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Semester:

Title: *The effects of direct daylight on light shelfs performance: A comparison study between building cases located in temperate zone, subtropical zone and tropical zone.*

Project Period: *31.03.2019 – 01.08.2019*

Semester Theme: *Master Thesis*

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Abstract:

This thesis is a comparison study, investigating the performance of the passive daylight technology of light shelves. Implemented in three different cities located within three different climate zones: Temperate, sub-tropical and tropical.

The theories and analysis of natural direct daylight and the performance of light shelves. Experiments were performed to evaluate the light shelves' performance within a case study building.

4 different scenarios were developed to investigate how the addition of light shelves can enhance the supply of daylighting in an interior space. And if it is possible to create a design which works for all 3 different climate zones.

The effects of direct daylight on light shelfs performance: A comparison study between building cases located in temperate zone, subtropical zone and tropical zone.

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Acknowledgements

I would like to firstly thank my supervisor and my guide throughout this whole master thesis. Nanet Mathiasen. For helping whenever I lost track of the overall narrative which I tried to create through this thesis work. For supplying literature, books, and other usual information when starting the project, while also offering her own expertise in the field. lastly, also for helping with the experiment at KADK, without you I would not have gained access to the light lab so that we could conduct experiments which were very insightful.

My mother Halima for being my mental support and partially being the inspiration for the project.

To my friends and colleagues who have been challenging my ideas and interests which has led me to write this thesis. Special thanks go to Monika and Ieva for reading the paper and giving constructive feedback.

To my family members in Somalia and friends in Portugal which have helped me find images and information on those locations.

Introduction

Sunlight is often something we take for granted. With alternative light sources integrated so deeply into our lives, it's easy to forget the great importance and benefits from daylight exposure.

If you've ever lived somewhere with short winter days, you will know that humans respond well to sunlight. It is an essential part of our well-being. And it has huge effects on our health and environment can offer great ways to orchestrate sustainable relationships with our environment. The improving effects which daylight can have on architecture and human's wellbeing is yet to be fully understood.

Another way in which daylight is being utilized is as a way of positively affecting the inhabitants of a building. The natural cycle of light and darkness is essential for our biological clock as well as our circadian rhythm, both of which have a huge effect on our general health and wellbeing. (Hvad med dagslys, Technical university of Denmark. designmanual med forslag til helhedsrenovering)

When creating new buildings these days, one of the issues that comes up is sustainability. Especially energy savings and the highly debated topic of climate change. Some of the solutions to these issues are to build low-energy buildings, passive solar houses and how to utilise the emitted energy from the sun. However, it's seldom implemented in the early design phases of a building project.

Rather than lighting up a whole room, highlighting and focusing on certain areas can create a powerful contrast. In this sense the light permitted into a room can be a tool used to create a narrative throughout the interior design.

Daylight and how it effects our vision is common to all sighted human beings. Thus, do we all perceive light in the same way? And, if we do see light in the same way, why are our lighting cultures then so vast and different from each other? How can we explain designing with daylight within vernacular architecture and design habits in different cultures?

This work analyses and compares the impact of daylight and the use of daylight in architecture, in different climate zones: Temperate, sub-tropical and tropical climate zones. 3 cities have been chosen for each respective climate zone. Copenhagen, Lisbon and Mogadishu.

The topic of this theoretical and investigative work is daylight and how it is used in design within different cultures and locations. The first impulse that led to the research presented here is personal, and it would be impossible to talk about this experience without conjugating it in the first person. This work intends to explain the light that I have experienced in the 3 different countries which are used as case studies. While living in all 3 cities, I had the opportunity of experiencing the natural light of three different cities and how their respective cultures deal with the sun and daylight habits.

This work is investigating different latitudes and consequently, different cultures, explaining the sunlight and weather conditions throughout the seasons in these different locations, is part of the work and it explains some of the light phenomena that are so characteristic of these climate zones, but it does not intend to embrace all the aspects of light in these cities. To live in a city relates to not only climate aspects but also culture. It involves history, social economic conditions, different architecture styles, marketing trends, behaviour etc.

Therefore, this report is documenting the daylight and direct sun lighting of a specific office space in Lisbon, Copenhagen and Mogadishu. Cultural aspects or behaviour explanations won’t be discussed through this work.

But what was the criteria for choosing these cities?

I was born in Mogadishu, one of Africa’s largest cities on the country with longest coastline in the continent, Somalia. Raised in these lighting conditions: Right above equator at a latitude of 02°, one of the cities with highest sun incidence in the world and with a majority of sunny days throughout the year. It is unnecessary to say how much this shaped my comprehension of light or how natural light would affect, consciously or subconsciously through culture.

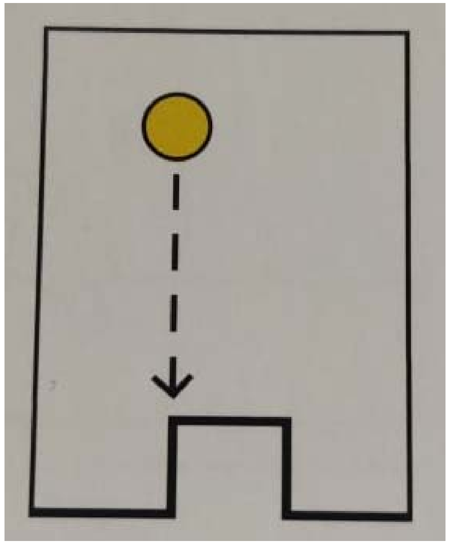


Figure 1. Sun position in hot climate zone, Mogadishu. Climate and architecture, Torben dahl

The second city chosen for this project is Copenhagen. living in Denmark for that last 20 years, located in the northern hemisphere, 55° North from the equator. Compared to other cities that I have visited, the specificity on the Scandinavian light was obvious.

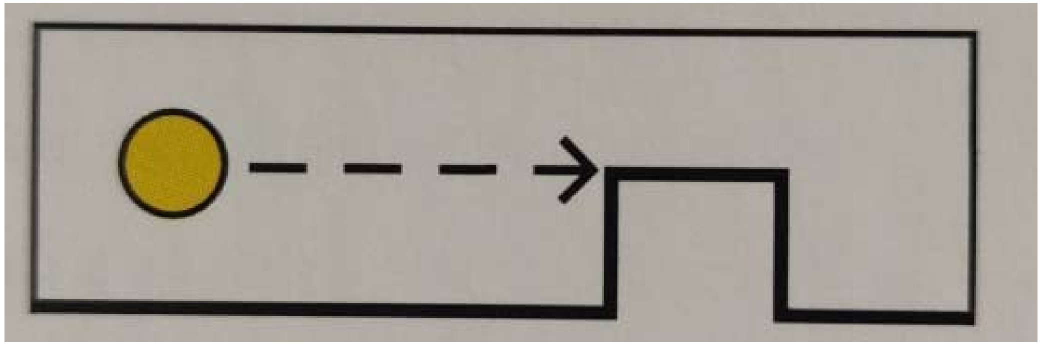


Figure 2. Sun position in cold climate zone, Copenhagen. Climate and architecture, Torben dahl

The third city, which I lived in through an Erasmus stay for 7 months is Lisbon. Lisbon is situated in 38° North from the equator. The inclusion of Lisbon in the research is based not only in my personal curiosity, but also in methodological approach. The simple comparison between Mogadishu and Copenhagen, two cities in such different latitudes and cultures would create two opposite conclusions. Therefore, a third point in in-between the two locations will hopefully clear the differences between the natural conditions and the cultural aspects.

Lisbon is the third point of comparison to avoid bias and to prove that we all see and have to deal with daylight and designing using vernacular architecture has to be taken into consideration when implementing daylight design.

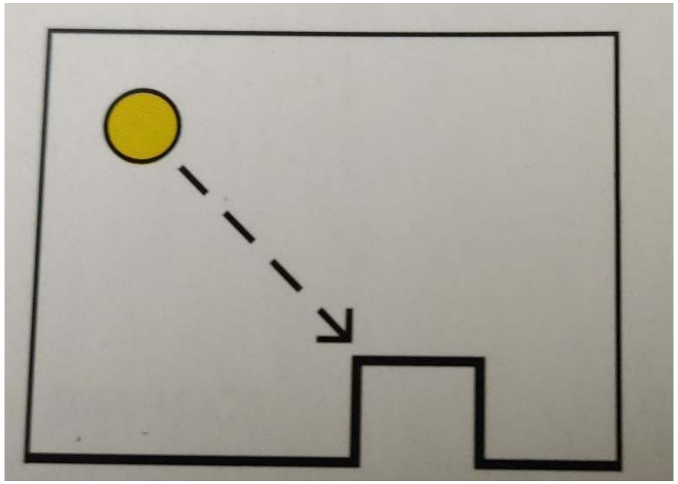


Figure 3. Sun position in moderate climate zone, Lisbon. Climate and architecture, Torben dahl

The focus points of this report is to analyse daylight, weather condition and test daylight technology, in this case light shelf performance in 3 different locations with vastly different climates, latitudes and sun positioning.

The thesis is divided into different chapters as follows:

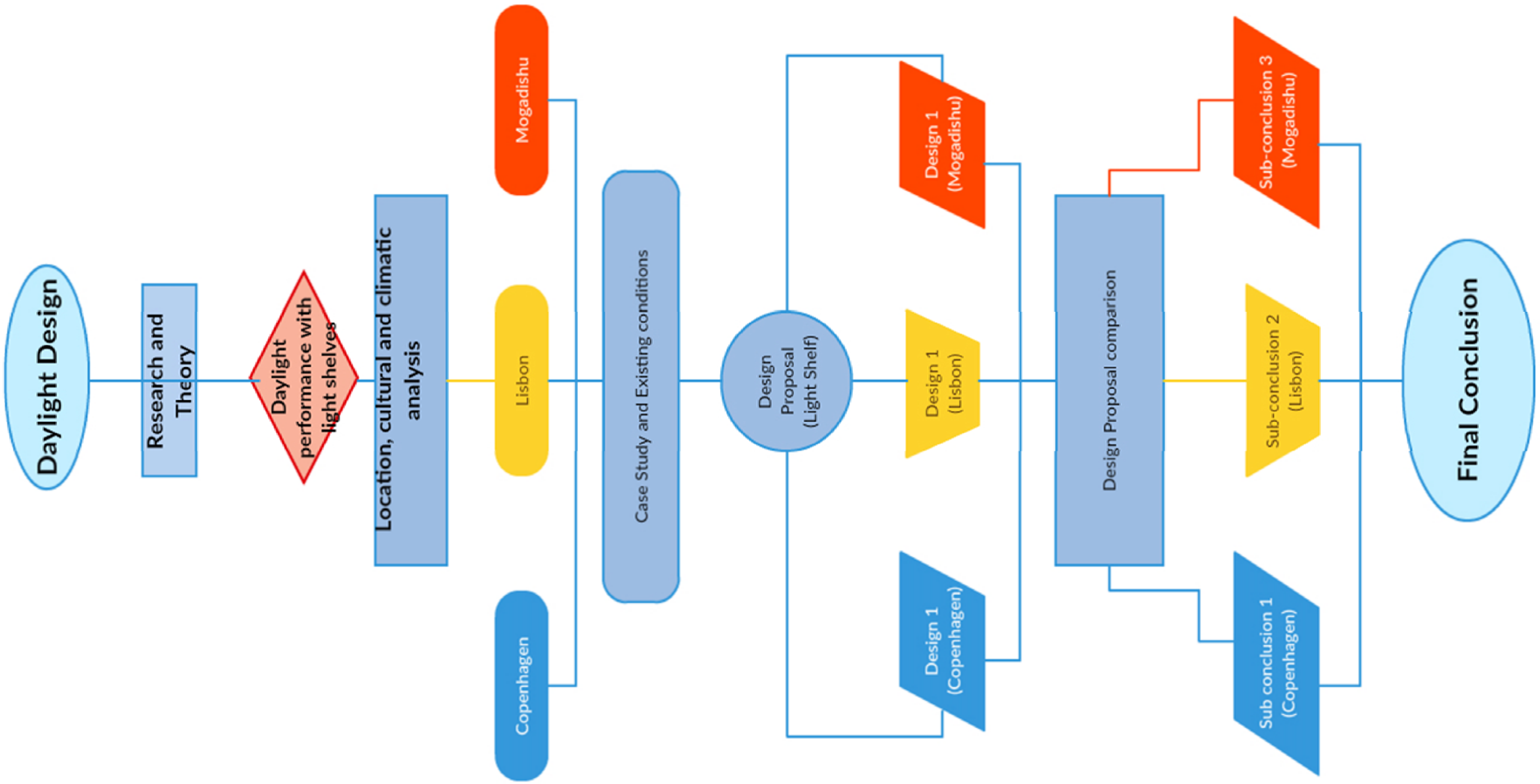


Figure 4. Methodology flow chart

The first theoretical base of the analysis is the locational information such as sun path, weather conditions, vernacular architecture and daylight performance. This section introduces the data that will be used throughout the report and introduce how to evaluate the daylight conditions. The lighting conditions will be analysed and expressed with its surroundings: i.e. how it moves and affects the space.

Analytical comparison between the daylight visuality in the three chosen cites, the second part of the theoretical background describes the day light conditions in each of the respective latitudes and the consequences on the spatial impressions and light quality will be explored.

The third part is a hands-on approach of the analysis. Testing and simulating the light within the chosen case study, while changing the location.

These case studies intend to document the reality of designing with daylight in the presented latitudes.

Methodology

The work process I have used for this report and the methodology used are as follows:

Starting with:

- Analysis of the case: Laying out the existing building conditions of the case study.

- Problem statement. After a thorough research it is time to clarify and set the focus point, which is the problem statement, which is intended to be answered throughout the design process.

- Design Solution (Light shelves). Presenting and investigating the light shelves in the case studies.

- Evaluating the Light shelf performance. Then it's time to evaluate the solution more thoroughly through quantitative and qualitative measures.

- Optimisation. This is where the design solutions are optimised. Creating 4 scenarios using light shelves.

- Conclusion. Finally, summarizing the results of the test. Evaluate and conclude.

The step by step procedure is shown in the methodology table. Starting point being, finding and understanding the case building. Followed by an in-depth analysis of the issue at hand, case study building with its existing daylight conditions. Leading to a problem statement.

Then there's an implementation of light shelves, inserting them in the case building and comparing their pros and cons, using the success criteria mentioned earlier: illuminance and uniform lighting.

The 4 sets of variables which investigated, were presented and compared between each other which then led to an open conclusion.

Success Criteria’s

When working with daylight, it is critically important to look at different aspects of daylight. Especially when it is required to create good daylighting conditions. Because there are different factors, which makes for good lighting conditions, and those conditions can be met by setting up various success criteria that I am to fulfil, which are as follows, in order:

1. Illuminance.
2. Uniform Lighting.

Illuminance

Illuminance is the luminous flux on a surface per unit area, meaning it’s a measure of how munch incident light illuminates a surface. The reason for why illuminance is a criterion for this project is because, the goal is to improve the lighting conditions and also to meet the standards within a room with poor daylight conditions. Therefore, the incident light on a surface, in this case working station/table is a good measure for illumination levels for a working area.

Uniform Lighting

Light uniformity or evenness of lighting is a measure of how evenly and uniformly the light in a setting is distributed. It is also a description of the smoothness of the lighting pattern or the degree of light intensity and dark areas in the area to be lighted. Uniform light is usually expressed as a ratio such as max to min. The lower the ratio the more uniform the lighting design.

This measure of uniform lighting is the 3rd success criteria for the project, which conveys very important information about how the user of the space perceives the environment.

When a person enters a new lighting environment, the pupil in the human eye automatically constricts or dilates to allow light into the eye. The human eye will fully adjust itself to even lighting in a new setting, even at very low light levels. However, if an environment has uneven lighting the eye will not fully adjust, and some areas will always appear darker than others. Uniform lighting in an environment is generally created by having many lights spread out to cover the area, as opposed to having only a few very bright lights which creates high contrast in the space. Working under excessive contrast can be tedious for the eye.

But there is a very fine balance between finding a variation level between complete uniformity and contrast. Low contrast and high degree of uniform lighting in the office spaces is a high priority for the success criteria of this paper.

Architectural Differences

Vernacular architecture is defined by building through necessity. The art of building specifically for a location, using construction materials and building with the knowledge acquired through tradition. It's a form of architecture which are indigenous to both location and time that cannot be replicated anywhere else. Vernacular architecture is usually developed by local builders who learn the trade and pass on the knowledge, in contrast to formally trained architects.

This is interesting because it is design through need, going back decades. So is there are difference in how Denmark, Portugal and Somalia builds and incorporate daylight within their respective vernacular architecture?

In this chapter we will go through the differences in architecture within the 3 different locations. How they differ in daylight design and why location and culture have an impact on daylight design.

Danish Architecture

Danish architecture springs back hundreds of years, back in Viking age where Viking houses which were built with the weather conditions in mind, cold, wind and rain. Those weather conditions resulted in buildings with few windows, thatched roof and the shape of the room also made so that the heat was trapped in the construction for as long as possible. Ventilation and heat was not an issue compared to other locations (Portugal and Somalia)

In todays

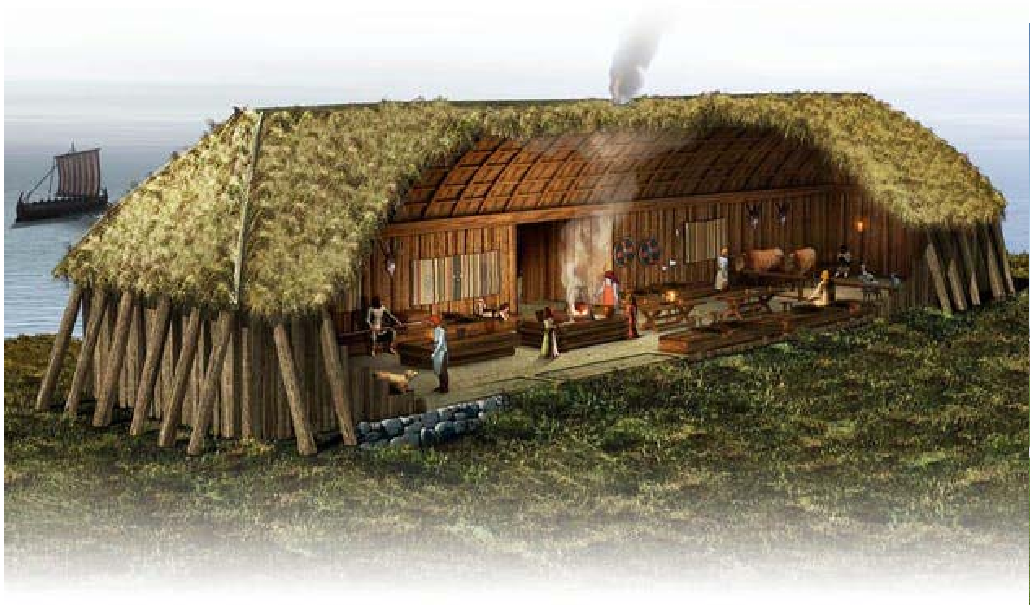


Figure 5. Viking house, c.980 , Historia.dk

Figure 6. Modern Danish home, 2017 , Decoist.com

Today's architecture in Denmark is focused on some of the same issues. Heating the indoor spaces while keeping the cold, rain and snow outside is still majorly part of how Danish architecture is defined in its basic functions. One aspect which is very different from back in the Viking ages was daylight. Because of the limited amount of daylight hours, especially in the winter has shifted an importance of Danish architecture which is the focus on daylight inlet, through windows, skylights and other components.

Copenhagen – Weather Conditions

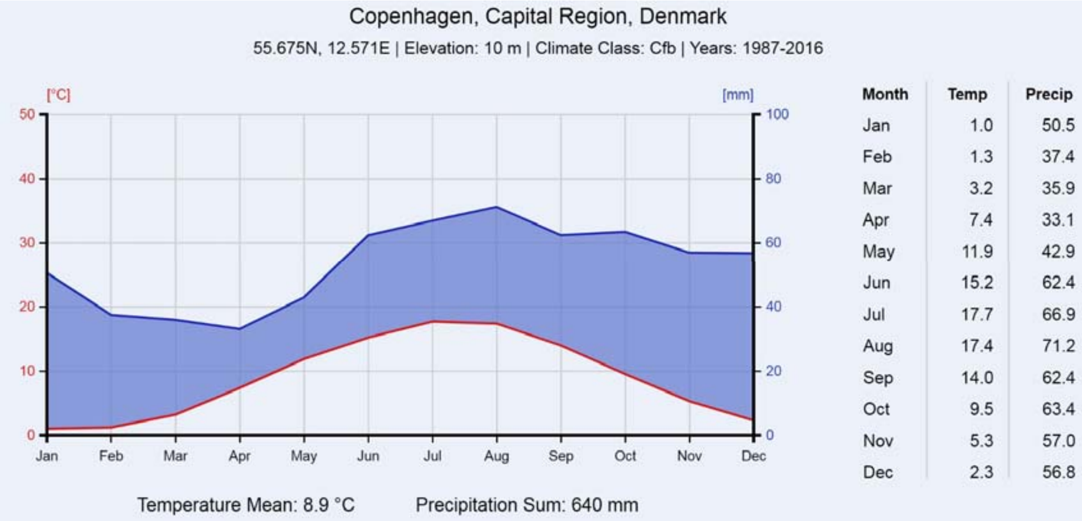
Copenhagen is in the temperate climate zone. Its weather is subject to low-pressure systems from the Atlantic ocean which result in unstable conditions throughout the year. Apart from slightly higher rainfall from July to September, precipitation is moderate.

GEOGRAPHIC LOCATION		SOLAR INFORMATION		TWILIGHT TIMES	
Latitude:	55.67769878°	Azi / Alt:	148.47° / 30.36°	Civil:	05:34 / 19:01
Longitude:	12.585868835°	Rise / Set:	06:11 / 18:24	Nautical:	04:50 / 19:45
Timezone:	GMT+01:00	Daylight:	12:13 Hrs	Astronom.:	04:03 / 20:31

Figure 7, weather condition Copenhagen. http://andrewmarsh.com/apps/staging/sunpath3d.html

June is the most sunny month of the year in Denmark, with an average of about eight hours of sunshine a day. July is the warmest month with an average daytime high of 21 °C. By contrast, the average hours of sunshine are less than two per day in November and only one and a half per day from December to February. In the spring, it gets warmer again with four to six hours of sunshine per day from March to May. February is the driest month of the year. Exceptional weather conditions can bring as much as 50 cm of snow to Copenhagen in a 24-hour period during the winter months] while summer temperatures have been known to rise to heights of 33 °C

Because of Copenhagen's northern latitude, the number of daylight hours varies from summer and winter. On the summer solstice, the sun rises at 04:26 and sets at 21:58, providing 17 hours 32 minutes of daylight. On the winter solstice, it rises at 08:37 and sets at 15:39 with 7 hours and 1 minute of daylight. There is therefore a difference of 10 hours and 31 minutes in the length of days and nights between the summer and winter solstices.



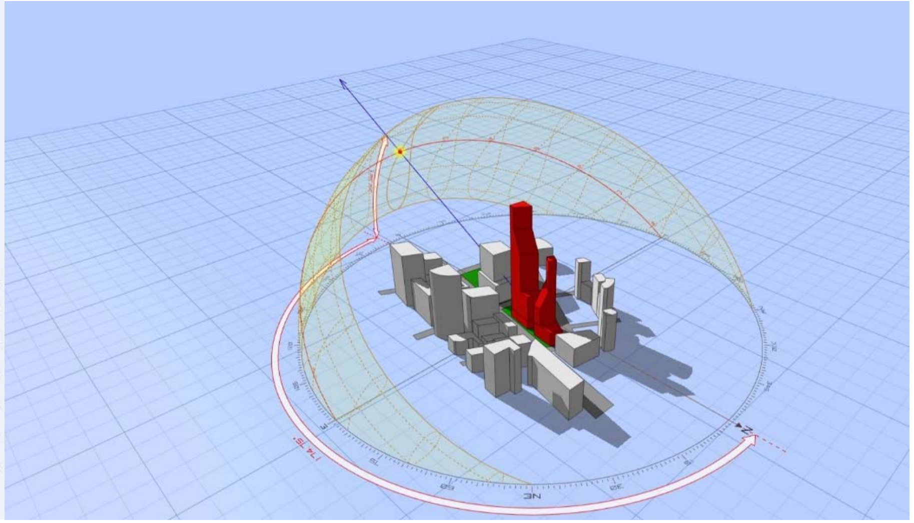


Figure 7, Average temperature and average rainfall in Copenhagen

Figure 8, 3D Sunpath diagram of Copenhagen, http://andrewmarsh.com/apps/staging/sunpath3d.html

At middle latitudes, far from both the Equator and the poles, variations in the length of daytime are moderate. In the higher middle latitudes where Montreal, Paris and Ushuaia are located, the difference in the length of the day from summer to winter can be very noticeable: the sky may still be lit at 10 pm in summer, but may be dark at 5 pm in winter. In the lower middle latitudes where Southern California, Egypt and South Africa are located, the seasonal difference is smaller, but still results in approximately 4 hours difference in daylight between the winter and summer solstices. The difference becomes less pronounced the closer one gets to the equator. An approximation to the monthly change can be obtained from the rule of 12ths. With 4 hours change over the six months from winter to summer the day lengthens by about 4*1/12 of an hour (20 mins) in the first month, 4*2/12 (40 mins) in the second month, 4*3/12 (1 hr) in the third month, then 1 hr, 40 mins and 20 mins in the fourth, fifth and six months.

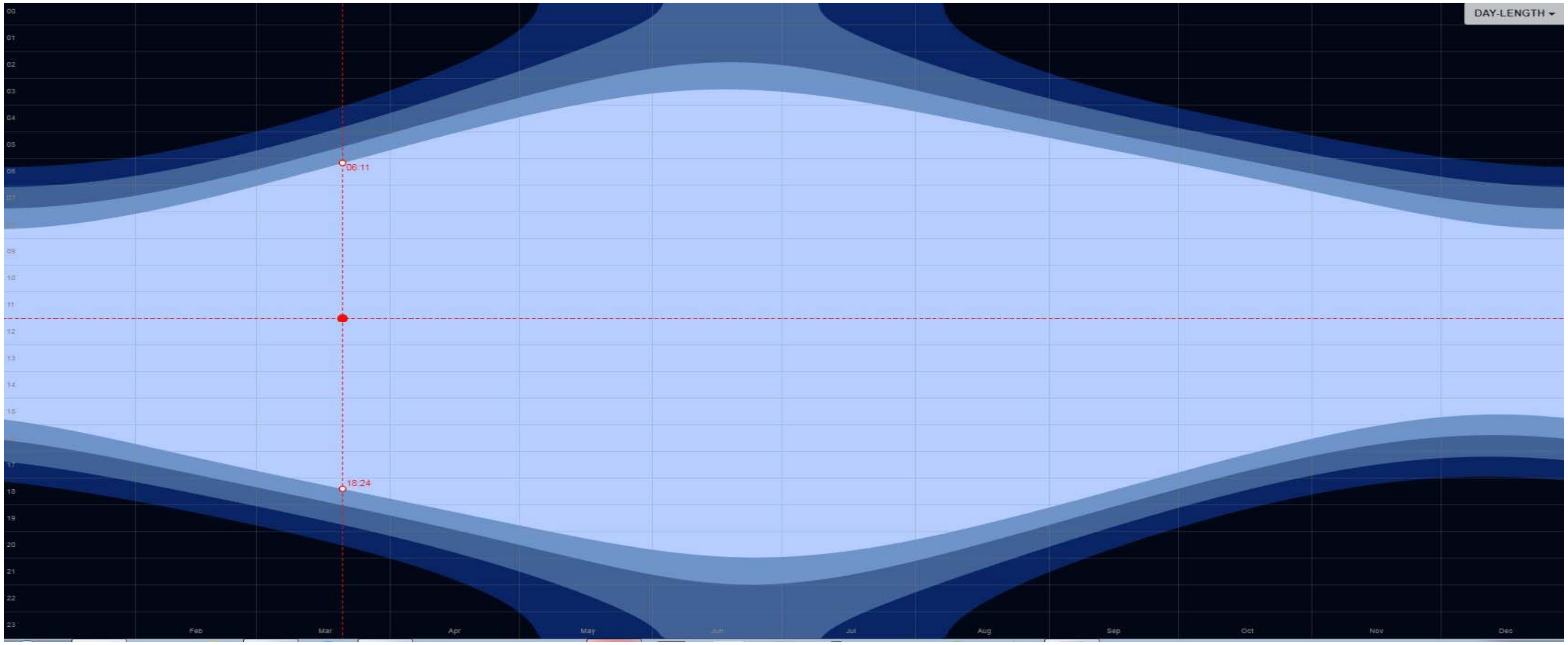


Figure 9, Day length for every month of the year in Copenhagen http://andrewmarsh.com/apps/staging/sunpath3d.html

Also in the middle latitudes, the seasonal climate variations produced by changes in the length of daytime are the most marked, with very distinct periods of cold and heat, and other secondary seasonal changes such as snow and ice in winter that disappear in summer and so on. At high latitudes, it is cold most of the time, with constant snow and ice, so the seasons are less obvious; and in the tropics, it is hot most of the time, with no snow or ice at all, so again the seasons are less obvious.

Portuguese Architecture

Portugal's longstanding traditions, geographic isolation, extended period under an authoritarian government, along with a group of very talented architects, have kept Portuguese architecture clean of capricious imitations. Portugal has an architecture that carefully evolved within the local tradition through a balanced process of absorbing universal influences. Because of portugals location on the world map, it was open for influence from the world. But still kept it's identity Vernacular architecture differs greatly according to locally available building materials and climatic conditions. As in most Southern European countries, most houses are built in stone and painted in vivid colours. In the south most houses are whitewashed, with the doors and windows framed in yellow or blue. Portugal is country which gets a fair number of sunshine hours with 2,806 per year resulting in few windows placement around the façade and blinds to keep the sunlight and heat at bay.

Figure 10. Portugeese house, https://thearchitectstake.com/editorials/portuguese-modern-an-architectural-tour/

Lisbon – Weather Conditions

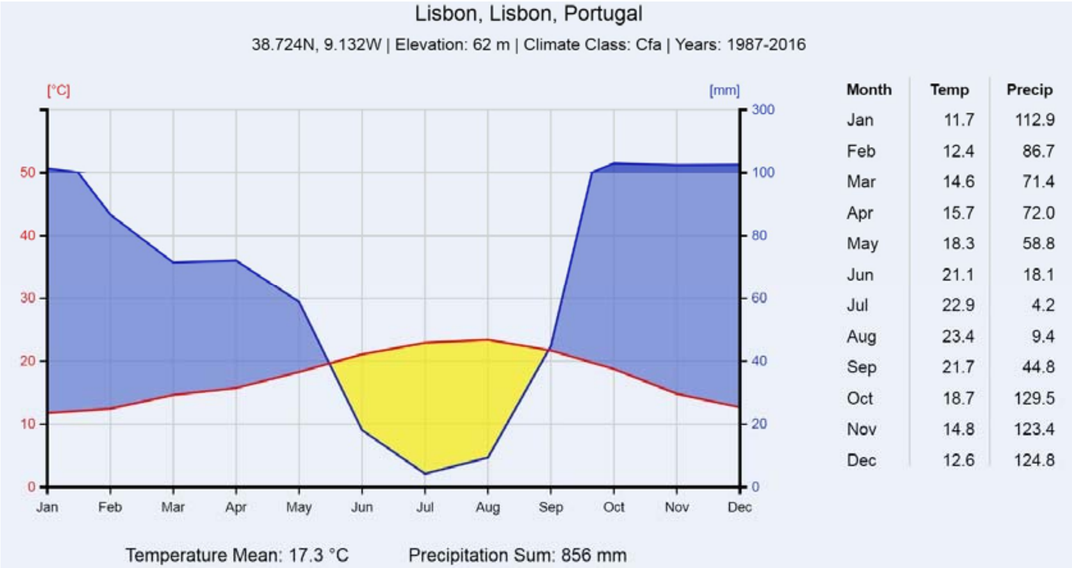
GEOGRAPHIC LOCATION		SOLAR INFORMATION		TWILIGHT TIMES	
Latitude:	38.732357128°	Azi / Alt:	151.74° / 47.83°	Civil:	05:13 / 18:15
Longitude:	-9.12689209°	Rise / Set:	05:39 / 17:49	Nautical:	04:42 / 18:46
Timezone:	GMT-01:00	Daylight:	12:09 Hrs	Astronom.:	04:10 / 19:18

Figure 10, weather condition Lisbon. http://andrewmarsh.com/apps/staging/sunpath3d.html

Lisbon is located at 38°″N 9° W, situated at the mouth of the Tagus River and is the westernmost capital of a mainland European country. Lisbon has a Mediterranean climate (Köppen: Csa) with mild, rainy winters and warm to hot, dry summers. The average annual temperature is 17.4 °C In the coldest month – January – the highest temperature during the day typically ranges from 10 to 18 °C . In the warmest month – August – the highest temperature during the day typically ranges from 25 to 32 °C

Among European cities with a population above 500,000, Lisbon ranks with one of the warmest winters (less than Valencia or Málaga) and one of the mildest night time temperatures, from an average of 8.3 °C in the coldest month, and 18.6 °C in the warmest month.

Sunshine hours are 2,806 per year, from an average of 4.6 hours of sunshine duration per day in December to an average of 11.4 hours of sunshine duration per day in July. The annual average rainfall is 774 mm (30.5 in), being November the wettest month.



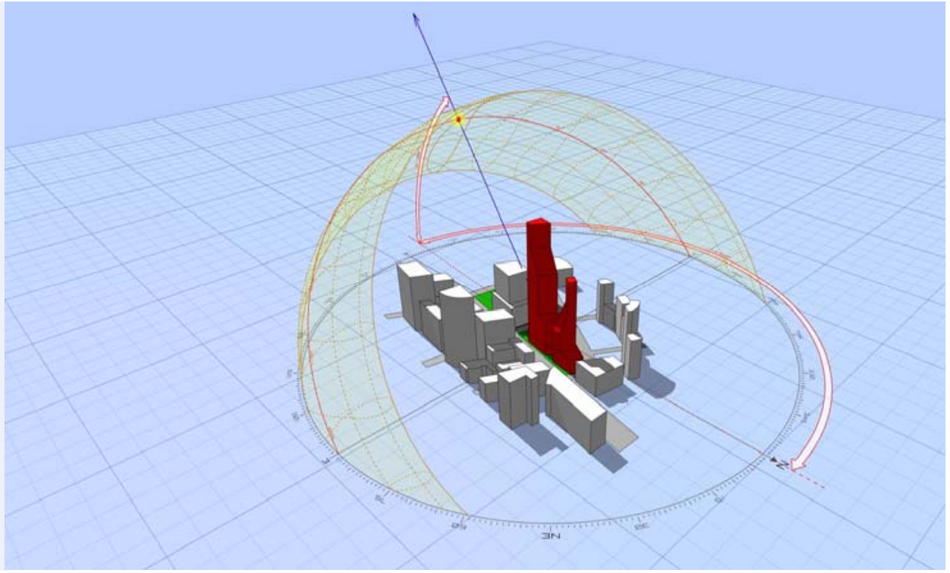


Figure 11, Average temperature and average rainfall in Lisbon

Figure 12, 3D Sunpath diagram of Lisbon, http://andrewmarsh.com/apps/staging/sunpath3d.html

The tropics occupy a zone of Earth's surface between 23.5° north and 23.5° south of the Equator. Within this zone, the Sun will pass almost directly overhead (or culminate) on at least one day per year. The line of 23.5° north latitude is called the Tropic of Cancer, because when it was named, the Sun passed overhead at this location at the time of year when it was within the zodiac sign of Cancer. The equivalent line of south latitude is called the Tropic of Capricorn, for similar reasons. If they had been named today using the constellation in which the sun is currently in at the time it is directly overhead the tropic line, they would have been called, respectively, the Tropics of Gemini and Sagittarius.[citation needed] The sun enters and leaves each sign of the zodiac slightly later each year at the rate of about 1 day every 72 years. For more information, see precession of the equinoxes.

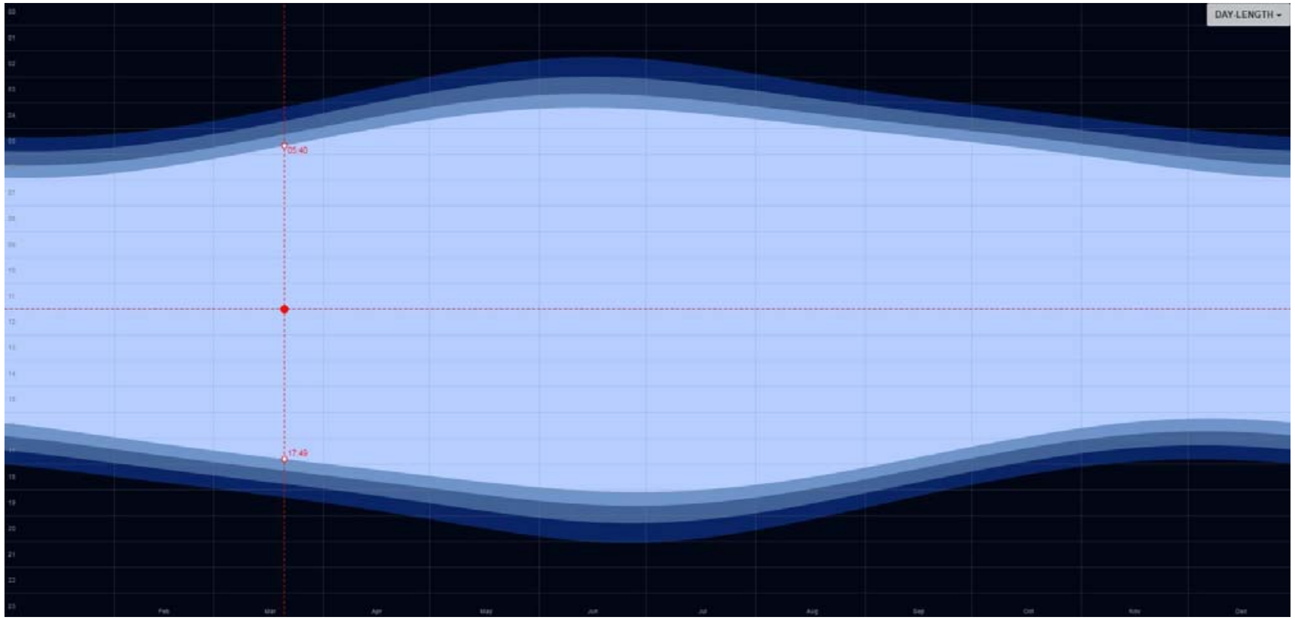


Figure 13, Day length for every month of the year in Copenhagen http://andrewmarsh.com/apps/staging/sunpath3d.html

On the Tropical Circles, the Sun is directly overhead only once per year, on the corresponding solstice. At latitudes closer to the Equator and on the Equator itself, it will be overhead twice per year (on the equinoxes in the case of the Equator). Outside the tropics, the Sun never passes directly overhead

Somali Architecture -Building Culture

The traditional Somali house is known as Guri. The main characteristics of a guri is either having a central courtyard that is nor equipped with a roof or in some cases only covered slightly with a detachable cloth material (rainfall is low in Somalia). The other main characteristic of the guri is of having an extended patio which functions as a both as shading and as an extra inlet of ventilation. The patio is often open without any enclosed window or door on the outside façade. The roofs are high and the rooms are narrow and long to support in ventilation throughout the rooms. As in other muslim countries, the architecture is designed with privacy in mind. For example are the main corridor not leading directly into any private rooms, and the front entrance is positioned so that it is aligned with the main corridor to minimise view between the outdoor and rooms.

Figure (14) Houses in central Mogadishu showing the extended patio.

Figure (15) Houses in central Mogadishu showing a shared courtyard.

The amounts of windows facing the main streets are few, with most of the openings facing the courtyard. The windows are mounted high so that outside pedestrians wont be able to peek inside. The architecture is design with privacy and functionality in mind, high ceilings and flexible rooms (rooms which doesn’t have a specific purpose). The inside courtroom opening let’s in both fresh air and daylight. The sun is set high throughout the whole year, so this design is beneficial for limiting the light and heat, while the opening let’s in air through natural ventilation. While maintaining good daylight conditions in the courtyard.

Mogadishu – Weather Conditions

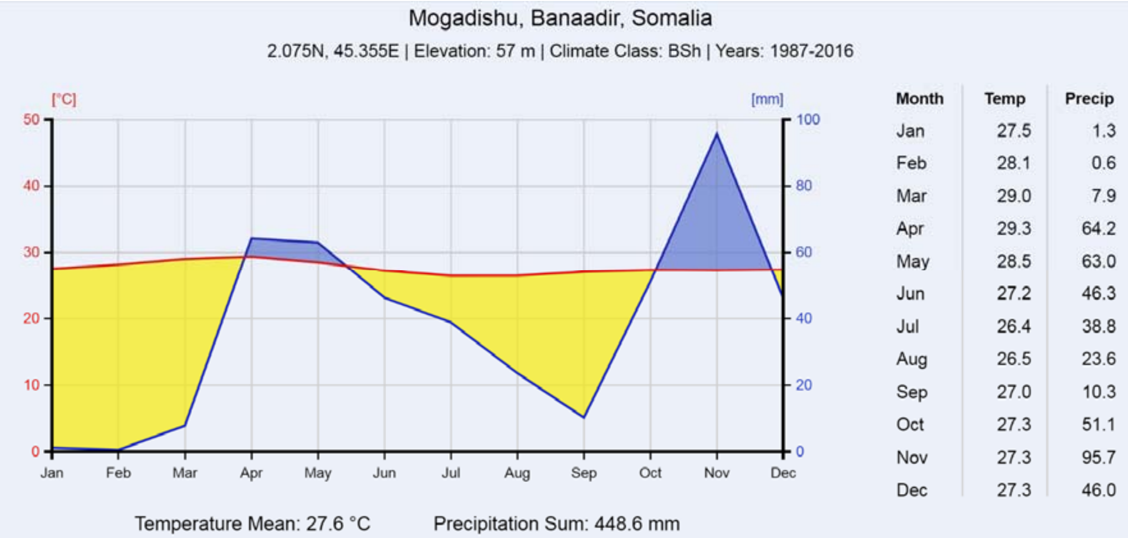
GEOGRAPHIC LOCATION		SOLAR INFORMATION		TWILIGHT TIMES	
Latitude:	2.018357631°	Azi / Alt:	94.19° / 65.84°	Civil:	05:42 / 18:30
Longitude:	45.315856934°	Rise / Set:	06:03 / 18:10	Nautical:	05:18 / 18:54
Timezone:	GMT+03:00	Daylight:	12:07 Hrs	Astronom.:	04:54 / 19:18

Figure 16, weather condition Mogadishu. http://andrewmarsh.com/apps/staging/sunpath3d.html

For a city situated so near to the equator, Mogadishu has a relatively hot and dry climate. It is classified as hot and semi-arid (Köppen climate classification BSh), as with much of southeastern Somalia. By contrast, towns in northern Somalia generally have a hot arid climate.

Mogadishu is located in the tropical climate zone. The mean temperature in the city year-round is 27 °C, with an average maximum of 30 °C and an average minimum of 24 °C. Mean temperature readings per month vary by 3 °C.

Precipitation per year averages 429.2 millimeters. There are 47 wet days annually, which are associated with a 12% annual daily probability of rainfall. The city has an average of 3,066 hours of sunshine per year, with 8.4 hours of sunlight per day. Mean daylight hours and minutes per day are 8h 24'. The annual percentage of sunny versus cloudy daylight hours is 70 and 30, respectively. Average sun altitude at solar noon on the 21st day of the month is 75.



Month	Temp	Precip
Jan	27.5	1.3
Feb	28.1	0.6
Mar	29.0	7.9
Apr	29.3	64.2
May	28.5	63.0
Jun	27.2	46.3
Jul	26.4	38.8
Aug	26.5	23.6
Sep	27.0	10.3
Oct	27.3	51.1
Nov	27.3	95.7
Dec	27.3	46.0

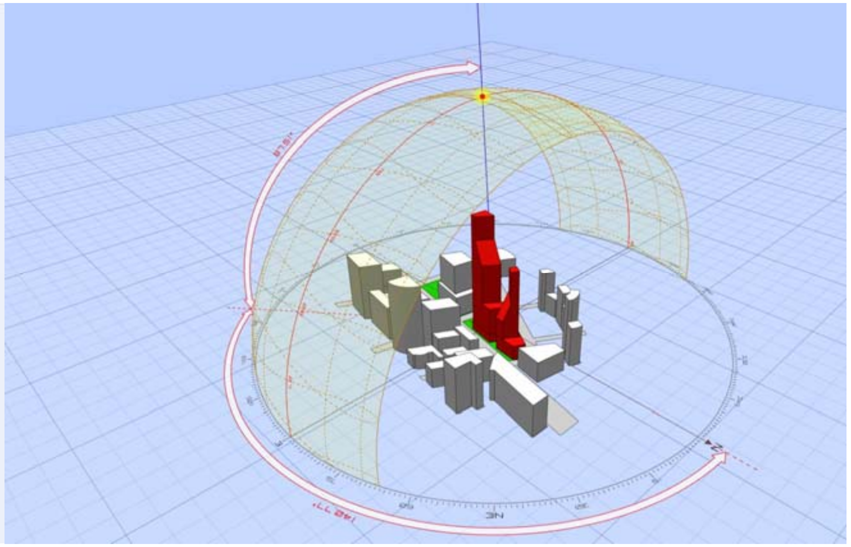


Figure 17, Average temperature and average rainfall in Mogadishu http://andrewmarsh.com/apps/staging/sunpath3d.html

Figure 18, 3D Sunpath diagram of Mogadishu, http://andrewmarsh.com/apps/staging/sunpath3d.html

At the Equator, the daytime period always lasts about 12 hours, regardless of season. As viewed from the Equator, the Sun always rises and sets vertically, following an apparent path nearly perpendicular to the horizon. Due to the axial tilt of Earth, Sun always lies within 23.5° north or south of the celestial equator, so the subsolar point always lies within the tropics.

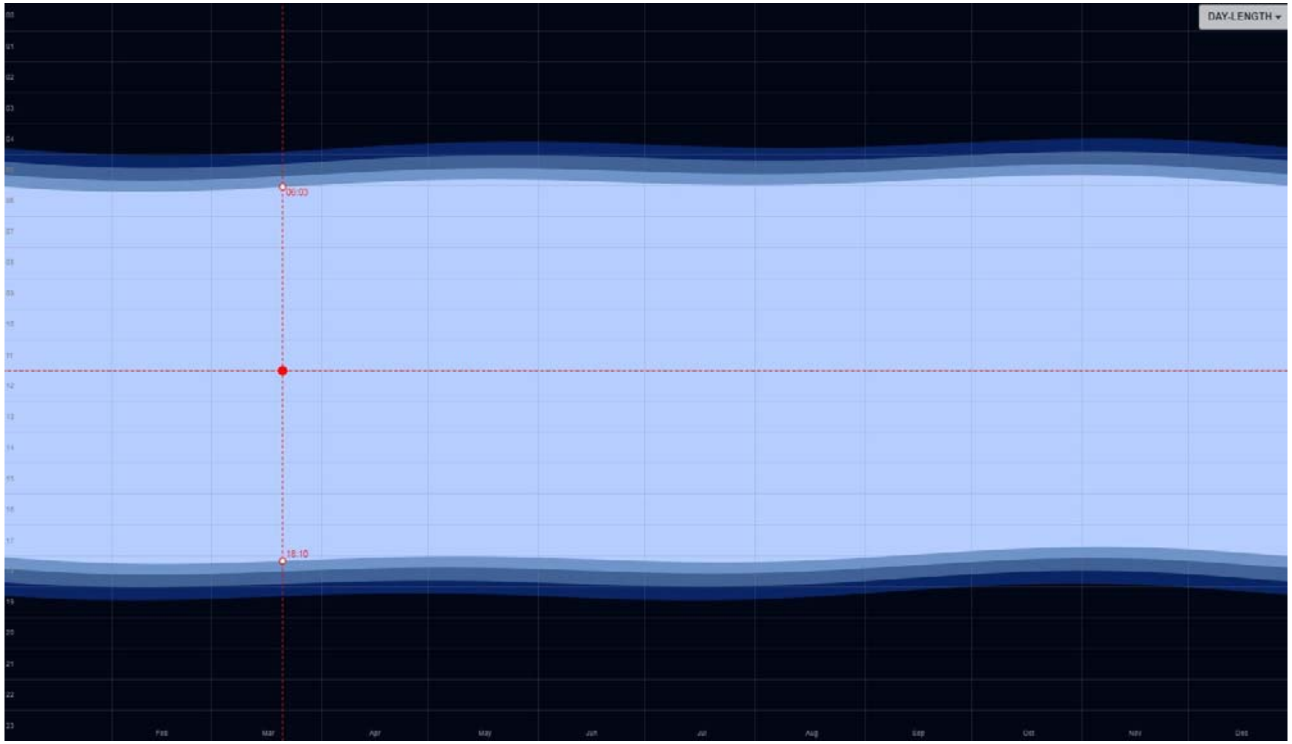


Figure 19, Day length for every month of the year in Mogadishu http://andrewmarsh.com/apps/staging/sunpath3d.html

From the March equinox to the September equinox, the Sun rises within 23.5° north of due east, and sets within 23.5° north of due west. From the September equinox to the March equinox, the Sun rises within 23.5° south of due east and sets within 23.5° south of due west. The Sun's path lies entirely in the northern half of the celestial sphere from the March equinox to the September equinox, but lies entirely in the southern half of the celestial sphere from the September equinox to the March equinox. On the equinoxes, the equatorial Sun culminates at the zenith, passing directly overhead at solar noon.

The fact that the equatorial Sun is always so close to the zenith at solar noon explains why the tropical zone contains the warmest regions on the planet overall. Additionally, the Equator sees the shortest sunrise or sunset because the Sun's path across the sky is so nearly perpendicular to the horizon. On the equinoxes, the solar disk takes only two minutes to traverse the horizon (from top to bottom at sunrise and from bottom to top at sunset).

Building Orientation

Building orientation refers to the way a building is situated on a site and the positioning of windows. A building oriented for solar design takes advantage of passive solar strategies. Passive solar strategies use energy from the sun to heat and illuminate buildings. Building orientation and building materials also facilitate temperature moderation and natural daylighting

Passive solar heating makes use of the building components to collect, store, distribute, and control solar heat gains to reduce the demand for fossil fuel powered space heating.2 Passive solar heating strategies also provide opportunities for daylighting and views to the outdoors through well positioned windows.

Light shelves benefit of being mounted on south facing facades and south facing windows, simply for the fact that it allows most daylight in. For this project specifically we are investigating performance of the passive daylight technology; Light shelf.

Problem statement

How can the addition of light shelves, enhance the supply of daylighting in an interior space? And is it possible to create a design which works for all 3 different climate zones?

Case study condition

Why use a case study building.

The case study building in this project are made to be able to exercise real life solutions into a hypothetical scenario. Creating a case study building enables me as a student to apply theoretical knowledge and experience in a real-world situation.

The aim of this project is to figure out if there is a problem and how to solve if there is one. Which is why a case study building is fundamental for the success of this thesis in particular.

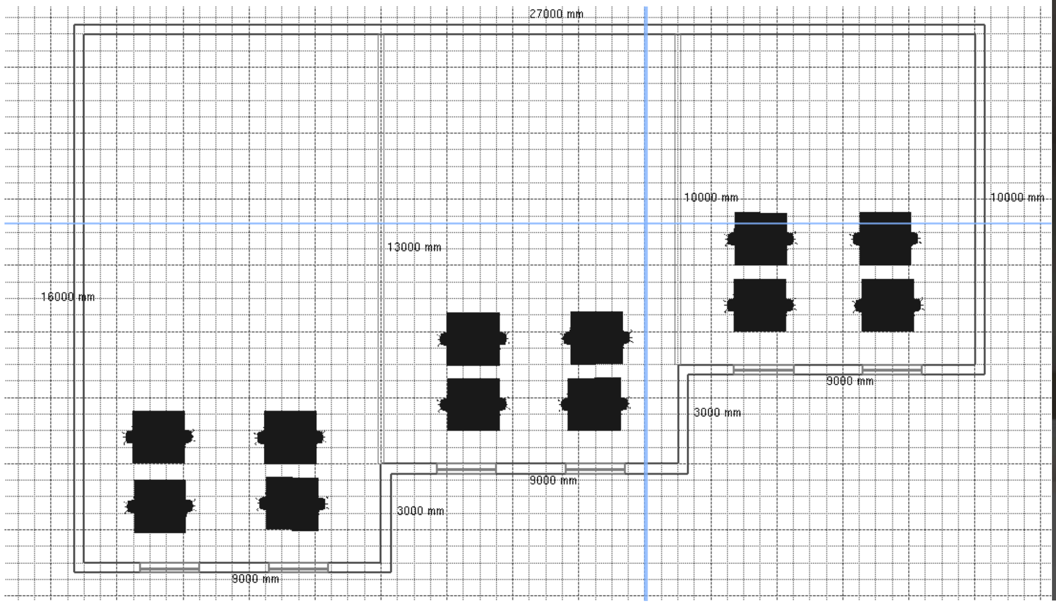


Figure 20, Floor plan of the study case office building

Figure 21, Cross section of the study case office building

The case is an office building comprised of 3 rooms. The rooms all have the same length of being 5 m long. Window placement is the same for all the rooms and are south facing because that is the façade that allows the most amount of daylight throughout the year (if situated on the northern hemisphere). The variable in the 3 rooms is the depth of the rooms. 1^{st} room (west facing room) is 16 m in depth, 2^{nd} room (centre room) is 13 m in depth and the 3^{rd} room (smallest and facing room) is 10m in depth

Introduction to Light shelves

A light shelf is a passive architectural technology which has the capability to reflect daylight deep into a room and building. Light shelves have a horizontal surface, which gives it its ability to redirect sunlight evenly and deeply into a building. The surface of the light shelf is made with a high reflecting surface which are good at conducting and reflecting light. Therefore, light shelf is a good device to minimize dark spots in a room whilst also reducing direct glare, near to the window openings. Which is an issue when the suns angle is very high.

Interior light shelves in particular divide windows into the top window being the window which reflects and let's daylight in, deep into the room. So, light bounces off the light shelf, then the ceiling and then into the room. While the lower window is reserved for the view. As in figure (?)

This project uses interior light shelf instead of exterior light shelves, because the case study used in this project is rather small with only 1 floor and 3 m to the ceiling. Which means that if exterior light shelves were used, they would block the inlet of daylight in the lower window. Which ultimately would decrease the total amount of daylight that entered the whole building.

Exterior light shelves are better at reducing glare and creating shade. But with this thesis focusing on the increase of direct daylight in architecture. It was not suited for this investigation. Exterior light shelves are also harder and more costly to main, due them being affected by weather conditions. Where interior light shelves are very easily accessible, say if they were used on a multi-story building.

Figure (22) representation of window placement upper and lower, with light shelf in between

For the most amount of sunlight collection, light shelves are facing towards the equator. So in the northern hemisphere that would conclude in south facing facades. Placing them in the other orientations wouldn't be efficient when we are looking at daylight and direct daylight specifically.

Placing the light shelves north facing would act as a shading instruments because the north facing windows would get minimal direct daylight. east and west facing wouldn't as well be as optimal. From design perspective, some architectural projects would benefit from having morning or evening sun. But this project is mainly investigating peak daylight availability.

The build up of a light shelf can vary, with it being made with wood, metal boards, plaster or plastic. The material of the coating is more important though to be able to distribute light evenly in the room. The surface doesn't require to have reflective properties but should ideally be matte white with specular properties.

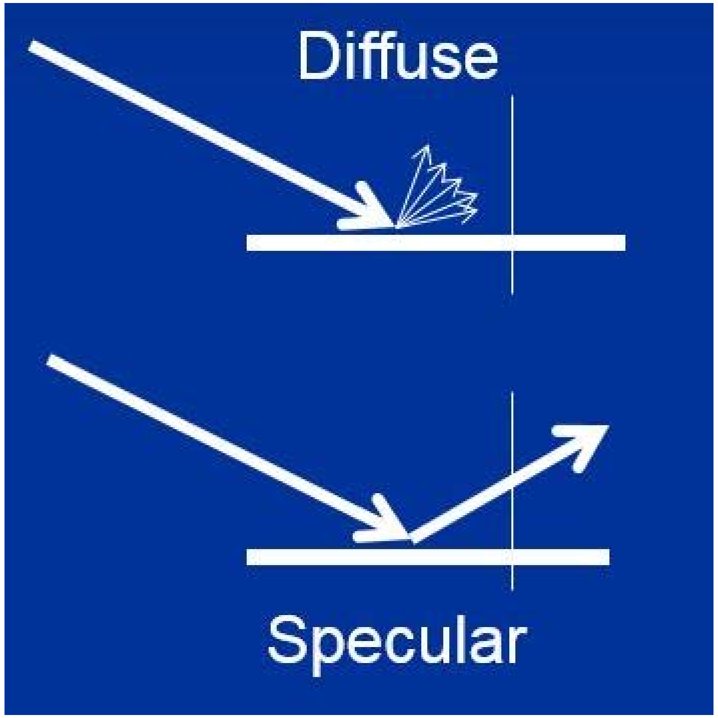


Figure (23) Improves daylight penetration. (sketch made in powerpoint)

Benefits of light shelves

Light shelves are able to enhance the daylight quality in a building, by increasing the total illuminance of light in the room while also increase uniform lighting for a whole room. By enhancing the daylight quality in a room, we also subsequently reduce the need for electrical/artificial lighting, which in conclusion reduces the overall energy consumption. A grand benefit of light shelves is that it's possible to increase the total amount of daylight in the room, while in the meantime decreasing direct glare, near the light inlets, windows.

When there is benefits, there might also be limitations, which is also the case for light shelves. Light shelves tend to used more in temperate climate zones rather than sub-tropical or tropical climates. That is the conception, but that will be investigated in this thesis. In some cases, the design of the building and architecture does not allow for the implementation of light shelves. So, it is suited for a building that has yet to be erect or it comes to down to existing conditions if light shelves can be implemented. Maintenance is also a condition that has to be met. Even though interior light shelves are used for this project, which has less maintenance than exterior ones. We are still applying a technology which has to be repaired and maintained if need be.

Interior Light shelves

Interior light shelves are able to be constructed with very light weight material and coating. They are also able to be fitteded multiple times and easily retrofitted if damaged. Regarding how little vertical space they take, they have the capability to increase the daylight penetration twice fold. So for example with a 3 m tall ceiling it is able to penetrate 7.5 m into a room. (reference)

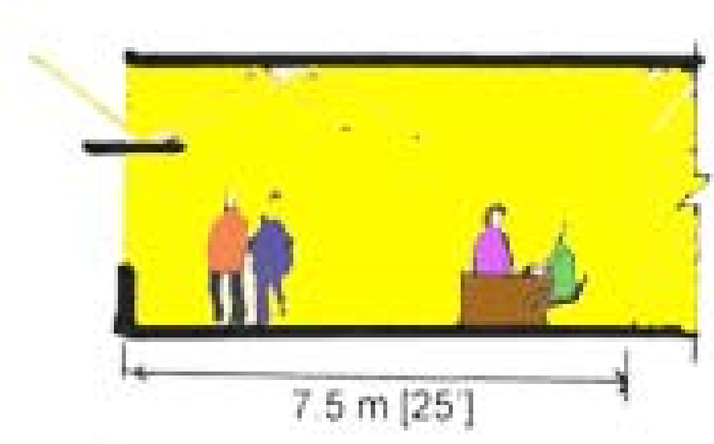


Figure (24) Daylight penetration with light shelf (Inlighten™ Light shelf) **Figure (25) Example of interior light shelf in a multistory building.(Inlighten™ Light shelf)**

Lastly, the availability of using light shelves are high. Most of the light shelves are built on the building/construction site, with some still being constructed industrially and sold worldwide, even for commercial use.

Experiment 1: Daylight Visualisations

Daylighting simulation tools make it possible to evaluate the quantity and distribution of daylight in a room, while taking into account key influential parameters such as window placement, building geometry, external obstruction, interior divisions and material properties.

Most CAD visualisation programs used today are capable of generating images that look realistic, but they do not provide information about the quantity and quality of daylight in the rooms. However, simulation tools such as Daylight Visualizer are capable of producing images with daylight data in different sky conditions, overcast sky 1, intermediate 7 and clear sky 12

The use of daylight visualisations is to understand how the daylight acts throughout the day, in different sky conditions, year and within the different locations. Following the success criteria of Illuminance and Uniform lighting we will test few scenarios.

- The 3 locations without light shelves.
- The 3 locations with light shelves
- Summer solstice, winter solstice, autumn and spring equinoxes.
- Morning (8'oclock), Noon (12'o clock) and Afternoon (16'o clock)

Following the specified scenarios, a matrix was created to keep track of which scenarios are being investigated and how the relate to each other, on a scientific note it is also very easy to get lost in which is the constant and variables when investigating multi factored experiments.

Variable Matrix		
CPH - Windows	LIS - Windows	MOQ - Windows
Winter solstice	Equinox	Summer Solstice
8 o'clock	12 o'clock	16 o'clock
CPH - Light Shelf	LIS - Light Shelf	MOQ - Light Shelf

Figure(26) Variable matrix for keeping track of constants and variables.

These are specific scenarios aimed to fulfil the criteria, investigate the possibilities of using light shelves as a design solution.

Results and discussion of experiment 1: Daylight Visualisations

In this section we will delve into the findings, results and discuss them. The 4 different scenarios that have been set up, to explore the project in different aspects and views regarding light shelves and their impact on the case study building. The Scenarios are as follows:

1. Scenario 1. Current daylight conditions. Which are the case study building in all 3 different locations, Copenhagen (CPH), Lisbon (LIS) and Mogadishu (MOQ). Current conditions also mean that the light shelves are not yet implemented, to get some data and feel for how the conditions are, currently. The time and date for the Scenario 1 is at noon (12 o’clock) and at summer solstice which is 21st June 2019.

2. Scenario 2. has a similar setup as scenario 1. In which the date and time is the same, at noon (12 o’clock) and at summer solstice which is 21st June 2019. The difference is that in Scenario 2, we implement the light shelves. Using the same constants and using the light shelves as the only variable, we are able to see the impact that light shelves have on the case study building within the three different locations. Which will give us the data needed to be able to conclude if light shelves actually bring an improvement in daylight conditions.

3. Scenario 3. After comparing scenario 2 and 1 which will show us the difference which light shelves create. We can then start choosing other variables. In this case looking at Equinoxes. Because both equinoxes, 21st march and 21st September are mirrored in daylight conditions. We can just use one data set instead of making two identical ones. The time of day has also been changed to morning (8 o'clock), to investigate how the light shelves performs in the three different locations, in the morning.

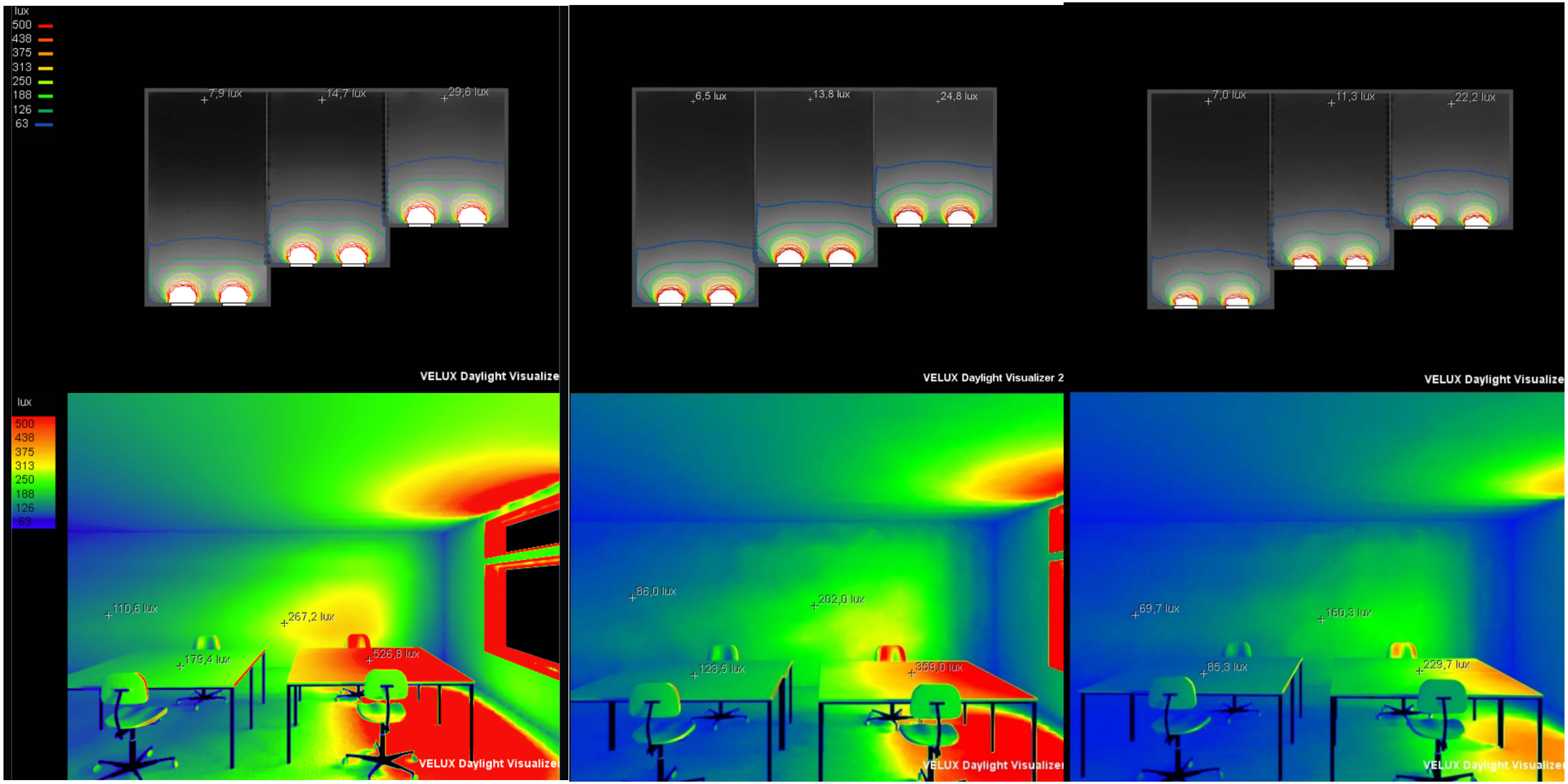
4. The last scenario is to investigate the other end of the spectrum, winter solstice. This is where we've hypothesised that daylight will be very insufficient in CPH, due to the short daylight hours around winter solstice. But still, to compare all three locations, we must see how light shelves performs and if they can improve the daylight conditions in the winter months.

Scenario 1 – Windows, Noon at summer solstice

First of all, we will have to evaluate the daylight conditions in each specific location. The way we do that is by comparing the conditions for each location. While keeping the time of day and time of year constant, the variable in this scenario is the 3 different locations. This will give us a first glance of how well the daylight conditions are in set climate zones.

Variable Matrix		
CPH - Windows	LIS - Windows	MOQ - Windows
Winter solstice	Equinox	Summer Solstice
8 o'clock	12 o'clock	16 o'clock
CPH - Light Shelf	LIS - Light Shelf	MOQ - Light Shelf

Figure(27) Variable matrix, Scenario 1.



Figure(28) Illuminance plan and cross section CPH at 12 o'clock, summer solstice

Figure(29) Illuminance plan and cross section LIS at 12 o'clock, summer solstice

Figure(30) Illuminance plan and cross section MOQ at 12 o'clock, summer solstice

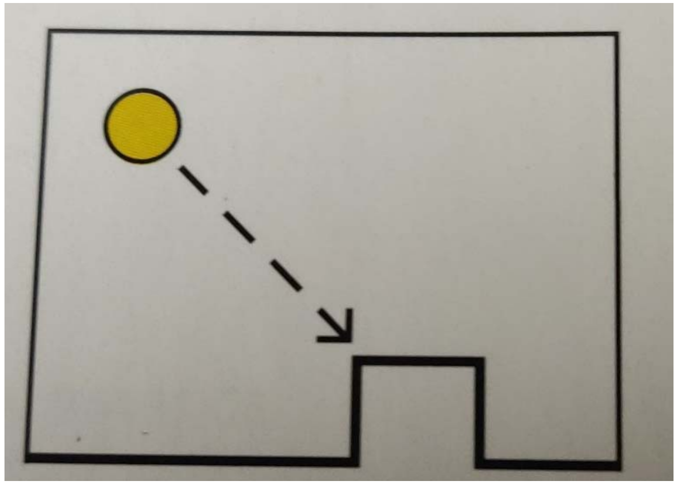
As showed in the matrix variable, the first is the location. Comparing daylight situation in Copenhagen(CPH), Lisbon(LIS) and Mogadishu (MOQ) at summer solstice,12 o'clock at noon. Therefore, the constants are the date of the year and the time of day. The suns angle at this specific point in time (at 21. June 2019) is, 58.34 ° in Copenhagen, 74.68° degrees in Lisbon and lastly 68.57 ° in Mogadishu.

CPH is the case with the lowest sun angle at 58° compared to LIS and MOQ with around 70° sun angle. Which results in deeper penetration of daylight into the rooms. The reason for this is that the angle of the sun is a big factor of how deep the light can enter the room. CPH is close to a 45° angle which is the optimal for daylight entering a room (with no obstructions). While both LIS and MOQ have a higher sun angle which results in the roof acting as a shading component, blocking a more direct sunlight which enters the room.

CPH looks to be the best environment for good daylight conditions. Both illuminance and uniform lighting throughout the room. Looking at fig (?) and fig (?) we see the difference in illuminance of CPH and MOQ. As stated in the chapter regarding the case study conditions. The case study is consisting of 3 rooms with different depths first room is 16m deep, 2nd room is 13 m deep and the 3rd room is 10 m deep. Case study was designed in this fashion so that it would be able to investigate how deep the daylight could penetrate with and without light shelves. As a point of reference, the end of the 4 office tables indicate 5 m, so half of the room smallest room, 3rd room which is 10 m.

CPH illuminance value 5 m in the 3rd room is 111 lx. While MOQ illuminance value 5m in the 3rd room is 70 lx. And if measure the illuminance values 2.5 m in to the 3rd room CPH illuminance value is approx. 267 lx, while MOQ is only at 160 lx.

In both instance (5m or 2.5 into the room) there is between a 37% - 40% increase.



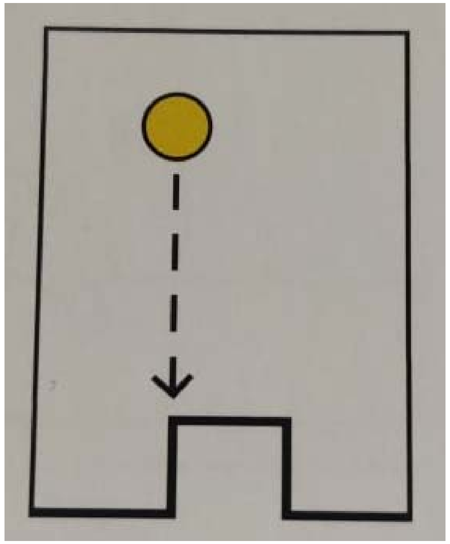


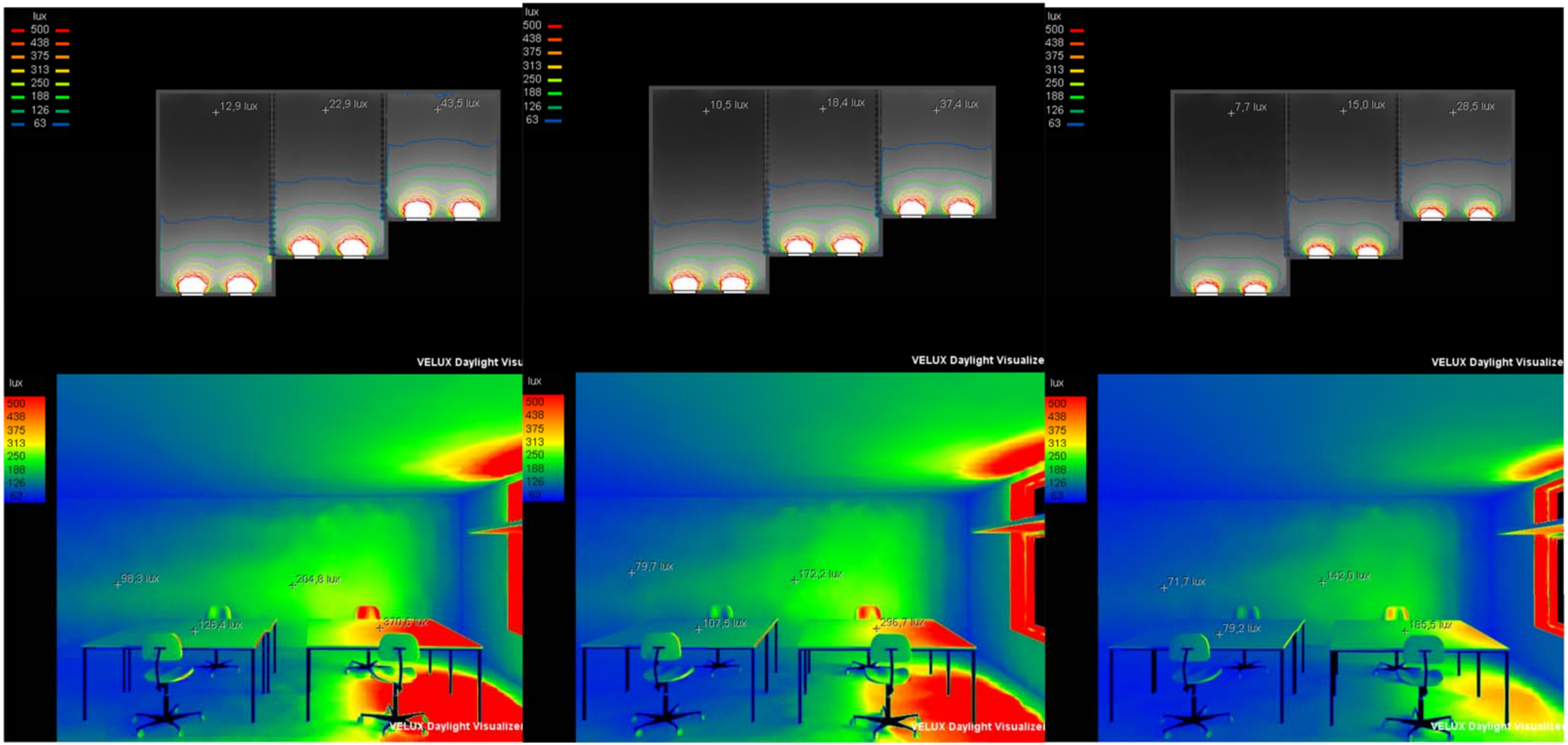
Figure 3. Sun position in moderate climate zone, Lisbon. Climate and architecture, Torben dahl

Figure 1. Sun position in hot climate zone, Mogadishu. Climate and architecture, Torben dahl

Scenario 2 – Light Shelf, Noon at summer solstice

Variable Matrix		
CPH - Windows	LIS - Windows	MOQ - Windows
Winter solstice	Equinox	Summer Solstice
8 o'clock	12 o'clock	16 o'clock
CPH - Light Shelf	LIS - Light Shelf	MOQ - Light Shelf

Figure(31) Variable matrix, Scenario 2.



Figure(32) Illuminance plan and cross section CPH with light shelves at 12 o’clock, summer solstice

Figure(33) Illuminance plan and cross section LIS with light shelves at 12 o’clock, summer solstice

Figure(34) Illuminance plan and cross section MOQ with light shelves at 12 o’clock, summer solstice

As showed in the matrix variable, the first is the location. Comparing daylight situation in Copenhagen(CPH), Lisbon(LIS) and Mogadishu (MOQ) at summer solstice,12 o'clock at noon. Therefore, the constants are the date of the year and the time of day. The suns angle at this specific point in time (at 21. June 2019) is, 58.34 ° in Copenhagen, 74.68° degrees in Lisbon and lastly 68.57 ° in Mogadishu.

At first glance it looks like the room is less lit , than in scenario 1. Taking fig(cph scenario1) and fig(cph scenario 2) the illuminance values show lower than in scenario 1. 2.5 m deep into the room in scenario 1 = 267 lx while it is only 205 lux in scenario 2. Which is a 30 decrease in light level in that spot. But if you look at the plan we can see that there is an increase in daylight. Looking at the wall in smallest room (3rd room) and look at the illuminance measure at the end of the wall 10 m deep into the room. Scenario 1 shows an illuminance value of 29.6 lux. While scenario 2 measures and illuminance value of 43.5 lux. Which results in a 47% increase in illuminance in at the back of the room. Concluding that the daylight is penetrating further into the room, and creates a more uniform lighting design.

CPH in this instance has the lowest sun angle at 58° compared to LIS and MOQ with around 70° sun angle. Which results in deeper penetration of daylight into the rooms. Which was an issue in scenario 1 without the light shelves. But now that the light shelves are bouncing light further into the room. We see and increase in all 3 locations.

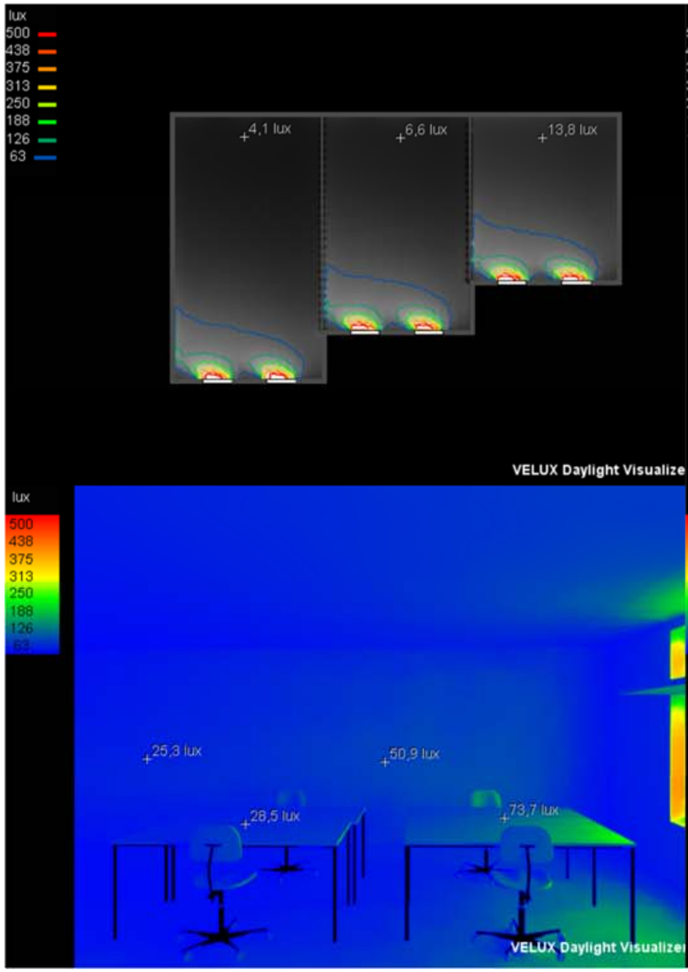
In case of LIS, in scenario 1 with only windows, the 3rd room back wall, measured and illuminance value of 24.8 lx while in scenario 2 with the light shelves implemented, the illuminance measurement is 37.4 lux. Which is a 34% increase in light level.

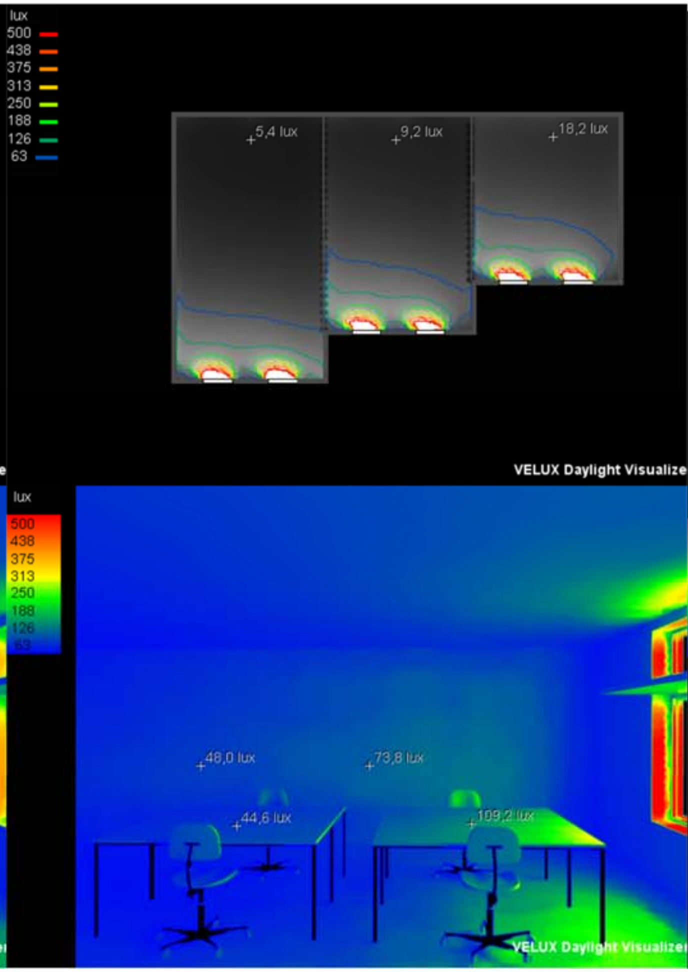
The reason why the cross-section illuminance image shows lower values, is because the light shelf reduces the incident direct daylight hitting the worktables nearest to the windows. Which reduces the daylight in that are, near the windows, but the light shelf distributes the daylight further and deeper into the room, which makes for a more uniform lighting environment.

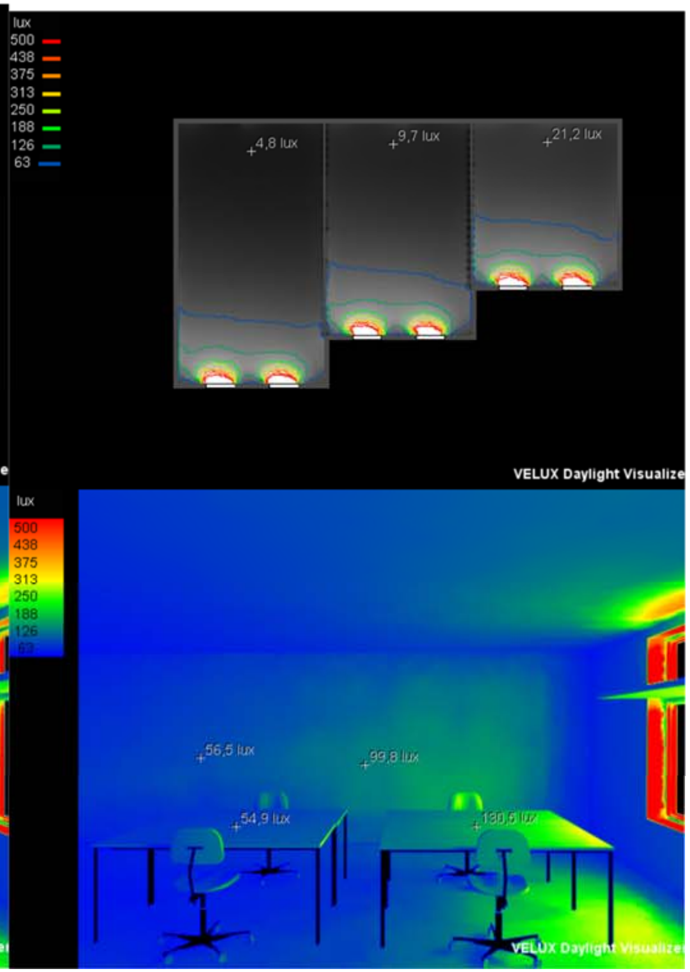
Scenario 3 – Light Shelf, morning at equinox.

Variable Matrix		
CPH - Windows	LIS - Windows	MOQ - Windows
Winter solstice	Equinox	Summer Solstice
8 o'clock	12 o'clock	16 o'clock
CPH - Light Shelf	LIS - Light Shelf	MOQ - Light Shelf

Figure(35) Variable matrix, Scenario 3.







Figure(36) Illuminance plan and cross section CPH with light shelves at 8 o'clock, equinox

Figure(37) Illuminance plan and cross section LIS with light shelves at 8 o'clock, equinox

Figure(38) Illuminance plan and cross section MOQ with light shelves at 8 o'clock, equinox

Scenario 3 is an interesting scenario because most of the year is spent around the equinoxes. Summer and Winter solstices are the opposites when it comes to sun availability. In Denmark we go from having around 7-8 hours of daylight around winter solstice, where in contrast in the summer we have around 20-21 hours of daylight. We could call both of those conditions extreme because they only happen in a short time span. Most of the year are between equinoxes and both he solstices. Therefore, the climate zone and location which performs best around equinox are the most reliable ones when it comes to daylight inlet. We will explore this thought in the conclusion.

Interestingly enough if we look at the sun angle at equinoxes for the three locations: CPH at 35,00°, LIS at 51,95° and MOQ at 87,32°. We could make the assumption that the location which is close to the 45° should be the best performer. So LIS should perform the best with CPH being the second best and MOQ as the worst performer. But no, it's quite different. MOQ is the best performer, LIS as the second and CPH as the worst performer. Why is this? Sunlight hours is the answer. Because we in this scenario are looking at morning data (8 o'clock) we stumble in the issue of reliability. Yes, LIS and CPH have better conditions for good daylight when looking at sun angle. But we stated earlier in the weather chapter that there was a difference in how many sun light hours each location and each climate zone receive per year.

Copenhagen gets around 1780sunshine hours per year, Lisbon with 2806 sunshine hours per year and Mogadishu with 3066 sunshine hours a year. With Mogadishu getting almost double the number of sunshine hours per year, makes it a more reliable location for implementing light shelves and being able to be less reliable of electrical lighting.

MOQ looks to be the best environment for good daylight conditions. Both illuminance and uniform lighting throughout the rooms. Let's take the 3rd room as an example, looking at fig (?) and fig (?) we see the difference in illuminance of MOQ and CPH. As stated in the chapter regarding the case study conditions. The case study is consisting of 3 rooms with different depths first room is 16m deep, 2nd room is 13 m deep and the 3rd room is 10 m deep. Case study was designed in this fashion so that it would be able to investigate how deep the daylight could penetrate with and without light shelves. As a point of reference, the end of the 4 office tables indicate 5 m, so half of the room smallest room, 3rd room which is 10 m.

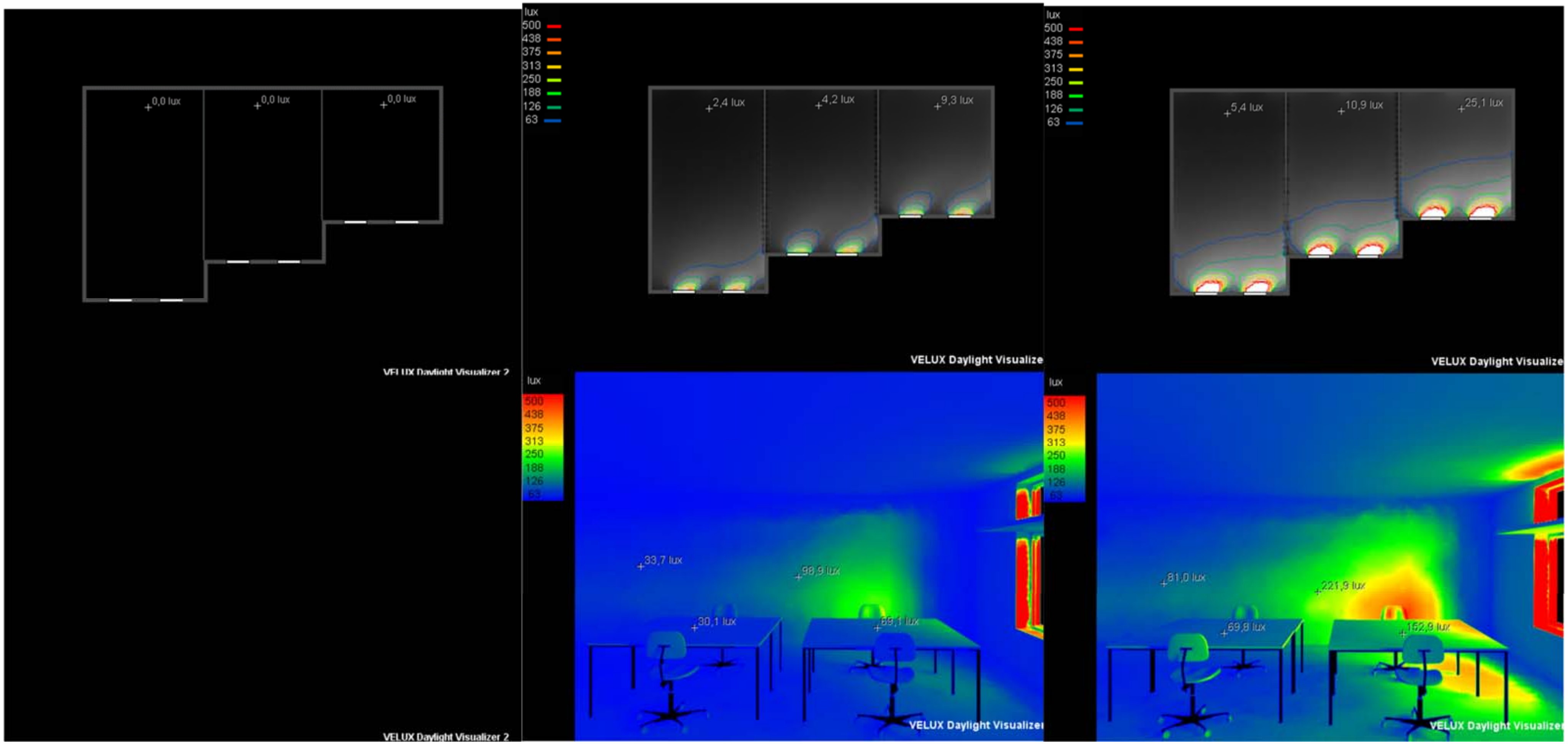
MOQ illuminance value 5 m in the 3rd room is 57 lx. While CPH illuminance value 5m in the 3rd room is 25 lx. And if measure the illuminance values 2.5 m in to the 3rd room MOQ illuminance value is approx. 100 lx, while CPH is only at 51 lx.

In both instance (5m or 2.5 into the room) there is between a 56% - 49% increase.

Scenario 4 – Light Shelf, afternoon at winter solstice.

Variable Matrix		
CPH - Windows	LIS - Windows	MOQ - Windows
Winter solstice	Equinox	Summer Solstice
8 o'clock	12 o'clock	16 o'clock
CPH - Light Shelf	LIS - Light Shelf	MOQ - Light Shelf

Figure(39) Variable matrix, Scenario 4.



Figure(40) Illuminance plan and cross section CPH with light shelves at 16 o'clock, winter solstice

Figure(41) Illuminance plan and cross section LIS with light shelves at 16 o'clock, winter solstice

Figure(42) Illuminance plan and cross section MOQ with light shelves at 16 o'clock, winter solstice

Lastly we have scenario 4. Which like scenario 3 showcases the issues of light shelves in some locations and climate zones. Looking at variable matrix above fig(?). the variables we changed once again are time of day and date of the year, while keeping the 3 locations with light shelves implemented as the constant.

Winter solstice is at 21st December 2019, and time of date is afternoon (16 o'clock)

The sun angle for all 3 locations are as follows: CPH at 11.62°, LIS at 28,29 ° and MOQ 64,57 °. Once again, the hypothesis is that the location with sun angle closest to 45° will be the best performer.

Looking at all three instances Fig(40), Fig(41) and Fig(42). we can see a vast difference in light levels.

CPH illuminance values in scenario 4 is 0. Because the sun has likely already set or is close to setting, then there is no daylight entering the room at afternoon in winter solstice. LIS illuminance value 5 m in the 3rd room is 34 lx. While MOQ illuminance value 5m in the 3rd room is 81 lx. And if measure the illuminance values 2.5 m in to the 3rd room CPH illuminance value is approx. 99 lx, while MOQ is only at 222 lx.

This is where there's a huge difference in light levels. And reliability of the technology should be questioned before being used. The performance of light shelves are highly depended on location.

Experiment 2: Analog Test

The analogue test was conducted to understand if an actual model would behave the same way as the visualisations and the digital analysis. The test was conducted at the Daylight Lab at KADK, Philip De Langes Allé 10, 1435 København. With the help of my supervisor Nanet Mathiasen. Using a 1:100 scale of the model. Using the light lab would apply hand-to-hand experiment with how the sun path would affect the incident daylight in building, at different locations, time of year and time of day. Meaning that we could change the variables and observe the changes which would happen on the situation.

Figure(43) Setup of experiment 2, in KADK,1

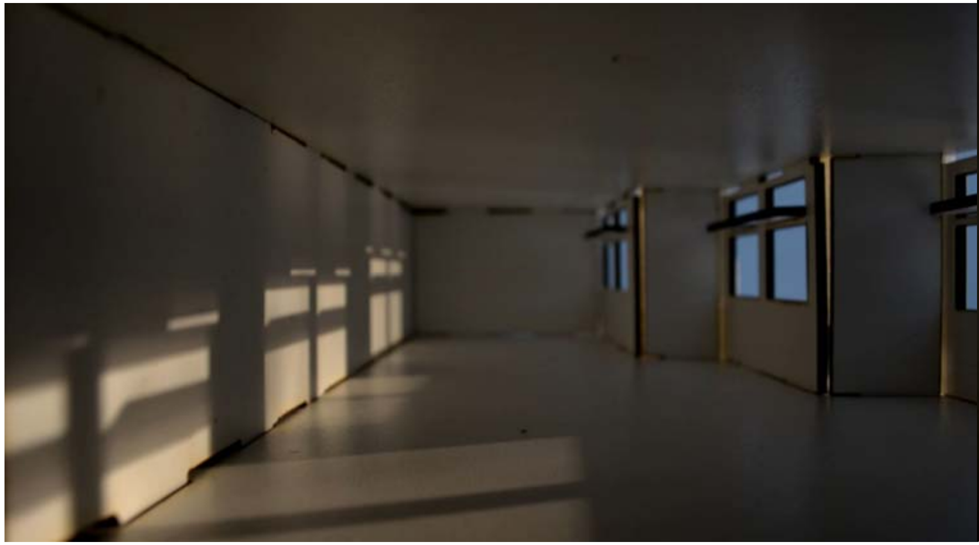
Figure(44) Setup of experiment 2, in KADK,2

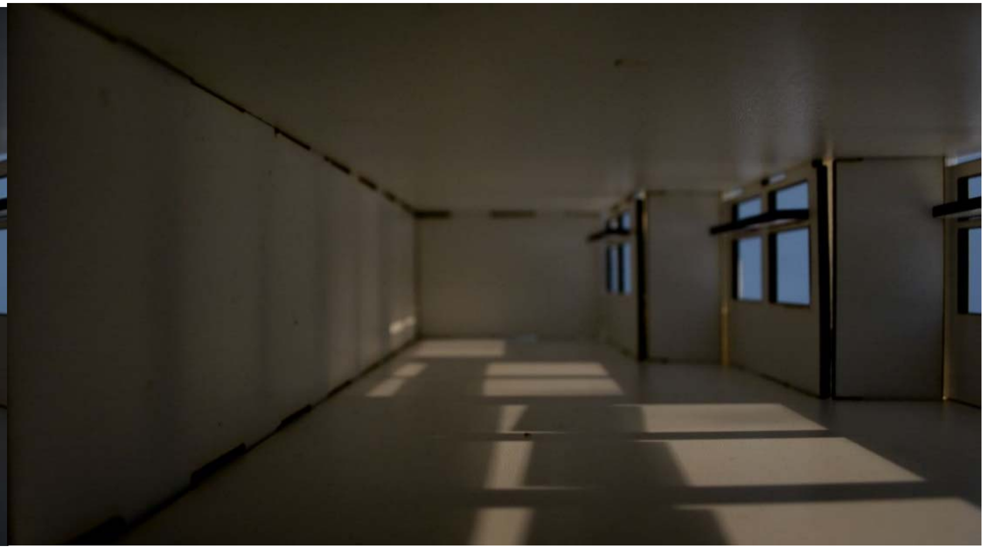
Figure(45) Setup of experiment 2, in KADK,3

For example, changing the location of the case building from Copenhagen to Lisbon, is as easy as pulling the latitude lever from 55° to 38°, without physically moving the model at all. The same goes for changing the time of year and the time of day. The whole lab is analogue, so the variables can be changed simply by pushing, pulling and turning the sun apparatus.

Results – Analogue

The analogue test was able to give me an understanding of how light behaved in a space I wasn't able to access myself. I knew that just looking at the numbers and the visualisations created were not enough. The results and the meaning of the analogue test was not to get numbers, but to get a comprehension of light and if the sunlight actually behaved as I hypothesised and simulated.





Being able to change the daylight conditions by moving the sun manually and analogically made the experience and the understanding of the light much more comprehendible. The post processing videos and images show a clear change in daylight conditions when looking at them. Being able to see light conditions of Lisbon (above images) makes it feel like you're in the space at the exact moment and see the difference very clearly and digestibly.

Looking at the contrast we see daylight conditions in Copenhagen as the sun is setting.

Conclusion

The narrative is coming to an end with conclusion. We have investigated the importance of daylight in architecture, the difference which vernacular architecture makes for climate based and location bade construction. We have analysed the weather conditions of three locations with very different conditions, cultures and ways of approaching daylight within architecture. Followed up with introducing and analysing a daylight enhancing and passive light technology: Light shelves. Undergone the pros and cons, what benefits it can provide and which solution it can solve.

The case study building was then introduced, analysed and then implemented the light shelves. The performance of the light shelves was then experimented, visualised and collected data on. Finally, 4 different scenarios were created to fully understand when and where the light shelves are performing well or are failing.

The problem formulation was as follows:

How can the addition of light shelves, enhance the supply of daylighting in an interior space? And is it possible to create a design which works for all 3 different climate zones?

Light shelves have the ability to greatly enhance the supply of daylight with a interior space. In some cases, such as the summer solstice in a country located in temperate climate zone, it performs slightly better or in some situations slightly worse.

As shown in Copenhagen (fig (32,36 and 40) while in some temperate zones they also perform well in some time frames such as when the sun has a higher angle than 45 while still enhancing the supply of daylight when the sun has a higher or lower angle. Fig (33,37 and 41)

The biggest increase and enhancement of daylight supply happens in tropical zones, where there are a high number of sun hours throughout the year. Which is the biggest factor of light shelves being able to bounce light, the more direct sunlight, that hits the light shelves.

Countries which are located in the tropical climate zones and near equator usually have a constant sun angle with little variations throughout the year such as Mogadishu. That creates an issue where the daylight simply doesn't enter the depth of the rooms, especially when they are longer than 10 m (see fig 41)

It is unlikely that a common daylight design can be created for all the 3 climate zones which enhances the supply of daylight. Looking at the 4 scenarios which were established, it can be concluded that different scenarios favour different locations.

Limitations and further developments

This project aimed to investigate a narrow field with lighting design and more precisely architectural daylight design. The thesis aimed to answer specific questions if the effects of direct daylight on light shelfs performance, which is a comparison study between building cases located in temperate zone, subtropical zone and tropical zone.

This aim has secluded many variables and aspects such as: Changing the case study building after it was defined, working with electrical lighting because, limiting the passive light technology to light shelves, being able to use real life data and investigating in an actual erected case building

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-Study on movable light-shelf system with location-awareness technology for lighting energy saving

Climate and Architecture , Torben dahl

Appendix

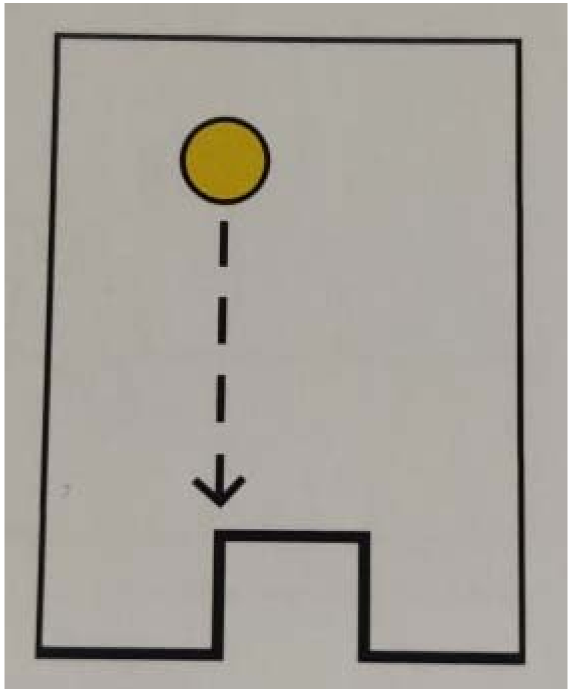


Figure 1. Sun position in hot climate zone, Mogadishu. Climate and architecture, Torben dahl

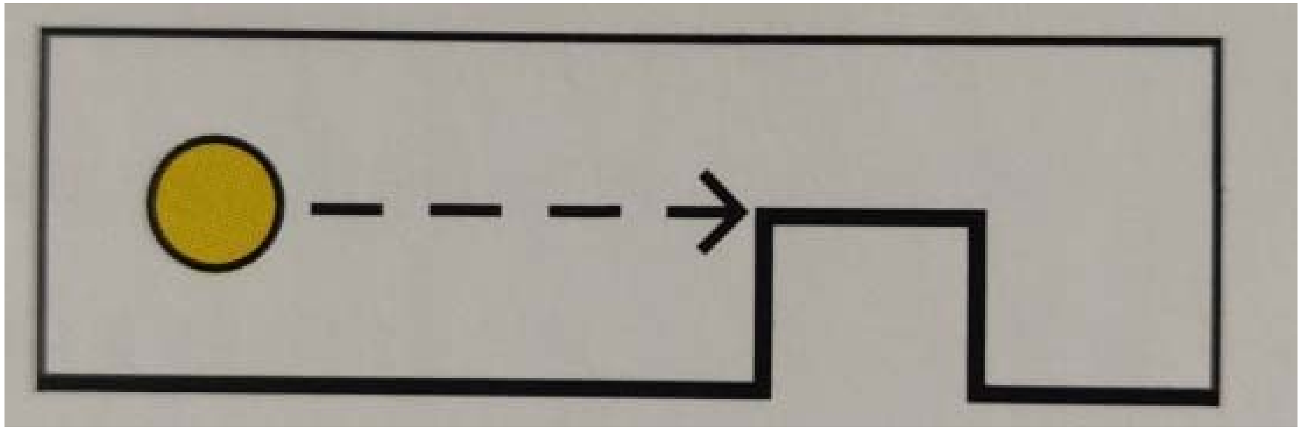


Figure 2. Sun position in cold climate zone, Copenhagen. Climate and architecture, Torben dahl

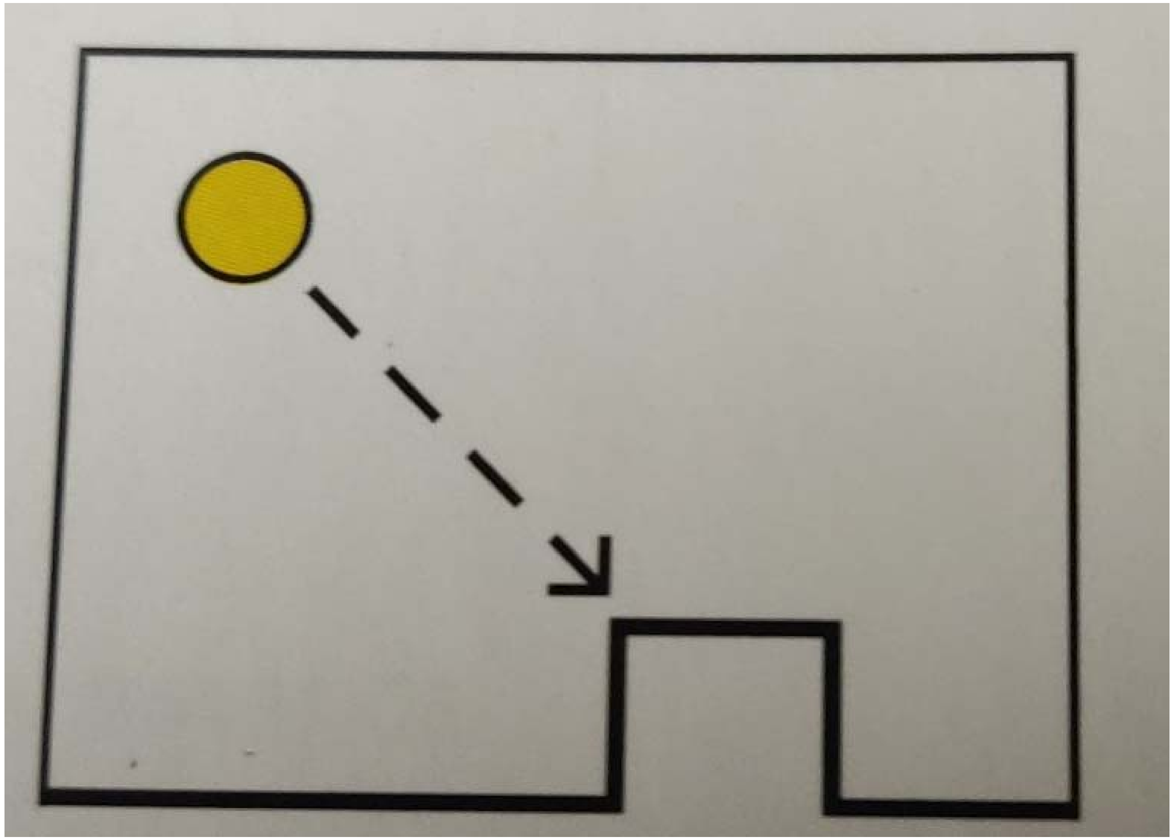


Figure 3. Sun position in moderate climate zone, Lisbon. Climate and architecture, Torben dahl

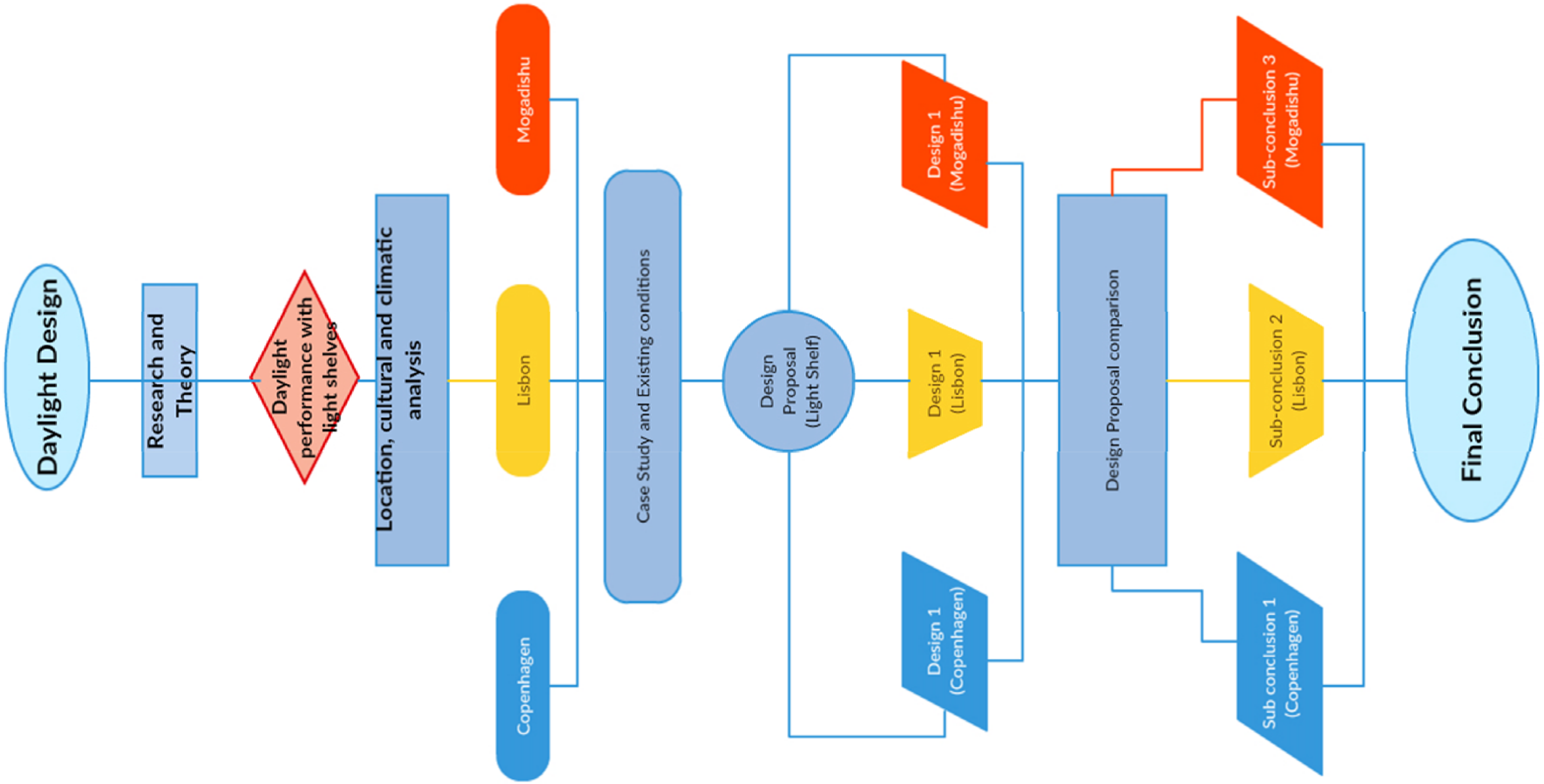


Figure 4. Methodology flow chart

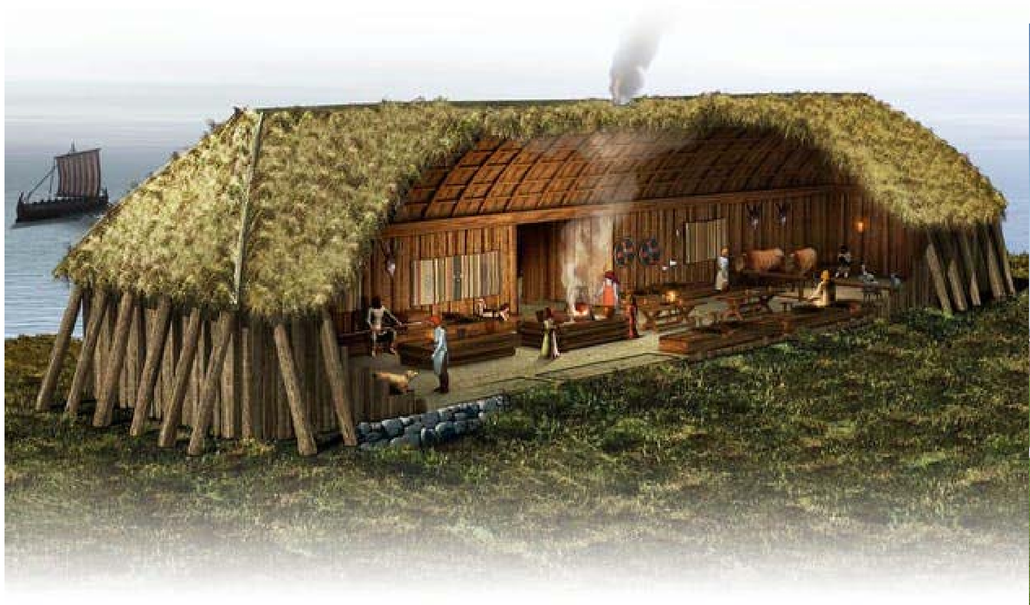


Figure 5. Viking house, c.980 , Historia.dk

Figure 6. Modern Danish home, 2017 , Decoist.com

GEOGRAPHIC LOCATION		SOLAR INFORMATION		TWILIGHT TIMES	
Latitude:	55.67769878°	Azi / Alt:	148.47° / 30.36°	Civil:	05:34 / 19:01
Longitude:	12.585868835°	Rise / Set:	06:11 / 18:24	Nautical:	04:50 / 19:45
Timezone:	GMT+01:00	Daylight:	12:13 Hrs	Astronom.:	04:03 / 20:31

Figure 7, weather condition Copenhagen. http://andrewmarsh.com/apps/staging/sunpath3d.html

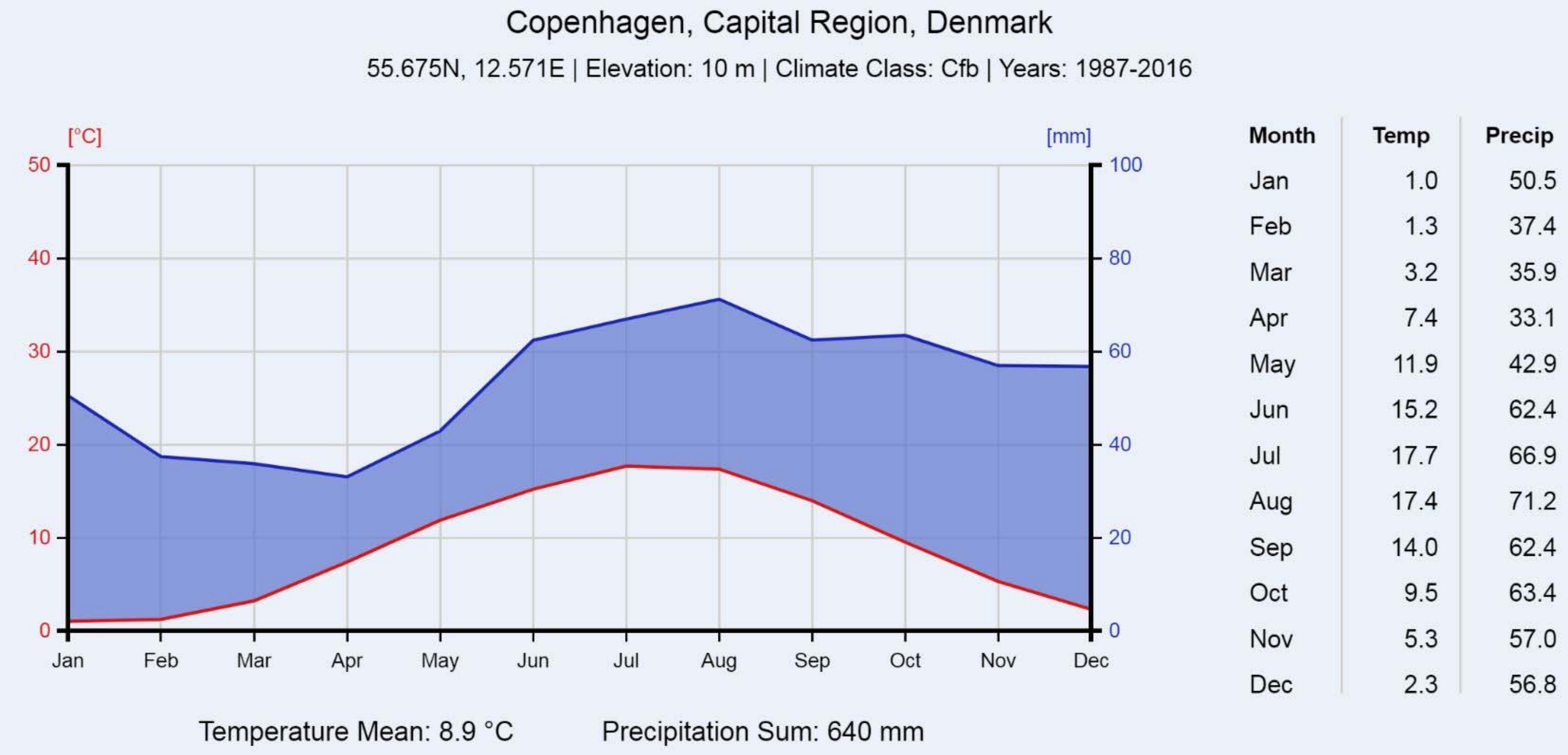


Figure 7, Average temperature and average rainfall in Copenhagen

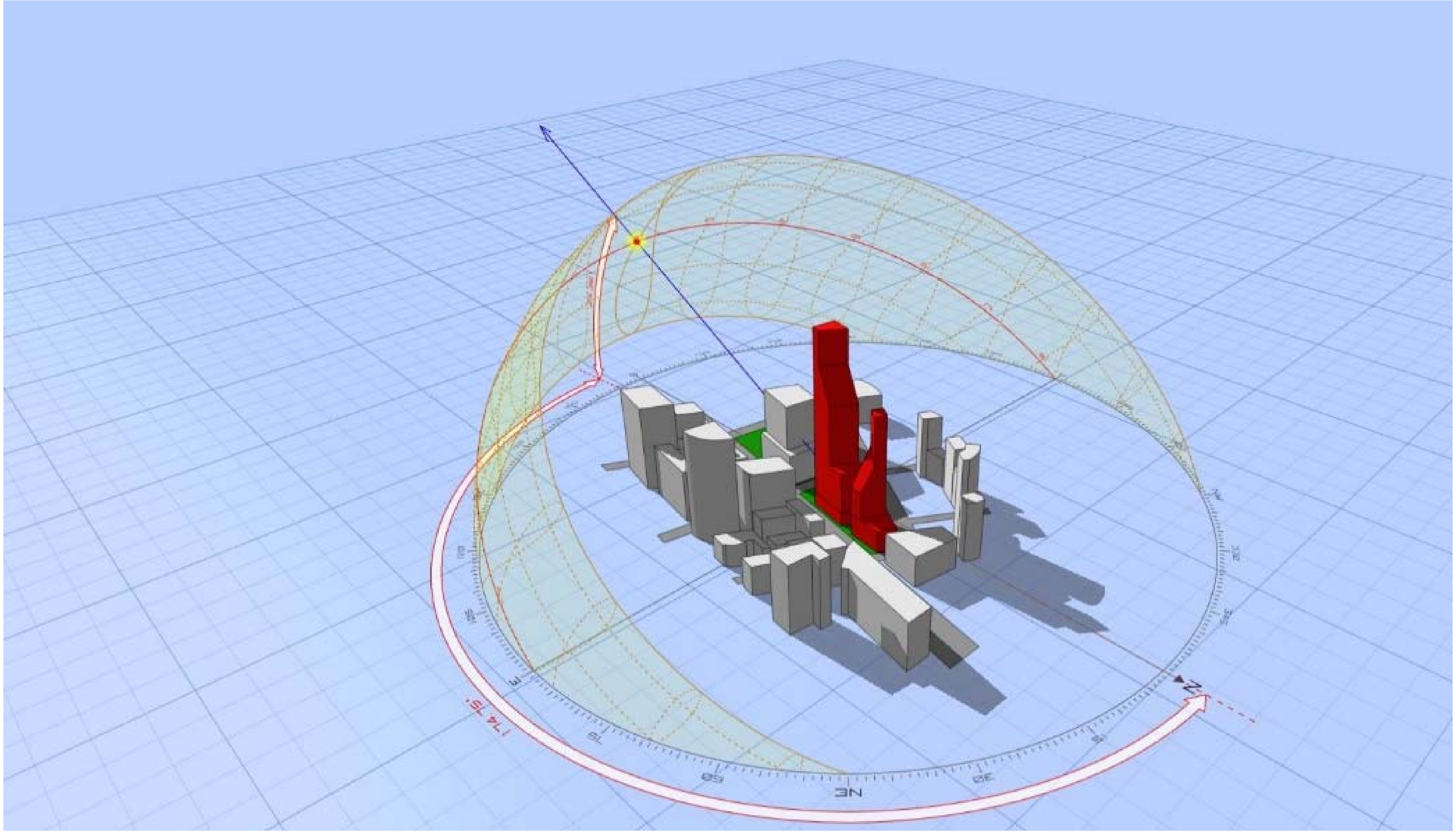


Figure 8, 3D Sunpath diagram of Copenhagen, http://andrewmarsh.com/apps/staging/sunpath3d.html

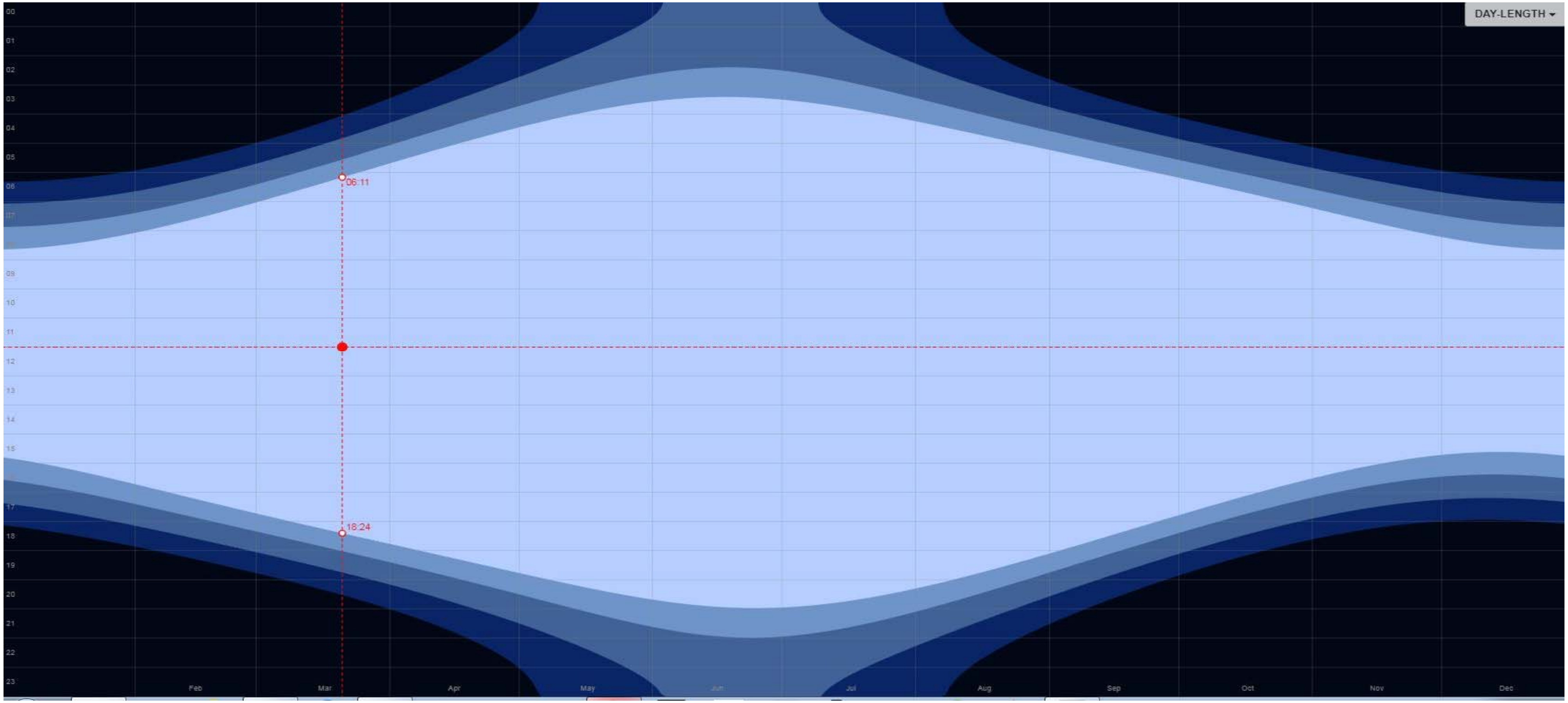


Figure 9, Day length for every month of the year in Copenhagen http://andrewmarsh.com/apps/staging/sunpath3d.html

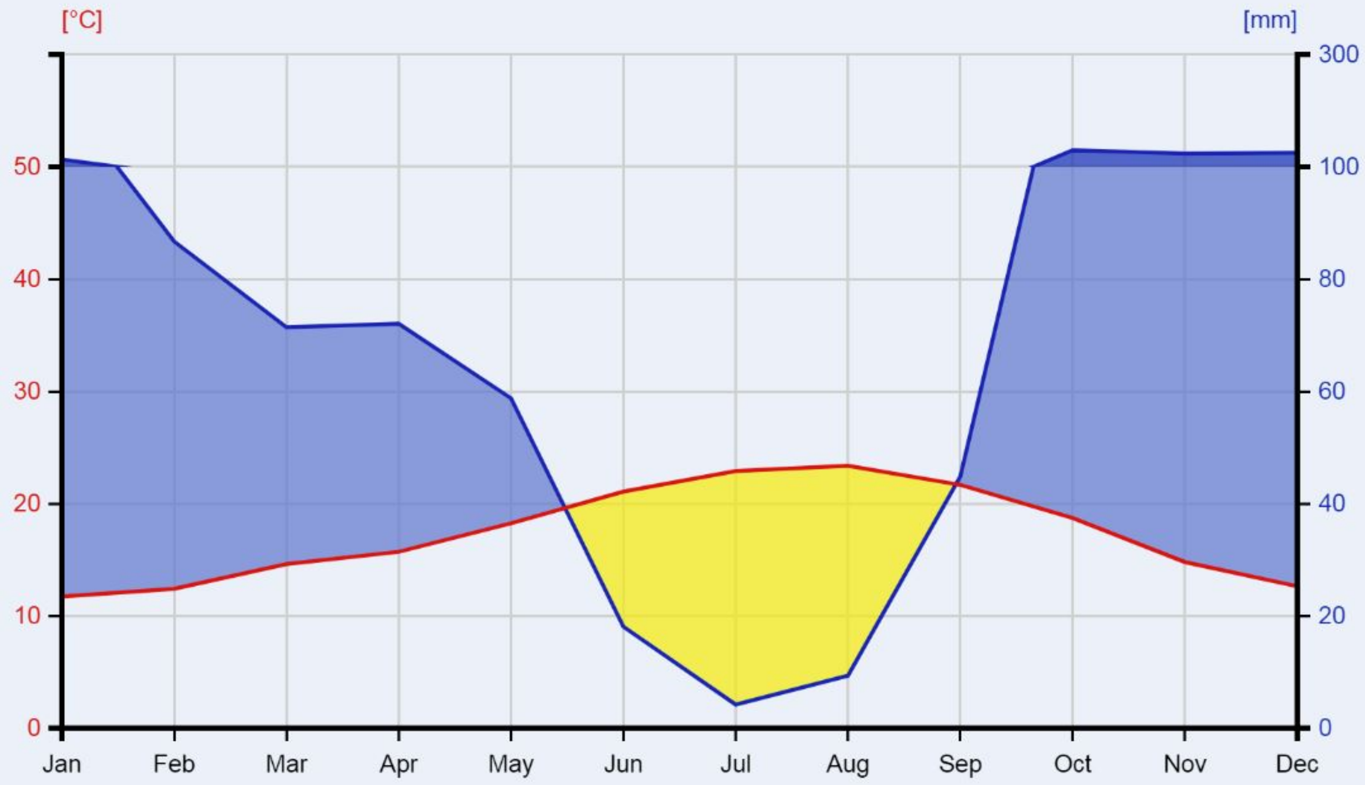
Figure 10. Portugeese house, https://thearchitectstake.com/editorials/portuguese-modern-an-architectural-tour/

GEOGRAPHIC LOCATION		SOLAR INFORMATION		TWILIGHT TIMES	
Latitude:	38.732357128°	Azi / Alt:	151.74° / 47.83°	Civil:	05:13 / 18:15
Longitude:	-9.12689209°	Rise / Set:	05:39 / 17:49	Nautical:	04:42 / 18:46
Timezone:	GMT-01:00	Daylight:	12:09 Hrs	Astronom.:	04:10 / 19:18

Figure 10, weather condition Lisbon. http://andrewmarsh.com/apps/staging/sunpath3d.html

Lisbon, Lisbon, Portugal

38.724N, 9.132W | Elevation: 62 m | Climate Class: Cfa | Years: 1987-2016



Month	Temp	Precip
Jan	11.7	112.9
Feb	12.4	86.7
Mar	14.6	71.4
Apr	15.7	72.0
May	18.3	58.8
Jun	21.1	18.1
Jul	22.9	4.2
Aug	23.4	9.4
Sep	21.7	44.8
Oct	18.7	129.5
Nov	14.8	123.4
Dec	12.6	124.8

Temperature Mean: 17.3 °C Precipitation Sum: 856 mm

Figure 11, Average temperature and average rainfall in Lisbon

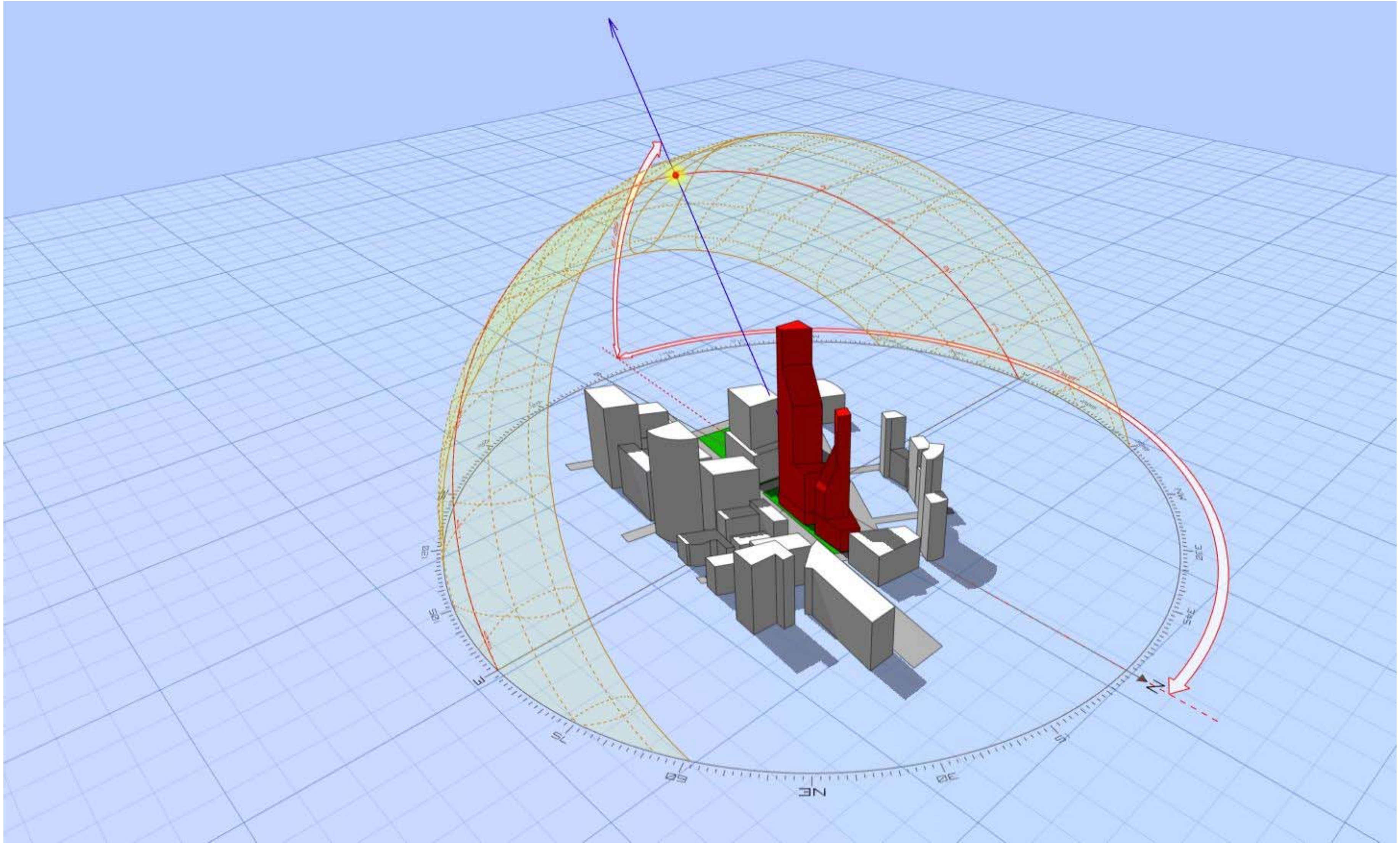


Figure 12, 3D Sunpath diagram of Lisbon, http://andrewmarsh.com/apps/staging/sunpath3d.html

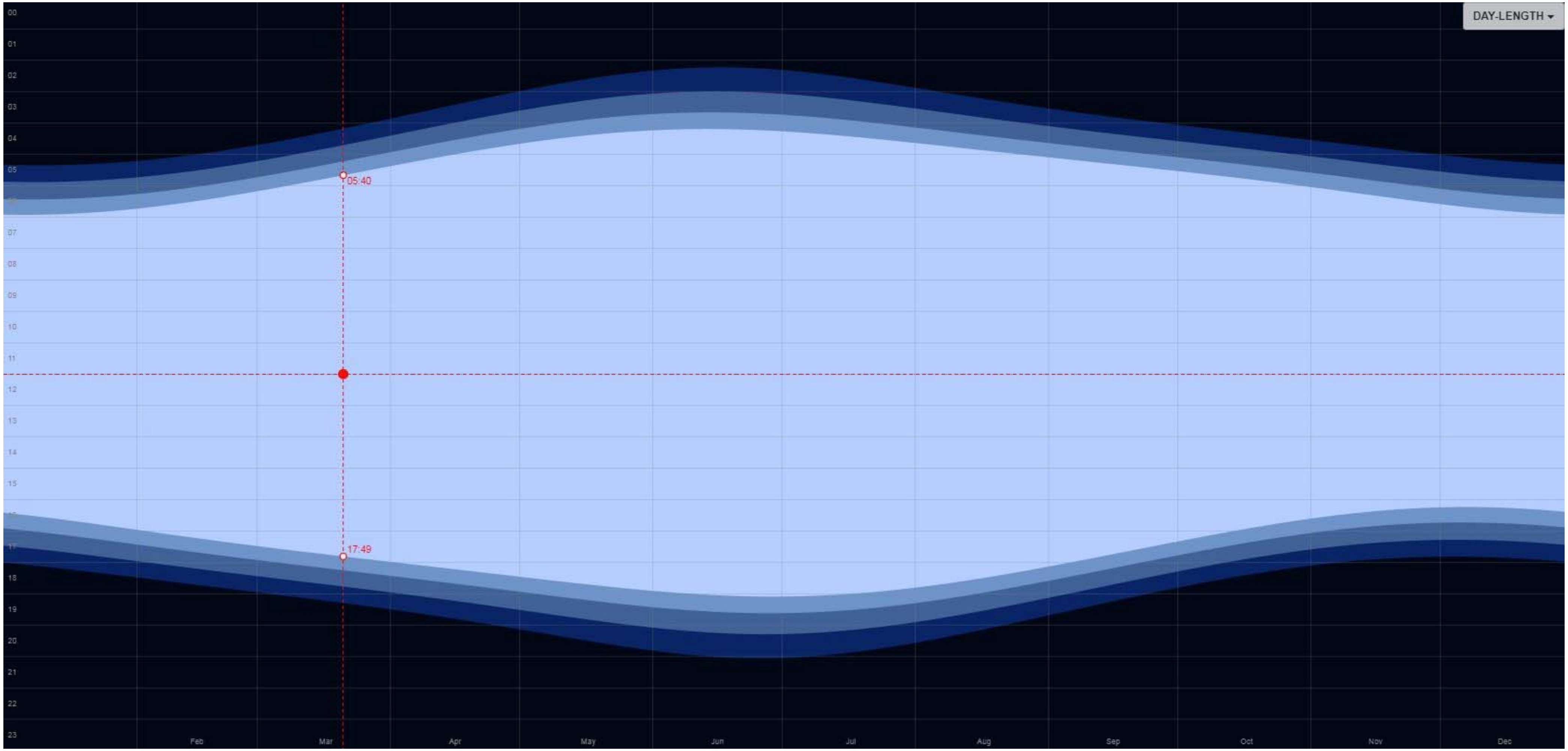


Figure 13, Day length for every month of the year in Copenhagen http://andrewmarsh.com/apps/staging/sunpath3d.html

Figure (14) Houses in central Mogadishu showing the extended patio.

Figure (15) Houses in central Mogadishu showing a shared courtyard.

GEOGRAPHIC LOCATION		SOLAR INFORMATION		TWILIGHT TIMES	
Latitude:	2.018357631°	Azi / Alt:	94.19° / 65.84°	Civil:	05:42 / 18:30
Longitude:	45.315856934°	Rise / Set:	06:03 / 18:10	Nautical:	05:18 / 18:54
Timezone:	GMT+03:00	Daylight:	12:07 Hrs	Astronom.:	04:54 / 19:18

Figure 16, weather condition Mogadishu. http://andrewmarsh.com/apps/staging/sunpath3d.html

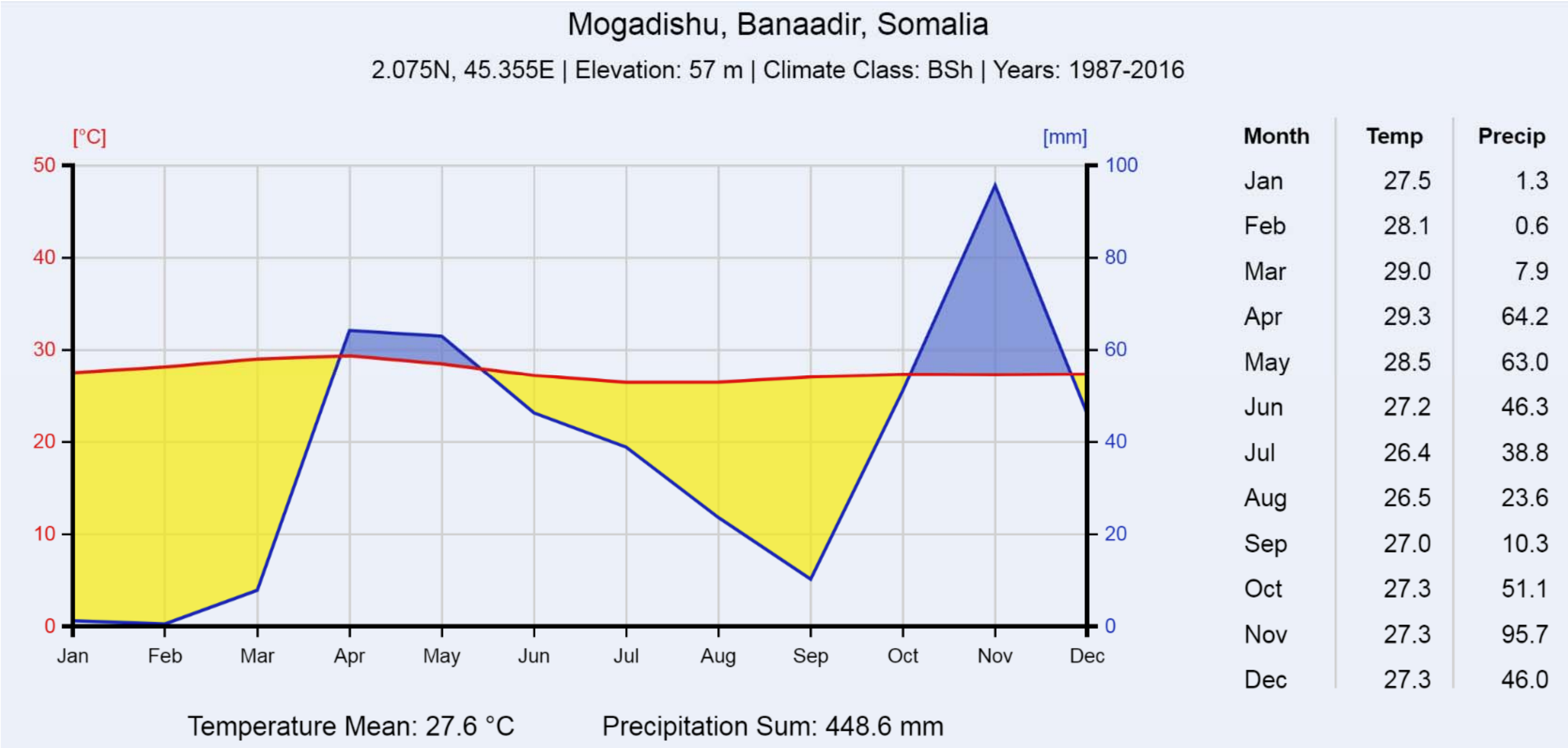


Figure 17, Average temperature and average rainfall in Mogadishu http://andrewmarsh.com/apps/staging/sunpath3d.html

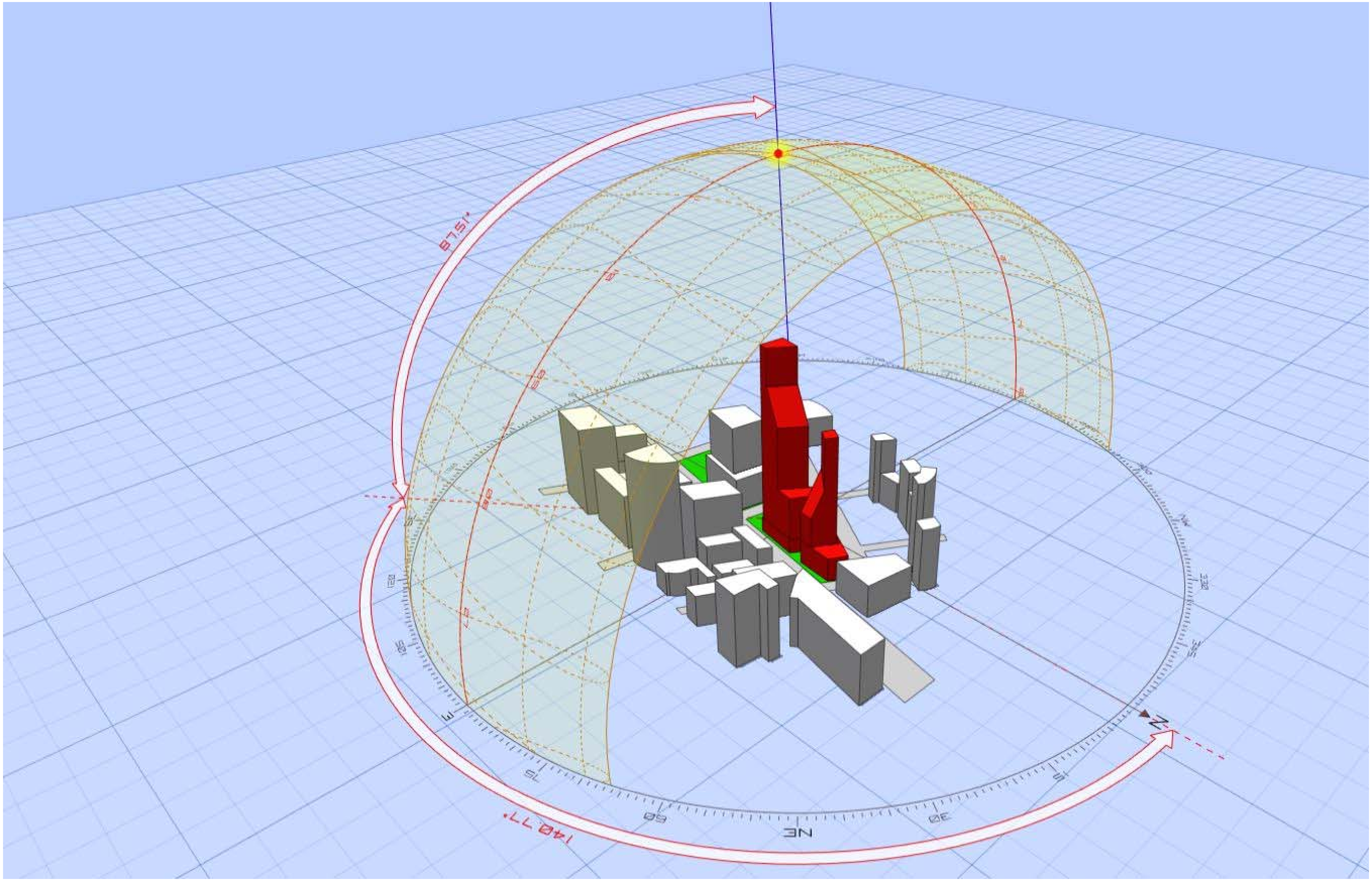


Figure 18, 3D Sunpath diagram of Mogadishu, http://andrewmarsh.com/apps/staging/sunpath3d.html

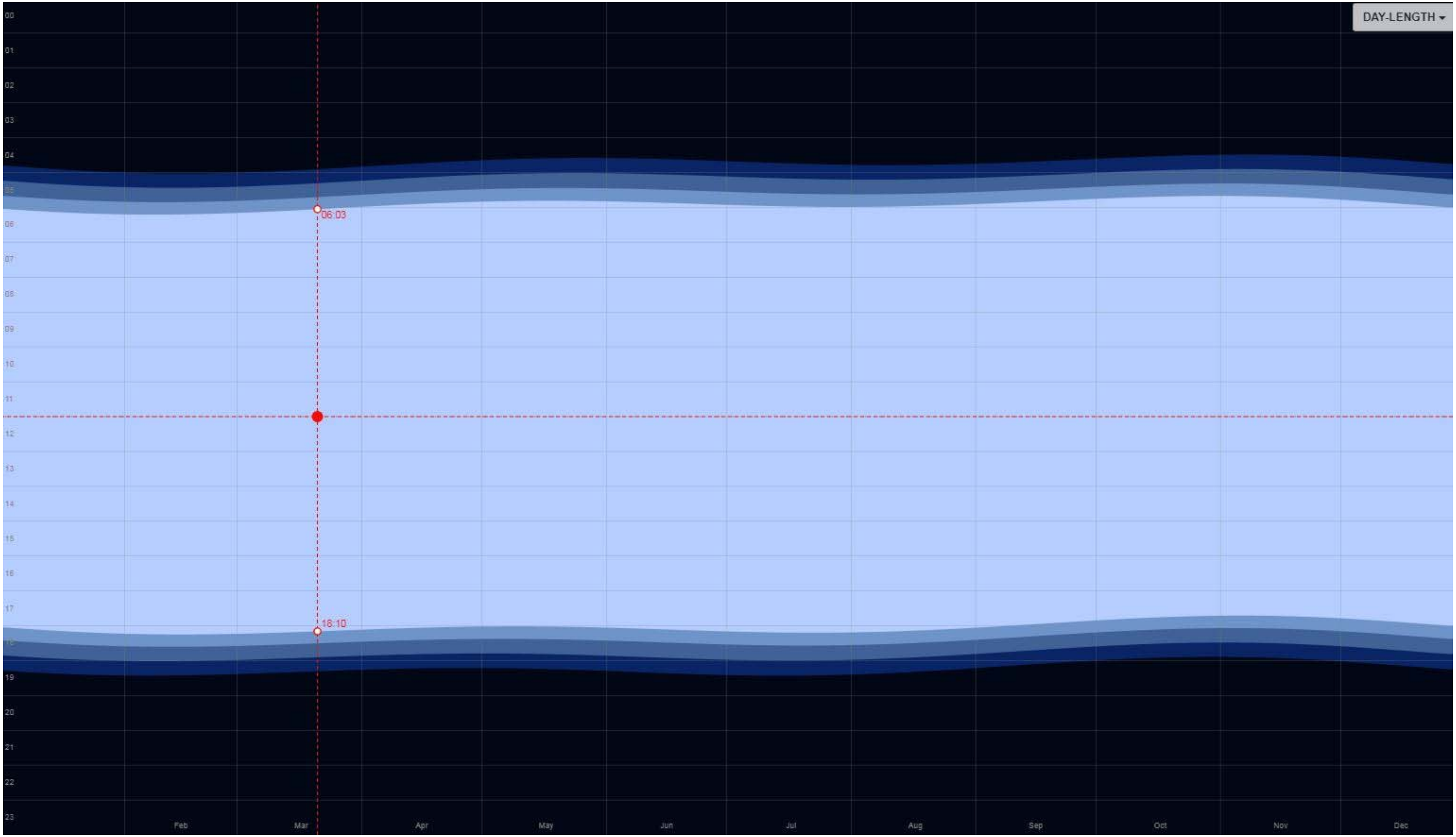


Figure 19, Day length for every month of the year in Mogadishu http://andrewmarsh.com/apps/staging/sunpath3d.html

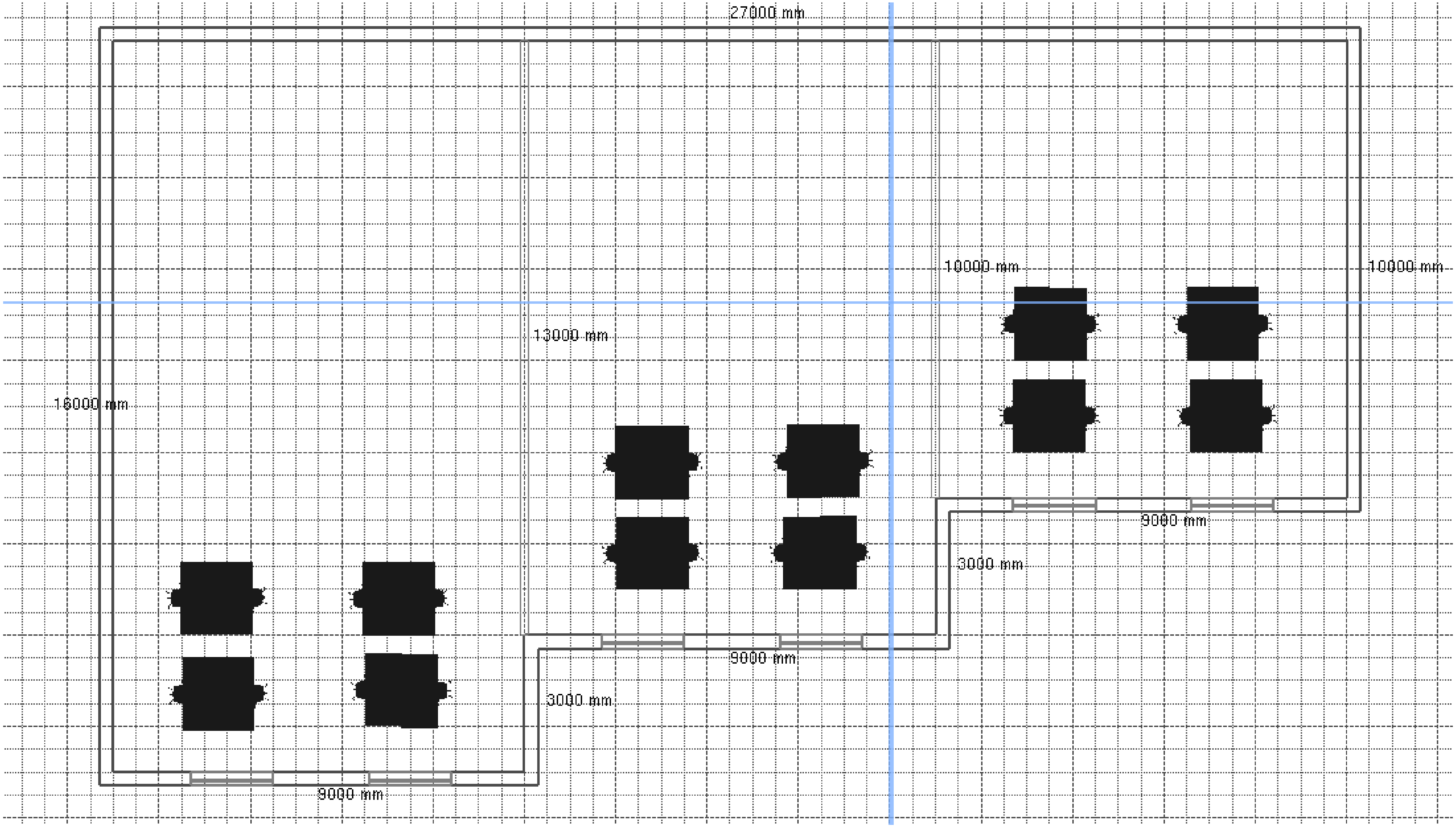


Figure 20, Floor plan of the study case office building

Figure 21, Cross section of the study case office building

Figure (22) representation of window placement upper and lower, with light shelf in between

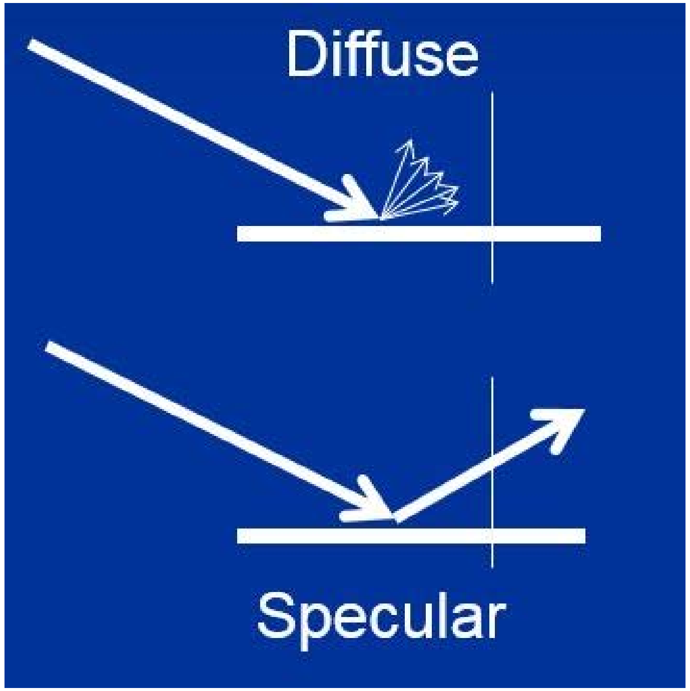


Figure (23) Improves daylight penetration. (sketch made in powerpoint)

Figure (24) Daylight penetration with light shelf (Inlighten™ Light shelf)

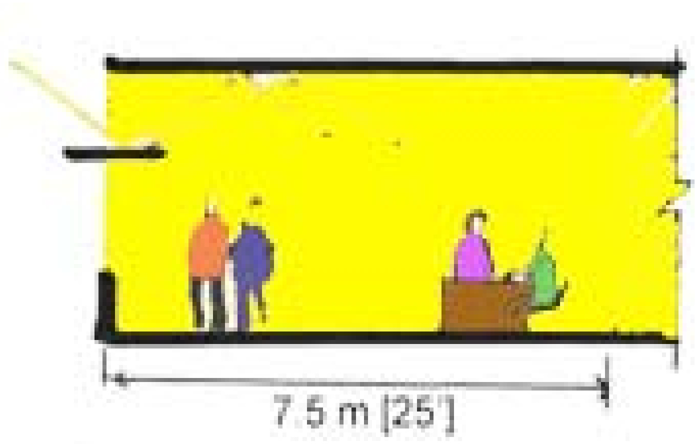
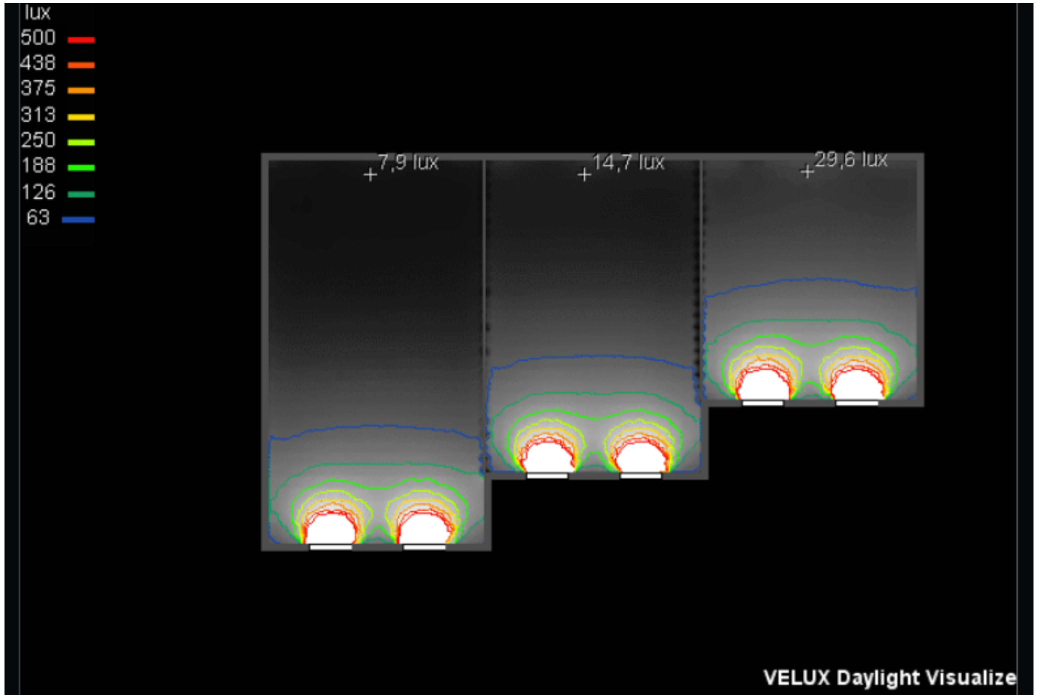
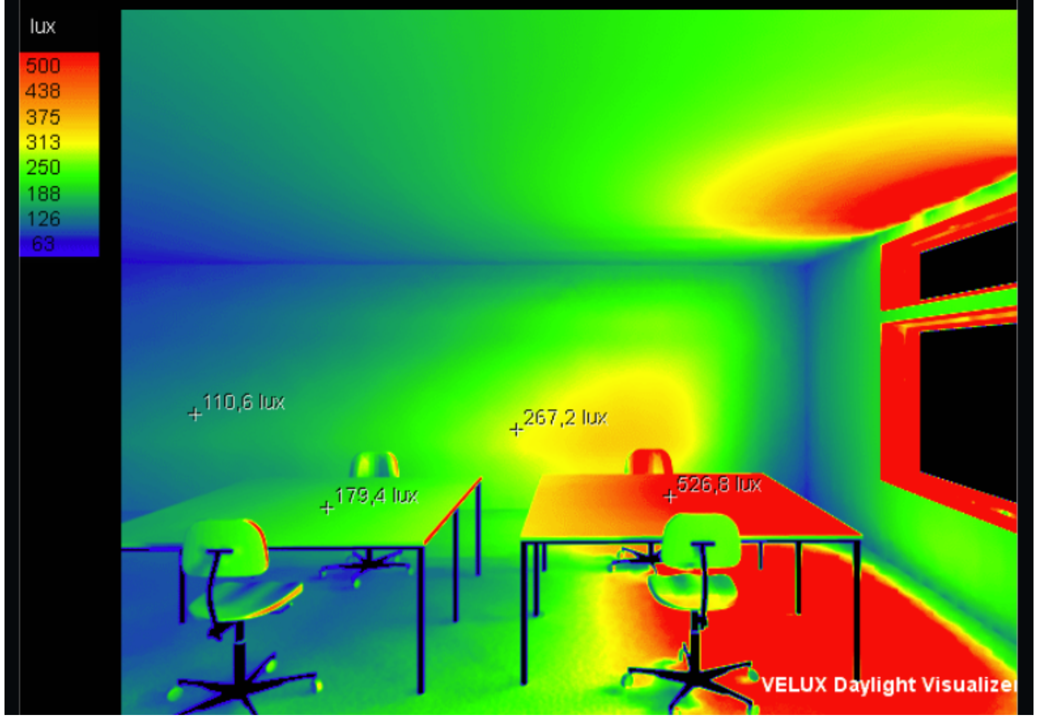


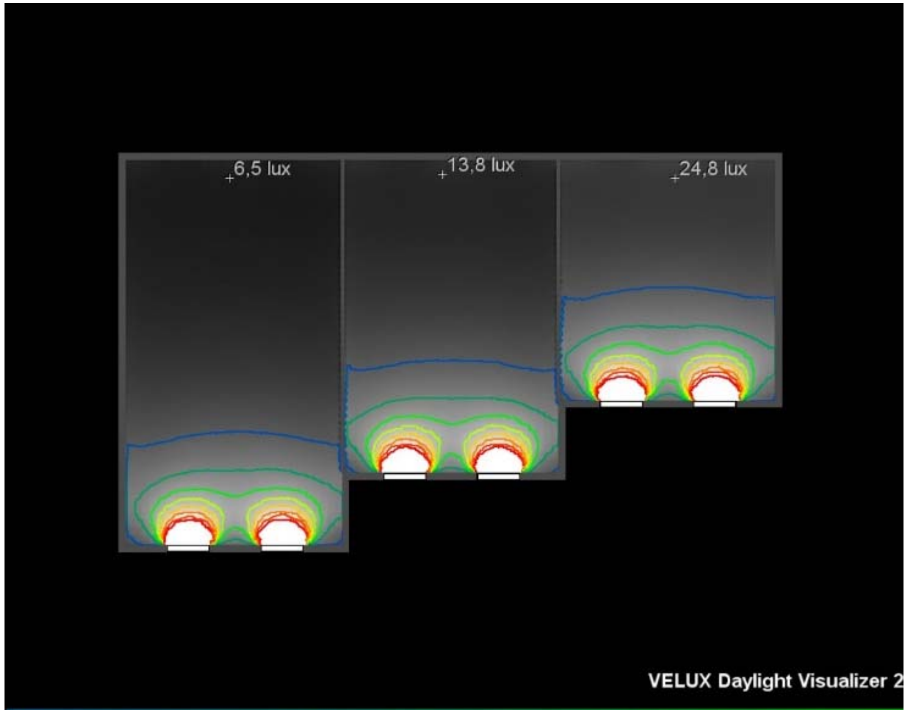
Figure (25) Example of interior light shelf in a multistory building.(Inlighten™ Light shelf)

Variable Matrix		
CPH - Windows	LIS - Windows	MOQ - Windows
Winter solstice	Equinox	Summer Solstice
8 o'clock	12 o'clock	16 o'clock
CPH - Light Shelf	LIS - Light Shelf	MOQ - Light Shelf

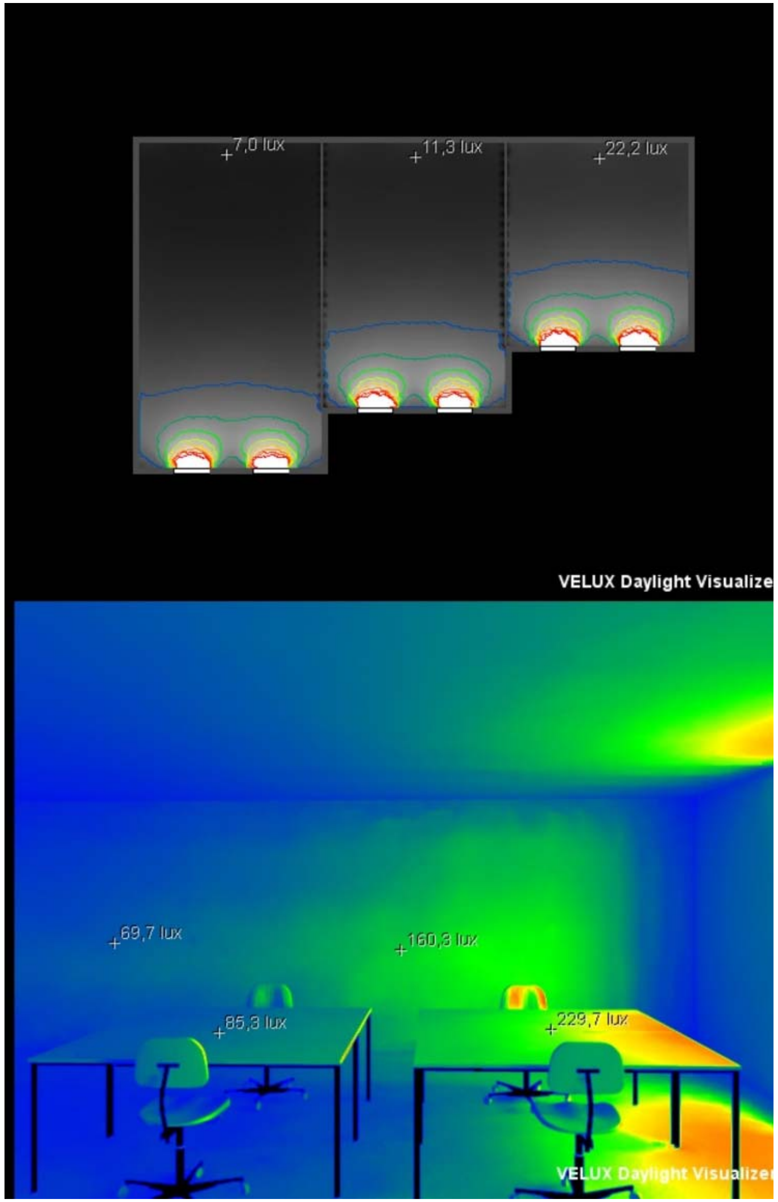
Figure(26) Variable matrix for keeping track of constants and variables.


lux
500
438
375
313
250
188
126
63
7,9 lux
14,7 lux
29,6 lux
VELUX Daylight Visualize


lux
500
438
375
313
250
188
126
63
110,6 lux
267,2 lux
179,4 lux
526,8 lux
VELUX Daylight Visualizer


6,5 lux
13,8 lux
24,8 lux
VELUX Daylight Visualizer 2

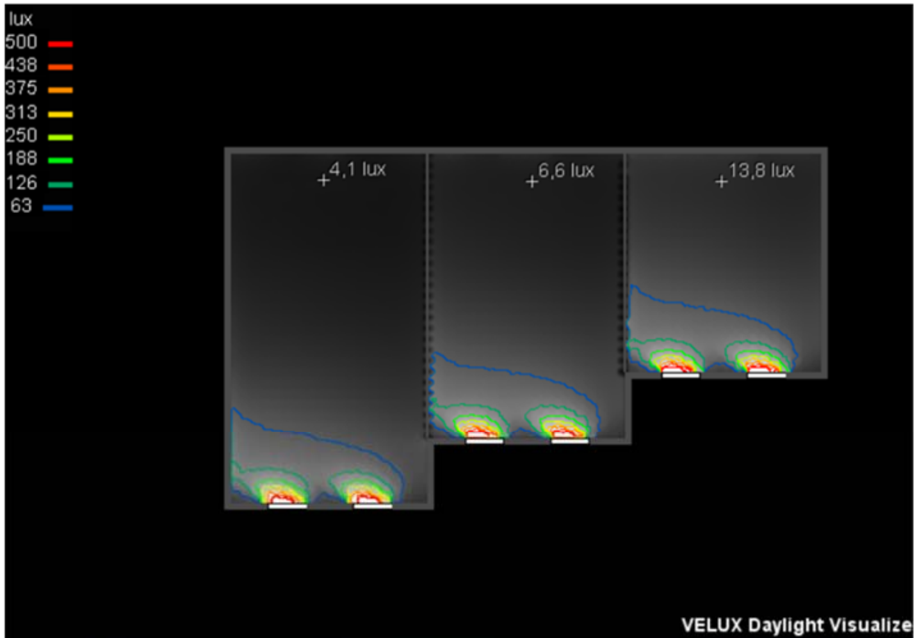

86,0 lux
202,0 lux
123,5 lux
358,0 lux
VELUX Daylight Visualizer

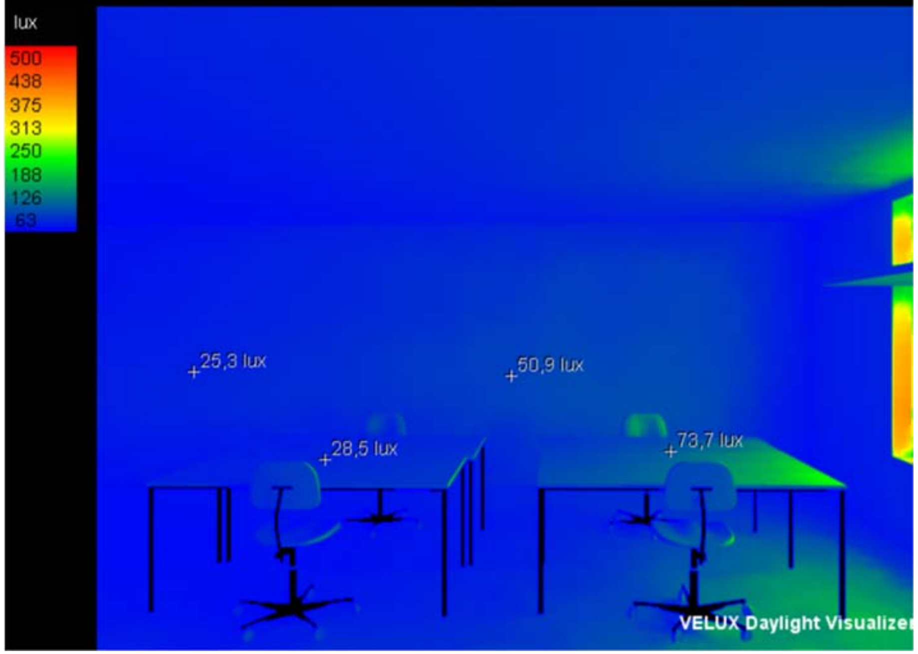


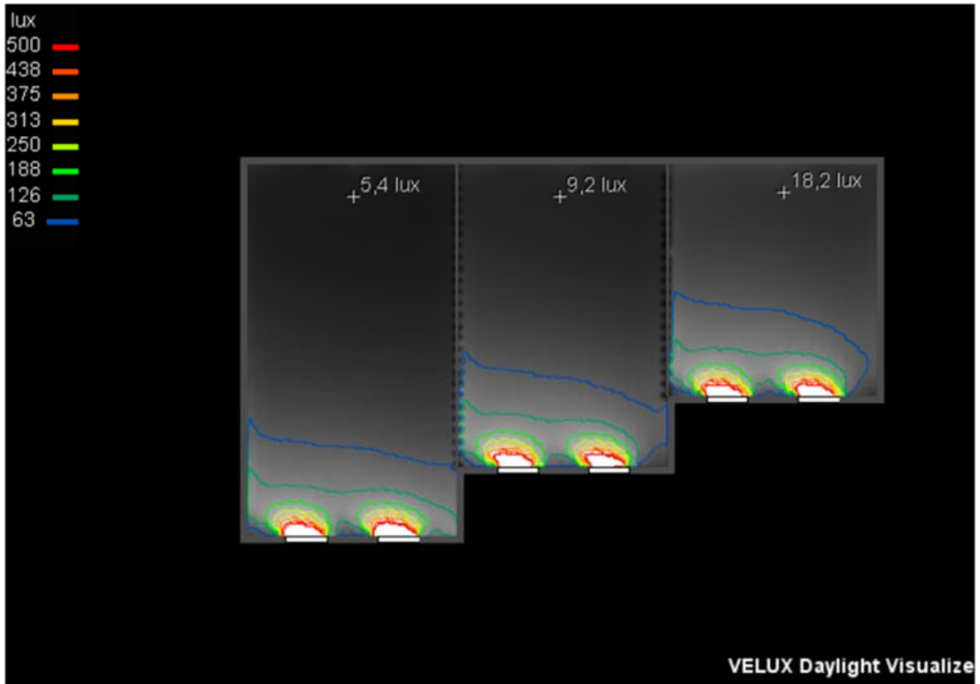
Figure(28) Illuminance plan and cross section CPH at 12 o'clock, summer solstice

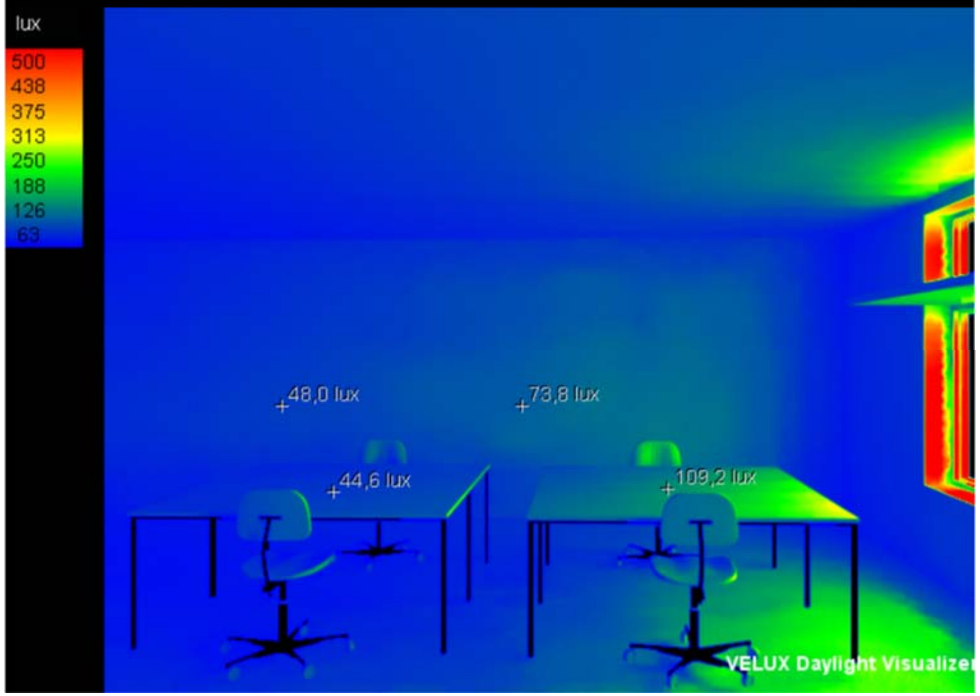
Figure(29) Illuminance plan and cross section LIS at 12 o'clock, summer solstice

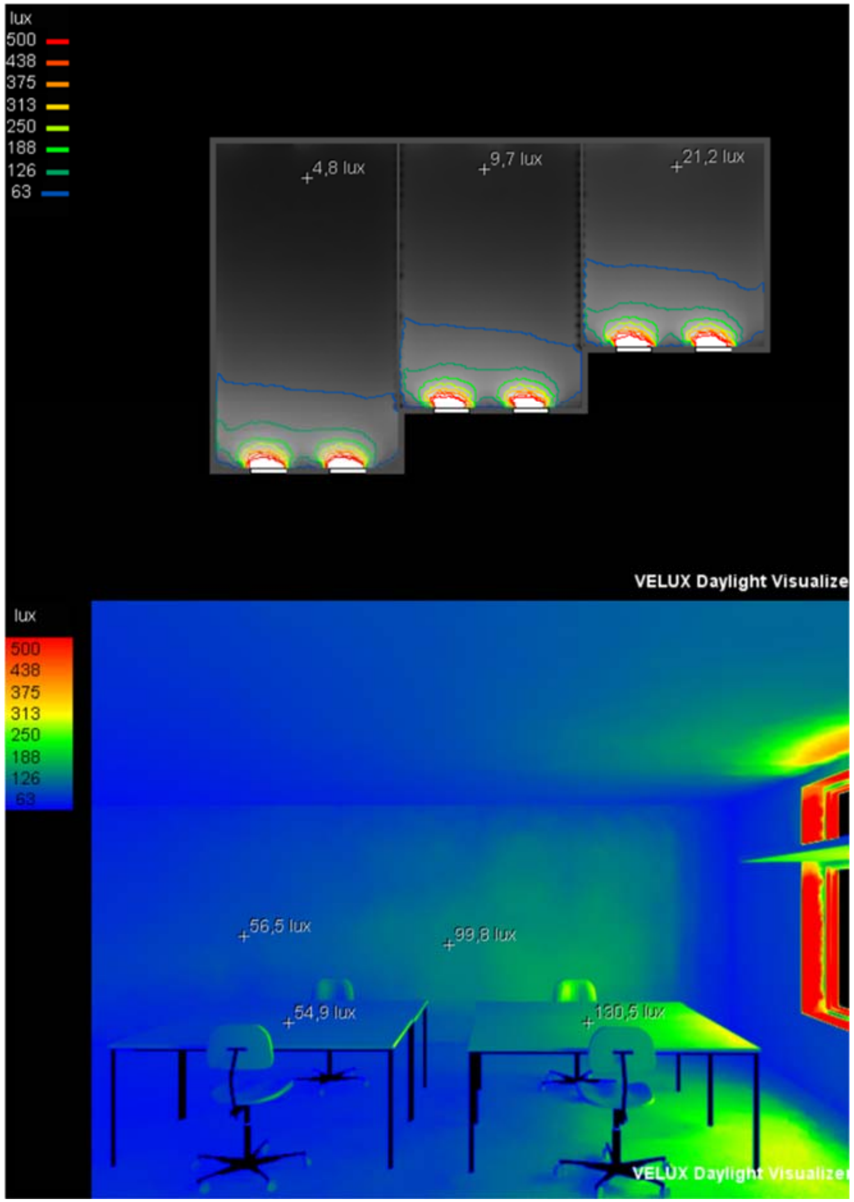
Figure(30) Illuminance plan and cross section MOQ at 12 o'clock, summer solstice


lux
500
438
375
313
250
188
126
63
4,1 lux
6,6 lux
13,8 lux
VELUX Daylight Visualize


lux
500
438
375
313
250
188
126
63
25,3 lux
50,9 lux
28,5 lux
73,7 lux
VELUX Daylight Visualizer


lux
500
438
375
313
250
188
126
63
5,4 lux
9,2 lux
18,2 lux
VELUX Daylight Visualize

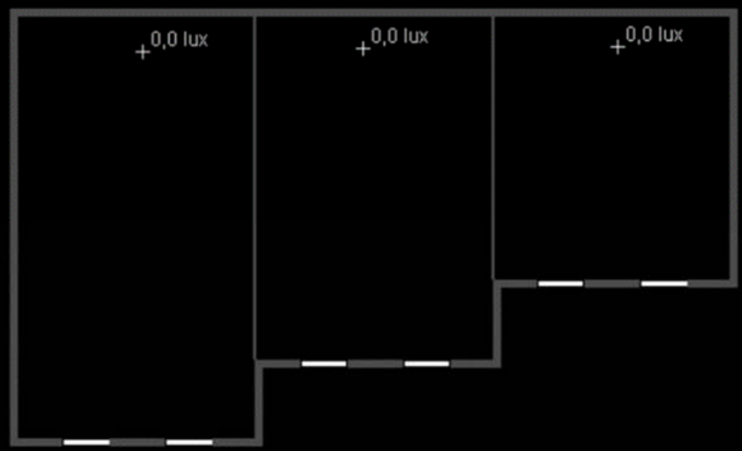

lux
500
438
375
313
250
188
126
63
48,0 lux
73,8 lux
44,6 lux
109,2 lux
VELUX Daylight Visualizer



Figure(36) Illuminance plan and cross section CPH with light shelves at 8 o'clock, equinox

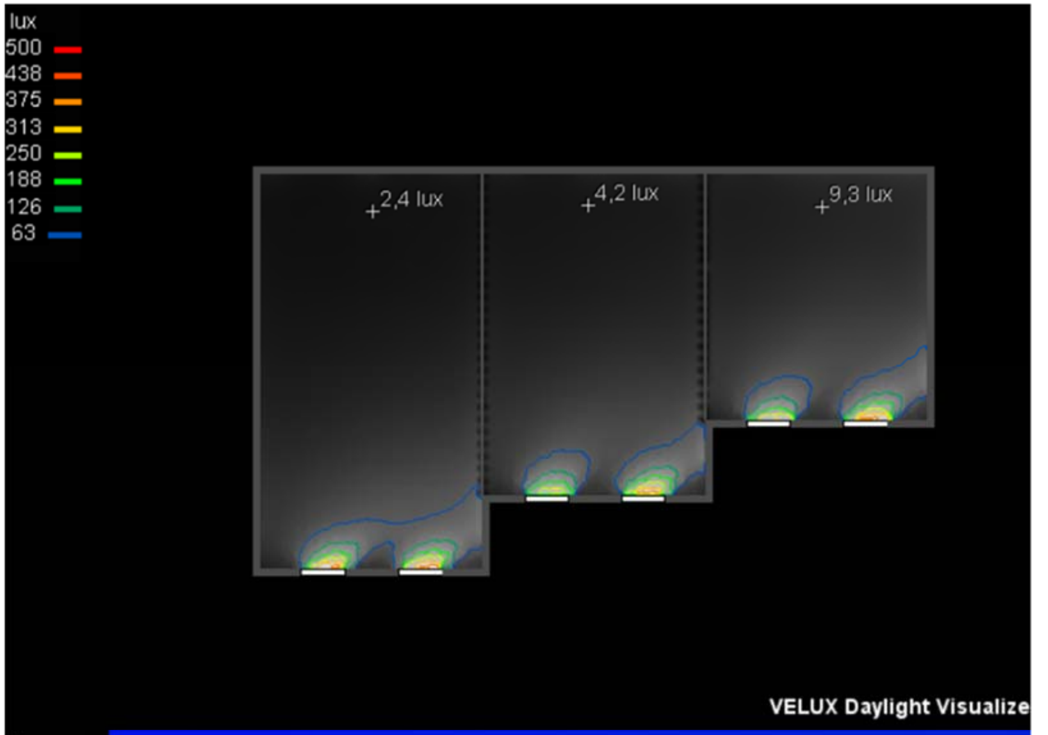
Figure(37) Illuminance plan and cross section LIS with light shelves at 8 o'clock, equinox

Figure(38) Illuminance plan and cross section MOQ with light shelves at 8 o'clock, equinox

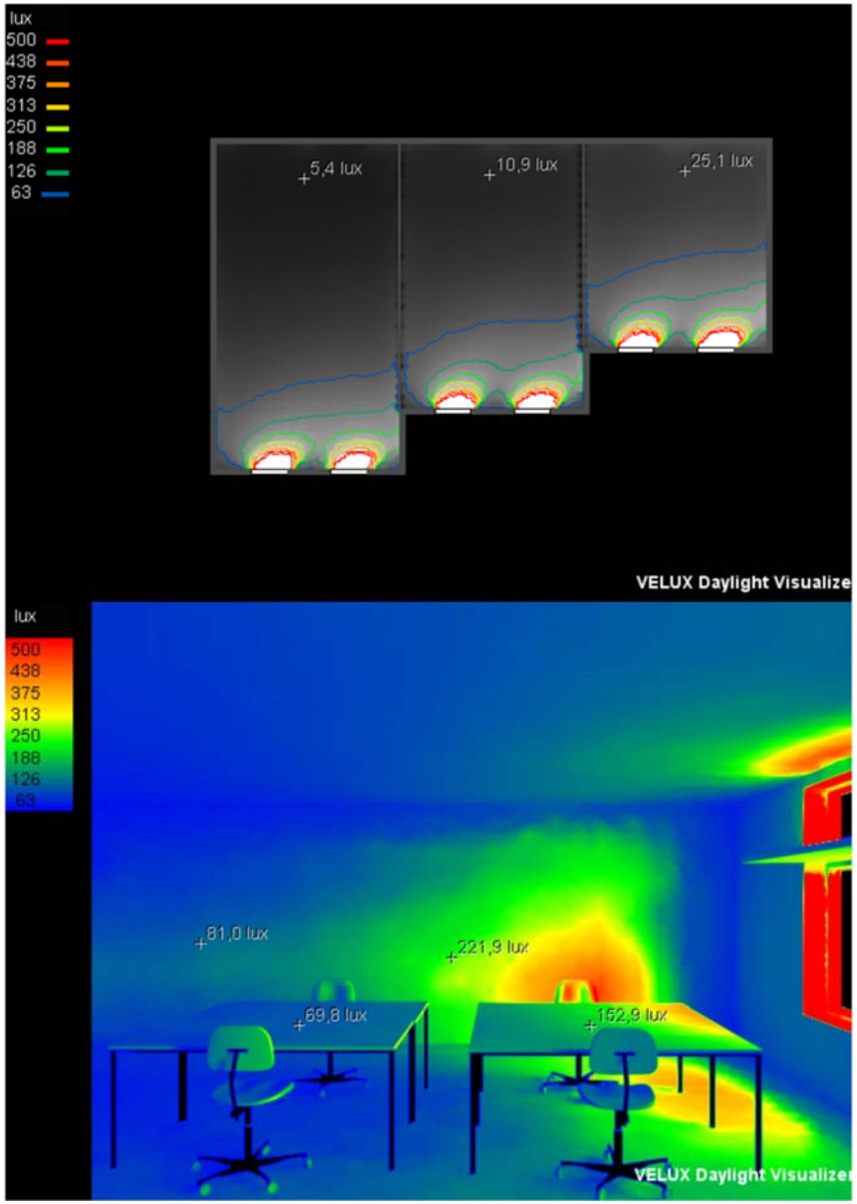


VELUX Daylight Visualizer 2

VELUX Daylight Visualizer 2


lux
500
438
375
313
250
188
126
63
2,4 lux
4,2 lux
9,3 lux
VELUX Daylight Visualize


lux
500
438
375
313
250
188
126
63
33,7 lux
98,9 lux
30,1 lux
69,1 lux
VELUX Daylight Visualizer



Figure(40) Illuminance plan and cross section CPH with light shelves at 16 o'clock, winter solstice

Figure(41) Illuminance plan and cross section LIS with light shelves at 16 o'clock, winter solstice

Figure(42) Illuminance plan and cross section MOQ with light shelves at 16 o'clock, winter solstice