative and melanopic illuminance. Due to time management, the measurement and simulation results are only compared to each other to see how well the model represents the reality. The hobo loggers had a small deviation with the simulation results, but the hobo calibration and the weather data both have errors that could explain that. The melanopic illuminance measurements had a better match with the simulation results when there was a clear sky. This is probably the case because the settings in Lark have a clear sky as default.

5. What design choices in school buildings can be made to decrease myopia?
The design adaptations mentioned in section 6.1 are rated on their effectivity, feasibility and costs in a design matrix. The main conclusions are listed here.

Enlarging the windows may be effective, but it is not realistic for renovation. A possibility that can be further explored is the use of roof windows and daylight tubes. For new build schools it is recommended to make the windows wider, considering the thermal conditions of the building. Painting the walls is not very expensive considering that they will be painted every few years already for maintenance, however it is not effective so this design adaptation is not recommended.
Replacing the floor is in some cases far more expensive than painting the walls, but it has a good feasibility. Light-coloured floors are usually not used because they will get dirty, but using a light-coloured floor with a pattern is possible. Considering how effective this is, this design adaptation is recommended for both renovation and new buildings. Replacing the whole ceiling for a white plastered ceiling is not realistic for renovation, but looking at the effectiveness, other possibilities can be considered, such as a whiter ceiling tile. It will be hard to not have a suspended ceiling in new buildings because they are light weighted and installations are accessible.
Changing the glazing is expensive and not realistic because the glazing is most likely already optimised for both thermal and light conditions. Changing the sun shading is feasible, however, thin white sun shading on the outside is not realistic because it will get dirty. Thin white sun shading is possible on the inside, however, for thermal reasons exterior sun shading is preferred. Possibilities that can be further explored are using venetian blinds, using two colours of sun shading in front of each other and only using sun shading on the lower part of the window. In this way more light is coming inside and the sun shading can still prevent glare.

In conclusion, some of the design adaptations can significantly improve the illuminance inside classrooms and other design adaptations can lower them remarkably. However, these specific design adaptations with their effects are only tested on two case studies, and they could perform different in other buildings. More design adaptations can be tested, also in combination with artificial lighting. Therefor further research on this important topic is recommended.

7

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8

Appendices

A: Measurement results

	blinds 0%, AL 0% (lx)				blinds 50%, AL 0% (lx)				blinds 100%, AL 0% (lx)			
spot	time	↑	→	←	time	↑	→	←	time	↑	→	←
1	**10:38**	451	829	294	**11:05**	183	317	138	**11:16**	61	126	51
2	**10:43**	388	634	242	**11:07**	188	266	113	**11:17**	77	126	45
3	**10:50**	566	1280	274	**11:09**	244	522	139	**11:18**	89	248	53
4	**10:55**	693	2299	865	**11:11**	480	692	363	**11:20**	120	377	82
5	**10:58**	1598	2044	459	**11:12**	977	1664	227	**11:21**	424	634	89
	blinds 0%, AL 100% (lx)				blinds 50%, AL 100% (lx)				blinds 100%, AL 100% (lx)			
spot	time	↑	→	←	time	↑	→	←	time	↑	→	←
1	**11:42**	259	522	209	**11:33**	151	252	124	**11:25**	82	163	78
2	**11:44**	290	526	169	**11:35**	172	237	110	**11:26**	107	159	71
3	**11:45**	399	1060	226	**11:37**	222	435	131	**11:28**	123	274	78
4	**11:46**	800	6720	596	**11:38**	475	1271	290	**11:29**	163	570	117
5	**11:47**	1416	1905	642	**11:39**	810	1402	235	**11:30**	400	464	119

Ds Abraham Hellenbroekschool, classroom 1, 3rd of March

	blinds 0%, AL 0% (lx)				blinds 50%, AL 0% (lx)				blinds 100%, AL 0% (lx)			
spot	time	↑	→	←	time	↑	→	←	time	↑	→	←
1	**10:58**	431	1031	427	**10:38**	340	765	351	**10:21**	186	467	194
2	**10:58**	522	1112	306	**10:38**	411	825	255	**10:21**	211	475	156
3	**10:59**	900	2185	445	**10:39**	698	1514	373	**10:22**	330	985	179
4	**11:00**	1211	2895	1556	**10:40**	1082	2564	828	**10:22**	491	1677	311
5	**11:00**	5400	4020	1433	**10:40**	5240	4230	1328	**10:23**	1846	2179	336
	blinds 0%, AL 100% (lx)				blinds 50%, AL 100% (lx)				blinds 100%, AL 100% (lx)			
spot	time	↑	→	←	time	↑	→	←	time	↑	→	←
1	**11:03**	682	1306	642	**10:32**	584	1043	534	**10:26**	435	767	433
2	**11:03**	847	1394	476	**10:33**	739	1119	417	**10:26**	550	800	331
3	**11:04**	1261	2514	650	**10:33**	1031	1912	618	**10:27**	663	1379	446
4	**11:04**	1236	2520	1614	**10:34**	1394	2477	1213	**10:28**	806	1835	672
5	**11:04**	5060	4110	1779	**10:34**	5380	4580	1785	**10:29**	2387	1933	669

Ds Abraham Hellenbroekschool, classroom 1, 3rd of May

	blinds 0%, AL 0% (lx)				blinds 50%, AL 0% (lx)				blinds 100%, AL 0% (lx)			
spot	time	↑	→	←	time	↑	→	←	time	↑	→	←
1	**13:00**	117	246	141	**13:08**	81	146	93	**13:16**	49	28	51
2	**13:01**	135	366	130	**13:09**	61	271	53	**13:17**	19	56	18
3	**13:02**	132	407	110	**13:10**	73	240	84	**13:18**	18	48	25
4	**13:03**	152	903	156	**13:11**	82	686	97	**13:20**	25	108	25
5	**13:04**	300	630	276	**13:12**	190	531	156	**13:21**	39	71	34
	blinds 0%, AL 100% (lx)				blinds 50%, AL 100% (lx)				blinds 100%, AL 100% (lx)			
spot	time	↑	→	←	time	↑	→	←	time	↑	→	←
1	**13:40**	191	387	240	**13:31**	185	273	215	**13:24**	149	212	154
2	**13:41**	319	445	218	**13:32**	282	435	187	**13:25**	247	225	156
3	**13:42**	257	494	304	**13:33**	216	396	271	**13:26**	183	212	233
4	**13:44**	226	840	326	**13:34**	174	751	263	**13:27**	125	193	197
5	**13:45**	447	575	437	**13:35**	237	356	375	**13:28**	191	170	230

Ds Abraham Hellenbroekschool, classroom 2, 3rd of March

	blinds 0%, AL 0% (lx)				blinds 50%, AL 0% (lx)				blinds 100%, AL 0% (lx)			
spot	time	↑	→	←	time	↑	→	←	time	↑	→	←
1	**12:33**	135	267	133	**12:16**	96	158	83	**12:09**	64	38	42
2	**12:33**	154	361	137	**12:17**	94	255	84	**12:09**	29	70	25
3	**12:34**	170	493	125	**12:17**	91	355	71	**12:10**	31	71	24
4	**12:34**	175	716	134	**12:18**	106	631	85	**12:11**	36	104	32
5	**12:35**	327	617	230	**12:19**	217	512	148	**12:11**	54	100	54
	blinds 0%, AL 100% (lx)				blinds 50%, AL 100% (lx)				blinds 100%, AL 100% (lx)			
spot	time	↑	→	←	time	↑	→	←	time	↑	→	←
1	**12:28**	203	375	215	**12:23**	158	283	156	**12:03**	128	173	131
2	**12:29**	275	441	203	**12:24**	211	345	138	**12:03**	158	175	98
3	**12:29**	306	566	250	**12:24**	221	439	199	**12:04**	173	184	162
4	**12:30**	245	785	230	**12:24**	181	683	179	**12:05**	108	155	130
5	**12:30**	427	625	323	**12:25**	318	572	235	**12:06**	162	150	145

Ds Abraham Hellenbroekschool, classroom 2, 3rd of May

	blinds 0%, AL 0% (lx)				blinds 50%, AL 0% (lx)				blinds 100%, AL 0% (lx)			
spot	time	↑	→	←	time	↑	→	←	time	↑	→	←
1	**14:36**	716	1305	1102	**14:44**	460	631	538	**14:51**	243	422	273
2	**14:37**	1024	1351	1506	**14:45**	710	1669	1709	**14:52**	329	1223	863
3	**14:38**	832	1135	1362	**14:46**	473	569	654	**14:54**	216	307	414
4	**14:39**	635	631	916	**14:47**	381	396	613	**14:55**	197	208	332
5	**14:41**	2064	392	8050	**14:48**	649	1206	1544	**14:56**	306	377	871
	blinds 0%, AL 100% (lx)				blinds 50%, AL 100% (lx)				blinds 100%, AL 100% (lx)			
spot	time	↑	→	←	time	↑	→	←	time	↑	→	←
1	**15:19**	764	1255	1011	**15:11**	590	801	603	**14:59**	394	461	382
2	**15:20**	1617	1654	1565	**15:12**	1209	1705	2212	**15:00**	472	1280	965
3	**15:21**	1085	1170	1823	**15:13**	642	678	851	**15:01**	363	408	449
4	**15:22**	919	903	1266	**15:14**	666	555	724	**15:03**	408	316	456
5	**15:23**	1878	2341	1183	**15:15**	1288	1409	2578	**15:04**	422	507	960

Ds Abraham Hellenbroekschool, classroom 3, 3rd of March

	blinds 0%, AL 0% (lx)				blinds 50%, AL 0% (lx)				blinds 100%, AL 0% (lx)			
spot	time	↑	→	←	time	↑	→	←	time	↑	→	←
1	**13:57**	442	936	601	**13:51**	362	630	448	**13:28**	157	242	175
2	**13:57**	850	3420	2022	**13:51**	653	2854	1559	**13:28**	199	685	494
3	**13:58**	524	882	775	**13:51**	394	563	648	**12:29**	140	241	183
4	**13:59**	553	583	702	**13:52**	439	442	475	**12:30**	158	177	213
5	**13:59**	976	1683	1971	**13:52**	797	1355	1481	**12:31**	267	636	496
	blinds 0%, AL 100% (lx)				blinds 50%, AL 100% (lx)				blinds 100%, AL 100% (lx)			
spot	time	↑	→	←	time	↑	→	←	time	↑	→	←
1	**13:40**	620	1159	731	**13:46**	504	842	557	**13:35**	342	492	357
2	**13:40**	1096	3630	2188	**13:47**	804	2970	1663	**13:35**	426	946	538
3	**13:41**	719	912	860	**13:47**	596	783	872	**13:36**	342	420	436
4	**13:41**	733	752	855	**13:47**	654	652	676	**13:37**	381	359	374
5	**13:42**	1130	1707	2102	**13:48**	1042	1672	1690	**13:38**	455	733	629

Ds Abraham Hellenbroekschool, classroom 3, 3rd of May

	spot	blinds 0%, AL 100% (lx)			
		time	↑	→	←
Hallway downstairs	1	**12:32**	138	140	178
	2	**15:39**	114	169	168
Hallway upstairs	1	**15:25**	445	426	800
	2	**15:26**	436	405	473
	3	**15:28**	734	682	1629
	4	**15:38**	724	208	534
		Daylight (lx)			
Courtyard (looking up)	1	**16:04**	8230		
	2	**16:04**	7310		
	3	**16:04**	5720		
Playground (looking up)	1	**16:12**	32000		
	2	**16:12**	13270		
	3	**16:13**	26000		
	4	**16:14**	27010		

Ds Abraham Hellenbroekschool, common spaces, 3rd of March

	spot	blinds 0%, AL 100% (lx)			
		time	↑	→	←
Hallway downstairs	1	**13:05**	146	151	189
	2	**13:06**	107	182	173
Hallway upstairs	1	**13:08**	382	401	504
	2	**13:09**	505	449	582
	3	**13:09**	636	565	466
	4	**13:10**	420	164	315
		Daylight (lx)			
Courtyard (looking up)	1	**14:02**	11780		
	2	**14:02**	9520		
	3	**14:03**	8700		
Playground (looking up)	1	**14:12**	39000		
	2	**14:12**	15620		
	3	**14:13**	28000		
	4	**14:14**	31010		

Ds Abraham Hellenbroekschool, common spaces, 3rd of May

	blinds 0%, AL 0% (lx)				blinds 100%, AL 0% (lx)			
spot	time	←	↑	→	time	←	↑	→
1	**10:08**	100	314	126	**10:10**	56	88	72
2	**10:08**	663	259	196	**10:10**	126	89	107
3	**10:09**	1262	630	169	**10:11**	291	122	96
	blinds 0%, AL 100% (lx)				blinds 100%, AL 100% (lx)			
spot	time	←	↑	→	time	←	↑	→
1	**09:48**	460	646	379	**10:12**	501	492	349
2	**09:50**	894	513	419	**10:13**	634	498	612
3	**09:51**	1209	745	470	**10:13**	668	523	485

Pniëlschool, classroom 1, 7th of March

	blinds 0%, AL 0% (lx)				blinds 100%, AL 0% (lx)			
spot	time	←	↑	→	time	←	↑	→
1	**10:05**	125	265	57	**10:01**	71	77	27
2	**10:06**	503	166	105	**10:01**	119	49	52
3	**10:07**	865	328	115	**10:02**	216	85	72
	blinds 0%, AL 100% (lx)				blinds 100%, AL 100% (lx)			
spot	time	←	↑	→	time	←	↑	→
1	**9:54**	648	944	409	**9:58**	436	541	327
2	**9:54**	1294	643	418	**9:59**	620	437	380
3	**9:55**	1731	984	548	**9:59**	597	530	470

Pniëlschool, classroom 1, 15th of May

	blinds 0%, AL 0% (lx)				blinds 100%, AL 0% (lx)			
spot	time	←	↑	→	time	←	↑	→
1	**12:23**	631	482	270	**12:31**	54	12	13
2	**12:23**	856	495	861	**12:31**	70	27	68
3	**12:24**	488	619	246	**12:32**	29	61	52
	blinds 0%, AL 100% (lx)				blinds 100%, AL 100% (lx)			
spot	time	←	↑	→	time	←	↑	→
1	**12:27**	290	142	39	**12:35**	407	374	232
2	**12:28**	495	116	422	**12:35**	345	395	391
3	**12:29**	127	295	65	**12:36**	381	380	201

Pniëlschool, classroom 2, 7th of March

	blinds 0%, AL 0% (lx)				blinds 100%, AL 0% (lx)			
spot	time	←	↑	→	time	←	↑	→
1	**11:08**	198	102	35	**11:11**	35	21	10
2	**11:08**	316	57	154	**11:12**	32	14	26
3	**11:10**	49	172	52	**11:13**	13	36	15
	blinds 0%, AL 100% (lx)				blinds 100%, AL 100% (lx)			
spot	time	←	↑	→	time	←	↑	→
1	**11:04**	565	477	342	**11:15**	390	396	327
2	**11:04**	513	397	432	**11:16**	288	363	317
3	**11:05**	376	520	297	**11:16**	348	401	271

Piëlschool, classroom 2, 15th of May

	blinds 0%, AL 0% (lx)					blinds 100%, AL 0% (lx)				
spot	time	←	↑	→	↓	time	←	↑	→	↓
1	**14:45**	72	144	495	181	**15:01**	9	14	26	21
2	**14:47**	80	156	408	248	**15:02**	10	16	43	26
3	**14:48**	77	150	427	205	**15:02**	9	13	25	20
	blinds 0%, AL 100% (lx)					blinds 100%, AL 100% (lx)				
spot	time	←	↑	→	↓	time	←	↑	→	↓
1	**14:49**	277	326	689	405	**14:57**	228	202	288	207
2	**14:53**	264	307	585	384	**14:59**	212	182	275	187
3	**14:54**	300	362	587	414	**14:59**	248	262	273	264

Pniëlschool, classroom 3, 7th of March

	blinds 0%, AL 0% (lx)					blinds 100%, AL 0% (lx)				
spot	time	←	↑	→	↓	time	←	↑	→	↓
1	**12:15**	229	713	130	72	**12:25**	43	106	23	15
2	**12:15**	196	394	154	63	**12:25**	45	56	27	16
3	**12:16**	153	308	102	55	**12:26**	38	76	25	15
	blinds 0%, AL 100% (lx)					blinds 100%, AL 100% (lx)				
spot	time	←	↑	→	↓	time	←	↑	→	↓
1	**12:18**	303	673	266	237	**12:22**	189	312	177	200
2	**12:19**	317	482	244	250	**12:22**	177	253	167	208
3	**12:19**	312	506	392	252	**12:23**	206	268	210	216

Pniëlschool, classroom 3, 15th of May

	spot	blinds 0%, AL 100% (lx)			
		time	←	↑	→
Hallway downstairs	1	**13:43**	369	269	353
Hallway middle	1	**13:20**	286	372	214
	2	**13:21**	233	343	266
	3	**13:22**	241	277	243
	4	**13:23**	231	302	237
	5	**13:25**	263	306	237
	6	**13:25**	216	308	248
Hallway upstairs	1	**10:32**	810	1981	667
	2	**11:14**	302	1389	573
	3	**11:17**	395	1152	286

Pniëlschool, common spaces, 7th of March

	spot	blinds 0%, AL 100% (lx)			
		time	←	↑	→
Hallway downstairs	1	**11:52**	351	911	1147
Hallway middle	1	**11:55**	370	422	316
	2	**11:56**	263	388	305
	3	**11:56**	303	399	325
	4	**11:56**	419	378	329
	5	**11:58**	312	367	374
	6	**11:58**	334	381	274
Hallway upstairs	1	**10:41**	1450	502	636
	2	**10:41**	935	361	422
	3	**10:42**	1013	379	434

Pniëlschool, common spaces, 15th of May

B: Simulation results

Ds Abraham Hellenbroekschool, classroom 1, 2nd of March, blinds 0%, AL 0%

Spot	Direction	Measured (lx)	Simulated (lx)	Windows 25% bigger - lower	Windows 25% bigger - wider	Windows 25% bigger – overall
1	←	294	237	395	442	327
	↑	451	228	381	428	319
	→	829	733	1106	1238	939
2	←	242	331	357	410	430
	↑	388	388	429	482	515
	→	634	767	840	947	980
3	←	274	325	508	585	419
	↑	566	552	863	912	663
	→	1280	1480	2234	2457	2142
4	←	864	755	838	905	943
	↑	693	649	832	826	831
	→	2299	1745	1919	2409	2689
5	←	459	620	711	751	749
	↑	1598	1123	1172	1344	1322
	→	2044	1593	1398	2008	1734

Spot	Direction	Simulated (lx)	Red interior walls	Blue interior walls	Yellow interior walls	Light wooden floor	White painted ceiling	Low E glass
1	←	237	60	72	167	400	357	234
	↑	228	110	118	145	407	352	222
	→	733	679	677	706	1176	1095	709
2	←	331	74	89	197	384	341	242
	↑	388	225	237	304	472	412	279
	→	767	689	699	737	868	790	558
3	←	325	242	246	282	432	348	317
	↑	552	458	466	503	709	577	539
	→	1480	1460	1460	1472	1613	1504	1464
4	←	755	417	608	681	1005	804	544
	↑	649	326	490	565	747	674	460
	→	1745	1170	1729	1732	1776	1747	1261
5	←	620	472	481	524	757	625	387
	↑	1123	905	913	952	1166	1031	655
	→	1593	1223	1225	1226	1267	1241	891

Ds Abraham Hellenbroekschool, classroom 1, 2nd of March, blinds 100%, AL 0%

Spot	Direction	Measured (lx)	Simulated (lx)	Windows 25% bigger - lower	Windows 25% bigger - wider	Windows 25% bigger - overall
1	←	51	62	88	89	69
	↑	61	60	86	75	71
	→	126	191	198	211	202
2	←	45	60	67	79	71
	↑	77	72	78	87	91
	→	126	141	151	175	157
3	←	53	55	67	73	71
	↑	89	94	106	121	109
	→	248	264	288	300	291
4	←	82	115	174	192	181
	↑	120	122	161	156	154
	→	377	353	427	521	486
5	←	89	136	152	189	133
	↑	424	236	245	267	245
	→	634	415	434	456	439

Spot	Direction	Simulated (lx)	Red interior walls	Blue interior walls	Yellow interior walls	Light wooden floor	White painted ceiling	Low E glass	Thin white sun shading
1	←	63	12	14	40	75	69	48	85
	↑	60	21	22	46	76	66	46	81
	→	191	130	130	191	221	208	147	261
2	←	62	15	18	39	73	68	48	81
	↑	72	43	45	58	90	80	52	96
	→	149	140	149	150	170	159	107	190
3	←	55	41	42	49	109	61	61	110
	↑	94	80	82	89	181	103	106	189
	→	264	272	269	273	426	275	290	522
4	←	115	93	93	107	158	129	121	227
	↑	122	94	96	110	140	130	124	198
	→	353	369	369	375	380	376	371	551
5	←	136	109	113	127	182	149	102	175
	↑	236	225	231	235	287	255	181	288
	→	415	414	425	429	424	417	301	436

Ds Abraham Hellenbroekschool, classroom 1, 3rd of May, blinds 0%, AL 0%

Spot	Direction	Measured (lx)	Simulated (lx)	Windows 25% bigger - lower	Windows 25% bigger - wider	Windows 25% bigger – overall
1	←	427	621	814	909	946
	↑	431	609	702	837	871
	→	1031	1819	2187	2349	2455
2	←	306	509	887	901	949
	↑	522	589	1000	1030	1110
	→	1112	1127	2044	2042	2097
3	←	445	400	623	734	772
	↑	900	983	1527	1761	1891
	→	2185	3299	5368	5553	5981
4	←	1556	1637	1648	2493	2696
	↑	1211	1809	2704	3028	3071
	→	2895	2872	3672	5322	5912
5	←	1433	2141	2618	2416	2389
	↑	5400	4423	5963	5170	5083
	→	4020	3182	4693	4853	4341

Spot	Direction	Simulated (lx)	Red interior walls	Blue interior walls	Yellow interior walls	Light wooden floor	White painted ceiling	Low E glass
1	←	621	176	211	447	850	784	546
	↑	609	284	306	453	797	718	493
	→	1819	1766	1795	1875	2182	2073	1442
2	←	509	111	135	299	833	775	503
	↑	589	349	349	408	1012	920	579
	→	1127	1015	1020	1074	1864	1772	1135
3	←	400	207	219	300	508	446	403
	↑	983	763	774	875	1228	1058	985
	→	3299	3202	3220	3252	3744	3363	3270
4	←	1637	1177	1196	1277	2748	2198	1490
	↑	1809	1283	1316	1455	2908	2503	1735
	→	2872	2693	2698	2717	4310	4111	2947
5	←	2141	1091	1097	1726	2418	1963	1234
	↑	4423	2444	2440	3761	4672	4013	2571
	→	3182	2007	2001	3016	3181	3057	2174

Ds Abraham Hellenbroekschool, classroom 1, 3rd of May, blinds 100%, AL 0%

Spot	Direction	Measured (lx)	Simulated (lx)	Windows 25% bigger - lower	Windows 25% bigger - wider	Windows 25% bigger – overall
1	←	194	344	392	374	400
	↑	186	322	374	371	392
	→	467	876	1001	943	1001
2	←	156	353	406	376	396
	↑	211	429	494	456	486
	→	475	798	893	821	858
3	←	179	320	363	340	361
	↑	330	809	920	875	963
	→	985	2585	2854	2419	2657
4	←	311	924	977	1055	1129
	↑	491	874	1210	1054	1059
	→	1677	919	1216	1371	1551
5	←	336	1404	1504	1485	1438
	↑	1846	2484	2847	2776	2785
	→	2179	1136	1542	1744	1642

Spot	Direction	Simulated (lx)	Red interior walls	Blue interior walls	Yellow interior walls	Light wooden floor	White painted ceiling	Low E glass	Thin white sun shading
1	←	344	112	181	260	370	339	230	310
	↑	322	104	168	257	379	340	225	304
	→	876	587	647	699	947	859	578	790
2	←	353	135	198	257	359	336	211	208
	↑	429	246	278	306	460	422	259	257
	→	798	577	601	624	776	731	464	454
3	←	320	101	148	199	364	325	186	281
	↑	809	536	589	664	936	808	496	732
	→	2585	2146	2194	2288	2534	2196	1430	2107
4	←	924	756	813	869	1163	921	864	1280
	↑	874	655	693	774	1069	870	840	1238
	→	919	647	733	798	1143	1049	1035	1553
5	←	1404	1121	1246	1287	1477	1181	789	1098
	↑	2484	2057	2142	2195	2672	2195	1506	2111
	→	1136	957	985	1001	1245	1146	791	1107

Ds Abraham Hellenbroekschool, classroom 2, 2nd of March, blinds 0%, AL 0%

Spot	Direction	Measured (lx)	Simulated (lx)	Windows 25% bigger - lower	Windows 25% bigger - wider	Windows 25% bigger -overall
1	←	141	116	134	148	151
	↑	117	95	110	120	121
	→	246	240	258	303	302
2	←	130	120	143	172	160
	↑	135	145	163	183	182
	→	366	389	403	465	463
3	←	110	119	135	145	147
	↑	132	138	156	174	173
	→	407	423	459	519	523
4	←	156	204	229	255	372
	↑	152	289	318	416	550
	→	903	1077	1097	1415	1876
5	←	276	345	396	419	410
	↑	300	303	343	401	382
	→	630	622	733	756	739

Spot	Direction	Simulated (lx)	Red interior walls	Blue interior walls	Yellow interior walls	Light wooden floor	White painted ceiling	Low E glass
1	←	116	28	33	71	128	119	84
	↑	95	34	38	63	103	101	66
	→	240	223	225	229	258	259	172
2	←	120	21	25	76	124	124	81
	↑	145	60	63	116	157	154	99
	→	389	258	257	385	405	404	267
3	←	119	70	73	92	128	125	80
	↑	138	90	93	113	150	148	93
	→	423	408	410	414	444	439	296
4	←	204	141	144	171	225	215	204
	↑	289	213	218	250	297	291	288
	→	1077	1058	1063	1057	1067	1067	1072
5	←	345	218	219	334	366	361	251
	↑	303	186	187	292	318	312	217
	→	622	426	427	621	634	631	462

Ds Abraham Hellenbroekschool, classroom 2, 2nd of March, blinds 100%, AL 0%

Spot	Direction	Measured (lx)	Simulated (lx)	Windows 25% bigger - lower	Windows 25% bigger – wider	Windows 25% bigger – overall
1	←	51	14	24	27	24
	↑	49	12	18	20	18
	→	28	29	48	54	48
2	←	18	19	33	38	35
	↑	19	24	40	44	40
	→	56	63	107	105	105
3	←	25	13	22	34	24
	↑	18	16	25	40	27
	→	48	50	84	124	85
4	←	25	23	39	45	39
	↑	25	40	61	63	63
	→	108	125	201	220	208
5	←	34	34	60	90	90
	↑	39	32	48	78	73,5
	→	71	71	120	174	172

Spot	Direction	Simulated (lx)	Red interior walls	Blue interior walls	Yellow interior walls	Light wooden floor	White painted ceiling	Low E glass	Thin white sun shading
1	←	14	3	4	9	16	16	14	30
	↑	12	4	5	8	13	13	12	61
	→	29	28	28	29	32	31	30	23
2	←	19	5	6	13	20	21	14	27
	↑	24	15	16	20	28	27	18	93
	→	63	65	63	64	68	66	49	35
3	←	13	8	9	11	15	22	14	28
	↑	16	11	11	14	18	27	17	105
	→	50	52	51	53	55	80	54	63
4	←	23	18	19	21	18	26	16	49
	↑	40	34	34	39	28	44	27	71
	→	125	129	131	132	91	133	90	269
5	←	34	32	34	35	57	38	37	79
	↑	32	29	30	32	52	34	33	65
	→	71	73	75	75	110	75	75	151

Ds Abraham Hellenbroekschool, classroom 2, 3rd of May, blinds 0%, AL 0%

Spot	Direction	Measured (lx)	Simulated (lx)	Windows 25% bigger - lower	Windows 25% bigger - wider	Windows 25% bigger -overall
1	←	133	217	276	278	396
	↑	135	176	223	218	324
	→	267	405	513	544	749
2	←	137	208	475	423	430
	↑	154	264	524	471	495
	→	361	543	1474	1016	1018
3	←	125	297	420	361	385
	↑	170	352	455	435	461
	→	493	963	1249	1268	1233
4	←	134	253	495	415	467
	↑	175	289	626	618	599
	→	716	1318	2180	2369	2490
5	←	230	397	780	771	790
	↑	327	449	623	834	930
	→	617	745	1392	1518	1455

Spot	Direction	Simulated (lx)	Red interior walls	Blue interior walls	Yellow interior walls	Light wooden floor	White painted ceiling	Low E glass
1	←	217	53	63	136	339	224	198
	↑	176	63	70	119	271	215	165
	→	405	374	381	400	644	432	381
2	←	208	101	117	155	392	308	199
	↑	264	177	198	233	458	299	234
	→	543	454	471	498	1100	567	541
3	←	297	131	203	260	360	267	284
	↑	352	165	245	300	398	289	338
	→	963	677	878	951	1068	734	942
4	←	253	197	204	231	437	302	234
	↑	289	206	213	252	476	314	255
	→	1318	1282	1276	1287	1898	1268	1126
5	←	397	384	387	391	991	652	384
	↑	449	398	423	432	761	514	421
	→	745	701	712	723	1364	965	733

Ds Abraham Hellenbroekschool, classroom 2, 3rd of May, blinds 100%, AL 0%

Spot	Direction	Measured (lx)	Simulated (lx)	Windows 25% bigger - lower	Windows 25% bigger – wider	Windows 25% bigger – overall
1	←	38	25	32	50	32
	↑	64	20	25	38	25
	→	42	48	62	98	60
2	←	25	23	32	49	31
	↑	29	29	38	54	37
	→	70	62	104	118	77
3	←	24	23	47	43	44
	↑	31	28	53	52	52
	→	71	83	149	161	149
4	←	32	28	52	48	51
	↑	36	36	76	75	69
	→	104	148	242	281	275
5	←	54	68	81	82	86
	↑	54	76	61	87	91
	→	100	138	156	188	174

Spot	Direction	Simulated (lx)	Red interior walls	Blue interior walls	Yellow interior walls	Light wooden floor	White painted ceiling	Low E glass	Thin white sun shading
1	←	25	13	14	19	38	26	27	166
	↑	20	12	13	14	31	22	21	132
	→	48	28	28	29	74	52	52	313
2	←	23	11	13	15	35	37	22	158
	↑	29	15	16	20	47	48	30	200
	→	62	35	41	48	95	97	62	422
3	←	23	8	9	11	25	25	25	108
	↑	28	11	11	14	30	31	30	128
	→	83	52	58	67	85	86	88	359
4	←	28	14	16	21	30	31	29	127
	↑	36	19	21	22	38	39	40	145
	→	148	109	111	124	149	149	157	676
5	←	68	36	38	54	68	72	48	220
	↑	76	29	30	49	77	80	52	220
	→	138	73	75	97	139	139	100	414

Ds Abraham Hellenbroekschool, classroom 3, 2nd of March, blinds 0%, AL 0%

Spot	Direction	Measured (lx)	Simulated (lx)	Windows 25% bigger - lower	Windows 25% bigger - wider	Windows 25% bigger – overall
1	←	1102	1300	1393	1575	1755
	↑	716	596	661	725	729
	→	1305	1418	1595	1752	1711
2	←	1506	1682	2928	3139	2837
	↑	1024	1379	2227	2395	2338
	→	1351	1223	2179	2399	2314
3	←	1362	1369	1488	1722	1667
	↑	832	824	910	1004	995
	→	1135	1433	1658	1819	1724
4	←	916	972	1110	1245	1195
	↑	635	1360	1614	1653	1638
	→	631	560	669	729	697
5	←	8050	1124	1436	1421	1363
	↑	2064	736	988	974	960
	→	392	1516	1846	1877	1841

Spot	Direction	Simulated (lx)	Red interior walls	Blue interior walls	Yellow interior walls	Light wooden floor	White painted ceiling	Low E glass
1	←	1300	439	497	852	1530	1313	935
	↑	596	172	197	367	684	609	423
	→	1418	1174	1201	1293	1577	1451	1020
2	←	1682	454	532	1060	2676	2514	1675
	↑	1379	658	706	1008	2393	2061	1365
	→	1223	1135	1127	1181	2088	1880	1227
3	←	1369	780	807	1063	1677	1415	930
	↑	824	399	422	590	973	832	535
	→	1433	1244	1270	1324	1637	1473	966
4	←	972	650	673	811	1195	1013	664
	↑	1360	404	463	865	1405	1363	889
	→	560	375	391	467	584	561	365
5	←	1124	775	802	941	1322	1154	801
	↑	736	473	495	611	882	794	534
	→	1516	1470	1468	1482	1536	1531	1112

Ds Abraham Hellenbroekschool, classroom 3, 2nd of March, blinds 100%, AL 0%

Spot	Direction	Measured (lx)	Simulated (lx)	Windows 25% bigger - lower	Windows 25% bigger – wider	Windows 25% bigger – overall
1	←	273	349	550	634	592
	↑	243	160	256	300	262
	→	422	388	606	720	637
2	←	863	694	1122	1279	1123
	↑	329	545	850	981	868
	→	1223	471	780	880	781
3	←	414	296	460	690	478
	↑	216	167	259	390	268
	→	307	310	495	670	508
4	←	332	207	321	327	328
	↑	197	274	445	442	439
	→	208	114	183	187	184
5	←	871	289	564	543	535
	↑	306	186	367	363	366

Spot	Direction	Simulated (lx)	Red interior walls	Blue interior walls	Yellow interior walls	Light wooden floor	White painted ceiling	Low E glass	Thin white sun shading
1	←	349	93	133	234	484	415	300	412
	↑	160	37	54	101	216	197	136	186
	→	388	262	338	361	510	458	331	450
2	←	694	147	173	350	868	820	529	792
	↑	545	206	218	315	745	648	458	643
	→	471	348	347	357	635	573	402	560
3	←	296	169	177	231	364	305	293	436
	↑	167	84	87	122	198	176	167	245
	→	310	269	274	286	341	317	307	453
4	←	207	138	144	172	383	316	203	307
	↑	274	84	96	178	443	419	274	415
	→	114	80	88	96	183	181	115	166
5	←	289	160	161	194	403	354	246	346
	↑	186	96	99	123	264	237	164	225
	→	412	319	321	323	486	478	349	487

Ds Abraham Hellenbroekschool, classroom 3, 3rd of May, blinds 0%, AL 0%

Spot	Direction	Measured (lx)	Simulated (lx)	Windows 25% bigger - lower	Windows 25% bigger - wider	Windows 25% bigger – overall
1	←	601	785	1030	1000	981
	↑	442	603	915	774	758
	→	936	1273	1837	1547	1561
2	←	2022	2904	3461	3786	3365
	↑	850	1595	1793	2013	2066
	→	3420	3292	3888	4100	4198
3	←	775	986	698	1219	1217
	↑	524	791	804	987	981
	→	882	1483	1823	1872	1824
4	←	702	947	1710	1795	1826
	↑	553	1595	3048	3028	3063
	→	583	859	1745	1748	1733
5	←	1971	2182	4134	4271	4041
	↑	976	1579	2978	3061	3041
	→	1683	2169	4847	3878	4024

Spot	Direction	Simulated (lx)	Red interior walls	Blue interior walls	Yellow interior walls	Light wooden floor	White painted ceiling	Low E glass
1	←	785	192	228	479	1366	1277	989
	↑	603	191	216	390	1051	966	743
	→	1273	1044	1040	1143	2113	1969	1476
2	←	2904	1369	1450	2130	5328	4496	2987
	↑	1595	999	1036	1302	3060	2568	1841
	→	3292	3186	3206	3250	6248	5198	3758
3	←	986	515	543	738	1780	1049	790
	↑	791	335	363	556	1382	846	623
	→	1483	1274	1284	1384	2540	1582	1091
4	←	947	611	628	772	1159	1034	832
	↑	1595	546	615	1068	1719	1651	1312
	→	859	627	632	746	972	886	701
5	←	2182	1899	1912	2049	2725	2286	1544
	↑	1579	1259	1274	1414	1979	1641	979
	→	2169	2123	2115	2128	2308	2156	1751

Ds Abraham Hellenbroekschool, classroom 3, 3rd of May, blinds 100%, AL 0%

Spot	Direction	Measured (lx)	Simulated (lx)	Windows 25% bigger - lower	Windows 25% bigger – wider	Windows 25% bigger – overall
1	←	175	128	222	158	230
	↑	157	101	176	125	184
	→	142	206	357	252	366
2	←	494	713	819	893	790
	↑	199	370	406	444	469
	→	685	754	885	918	920
3	←	183	234	274	288	280
	↑	140	188	223	229	229
	→	241	358	432	445	433
4	←	213	153	268	186	285
	↑	158	246	438	291	440
	→	177	139	260	161	254
5	←	496	513	607	616	587
	↑	267	369	425	440	430
	→	636	526	770	620	641

Spot	Direction	Simulated (lx)	Red interior walls	Blue interior walls	Yellow interior walls	Light wooden floor	White painted ceiling	Low E glass	Thin white sun shading
1	←	128	94	97	106	147	136	129	319
	↑	101	67	74	83	116	109	102	251
	→	206	109	112	156	234	222	204	515
2	←	713	456	487	523	872	725	476	1153
	↑	370	188	209	298	467	383	247	639
	→	754	460	489	566	936	786	503	1300
3	←	234	156	167	201	284	253	159	397
	↑	188	98	102	134	218	206	128	317
	→	358	245	278	314	412	388	246	606
4	←	153	93	104	126	278	166	152	575
	↑	246	178	199	211	403	256	249	957
	→	139	82	89	107	239	146	136	518
5	←	513	424	432	478	630	533	333	1322
	↑	369	296	303	322	453	388	239	938
	→	526	452	466	497	564	531	353	1297

Pniëlschool, classroom 1, 7th of March, blinds 0%, AL 0%

Spot	Direction	Measured (lx)	Simulated (lx)	Windows 25% bigger – lower
1	←	100	188	220
	↑	314	426	499
	→	126	150	176
2	←	663	894	1474
	↑	259	294	502
	→	196	111	193
3	←	1262	1741	1967
	↑	630	633	739
	→	169	175	207

Spot	Direction	Simulated (lx)	Red interior walls	Blue interior walls	Yellow interior walls	Light wooden floor	White painted ceiling	Low E glass
1	←	188	106	112	144	219	192	188
	↑	426	372	375	396	474	435	429
	→	150	56	61	100	174	155	151
2	←	894	850	850	873	1407	910	899
	↑	294	206	213	250	511	302	293
	→	111	37	41	73	213	114	110
3	←	1741	1717	1725	1727	1795	1758	1742
	↑	633	577	585	599	725	647	632
	→	175	81	87	126	243	183	173

Pniëlschool, classroom 1, 7th of March, blinds 100%, AL 0%

Spot	Direction	Measured (lx)	Simulated (lx)	Windows 25% bigger – lower
1	←	56	53	85
	↑	88	99	153
	→	72	32	52
2	←	126	138	340
	↑	89	34	87
	→	107	14	36
3	←	291	678	1066
	↑	122	103	165
	→	96	35	58

Spot	Direction	Simulated (lx)	Red interior walls	Blue interior walls	Yellow interior walls	Light wooden floor	White painted ceiling	Low E glass	Thin white sun shading
1	←	53	25	25	30	60	54	33	77
	↑	99	59	59	60	109	109	63	164
	→	32	7	8	14	36	33	21	40
2	←	138	137	136	138	230	221	142	241
	↑	34	22	23	27	65	54	35	51
	→	14	5	6	10	29	23	14	30
3	←	678	450	446	446	700	686	450	734
	↑	103	55	59	58	130	99	63	113
	→	35	13	13	17	53	39	21	47

Pniëlschool, classroom 1, 15th of May, blinds 0%, AL 0%

Spot	Direction	Measured (lx)	Simulated (lx)	Windows 25% bigger – lower
1	←	125	136	157
	↑	256	306	353
	→	57	106	125
2	←	503	920	942
	↑	166	311	448
	→	105	116	293
3	←	865	1241	1643
	↑	328	483	625
	→	115	129	256

Spot	Direction	Simulated (lx)	Red interior walls	Blue interior walls	Yellow interior walls	Light wooden floor	White painted ceiling	Low E glass
1	←	136	73	78	101	156	137	133
	↑	306	267	266	282	340	309	303
	→	106	38	43	71	123	107	105
2	←	920	603	616	627	704	655	633
	↑	311	151	153	181	253	217	211
	→	116	26	29	50	103	81	79
3	←	1241	1227	1226	1231	1279	1248	1231
	↑	483	437	441	457	543	493	477
	→	129	60	64	92	175	134	126

Pniëlschool, classroom 1, 15th of May, blinds 100%, AL 0%

Spot	Direction	Measured (lx)	Simulated (lx)	Windows 25% bigger – lower
1	←	71	32	37
	↑	77	59	71
	→	27	20	24
2	←	119	108	119
	↑	49	27	32
	→	52	12	16
3	←	216	223	248
	↑	85	33	35
	→	72	11	12

Spot	Direction	Simulated (lx)	Red interior walls	Blue interior walls	Yellow interior walls	Light wooden floor	White painted ceiling	Low E glass	Thin white sun shading
1	←	32	23	25	27	23	21	20	107
	↑	59	55	59	60	42	40	39	242
	→	20	11	14	14	14	13	12	84
2	←	108	76	89	96	95	91	87	516
	↑	27	22	23	25	25	22	22	166
	→	12	5	6	10	11	9	9	63
3	←	223	144	167	190	284	274	270	1001
	↑	33	16	18	24	52	44	41	357
	→	11	6	6	9	21	15	14	99

Pniëlschool, classroom 2, 7th of March, blinds 0%, AL 0%

Spot	Direction	Measured (lx)	Simulated (lx)	Windows 25% bigger – lower	Windows 25% bigger - wider	Windows 25% bigger – overall
1	←	631	901	1019	1131	916
	↑	482	399	466	499	415
	→	270	266	307	338	265
2	←	865	812	1413	1649	1736
	↑	495	248	419	452	508
	→	861	867	1494	1569	1651
3	←	488	411	471	512	538
	↑	619	910	1023	1125	1258
	→	246	265	302	333	395

Spot	Direction	Simulated (lx)	Red interior walls	Blue interior walls	Yellow interior walls	Light wooden floor	White painted ceiling	Low E glass
1	←	901	534	693	760	975	918	664
	↑	399	183	185	227	456	424	301
	→	266	45	59	113	298	283	196
2	←	812	693	696	759	905	815	818
	↑	248	151	158	197	342	265	248
	→	867	772	780	811	960	873	854
3	←	411	186	185	227	463	430	299
	↑	910	543	769	815	986	927	668
	→	265	52	52	109	304	275	196

Pniëlschool, classroom 2, 7th of March, blinds 100%, AL 0%

Spot	Direction	Measured (lx)	Simulated (lx)	Windows 25% bigger – lower	Windows 25% bigger - wider	Windows 25% bigger – overall
1	←	54	49	78	99	94
	↑	12	18	31	37	33
	→	13	12	19	21	22
2	←	70	56	91	98	96
	↑	27	11	18	18	19
	→	68	62	97	100	99
3	←	29	31	49	61	55
	↑	61	77	118	141	136
	→	52	17	27	37	30

Spot	Direction	Simulated (lx)	Red interior walls	Blue interior walls	Yellow interior walls	Light wooden floor	White painted ceiling	Low E glass	Thin white sun shading
1	←	49	49	49	48	52	51	47	106
	↑	18	15	15	17	21	19	19	46
	→	12	3	4	8	13	13	12	31
2	←	56	48	47	52	88	81	53	145
	↑	11	7	7	9	31	24	11	42
	→	62	47	46	61	103	96	60	137
3	←	31	16	15	18	33	32	20	48
	↑	77	56	56	49	78	77	50	107
	→	17	3	4	7	18	17	10	30

Pniëlschool, classroom 2, 15th of May, blinds 100%, AL 0%

Spot	Direction	Measured (lx)	Simulated (lx)	Windows 25% bigger – lower	Windows 25% bigger - wider	Windows 25% bigger – overall
1	←	198	274	314	343	412
	↑	102	123	140	156	183
	→	35	81	93	104	118
2	←	316	374	436	488	573
	↑	57	110	127	139	162
	→	154	411	473	520	602
3	←	49	181	203	226	183
	↑	172	396	411	423	419
	→	52	117	143	152	119

Spot	Direction	Simulated (lx)	Red interior walls	Blue interior walls	Yellow interior walls	Light wooden floor	White painted ceiling	Low E glass
1	←	274	234	240	256	300	280	277
	↑	123	82	82	99	141	124	121
	→	81	19	23	48	92	83	80
2	←	374	320	329	347	421	383	372
	↑	110	67	70	87	156	118	110
	→	411	370	372	392	457	418	410
3	←	181	84	85	101	144	129	126
	↑	396	235	238	258	301	285	278
	→	117	22	25	49	94	82	80

Pniëlschool, classroom 2, 15th of May, blinds 100%, AL 0%

Spot	Direction	Measured (lx)	Simulated (lx)	Windows 25% bigger – lower	Windows 25% bigger - wider	Windows 25% bigger – overall
1	←	54	42	46	48	58
	↑	12	17	25	19	22
	→	13	11	10	12	14
2	←	70	49	47	51	53
	↑	27	11	14	17	17
	→	68	84	96	99	113
3	←	29	20	24	22	27
	↑	61	39	45	59	70
	→	52	14	15	12	14

Spot	Direction	Simulated (lx)	Red interior walls	Blue interior walls	Yellow interior walls	Light wooden floor	White painted ceiling	Low E glass	Thin white sun shading
1	←	42	26	31	39	43	42	39	394
	↑	17	12	15	16	19	17	16	177
	→	11	5	7	8	11	10	10	116
2	←	49	39	43	45	48	38	41	479
	↑	11	7	7	9	19	13	10	189
	→	84	67	74	80	91	81	85	908
3	←	20	16	15	18	22	20	19	203
	↑	39	26	33	36	52	50	52	477
	→	14	3	6	11	12	12	11	138

Pniëlschool, classroom 3, 7th of March, blinds 0%, AL 0%

Spot	Direction	Measured (lx)	Simulated (lx)	Windows 25% bigger – lower	Windows 25% bigger - wider	Windows 25% bigger – overall
1	←	144	139	217	180	238
	↑	495	425	653	534	706
	→	181	170	267	218	287
	↓	72	93	143	119	155
2	←	156	236	275	294	238
	↑	408	484	573	607	485
	→	248	234	280	296	234
	↓	80	123	149	156	125
3	←	150	171	203	282	285
	↑	427	422	505	675	697
	→	205	137	163	223	228
	↓	77	92	111	146	151

Spot	Direction	Simulated (lx)	Red interior walls	Blue interior walls	Yellow interior walls	Light wooden floor	White painted ceiling	Low E glass
1	←	139	92	94	114	174	144	140
	↑	425	415	417	420	468	433	424
	→	170	141	142	155	210	179	171
	↓	93	28	32	60	122	97	93
2	←	236	185	190	207	284	239	190
	↑	484	468	481	474	538	493	403
	→	234	191	194	214	292	242	197
	↓	123	39	44	81	161	128	105
3	←	171	138	139	154	273	175	167
	↑	422	409	408	416	601	427	418
	→	137	84	88	109	221	139	134
	↓	92	27	31	58	156	96	92

Pniëlschool, classroom 3, 7th of March, blinds 100%, AL 0%

Spot	Direction	Measured (lx)	Simulated (lx)	Windows 25% bigger – lower	Windows 25% bigger - wider	Windows 25% bigger – overall
1	←	14	21	39	51	45
	↑	26	64	124	153	135
	→	21	25	46	61	52
	↓	9	11	22	28	25
2	←	16	32	61	45	40
	↑	43	67	127	96	84
	→	26	32	64	46	42
	↓	10	15	30	22	19
3	←	13	32	61	60	52
	↑	25	82	157	153	133
	→	20	25	49	49	42
	↓	9	14	28	28	24

Spot	Direction	Simulated (lx)	Red interior walls	Blue interior walls	Yellow interior walls	Light wooden floor	White painted ceiling	Low E glass	Thin white sun shading
1	←	21	21	21	23	24	22	18	35
	↑	64	3	4	7	68	66	58	103
	→	25	4	4	8	29	27	22	42
	↓	11	3	4	7	14	13	9	24
2	←	32	49	50	50	35	33	28	52
	↑	67	62	63	65	72	70	61	108
	→	32	14	14	17	36	35	29	51
	↓	15	21	21	23	19	17	12	30
3	←	32	21	21	23	35	33	27	53
	↑	82	20	20	22	88	86	74	126
	→	25	15	15	16	30	27	21	43
	↓	14	62	63	63	18	16	10	27

Pniëlschool, classroom 3, 15th of May, blinds 0%, AL 0%

Spot	Direction	Measured (lx)	Simulated (lx)	Windows 25% bigger – lower	Windows 25% bigger - wider	Windows 25% bigger – overall
1	←	229	166	189	205	210
	↑	713	503	585	631	649
	→	130	195	224	247	254
	↓	72	104	124	133	134
2	←	196	313	345	367	389
	↑	394	641	716	734	731
	→	154	302	344	360	381
	↓	63	160	191	203	211
3	←	153	295	331	368	393
	↑	308	736	778	831	843
	→	102	228	246	276	302
	↓	55	150	174	183	191

Spot	Direction	Simulated (lx)	Red interior walls	Blue interior walls	Yellow interior walls	Light wooden floor	White painted ceiling	Low E glass
1	←	166	115	123	147	250	180	177
	↑	503	502	507	515	553	526	519
	→	195	173	176	189	195	217	210
	↓	104	38	44	76	142	121	117
2	←	313	182	186	202	254	230	223
	↑	641	453	448	456	493	462	461
	→	302	182	183	201	255	229	223
	↓	160	42	47	80	145	126	123
3	←	295	175	177	193	245	219	212
	↑	736	492	497	510	549	523	520
	→	228	107	113	137	196	172	168
	↓	150	37	43	76	134	119	115

Pniëlschool, classroom 3, 15th of May, blinds 100%, AL 0%

Spot	Direction	Measured (lx)	Simulated (lx)	Windows 25% bigger – lower	Windows 25% bigger - wider	Windows 25% bigger – overall
1	←	9	27	35	40	39
	↑	14	86	88	95	107
	→	26	32	36	44	37
	↓	21	15	20	22	24
2	←	10	32	41	32	35
	↑	16	67	61	61	69
	→	43	33	47	33	36
	↓	26	15	19	18	20
3	←	9	31	37	40	45
	↑	13	83	89	94	107
	→	25	25	31	32	38
	↓	20	14	24	21	24

Spot	Direction	Simulated (lx)	Red interior walls	Blue interior walls	Yellow interior walls	Light wooden floor	White painted ceiling	Low E glass	Thin white sun shading
1	←	27	21	21	23	31	29	28	76
	↑	86	71	74	81	91	89	87	233
	→	32	24	25	30	37	35	33	97
	↓	15	9	11	14	18	17	16	50
2	←	32	24	25	29	37	35	33	99
	↑	67	62	63	65	71	69	67	199
	→	33	21	23	29	38	36	34	94
	↓	15	8	9	11	19	18	16	53
3	←	31	22	23	28	36	34	33	92
	↑	83	66	67	75	90	87	85	231
	→	25	15	15	16	30	27	26	75
	↓	14	7	8	10	18	16	16	51

C: Cumulative illuminance

Hellenbroekschool classroom 1

Least day 4/3

Time	Measured (lx)	Simulated (lx)
8:30	185	215
9:30	272	322
10:30	508	417
11:30	508	787
12:30	351	280
13:30	590	643
14:30	106	274
15:30	99	198

Best day 6/3

Time	Measured (lx)	Simulated (lx)
8:30	1623	1485
9:30	1486	1061
10:30	2011	1534
11:30	2560	2291
12:30	3596	2806
13:30	3824	3510
14:30	3510	2070
15:30	2729	903

Least day 7/5

Time	Measured (lx)	Simulated (lx)
8:30	351	806
9:30	436	2671
10:30	2013	2632
11:30	4459	3303
12:30	2010	1194
13:30	1148	2103
14:30	2011	1159
15:30	2003	1513

Best day 8/5

Time	Measured (lx)	Simulated (lx)
8:30	3422	3113
9:30	5240	4559
10:30	3981	4010
11:30	6349	6682
12:30	4132	4171
13:30	4005	4044
14:30	4039	3930
15:30	2233	2217

Hellenbroekschool classroom 2

Least day 4/3

Time	Measured (lx)	Simulated (lx)
8:30	200	735
9:30	670	1361
10:30	430	1096
11:30	510	1460
12:30	990	675
13:30	990	752
14:30	1220	560
15:30	1620	542

Best day 6/3

Time	Measured (lx)	Simulated (lx)
8:30	1060	2390
9:30	1700	1426
10:30	1620	1072
11:30	930	959
12:30	1510	1016
13:30	1270	1516
14:30	1900	1442
15:30	1410	724

Least day 7/5

Time	Measured (lx)	Simulated (lx)
8:30	360	1152
9:30	910	1854
10:30	1540	2641
11:30	2330	1447
12:30	2480	750
13:30	2640	912
14:30	430	860
15:30	430	750

Best day 8/5

Time	Measured (lx)	Simulated (lx)
8:30	1620	2238
9:30	2410	4102
10:30	2410	2225
11:30	3190	5067
12:30	2800	4864
13:30	6350	3166
14:30	3270	3185
15:30	6110	2929

Hellenbroekschool classroom 3

Least day 4/3

Time	Measured (lx)	Simulated (lx)
8:30	143	138
9:30	232	227
10:30	293	134
11:30	217	336
12:30	1257	161
13:30	303	184
14:30	256	790
15:30	246	248

Best day 6/3

Time	Measured (lx)	Simulated (lx)
8:30	1257	1012
9:30	3055	1718
10:30	1312	1085
11:30	1296	2377
12:30	2455	1873
13:30	3646	1373
14:30	3078	1364
15:30	319	453

Least day 7/5

Time	Measured (lx)	Simulated (lx)
8:30	1598	1368
9:30	4914	4107
10:30	1852	2580
11:30	3660	2276
12:30	2248	1754
13:30	1264	1548
14:30	1275	1458
15:30	1432	1273

Best day 8/5

Time	Measured (lx)	Simulated (lx)
8:30	1406	1701
9:30	1548	1645
10:30	1603	2204
11:30	3627	3574
12:30	3595	2375
13:30	5879	3686
14:30	1580	1641
15:30	1753	1555

Pniëlschool classroom 1

Least day 10/3

Time	Measured (lx)	Simulated (lx)
8:30	2250	487
9:30	2643	1340
10:30	1388	3962
11:30	3276	3612
12:30	3913	1920
13:30	2802	2600
14:30	3114	1520
15:30	2881	2017

Best day 11/3

Time	Measured (lx)	Simulated (lx)
8:30	2172	4463
9:30	6583	6700
10:30	3271	14605
11:30	3822	7055
12:30	13120	6467
13:30	15410	6151
14:30	12890	6277
15:30	9195	6024

Least day 16/5

Time	Measured (lx)	Simulated (lx)
8:30	335	545
9:30	267	701
10:30	656	1195
11:30	813	819
12:30	878	536
13:30	512	458
14:30	439	299
15:30	734	696

Best day 22/5

Time	Measured (lx)	Simulated (lx)
8:30	473	815
9:30	499	923
10:30	668	696
11:30	781	726
12:30	738	1014
13:30	693	903
14:30	651	766
15:30	693	605

Pniëlschool classroom 2

Least day 10/3

Time	Measured (lx)	Simulated (lx)
8:30	168	238
9:30	204	276
10:30	864	654
11:30	840	890
12:30	297	414
13:30	168	233
14:30	201	178
15:30	135	133

Best day 11/3

Time	Measured (lx)	Simulated (lx)
8:30	627	347
9:30	1383	796
10:30	555	623
11:30	531	718
12:30	2520	1935
13:30	4056	3280
14:30	4743	3817
15:30	1785	2364

Least day 16/5

Time	Measured (lx)	Simulated (lx)
8:30	218	233
9:30	332	289
10:30	596	611
11:30	614	605
12:30	684	578
13:30	974	877
14:30	624	546
15:30	268	234

Best day 22/5

Time	Measured (lx)	Simulated (lx)
8:30	120	134
9:30	420	376
10:30	624	546
11:30	920	873
12:30	1046	891
13:30	712	628
14:30	752	514
15:30	466	508

D: Melanopic illuminance

Tables

Hellenbroekschool classroom 1

March 2nd

		Spot 1		Spot 2		Spot 3		Spot 4		Spot 5	
		Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)
DAYLIGHT	Photopic illuminance	316	413	408	428	547	706	2821	1416	1936	1449
	Melanopic illuminance	250	397	323	442	433	708	2233	1374	1533	1447
DAYLIGHT + ELECTRICAL LIGHT	Photopic illuminance	355	974	352	1008	562	1238	2417	1906	2000	1958
	Melanopic illuminance	281	682	279	716	445	963	1914	1623	1584	1711

May 3rd

		Spot 1		Spot 2		Spot 3		Spot 4		Spot 5	
		Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)
DAYLIGHT + ELECTRICAL LIGHT	Photopic illuminance	1201	1268	5394	1362	597	2081	802	3531	1113	3483
	Melanopic illuminance	884	1169	4106	1281	377	1950	517	2957	749	3364

Hellenbroekschool classroom 2

March 2nd

		Spot 1		Spot 2		Spot 3		Spot 4		Spot 5	
		Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)
DAYLIGHT	Photopic illuminance	109	558	113	394	100	389	163	624	338	851
	Melanopic illuminance	86	353	90	395	79	386	129	637	267	872
DAYLIGHT + ELECTRICAL LIGHT	Photopic illuminance	210	147	293	859	207	823	255	995	453	1236
	Melanopic illuminance	166	140	232	834	164	615	202	974	359	1073

May 3rd

		Spot 1		Spot 2		Spot 3		Spot 4		Spot 5	
		Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)
DAYLIGHT + ELECTRICAL LIGHT	Photopic illuminance	192	414	250	561	251	509	248	613	370	826
	Melanopic illuminance	107	375	153	518	147	473	149	571	248	792

Hellenbroekschool classroom 3

March 2nd

		Spot 1		Spot 2		Spot 3		Spot 4		Spot 5	
		Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)
DAYLIGHT	Photopic illuminance	662	410	1201	767	725	487	600	683	1452	667
	Melanopic illuminance	524	382	951	727	574	457	475	651	1150	635
DAYLIGHT + ELECTRICAL LIGHT	Photopic illuminance	806	565	1325	1045	844	878	786	999	1516	1027
	Melanopic illuminance	638	458	1049	872	688	837	622	804	1200	822

May 3rd

		Spot 1		Spot 2		Spot 3		Spot 4		Spot 5	
		Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)
DAYLIGHT +	Photopic illuminance	613	1414	994	2718	686	2232	732	4147	1009	3432
ELECTRICAL LIGHT	Melanopic illuminance	293	1254	664	2492	652	2001	501	3721	744	3142

Pniëlschool classroom 1

March 7th

		Spot 1		Spot 2		Spot 3	
		Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)
DAYLIGHT	Photopic illuminance	449	145	384	134	518	333
	Melanopic illuminance	355	74	304	68	410	175
DAYLIGHT +	Photopic illuminance	599	631	464	456	864	1139
ELECTRICAL LIGHT	Melanopic illuminance	474	592	367	398	684	1010

May 15th

		Spot 1		Spot 2		Spot 3	
		Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)
DAYLIGHT +	Photopic illuminance	632	499	475	364	721	938
ELECTRICAL LIGHT	Melanopic illuminance	348	449	251	361	438	952

Pniëlschool classroom 2

March 7th

		Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)
DAYLIGHT	Photopic illuminance	383	113	325	333	318	113
	Melanopic illuminance	303	105	257	176	252	105
DAYLIGHT +	Photopic illuminance	717	404	475	591	458	845
ELECTRICAL LIGHT	Melanopic illuminance	567	360	376	432	363	847

May 15th

		Spot 1		Spot 2		Spot 3	
		Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)
DAYLIGHT + ELECTRICAL LIGHT	Photopic illuminance	449	235	380	446	556	432
	Melanopic illuminance	273	227	231	437	338	437

Pniëlschool classroom 3

March 7th

		Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)
DAYLIGHT	Photopic illuminance	257	535	264	482	267	525
	Melanopic illuminance	204	571	209	515	211	561
DAYLIGHT + ELECTRICAL LIGHT	Photopic illuminance	492	597	488	553	503	582
	Melanopic illuminance	390	601	386	549	398	590

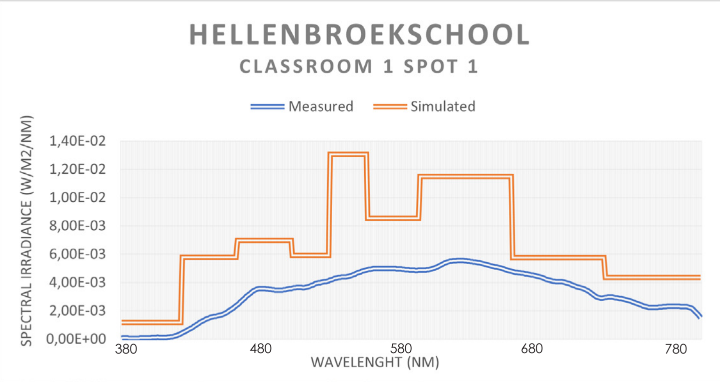
May 15th

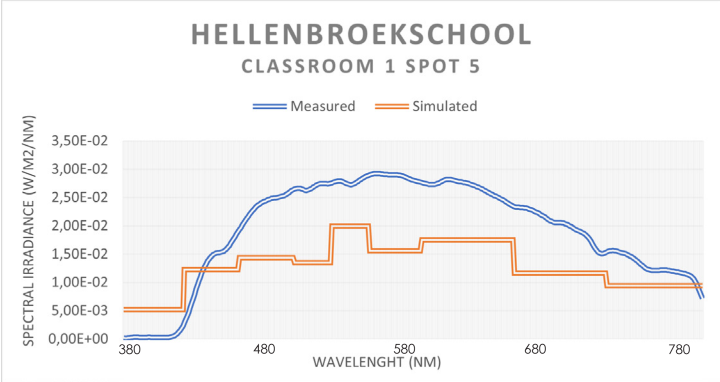
		Spot 1		Spot 2		Spot 3	
		Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)	Measured (lx)	Simulated (lx)
DAYLIGHT + ELECTRICAL LIGHT	Photopic illuminance	607	693	471	633	481	693
	Melanopic illuminance	369	731	286	670	293	736

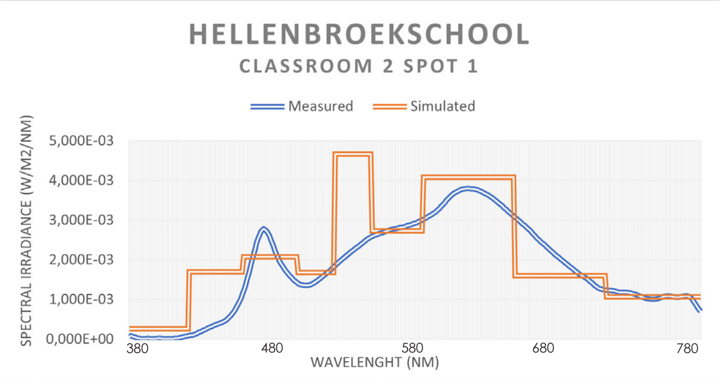
Graphs

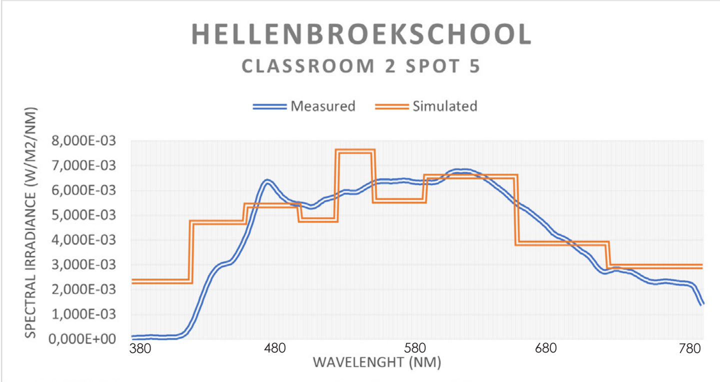
March 2nd

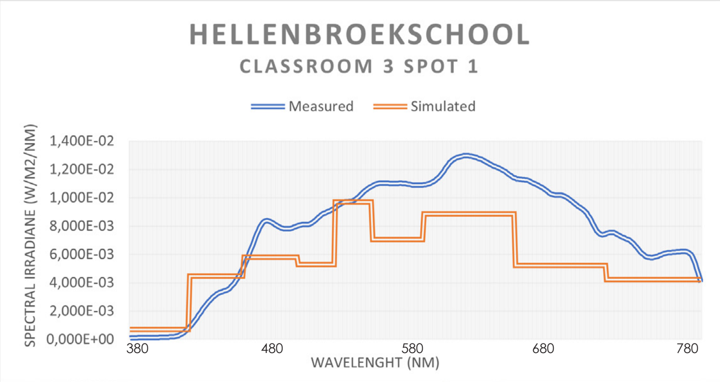
blinds 0%, AL 100%

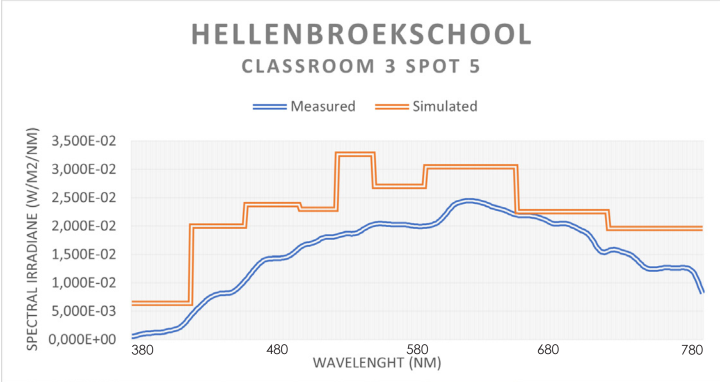






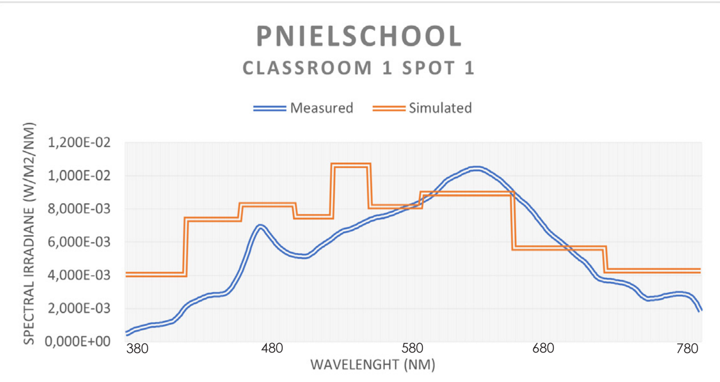


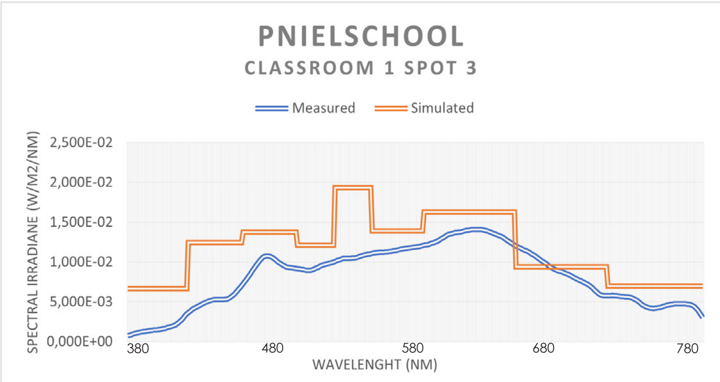


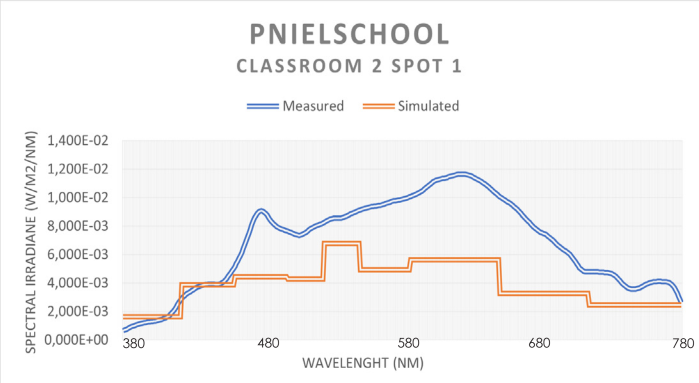


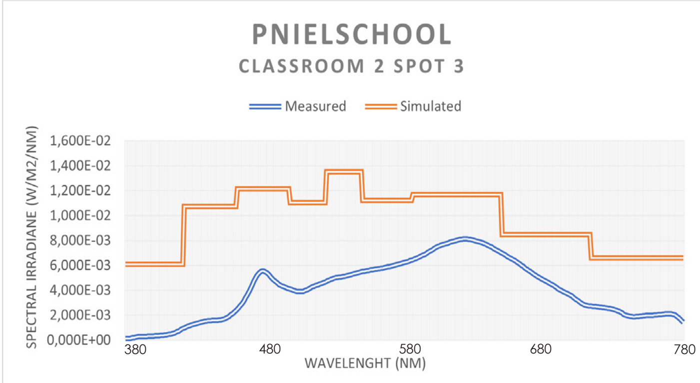
March 7th

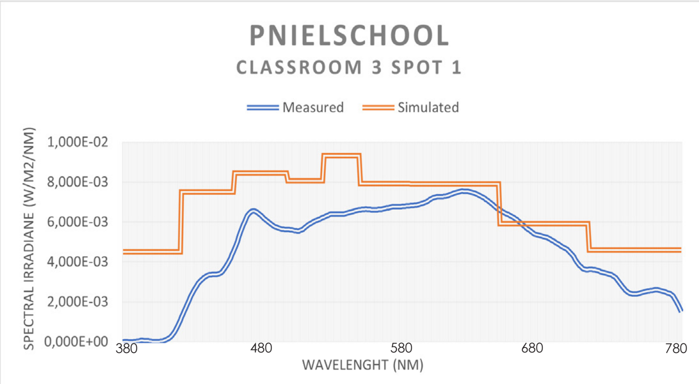
blinds 0%, AL 100%

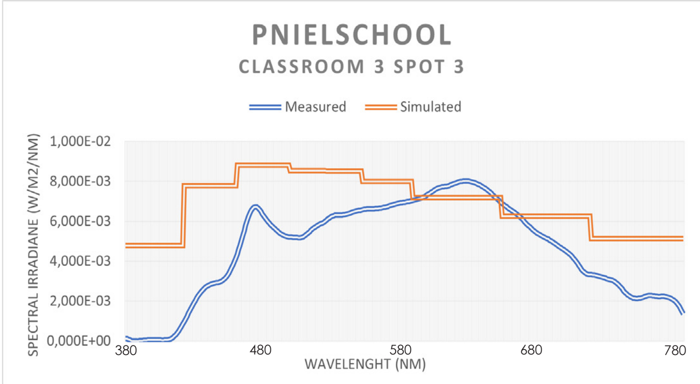






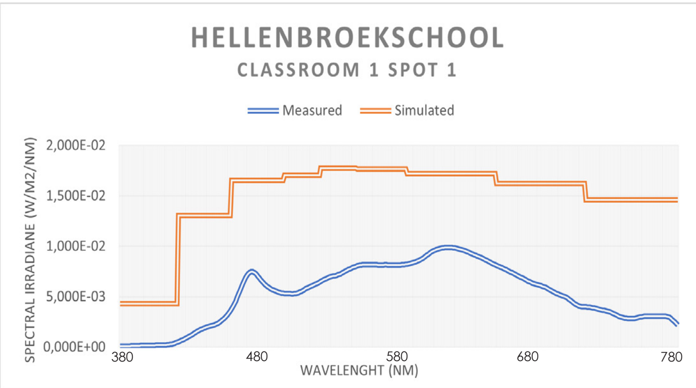


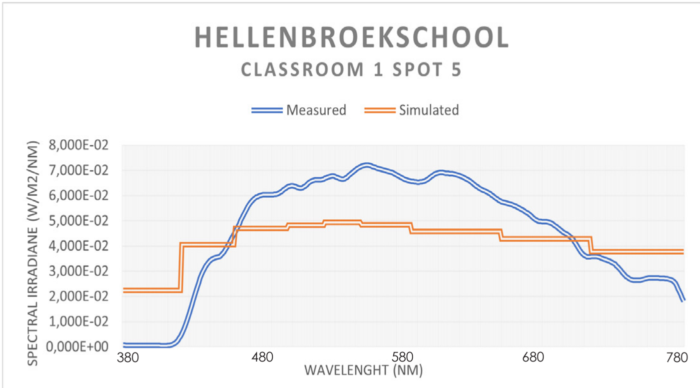


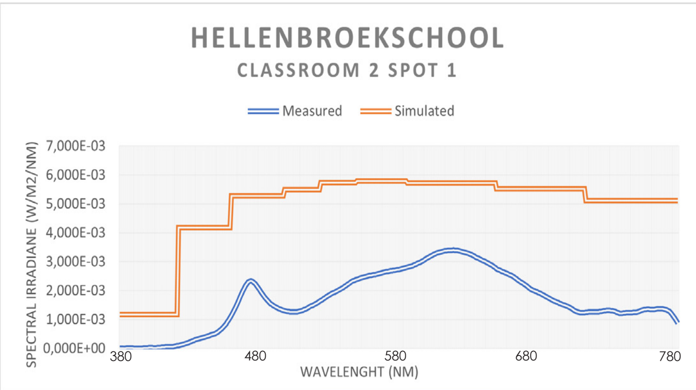


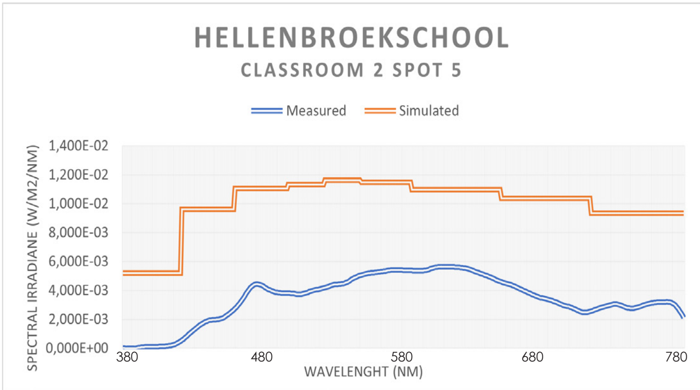
May 3rd

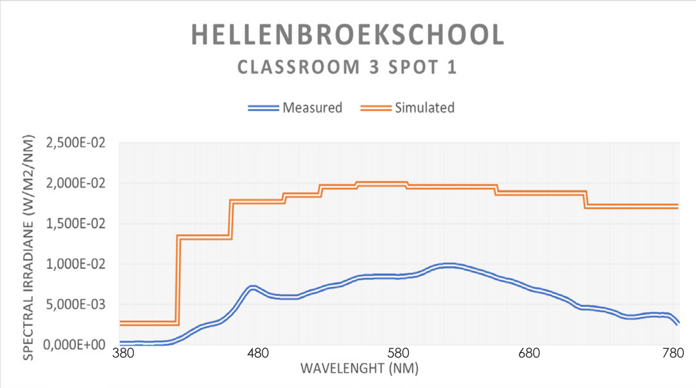
blinds 0%, AL 100%

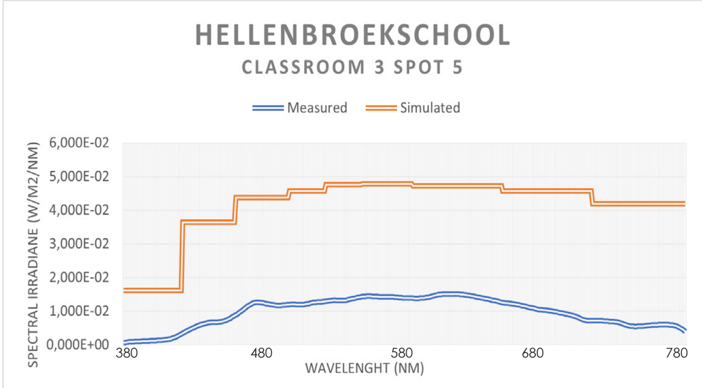






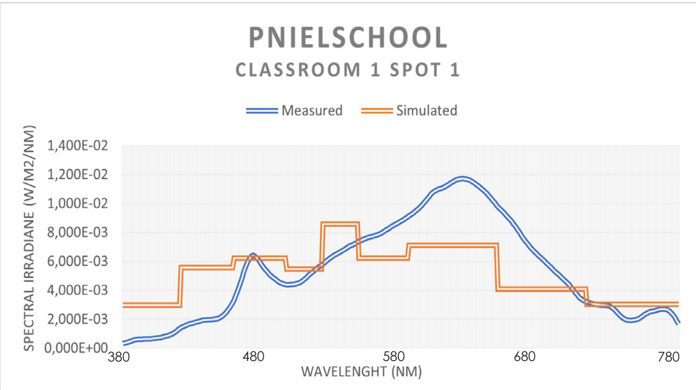


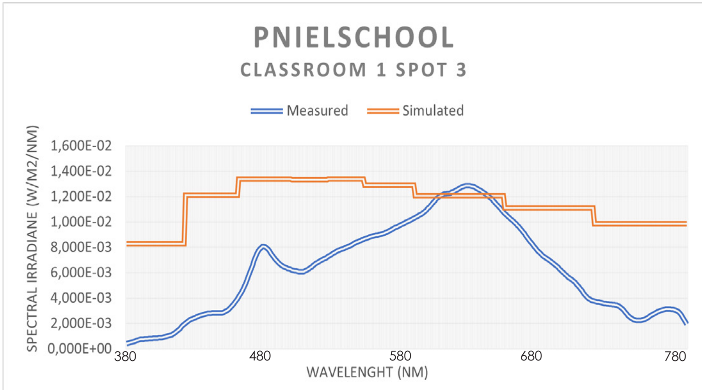


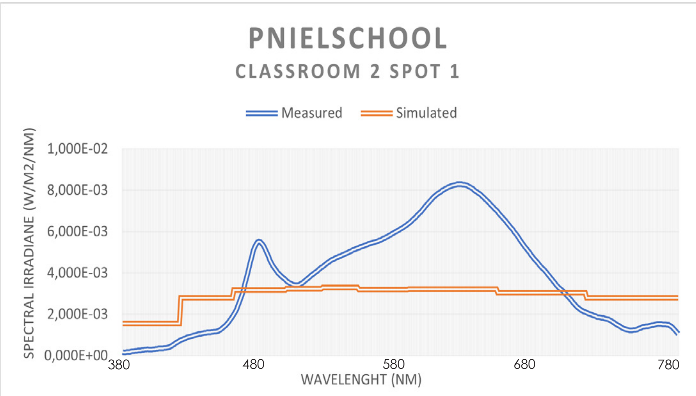


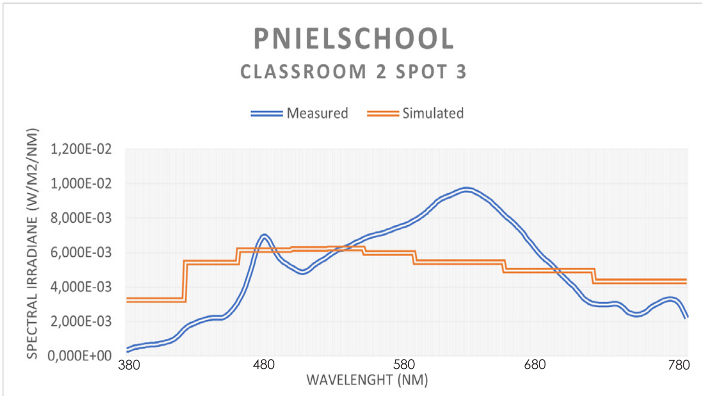
May 15th

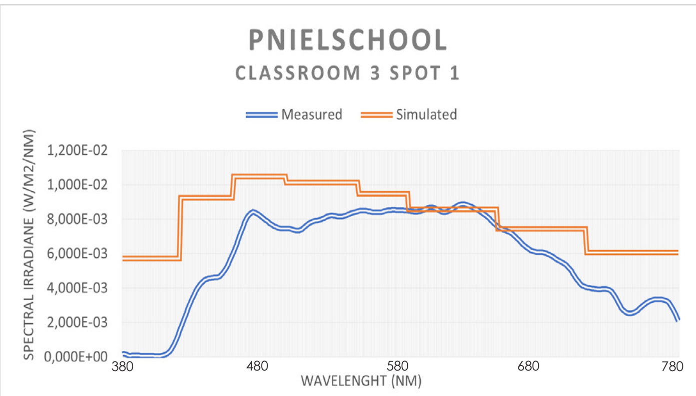
blinds 0%, AL 100%

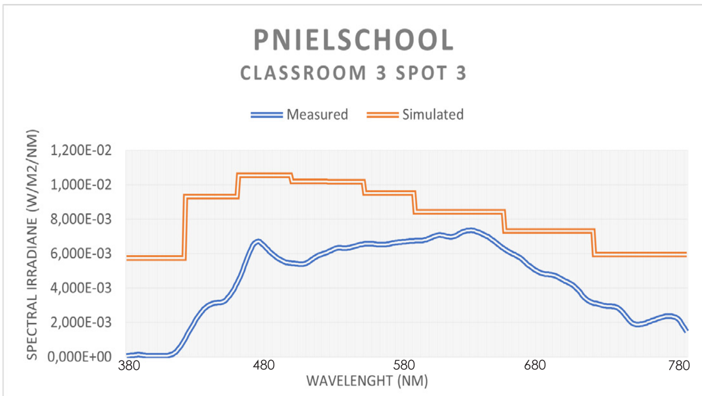






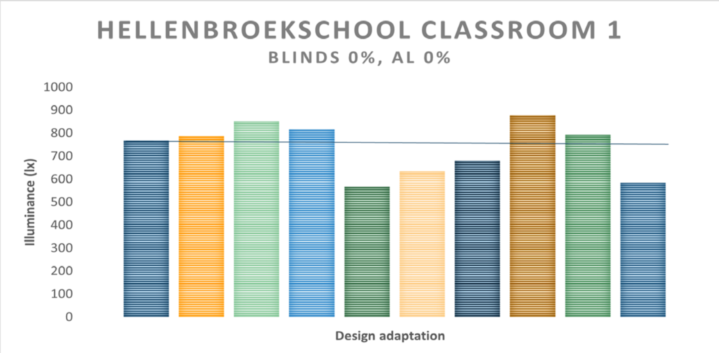


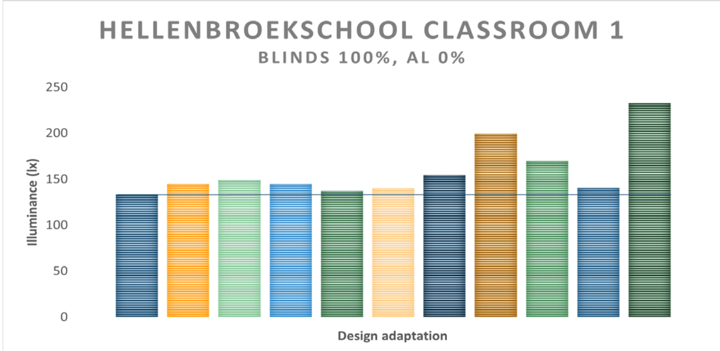


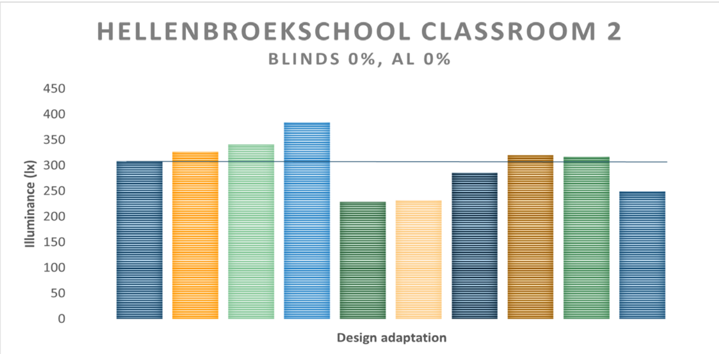


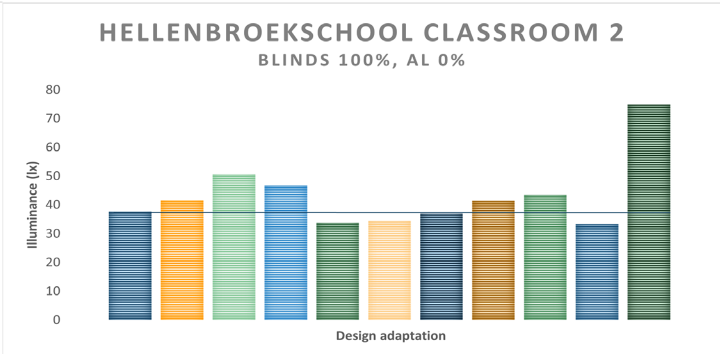
E: Design adaptations

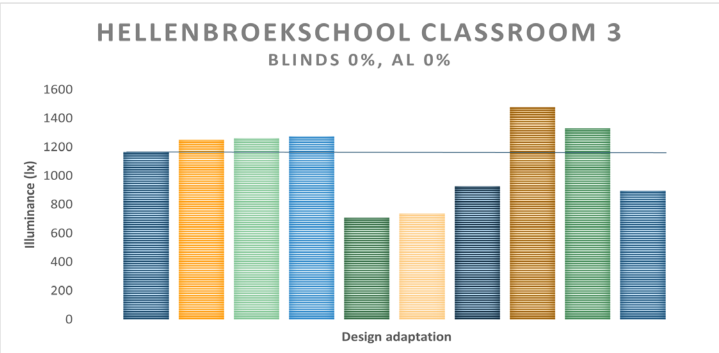
March 2nd

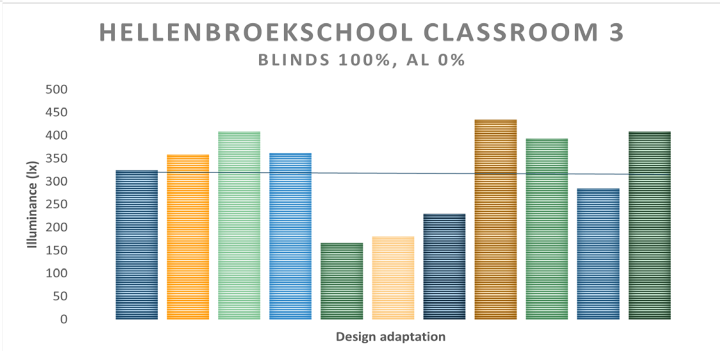






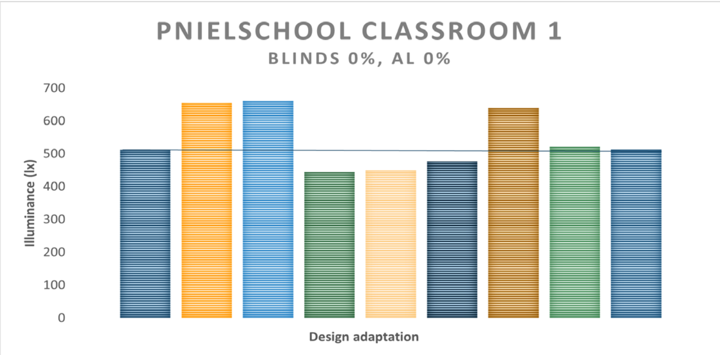


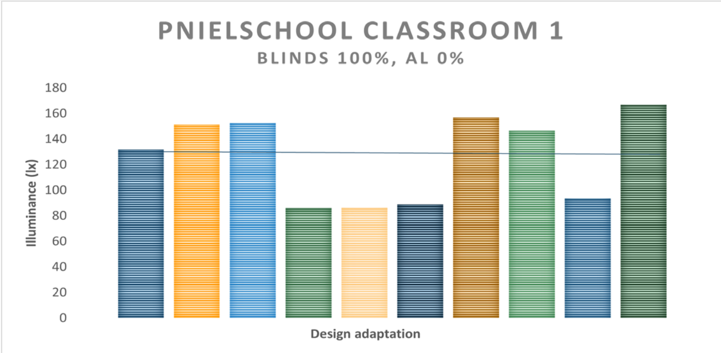


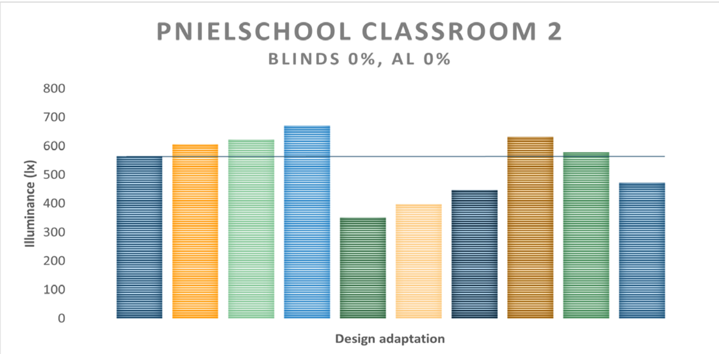


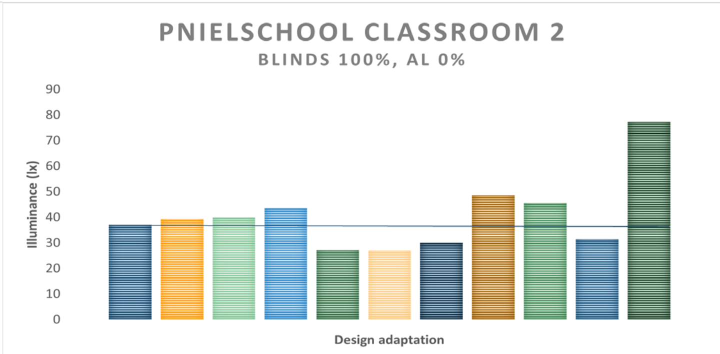
- Simulated
- Windows 25% bigger - lower
- Windows 25% bigger - wider
- Windows 25% bigger - overall
- Red interior walls
- Blue interior walls
- Yellow interior walls
- Light wooden floor
- White painted ceiling
- Low E glass
- White thin sun shading

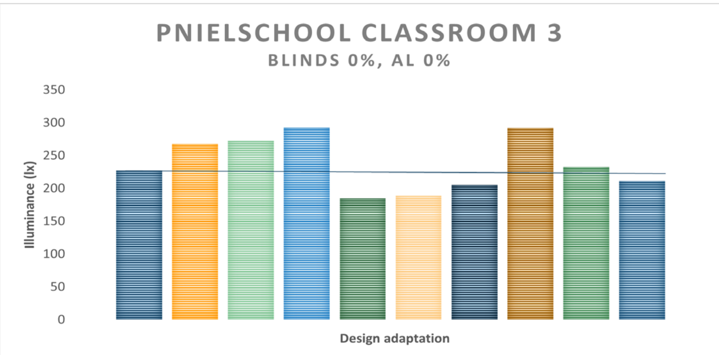
March 7th

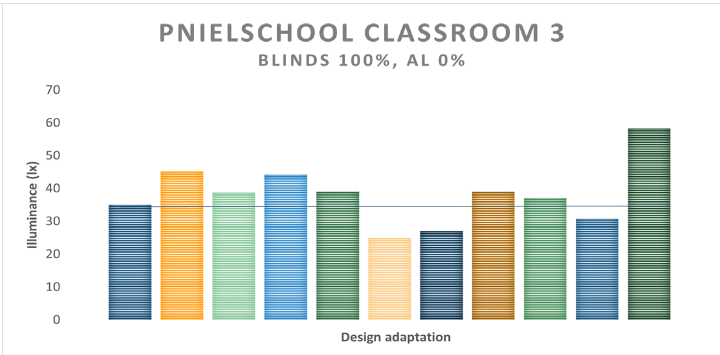






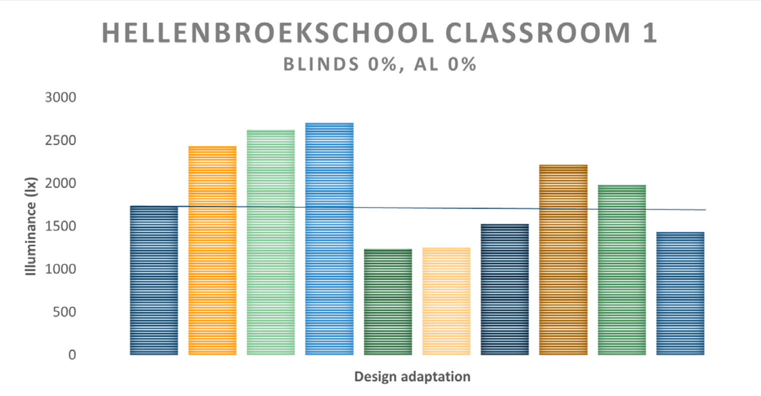


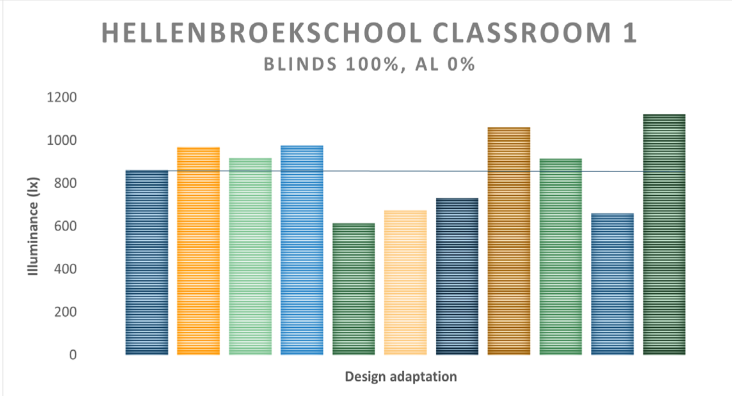


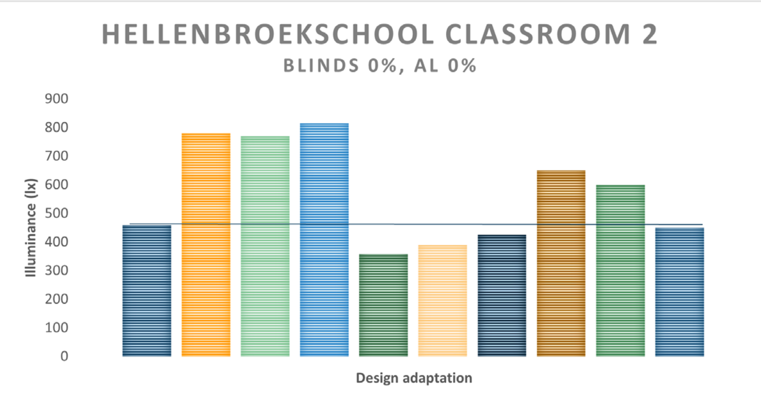


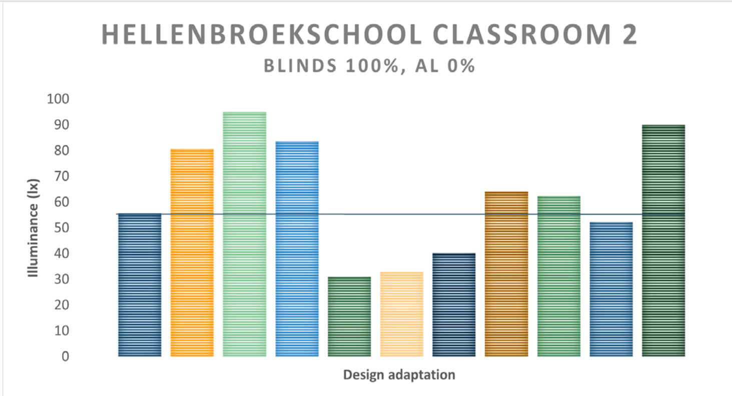
- Simulated
- Windows 25% bigger - lower
- Windows 25% bigger - wider
- Windows 25% bigger - overall
- Red interior walls
- Blue interior walls
- Yellow interior walls
- Light wooden floor
- White painted ceiling
- Low E glass
- White thin sun shading

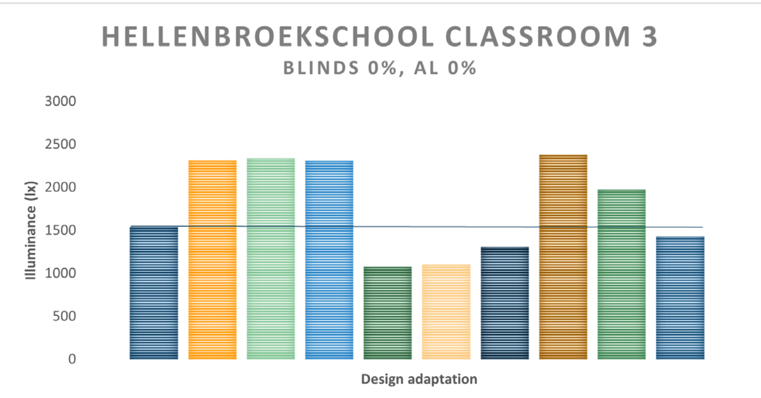
May 3rd

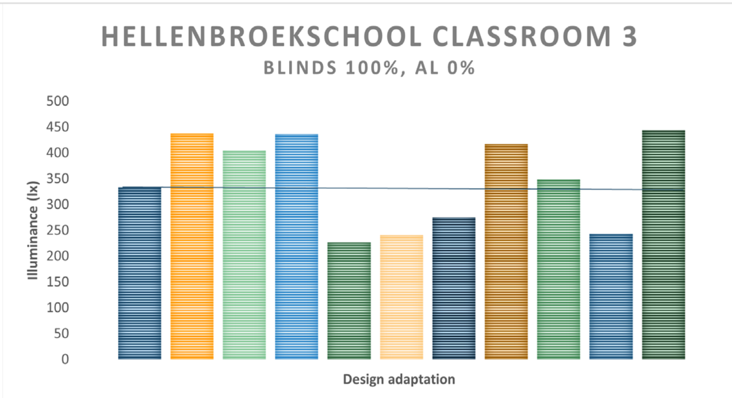






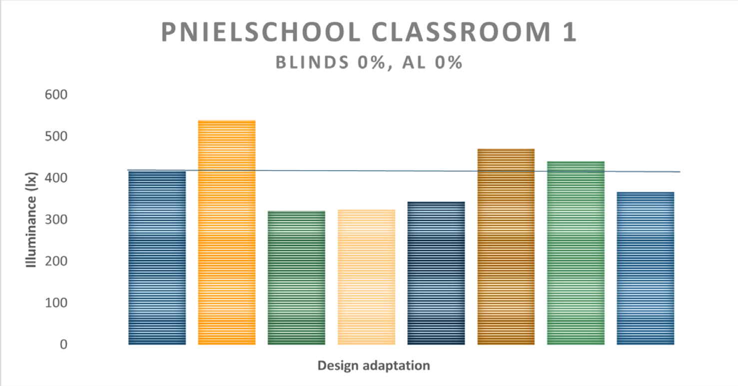


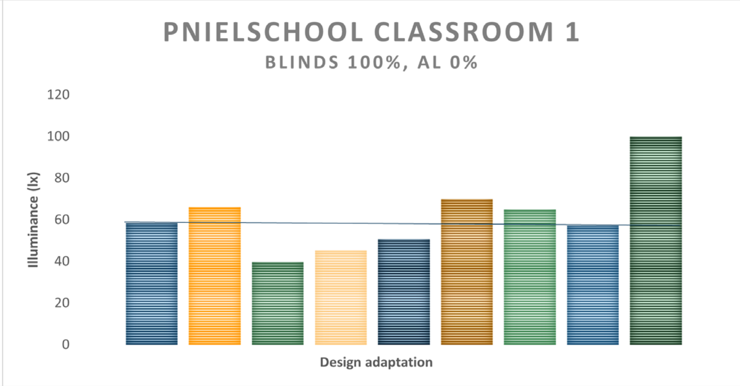


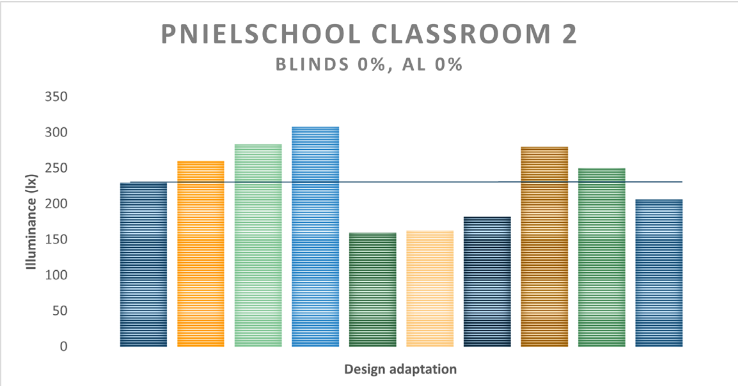


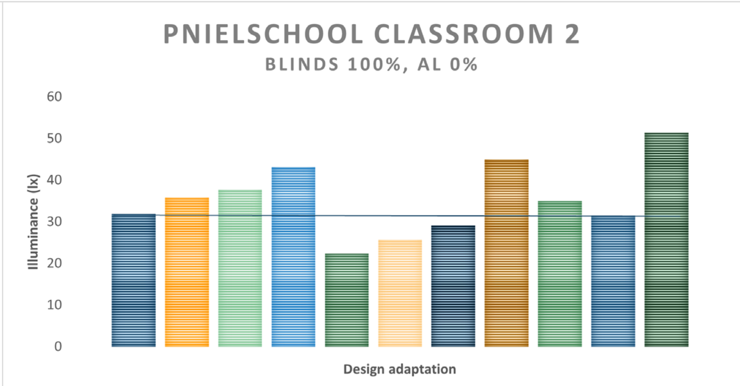
- Simulated
- Windows 25% bigger - lower
- Windows 25% bigger - wider
- Windows 25% bigger - overall
- Red interior walls
- Blue interior walls
- Yellow interior walls
- Light wooden floor
- White painted ceiling
- Low E glass
- White thin sun shading

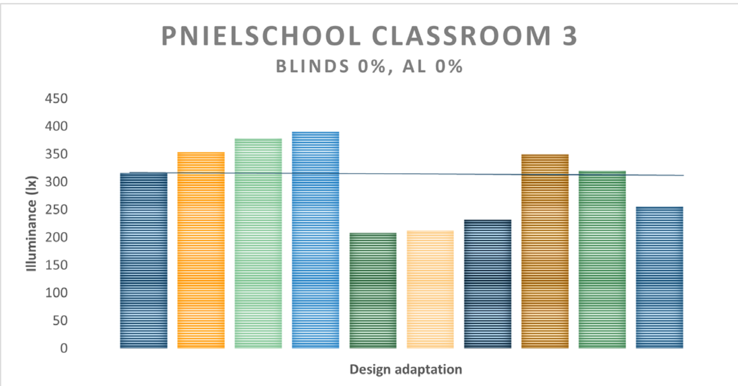
May 15th

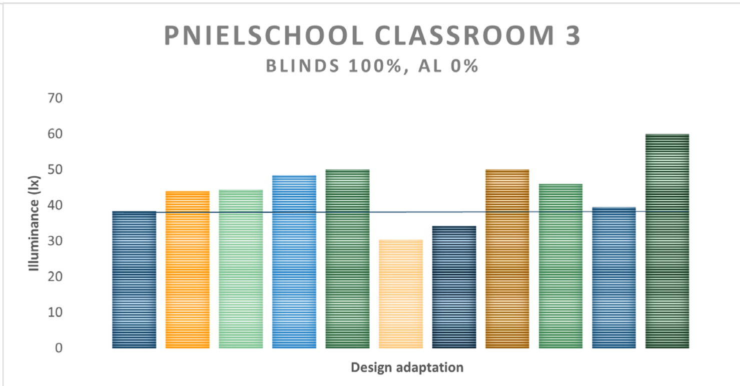












- Simulated
- Windows 25% bigger - lower
- Windows 25% bigger - wider
- Windows 25% bigger - overall
- Red interior walls
- Blue interior walls
- Yellow interior walls
- Light wooden floor
- White painted ceiling
- Low E glass
- White thin sun shading