OPTIMIZATION OF NATURAL LIGHT IN EDUCATIONAL BUILDINGS THROUGH A PARAMETRIC DESIGN APPROACH: CASE STUDY OF "SAMI FRASHERI" HIGH SCHOOL IN TIRANA, ALBANIA

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Approval sheet of the thesis

This is to certify that we have read this thesis entitled **"Optimization of natural light in educational buildings through a parametric design approach: the case study of "Sami Frasheri" high school in Tirana, Albania"** and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

OPTIMIZATION OF NATURAL LIGHT IN EDUCATIONAL BUILDINGS THROUGH A PARAMETRIC DESIGN APPROACH: CASE STUDY OF “SAMI FRASHERI” HIGH SCHOOL IN TIRANA, ALBANIA

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As light is one of the mediums to help architecture bring forth its full potential, it has a rather significant impact on how architecture is understood and adds value in creating the right atmosphere for its occupants. [1]. According to some studies, when the learning environment is human-centered and sensitive towards the surroundings, it brings forth better feedbacks and reactions. Moreover, the lack of guidelines that involve the daylight parameter during the design process in the Albanian design guidelines for the educational buildings is noticed. Many school buildings are built so that there is too much daylight (the glare effect) or less daylight in the classroom that brings negative feedback from the students’ academic results and causes to the state of mind. Therefore, this thesis aims to provide optimization of daylight in schools by making a study of Sami Frasheri school, conducted mainly through light simulations. It has selected as a case study due to the new version is being built with a parametric design approach, as well as being able to compare it with the old version. This study is a step further towards integrating daylighting design strategies as part of Albania's design process.

Keywords: daylight, light optimization, educational building, parametric design, urban scale, simulation software, light simulation, learning environment

ABSTRAKT

OPTIMIZIMI I DRITËS NATYRALE NË NDËRTESA TË ARSIMIT ME ANË TË NJË QASJE PARAMETRIKE: STUDIMI I SHKOLLËS SË MESME "SAMI FRASHERI" NË TIRANA, SHQIPËRI

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Meqënëse, drita është një metodë për të ndihmuar arkitekturën për të nxjerrë në pahë potencialin e saj, drita ka një ndikim të madh në mënyrën se si arkitektura është përcjellë dhe shton vlerën e krijimit të atmosferave për përdoruesit e saj. Sipas disa studimeve të kryera, kur mjedisi mësimor është i përqënduar në qenien njërezore dhe është i ndjeshme ndaj mjedisit përreth, sjell reagime dhe përgjigje positive nga përdoruesit. Për më tepër, është vënë re një mungesë e të dhënave lidhur me parametrat e dritës gjatë procesit të dizajnit në udhëzuesit e dizajn të Shqipërisë për shkollat. Shumica e shkollave janë të ndërtuara në mëyrë të tillë që të ketë nivele të larta drite (glare effect) ose të ketë ndricim të ulët në klasë, ku rezultatet akademike të studentëve jane negative. Për rrjedhojë, kjo teze do të sigurojë optimizimin e dritës nëpër shkolla, duke marrë nën studim rastin e shkollës Sami Frasheri nëpërmjet simulimeve të dritës të ndryshme. Shkolla u zgjodh si rast studimi për arsyjen se version i ri i saj do të ketë një qasje parametrike në fasadë, si dhe është e mundur krahasimi i saj me versionin e vjetër të shkollës. Kjo gjë sjell më afër intergrimin e udhëzuesve të dizajnit të dritës, si pjesë e procesit të dizajit në Shqipëri.

Fjalët kyçe: drita e diellit, optimizimi I drites, ndertesat educative, dizajn parametrik, shkalle urbane, program simulimi, simulime drite, mjedis mesimor

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Finally, I must express my very profound gratitude to my family, especially to my aunt, for providing me with unfailing support and continuous encouragement towards reaching the highest achievements throughout my years of study and through the process of researching and writing this thesis. This journey would not have been possible without neither of them. Thank you.

Kristel Dauti

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Natural Daylight impact

Nowadays, natural light has become an important factor taken into consideration during the design process. Its presents help in defining the mood of said space, as it emphasizes certain aspects of architecture. On each type of building, daylight has a different impact on the atmosphere created for the occupants of the building,

The impact of daylight in educational buildings is significant. It requires a thoughtful approach as a design factor since it should satisfy the occupants' needs and demands while developing a sustainable academic building. There can be used guidelines that help design spaces within the sustainable building that benefit from the day with high levels of available daylight/sunlight—keeping in mind the urban environment factors that may prevent the sunlight and available daylight on the windows and within the building itself.

It directly affects children's learning abilities, their comfort in an everyday environment, and well-being. According to different researches, it is shown that students perform better and more when exposed to natural daylight through multiple types of fenestrations. The students prefer more a high visual stimulus than a low one since the features attract them that the fenestrations bring into the mix, such as the natural daylight, the view out and content, visible activities, etc. [2]

The orientation, classroom proportions, and interior layout influence how much daylight the students come across. By designing it correctly, the sources of natural light (together with shading devices that prevent the glare effect and excessive solar heat gains), and the building characteristics, the daylight level can be maximized.

1.2 Motivation

However, Albania's learning environment has started to change its standards only this past eight years, with 17 schools being built and rebuilt. Daylight optimization and energy efficiency are extremely new topics in Albania, especially in educational buildings and learning environments. Few guidelines require studying daylight levels and its' influence on the student's health and performance in those conditions. According to *vendim_i_KM_671_29.07.2015_2* [3], based on the classroom typologies, the design of educational buildings (high school buildings in this case) should accommodate areas of 20 m2 - 30 m2 per student, as well as all of the essential facilities needed around the school area. The layout, orientation, and interior are the most vital factors in deciding the correct classroom typology that provides the most impact on improving/optimizing the daylight levels within the educational building

Different simulations, focused mostly on the daylight parameter, can identify the optimal natural light levels required to create a thriving learning environment. With a parametric design approach, we can improve the occupants' conditions and increase their comfort level.

For this thesis goal, the Sami Frasheri high school (Figure 1) has been taken into study due to its history of reconstruction, demolishment, and rebuilding that will fit different standards and typologies from those observed so far. The old Sami Frasheri included classrooms (rectangle typology and organically shaped typology) for 38-39 students, several laboratories, and facilities spread through the four floors of the building. The new building has taken a different approach. It will have a parametric-designed façade that includes vertical wooden panels as a shading device. It will focus on maximizing the space within the building to host twice the students and academic staff.

***Figure 1*: Sami frasheri school**

1.3 Aim and objectives

This thesis starts its research from a macro level- in this case, the City of Tirana- towards a micro one – Sami Frasheri school- that focuses on analyzing through simulations of the building's two versions (old and new). The analysis will be focused on the light parameter that, according to studies, it has a positive effect on the mental and physical health of the students. Both of the versions have a different approach in creating a comfort zone for the users, even though the old school places the light design second in its design process. On the other hand, the new version is following a parametric façade approach that keeps in mind the optimal light levels within a building. As such, this thesis focuses on answering and providing further for these questions:

1. How does daylight influence the students' behavior and comfort in a learning environment?
2. What is the daylight's impact during the design process in Albania?
3. What kind of daylight strategies and technics should use to achieve optimal daylight in an educational building in Albania?

1.4 Organization of the Thesis

This thesis is divided in 7 chapters. The organization is done as follows:

In Chapter 1, the overview, the problem statement, and the research questions are presented. Chapter 2, includes the literature review that is focused on the relationship of the learning environment with children under the influence of light. It, also brings to focus the different parameters and guideline used to create light design and merge it with the needs of the users. In this chapter, there are a series of case studies mention and analyses on how they dealt with the daylight needs of the user. Chapter 3, consists of the methodology followed in this study. It talks about the two case studies, both of Sami Frasheri high school, as well as the simulation program used for the analysis made. In Chapter 4, it talks about the data that is gathered on site and through the survey made to the students. It analyses the data that will be used as a reference for the simulation phase. In Chapter 5, it describes the simulation scenarios of the two buildings and the ones redesigned with the different shading devices. Chapter 6 focuses on the results of the simulation and analysis them accordingly. In Chapter 7, conclusions and recommendations for further research are stated.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This literature review will emphasize the relation between daylight and occupants' behavior and comfort through daylight optimization in learning environments, shown through case studies (mostly) near the Mediterranean. The impact of daylight can be seen in not just the general occupants' behavior but on a specific target group, such as students and the academic staff. Several studies have studied the connection between them by comparing the side effects that the optimal level of daylight leaves on people's health and psychology, especially on a child's behavior in school. The windows and fenestrations (such as skylight, atriums, massive windows, glass façade, etc.) are architectural elements that decide the level of sunlight entering the building. Different methodologies and strategies use simulation scenarios to optimize daylight levels through these architectural elements before the developed facilities' design process comes to its final product.

2.2 Children and daylight

Daylight is a crucial factor in the energy efficiency and sustainable design that buildings/architecture is trying to achieve and has managed to create specific standards and human health and behavior impacted by its surroundings. As such, the influence that leaves on a general healthy growth of a child is immense.

The environment aids in increasing or decreasing the daylight levels that a child can take, especially if they spend a tremendous amount of time in it. They spend most days in educational facilities after they reach a certain age of seven to eight.

Piaget states that the children have a more balanced view of their surroundings during that age and above, be it their classrooms, the playground, or any other space where they spend time in. [4] They can communicate their dissatisfaction with the general areas and rooms that lack in fulfilling their basic needs. As the teaching methodology has evolved on how they bring through the students' best performance, the school structure's design has changed along with it in order to fulfill the requirements needed. They have gone towards the child-oriented education method as supported by the different education pioneers. Froebel, a German educator who believed the best way to learn for a child, was through the medium of guided play in a friendly natural environment, created an entire program focused on each child's specific needs. [5]

As the 3rd teacher, the learning environment can positively stimulate their social and academic performance. As part of its natural conditions, daylight design is relevant because daylight can improve mood and increase concentration. Therefore, the classroom windows as an architectural element became vital in the educational facilities that produce the sunlight inside. In contrast, windowless classrooms negatively affected the students' overall psyche, decreased their confidence, and made them prone to absence. As a result, the logical approach would be to use a child-centered design for educational buildings to have all the requirements parameters needed to follow these theories.

In 2001, the Heschong Mahone Group remade a study about students' progress in a well-lit environment. According to the study [6], students increase their academic performance by 21% when exposed to the right amount of daylight (as shown in the results of one of the schools in *Table 1*). They analyzed three different schools in three other districts to see the change that the climate brings. Based on the information they had gathered previously; the classrooms had a nearly portable typology. They extracted 20-50 variables as well as information from the standardized tests and external/internal factors. These variables were part of the study to estimate the impact a well-lit room brings. The classrooms with large windows and/or with a skylight were the ones with the better results. In the long term, there was an average of 14% change for the better in the students' results located in the classroom with windows than those in a school with not enough daylight.

Table 1: Improvements in test score (fall to spring in Capistrano School District) of students in classrooms with better daylighting ***[6]***.

Daylighting Conditions in Classrooms	**Percent Average Improvement (Probability t Observed Association with Improved Test Scores is Due to Chance)**	
	Reading	Math
Classrooms with most overall daylighting (from skylight and windows) relative to classrooms with least overall daylighting	26% (0.1%)	20% (0.1%)
Classrooms with most window area compared to classrooms with least window area	2 3% (0.1%)	15% (0.1%)
Skylight A (diffused illumination with manual operation for controlling illumination level) relative to no skylight	19% (0.3%)	20% (0.1%)
Skylight B (direct illumination with no controls) relative to no skylight	– 21% (5.1%)	-
Operable windows, relative to classrooms without operable windows	8% (0.4%)	7% (0.1%)

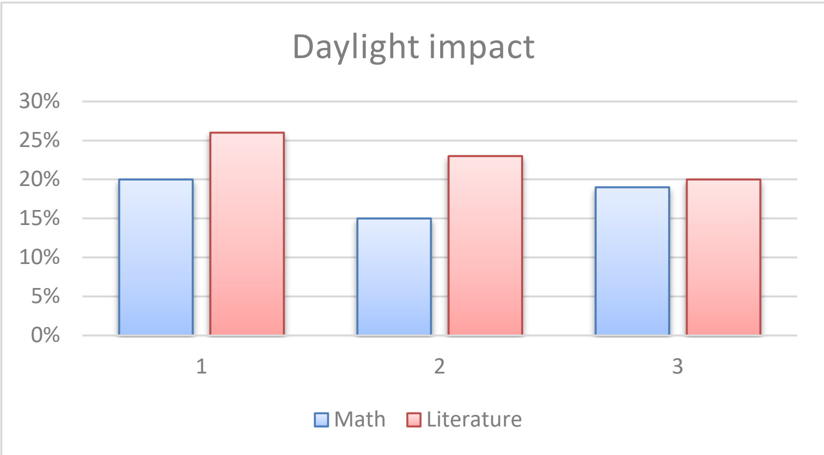


Figure 2: Heschong Mahone Group study graphic

Almost the same results were achieved by other studies that focused on human behavior towards daylighting. The UPMC / INSERM study (Epidemiology of Allergic and Respiratory Disease (EPAR) Department, IPLESP) involved 2,387 children across Europe, where the students' performance in classes varied the designed typology of the classroom [7]. The study used the window to floor ratio as a measurement mean. In the findings, the students respond better in open like area and were more relaxed to focus on their lessons. They are much more enthusiastic during the learning process when large windows facing south and robust shading devices are part of the initial school design. These components increase the positive performance of the students by 15%.

Abundant natural daylight affects the health and the psyche of the children. It stimulates them to participate more in the learning process and affecting their well-being for the better. In a well-lit environment, they are more relaxed and open towards the learning process.

2.3 Daylight design in educational schools

As mentioned, the children achieve better academic performance and a willingness to learn when windows and shading devices are present in the overall design. Moreover, the daylight design favors natural ventilation, that when fused with the electrical system, can create a sustainable facility. There are certain factors that dictate whether the building has enough daylight to sustain itself (with little help from the artificial light). Daylight factor is one of the popular methods used to understand the level of the natural light in a facility in relation to the building code and regulations. Although, it brings some limitations. [8] The DF does not take into account the location of the building, which have a prominent effect on the natural light design in the building. Also, it does not give proper reading on the glare effect that is caused. Therefore, based on the IES decisions, there are also two metrics taken into study, to fill the gabs that DF leaves behind. Those are the Spatial Daylight Anatomy (sDA) and the Annual Sunlight Exposure. These metrics will be explained further on in this paper.

As we mention these metrics, there are standards and regulation that need follow, depending on the building code of each country. In different countries, there are used alternate methods to optimize the levels of daylight and to maintain a certain designing balance within the buildings, especially in educational facilities.

2.4. European light standards in educational buildings

As shown by the case studies, different countries have different standards for the building's design process related to daylight and artificial light. This is due to the natural conditions, the number of days with sunlight, wind direction, the shadows created by the high-rise buildings around, natural landmarks, climate, etc. Different academic rooms have different daylight standards. Essential components are the different types of windows and materials. They are merely a mean to provide light within the building for it to function as well as to bring ventilation in.

Based on space's function within the educational buildings, the room's illumination changes from one to the other. They require different light levels that increase the comfort and visual levels of the occupants. Referring to European Lighting Standard EN12464-1, the standard requirements are considered when designing the school's electrical plan, kindergarten, high school, university, etc., after defining the natural light levels. The illuminance is measured in lux (lx), and the values recommended for the educational buildings according to the European Lighting Standard EN12464-1 are listed as below.

Table 2: European Lighting Standard EN12464-1

Type of room	Maintained illuminance $\bar{E}m$ (lx)	Uniformity U_0
Classrooms	300	0.6
Lecture halls and workshop rooms	500	0.6
Sport hall	300	0.6
Technical drawing rooms	750	0.7
Computer rooms	300	0.6
Library - bookshelves	200	0.6
Library - reading areas	500	0.6

2.5. Albanian daylight design in educational buildings

Due to its climate, Albania has almost 300 days with sun, making it ideal for a better learning environment for the students and academic staff. It requires elements that help adjust the levels and angle from which the light reflects within the building. The type of windows and materials used, shading devices, and the building's orientation are part of the educational buildings' design process.

The glass windows get heated when they stay for long periods under the sunlight, and that gathered heat is kept inside the building, rising the temperature. That is optimal during the winter months, where the buildings self-heated, and it does not need an additional heating system. However, during the summer ones, it turns the facilities into a greenhouse. The method prevents the sun from hitting the sun directly through the proper orientation and the reflective subfactors.

The best orientation for more natural light in Albania is when the building is oriented north-south. [9] The light coming from the north does not reflect directly on the windows (creating the glare effect), while from the south, it reflects the minimal amount of sun rays. However, the sunrays' angle is quite unpredictable, and there are used curtains or a shelter above the window to create shade as shown below in *Figure 3*.

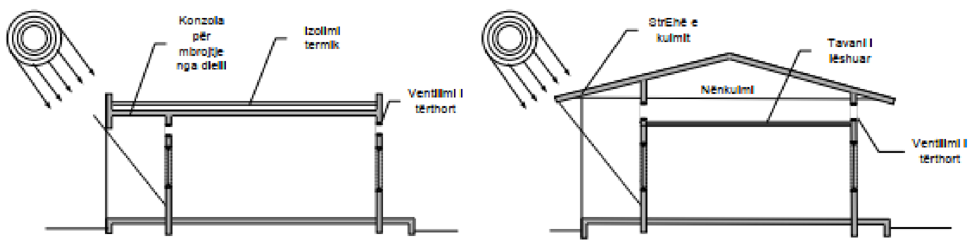


Figure 3: Thermal comfort- sunlight protection in Albanian cases studies ***[9]***

The glare effect can cause massive headaches and make the students' performance ineffective. The amount of sunlight on an unshaded working space is 1000 lux in Albania (due to climate conditions), while the standard comfort should be 300 to 400 lux. The circulation areas (hallways etc.) should have optimal levels of daylight to avoid accidents. According to Albanian standards, the window to floor area ratio should be 15 to 20%, and the classroom's length should not be above 7 m. [9] The usage of vegetation is essential as it can reduce the light intensity, depending on the dimensions and shapes, vegetation, and the distance from the surrounding buildings.

An important role has even the artificial light that can increase the working and learning hours after dark or when the weather is not sunny. Although Albania does not have specific standards towards artificial light, it proposes the following values shown on Table 3.

Table 3: Recommended lux values in Albanian schools

The educational spaces in Albania	Threshold	Work plane
Archives and depos	200	none
Classrooms	300 - 500	375
Labs and Library	500 - 600	450
Administration offices	400 -500	375
Stairways and hallways	200	none
Waiting rooms and hallways	250	none
Multifunctional rooms	350	none
Light on the black board (75 cm above the work plane)	none	400

Nowadays, some of these design methods are not able to fulfill the requirements that are requested by the masses. It is a domino effect that effects every aspect of the design of the building and comfort of the users. The urban pattern of the cities in Albania, especially in Tirana as an overgrowing city, has changed and influences it even more.

This past decade, there has been a program towards the rebuilding of educational buildings. These buildings needed maintenance, repairs, to the point of being designed for the users and not for the sake of building a school. In this program, almost 17 schools have been rebuilt so far. It is noticed the difference between the old version and the new one due to the attention put on certain aspects and elements that influences for the better in a space. Bigger windows and glass facades are used instead of the smaller ones to bring light in, the size and the number of floors has increased etc.

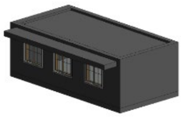
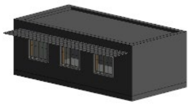
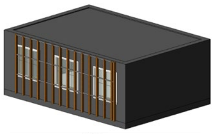
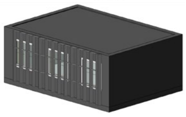
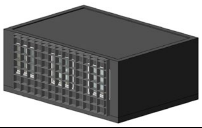
2.6. Daylight optimization methods

The International Energy Agency (IEA) issued a report stating that almost 14% of the EU's electricity consumption is due to artificial lighting, making natural lighting a critical factor in energy reduction and sustainability. As such, many studies have involved daylight optimization within the design process. In them is noticed that this sensitivity towards daylight optimization comes from making the design about the occupant, instead of just designing a utopic space. It focuses on the thermal and visual comfort of the user of the area. A series of criteria are used to evaluate the optimal daylight levels through qualitative research and quantitative research. With the new technological advances, simulation software has been part of the best medium to gather the necessary data needed for the analysis/optimization. These programs are parametric based, where they try and replicate the natural conditions as much as possible. Similar parties have come to the same conclusion, depending on their location study and typologies under investigation.

Many pieces of evidence state that the multiple windows, large and clear tinted ones, bring a higher rate of learning by 15-23% up. In contrast, windows with lower qualities and materials have shown the opposite effect [10]. Materials (paint, glass type etc.) used to create the interior of the classroom have a role as to increasing the light inside. The darker the colors and the reflectance of the surfaces of tables, chairs, board etc. reflect less light then if the colors were lighter and the reflectance rate higher. This is due to the fact that brighter surfaces create more indirect light that does not harm the health of the students. Another aspect of the lighting is the location of the windows depending the orientation of them. As different orientations have different levels of daylight. [11] Mostly, it is recommended to orient the classrooms towards north, where it has the best light. It is softer and it helps to illuminate the space better and slowly increasing the light during different time periods. Whereas the other orientations (south, east and west) provide direct sunlight, that it can concentrate into a specific spot. This may lead toward a high glare effect, that impacts negatively on the comfort and health of the students.

The diverse shading devices are recommended to be implemented as to control the glare effect and the overheating problems that may happened in direct exposure. [12] They are part of the passive design strategies that intends on reducing the energy cost of the building. Depending on the orientation and the depth of the shading device, we can control the ratio of daylight and shadows. Each shading devices have a different impact in daylight levels within a space depending on which orientation is best, as recommended in *Table 4* that shows each shading devices is best suited for a certain orientation.

Table 4: Shading devices and their best orientations

Shading device	***3D***	***Orientation***
Overhang		south, west, east
Horizontal Louvers		south, west, east
Multi blade		south, west, east
Vertical fins		south, west, east
Slated vertical fins		west, east, north
Eggcrate		west, east
		west, east

These characteristics are important as they influence the levels of the daylight metrics used for calculating it. This information provides the insight on the classification of the shading devices as fixed elements and adjustable ones. [12] Fixed shading devices are mostly horizontal, vertical of egg crate such as overhangs, fins, louvers and light shelves. On the other hand, the fixed shading devices differ from the adjustable ones for being external ones. As part of the façade of the building, they have to provide shade and better thermal, visual comfort as well as becoming integrated on the design façade aesthetic.

The adjustable shading devices are both external and internal, depending on the time period. Part of the group of pergolas, blinds, tents etc. (the external adjustable) are also the vegetation. That is important in creating green ad sustainable buildings, especially educational buildings. They can act as a buffer zone between the building and the outer elements by creating natural shade that has a temperature 5 degree Celsius lower than the temperature of the surrounding environment. Its crown filters the sunlight and reduces the radiation from it.

2.7. International Case Studies

2.7.1 The Hessenwald School

The Hessenwald School is located in Gräfenhausen, Weiterstadt (Darmstadt), Germay. It is placed on the glade, fully intergrated with its surroundings. The 3 main pavillion within the design are cluster-like ones that aid in making the building as part of the environment. The design intents on creating common areas in the central part of the building while maintaining a sense of individuality and identity as well as fullfilling the needs of each educational grade seperatedly. The overall open design applied reflects the open teaching-learning approach that the school implements in its program.

Figure 4: The main entrance of the Hessenwald School (external shading devices present)

Due to its location in south-west region of Germany, there are 159 days of sunlight with 5 hours per day. This fact is used by the three-storey atrium designed in the center of the model and school. [13]It provides plenty of light and ventilation from outside thorugh six Velux Modular 'Longlights' (resining on top of the atrium as shown in Figure 5) and the large horizontal windows with low sills. The Longlights diffuse the light entering the buiding and with the help of the perforated sunscreen panels implanted on the fasade, they create a balanced atmosphere like under the trees. In different time of the year, the large glazed areas help in alternating the light levels depending on the needs that are required on that time.

Figure 5: Velux Modular "Longlights" resining on top of the atrium, used for ventilation and daylight

During the winter, the light coming from teh roof warms the air within the atrium and pavilions, keeping the building warm and lowering the cost energy. Moreover, during the warm months, the ventilation inside the school is maximised through the venting modules that the Longlights has. Doing so, it lowers the temperature and keeps the building fresh. [14] This aids in facilitating the open approach learning that the school uses. These features make the building energy efficent, according to the guidelines of the district of Damburg-Dieburg.

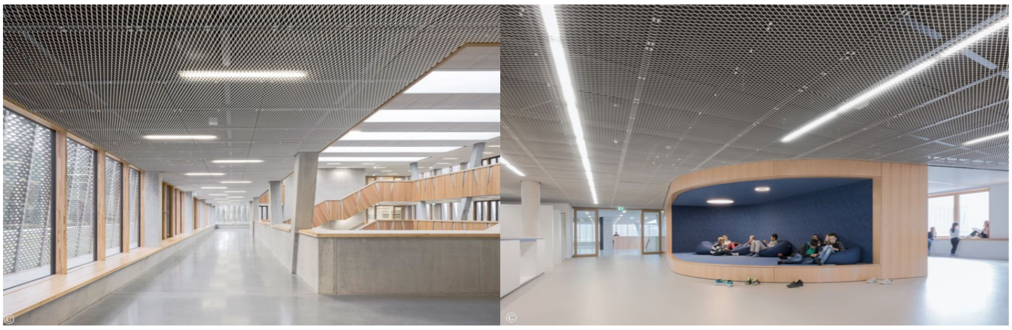


Figure 6: The interior of the common spaces

2.7.2. County Elementary School by Vectors Architects

In other cases, different green technologies are applied to increase the effects of daylight. In China, County Elementary School by Vectors Architects is one of these examples. It has 48 irregular shaped classrooms that protrude from the façade on the first floor. The aim of the school of the create a place that links the academic staff with its students during the daily learning-teaching life methods implemented in their curriculum.

Figure 7: County Elementary School

In the spatial organization of the school, the classrooms are organized around a main atrium, so that the natural ventilation is obtained by the skylight on top of it as shown in *Figure 8*. This is important also for the optimization of the daylight that is needed on a daily basis. Through the three massive light-wells, that are located on the roof, the first floor receives even more natural daylight. Moreover, there are used shading devices, such as the vertical fins, that regulate the glare effect within the classrooms. [15]This makes sure that the whole building is well-lit and lowers the need for the artificial light and energy consumption cost.

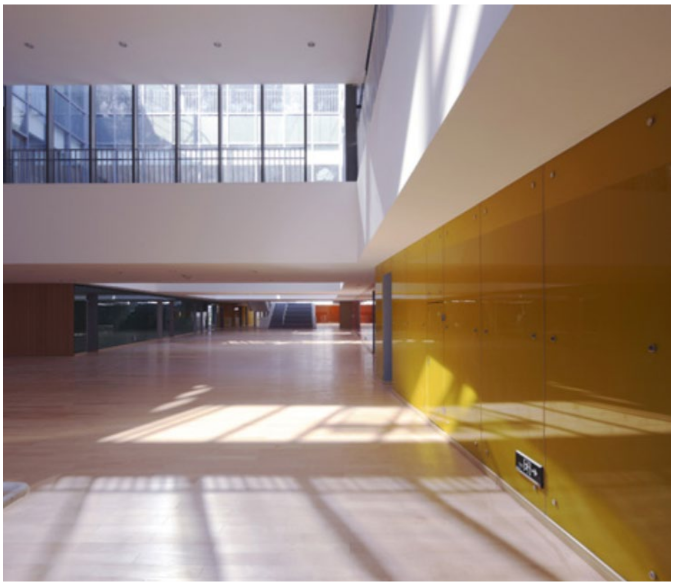


Figure 8: The main atrium (notice the amount of daylight within)

The architect focused greatly on making this school a sustainable building from the recycled material used in its building part, storm water management, its green roof that can be access through stairs and ramps, etc. These green-blue infrastructures make the whole campus (for the landscape surrounding the school as well as its outdoor areas are used impervious materials to bring the sustainability of the building a step further) a green building/campus (*Figure 9).*

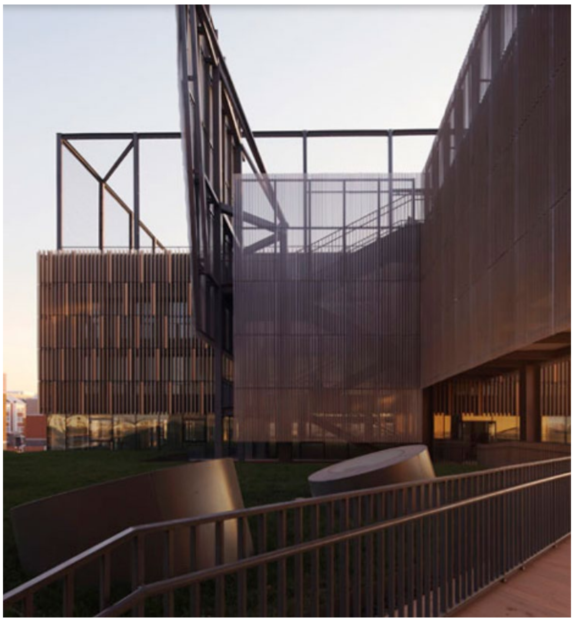


Figure 9: GBI surrounding the premises of the school and its façade

While having the GBI (green- blue infrastructure) at hand as a mean to further the optimization of the light is great, the natural conditions can have a positive effect or a negative one that impact greatly on the light design. Therefore, many of the educational facilities try to put to use the natural environment and its climate in its advantage.

2.7.3. Humanities building at Kingswood School

The Humanities building at Kingswood School in Bath, England uses the long vertical windows to brighten the classrooms and create a comfortable atmosphere for the students to learn. As it is located on the historical part of the city, there are some regulations on the materials used and the continuity of the semi uniform façade of the old architecture present on site. The school was designed by Mitchell Taylor Workshop. Due to the site constrictions and the building regulations, devised a methodology on maximizing the daylight within the educational building while maintaining the values of the old architecture. [16] The site dictated the form of the building and the best orientation of it. This meant that the focus of the design was to reach the highest optimized levels of daylight and ventilation, as well as keeping the standard solar gains at bay.

Figure 10: The Humanities building at Kingswood School (sloped terrain)

The school is build facing north-east (*Figure 11)* as the two orientations offer the ideal daylight for the students. While on the south, it faces a green open space that influences on the students psyche for the better, as it has an impact on the view. The windows on the southern façade are design to provide shading from the solar light and circulating the ventilation of the building. They are surrounded by grey frames and perforated panels for the solar shading (*Figure 12*).

Figure 11: Southern façade

Figure 12: The windows surrounded by grey frames and perforated panels

The school also has skylights on its pitched roof that enhances the natural illuminance of the building, so that every part of the school is under the influence of the daylight (*Figure 13)*.

Figure 13: Skylights on the pitched roof

2.7.4. Reeds Spring Middle School

Almost the same approach was followed in Reeds Spring Middle School in the USA, relating to the light design strategies. As it is located in Reeds Spring- an area prone to tornados- one of the main focuses was the safety of the students from the storms and maintaining the natural environment on which the school lays. The building is positioned on a 150-acre wood site, while being surrounded by hills, making the building seem as if is emerging from the natural landscape.

Figure 14: Reeds Spring Middle School surroundings

The design of the school derived from preserving the natural environment and its organization is thanks to four main features: the retaining wall (bluff) that secure the gymnasium and the auditorium beneath (caves), the three-story stair (stream) is found under the skylight and green roof and the school box (shed) that contains the classroom and other educational facilities. A three-story atrium in the center of the building connects all of the four components (Figure 15*)*.

Figure 15: The three stores atrium for ventilation and natural daylight

The skylight on top of the atrium makes sure that the building is flooded with daylight that enhances the stream as common area where social interactions would begin. According to ASHRAE 90.1-2007 baseline, this project saves over 29.9% of energy cost stated by the base line (Figure 16) (Figure 17*)*. [17]

Figure 16: Ground floor of the school

Figure 17: The classrooms have the optimal amount of natural daylight

Overall, in all of the mention case studies and more, the light design revolves around the natural surroundings and climate, the orientation of the building and the shading devices that are used. These factors are important for the maximizing and optimizing the levels of daylights inside the building. When oriented on mostly towards north-east, the case studies seem to have a better usage of light and the students are rather comfortable in their surroundings.

2.8. National Case Studies

2.8.1 Severte Maci school

In the case of **Severte Maci school,** the school is located in a very dense part of Tirana, near rruga e Dibres that is highly populated in different times of the day.

The old school had rows of medium rectangle windows and classrooms oriented toward the south and north. No shading devices, beside the curtain and shutters, were present in that time as it was not needed as shown in *Figure 18*.

Figure 18: previous Servete Maci school

However, the latest version of the school - design by StudioArch4 - has enlarged windows, hallway surrounded by glass curtain walls that bring the light in. All of these elements are positioned towards the south, which makes it easier to have an abondance of natural lighting. [18]

Figure 19: The latest version of Servete Maci

The classrooms watch over the courtyard that is one story below the street. This gives the students a semi private space where they can gather, as well as making the learning process in the classrooms quieter and the students are more eager to be involved in the process.

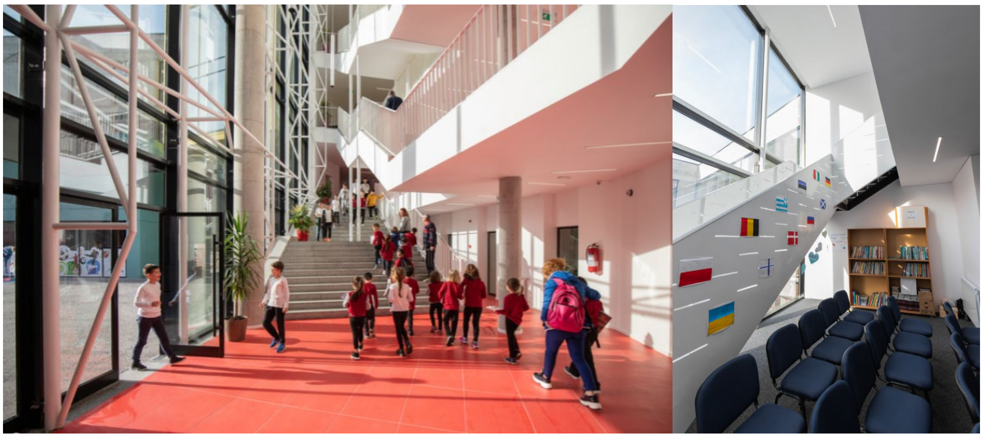


Figure 20: The interior of the school with natural daylight within

2.8.2. Qazim Turdiu School

Qazim Turdiu School is a primary-elementary school that is located in the Don Bosko area of Tirana, another area with a high dense in building and traffic. The building is surrounded mostly by 3-4 story private villas and high-rise buildings. The school is being rebuilt as we speak.

It used to have an almost rectangle shape, three story highs. The school had an enormous backyard, where different outdoor activities happened. There were rows of medium rectangle windows and classrooms oriented toward the south and north. Its' classrooms had only internal shading devices such as curtains, blinders or shutters.

Figure 21: The old version of Qazim Turdiu school

The new school is already being built. It has a 4-story high, L shaped form. Comparing with the old one, the school was designed to hold 900 pupils and it is separated in 3 functional volumes that are connected through the public balconies. Together with the front yard and the terrace on the third floor of this building, they are common spaces for the community to come together as shown the layout in *Figure 22.*

Figure 22: The new proposed version of the school

There is noticed that the school will have glass façade (*Figure 24)* and the classroom with have bigger windows for the light to come in. [19] The classrooms are mostly placed on the east and west side of the building. From the 3d model and the atmospheres provided by the architects, it is shown that the school leans more towards classrooms and other multifunctional spaces such as the library (*Figure 23)* where the visual comfort is achieved best.

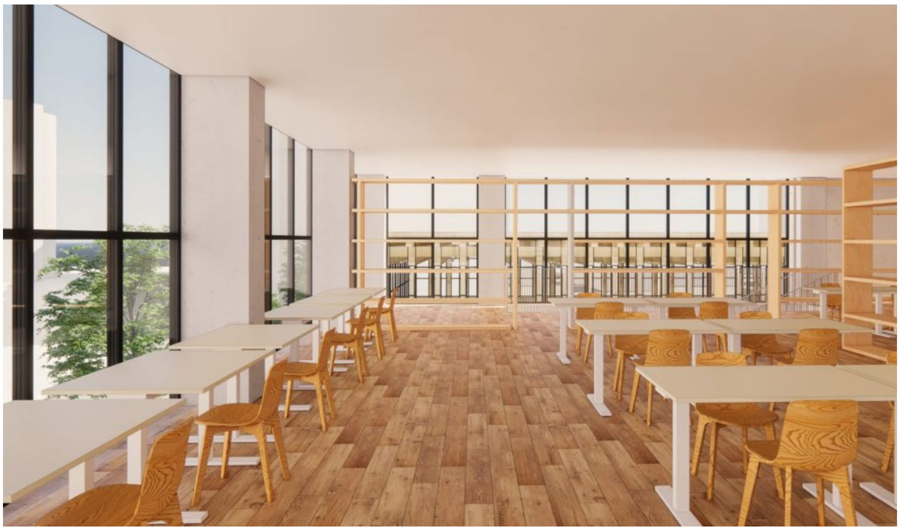


Figure 23: The proposed study area for the students

Figure 24: The outer façade of the school with external shading devices

As many educational schools in Tirana are built as a new or reconstructed, it is noticed more and more the European design standards implemented that differs from the old design-building methodology that were used in the beginning. This fact proves that with the innovations of science and technology as well as the changes in climate have started to influence in the thought process of designing educational facilities. It is noticed the increased usage of larger window area or glazed panels, as well as putting an emphasis on shading devices as a passive strategy that lowers the energy cost.

Such are the examples from the city of Tirana, like the Kosova middle school, that was demolished and burnt, leaving no trace of the original school other than the surrounding walls of the courtyard. Nowadays, the school has numerous large vertical windows on its east and west facades, as shown in *Figure 25.* It was one of the first school built from the renovation project of the educational schools by the municipia of Tirana. In other renovation project, the change has been made on the materials in the educational building as well as in the surroundings, such as the courtyard. As mentioned before, the materials have different norms of reflectiveness that impact on the glare effect levels as well as the temperature increase. The materials of the courtyard of "Konferenca e Pezes" school were changed during renovations into sustainable materials that reflect the light as well as the windows have been changed into a better-quality version of them (Figure 26/ Figure 27).

Figure 25: Kosova School

Figure 26: previous version of Konferenca e Pezes school

Figure 27: the renovated version Konferenca e Pezes school

CHAPTER 3

METHODOLOGY

3.1. Overview

From an architectural view, the educational buildings in Tirana consist of the same or similar typologies and constructional characteristics used in their design. They are mostly 3 to 4 floors high geometrical-shaped buildings that host many students and academic staff, depending on their position within a city. However, the urban pattern of Tirana has changed, and high-rise buildings have become popular nowadays. The natural conditions that favored the design previously have changed and slowly prove that the educational building's design standards have to change to accommodate the students and academic staff needs.

The case study of Sami Frasheri was selected due to its architectural elements present. The school is being built anew with a parametric façade that intents on optimizing the natural daylight. However, before the damage caused by the earthquake that caused its demolishment, the building did not have any shading device other the internal shading devices as shown in *Figure 28*. This made the cases study interesting as to see the difference between the two, as well as providing new methods and strategies for the light optimization.

Figure 28: 3D view of site surroundings

Due to the fact the one building is now non-existent and the other one is being built as we speak, the digital models from their plans are the best choice to use in simulation program and try and see the outcomes. It will give a clean insight on the daylight metrics changes on different orientation and layout. The program used for the modeling of the buildings is mainly Revit while for simulations is Lightstanza.

The daylight data references for this thesis were taken from Velux (a website that specializes on the light and energy consumption) as well as other online sources. These data are used on the simulation program- Lightstanza- as references of an optimal daylight levels. Several classrooms are taken into study, based on the window orientation. Each classroom was taken separately into study through the daylight metrics used in Lightstanza. Each classroom was put into simulations with different types of shading devices to try and see the best approach as well as the how the previous building differs from the new one.

This was in the case of the demolished school as it was the one without any external shading devices, other than the internal one provided by the school/students. Different shading devices have different inputs based on their orientation. So, the first thing was to divide the shading devices into their respective orientation and then implementing them on the classrooms to see the difference between the simulation with no shading and the ones with external shading.

As for the case of the new school, it was taken a different approach. The school is going to have a wave wooden vertical louvers façade that it will cover the entire glass curtain wall that starts at the first floor. This makes sure that the school gets a diffused version of the direct light that comes from the east that the glass façade is oriented.

The first data were gathered from both of the schools based on the information from the renders and the plans and then complied into *Table 5*. Each classroom selected for the research is given an ID correlating with their window openings orientation. It is noticed from *Table 5* that the old school has the WFR (wall-to-floor ratio) within the 15% to 20 % threshold where the maximal WFR of the Southern classroom is 18% and the minimal one is 13% for Northern classroom. While the WWR (wall-to-wall ratio) is as well within the required values of not exceeding the maximum of 95%, where the maximum of WWR is 28% for the Eastern and Western classrooms, while the minimum WWR is 21% for the Northern classroom. On the other hand, the values of WFR and WWR of the 2020 version of Sami Frasheri are within the threshold mentioned, expect for the Eastern classroom that has higher values of WFR of 40% and a WWR of 100%. It is due to the fact that the Eastern classroom of 2020 has a glass wall of a mean to bright daylight inside.

These values are also influenced from the type of the layout of the classrooms and the length of the wall where the openings are located.

Table 5: Initial data of WWR and WFR of the classrooms

School		**Classroom ID**	**Area (m2)**	**Type of orientation (based on the windows)**	**Shading devices**		**Window to floor ratio - WFR [%]**	**Window to wall ratio - WWR [%]**
					Internal	External		
"Sami Frasheri" high school (1963)		4O	40	North	Yes	No	13	21
		1O	40	East	Yes	No	16	28
		2O	36	South	Yes	No	18	25
		3O	40	West	Yes	No	16	28
"Sami Frasheri" high school (2020)		1N	42	East	Yes	Yes	40	100
		2N	42	South	Yes	No	20	49
		3N	42	West	Yes	No	20	42

For the classrooms located in the 1963 school, as said before, they were selected based on their orientation as shown in *Figure 29.* They were measured firstly as they originally were bare of any shading devices. Afterwards, depending of the window orientation, the classroom was redesigned with external shading devices, such as overhang, vertical fins, slated vertical fins, horizontal louvers, eggcrate, etc. Then the model is put through Lightstanza and assigned the light parameters needed. Each simulation done come back with different results, which were more inclined towards the vertical fins, horizontal louvers or the eggcrate.

Figure 29: The chosen classrooms in the previous 1963 Sami Frasheri school

However, the case of the 2020 school is different. As in its original shape, the building has a parametric façade made of vertical fins (louvers) that follow a wave-like pattern, it has predetermined what kind of shading devices is going to use. Therefore, the difference is based on the present of internal devices. This is to see if having both internal and external shading is imperative in coordinating the daylight levels in the building. Unfortunately, the new school does not seem to have any opening (windows) oriented towards the north. The lack of information from the plans of the building is present. As we only have the ground floor plan, it was taken a classroom as a typology for the school and was replicated in the other three orientations as shown in *Figure 30*.

Figure 30: The chosen classrooms in the 2020 version of Sami Frasheri school

3.2. Simulation Software: Lightstanza

LightStanza is an advanced daylight analysis tool, that will help in getting insight on how the natural light interacts in our model by putting the exact location of the real-life model. The program acts as a plugin of Revit and Rhino and allows us to bring the model created in them directly into its platform, where we can put the exact location of the building for more correct simulations. It allows you to sync the model with the platform where every change made to the model, it is changed in the platform at the same time. This makes the simulation much easier and faster to concur. We can pinpoint the underlit or over lit areas in the model and get e detailed LEED, calculate sDA (special Daylight Autonomy) based on the daylight hours.

As a program that bases its references on the *CEN European Daylight Standard (EN 17037)* [20] , Lightstanza uses the standards metrics when first is used.

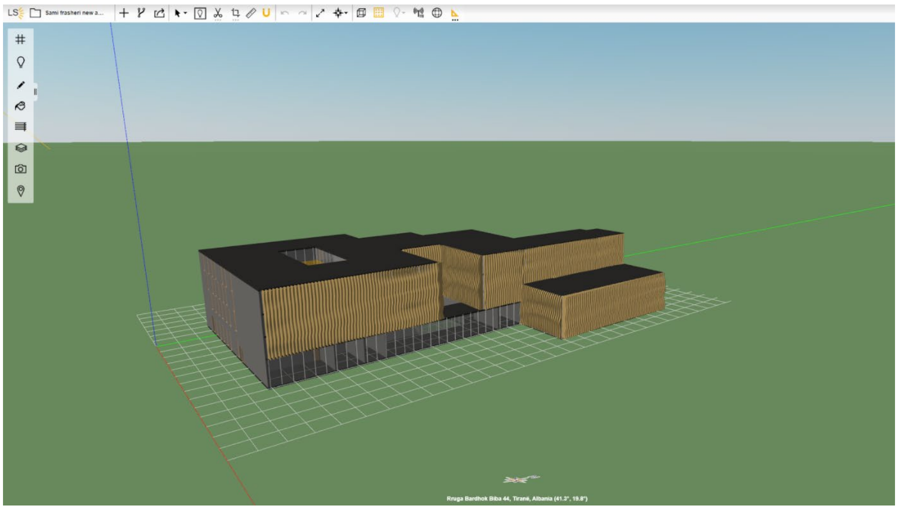


Figure 31: Lightstanza graphic interface

When creating a new project in the program, it is important to create the illuminance grid plane, as shown below. The work plane has to be 0.8 m above the floor to get correct results. In the command bar of the illuminance grid, the software gives us different option, such as changing the materials on Lightstanza, rendering, assigning the artificial lighting to the building, the create something from scrap, etc. Whereas, the command panel on top, is very easy to understand and use as it gives a feeling of SketchUp.

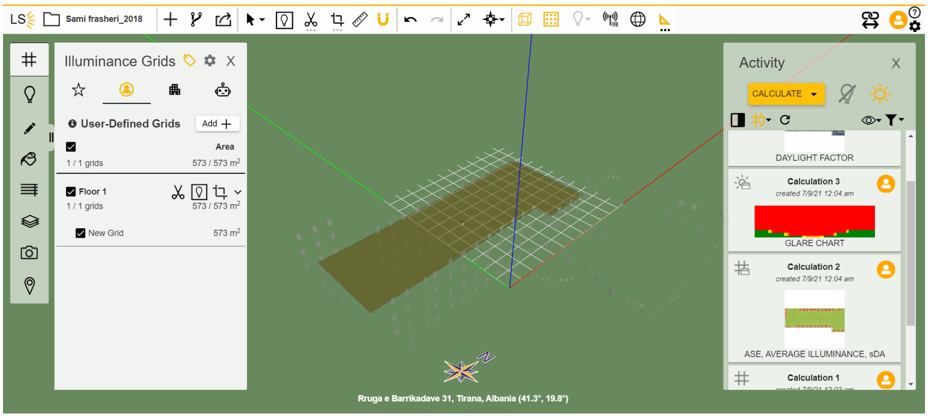


Figure 32: Lightstanza: creating an illuminance grid

The location of the building should be put as to some of the daylight metrics relays heavily on the orientation of the location. When choosing, it also gives information around the nearest of the weather station, what are the exact coordinates of the building as shown in *Figure 33*. It also displays the climate station that the program gets the data from. The closes one, that Lightstanza gets the climate data for Albania, is the one in Podgorica.

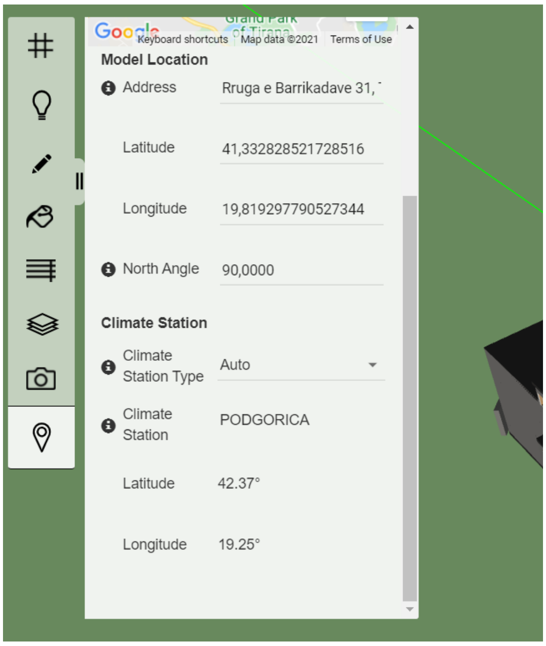


Figure 33: Lightstanza: the location of the model

In the activity section, listed are the daylight parameters that this software uses. They are going to be explain further in the next section.

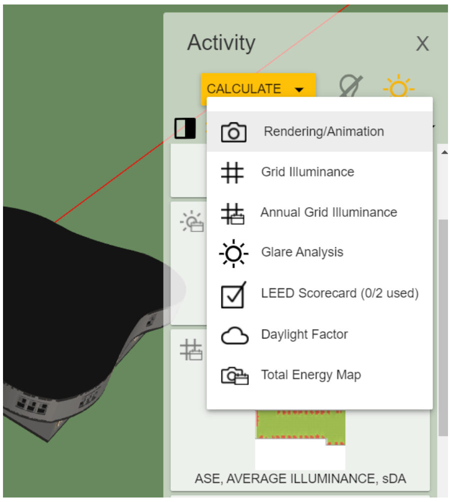


Figure 34: Lightstanza: the daylight metrics simulation commands

3.3. Daylight parameters

There are important metrics that are used for the optimization of light. Below, it will continue with describe each one of them.

DF- daylight factor: It is the ratio of the light level inside a structure to the light level outside the structure. It has specific level of threshold for the classroom space and that is 2%. However, the DF has had some backlashes on how it does not take into consideration the climate, weather, location a building. It takes under study just the orientation of the building.

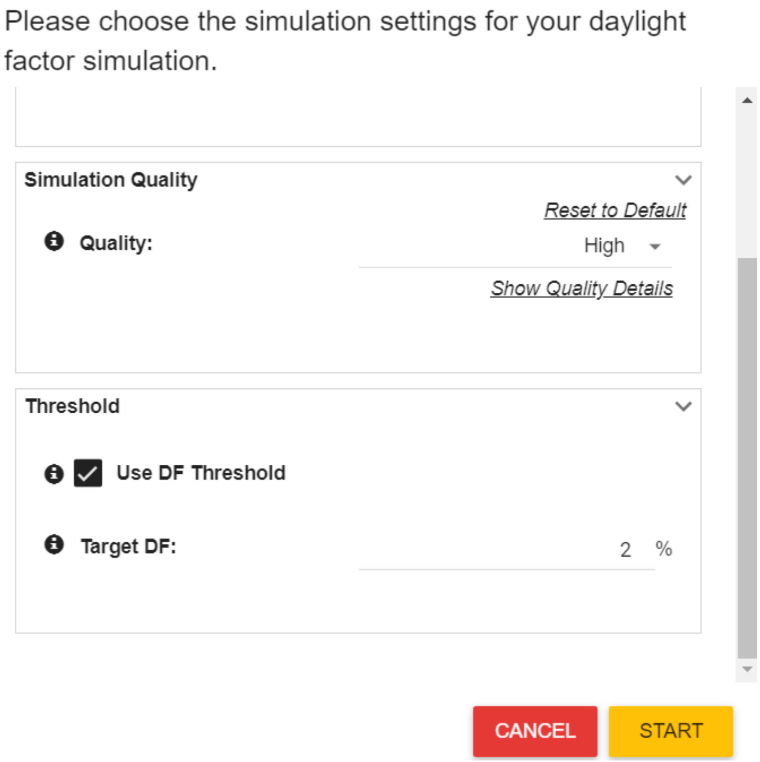


Figure 35: LightStanza: DF- daylight factor

sDA- spatial Daylight Autonomy: IT provides information on how much of a space receives sufficient daylight levels. It is the percentage of floor area that receives at least 300 lux for at least 50% of the annual occupied hours. Based on the sDA value, the space can be determined as a preference work place by the occupants if said value can reach 74%. The need for artificial light would automatically drop. However, if sDA reaches a value of 55%-74%, it would make the space only nominally acceptable by the users. Below than 55%, it would mean that the space does not receives enough daylight. [21]

ASE -Annual Sun Exposure: ASE gives insight on a certain space that receives a large amount of direct sunlight, that can cause the glare effect. It is a proxy in seeing the glare effect, but not a glare metric. Its intents to limit the excessive sunlight ASE measures the percentage of floor area that receives at least 1000 lux for at least 250 occupied hours per year. As such lower ASE values are recommended to reduce the glare effect. [21]

Illuminance- Point-in-time measures: It provides the best and worst scenarios and the threshold of 300-500 lux for the educational building. However, does not explain if the building is doing well overall.

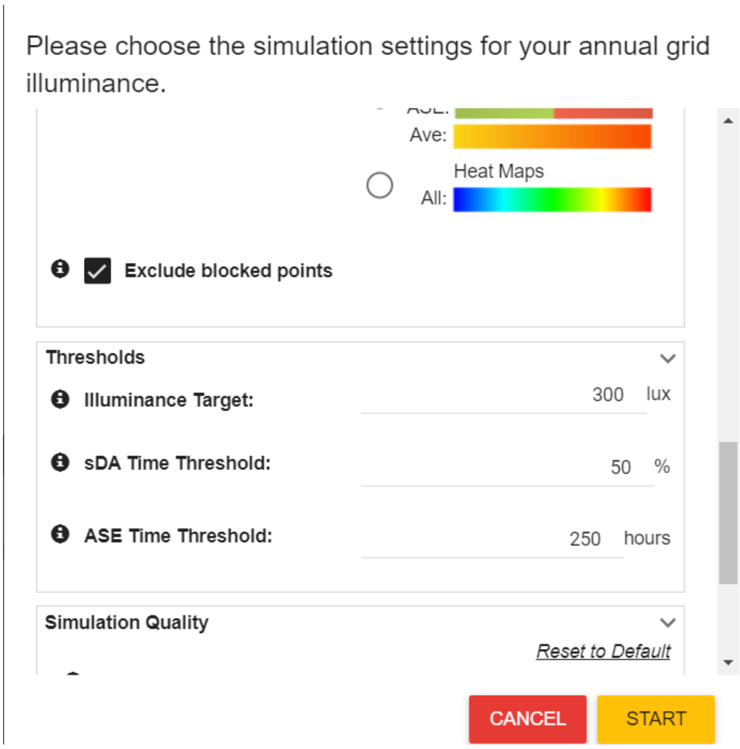


Figure 36: LightStanza: Annual grid Illuminance

DGPs- Daylight Glare Possibility: To make it bearable, the DGPs should not go above 5% of the usage time of space [20].

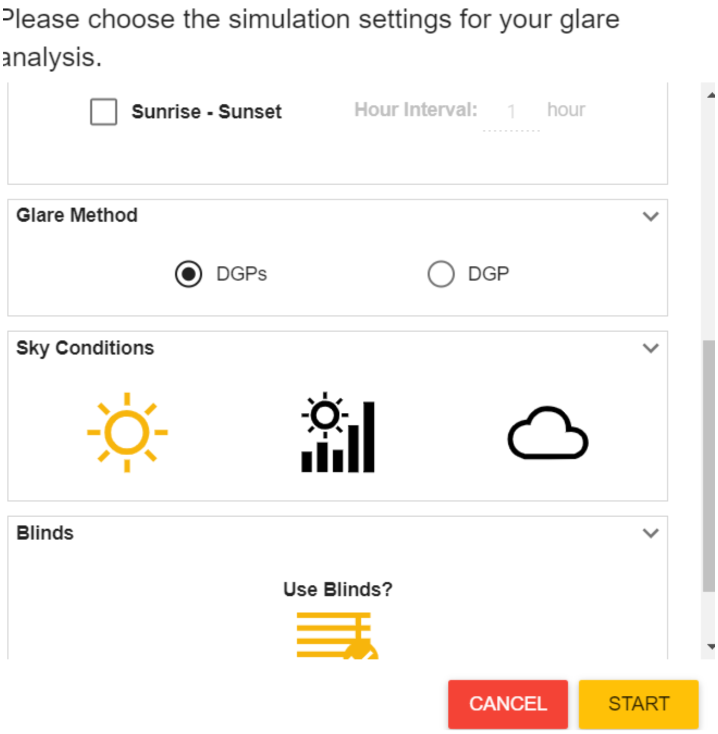


Figure 37: LightStanza: DGPs- Daylight Glare Possibility

CHAPTER 4

DATA ANALYSIS

4.1 Data gathering through the site visit

The site is located between “rruga e Barrikadave” and “rruga Bardhok Biba”, in Tirana. It is part of the infrastructure system that connects the area of “Stacioni I trenit” with the city square. On west, the site overlooks the busy street that is heavily used by different vehicles, while on east it overlooks a quiet neighborhood road. All around the site, there are apartment blocks with shops located on the ground level. A religion building known as “Teqeja e Sheh Dyrrit” considered cultural heritage, is located nearby south of the site.

Figure 38: Site Update

During the 90’, the school was surrounded by low rise buildings where the tallest was a 5 floor one made out of apartment units and small shops. Nowadays, new developments have changed slightly the urban pattern in this area. Newer buildings are built especially around the site. They start from nine floors building to 11 story high on the site's west side as shown in Figure 39.

Figure 39: *Building Height Analysis*

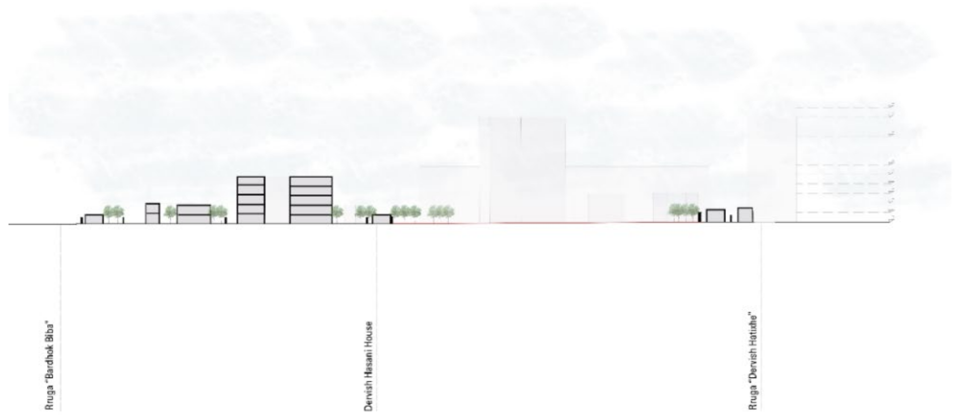


Figure 40: Section 1-1

Figure 41: Section 2-2

Due to the high number of students that followed classes in Sami Frasheri, the school had to separate the classroom into two shifts (one in the morning and the other during the afternoon) to fulfil the needs of the students. The first class starts at 8 AM and continues till 2 PM, followed by the second shift that concludes at 5 PM. The new buildings have an impact on the amount of daylight and shade that the site and consequently the school has during the day for the students. Moreover, the buildings acts as a natural factor in the daylight levels as well as in the glare effect, depending on how much shade falls on the site during different time periods.

In Figure 42, it is shown the shadow analysis for the period of 8 Am in 21st March and 21st December. It is noticed that the site is completely under shadows during the winter as the sun does rise later on, while during March, it is slightly under the sunlight. Whereas, during 12 PM, the site is under the sun's influence more and there are not any shade. As seen in Figure 43, in March the site gets more sunlight than in December. On the other hand, during 5 PM (Figure 44*)* the impact of sunlight in the glare effect in site is much lower in December -due to the sun setting at 4 pm- and slightly lower during March as the sun is still up and shining.

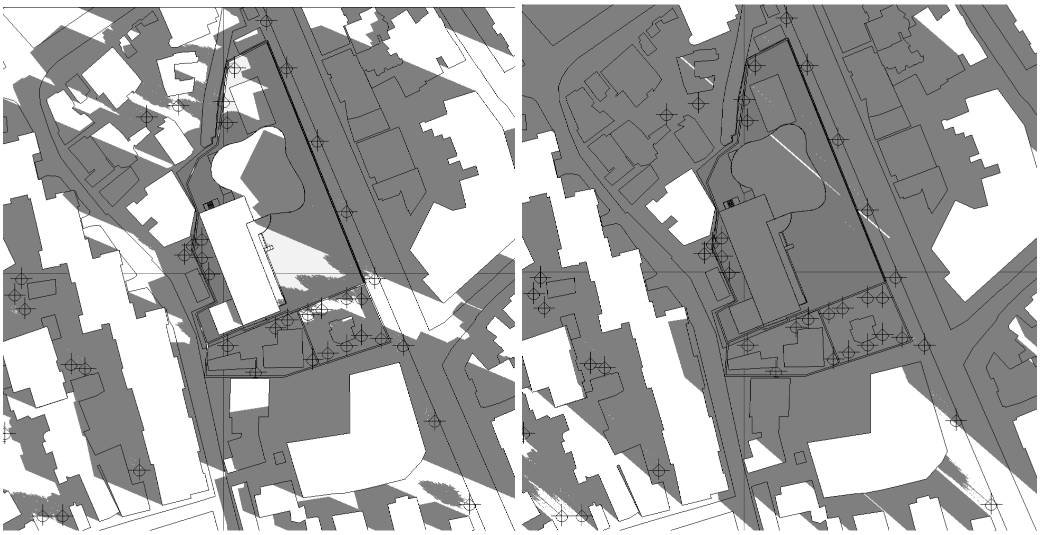


Figure 42: Shadow Analysis made at 8:00 AM for 21 March (left figure) and 21 December (right figure)

Figure 43: Shadow Analysis made at 12:00 PM for 21 March (left figure) and 21 December (right figure)

Figure 44: Shadow Analysis made at 5:00 PM for 21 March (left figure) and 21 December (right figure)

4.2. Case study: Sami Frasheri school – Old and New

4.2.1. 1963 Sami Frasheri school

The previous school, which was built in 1963, had a four-floor high cuboid geometric shape merged with a cube that leads to an organic form on top of the second floor. Its main entrance is oriented towards east, where the courtyard can be accessed as well, as shown in *Figure 45*. It provided emergency stairs located on the north of the building and a ramp on the ground floor for the disabled people.

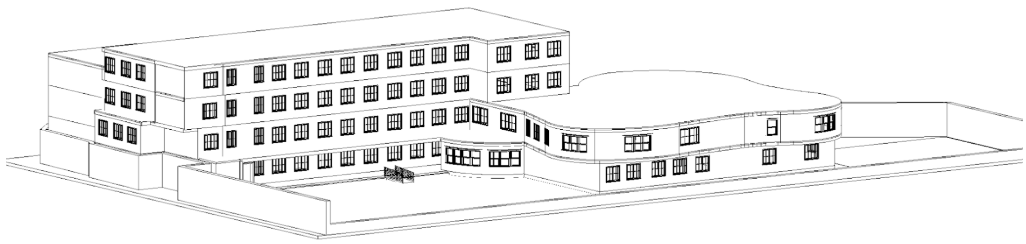


Figure 45: 3D model of Sami Frasheri school (1963)

It had classroom typologies designed to host 38-39 students each. The classrooms are situated on the west and east sides of the school body (*Figure 46- left)*, where they have faced high noise pollution and extreme daylight levels depending on the period (high and low). The regular shaped classrooms have an area of 42 m2 and each of them have 2-3 medium sized windows (140 cm x 150cm). These classrooms followed the same typology in the other floors as well as shown in *Figure 47.* While the irregular shaped classrooms can vary on size and they are located only on the first floor (*Figure 46- right)*.

Figure 46: Sami Frasheri school (1963) plans- ground floor (left) and first floor (right)

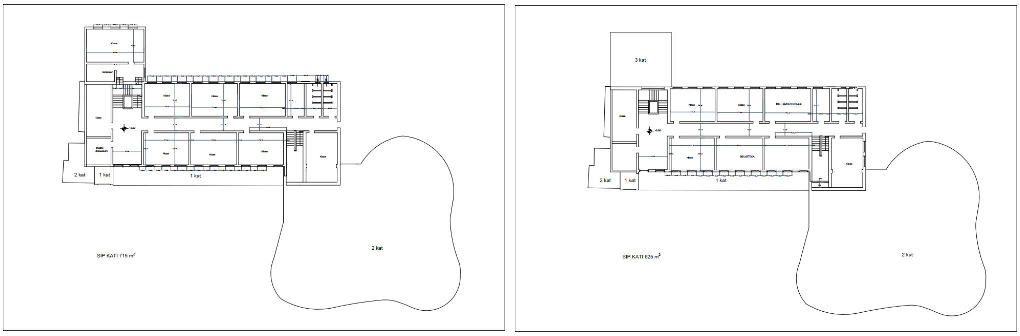


Figure 47: Sami Frasheri school (1963) plans- second floor (left) and third floor (right)

Figure 48: Sami Frasheri school, east façade

4.2.2. 2020 Sami Frasheri school

The new updated version of the school started construction during 2020 and still going. It is being built with modern Western-European features. [22] The features that comes to mind are the two main open atriums in the central part of the school body that redirects the sunlight in all of the floors and the parametric wooden façade that surrounds the glass facade on the east side.

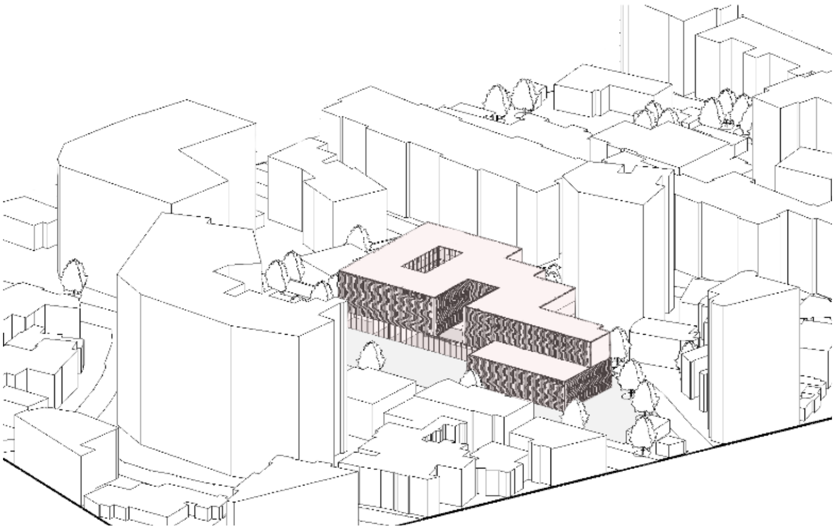


Figure 49: Sami Frasheri school (2020) model located in site

The parametric façade is made of wave like vertical louvers that diffuses the direct sunlight from the east and reduces the glare effect on the classroom with the glass façade wall. The school is design as a sustainable building that increases the thermal and the visual comfort of the users.

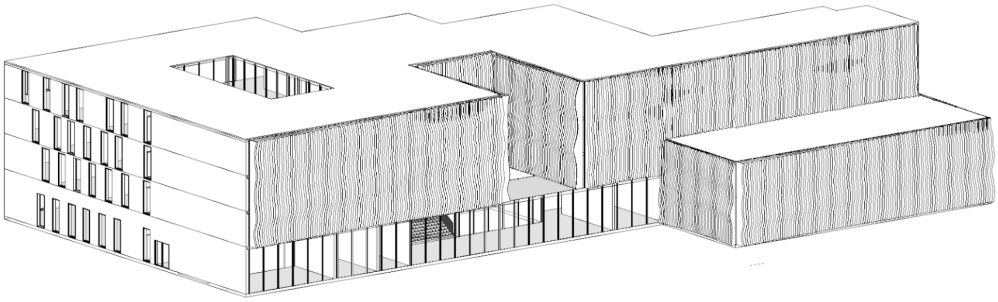


Figure 50: 3D model of the 2020 version

Including the underground floor that the atriums act as a light source and bring about natural ventilation. [22] The classrooms haves an area of 42 m2, mostly oriented on east, south and west. The windows on south and west are 2.8 m high and 1 m long that bring more sunlight within the building.

Figure 51: East façade render

Figure 52: the windows used on the west and south facades

4.3 Data gathering through a survey

The survey form sent to the students of different generations who have attended Sami Frasheri gathered their thoughts and feelings from different periods.

The school has been reconstructed several times until it was demolished in 2020 due to massive damage from the November 2019 earthquake. The surveys required from the former students to judge and estimate the three factors – layout, orientation, and interior- how they have influenced their academic achievements and which elements should be a vital factor in the design process. The survey was fill by 100 students (*Figure 53)* from different periods of studying at Sami Frasheri, from the year of 2012 till the academic year of 2019-2020. A large number of the participants had done their studies in the classrooms that have opening facing west (*Figure 54)*. Therefore, there might be more information concerning the western classroom (4O).

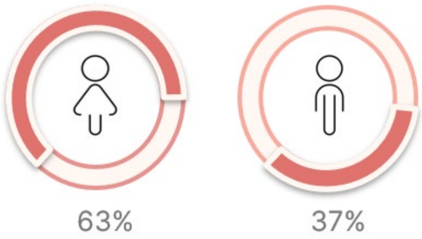


Figure 53: Female and Male percentage of the participants

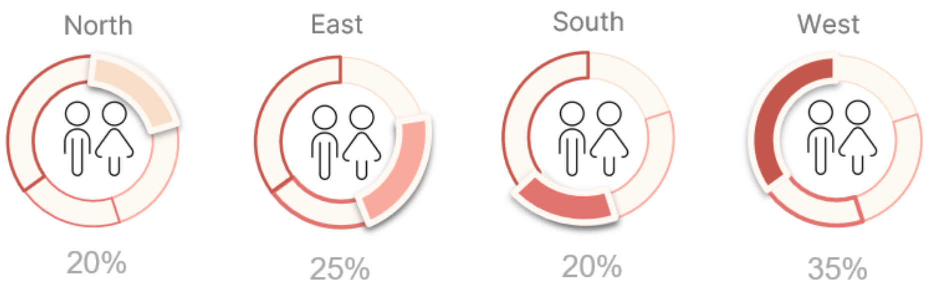


Figure 54: Participants' classroom orientation

Depending on the classroom's orientation (*Figure 55)*, the level of natural daylight reaching the classroom would be higher, resulting in the glare effect and hyper-heating, or low that would make the temperature drop during winter, making the students depend on other heating devices. Although, most of the students tended to say that only in certain periods of the day would the glare effect appear. This was during the early morning or in the beginning of the afternoon, around 12 PM.

According to the students, a majority of them would come across problems following the lesion due to the light reflecting off of the black board.

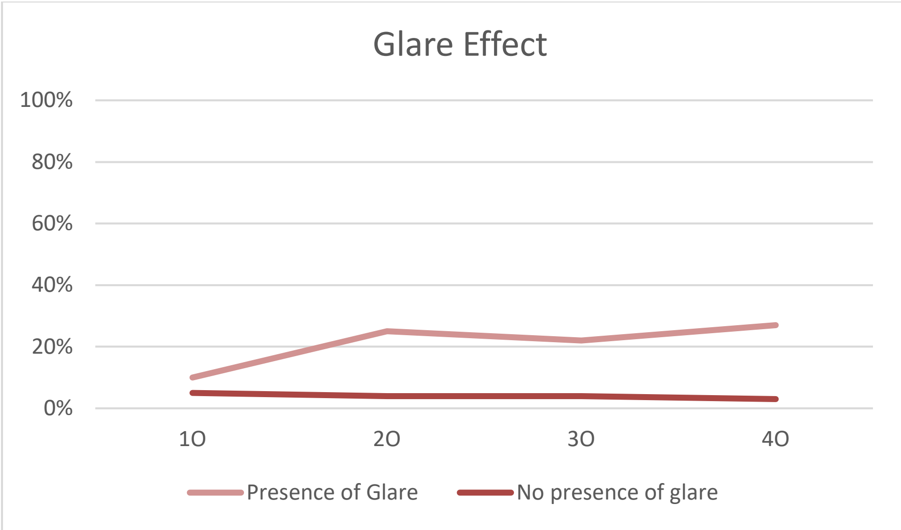


Figure 55: Glare effect levels based on the responses of the students

The layout was an important issue as well, due to the high number of students per class. The classrooms of the 1963 Sami Frasheri were designed to host 38-39 students each, and it wouldn't have enough space for the classroom body of 40-45 students (2 to 3 students per desk as shown in Figure 56). According to the responses, this factor brought overheating, stuffiness and a sense of discomfort for some of the classrooms that did not fulfill the students' needs.

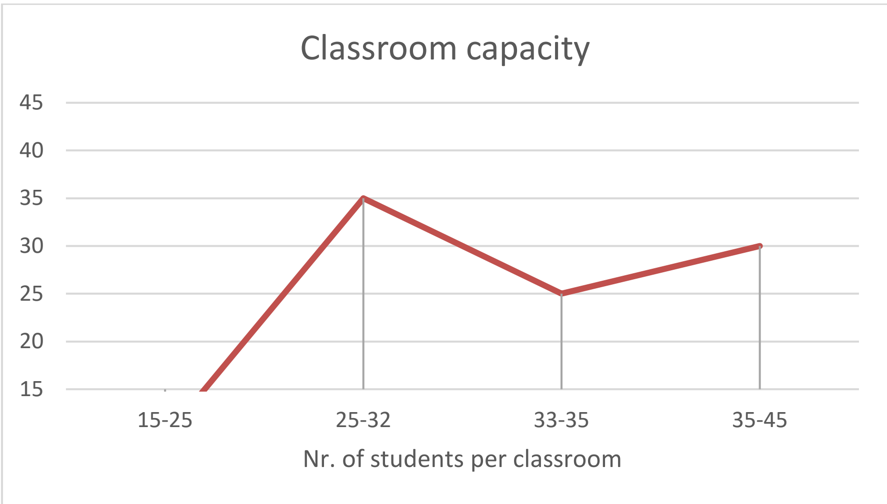


Figure 56: Classroom capacity

The interior of the classrooms was mostly bear or unmemorable for the students as well as the lack of the seats that and it was not a main issue for them like the heating and shading devices were. Based on the students' inputs, some of the classrooms were equipped with internal shading devices that were used regularly in controlling the glare effect and the overheating of the classroom. In others, they had to provide themselves the curtain or shutters (Figure 57*)*.

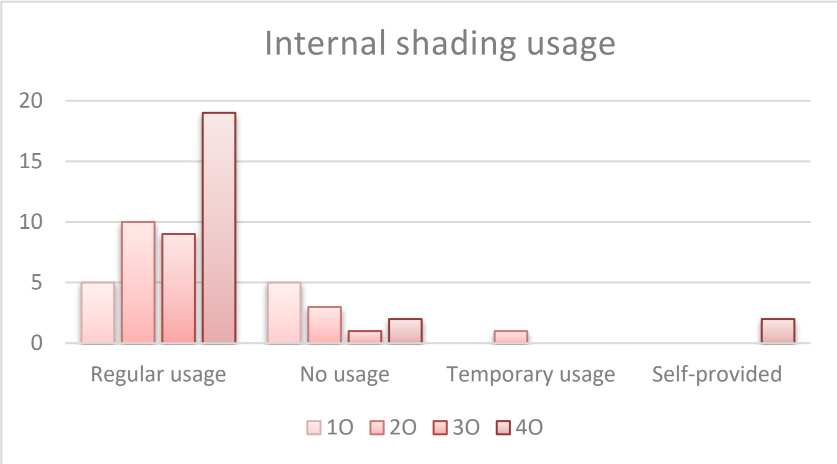


Figure 57: Internal shading usage

CHAPTER 5

SIMULATIONS

5.1. Simulation outline

To start the simulations in Lightstanza, it is needed the 3D model of the site and its surroundings. The site update done previously (Figure 38*)* is used as a base map of the buildings around the site and the orientation of the 1963 school model and the one of 2020. Moreover, the plans of the two school are used to create the model with its components, so that they can be recognized by the software and create the grid plans for the walls, floors and ceiling.

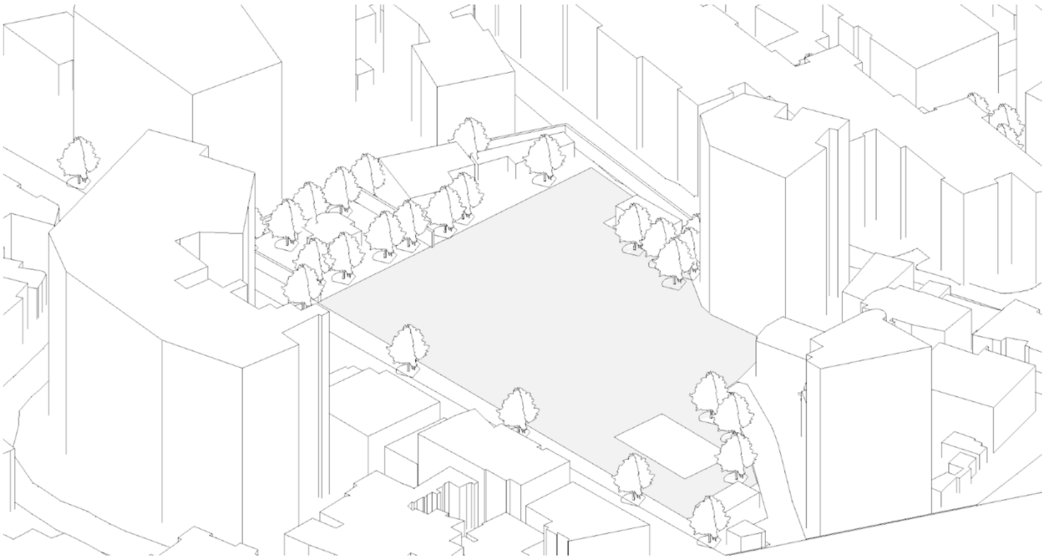


Figure 58: 3D model of the site

The models are assignment realistic materials (taken from the Revit 2020 material library), so that the reflective properties of each material can be taken into account during the simulation. The two schools' models are put in the 3D model site shown in Figure *58* (created in Revit with the massing command). Afterwards, each model is exported into Lightstanza while uploading all the components' characteristics in the simulation software database.

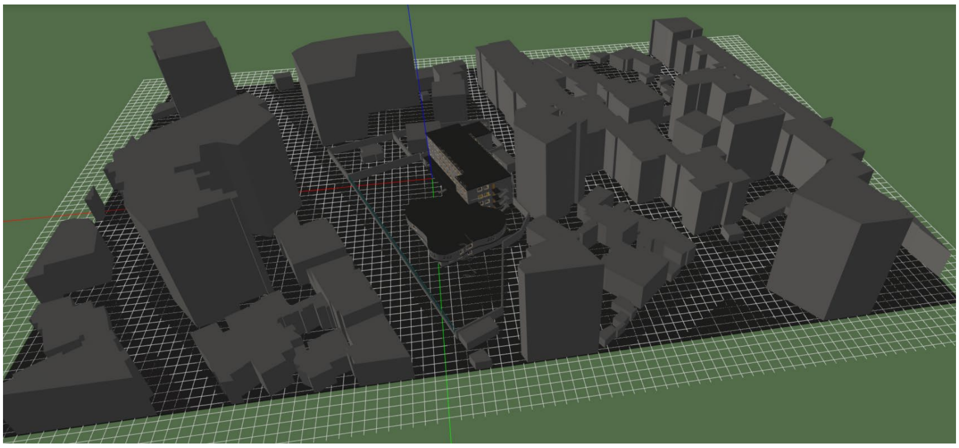


Figure 59: 3D model in Lightstaza interface

Once the model is uploaded in the software (this depends on the complexity of the model and how heavy it is in data as shown in *Figure 59*), the correct location is put and separate grid plans are created on the classrooms on the third floor (0.8 m above the floor of the classroom). The thresholds of the daylight metrics described previously are used in the simulation to provide the results from them.

The simulations made between the two schools are going to be compared among them to see the different result that each brings. Afterwards, based on *Table 4*, there will be simulations with different external shading devices to find the most optimal one.

5.2. Simulation 1963 (S63)

The simulations 1963 are the simulations of the old versions of the school. As mentioned before, the school did not have any shading devices on the top floor, while the ground floor had an overhang shading device that was used as shelter during the rainy days. The classrooms had only internal devices such as shutters, curtains or blinders, provided mostly by themselves as stated by in the survey. Four main illuminance grids are created, each for one of the classrooms taken under studies.

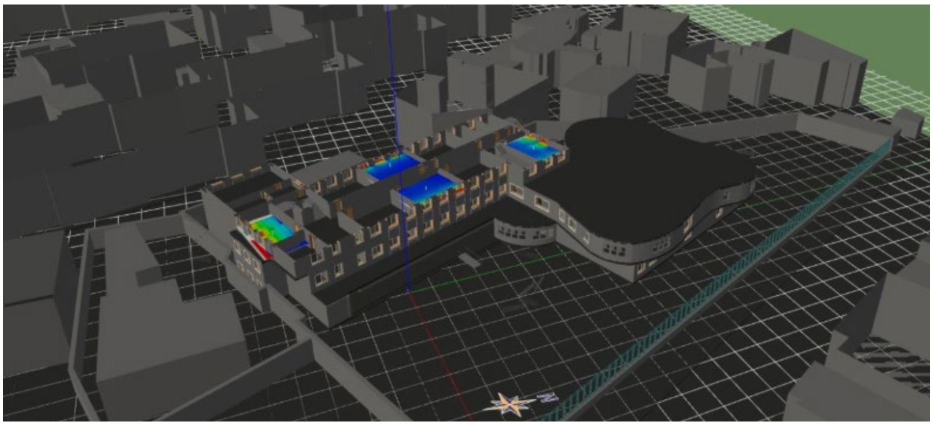


Figure 60: Illuminance point-to-point simulation (S63)

5.3. Simulation 2020 (S20)

The simulations of the new school (S20) have followed almost the same course as the ones of S63. However, it has differences on the results due to the external shading device that makes the eastern façade, as well as the glassed atrium that is used to bring the light in the lower floors. Three grid plans are created for the simulation of the daylight parameters, as there is no evidence of a north oriented classroom.

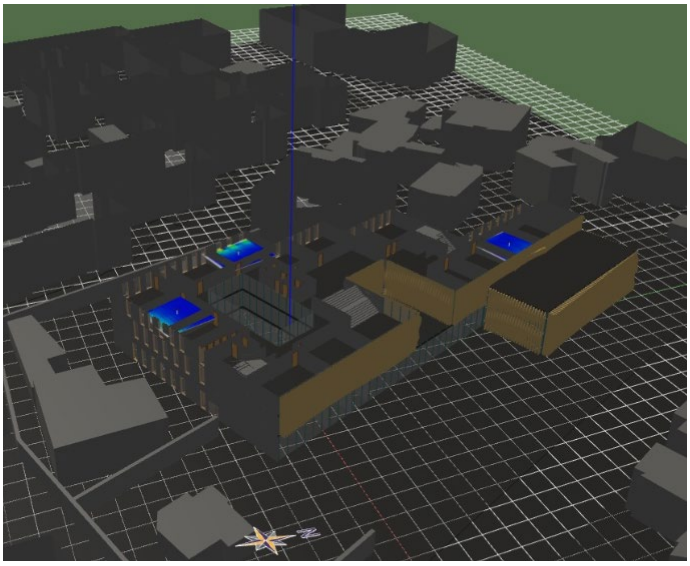
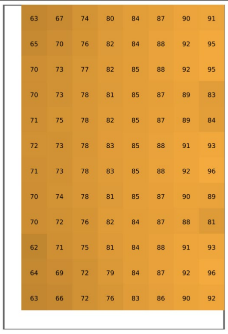
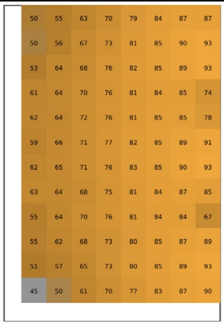
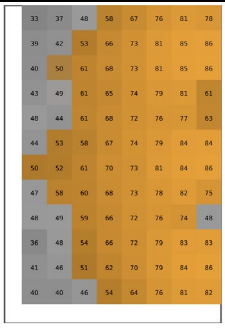
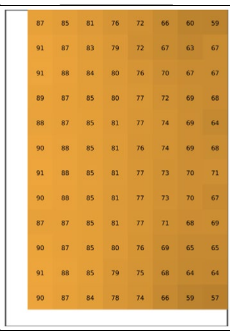
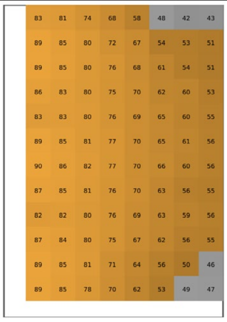
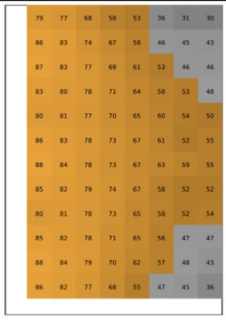
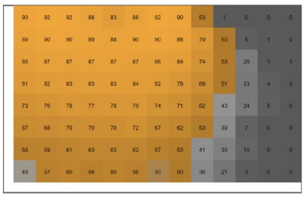
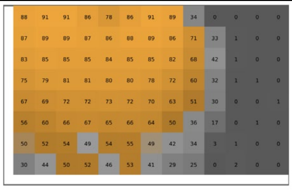


Figure 61: Illuminance point-to-point simulation (S20)

5.4. Optimization 1963 (OP63)

These simulations are going to be conducted on the 1963 model's classrooms. Each classroom will be designed with external shading devices to see the effect each have according to the right orientation. Moreover, it will see the difference between the external shading in different orientations, as shown in *Table 6* the difference in levels in the eastern, western and northern classrooms in model 1963.

Table 6: Comparison of sDA of the classrooms with external shading devices

Classroom ID	No shading device	Vertical Fins	Eggcrate
1O			
3O			
4O			

CHAPTER 6

RESULTS AND DISCUSSIONS

6.1. Overall

From the simulations done, it is noticed the different amount of daylight which each classroom came into contact daily. The results show that the levels of the light parameters depend on the orientation of the classroom. Moreover, its' layout influences the spread of light within the classroom, as the classrooms of the old version of Sami Frasheri are rectangle, while the ones of the modern one are more inclined towards a square layout. Interior is an important factor due to the furniture and the internal shading devices used during the day. In first glance from the simulations, the classrooms from the S20 have less daylight than the ones from S63. In *Table 7,* it shows that in general the old Sami Frasheri school has higher levels of daylight than its' newer version.

However, we can only see the difference between only three oriented classrooms (east, south and west), due to the new school that has no classroom oriented towards north, as it is mentioned before in this thesis.

Table 7: General outputs of the whole classrooms together

Daylight parameters	**Threshold**	**Sami Frasheri High school**	
		S63	**S20**
Shading Devices	-	None	Wave Vertical Louvers
Daylight factor	2%	17.68%	13.30%
sDA	50%	32.02%	15.88%
Average Illuminance	300-500 lux	2,158.98 lux	369.05 lux
ASE	250 hours/year	8.64%	6.65%

6.2. Comparison results

6.2.1. East-oriented simulations

During the process of simulations, the classrooms facing the east are noticed to have different outputs as the presence of external shading is emphasized. The 1O (eastern classroom in 1963 Sami Frasheri) and the 1N (eastern classroom in 2020 Sami Frasheri) were compared together. 1O is shown to have higher levels of sDA and DF, 22.31% and 1.6% respectively than the values received from the simulations of 1N. This means that the old classroom has better and much more daylight than the new one, according to *Table 8* and *Table 9.* The average illuminance results of *Table 11* shows that 1O receives 168,79 lux more than 1N.

Although the old classroom seems to have better results in daylight value than the new one, it also has higher score in ASE, which consequently impacts in a higher rate of glare effect. As mentioned before, the optimal levels of daylight that a classroom has to have are higher value of sDA and lower value of ASE. Therefore, the 1O classroom might have better results than 1N, but it lacks in methods to contain the glare effect. Whereas the 1N compensates with the external shading devices that have.

Table 8: Comparison table of Daylight Factor levels of the classrooms facing east

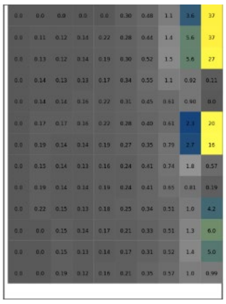
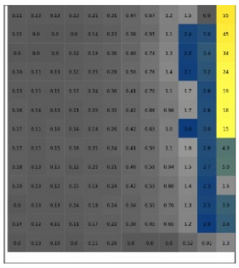
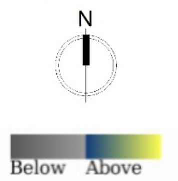
Daylight metric	Threshold	1O	1N
DF	2%	1.6 % 	2.0 % 
			

Table 9: Comparison table of sDA levels of the classrooms facing east

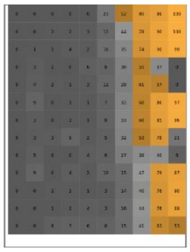
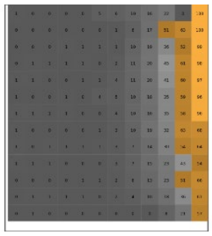
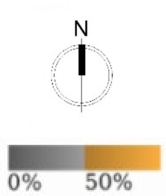
Daylight metric	Threshold	1O	1N
sDA	50%	22.31% 	14.74% 
			

Table 10: Comparison table of ASE levels of the classrooms facing east

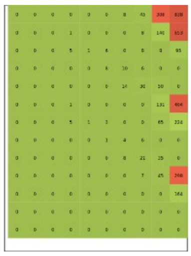
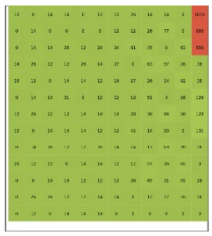
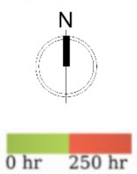
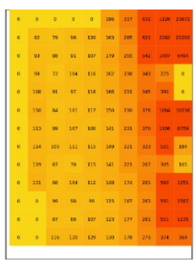
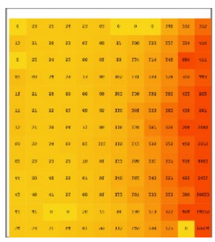
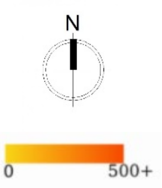
Daylight metric	Threshold	1O	1N
ASE	250 hours/year	3.85% 	1.92% 
			

Table 11: Comparison table of Average illuminance levels of the classrooms facing east

Daylight metric	Threshold	1O	1N
Average illuminance	300-500 lux	770.00 	601.21 
			

This comes as a result due to the vertical fins that diffuses the direct sunlight that these classroom faces on a daily basis. *Figure 62* provides evidence that the during March 21st, 1N has the highest exposure toward the sun at 9:00 AM. While, in December 21st the highest exposure is during 10:00 AM as shown in *Figure 63*. The 1O classroom has its peak at 8:00 AM in March 21st while in December 21st is at 10:00 AM. (See more in APPENDIX C and APPENDIX F)

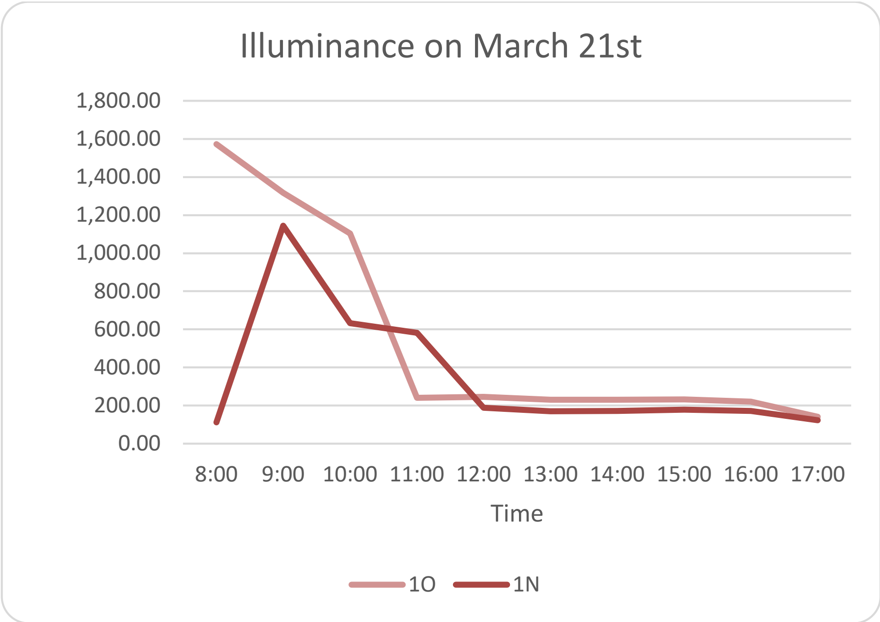


Figure 62: Illuminance on March 21st for the classrooms facing east

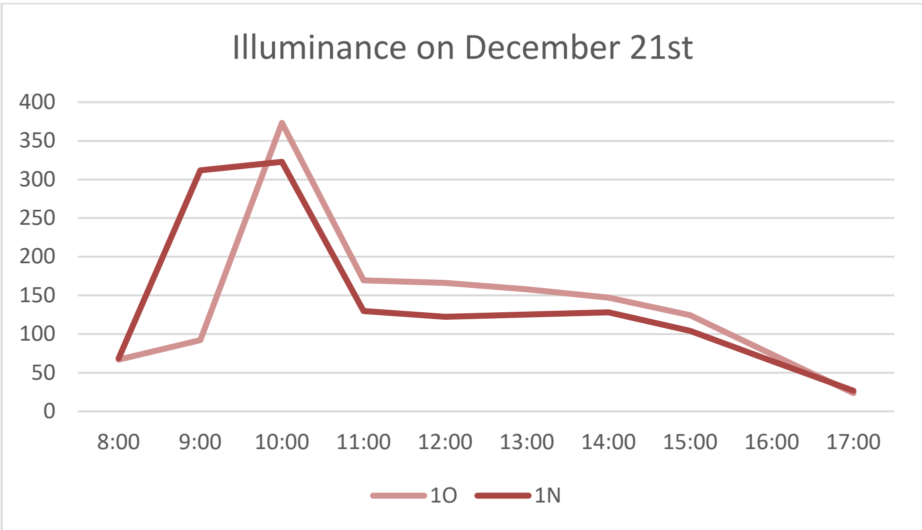


Figure 63:Illuminance on December 21st for the classrooms facing eas

6.2.2. South-oriented simulations

For the case of the classrooms facing south, neither of them has any shading. Almost the same outcomes have been achieved. The 2O classroom has a higher value of sDA than 2N classroom by 29.75% higher (*Table 13),* while the ASE levels of 2N classroom are lower than 2O, resulting in minimizing the glare effect (*Table 14).* The daylight factor seems to favorite the old classroom as well as it crosses the DF threshold of 2%.

The 2O classroom has more amount of daylight and a higher rate of having the glare effect, while the 2N classroom might have far lower levels of daylight, it also has lower rate of glare effect implement during class.

Table 12: Comparison table of Daylight Factor levels of the classrooms facing south

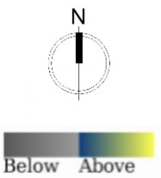
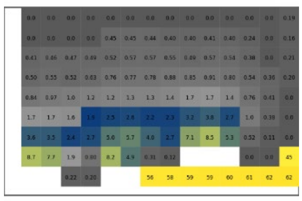
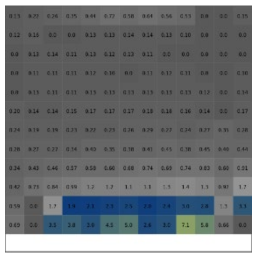
Daylight metric	Threshold	2O	2N
DF	2%	5.6 %	0.7 %
			

Table 13: Comparison table of sDA levels of the classrooms facing south

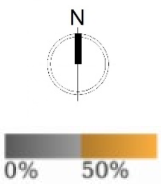
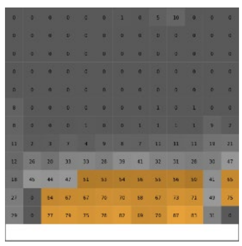
Daylight metric	Threshold	2O	2N
sDA	50%	47.06%	17.31%
			

Table 14: Comparison table of ASE levels of the classrooms facing south

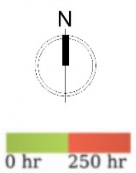
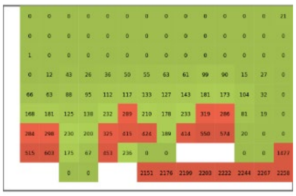
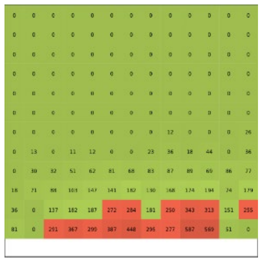
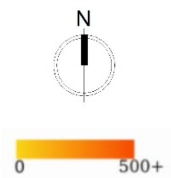
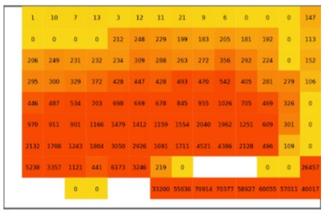
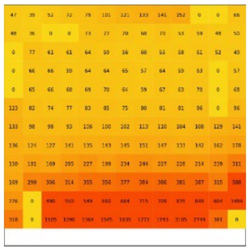
Daylight metric	Threshold	2O	2N
ASE	250 hours/year	19.33%	9.62%
			

Table 15: Comparison table of Average illuminance levels of the classrooms facing south

Daylight metric	Threshold	2O	2N
Average illuminance	300-500 lux	4,664.13	258.71
			

During the hours where the students spend their time, it can be noticed that at 2O classroom the highest illuminance is reach at 11:00 AM in March and 12:00 PM in December. However, it can be seen from *Figure 64* and *Figure 65* that the 2N classroom reaches its peak at 11:00 AM in December. (See more APPENDIX D and APPENDIX G)

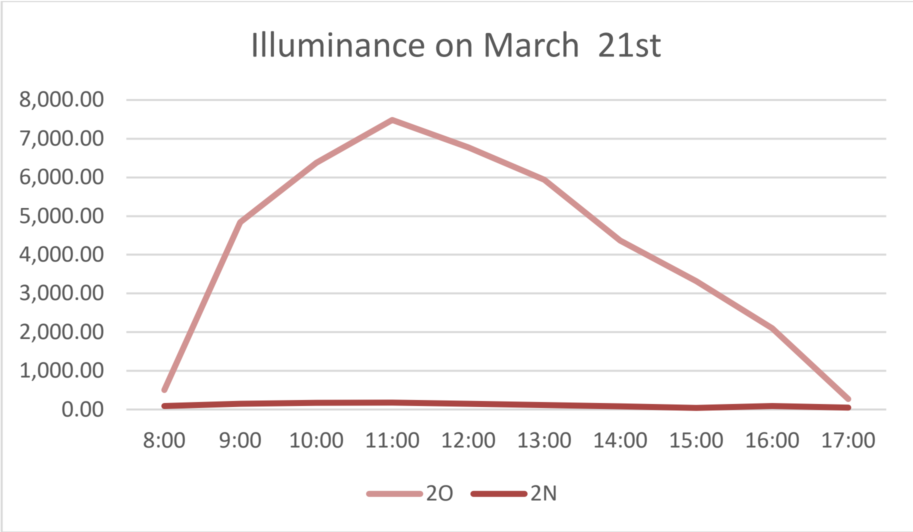


Figure 64:Illuminance on March 21st for the classrooms facing south

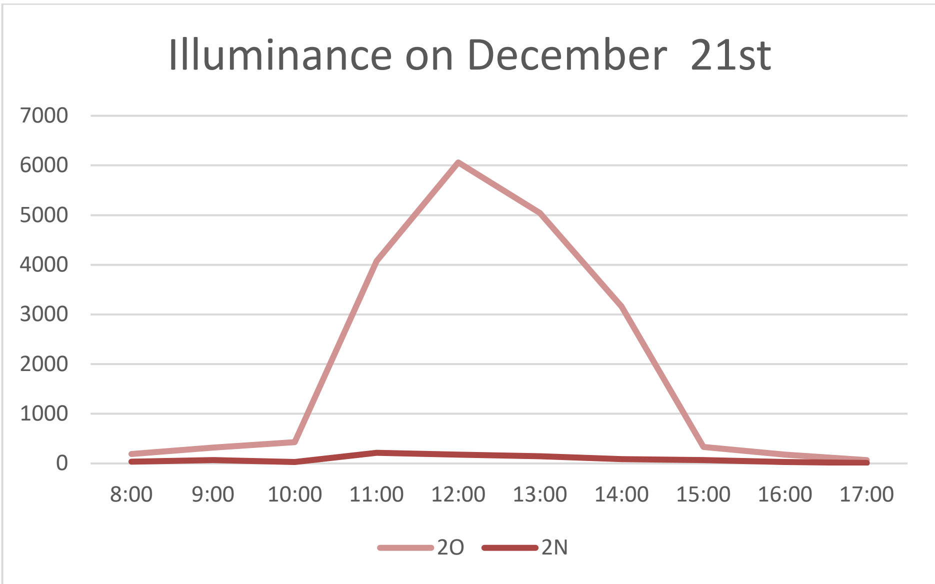


Figure 65: Illuminance on December 21st for the classrooms facing south

6.2.3. West-oriented simulations

The classrooms facing west do not have any shading devices. As the same with the other two comparisons, again the 3O classroom of the old school has higher score in DF and sDA in better values of daylight, while having the glare effect due to the high value of the ASE that determined the amount of direct sunlight has a certain space (Table 16, Table 17, Table 18). Whereas, the 3N classroom might not reach the given threshold in DF and score a lower value in sDA as shown in Table 17, it had a lower value in ASE simulation that makes the glare effect less prominent.

Table 16: Comparison table of Daylight Factor levels of the classrooms facing west

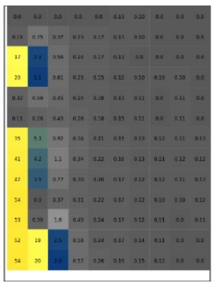
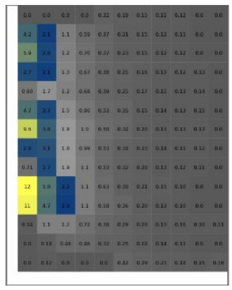
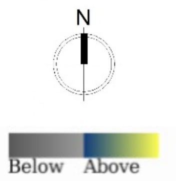
Daylight metric	**Threshold**	**3O**	**3N**
DF	2%	3.5 % 	0.9 % 
			

Table 17: Comparison table of sDA levels of the classrooms facing west

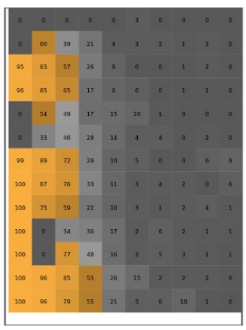
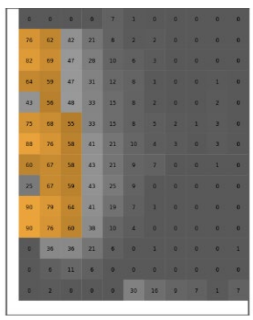
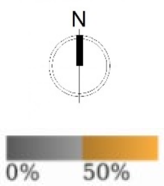
Daylight metric	**Threshold**	**3O**	**3N**
sDA	50%	21.54% 	15.58% 
			

Table 18: Comparison table of ASE levels of the classrooms facing west

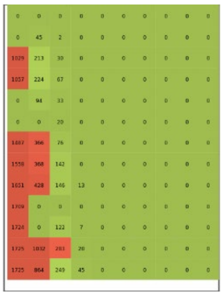
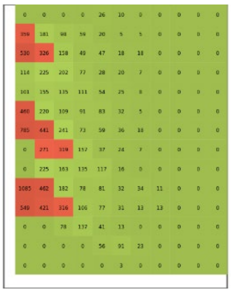
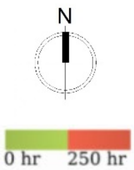
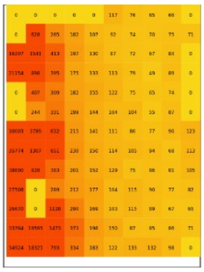
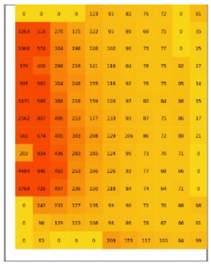
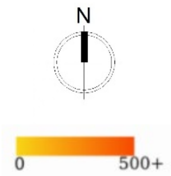
Daylight metric	Threshold	3O	3N
ASE	250 hours/year	11.54% 	8.44% 
 			

Table 19: Comparison table of Average illuminance levels of the classrooms facing west

Daylight metric	Threshold	3O	3N
Average illuminance	300-500 lux	2,534.19 	245.63 
 			

During classes take place, it can be noticed that at 3O classroom the highest illuminance is reach at 2:00 PM in March and 1:00 PM in December. However, it can be seen from Figure 66 and Figure 67 that the 3N classroom is in direct contact with the sunlight for less than 500 lux throughout March and December. (See more APPENDIX E and APPENDIX H)

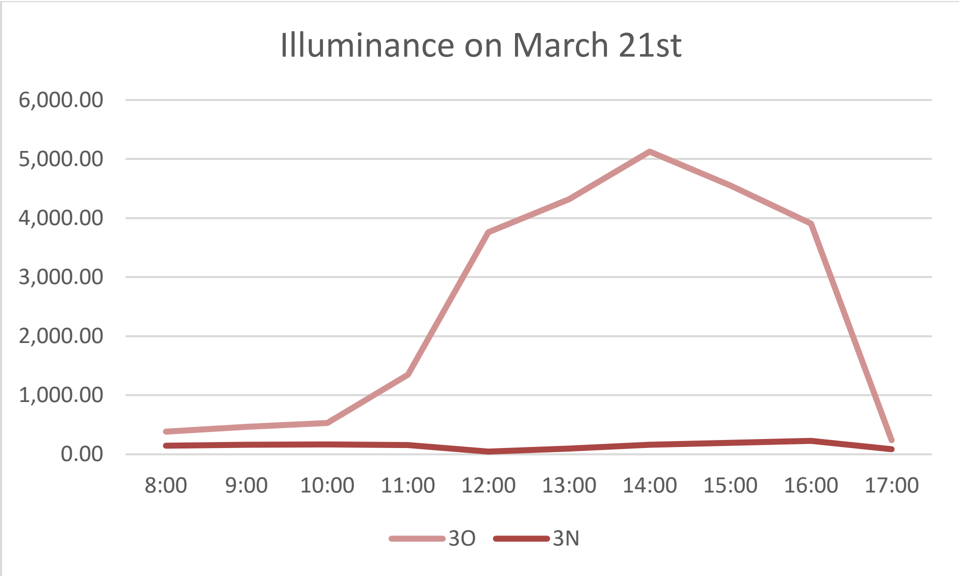


Figure 66: Illuminance on March 21st for the classrooms facing west

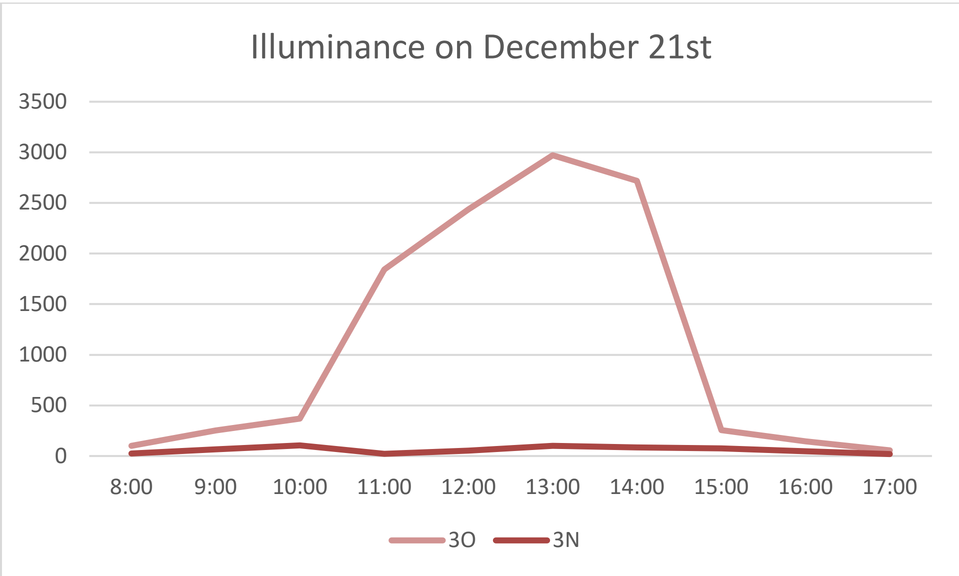


Figure 67: Illuminance on December 21st for the classrooms facing west

6.3. Optimization results

During this part of the simulations, the classrooms of the 1963 Sami Frasheri school have been taken separately and redesign with external shading devices that were explained previously in this research. Based on the outcomes of the simulation, it is noticed that the vertical elements or the horizontal-vertical one (eggcrate) has the best response for the classrooms oriented towards east and west. Whereas, the southern classroom is more inclined towards the multiple horizontal louvers (Figure 68)(Figure 69).

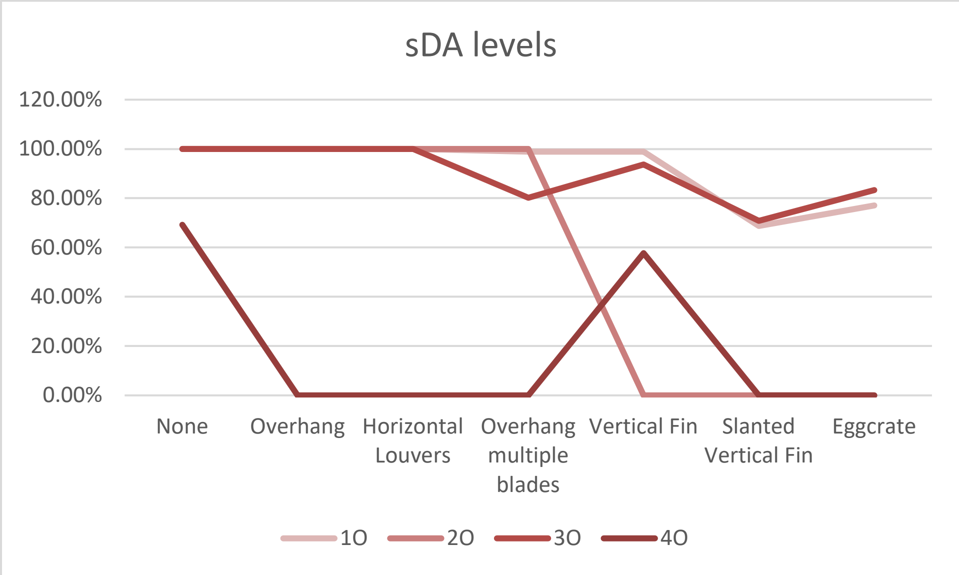


Figure 68: sDA levels of the shading devices, compared between the classrooms

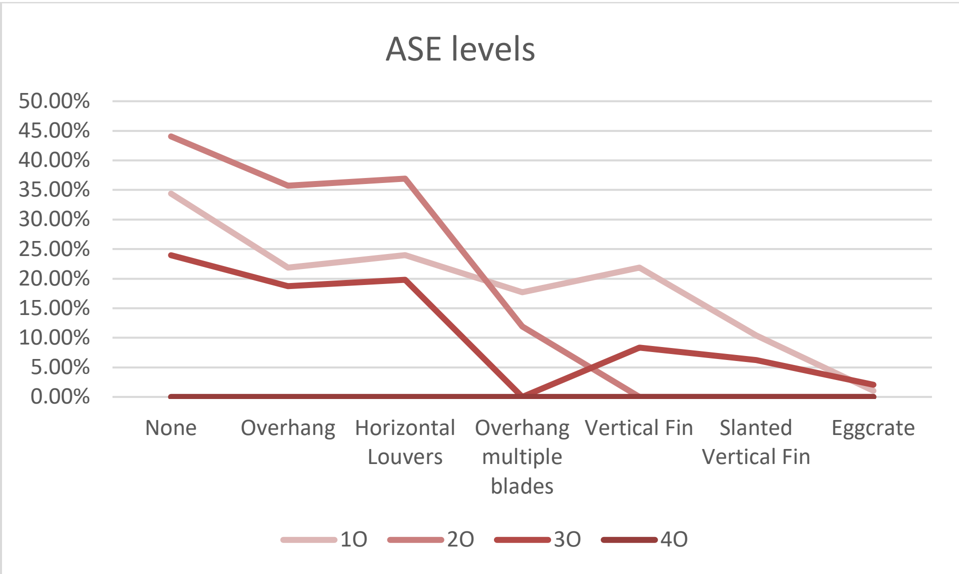


Figure 69: ASE levels of the shading devices, compared between the classrooms

The vertical fins, especially the slated version of them, have shown high sDA levels corelated with the low ASE levels, as well as the eggcrate shading devices. Although, the other devices may have had almost the perfect score in reaching the base threshold of 50% for sDA and more, the ASE score of each shading devices is higher than it should, due to the fact that it adds in the glare effect impact. Therefore, the eggcrate shading devices are the most optimal option, while the vertical louvers come in second place for the classrooms oriented towards the east, as shown in Figure 70. See Table 42: Point-to-point illuminance grid (December)

APPENDIX I

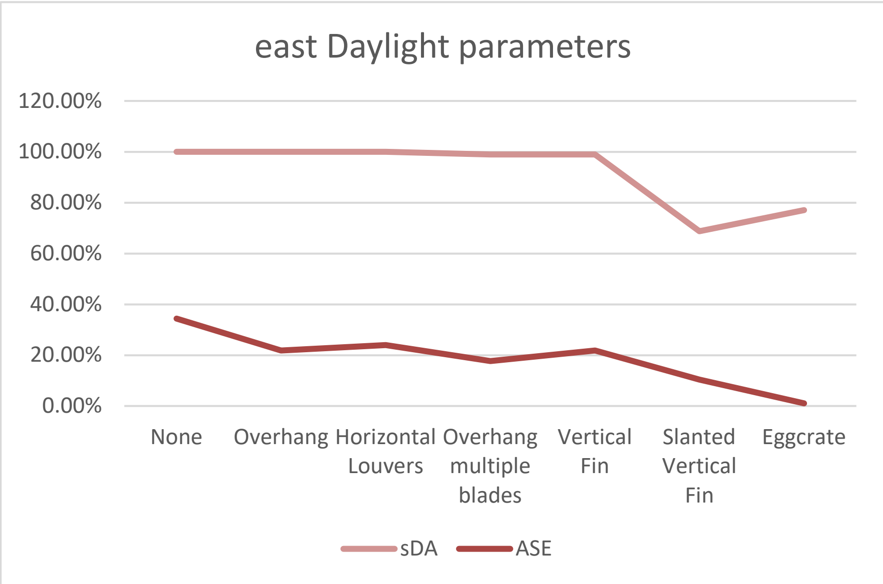


Figure 70: sDA and ASE levels for the east-oriented classroom

Almost the same can be said for the ones that are oriented west, as they are more inclined to use the eggcrate and the vertical fins as they have lower sDA and a higher ASE. However, from the results shown in Figure 71, the overhang multiple blades have also the better results of sDA and ASE scores. This gives the western classrooms more options on how to optimize the most of the direct daylight coming from the west. See APPENDIX K.

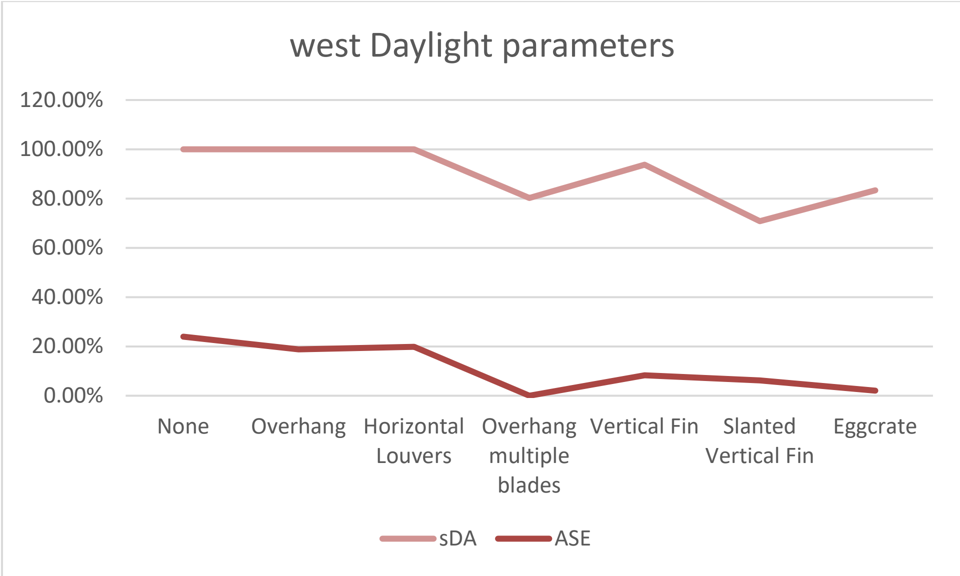


Figure 71:sDA and ASE levels for the west-oriented classroom

As for the southern one, the results seem to be different. Throughout the simulations with the external shading devices, the sDA levels stay at a constant of 100%, which leads to believe that none of the shading devices have an impact on the levels of daylight within the classroom. However, the ASE parameter gives different results, based on the shading devices. The overhang multiple blades have the lowest score, below 20% as shown in Figure 72. Therefore, the shading devices on south influences the levels of the glare effect in class. See APPENDIX J for more.

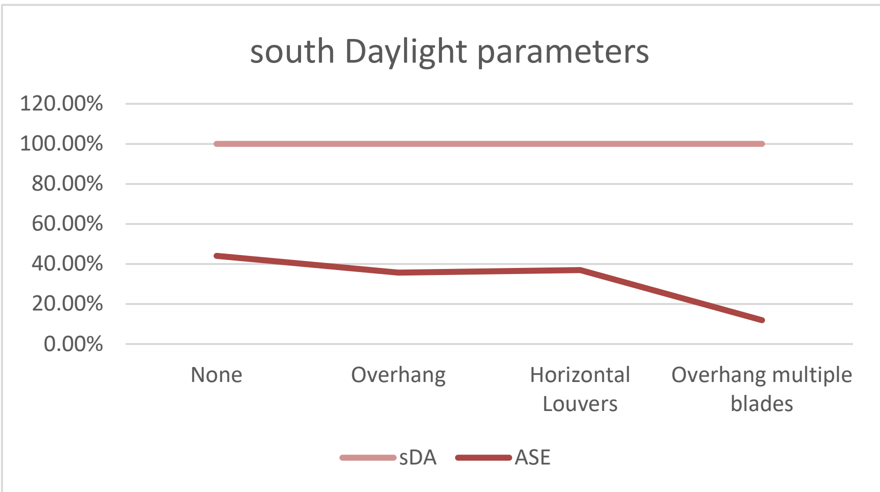


Figure 72: sDA and ASE levels for the south-oriented classroom

CHAPTER 7

CONCLUSIONS AND RECOMMENADTIONS

7.1 Conclusions

Throughout the whole process that this thesis has gone through researching, it has emphasized even more the role of light in the design of spaces that put the needs of the occupants first.

Daylight has an extremely high impact on the mental and physical health, especially on the younger children. They are the most affected if direct daylight comes and overheats the space, they stay for over 6 hours. As such, if the environment they are around has too much of everything, it comes as an on slaughter of their senses which could cause them health problems (depression etc.). Shading devices are a passive sustainable design method that help in reducing the energy costs that a building spend during its lifetime. Depending on the orientation of the openings of the wall, it can create opportunities for better visual comfort for the youngling.

From the results provided by the simulations made, as well as the studies made, having both external and internal shading device with an under stable opacity to block, diffuse the direct sunlight coming from the east, west or south, it makes it a strategy towards the optimization of daylight. It can be applied on the already existing schools, by analyzing the daylight parameters and noting down that shading devices is best for that specific orientation.

During the simulation phase, it comes to the conclusion that the 1963' version of Sami Frasheri may have had better daylight levels than the 2020' one. However, as it aims to have as much natural light as possible, the 1963' one had the glare impact on the students' performance higher than the one of 2020'.

The shading devices are imperative to optimize the daylight in classrooms, especially when the correct ones are implemented on the façade of the building. the combination of the external and the internal shading have shown the best results in the optimization simulations of the redesigned classrooms.

7.2. Limitations of the study

Throughout this study, there have been some setbacks that have limited this study. The fact that both buildings of Sami Frasheri are not entirely physical to conduct the analysis of its construction elements (window size and its pattern throughout the floor, etc.), as well as the lack of plans of the new school (due to internal affairs in the Municipality of Tirana) are some of the problems that this study faced.

The simulation software of Lghtstanza is an advanced software that shows the best results for daylight analysis. However, it limits its users due to the 14 days free trial, where you cannot access the result data after the free trial finishes. This is extremely hard for students conducting building simulations as the payment for the software is very pricy. Also, the software uses the weather data from the Climate station of Podgorica for the simulations located in Albania. This may cause changes in the results of the simulation due to the data not being accurate. There are far closer climate stations in Tirana.

7.3 Recommendations for future research

As the study was focused on the building scale analysis, as well as lacking the physical part of the site, it is recommended to conducted the research on the already built building of two different schools in two different locations. This may bring diverse inputs and outputs that will make the study more detailed in data regarding the natural daylight in educational buildings.

The materials used on the constructive elements are part of the recommendations, as they hold an impact on the reflective percentage of the daylight inside the classroom, due to their attributes.

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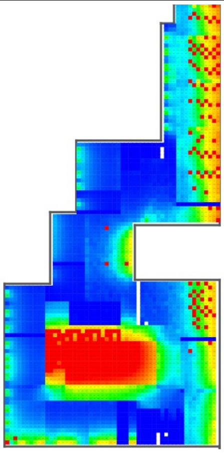
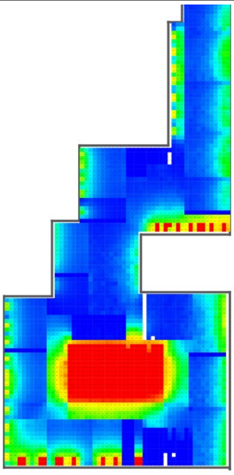
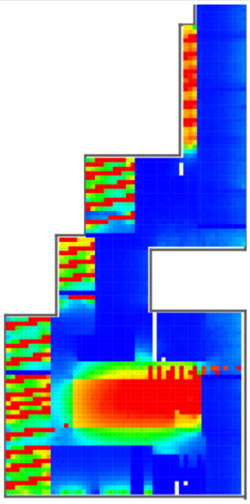
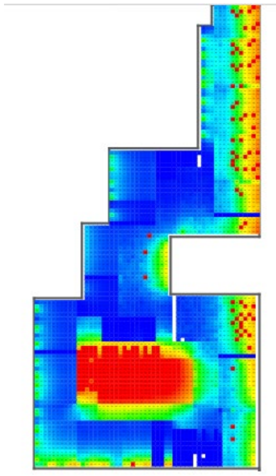
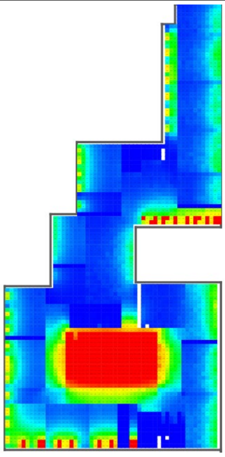
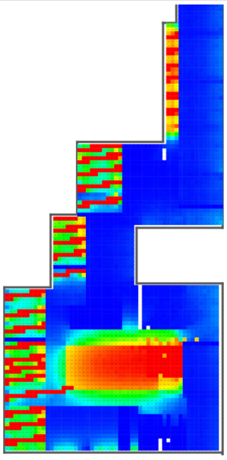
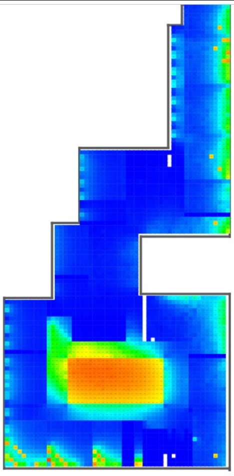
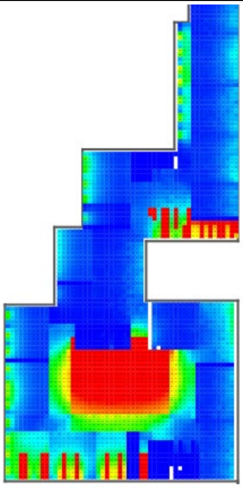
APPENDIX A

Table 20: Illuminance Grid for March- September – December_ New school

Illuminance Grid for March- September - December			
Overall Average = **2,268.87 lux**		Sami Frasheri school- New school	
Time	**Area (m2)** 1,426.60	**Results** 	**Summary**
Mar 21 8:00 AM			*Avg: 1,697.2 lux* *Max: 27,299.4 lux* *Min: 0.0 lux* *Avg/Min: ∞*
Mar 21 12:00 PM			*Avg: 4,020.1 lux* *Max: 64,314.6 lux* *Min: 0.0 lux* *Avg/Min: ∞*

Mar 21 5:00 PM		*Avg:* *1,088.7 lux* *Max:* *12,883.5 lux* *Min:* *0.0 lux* *Avg/Min:* ∞
Sep 21 8:00 AM		*Avg:* *2,033.1 lux* *Max:* *32,200.9 lux* *Min:* *0.0 lux* *Avg/Min:* ∞
Sep 21 12:00 PM		*Avg:* *4,429.3 lux* *Max:* *65,100.9 lux* *Min:* *0.0 lux* *Avg/Min:* ∞

Sep 21 5:00 PM		*Avg:* *745.6 lux* *Max:* *8,616.6 lux* *Min:* *0.0 lux* *Avg/Min:* ∞
Dec 21 8:00 AM		*Avg:* *241.8 lux* *Max:* *2,270.0 lux* *Min:* *0.0 lux* *Avg/Min:* ∞
Dec 21 12:00 PM		*Avg:* *2,085.2 lux* *Max:* *34,165.9 lux* *Min:* *0.0 lux* *Avg/Min:* ∞

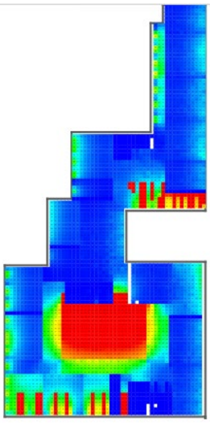
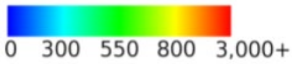
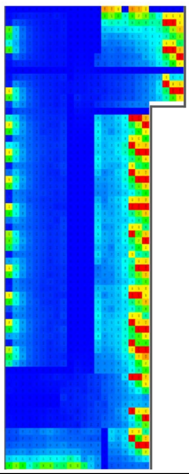
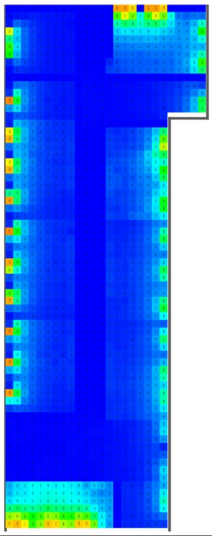
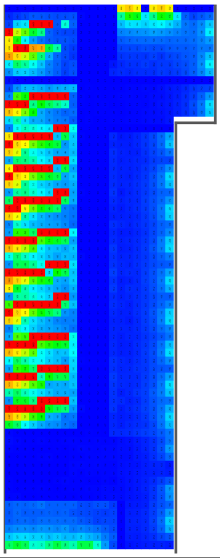
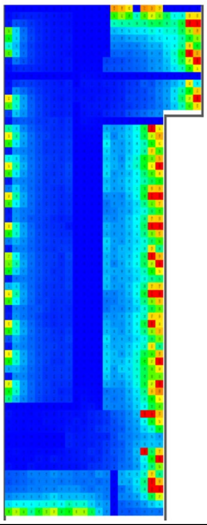
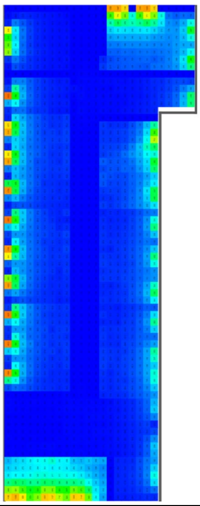
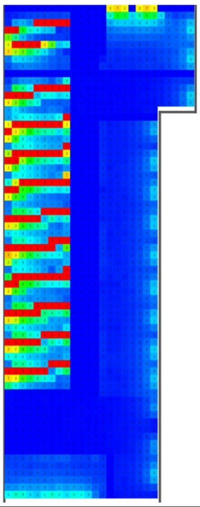
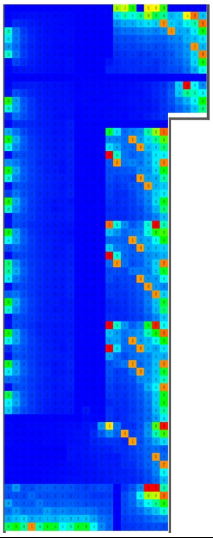
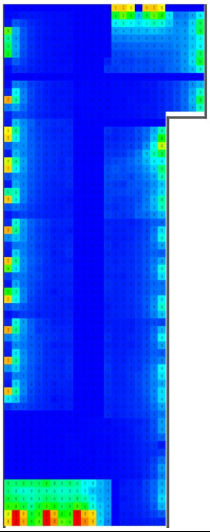
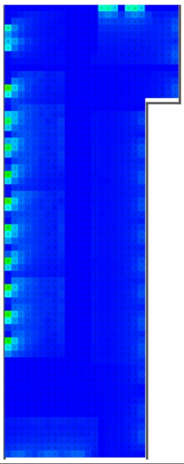
Dec 21 5:00 PM		*Avg:* *87.3 lux* *Max:* *862.0 lux* *Min:* *0.0 lux* *Avg/Min:* ∞

Table 21: Illuminance Grid for March- September – December_ Old school

Illuminance Grid for March- September - December			
Overall Average = **88.85 lux**		Sami Frasheri school- Old school- With blinders	
Time	**Area (m2)** 638.1	**Results** 	**Summary** 
Mar 21 8:00 AM			*Avg:* 68.5 lux *Max:* 2,113.1 lux *Min:* 0.0 lux *Avg/Min:* ∞

Mar 21 12:00 PM		*Avg:* 121.5 lux *Max:* 1,809.8 lux *Min:* 0.0 lux *Avg/Min:* ∞
Mar 21 5:00 PM		*Avg:* 683.0 lux *Max:* 11,356.9 lux *Min:* 0.0 lux *Avg/Min:* ∞
Sep 21 8:00 AM		*Avg:* 601.5 lux *Max:* 25,897.8 lux *Min:* 0.0 lux *Avg/Min:* ∞

Sep 21 12:00 PM		*Avg:* 124.2 lux *Max:* 2,033.1 lux *Min:* 0.0 lux *Avg/Min:* ∞
Sep 21 5:00 PM		*Avg:* 498.3 lux *Max:* 7,207.5 lux *Min:* 0.0 lux *Avg/Min:* ∞
Dec 21 8:00 AM		*Avg:* 154.8 lux *Max:* 4,565.5 lux *Min:* 0.0 lux *Avg/Min:* ∞

Dec 21 12:00 PM		*Avg:* 218.1 lux *Max:* 27,908.7 lux *Min:* 0.0 lux *Avg/Min:* ∞
Dec 21 5:00 PM		*Avg:* 39.1 lux *Max:* 556.9 lux *Min:* 0.0 lux *Avg/Min:* ∞

APPENDIX B

Classroom ID: 4O

Table 22: Point-to-point illuminance of north classroom

Time	March (lux)	December (lux)
8:00	427.50	141.9
9:00	870.80	251.5
10:00	532.50	331.9
11:00	438.90	327.00
12:00	413.60	300.90
13:00	385.30	279.40
14:00	353.70	259.70
15:00	332.60	206.3
16:00	303.90	132
17:00	224.1	58.4

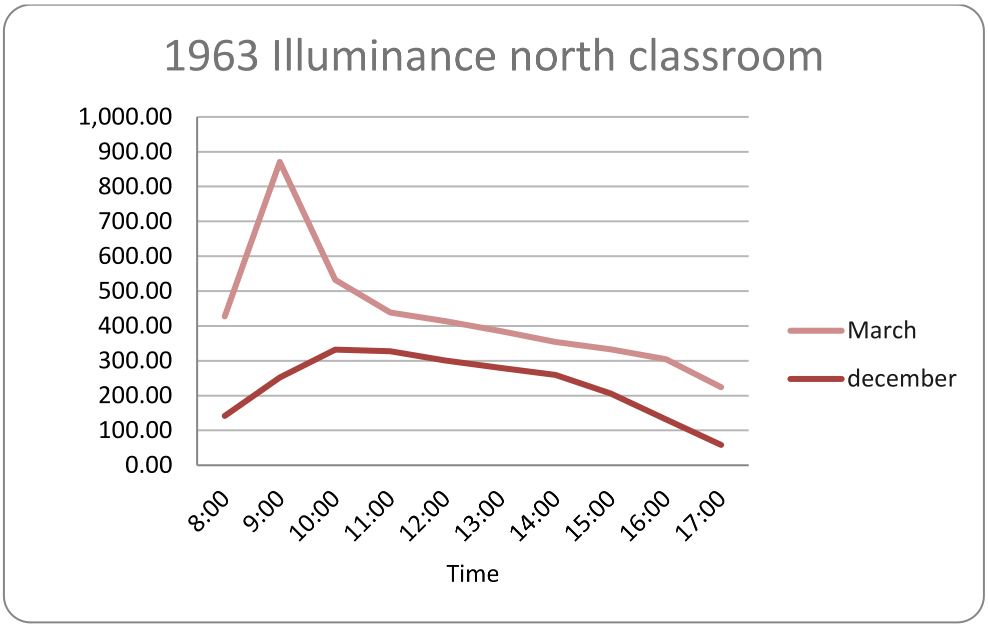
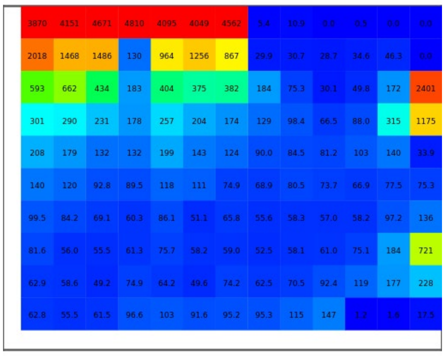
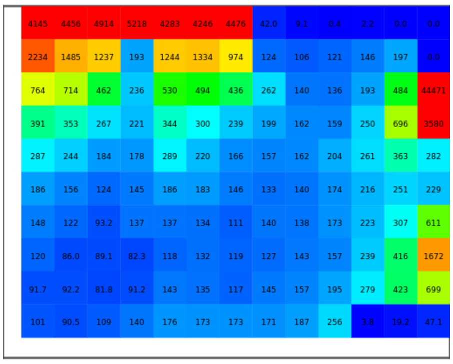
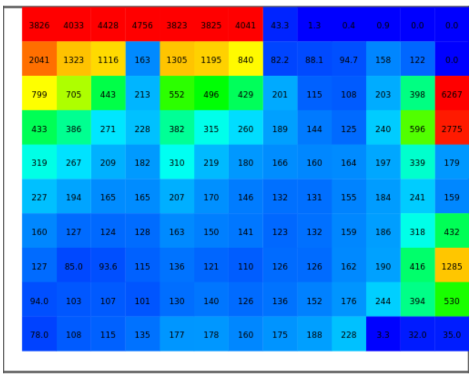
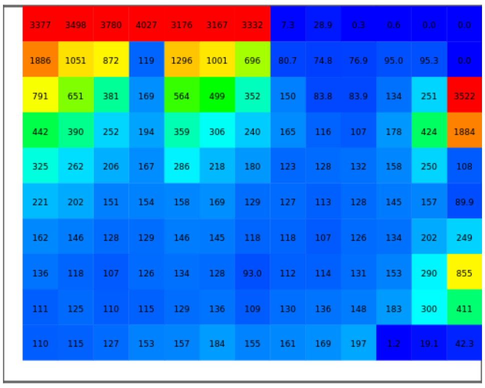


Figure 73: *1963 Illuminance north classroom*

Table 23: Point-to-point illuminance grid (March)

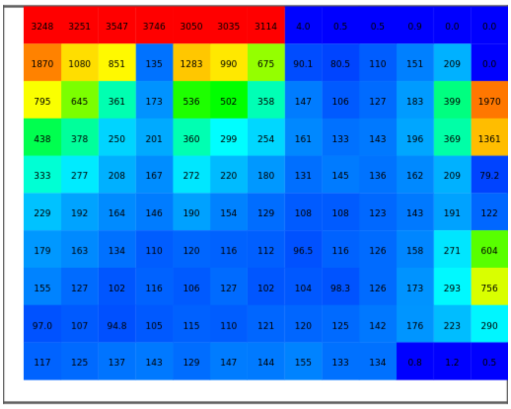
Illuminance Grid		
Overall Average = 328.60 lux		**Area (m2) = 40**
Time	**Results** 	**Summary** 
Mar 21 8:00 AM		*Avg:* 427.5 lux *Avg/Min:* ∞ *Max:* 4,809.7 lux *Min:* 0.0 lux
Mar 21 9:00 AM		*Avg:*870.8 lux *Avg/Min:*∞ *Max:*44,470.7 lux *Min:*0.0 lux
Mar 21 10:00 AM		*Avg:*532.5 lux *Avg/Min:*∞ *Max:*6,267.1 lux *Min:*0.0 lux

Mar 21
11:00
AM



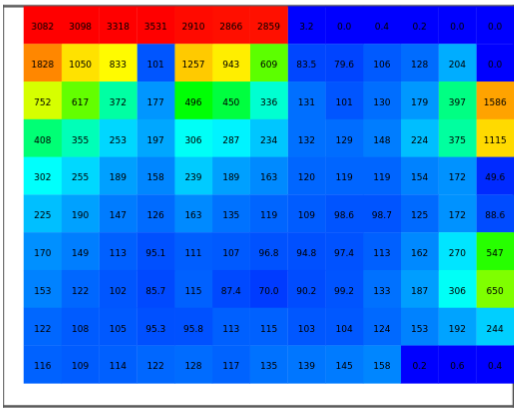
*Avg:*438.9 lux
Avg/Min:∞
*Max:*4,027.4 lux
*Min:*0.0 lux

Mar 21
12:00
PM



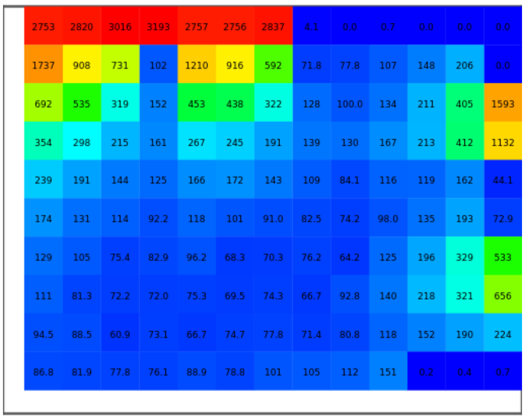
*Avg:*413.6 lux
Avg/Min:∞
*Max:*3,745.6 lux
*Min:*0.0 lux

Mar 21
1:00 PM



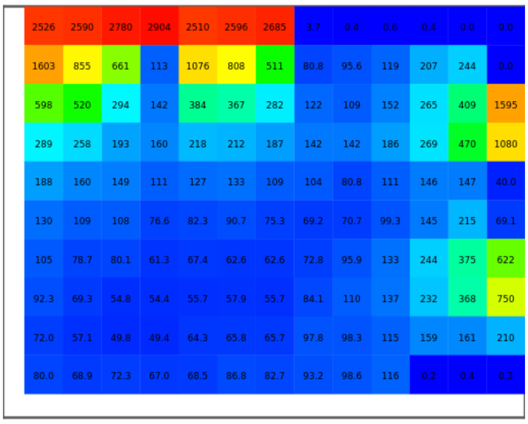
*Avg:*385.3 lux
Avg/Min:∞
*Max:*3,530.5 lux
*Min:*0.0 lux

Mar 21
2:00 PM



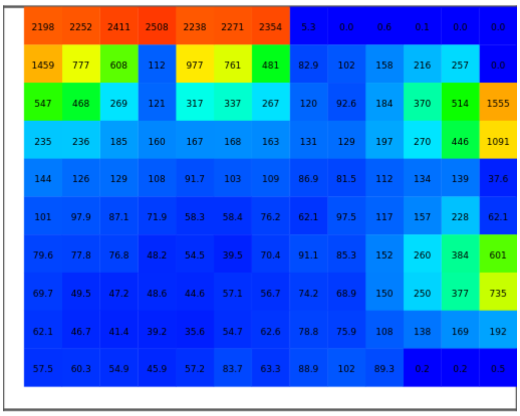
*Avg:*353.7 lux
Avg/Min:∞
*Max:*3,192.7 lux
*Min:*0.0 lux

Mar 21
3:00 PM



*Avg:*332.6 lux
Avg/Min:∞
*Max:*2,903.5 lux
*Min:*0.0 lux

Mar 21
4:00 PM



*Avg:*303.9 lux
Avg/Min:∞
*Max:*2,507.8 lux
*Min:*0.0 lux

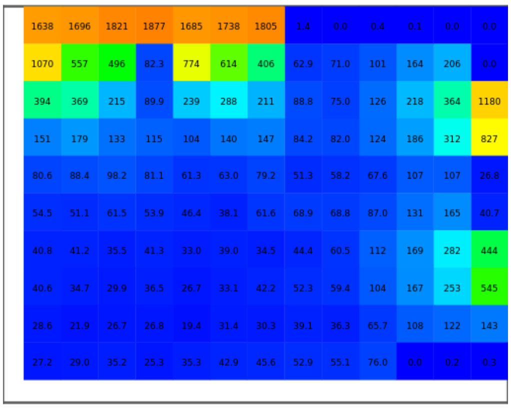
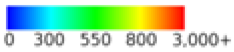
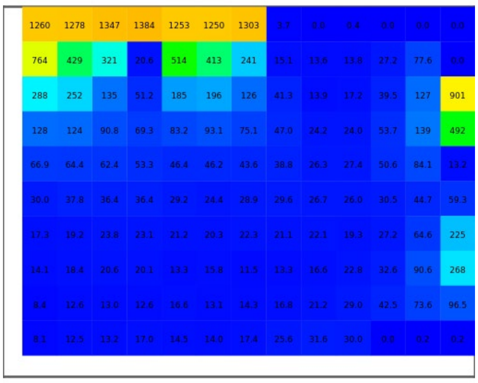
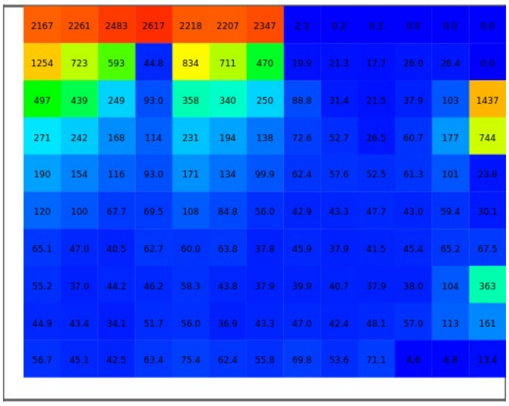
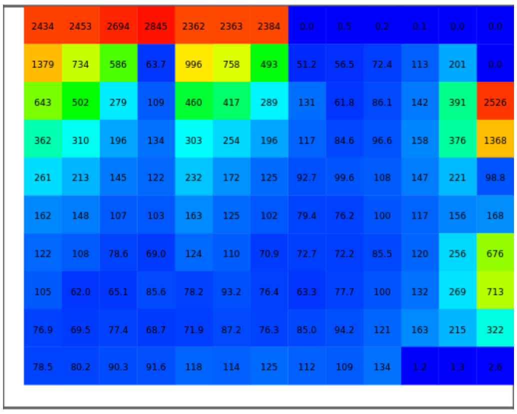
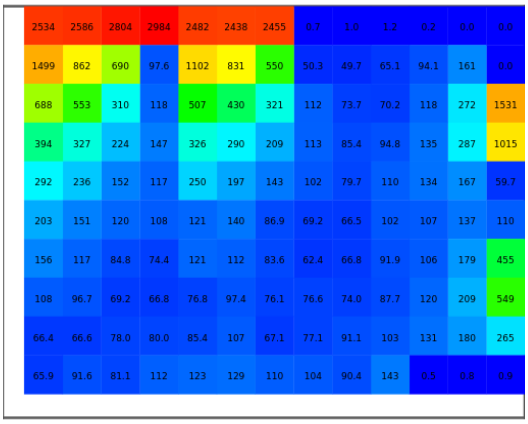
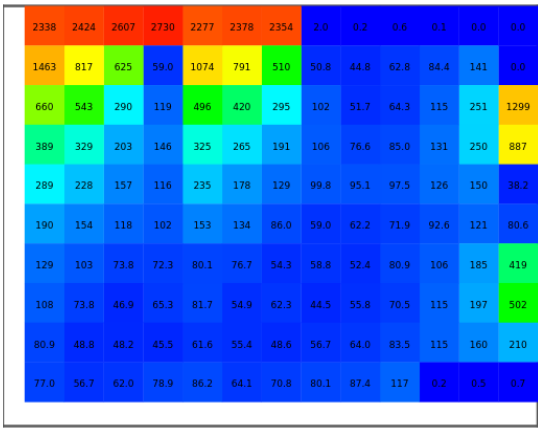
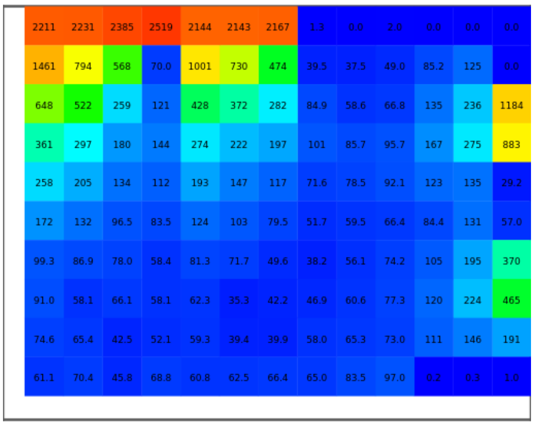
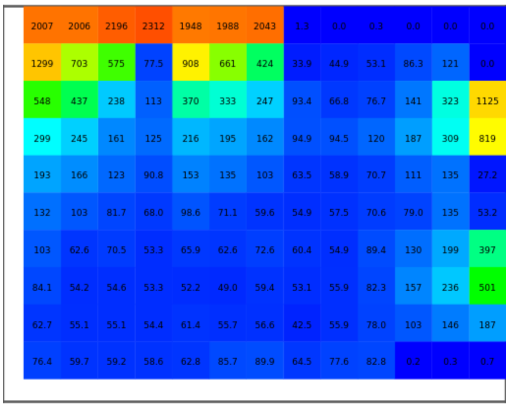
Mar 21 5:00 PM		*Avg:*224.1 lux *Avg/Min:*∞ *Max:*1,876.9 lux *Min:*0.0 lux

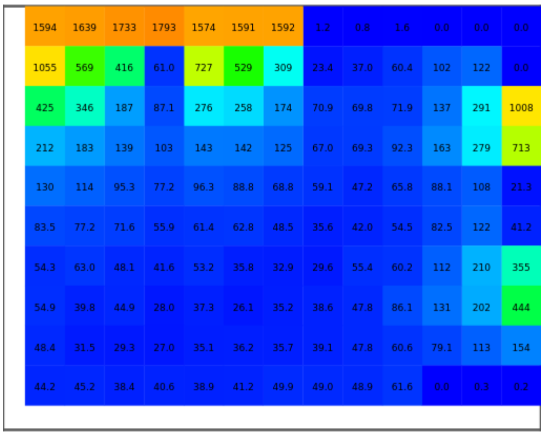
Table 24: Point-to-point illuminance grid (December)

Illuminance Grid		
Overall Average =328.60 lux		***Area (m2) =40***
Time	**Results** 	***Summary***
Dec 21 8:00 AM		*Avg:* 141.9 lux *Avg/Min:* ∞ *Max:* 1,383.7 lux *Min:* 0.0 lux

Dec 21 9:00 AM		*Avg: 251.5 lux* *Avg/Min: ∞* *Max: 2,617.5 lux* *Min: 0.0 lux*
Dec 21 10:00 AM		*Avg:*331.9 lux *Avg/Min:*∞ *Max:*2,845.5 lux *Min:*0.0 lux
Dec 21 11:00 AM		*Avg:*327.0 lux *Avg/Min:*∞ *Max:*2,983.5 lux *Min:*0.0 lux

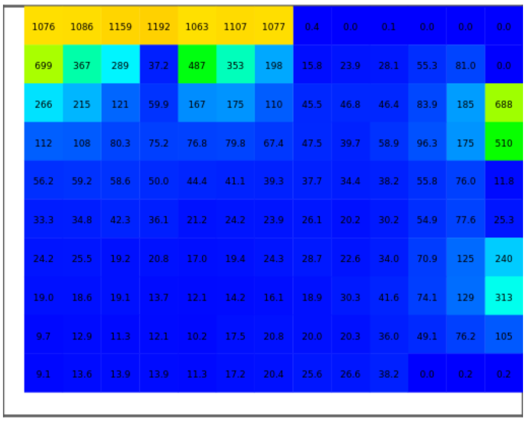
Dec 21 12:00 PM		*Avg:*300.9 lux *Avg/Min:*∞ *Max:*2,730.4 lux *Min:*0.0 lux
Dec 21 1:00 PM		*Avg:*279.4 lux *Avg/Min:*∞ *Max:*2,518.5 lux *Min:*0.0 lux
Dec 21 2:00 PM		*Avg:*259.7 lux *Avg/Min:*∞ *Max:*2,311.5 lux *Min:*0.0 lux

Dec 21
3:00 PM



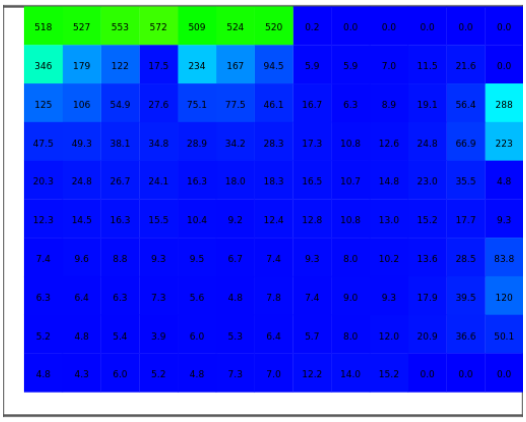
*Avg:*206.3 lux
Avg/Min:∞
*Max:*1,793.2 lux
*Min:*0.0 lux

Dec 21
4:00 PM



*Avg:*132.0 lux
Avg/Min:∞
*Max:*1,191.5 lux
*Min:*0.0 lux

Dec 21
5:00 PM



*Avg:*58.4 lux
Avg/Min:∞
*Max:*572.5 lux
*Min:*0.0 lux

APPENDIX C

Classroom ID: 1O

Table 25: Point-to-point illuminance of east classroom

Time	March (lux)	December (lux)
08:00	1.572,60	66,8
09:00	1.316,30	92
10:00	1.103,80	373,2
11:00	241,4	169,5
12:00	246,5	166,2
13:00	230,1	158,1
14:00	229,8	147,3
15:00	232,8	124,5
16:00	220,1	74,1
17:00	141,1	23,6

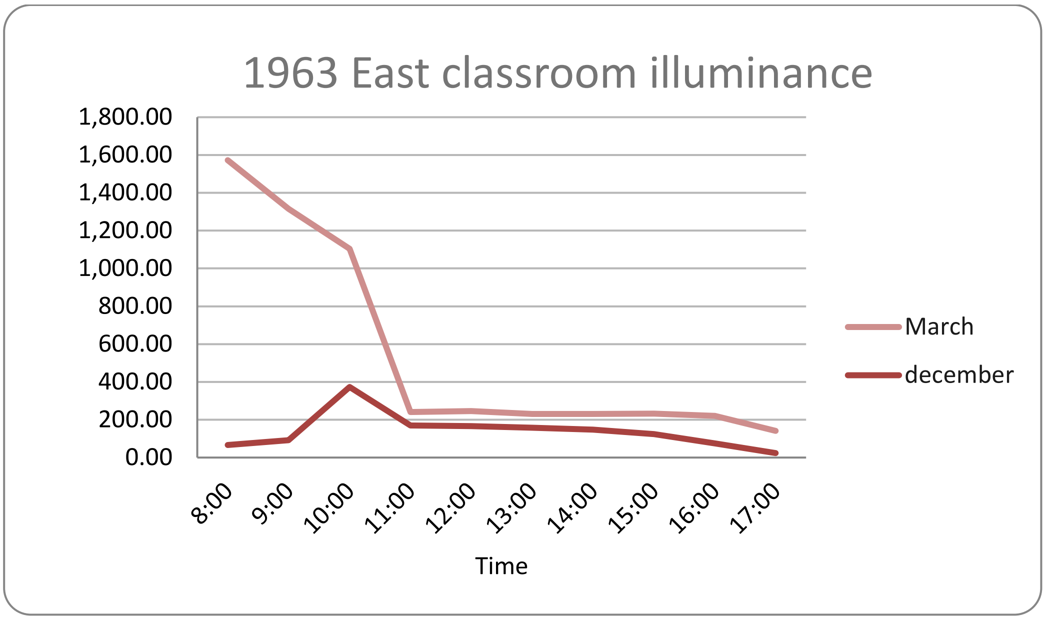
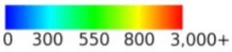
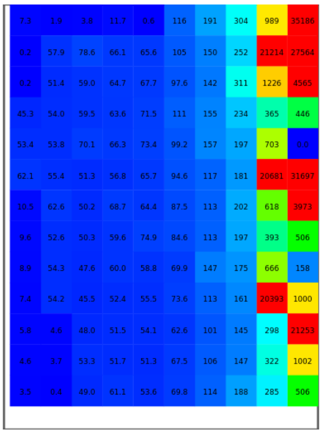
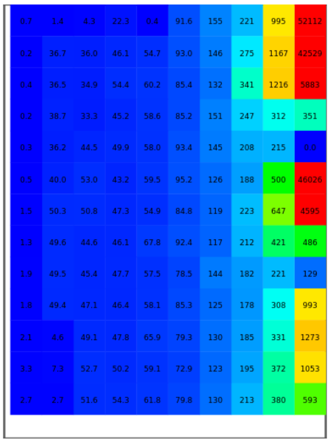
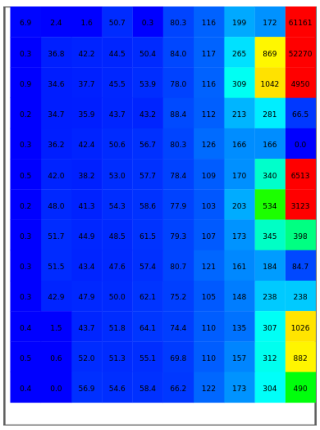
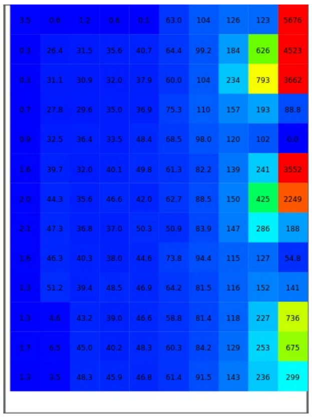
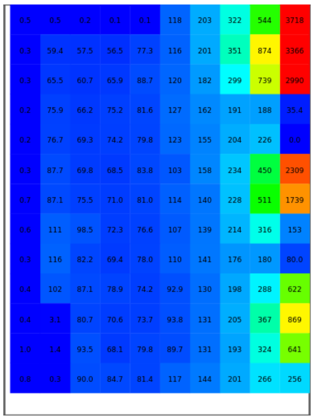
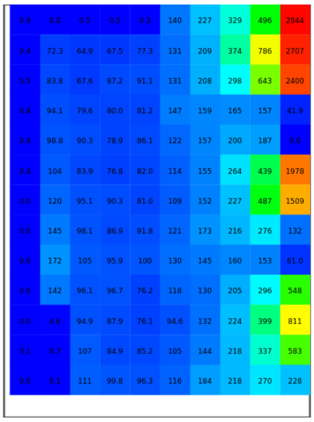
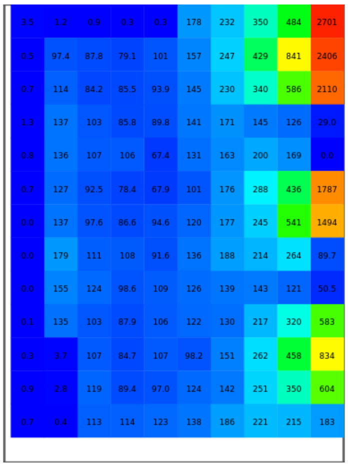
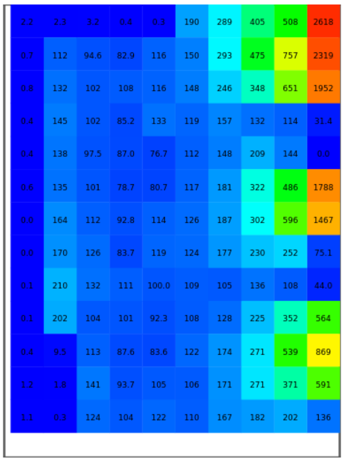
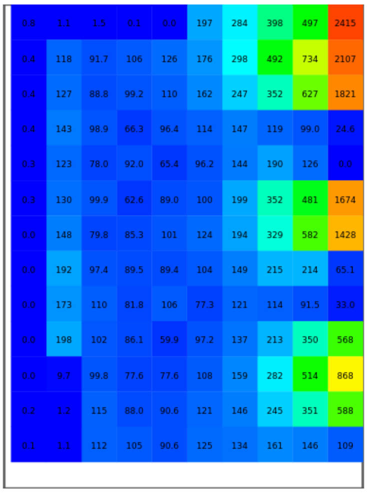


Figure 74: 1963 East classroom illuminance

Table 26: Point-to-point illuminance grid (March)

Illuminance Grid		
Overall Average = 346.50 lux		**Area (m2) = 40**
Time	**Results** 	**Summary** 
Mar 21 8:00 AM		*Avg:* 1,572.6 lux *Avg/Min:* ∞ *Max:* 35,185.9 lux *Min:* 0.0 lux
Mar 21 9:00 AM		*Avg:* 1,316.3 lux *Avg/Min:* ∞ *Max:* 52,112.5 lux *Min:* 0.0 lux
Mar 21 10:00 AM		*Avg:* 1,103.8 lux *Avg/Min:* ∞ *Max:* 61,160.9 lux *Min:* 0.0 lux

Mar 21 11:00 AM		*Avg:* 241.4 lux *Avg/Min:* ∞ *Max:* 5,675.8 lux *Min:* 0.0 lux
Mar 21 12:00 PM		*Avg:* 246.5 lux *Avg/Min:* ∞ *Max:* 3,718.2 lux *Min:* 0.0 lux
Mar 21 1:00 PM		*Avg:* 230.1 lux *Avg/Min:* ∞ *Max:* 2,944.0 lux *Min:* 0.0 lux

Mar 21 2:00 PM		*Avg:* 229.8 lux *Avg/Min:* ∞ *Max:* 2,700.9 lux *Min:* 0.0 lux
Mar 21 3:00 PM		*Avg:* 232.8 lux *Avg/Min:* ∞ *Max:* 2,618.0 lux *Min:* 0.0 lux
Mar 21 4:00 PM		*Avg:* 220.1 lux *Avg/Min:* ∞ *Max:* 2,415.0 lux *Min:* 0.0 lux

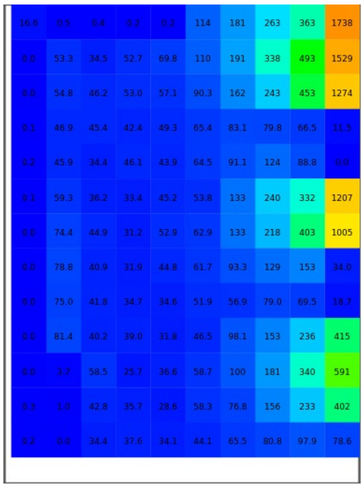
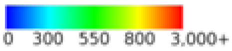
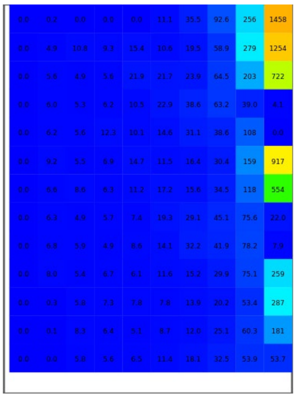
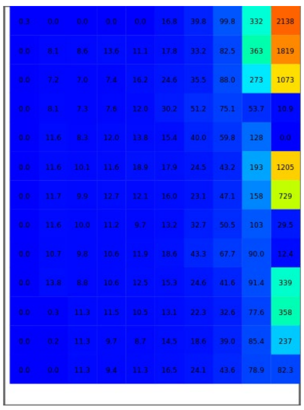
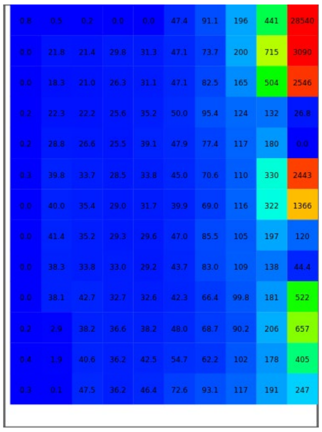
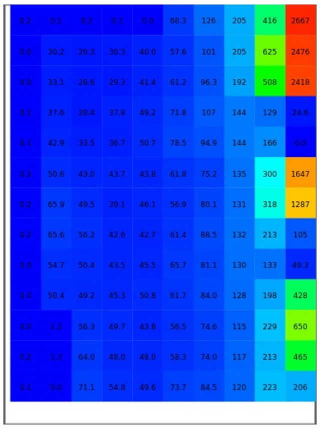
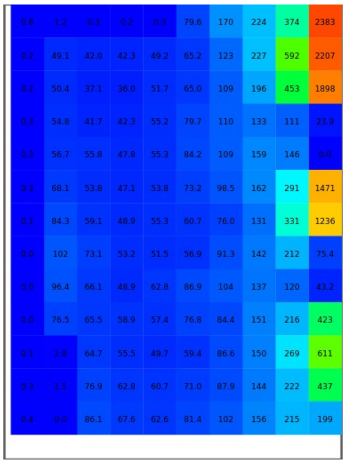
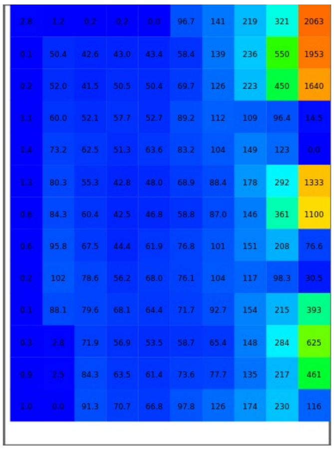
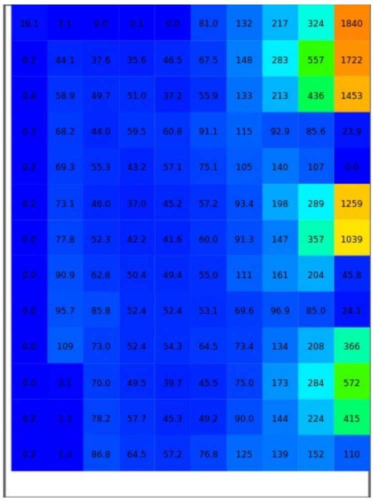
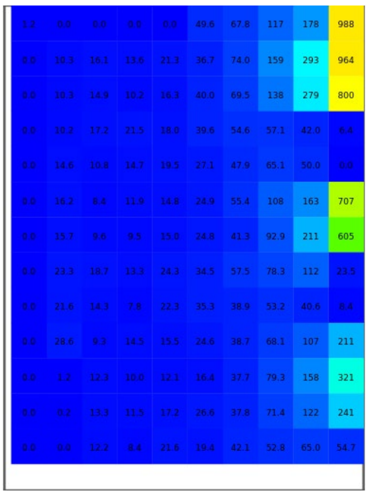
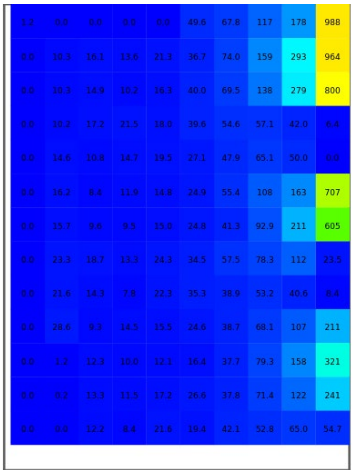
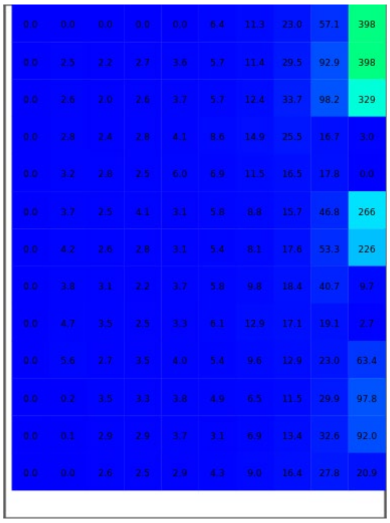
Mar 21 5:00 PM		*Avg:* 141.1 lux *Avg/Min:* ∞ *Max:* 1,738.0 lux *Min:* 0.0 lux

Table 27:Point-to-point illuminance grid (December)

Illuminance Grid		
Overall Average = 346.50 lux		***Area (m2) =40***
Time	**Results** 	***Summary***
Dec 21 8:00 AM		*Avg:* 66.8 lux *Avg/Min:* ∞ *Max:* 1,457.6 lux *Min:* 0.0 lux
Dec 21 9:00 AM		*Avg:* 92.0 lux *Avg/Min:* ∞ *Max:* 2,137.7 lux *Min:* 0.0 lux

Dec 21 10:00 AM		*Avg:* 373.2 lux *Avg/Min:* ∞ *Max:* 28,540.3 lux *Min:* 0.0 lux
Dec 21 11:00 AM		*Avg:* 169.5 lux *Avg/Min:* ∞ *Max:* 2,666.7 lux *Min:* 0.0 lux
Dec 21 12:00 PM		*Avg:* 166.2 lux *Avg/Min:* ∞ *Max:* 2,383.1 lux *Min:* 0.0 lux

Dec 21 1:00 PM		*Avg:* 158.1 lux *Avg/Min:* ∞ *Max:* 2,062.6 lux *Min:* 0.0 lux
Dec 21 2:00 PM		*Avg:* 147.3 lux *Avg/Min:* ∞ *Max:* 1,839.9 lux *Min:* 0.0 lux
Dec 21 3:00 PM		*Avg:* 124.5 lux *Avg/Min:* ∞ *Max:* 1,529.2 lux *Min:* 0.0 lux

Dec 21 4:00 PM		*Avg:* 74.1 lux *Avg/Min:* ∞ *Max:* 988.2 lux *Min:* 0.0 lux
Dec 21 5:00 PM		*Avg:* 23.6 lux *Avg/Min:* ∞ *Max:* 398.0 lux *Min:* 0.0 lux

APPENDIX D

Classroom ID: 2O

Table 28: Point-to-point illuminance of south classroom

Time	March (lux)	December (lux)
08:00	503,70	190,6
09:00	4.835,70	319,4
10:00	6.381,70	427,5
11:00	7.484,20	4.079,00
12:00	6.777,30	6.060,90
13:00	5.943,10	5.044,90
14:00	4.364,60	3.160,40
15:00	3.315,10	334,2
16:00	2.096,80	178,2
17:00	270,4	67,3

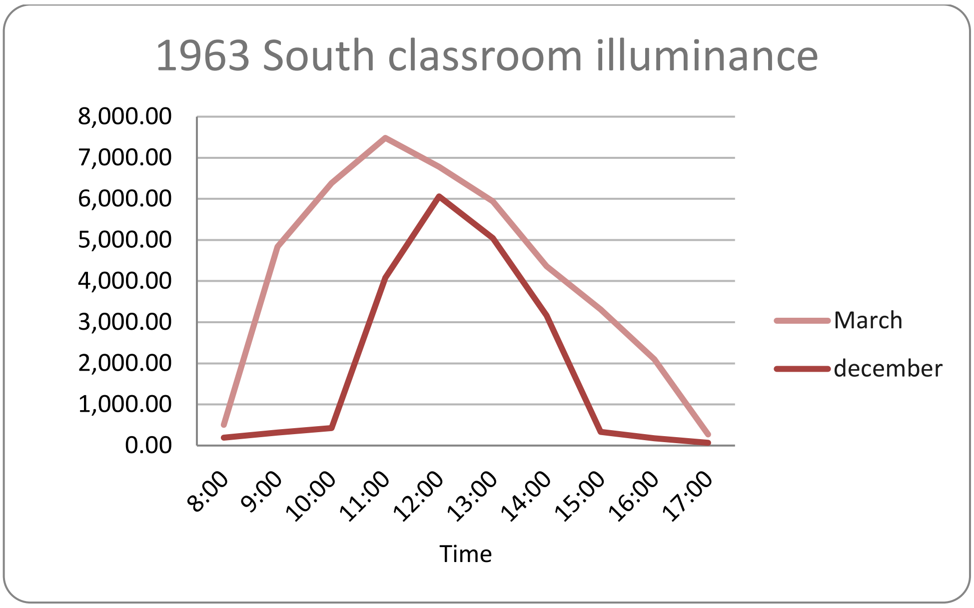
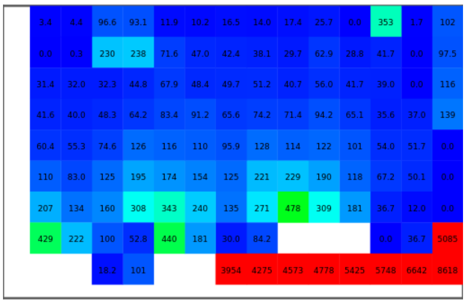
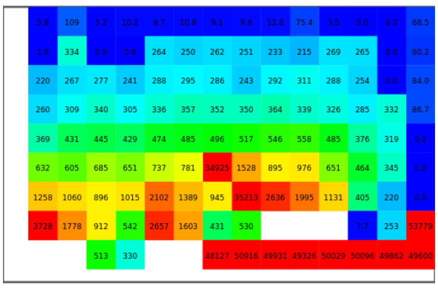
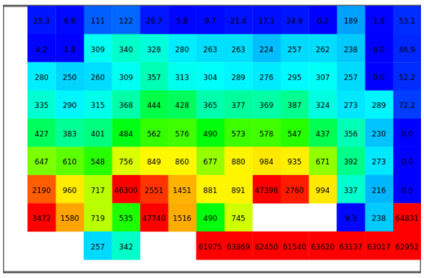
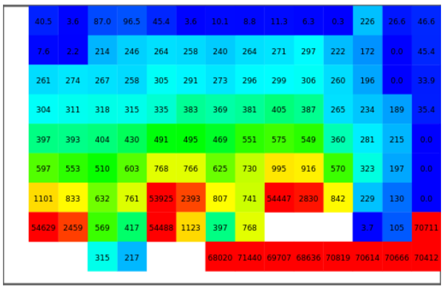
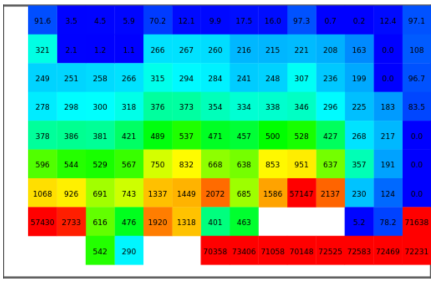
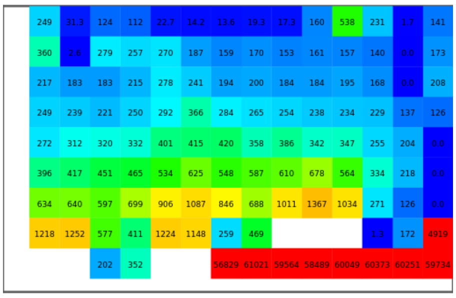
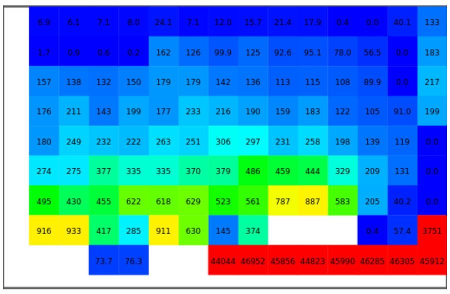


Figure 75: 1963 South classroom illuminance

Table 29: Point-to-point illuminance grid (March)

<table>
<tr><th colspan="3">Illuminance Grid</th></tr>
<tr><td colspan="2">Overall Average = 3,091.75 lux</td><td>Area (m2) = 40</td></tr>
<tr><th>Time</th><th>Results
</th><th>Summary
</th></tr>
<tr><td>Mar 21
8:00
AM</td><td></td><td>Avg:
503.7 lux
Avg/Min:
∞
Max:
8,617.7 lux
Min:
0.0 lux</td></tr>
<tr><td>Mar 21
9:00
AM</td><td></td><td>Avg:
4,835.7 lux
Avg/Min:
∞
Max:
53,778.7 lux
Min:
0.0 lux</td></tr>
</table>

Mar 21 10:00 AM		*Avg:* 6,381.7 lux *Avg/Min:* ∞ *Max:* 64,830.8 lux *Min:* 0.0 lux
Mar 21 11:00 AM		*Avg:* 7,484.2 lux *Avg/Min:* ∞ *Max:* 71,439.8 lux *Min:* 0.0 lux
Mar 21 12:00 PM		*Avg:* 6,777.3 lux *Avg/Min:* ∞ *Max:* 73,406.4 lux *Min:* 0.0 lux

Mar 21 1:00 PM		*Avg:* 5,943.1 lux *Avg/Min:* ∞ *Max:* 69,837.4 lux *Min:* 0.0 lux
Mar 21 2:00 PM		*Avg:* 4,364.6 lux *Avg/Min:* ∞ *Max:* 61,021.1 lux *Min:* 0.0 lux
Mar 21 3:00 PM		*Avg:* 3,315.1 lux *Avg/Min:* ∞ *Max:* 46,952.5 lux *Min:* 0.0 lux

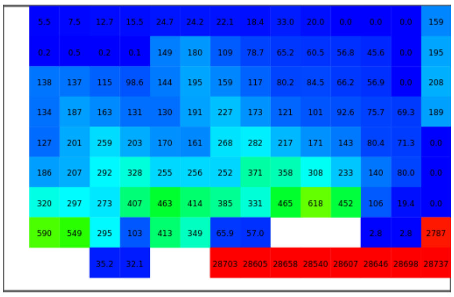
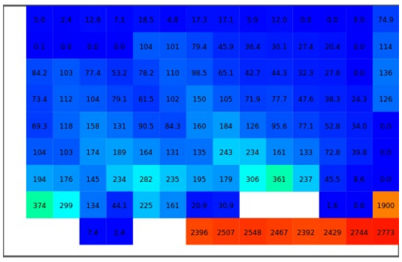
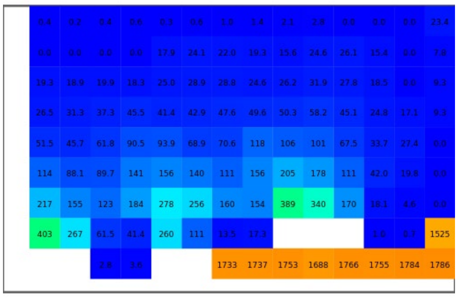
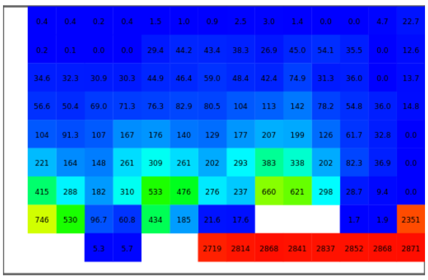
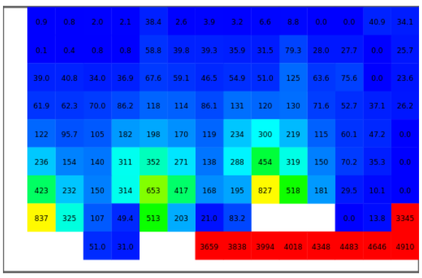
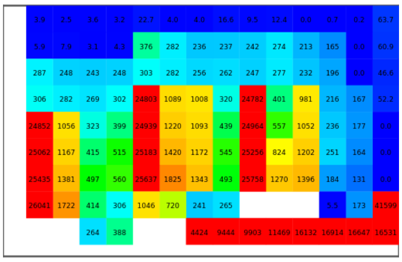
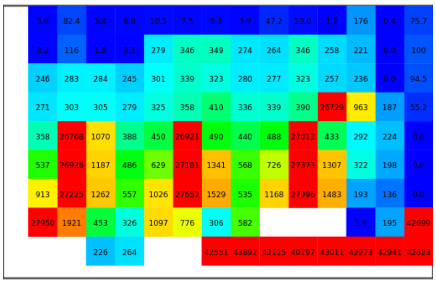
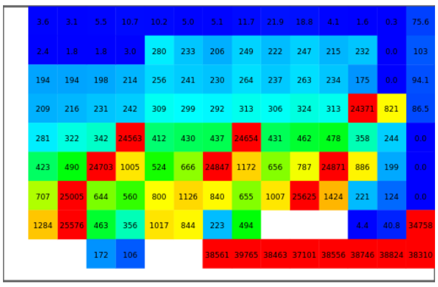
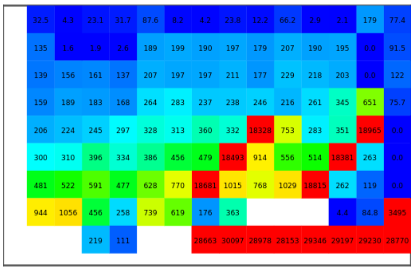
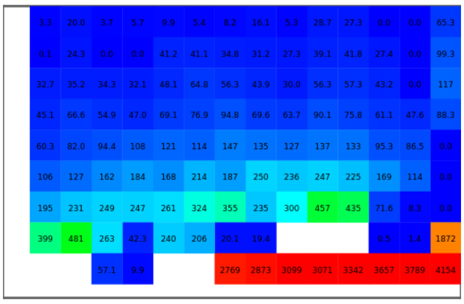
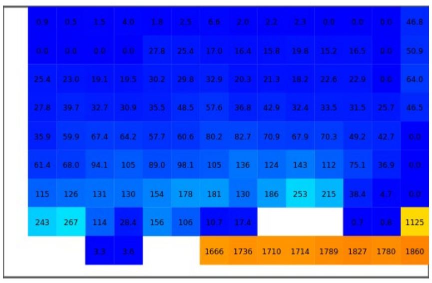
Mar 21 4:00 PM		*Avg:* 2,096.8 lux *Avg/Min:* ∞ *Max:* 28,737.3 lux *Min:* 0.0 lux
Mar 21 5:00 PM		*Avg:* 270.4 lux *Avg/Min:* ∞ *Max:* 2,772.5 lux *Min:* 0.0 lux

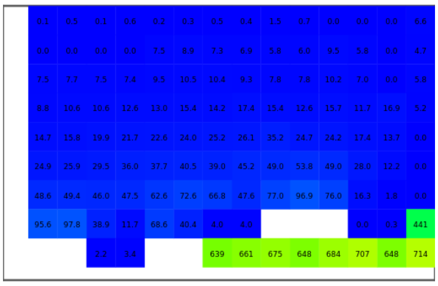
Table 30: Point-to-point illuminance grid (December)

Illuminance Grid		
Overall Average = 3,091.75 lux		***Area (m2) =40***
Time	**Results** 	***Summary***
Dec 21 8:00 AM		*Avg:* 190.6 lux *Avg/Min:* ∞ *Max:* 1,786.3 lux *Min:* 0.0 lux
Dec 21 9:00 AM		*Avg:* 319.4 lux *Avg/Min:* ∞ *Max:* 2,871.3 lux *Min:* 0.0 lux
Dec 21 10:00 AM		*Avg:* 427.5 lux *Avg/Min:* ∞ *Max:* 4,910.3 lux *Min:* 0.0 lux

Dec 21 11:00 AM		*Avg:* 4,079.0 lux *Avg/Min:* ∞ *Max:* 41,598.7 lux *Min:* 0.0 lux
Dec 21 12:00 PM		*Avg:* 6,060.9 lux *Avg/Min:* ∞ *Max:* 43,891.9 lux *Min:* 0.0 lux
Dec 21 1:00 PM		*Avg:* 5,044.9 lux *Avg/Min:* ∞ *Max:* 39,765.5 lux *Min:* 0.0 lux

Dec 21 2:00 PM		*Avg:* 3,160.4 lux *Avg/Min:* ∞ *Max:* 30,096.7 lux *Min:* 0.0 lux
Dec 21 3:00 PM		*Avg:* 334.2 lux *Avg/Min:* ∞ *Max:* 4,153.6 lux *Min:* 0.0 lux
Dec 21 4:00 PM		*Avg:* 178.2 lux *Avg/Min:* ∞ *Max:* 1,859.9 lux *Min:* 0.0 lux

Dec 21 5:00 PM



Avg: 67.3 lux
Avg/Min: ∞
Max: 714.0 lux
Min: 0.0 lux

APPENDIX E

Classroom ID: 3O

Table 31: Point-to-point illuminance of west classroom

Time	March (lux)	December (lux)
08:00	384,00	100,8
09:00	464,70	254,1
10:00	531,50	369,8
11:00	1.347,10	1.843,50
12:00	3.760,50	2.438,30
13:00	4.318,10	2.971,20
14:00	5.126,60	2.719,30
15:00	4.551,90	256
16:00	3.906,80	145,5
17:00	238,5	56,2

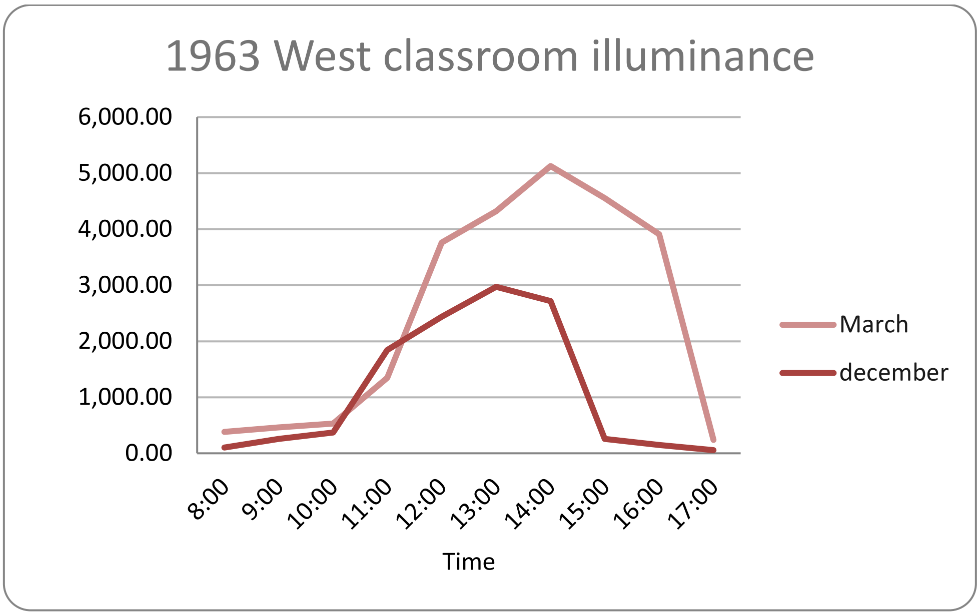
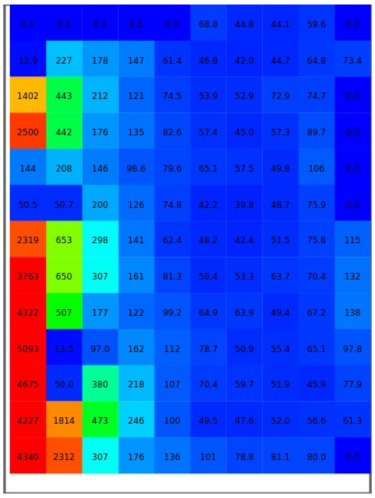
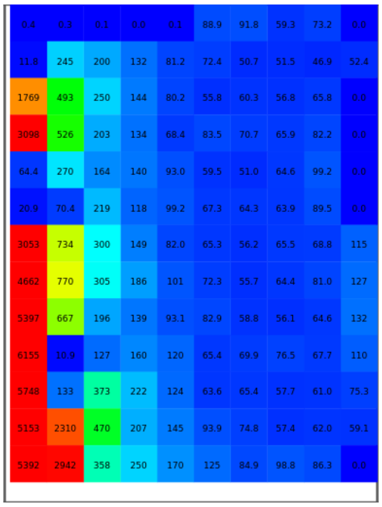
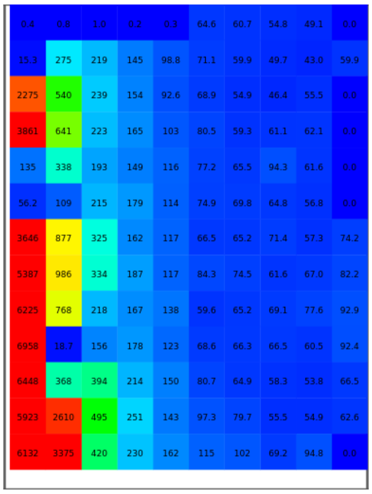
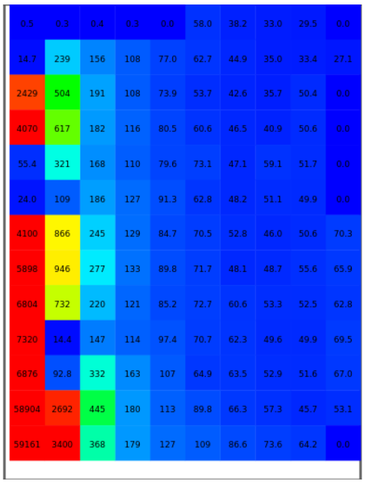
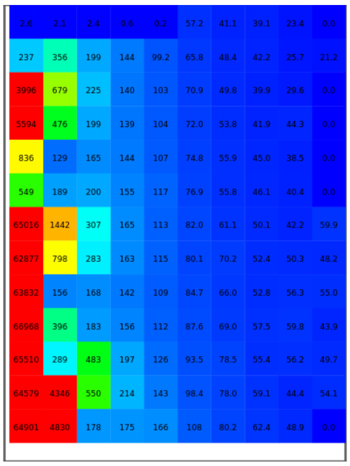
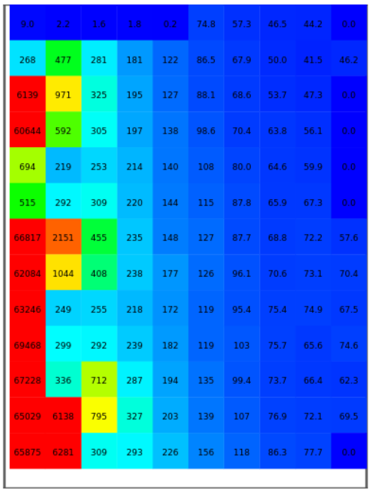
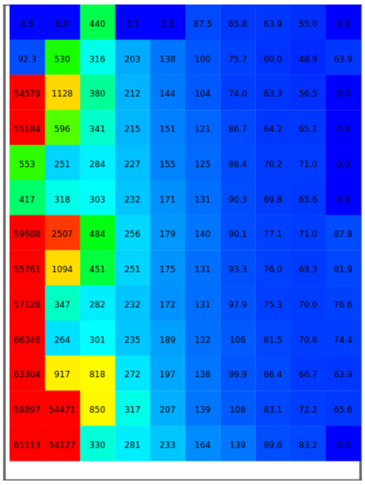
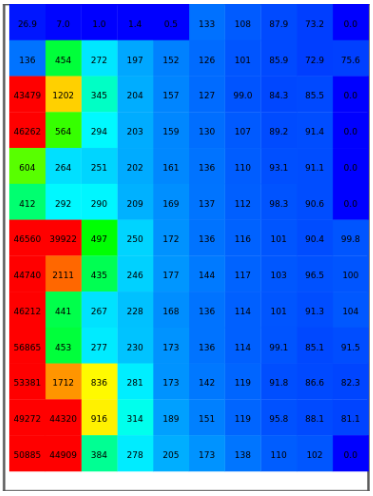


Figure 76: 1963 West classroom illuminance

Table 32: Point-to-point illuminance grid (March)

Illuminance Grid		
Overall Average = 1,789.22 lux		**Area (m2) = 40**
Time	**Results** 	**Summary** 
Mar 21 8:00 AM		*Avg:* 384.0 lux *Avg/Min:* ∞ *Max:* 5,093.0 lux *Min:* 0.0 lux
Mar 21 9:00 AM		*Avg:* 464.7 lux *Avg/Min:* ∞ *Max:* 6,154.5 lux *Min:* 0.0 lux

Mar 21 10:00 AM		*Avg:* 531.5 lux *Avg/Min:* ∞ *Max:* 6,957.7 lux *Min:* 0.0 lux
Mar 21 11:00 AM		*Avg:* 1,347.1 lux *Avg/Min:* ∞ *Max:* 59,160.9 lux *Min:* 0.0 lux
Mar 21 12:00 PM		*Avg:* 3,760.5 lux *Avg/Min:* ∞ *Max:* 66,967.8 lux *Min:* 0.0 lux

Mar 21 1:00 PM		*Avg:* 4,318.1 lux *Avg/Min:* ∞ *Max:* 69,468.4 lux *Min:* 0.0 lux
Mar 21 2:00 PM		*Avg:* 5,126.6 lux *Avg/Min:* ∞ *Max:* 66,346.1 lux *Min:* 0.0 lux
Mar 21 3:00 PM		*Avg:* 4,551.9 lux *Avg/Min:* ∞ *Max:* 56,865.2 lux *Min:* 0.0 lux

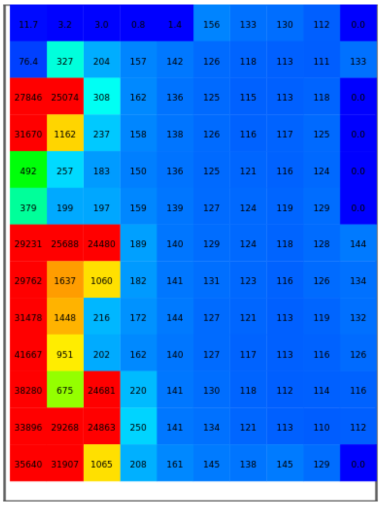
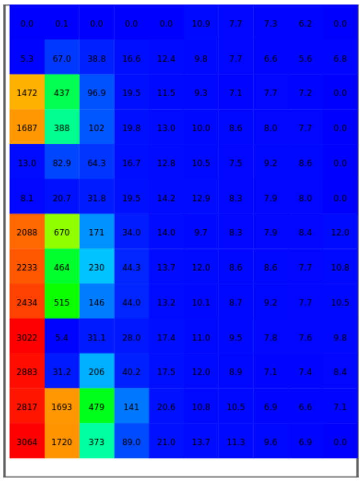
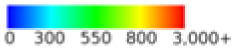
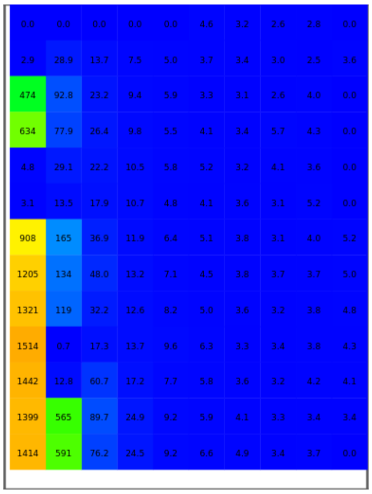
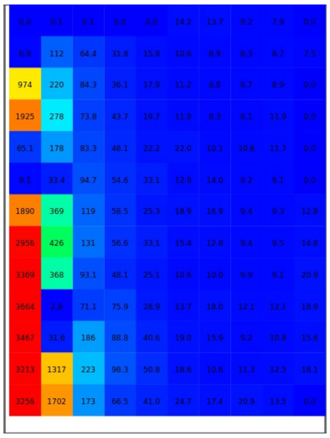
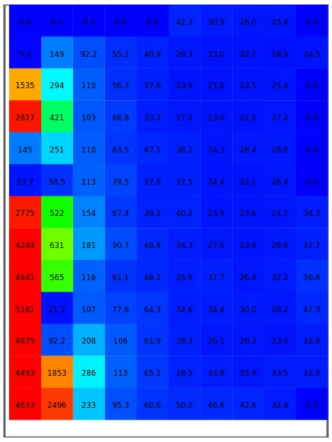
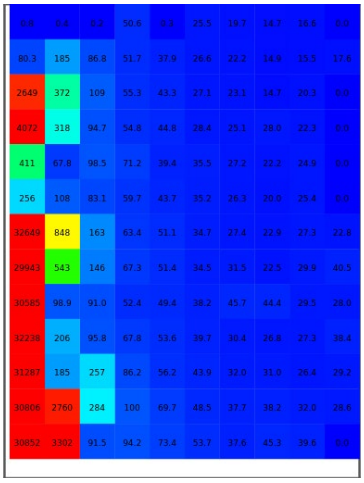
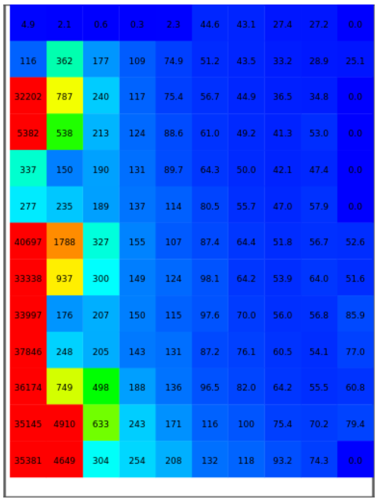
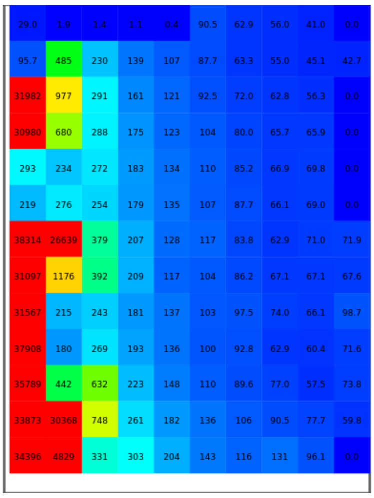
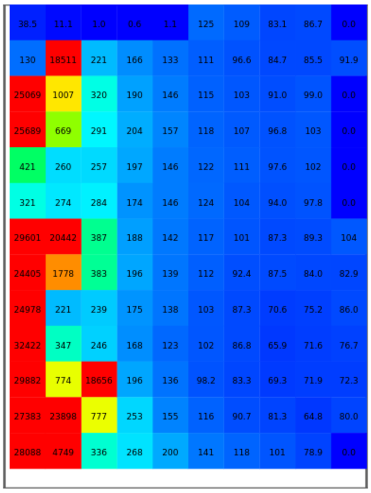
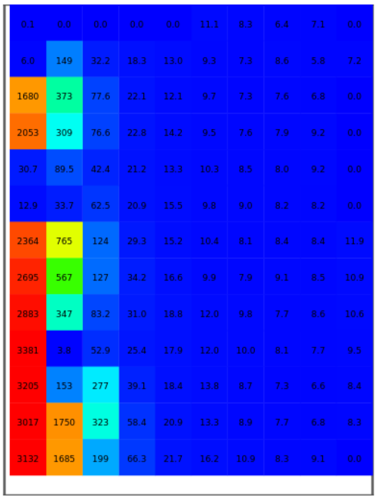
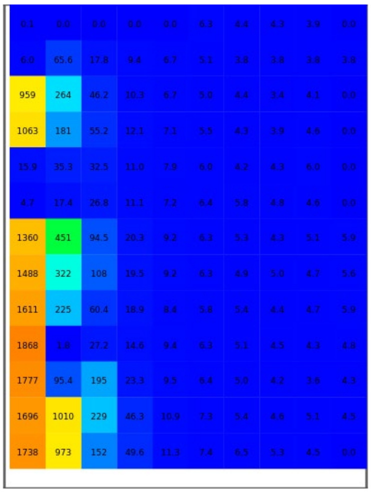
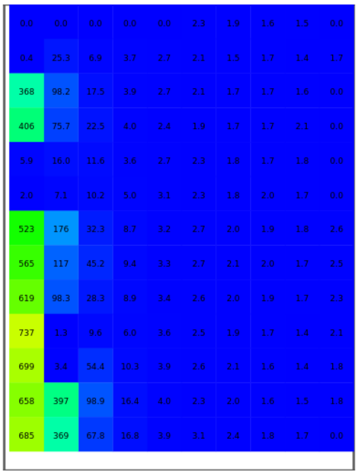
Mar 21 4:00 PM		*Avg:* 3,906.8 lux *Avg/Min:* ∞ *Max:* 41,666.8 lux *Min:* 0.0 lux
Mar 21 5:00 PM		*Avg:* 238.5 lux *Avg/Min:* ∞ *Max:* 3,064.4 lux *Min:* 0.0 l

Table 33: Point-to-point illuminance grid (December)

Illuminance Grid		
Overall Average = 1,789.22 lux		***Area (m2) =40***
Time	**Results** 	***Summary***
Dec 21 8:00 AM		*Avg:* 100.8 lux *Avg/Min:* ∞ *Max:* 1,513.6 lux *Min:* 0.0 lux
Dec 21 9:00 AM		*Avg:* 254.1 lux *Avg/Min:* ∞ *Max:* 3,663.7 lux *Min:* 0.0 lux

Dec 21 10:00 AM		*Avg:* 369.8 lux *Avg/Min:* ∞ *Max:* 5,181.1 lux *Min:* 0.0 lux
Dec 21 11:00 AM		*Avg:* 1,843.5 lux *Avg/Min:* ∞ *Max:* 32,648.6 lux *Min:* 0.0 lux
Dec 21 12:00 PM		*Avg:* 2,438.3 lux *Avg/Min:* ∞ *Max:* 40,697.0 lux *Min:* 0.0 lux

Dec 21 1:00 PM		*Avg:* 2,971.2 lux *Avg/Min:* ∞ *Max:* 38,313.9 lux *Min:* 0.0 lux
Dec 21 2:00 PM		*Avg:* 2,719.3 lux *Avg/Min:* ∞ *Max:* 32,421.6 lux *Min:* 0.0 lux
Dec 21 3:00 PM		*Avg:* 256.0 lux *Avg/Min:* ∞ *Max:* 3,381.4 lux *Min:* 0.0 lux

Dec 21 4:00 PM		*Avg:* 145.5 lux *Avg/Min:* ∞ *Max:* 1,867.9 lux *Min:* 0.0 lux
Dec 21 5:00 PM		*Avg:* 56.2 lux *Avg/Min:* ∞ *Max:* 737.5 lux *Min:* 0.0 lux

APPENDIX F

Classroom ID: 1N

Table 34: Point-to-point illuminance of east classroom

Time	March (lux)	December (lux)
08:00	111,8	68,7
09:00	1.144,40	311,8
10:00	633,2	322,8
11:00	581,8	129,7
12:00	188,5	122,3
13:00	170,4	125,4
14:00	170,9	128,3
15:00	178,4	104,3
16:00	172,4	65,2
17:00	123,5	26,7

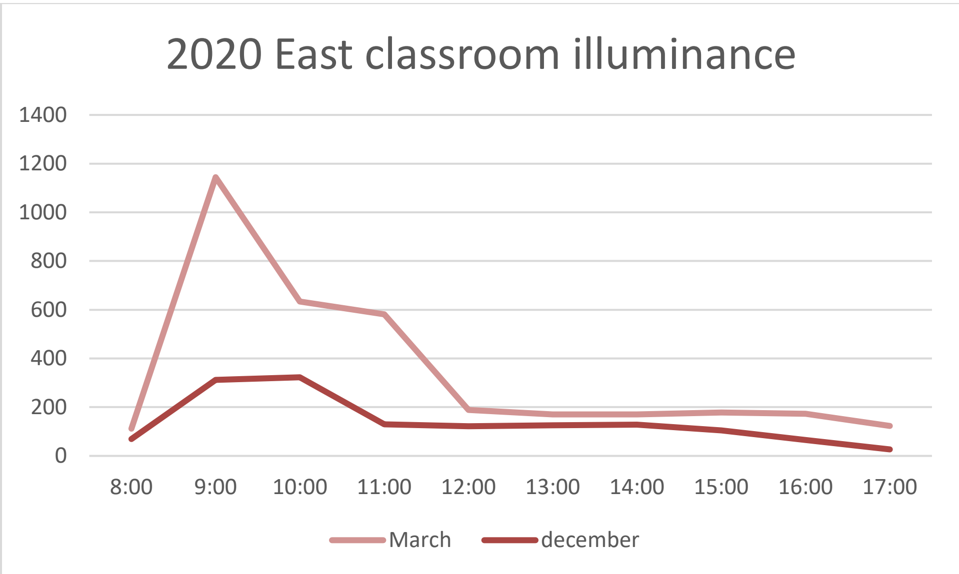
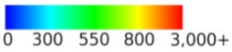
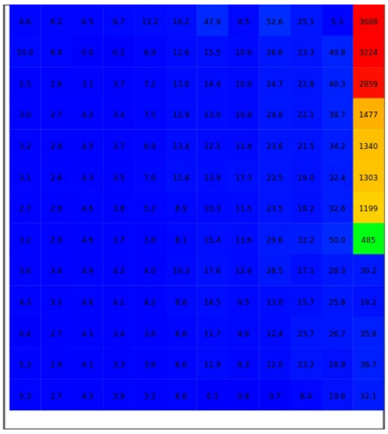
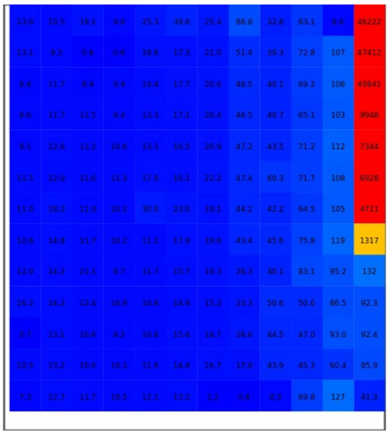
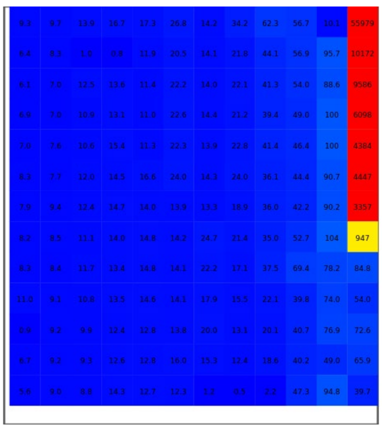
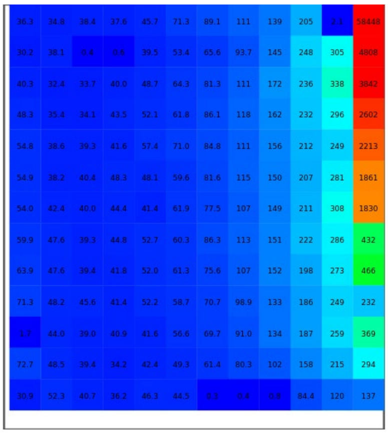
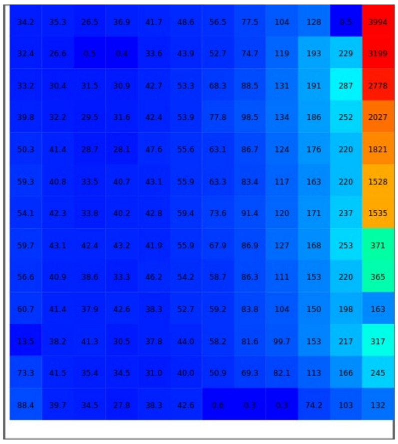
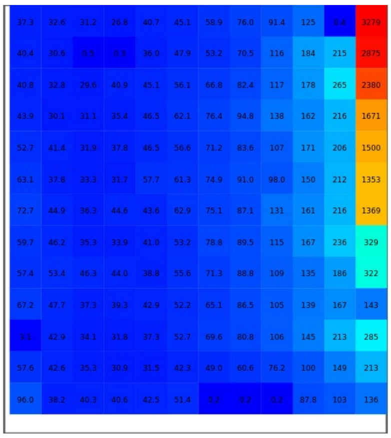
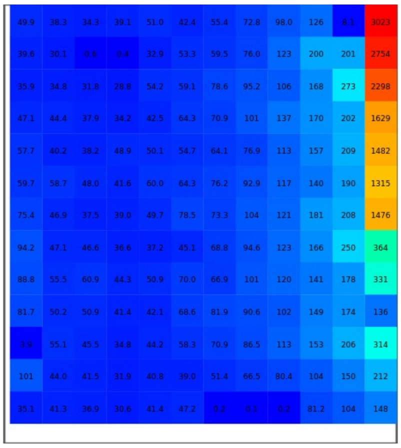
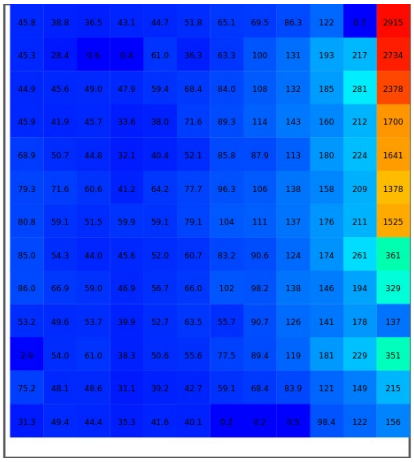
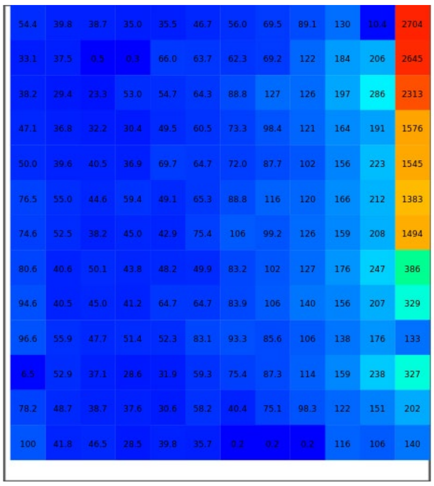


Figure 77: 2020 East classroom illuminance

Table 35: Point-to-point illuminance grid (March)

Illuminance Grid		
Overall Average = 244.03 lux		**Area (m2) = 40**
Time	**Results**  	**Summary**
Mar 21 8:00 AM		*Avg:* 111.8 lux *Avg/Min:* 1,880.4 *Max:* 3,688.1 lux *Min:* 0.1 lux
Mar 21 9:00 AM		*Avg:* 1,144.4 lux *Avg/Min:* 2,049.4 *Max:* 49,841.4 lux *Min:* 0.6 lux
Mar 21 10:00 AM		*Avg:* 633.2 lux *Avg/Min:* 1,195.0 *Max:* 55,978.6 lux *Min:* 0.5 lux

Mar 21 11:00 AM		*Avg:* 581.8 lux *Avg/Min:* 1,876.1 *Max:* 58,448.3 lux *Min:* 0.3 lux
Mar 21 12:00 PM		*Avg:* 188.5 lux *Avg/Min:* 652.1 *Max:* 3,994.2 lux *Min:* 0.3 lux
Mar 21 1:00 PM		*Avg:* 170.4 lux *Avg/Min:* 891.7 *Max:* 3,279.0 lux *Min:* 0.2 lux

Mar 21 2:00 PM		*Avg:* 170.9 lux *Avg/Min:* 1,521.2 *Max:* 3,023.0 lux *Min:* 0.1 lux
Mar 21 3:00 PM		*Avg:* 178.4 lux *Avg/Min:* 1,069.7 *Max:* 2,914.7 lux *Min:* 0.2 lux
Mar 21 4:00 PM		*Avg:* 172.4 lux *Avg/Min:* 1,101.8 *Max:* 2,704.4 lux *Min:* 0.2 lux

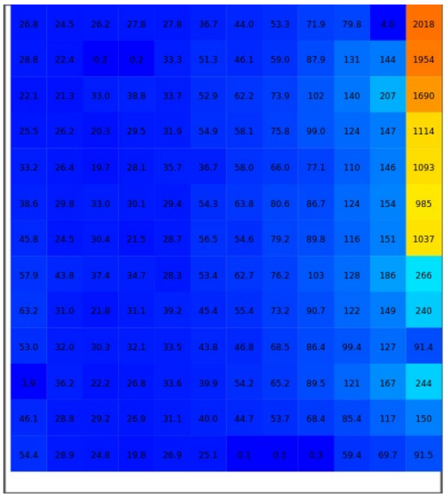
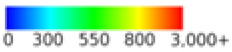
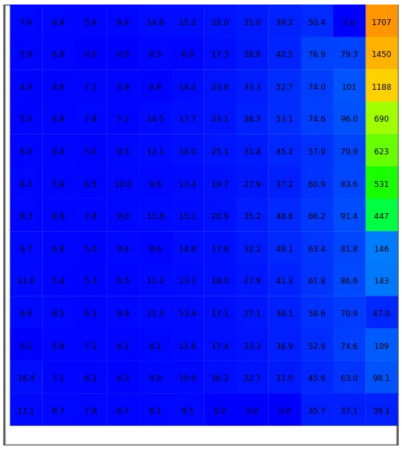
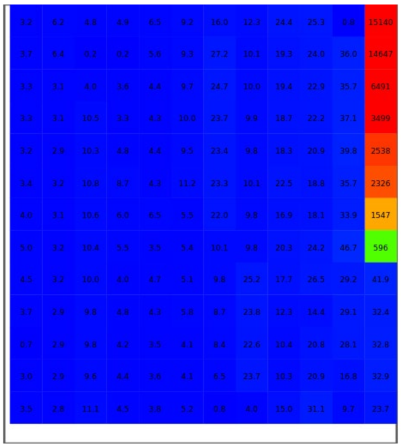
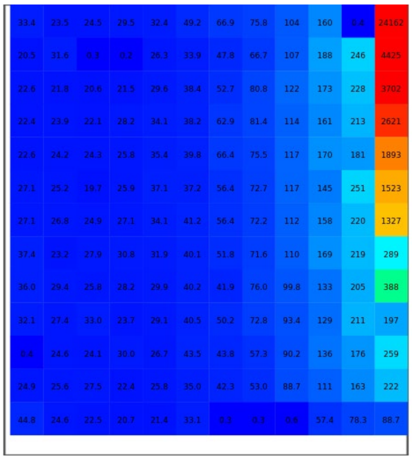
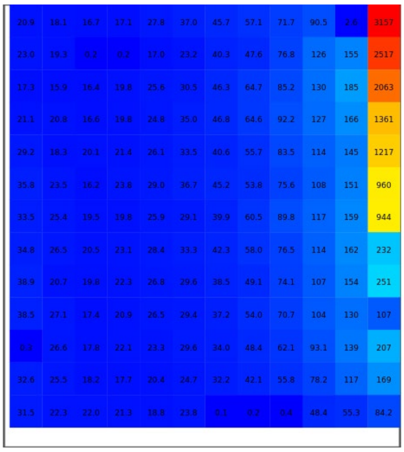
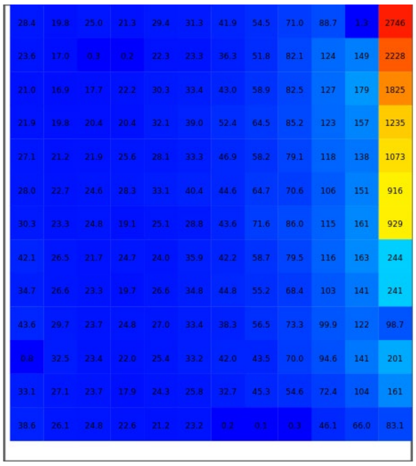
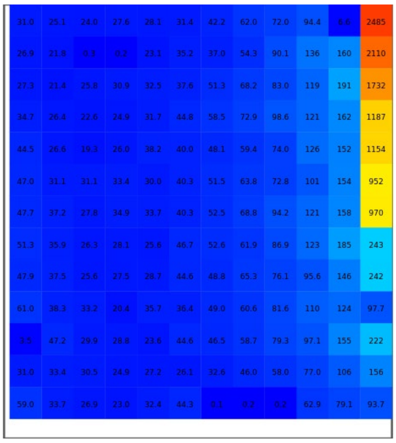
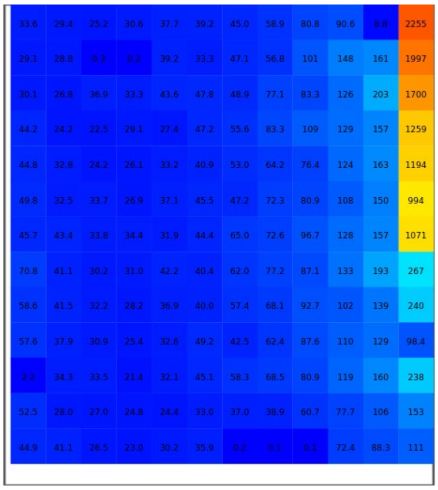
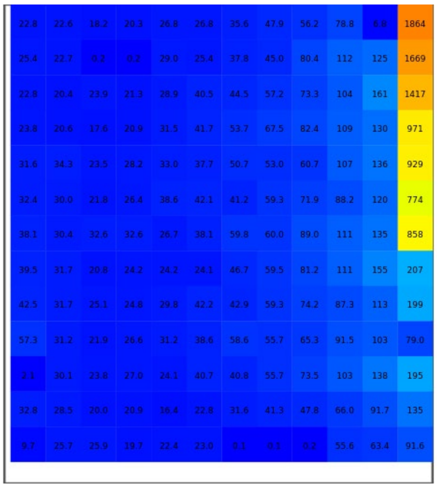
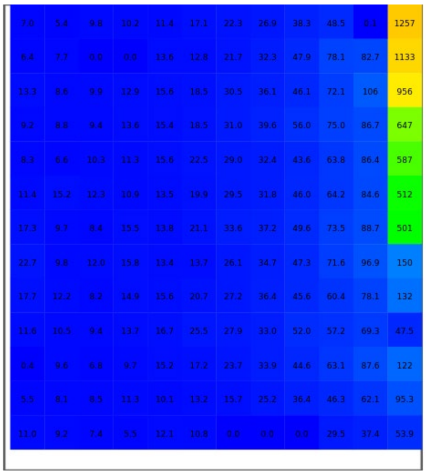
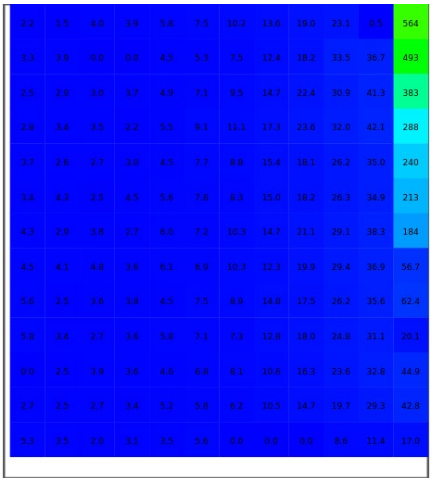
Mar 21 5:00 PM		*Avg:* 123.5 lux *Avg/Min:* 1,097.3 *Max:* 2,018.5 lux *Min:* 0.1 lux

Table 36: Point-to-point illuminance grid (December)

Illuminance Grid		
Overall Average = 244.03 lux		***Area (m2) =40***
Time	**Results** 	***Summary***
Dec 21 8:00 AM		*Avg:* 68.7 lux *Avg/Min:* 1,877.7 *Max:* 1,706.9 lux *Min:* 0.0 lux

Dec 21 9:00 AM		*Avg:* 311.8 lux *Avg/Min:* 1,470.4 *Max:* 15,140.5 lux *Min:* 0.2 lux
Dec 21 10:00 AM		*Avg:* 322.8 lux *Avg/Min:* 1,832.0 *Max:* 24,161.8 lux *Min:* 0.2 lux
Dec 21 11:00 AM		*Avg:* 129.7 lux *Avg/Min:* 1,055.2 *Max:* 3,157.1 lux *Min:* 0.1 lux

Dec 21 12:00 PM		*Avg:* 122.3 lux *Avg/Min:* 998.4 *Max:* 2,746.2 lux *Min:* 0.1 lux
Dec 21 1:00 PM		*Avg:* 125.4 lux *Avg/Min:* 892.3 *Max:* 2,485.1 lux *Min:* 0.1 lux
Dec 21 2:00 PM		*Avg:* 128.3 lux *Avg/Min:* 942.9 *Max:* 2,254.9 lux *Min:* 0.1 lux

Dec 21 3:00 PM		*Avg:* 104.3 lux *Avg/Min:* 956.9 *Max:* 1,864.0 lux *Min:* 0.1 lux
Dec 21 4:00 PM		*Avg:* 65.2 lux *Avg/Min:* 1,460.8 *Max:* 1,256.9 lux *Min:* 0.0 lux
Dec 21 5:00 PM		*Avg:* 26.7 lux *Avg/Min:* 1,759.2 *Max:* 563.7 lux *Min:* 0.0 lux

APPENDIX G

Classroom ID: 2N

Table 37: Point-to-point illuminance of south classroom

Time	March (lux)	December (lux)
08:00	87,4	36,3
09:00	151,80	67,6
10:00	173,2	27,8
11:00	178,2	214,5
12:00	146,5	179,3
13:00	113	143
14:00	79,4	89,2
15:00	41,3	69,9
16:00	89,5	28,6
17:00	50,1	10,7

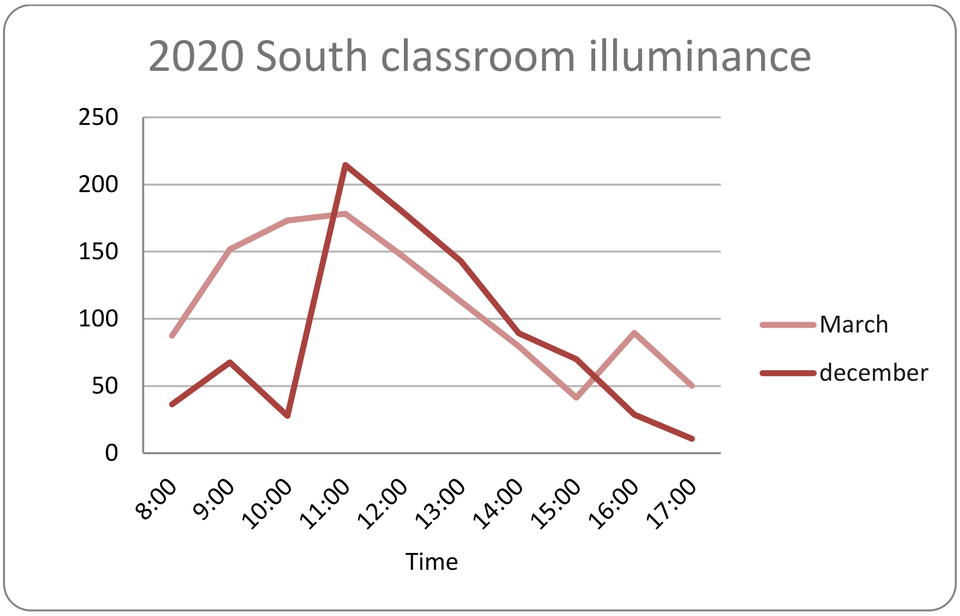
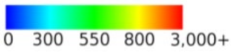
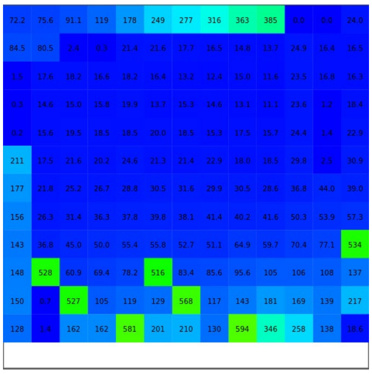
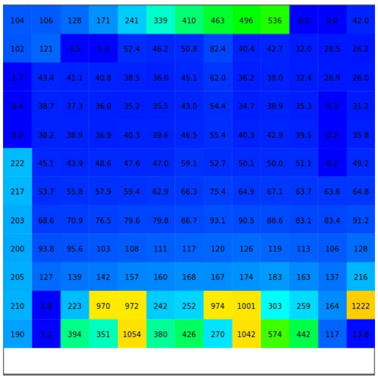
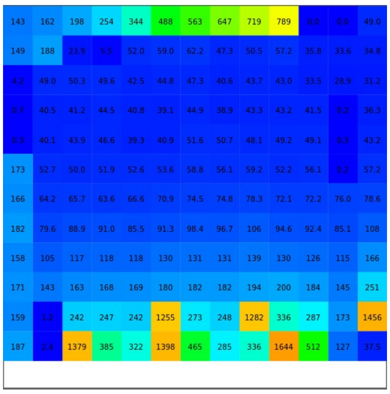
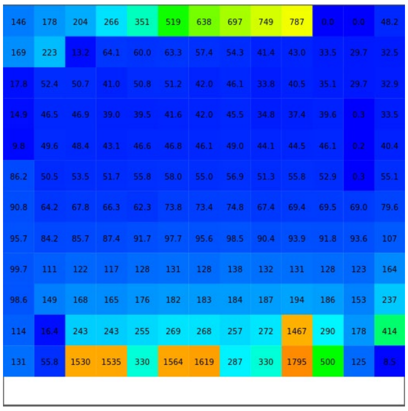
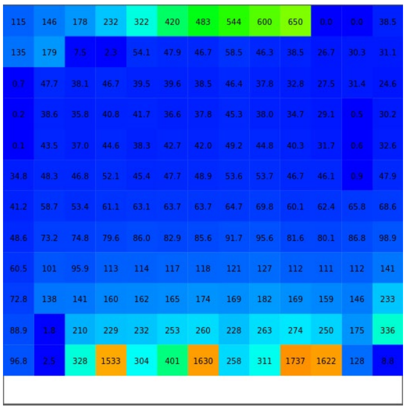
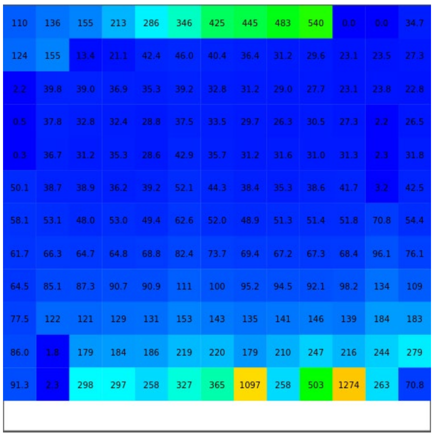
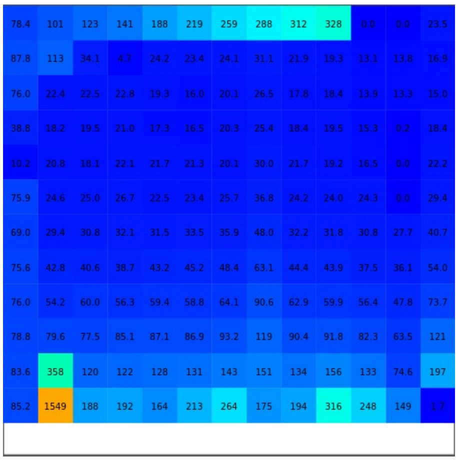
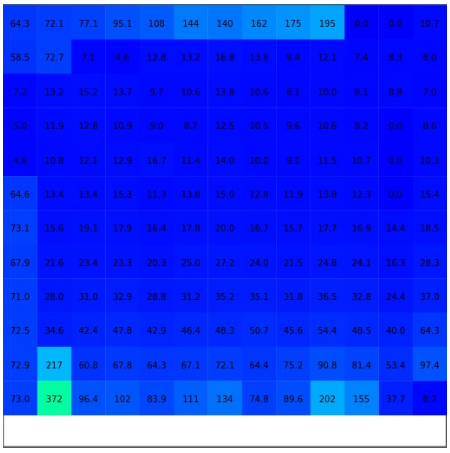
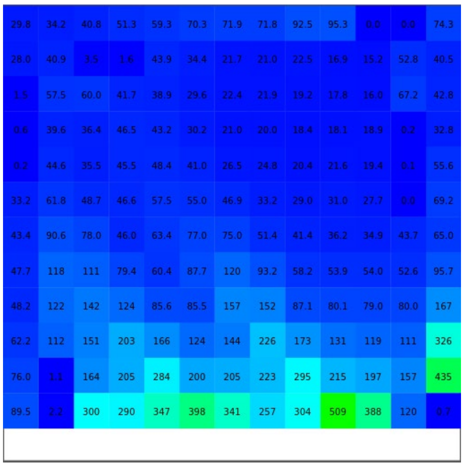


Figure 78: 2020 South classroom illuminance

Table 38: Point-to-point illuminance grid (March)

Illuminance Grid		
Overall Average = 98.85 lux		**Area (m2) = 40**
Time	**Results** 	**Summary** 
Mar 21 8:00 AM		*Avg:* 87.4 lux *Avg/Min:* 6,544.3 *Max:* 593.7 lux *Min:* 0.0 lux
Mar 21 9:00 AM		*Avg:* 151.8 lux *Avg/Min:* 6,080.4 *Max:* 1,221.9 lux *Min:* 0.0 lux
Mar 21 10:00 AM		*Avg:* 173.2 lux *Avg/Min:* 7,912.5 *Max:* 1,643.8 lux *Min:* 0.0 lux

Mar 21 11:00 AM		*Avg:* 178.2 lux *Avg/Min:* ∞ *Max:* 1,795.3 lux *Min:* 0.0 lux
Mar 21 12:00 PM		*Avg:* 146.5 lux *Avg/Min:* ∞ *Max:* 1,737.2 lux *Min:* 0.0 lux
Mar 21 1:00 PM		*Avg:* 113.0 lux *Avg/Min:* 4,682.0 *Max:* 1,273.7 lux *Min:* 0.0 lux

Mar 21 2:00 PM		*Avg:* 79.4 lux *Avg/Min:* ∞ *Max:* 1,548.7 lux *Min:* 0.0 lux
Mar 21 3:00 PM		*Avg:* 41.3 lux *Avg/Min:* ∞ *Max:* 372.1 lux *Min:* 0.0 lux
Mar 21 4:00 PM		*Avg:* 89.5 lux *Avg/Min:* 1,566.0 *Max:* 508.5 lux *Min:* 0.1 lux

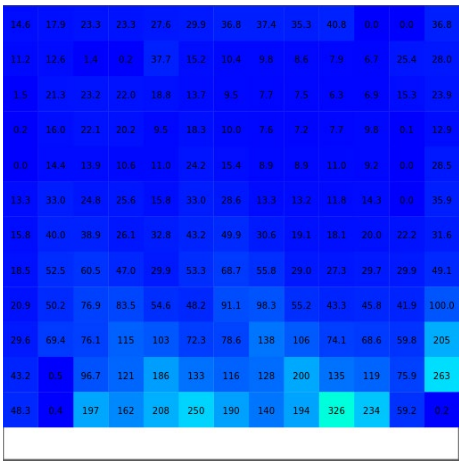
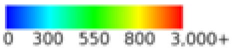
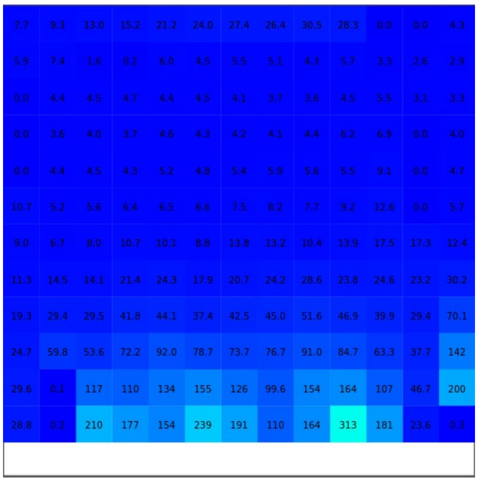
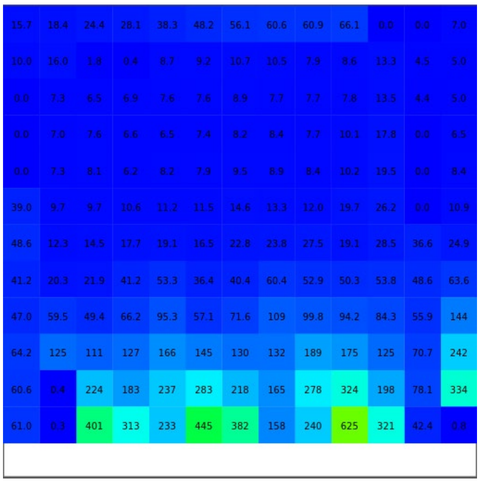
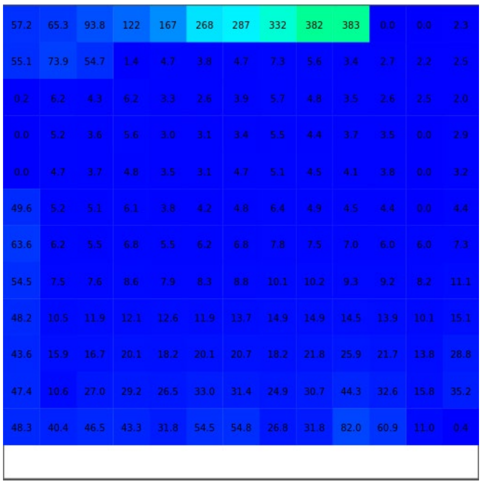
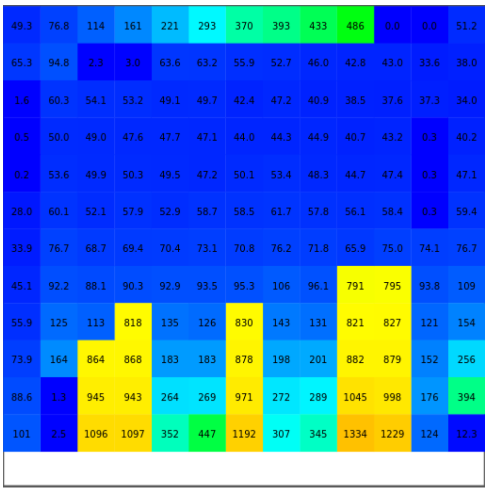
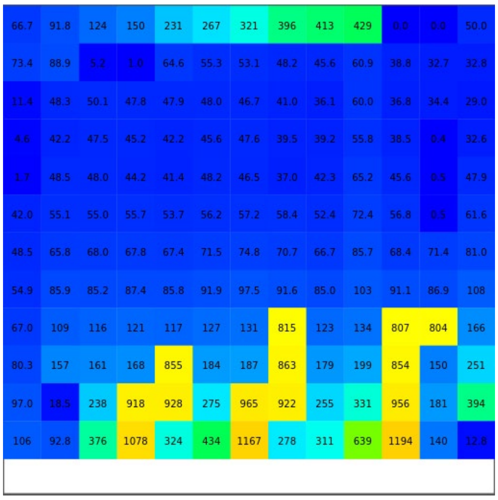
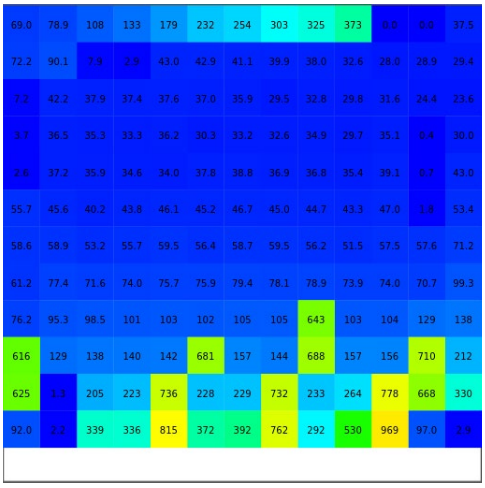
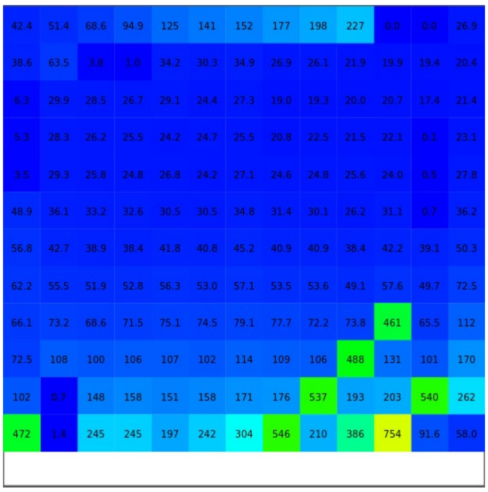
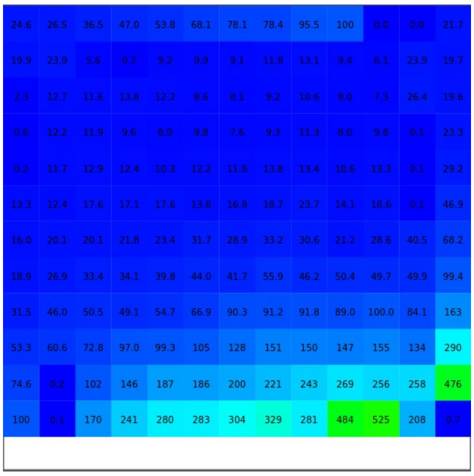
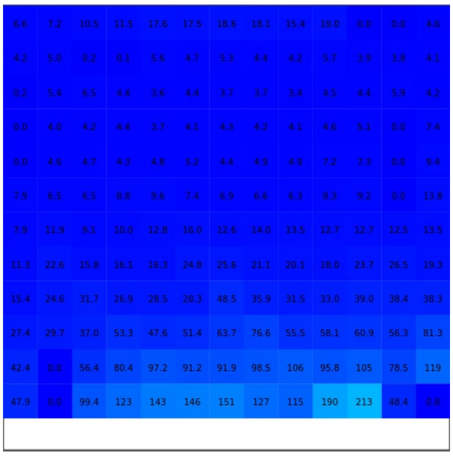
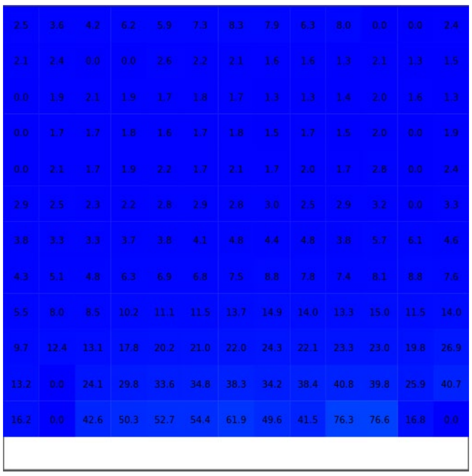
Mar 21 5:00 PM		*Avg:* 50.1 lux *Avg/Min:* 4,268.5 *Max:* 326.2 lux *Min:* 0.0 lux

Table 39: Point-to-point illuminance grid (December)

Illuminance Grid		
Overall Average = 98.85 lux		***Area (m2) =40***
Time	**Results**  	***Summary***
Dec 21 8:00 AM		*Avg:* 36.3 lux *Avg/Min:* ∞ *Max:* 313.4 lux *Min:* 0.0 lux

Dec 21 9:00 AM		*Avg:* 67.6 lux *Avg/Min:* ∞ *Max:* 624.7 lux *Min:* 0.0 lux
Dec 21 10:00 AM		*Avg:* 27.8 lux *Avg/Min:* ∞ *Max:* 383.0 lux *Min:* 0.0 lux
Dec 21 11:00 AM		*Avg:* 214.5 lux *Avg/Min:* ∞ *Max:* 1,333.6 lux *Min:* 0.0 lux

Dec 21 12:00 PM		*Avg:* 179.3 lux *Avg/Min:* 4,802.6 *Max:* 1,194.2 lux *Min:* 0.0 lux
Dec 21 1:00 PM		*Avg:* 143.0 lux *Avg/Min:* 6,005.1 *Max:* 969.1 lux *Min:* 0.0 lux
Dec 21 2:00 PM		*Avg:* 89.2 lux *Avg/Min:* ∞ *Max:* 754.4 lux *Min:* 0.0 lux

Dec 21 3:00 PM		*Avg:* 69.9 lux *Avg/Min:* 2,597.1 *Max:* 525.2 lux *Min:* 0.0 lux
Dec 21 4:00 PM		*Avg:* 28.6 lux *Avg/Min:* ∞ *Max:* 212.7 lux *Min:* 0.0 lux
Dec 21 5:00 PM		*Avg:* 10.7 lux *Avg/Min:* ∞ *Max:* 76.6 lux *Min:* 0.0 lux

APPENDIX H

Classroom ID: 3N

Table 40: Point-to-point illuminance of west classroom

Time	March (lux)	December (lux)
08:00	147,2	26,4
09:00	164,40	67
10:00	167,2	105
11:00	156,7	21,1
12:00	45,9	53
13:00	96,8	99,6
14:00	159,7	85,6
15:00	195,6	75,8
16:00	227,6	47,9
17:00	88,1	19,3

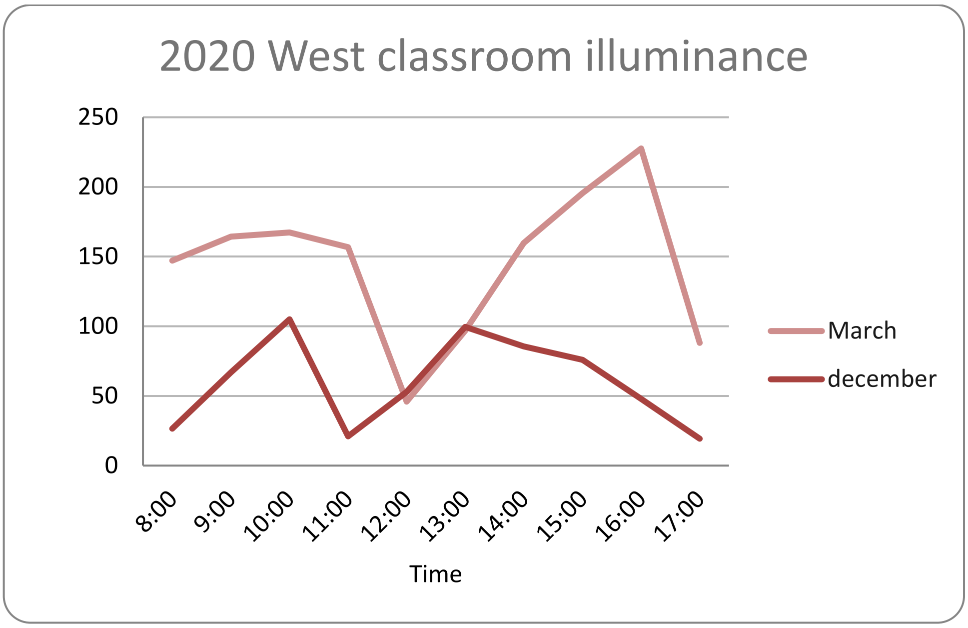
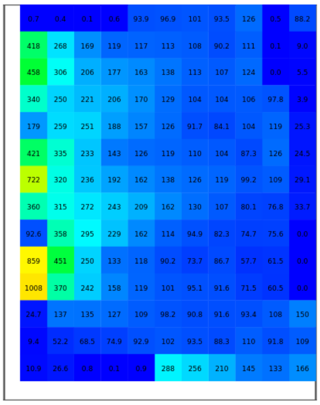
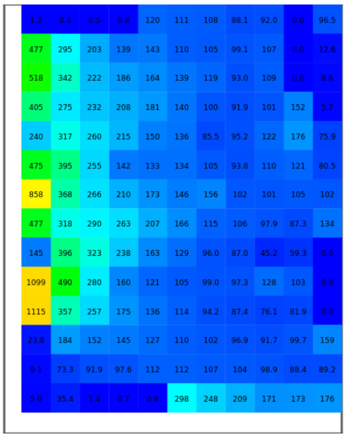
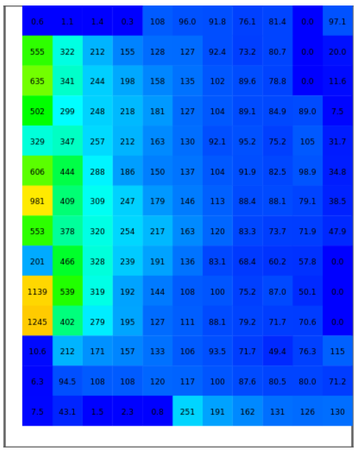
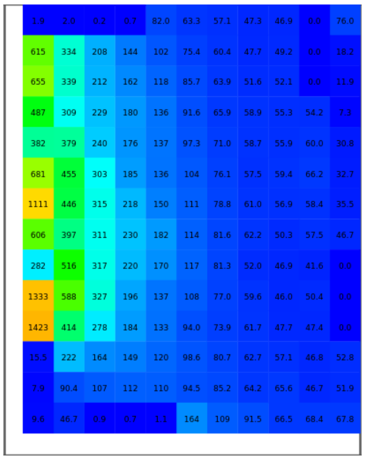
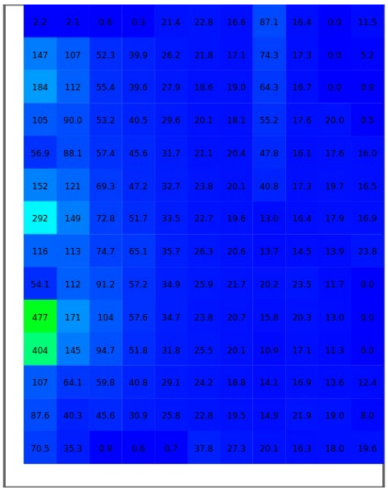
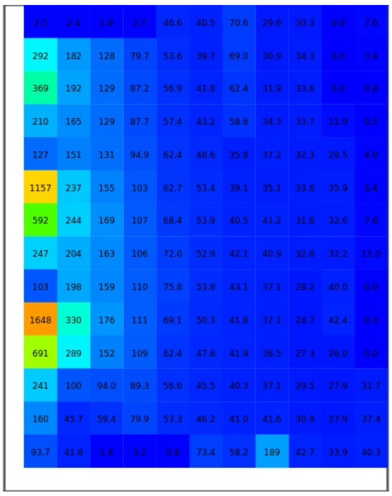
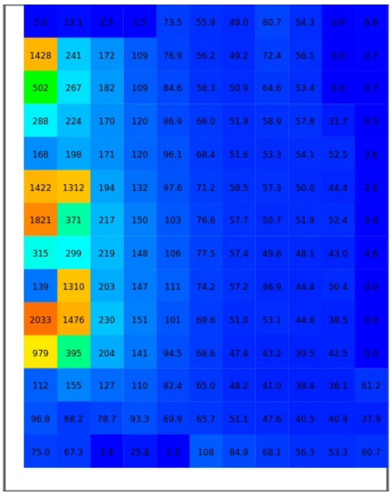
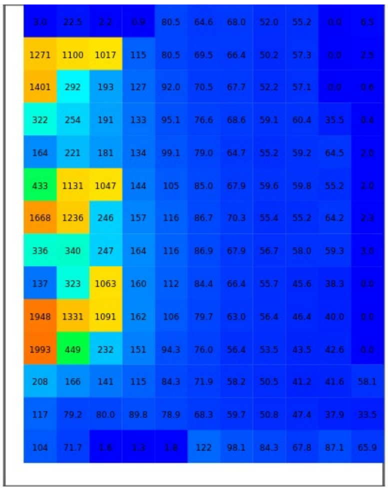
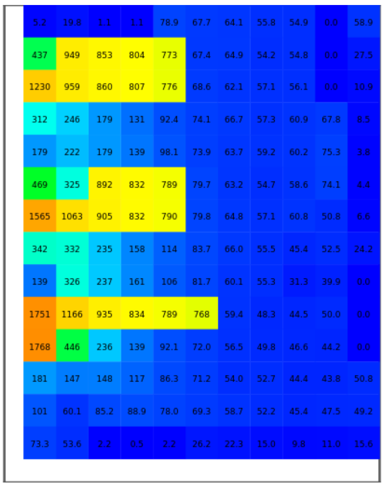


Figure 79: 2020 West classroom illuminance

Table 41: Point-to-point illuminance grid (March)

Illuminance Grid		
Overall Average = 102.49 lux		**Area (m2) = 40**
Time	**Results** 0 300 550 800 3,000+	**Summary**
Mar 21 8:00 AM		*Avg:* 147.2 lux *Avg/Min:* ∞ *Max:* 1,008.2 lux *Min:* 0.0 lux
Mar 21 9:00 AM		*Avg:* 164.4 lux *Avg/Min:* ∞ *Max:* 1,114.6 lux *Min:* 0.0 lux
Mar 21 10:00 AM		*Avg:* 167.2 lux *Avg/Min:* ∞ *Max:* 1,244.8 lux *Min:* 0.0 lux

Mar 21 11:00 AM		*Avg:* 156.7 lux *Avg/Min:* ∞ *Max:* 1,423.5 lux *Min:* 0.0 lux
Mar 21 12:00 PM		*Avg:* 45.9 lux *Avg/Min:* ∞ *Max:* 476.9 lux *Min:* 0.0 lux
Mar 21 1:00 PM		*Avg:* 96.8 lux *Avg/Min:* ∞ *Max:* 1,647.6 lux *Min:* 0.0 lux

Mar 21 2:00 PM		*Avg:* 159.7 lux *Avg/Min:* ∞ *Max:* 2,033.5 lux *Min:* 0.0 lux
Mar 21 3:00 PM		*Avg:* 195.6 lux *Avg/Min:* ∞ *Max:* 1,993.2 lux *Min:* 0.0 lux
Mar 21 4:00 PM		*Avg:* 227.6 lux *Avg/Min:* ∞ *Max:* 1,768.5 lux *Min:* 0.0 lux

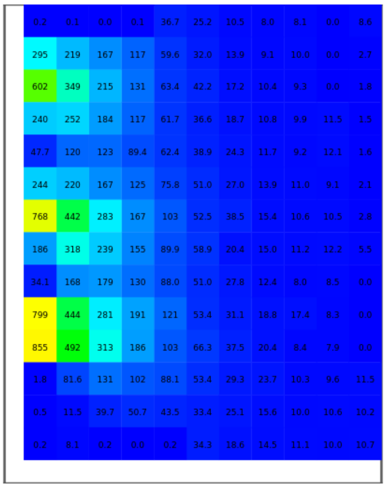
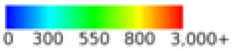
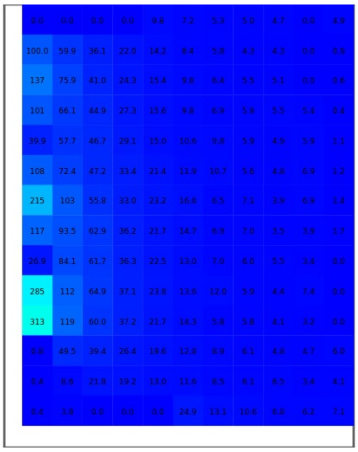
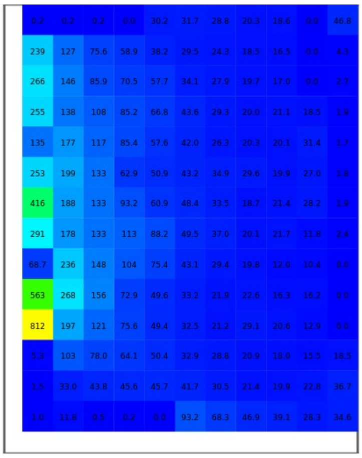
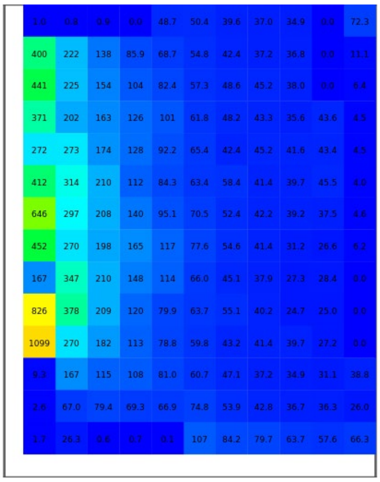
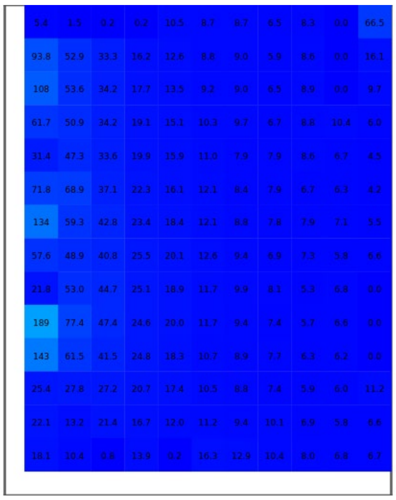
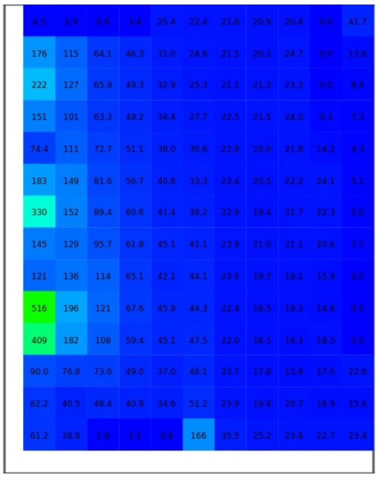
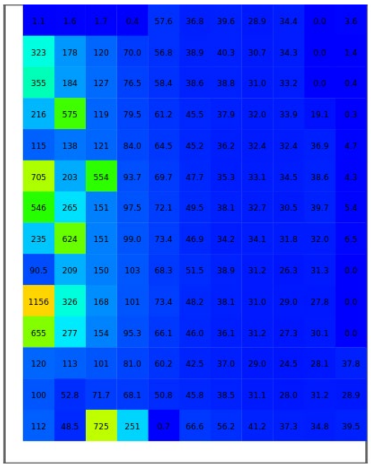
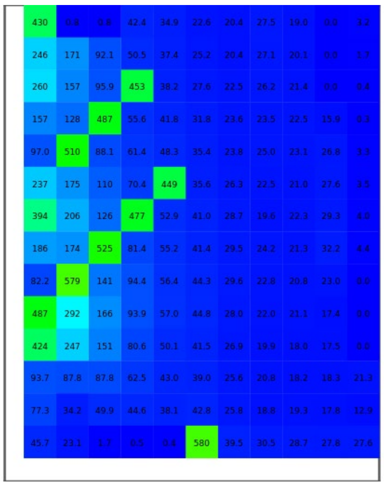
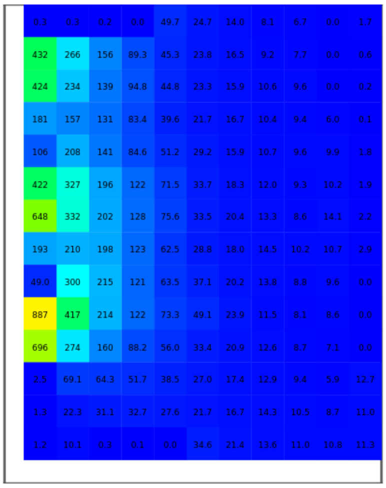
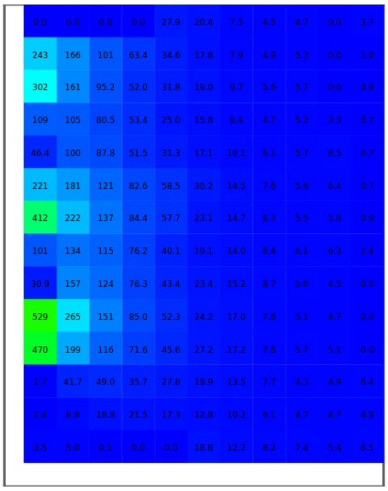
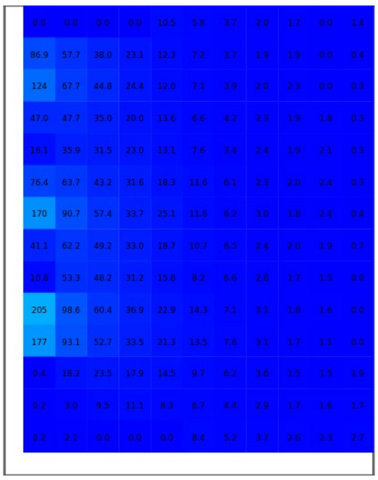
Mar 21 5:00 PM		*Avg:* 88.1 lux *Avg/Min:* ∞ *Max:* 854.8 lux *Min:* 0.0 lux

Table 42: Point-to-point illuminance grid (December)

Illuminance Grid		
Overall Average = 244.03 lux		***Area (m2) =40***
Time	**Results** 	***Summary***
Dec 21 8:00 AM		*Avg:* 26.4 lux *Avg/Min:* ∞ *Max:* 313.5 lux *Min:* 0.0 lux

Dec 21 9:00 AM		*Avg:* 67.0 lux *Avg/Min:* ∞ *Max:* 812.0 lux *Min:* 0.0 lux
Dec 21 10:00 AM		*Avg:* 105.0 lux *Avg/Min:* ∞ *Max:* 1,098.7 lux *Min:* 0.0 lux
Dec 21 11:00 AM		*Avg:* 21.1 lux *Avg/Min:* ∞ *Max:* 188.7 lux *Min:* 0.0 lux

Dec 21 12:00 PM		*Avg:* 53.0 lux *Avg/Min:* ∞ *Max:* 515.7 lux *Min:* 0.0 lux
Dec 21 1:00 PM		*Avg:* 99.6 lux *Avg/Min:* ∞ *Max:* 1,155.8 lux *Min:* 0.0 lux
Dec 21 2:00 PM		*Avg:* 85.6 lux *Avg/Min:* ∞ *Max:* 579.8 lux *Min:* 0.0 lux

Dec 21 3:00 PM		*Avg:* 75.8 lux *Avg/Min:* ∞ *Max:* 887.5 lux *Min:* 0.0 lux
Dec 21 4:00 PM		*Avg:* 47.9 lux *Avg/Min:* ∞ *Max:* 529.4 lux *Min:* 0.0 lux
Dec 21 5:00 PM		*Avg:* 19.3 lux *Avg/Min:* ∞ *Max:* 205.5 lux *Min:* 0.0 lux

APPENDIX I

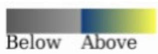
Optimization

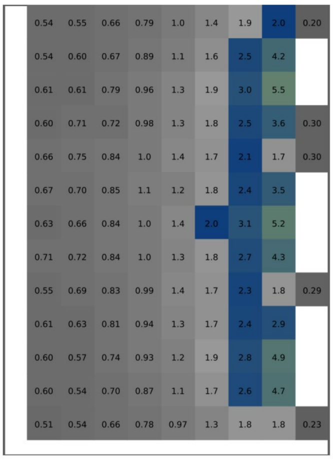
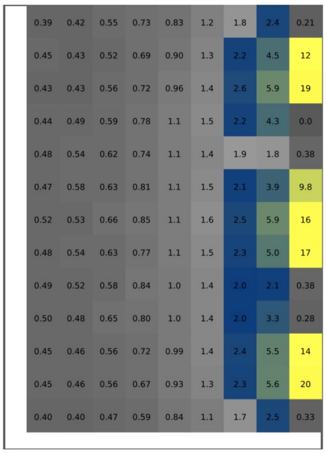
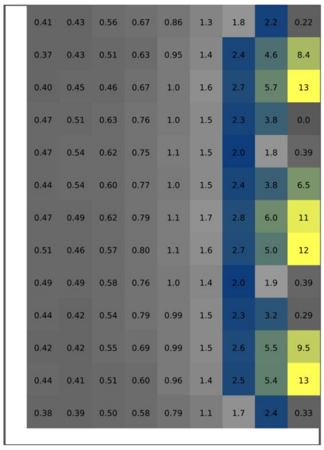
Classroom ID: 1O

Table 43: Daylight parameters for eastern shading devices

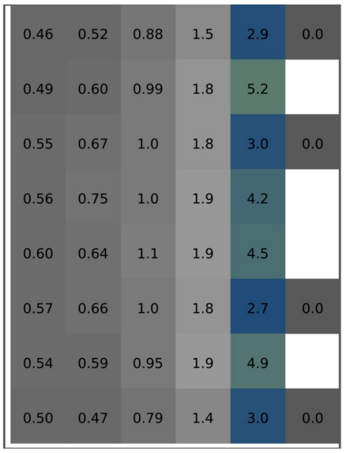
Shading Devices	Average DF	sDA	Average	ASE
None	2,50%	100,00%	1.495,40	34,38%
Overhang	1.4%	100,00%	1.028,09	21,88%
Horizontal Louvers	2.2%	100,00%	1.297,26	23,96%
Overhang multiple blades	1.9%	98,96%	1.077,72	17,71%
Vertical Fin	1.4%	98,96%	1.162,63	21,88%
Slanted Vertical Fin	1.2%	68,75%	895,75	10,42%
Eggcrate	1.1%	77,08%	730,06	1,04%

Table 44: Daylight factor of eastern shading devices

Shading devices		
Time	**Results** 	**DF**
None		2,50%

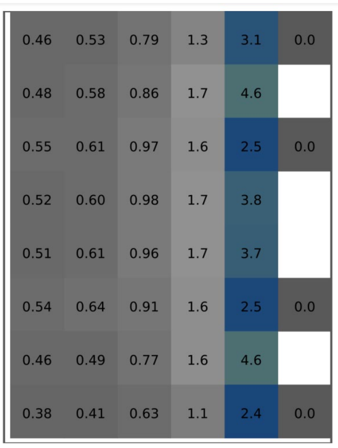
Overhang		1.4%
Horizontal Louvers		2.2%
Overhang multiple blades		1.9%

Vertical Fin



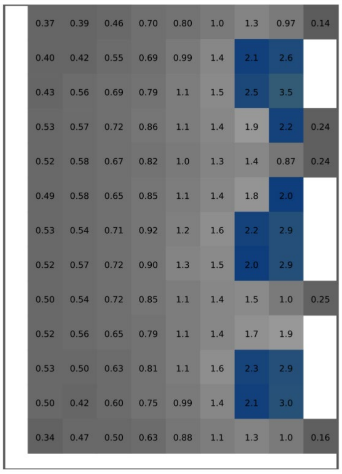
1.4%

Slanted Vertical Fin



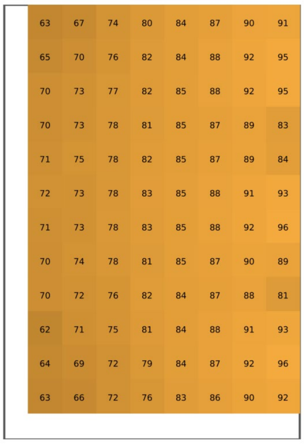
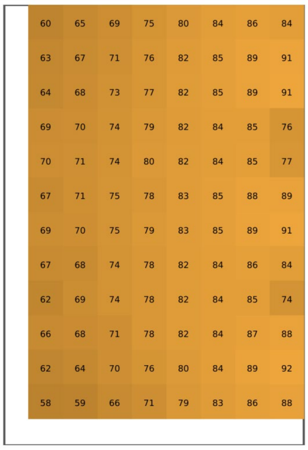
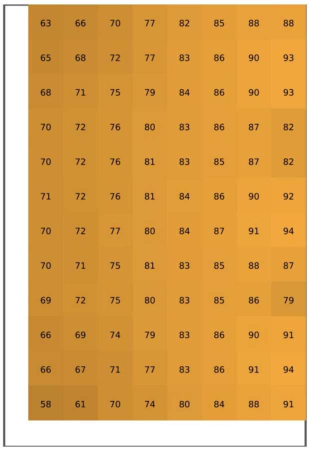
1.2%

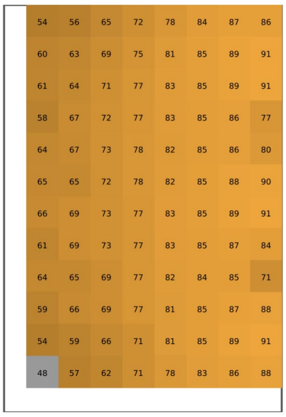
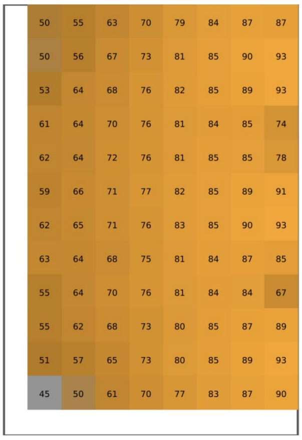
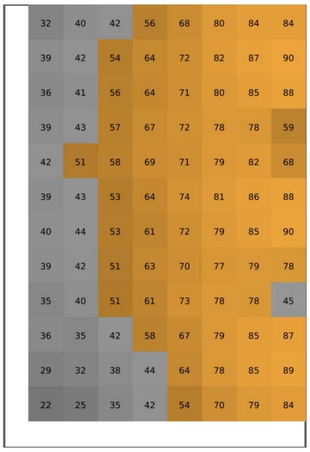
Eggcrate



1.1%

Table 45: sDA of eastern shading devices

<table>
<tr><th colspan="3">Shading devices sDA</th></tr>
<tr><th>Time</th><th>Results
</th><th>sDA</th></tr>
<tr><td>None</td><td></td><td>100,00%</td></tr>
<tr><td>Overhang</td><td></td><td>100,00%</td></tr>
<tr><td>Horizontal Louvers</td><td></td><td>100,00%</td></tr>
</table>

Overhang multiple blades		98,96%
Vertical Fin		98,96%
Slanted Vertical Fin		68,75%

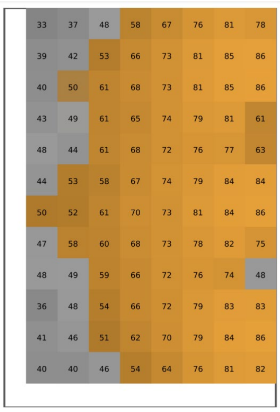
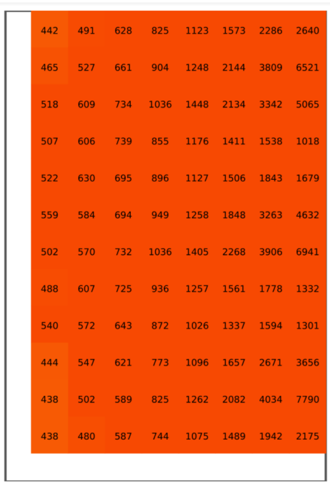
<table>
<tr><td>Eggcrate</td><td>
</td><td>77,08%</td></tr>
</table>

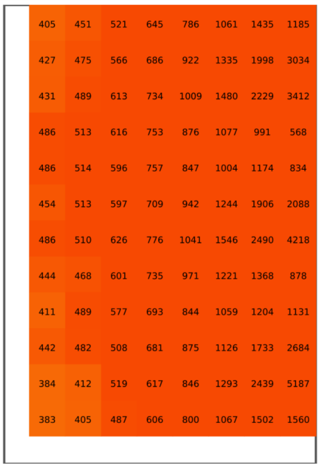
Table 46: Average lux of eastern shading devices

<table>
<tr><th colspan="3">Shading devices Average lux</th></tr>
<tr><th>Time</th><th>Results

</th><th>Average lux

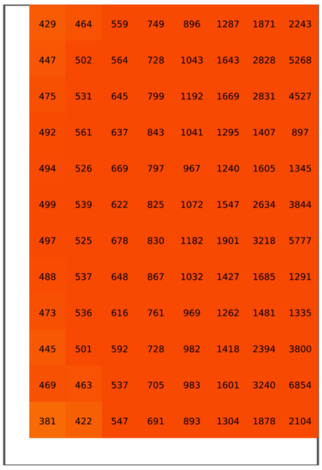
</th></tr>
<tr><td>None</td><td>
</td><td>1.495,40</td></tr>
</table>

Overhang



1.028,09

Horizontal Louvers



1.297,26

Overhang multiple blades

1.077,72

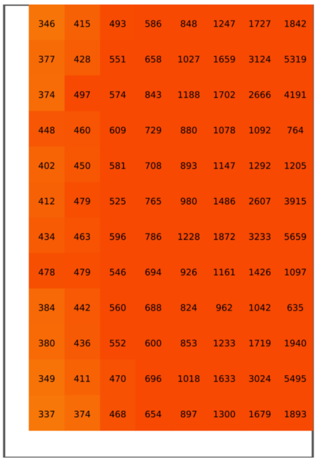
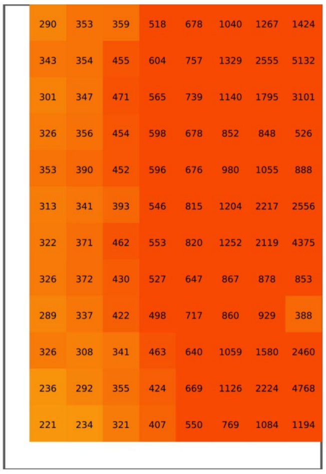
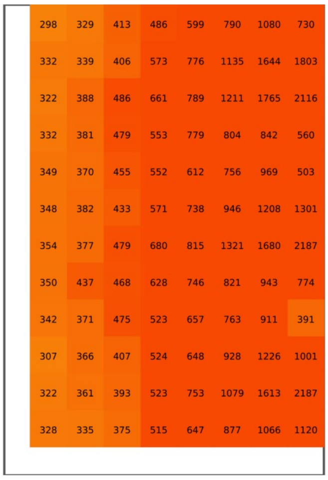
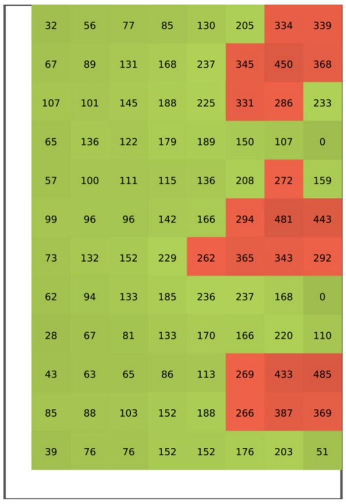
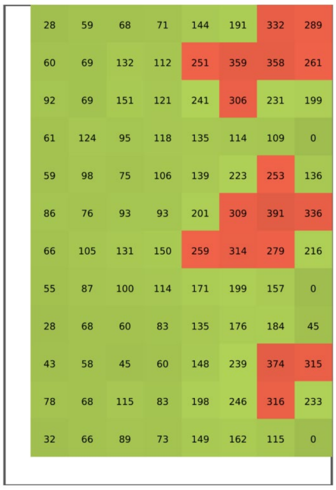
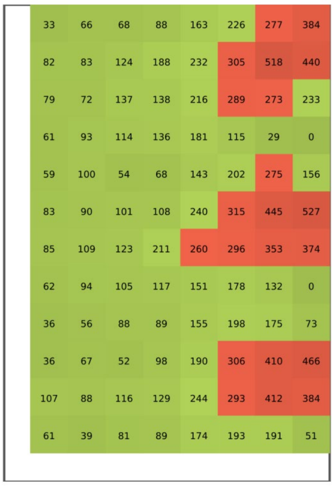
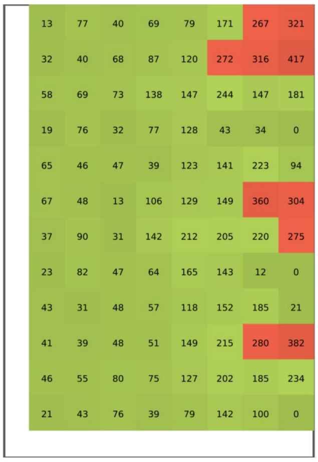
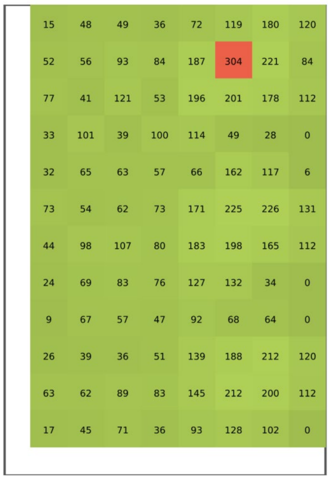
<table>
<tr>
<td>Vertical Fin</td>
<td>
</td>
<td>1.162,63</td>
</tr>
<tr>
<td>Slanted Vertical Fin</td>
<td>
</td>
<td>895,75</td>
</tr>
<tr>
<td>Eggcrate</td>
<td>
</td>
<td>730,06</td>
</tr>
</table>

Table 47: ASE of eastern shading devices

<table>
<tr><th colspan="3">Shading devices</th></tr>
<tr><th>Time</th><th>Results
0 hr 250 hr</th><th>ASE</th></tr>
<tr><td>None</td><td>
</td><td>34,38%</td></tr>
<tr><td>Overhang</td><td>
</td><td>21,88%</td></tr>
</table>

Horizontal Louvers		23,96%
Overhang multiple blades		17,71%
Vertical Fin		21,88%

<table>
<tr>
<td>Slanted Vertical Fin</td>
<td>
</td>
<td>10,42%</td>
</tr>
<tr>
<td>Eggcrate</td>
<td>
</td>
<td>1,04%</td>
</tr>
</table>

APPENDIX J

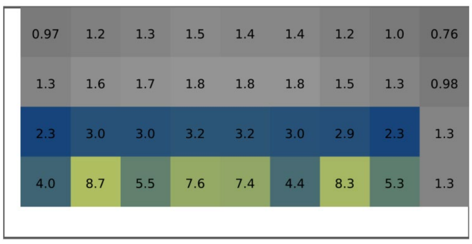
Optimization

Classroom ID: 2O

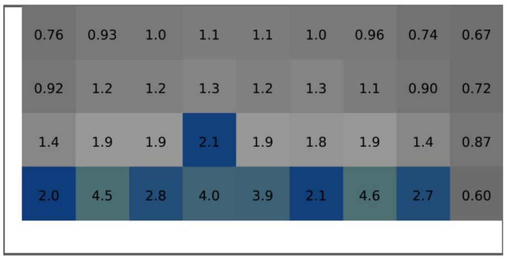
Table 48: Daylight parameters for southern shading devices

Shading Devices	Average DF	sDA	Average	ASE
None	2.8 %	100,00%	1.838,36	44,05%
Overhang	1.7 %	100,00%	1.406,35	35,71%
Horizontal Louvers	1.8 %	100,00%	1.564,91	36,90%
Overhang multiple blades	1.7 %	100,00%	1.345,71	11,90%
Vertical Fin	-	-	-	-
Slanted Vertical Fin	-	-	-	-
Eggcrate	-	-	-	-

Table 49: Daylight factor of southern shading devices

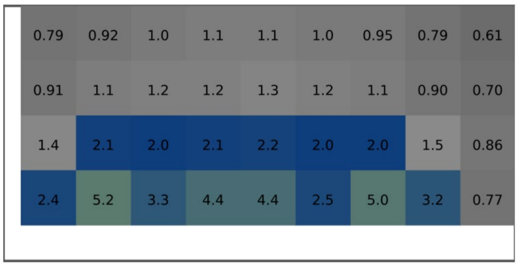
Shading devices		
Time	**Results** 	**DF** 
None		2.8 %

Overhang



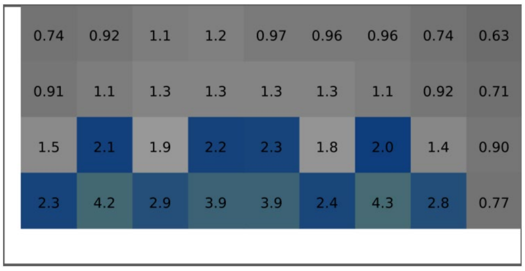
1.7 %

Horizontal Louvers



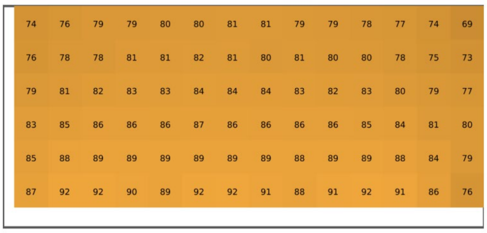
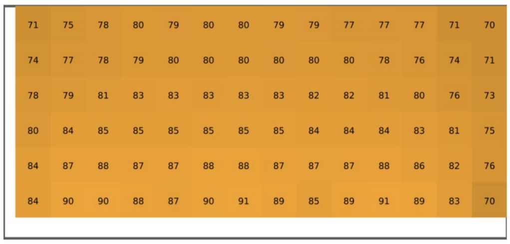
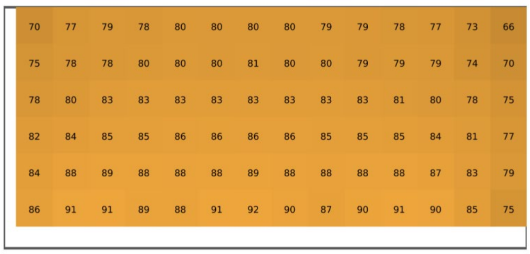
1.8 %

Overhang multiple blades



1.7 %

Table 50: sDA of southern shading devices

<table>
<tr><th colspan="3">Shading devices sDA</th></tr>
<tr><th>Time</th><th>Results
</th><th>sDA
</th></tr>
<tr><td>None</td><td></td><td>100,00%</td></tr>
<tr><td>Overhang</td><td></td><td>100,00%</td></tr>
<tr><td>Horizontal Louvers</td><td></td><td>100,00%</td></tr>
</table>

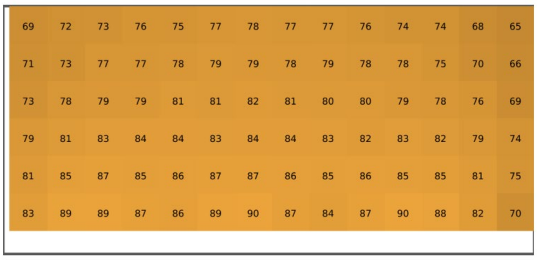
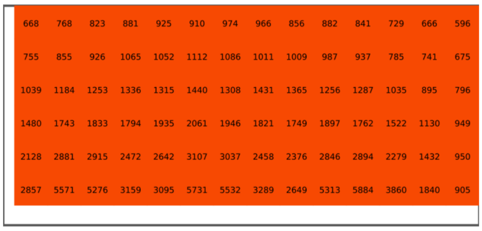
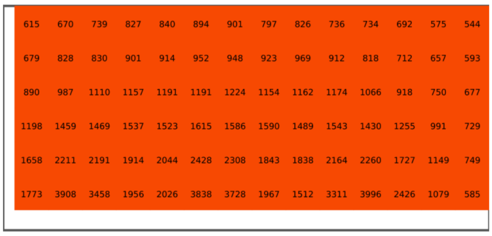
<table>
<tr><td>Overhang multiple blades</td><td>
</td><td>100,00%</td></tr>
</table>

Table 51: Average lux of southern shading devices

<table>
<tr><th colspan="3">Shading devices Average lux</th></tr>
<tr><th>Time</th><th>Results

</th><th>Average lux

</th></tr>
<tr><td>None</td><td>
</td><td>1.838,36</td></tr>
<tr><td>Overhang</td><td>
</td><td>1.406,35</td></tr>
</table>

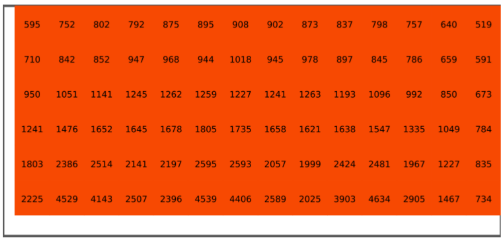
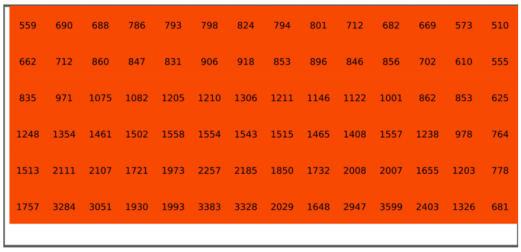
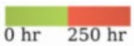
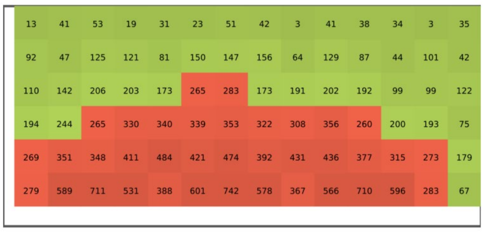
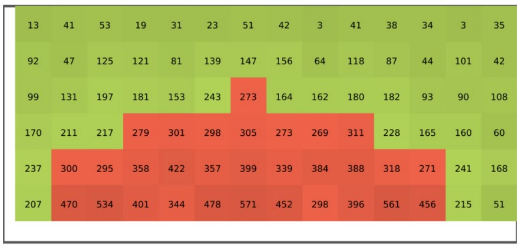
<table>
<tr><td>Horizontal Louvers</td><td>
</td><td>1.564,91</td></tr>
<tr><td>Overhang multiple blades</td><td>
</td><td>1.345,71</td></tr>
</table>

Table 52: ASE of southern shading devices

<table>
<tr><th colspan="3">Shading devices</th></tr>
<tr><th>Time</th><th>Results

</th><th>ASE

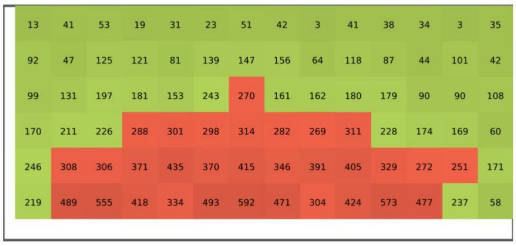
</th></tr>
<tr><td>None</td><td>
</td><td>44,05%</td></tr>
</table>

Overhang



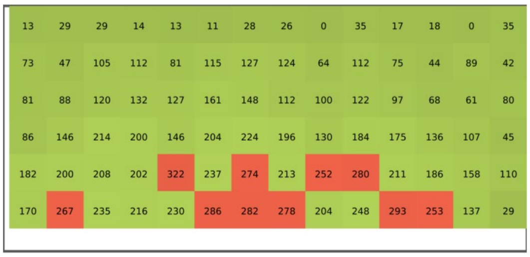
35,71%

Horizontal Louvers



36,90%

Overhang multiple blades



11,90%

APPENDIX K

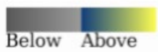
Optimization

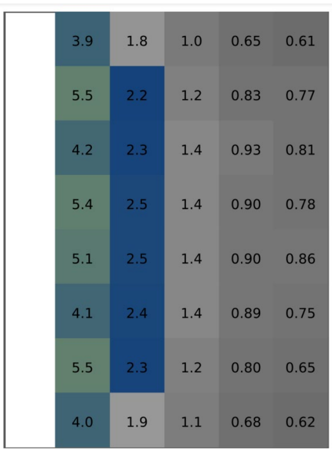
Classroom ID: 3O

Table 53: Daylight parameters for western shading devices

Shading Devices	Average DF	sDA	Average	ASE
None	2.0 %	100,00%	1.040,90	23,96%
Overhang	1.1 %	100,00%	886,86	18,75%
Horizontal Louvers	1.3 %	100,00%	950,06	19,79%
Overhang multiple blades	1.1 %	80,21%	642,54	0,00%
Vertical Fin	1.4 %	93,75%	833,29	8,33%
Slanted Vertical Fin	1.2 %	70,83%	664,83	6,25%
Eggcrate	1.1 %	83,33%	705,34	2,08%

Table 54: Daylight factor of western shading devices

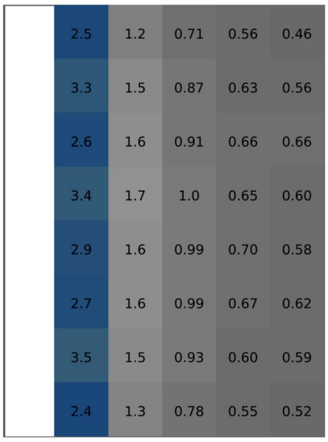
<table>
<tr><th colspan="3">Shading devices</th></tr>
<tr><th>Time</th><th>Results

</th><th>DF

</th></tr>
<tr><td>None</td><td>
</td><td>2.0 %</td></tr>
</table>

Overhang

1.1 %

Horizontal Louvers



1.3 %

Overhang multiple blades

1.1 %

Vertical Fin

2.8	1.3	0.71	0.45	0.43
3.9	1.7	0.89	0.56	0.51
2.5	1.6	0.94	0.67	0.55
3.9	1.7	0.99	0.74	0.62
3.4	1.5	0.97	0.65	0.61
2.4	1.5	0.97	0.57	0.59
4.1	1.5	0.86	0.58	0.56
2.8	1.3	0.76	0.55	0.43

1.4 %

Slanted Vertical Fin

2.2	1.1	0.59	0.37	0.34
3.1	1.4	0.69	0.45	0.41
2.7	1.3	0.74	0.55	0.41
3.1	1.3	0.82	0.50	0.44
3.0	1.4	0.81	0.53	0.49
2.2	1.4	0.73	0.59	0.43
3.3	1.4	0.74	0.51	0.47
2.9	1.2	0.69	0.51	0.36

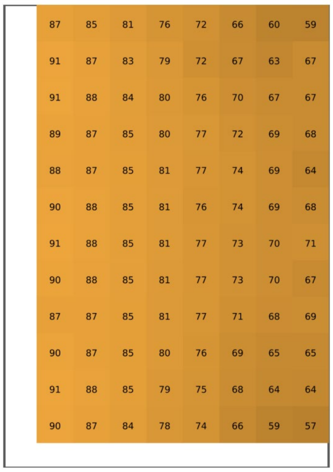
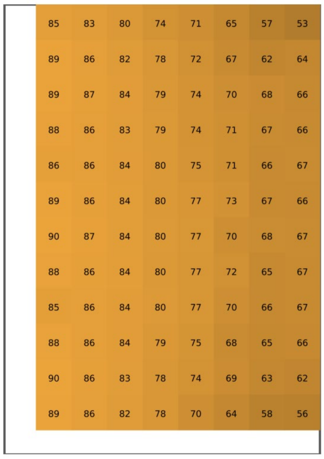
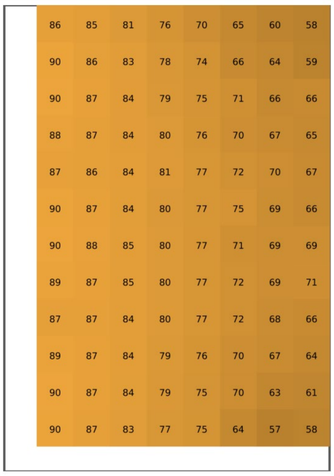
1.2 %

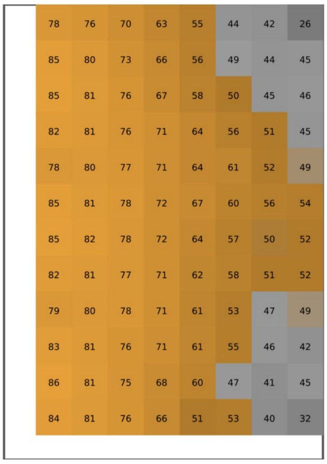
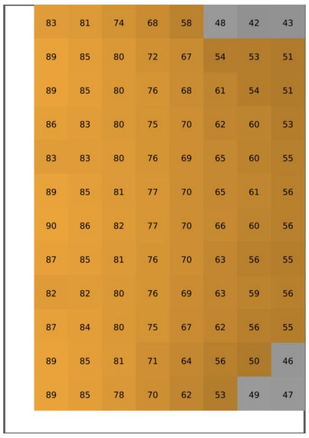
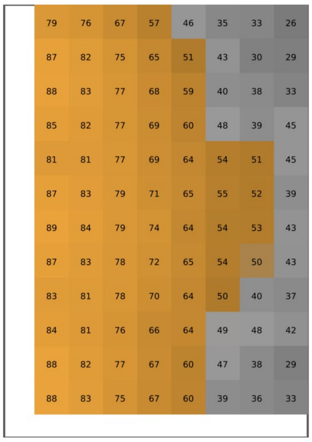
Eggcrate

2.1	1.1	0.62	0.43	0.35
3.2	1.4	0.79	0.52	0.46
2.2	1.5	0.82	0.54	0.55
2.8	1.4	0.89	0.63	0.50
2.9	1.4	0.91	0.59	0.50
2.2	1.4	0.87	0.56	0.51
3.2	1.3	0.81	0.53	0.46
2.2	1.2	0.70	0.46	0.37

1.1 %

Table 55: sDA of western shading devices

<table>
<tr><th colspan="3">Shading devices sDA</th></tr>
<tr><th>Time</th><th>Results
</th><th>sDA
</th></tr>
<tr><td>None</td><td></td><td>100,00%</td></tr>
<tr><td>Overhang</td><td></td><td>100,00%</td></tr>
<tr><td>Horizontal Louvers</td><td></td><td>100,00%</td></tr>
</table>

Overhang multiple blades		80,21%
Vertical Fin		93,75%
Slanted Vertical Fin		70,83%

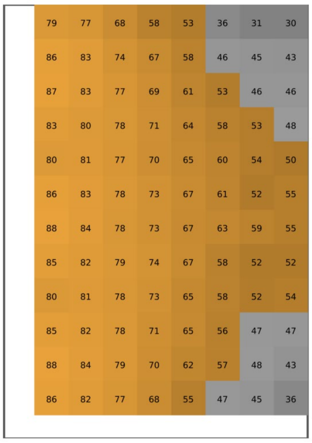
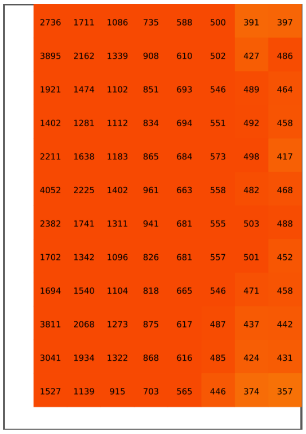
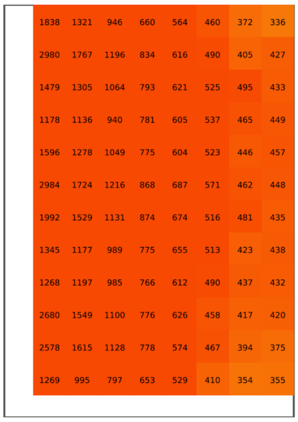
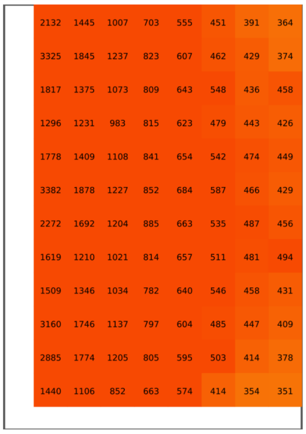
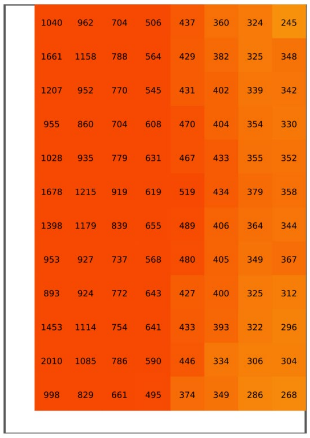
<table>
<tr><td>Eggcrate</td><td>
</td><td>83,33%</td></tr>
</table>

Table 56: Average lux of western shading devices

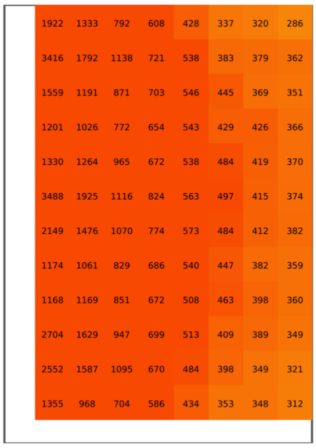
<table>
<tr><th colspan="3">Shading devices Average lux</th></tr>
<tr><th>Time</th><th>Results

</th><th>Average lux

</th></tr>
<tr><td>None</td><td>
</td><td>1.040,90</td></tr>
</table>

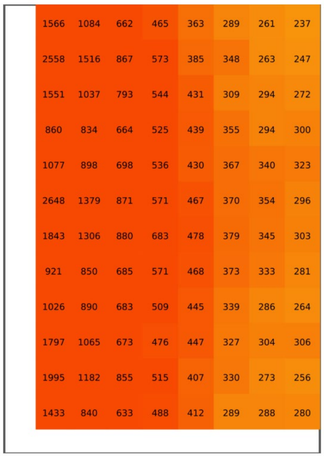
<table>
<tr>
<td>Overhang</td>
<td>
</td>
<td>886,86</td>
</tr>
<tr>
<td>Horizontal Louvers</td>
<td>
</td>
<td>950,06</td>
</tr>
<tr>
<td>Overhang multiple blades</td>
<td>
</td>
<td>642,54</td>
</tr>
</table>

Vertical Fin



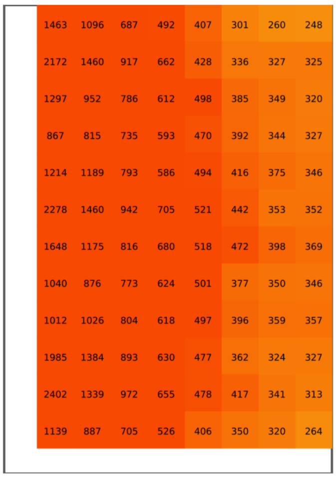
833,29

Slanted Vertical Fin



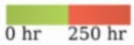
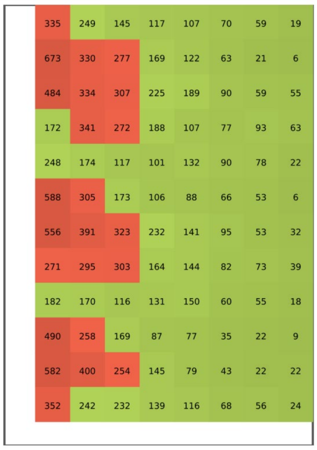
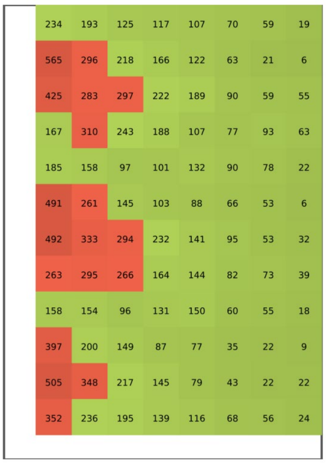
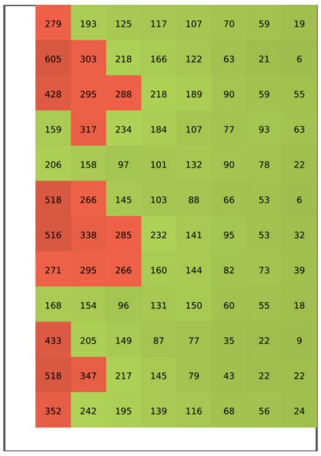
664,83

Eggcrate

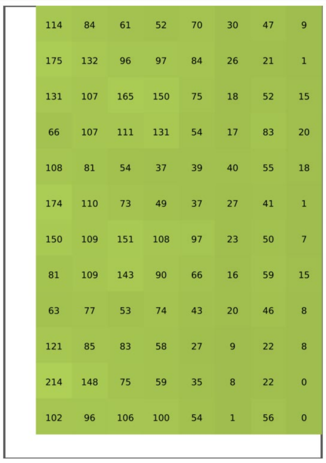


705,34

Table 57: ASE of western shading devices

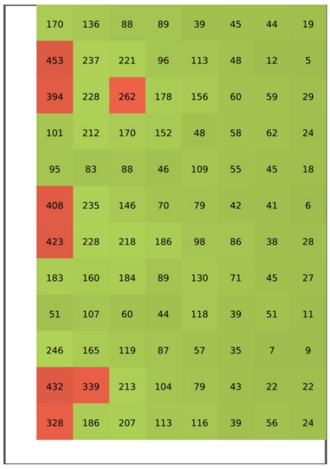
<table>
<tr><th colspan="3">Shading devices</th></tr>
<tr><th>Time</th><th>Results
</th><th>ASE
</th></tr>
<tr><td>None</td><td></td><td>23,96%</td></tr>
<tr><td>Overhang</td><td></td><td>18,75%</td></tr>
<tr><td>Horizontal Louvers</td><td></td><td>19,79%</td></tr>
</table>

Overhang multiple blades



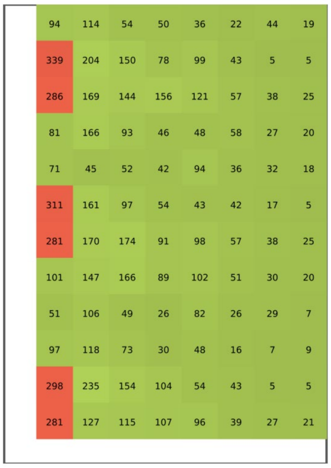
0,00%

Vertical Fin



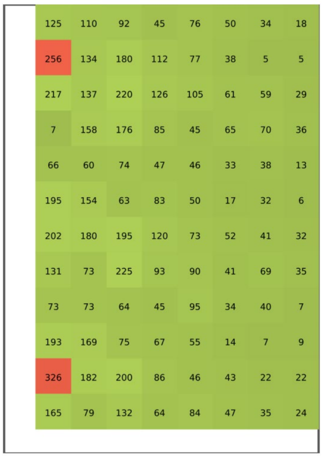
8,33%

Slanted Vertical Fin



6,25%

Eggcrate



2,08%

K.D.

Optimization of natural light in educational buildings through a parametric design approach: case study of " Sami Frasheri" high school in Tirana.

2021