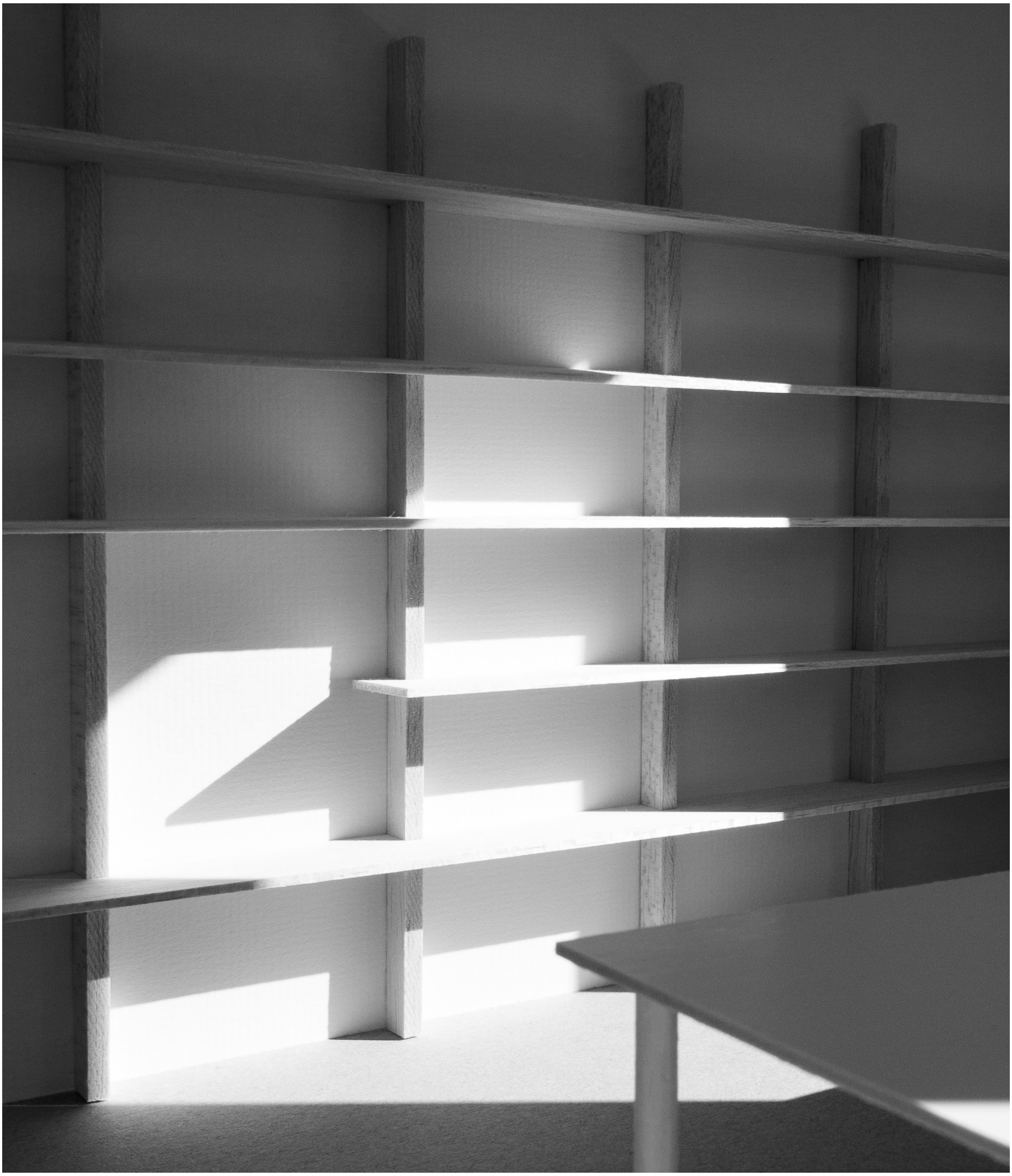

Let the Light in

Bringing back the attention to the qualities of daylight

Clara Wickberg and Hanna Bandmann

Master Thesis 2020
Matter Space Structure
Supervisor: Erica Hörteborn
Examiner: Morten Lund

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Chalmers School of Architecture
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CHALMERS
UNIVERSITY OF TECHNOLOGY

Abstract

This thesis is an investigation of the spatial qualities of daylight. It investigates how an increased knowledge can influence how we as architects choose to work with daylight, with the aim to create qualitative daylight conditions for human activities. Current Swedish daylight regulations are focusing on quantitative measurements when assessing luminance in buildings. While this is important to ensure good light conditions, this thesis aims to add other aspects to the discussion such as a focus on the program of the space, atmosphere and distribution of light.

To understand qualities and characteristics of daylight it is observed through various window configurations and in various weather conditions. This is made possible through a physical scale model where the user controls how light enters. The model provides the possibility to experience the space from inside. By analysing and comparing results knowledge is built in qualities of daylight. To apply light to specific activities and get a direction in the investigations the program workspace is part of the research.

The outcome is a design of a workspace and an image library of observed light qualities to use in the design process. It showcases possibilities to create atmosphere and support specific use of space and human activities. It includes various weather conditions, times of day and cardinal directions. The library including the design can be used to evaluate what would be appropriate in architectural projects and what would not be.

To fully evaluate the potential of daylight the current daylight regulations need to be reviewed. This thesis shows the need for new methods to evaluate a building design which should include all qualitative daylight aspects important for the specific program. As for the architectural design process it is recommended that daylight is studied in physical scale models parallel with design of facade and window placement.

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Acknowledgement

We would like to express our gratitude to our tutor Erica Hörteborn for constantly valuable discussions that pushed the project forward through development of our ideas. We would also like to thank Morten Lund for pushing us to make use of the knowledge gained in the project and present it in its full capacity. Thanks to our families and friends that have been supportive throughout this project.

01 Introduction

Preface

How would it be if we did not just choose a quick standard solution. If we carefully studied the specific site, could we then have an office space without artificial light? In the context of Gothenburg with limited hours of daylight the answer is no. But we believe that we to a great extent can avoid artificial light and make use of the existing daylight, its qualities and delicacy.

We are asking ourselves if the design process would look the same if all architects were trained in the qualities of daylight. Our belief and hope is that physical models and daylight studies as tools would have a wide spread.

Top picture
Final design of a workspace. This project lets us imagine what daylight qualities our study environment could have.

Bottom picture
Studio space for master students at Chalmers.

Student Background

Before beginning our studies at Chalmers we both received a bachelor of fine arts in architecture. In a previous common project and in individual studies we have found physical models to be an important tool in the design process. The models have mainly been used as site strategies, concept models of buildings have been evaluated on a site.

During our architecture education projects have all ended up at the same level of detail. The tasks focus on synthesizing complex situations to create an overall solution, while specific aspects seldom get the chance to be studied in detail. For this reason we have chosen to focus on one aspect for our master thesis, daylight. This topic relates to our interest in sustainable development and can provide us with new knowledge and tools to bring in to and develop in working life. Most importantly we find light being an exciting element to study due to its possibilities to bring essential and subtle qualities into architecture.

We would like to bring the experience of physical models into this master thesis although the model will have another focus. Now the focus will remain in a concept stage. We will look into the interior of a space and investigate how outer conditions and daylight inlets change the inside. Our belief is that the physical model tests in this project just as the previous ones will give us insights that are hard to grasp working with only digital tools and two dimensions.

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Purpose and aim

This thesis investigates the qualities of daylight. The project is performed in the daylight conditions specific to Gothenburg. The outcome is a library of different daylight inlets, which aims to:

- Support the architectural design process
- Showcase daylight's possibilities to create atmosphere
- Show how daylight can support specific use of space and human activities.

The outcome should be discussed in relation to Swedish daylight regulations, since the current evaluation method mainly focuses on quantity.

Research Questions

How can knowledge regarding daylight qualities influence the architect in the design process?

How can we as architects work more consciously with daylight to benefit human activities?

How can we find a method to make use of the local light?

How can a broader spectrum of daylight qualities be communicated?

Reading instructions

The introduction chapter has laid out the structure and aim of the thesis. The following chapter will present the theoretical foundation. It contains an overview of the current daylight regulations and recommendations as well as theory regarding the human visual system and how we experience space. The third chapter explains the method used to conduct the project followed by the chapter of the investigations. It starts with the first test of shape and proportion of windows then gradually adding variables such as cardinal direction and program. In the end of this chapter the final room design is presented. This is followed by a chapter containing the discussion on daylight regulations, method and representation.

Delimitations

The purpose of this thesis has been to explore the more subtle qualities of daylight and how they shape our perception of space and atmosphere. When assessing atmosphere we have used our own subjective experience. The terms used to discuss qualities of light are based on the definition of Liljefors (2000) and become part of the delimitations. Technical and quantitative aspects of daylight will not be investigated in this project but appear as references.

Normally when designing a space the combination of daylight and artificial light is taken into account. To be able to fully focus on qualitative daylight in this thesis artificial lightning is not included in the investigations. This thesis will not solve a whole building program, but the investigations will focus on a room.

In the investigations the window is explored as an opening and does not include glass materials, window frames or other details of the window. Aspects related to this, such as reflections in glass and different levels of transparency, have not been investigated. The surrounding has an inevitable effect on the light inside a space. The investigations are not exploring this further, but simply noting what major light effects are created from surrounding objects and textures.

02 Theory

Daylight regulations

Boverket

Boverket is the Swedish authority working with urban planning, construction and living (Boverket, 2019b). Boverket provides "Boverket´s building regulations" (BBR) which includes building regulations and advice (Boverkets byggregler {BBR}, BFS 2011:6) regarding the Swedish planning and building law (PBL) (Plan- och bygglag, SFS 2010:900) and the plan and building rescript (PBF) (Plan- och byggförordning, SFS 2011:338).

Regarding light in general it is stated that buildings should be designed having satisfying light conditions. Light intensity and luminance should be acceptable and disturbing glare and interrupting reflections should not exist. This also ensures a fair light distribution. Boverket´s mandatory provisions (BBR, BFS 2011:6) regarding daylight claims that "Rooms or separable parts of rooms where people are present other than occasionally shall be designed and oriented to ensure adequate access to direct daylight is possible, if this does not compromise the room's intended use" (p.98). An addition to this is that indirect daylight is acceptable in common spaces (BBR, BFS 2011:6). Boverket also gives advice regarding direct sunlight in housing and the possibility to have contact with the outdoors, making it possible to see seasonal change and change throughout the day (BBR, BFS 2011:6).

Arbetsmiljöverket

Swedish Arbetsmiljöverket pursues that laws regarding workplaces are fulfilled by companies and organizations. According to Arbetsmiljöverket lightning in workspaces should be adapted to the specific tasks. Drawing and reading small texts are examples of tasks where the light level in the room and on the specific desk should be extra lit. Of importance is also the specific worker and requisites of that person (Arbetsmiljöverket, 2020).

It is often possible to achieve satisfying light conditions using windows on a wall if the depth of the room is less than six to eight meters. The window area should be ten percent of the floor area. Depending on the surroundings such as other buildings this percentage might have to increase (Arbetsmiljöverkets författningssamling {AFS}, 2009:2).

Since the amount of daylight varies throughout the year a combination of daylight and electrical light often is required (AFS, 2009:2). An advantage of daylight and view is its capacity to vary, for people working indoors this is beneficial. Light has an impact on people's health in terms of mood, feelings and alertness. The colour of light is also a variable that has an impact (Svensk Standards Institute {SIS}, 2012). Possibility of a view is demanded and it prevents uniformity which is straining and as well the feeling of being confined (AFS, 2009:2).

Light can be disturbing in work spaces in terms of reflections and glare (Arbetsmiljöverket, 2020). By choosing matt surfaces and light colours in a space reflections and glare can be avoided. This includes glare from looking at a window (Ljuskultur, 2013). Sharp shadows should be avoided (SIS, 2012). Concerning daylight the main disturbing part is direct daylight. A computer screen should not have a window behind and windows should not be reflected in the screen (Arbetsmiljöverket, 2020).

Calculation methods

BBR refers to a method usable for rooms built within the frame of Swedish Institute for Standards, SIS, to calculate daylight. The method relies on calculating the area of window glass in a room and states a minimum of ten percent floor area, which will give a daylight factor around one percent. (BBR, BFS 2011:6) Window glass area is a simplified method. The size of the window glass area is divided with the floor area of the room (Sweden Green Building Council, 2017).

When rooms are not built within the frame of Swedish standard the method window glass area is not reliable. Instead calculating the daylight factor is recommended. The desired value is daylight factor one percent (Boverket, 2019a). Daylight factor measures the light intensity, how the intensity in a room relates to the intensity outdoors. Daylight factor one percent means that the intensity at the measured spot is one percent of the intensity outdoors. Calculations by hand and by digital tools are accepted. An overcast sky is always used in tests. Aspects included are the type of glass, distances and height of surrounding buildings and protruding parts of those buildings that could have an impact. Reflectance value of surfaces outdoors and inside the room must be included (Sweden Green Building Council, 2017).

The report "Räkna med dagsljus" written 1987 is referred to as an analog method for calculating daylight factor in one measure point (Boverket, 2019a). A calculation of daylight factor from one measuring point is described like this; the measuring point is 0,8 meters above the floor. It is one meter from the darkest side wall of the room and is placed in half of the depth of the room (Sweden Green Building Council, 2017).

The current swedish standard SS-EN 17037 claims that daylight should be calculated from a mesh of points, this to raise the level of precision (Boverket, 2019a). A median daylight factor is calculated with a simulation program from a mesh over the surface. 0,8 meters above the floor including a span of the distance from walls and maximum distance between measuring points (Sweden Green Building Council, 2017). All the points are placed in order and the middle one is the median daylight factor. This gives information regarding the daylight factor in different points of a room. When calculating the average daylight factor you use the previous method but instead of the median you calculate the average value (Dubois et. al. 2019).

Critique current regulations

In the report Rogers and Tillberg (2015) explains that other fields in the building process such as city densification, energy performance and maximizing of built area are marginalizing daylight. Regarding the chapter on daylight by BBR the critique takes off in the fact that daylight factor of one percent was used already in 1975. Nowadays digital tools have a capacity to simulate daylight that goes way beyond just looking at one specific spot. The method of using window area is also described as outdated since it seldom gives accurate results.

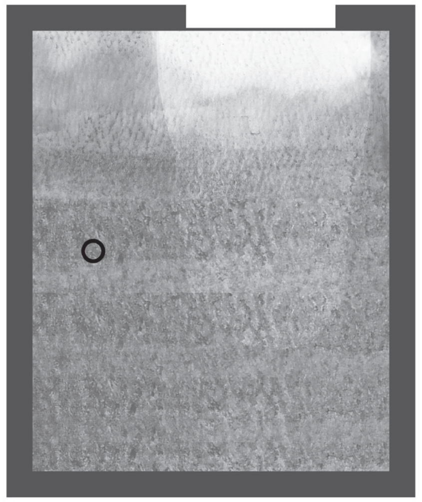
One important aspect that has been developed further in other countries is variation of daylight recommendations looking at the program of a building or a specific room. Rogers and Tillberg (2015) ask for a future where a method for evaluating a space as a whole is used. A problem is that current guidelines from BBR are vague which is also a reason for the limited use of them. Since green building certificates have become used more frequently more confusion has occurred (Rogers and Tillberg 2015).

Development within the field

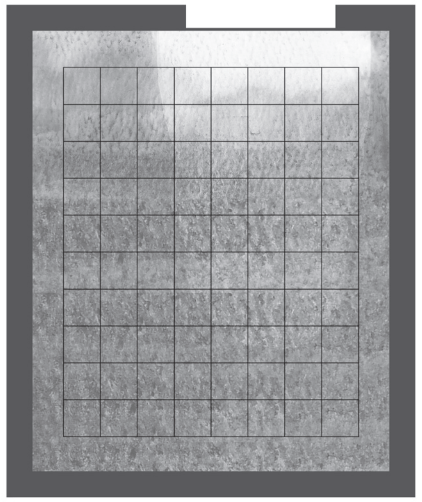
The article ”Paul Rogers brinner för dagsljus” (2019) discusses the field of daylight in architecture which is constantly in change. At the end of 2018 a European standards report was released. The report is implemented as Swedish standard, the previously mentioned SS-EN 17037. Worth mentioning is that the main report is not adapted to Nordic latitudes. An appendix of the report treats modernization of daylight standards and mainly focuses on Swedish law.

The recommendations on accepted levels of daylight in the report are ambitious and will need to be discussed in relation to other aspects when implicating them. It contains recommendations, not laws. The report suggests a new way of measuring daylight in housing, letting go of the calculations on rooms as separate units (“Paul Rogers brinner för dagsljus”, 2019).

One of the aspects the reports extends on is direct daylight, does a space get direct daylight at any point during the day? An aspect which daylight factor does not evaluate. It also includes levels of ambition regarding daylight which can be relevant to discuss in a project. Using the new report to perform computer simulations will give an accuracy at a much higher level than the calculation of daylight factor (“Paul Rogers brinner för dagsljus”, 2019).



Daylight factor: 0,8 meters above the floor. One meter from the darkest side wall of the room, placed in half of the depth of the room (Sweden Green Building Council 2017).



Average or median daylight factor: mesh over the surface. 0,8 meters above the floor, 0,1-0,5 meters from walls, maximum distance between measuring points is 0,5 meters (Sweden Green Building Council 2017).

Human Visual System

Light shapes our perception of space, therefore it is important to understand how we perceive things. Dubois, Gentila, Laike, Bournas and Alenius (2019) explains in their book how seeing is an interplay between our eyes and brain. When we see we do not perceive a clear image of millions of luminous points, but rather we recognize things that have meaning, such as “table” or “tree”. This means that attention plays an important role for what we see and what we perceive.

The expectations of a space are therefore crucial. When what we perceive is expected we can bring our attention to a particular task instead of analysing the surrounding. This is why designing lightning conditions that meet the expectations is so important (Dubois et. al. 2019).

The eyes

The eyes are the optical devices which allow us to perceive light. Dubois et. al. (2019) explain how light enters through the iris and an upside-down image of the surrounding is projected onto the inner lining of the eye, called the retina. The retina is a layer of light sensitive cells called rods and cones, converting the light into electrical signals. These two groups of photoreceptor cells have different characteristics, affecting how we perceive the world.

Rods

Rod cells dominate the peripheral visual field, perceiving shape and motion. They have slower reaction time but are much more sensitive to light and work well in low light levels. Since they are incapable of recognising colour the world is perceived more grey as it gets darker. Dubois et. al. (2019) point out that the rods are not used much in modern society which to a large extent is electrically illuminated for cone vision. They are however important to provide a general perception of space and context.

Cones

Cone cells are concentrated in the middle of the retina in a small dent – fovea centralis. They are able to adjust to very bright light, but have a hard time sensing low light levels. Instead they work faster and perform well in high light levels, producing detailed colour images (Dubois et. al. 2019).

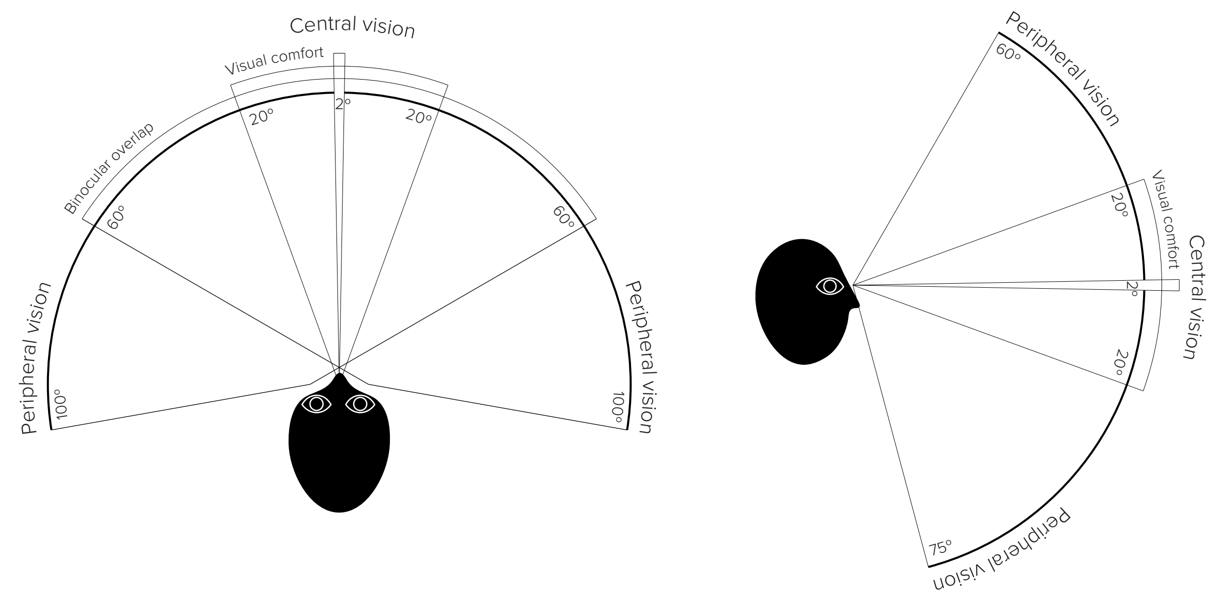
Visual field

Human vision consists of the overlapping of two visual fields. The small variations between the two images provides us with the perception of depth together with factors such as shadows, shape and colour. Humans usually perceive the whole visual field as sharp thanks to the eye constantly moving around. In reality only the central two degrees of the visual field is clear and detailed. The focused central vision usually receives more attention, but there is proof that our perceptual and mental system is more affected by what we perceive in the unfocused peripheral vision. In studies the central 30-40 degrees are stated to be more significant for visual comfort. For assessing room brightness the luminance of walls seems to be most important, especially those making up the background to a task. The front surface has a greater influence on the perceived brightness than the sides. However, even impressions from outside the 40 degrees impacts the perception of brightness. A dark ceiling has a darkening impact (Dubois et. al. 2019).

Adaptation

Adaptation takes place when the visual system adapts from one light level to another. This means that the previous light condition affects how we experience the new situation (Dubois et. al. 2019). Going from dark to light takes about ten minutes, while dark adaptation can take up to 60 minutes. During this time visibility might be limited. Dubois et. al. (2019) mentions three adaptation states:

- **Photopic adaptation** - takes place during the day in normal light conditions, cone cells are providing detailed and coloured vision.
- **Mesopic adaptation** - takes place in lower light levels, rod cells come into use resulting in a less coloured image of the world. The eyes also become more sensitive to blue light.
- **Scotopic adaptation** - takes place in the lowest levels of light, such as moonlight. Rod cells dominate completely which makes the world perceived as black and white.



Horizontal and vertical visual field. Diagrams based on Dubois et. al. (2019).

Visual performance

Visual performance is divided into two main categories, detailed vision and surround vision. For both of these two, contrasts are enhancing what you want to see (Liljefors, 2000). Surround vision and detail vision are terms with clear connection to peripheral and central vision. The conscious choice by Liljefors not to use the anatomical terms was made to enhance the importance of peripheral/surround vision and its essentiality for the understanding of space (Dubois et. al. 2019).

Surround vision

Surround vision grasps the environment as an entirety. The surround vision grasps the atmosphere of space, dimensions, proportions, shape, materiality, texture, colour and light (Liljefors, 2000).

Experience space

Liljefors (2000) explains that good vision in the case of experiencing space is defined as the ability to experience three dimensions. This includes spatiality, delimitations, objects and distances. To experience spatiality, atmosphere and orientation together with light distribution is important. Light distribution defines lighter and darker areas, shadows, reflections and gradients.

Diagram based on Liljefors (2000).

1. Clear field border 2. Unclear field border 3. Gradient border

The Surround vision is supported by clear field contrast. The eye creates various fields that are determined from brightness, colour and texture. Gradients within these fields are also of importance. Surround vision struggles from lack of field contrast together with monotone distribution of light (Liljefors, 2000).

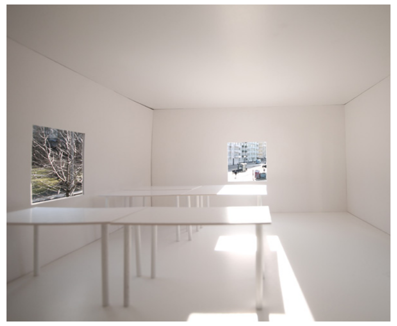
The perceived light level is much dependent on the reflectance of surfaces in a space, there is a big difference between white and dark surfaces. Current luminous flux is subordinated. Monotone light gives the impression of low light level (Liljefors, 2000).

Rich light encourages activity, darkness encourages rest. Appropriate light level is not constant, possibility to vary is positive. Variation of light emphasizes the presence of light in space while monotone light can be experienced as too dark and grey. On the other hand there is a limit where variation appears chaotic (Liljefors, 2000).

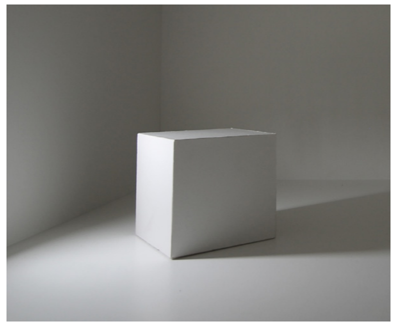
Glare occurs when it is not possible for the eye to adapt to a high brightness contrast (Dubois et. al. 2019). Glare can also change when you move in a space (Alenius, 2018). The colour of light is the colour tone perceived, a combination of the light source and surfaces in a space. Daylight has a great variety of light colour throughout the day and year (Dubois et. al. 2019). Colour is most commonly defined as perceived colour, a surface or an object are perceived to have a certain colour (Eriksson, Hult, Larsson, Sisefsky and Warell, 2020).

While part of how we experience space comes from evolution and is shared by most humans it is also important to acknowledge that atmosphere is partially individual and cultural. A room with a small window can be experienced as cool and pleasant for someone from a hot and humid climate, while for a person from a cold dark climate it will give a cold and unpleasant impression (Dubois et. al. 2019).

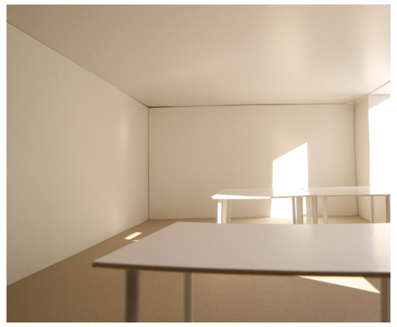
To conclude, the following seven terms are all of importance for light in space: reflections, distribution of light, shadows, light level, colour of light, glare, and colours (Dubois et. al. 2019).




Left: Reflections
Right: Distribution of Light




Left: Shadows
Right: Light Level




Left: Colour of Light
Right: Glare

Atmosphere

The word atmosphere derives from the Greek words atmos (vapor) and sphaira (ball/globe). It has two main meanings, defined by Oxford University Press (2019): “the envelope of gases surrounding the earth or another planet” (para.1) or “the pervading tone or mood of a place, citation, or work of art” (para.2).

In architecture, atmosphere is used to describe our experience and feelings of a space. Pallasmaa (2014) writes that it can be understood as an immediate form of our physical perception, which we grasp through our emotional senses. He explains that rather than through focused observations, atmosphere is perceived unconsciously by our diffuse peripheral vision. Therefore our normal reality is not the clear image we imagine, but rather an instant and unfocused sensation. Atmosphere is perceived before we understand what creates it. Instantly distinguishing danger from safety is an evolutionary advantage which has made us seek or avoid certain kinds of atmospheres. Pallasmaa (2014) brings up one of the clearest examples of this: our shared pleasant experience of being under a shaded tree, overlooking a sunlit field.

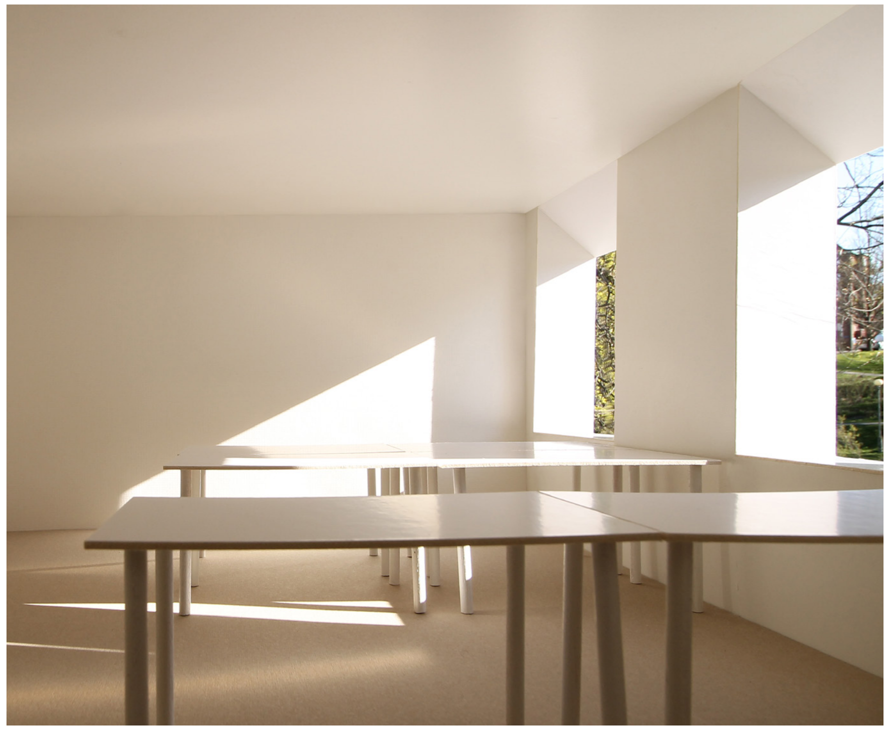
Atmosphere and mood are fundamental aspects of space, and peripheral vision is essential to perceive these qualities. Pallasmaa notes that observing and analysing these are somewhat lacking in architecture, which traditionally has been concentrating more on perception through focused vision. Pallasmaa states:

> Yet, when we see a thing in focus, we are outsiders to it, whereas the experience of being in a space calls for peripheral and unfocused perception. (Pallasmaa, J. 2014, abstract)

Architecture is often communicated through photos or two-dimensional renderings and as Pallasmaa (2014) highlights they usually never manage to translate the full experience of the space. This could be explained by our need for peripheral vision to grasp the atmosphere.

Atmosphere in this project

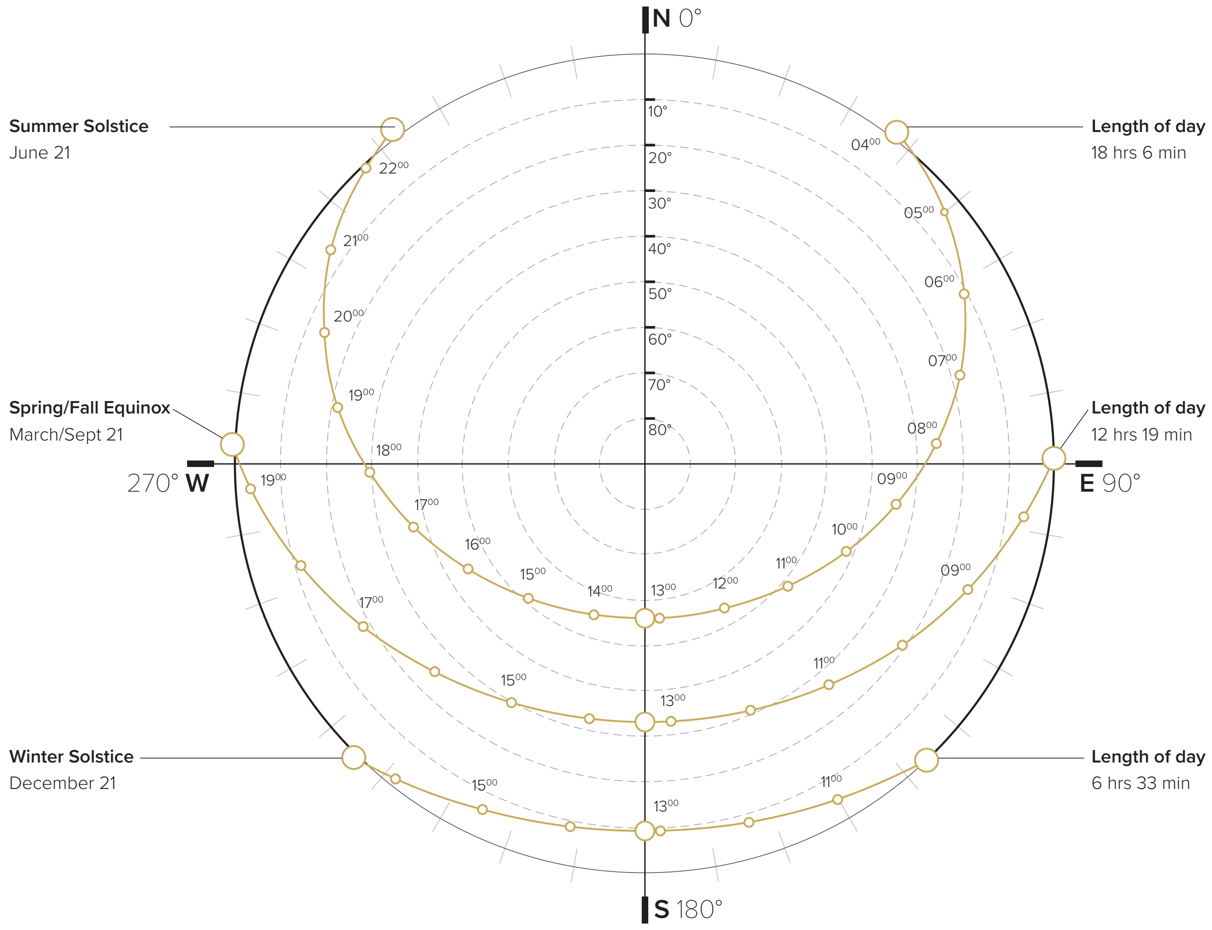
In this project we see atmosphere as the immediate experience and feeling for a space. We have used our own subjective experience of the space when assessing atmosphere. We try to describe the instant perception we get when entering the room with words like dramatic, calm, claustrophobic, spacious etc. To explain the experience of mood and intensity, whether we find it pleasant or unpleasant. It is also about the experience of brightness, which is not necessarily related to what the measured brightness would say. In the investigation we also notice that when adding a purpose to the room, workspace, our expectation affects how we experience the atmosphere. This is probably because of our definition of good atmosphere in relation to the specific program.



Nordic Daylight

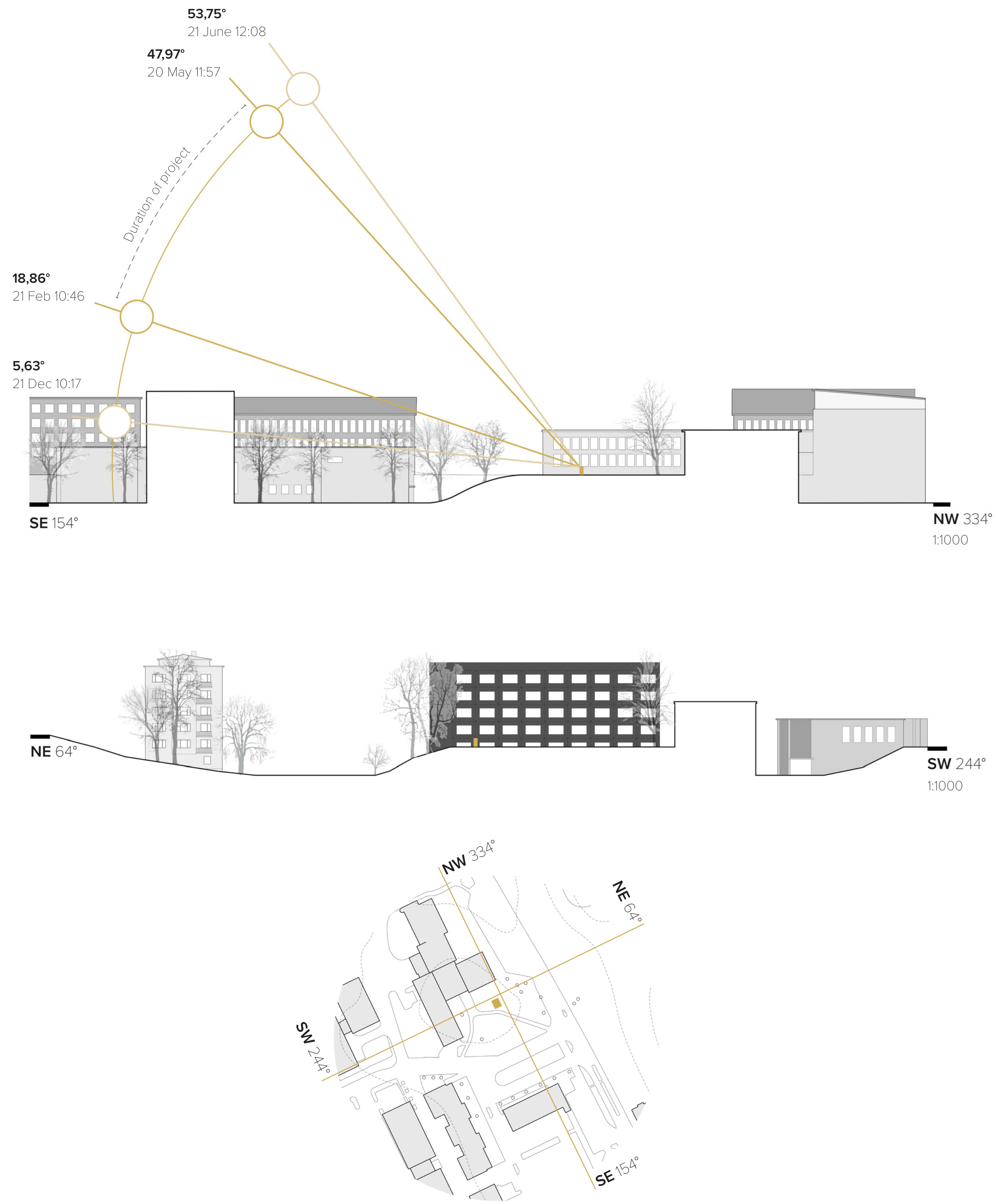
Light is specific to geographic location. How the sun moves over the sky decides at what angle light falls on an object. It decides shape, size and contrasts of highlights and shadows. Weather plays another part, filtering the light from the sun and altering its effects. This project takes place in the Nordic context of Gothenburg. These daylight conditions are described by Plummer (2012) and can be summarized as following:

- **Low solar angles:** The sun stays at low altitudes during the whole year, between 0 and 54 degrees. Shadows are long, the light is softer and colours are refracted.
- **Extreme ranges of illumination:** The length of the day varies greatly over the year. From the light summer nights to the short winter days dominated by twilight.
- **Twilight:** The long periods of twilight with very low solar altitudes.
- **Cloudy skies:** The weather is characterised by overcast weather and a low frequency of sunny skies. Clouds further soften the sun, making the light diffuse. Dubois et. al. (2019) explain that cloudy skies are more frequent during wintertime.

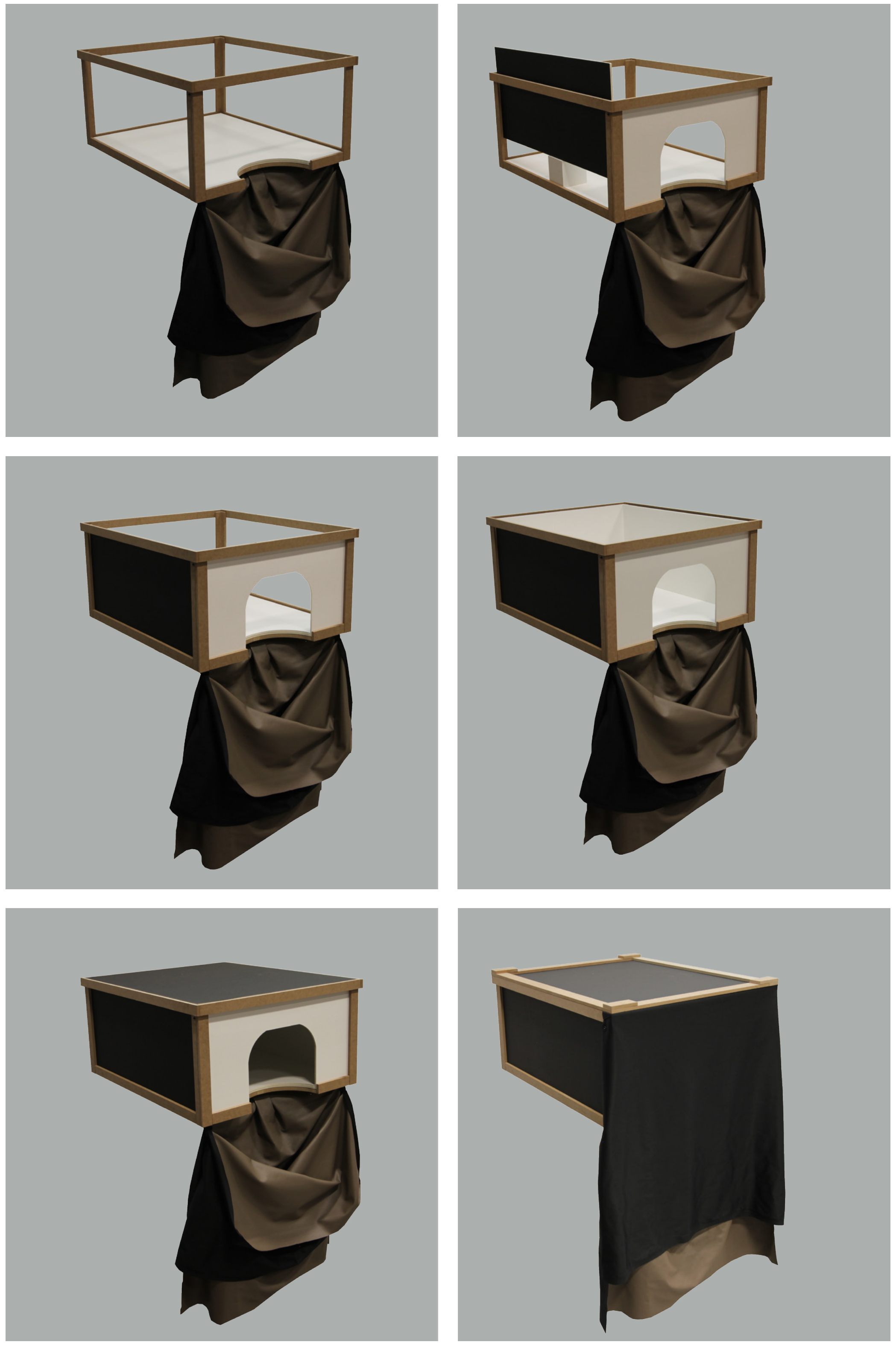


Gothenburg, Sweden
Lat: 57.6902265
Long: 11.9793899
(Based on data from suncalc.org)

03 Method



Context of the tests. Section including the highest and lowest solar positions in Southeast 154°.



Method | Model

The aim of building a model is to create an environment for light experiments and to try different sizes, placements and shapes of windows. To compare and draw conclusions on how they affect the light inside the room and how space is experienced.

This demands full control of the light, that the model itself does not let light in. Another request is to be able to experience the environment created inside the model, therefore it must be rather big. The experience of the tests is essential but also the mobility to be able to perform outside tests.

The size of the model is 60 x 50 x 28 centimetres. The proportions were decided after considering a common shape of a room together with the possibilities to document the space from inside with a camera. Therefore it is slightly longer than wide. The dimensions of it allows a room of a scale up to 1:10. To provide a wide range of possibilities four walls and the roof are all changeable. In one of the walls and the bottom pieces are carved out. There you can place your head and your eyes will be inside the model.

A test with the model starts with a decision of what window to try. Then follows the construction of a wall compatible with the model. A solid wall is then exchanged with this wall. The next step is to look inside the model to observe, experience and then document. The last part is taking a photo of the current scene, using the camera settings to catch the light level. All outdoor tests are taking place at the same spot, a hill outside Chalmers main library. This was one of the places at the campus that direct sunlight hit already in February. Appendix one further explains the decision of making the test outdoors.

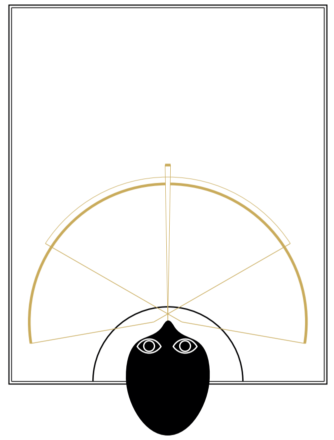
A series of performed tests provides experiences and observations that can be compared, discussed and then turned into conclusions of what daylight qualities are experienced and how they vary. Information is gathered regarding sizes and shapes of windows, variation of weather conditions and cardinal direction.

The frame holding the walls and the roof is limiting in terms of testing and experiencing windows that continue over corners. Observations are made only from one direction which affects the experience. This is limiting compared to a room 1:1 where you can walk around and make varied observations from changing your position. The model is not possible to vary in terms of room proportion.

The tests are performed at a certain time and date with a specific weather situation. This gives the tests unique characteristics. The way of performing the tests has a limitation when it comes to quantity of test series. It is hard to perform quantity in aspects of time and weather conditions. The tests performed are limited to the time of year the project is ongoing, February–May.

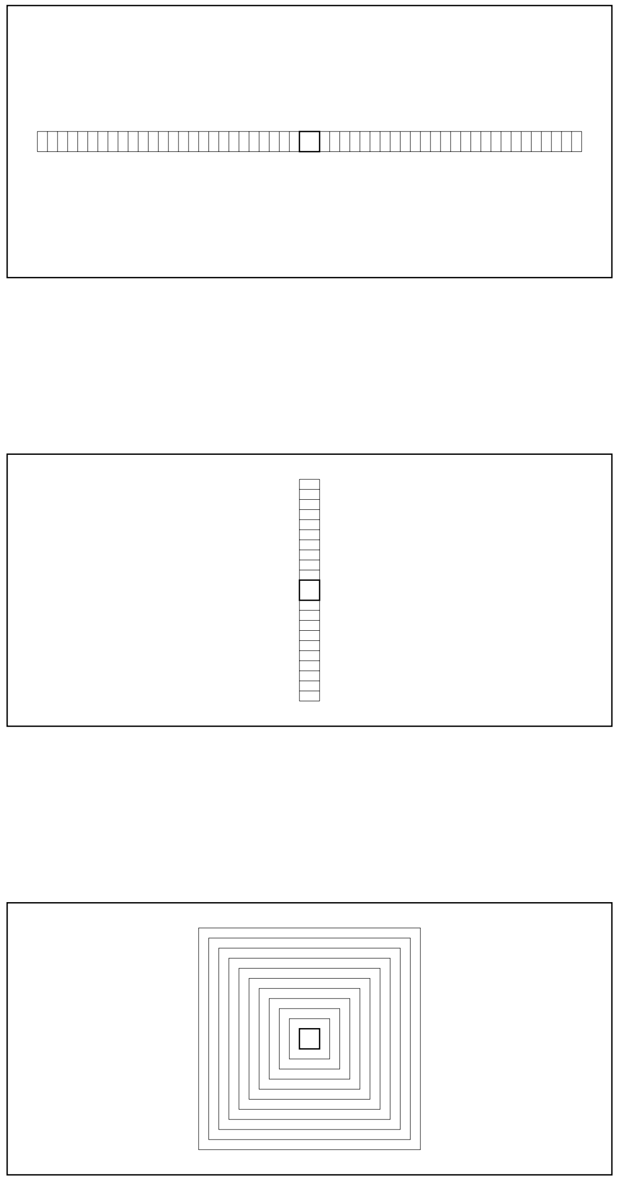
To be able to grasp some of these aspects the physical model tests are supplemented with light studies in the digital tool SketchUp. This to be able to analyse the light variation over the year looking at aspects such as sunrise, sunset and direct light. During the process other physical models are introduced when other proportions of space are tested.

Model seen from above, experienced through central and peripheral vision.



04 Investigations

Test 1



Shape and Size | The three different configurations for the window wall.

1| Intro

The first test is made as a starting point to see how the size and shape of the window would affect the light inside the model. By gradually increasing a shape in different ways it is possible to compare and draw conclusions on how it distributes the light and shapes the experience of the space.

The initial square throughout the test is 2 x 2 centimetres. In real life, this would be about 20 x 20 centimetres. A measurement that was chosen in order to see a greater variation of sizes. The square is then increased vertically, horizontally and proportionate with 2 centimetres each time.

Objects were placed in the model to see how light will fall on them depending on size and placement of the window. The cube was chosen as an object that has surfaces that are clearly separated from each other. The cylinder was chosen as an object with curved surfaces. These two can be interesting to compare, how the surfaces will shift in tones or stay monotone. The scale of the room can vary, but in scale 1:10 the cube has a height of a work surface. The objects are placed differently, the cube close to the window and the cylinder further back to the side of the observer.

1.1| Horizontal

When starting the test the room is experienced as dark. The window itself gives a very directed light with strong contrasts from dark to light fields, a dramatic light. The objects are giving the floor two large blurred shadows. The cylinder is quite monotone in the beginning of the tests due to the light being centred close to the window. As it widens and light enters from several directions the shadows are blurred out. The cylinder stands out more due to the right wall becoming more illuminated. The cube has clear fields and gradients within them appear during the observations which increases the three-dimensional perception.

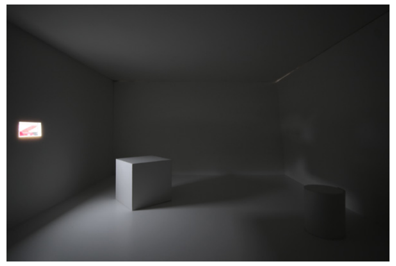
The floor close to where you observe is lit, just as the lower part of the right wall. Now the light in the room can be described as dull. In the 6th picture the impression of the room becomes more inviting and less claustrophobic. A connection with what is outside the room becomes present. The room is still quite dark but pleasant. A dramatic light is observed on the front and right wall of the room. The light on the front wall is stepwise coming closer to the window wall. From the 6th picture and onwards the space could be used without additional electric light, with the exception of detailed work. Throughout the test the floor under the window is a dark field that slightly narrows down and becomes more defined when the room becomes lighter.

Henceforth the light level is described as pleasant which exceeds in nice soft light. Walls, floor and ceiling have overall similar tones. It is rather the light patterns that are changing. The colour of light is quite static during the test and it can be described as neutral or slightly cold.

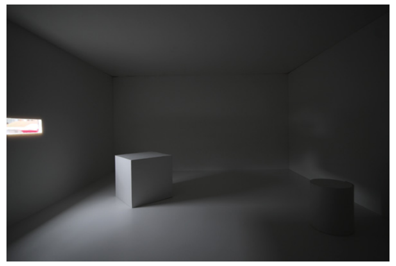
Date: 2020.02.24
Time: 15:20–16:40
Orientation: North

Cloudy

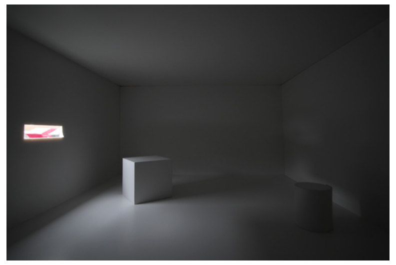
1. 2 x 2 cm



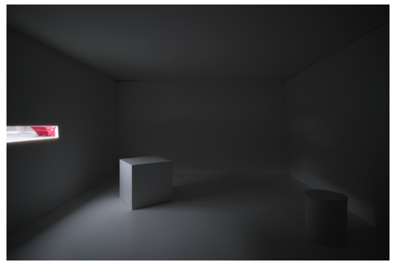
2. 4 x 2 cm



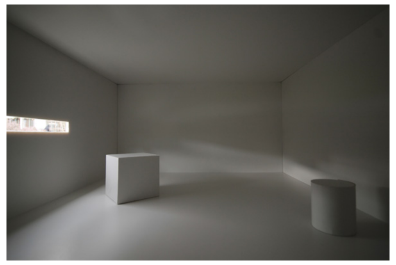
3. 6 x 2 cm



4. 8 x 2 cm

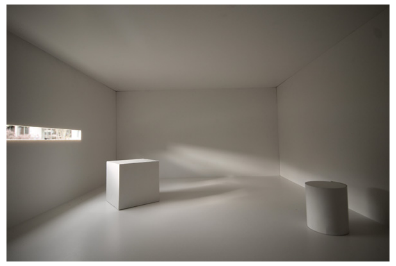


5. 12 x 2 cm



6. 18 x 2 cm

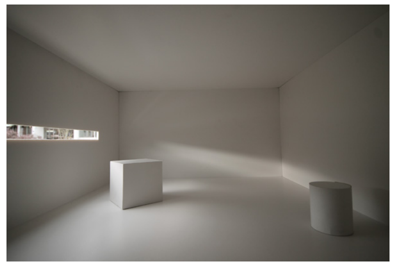
7. 22 x 2 cm



8. 26 x 2 cm

9. 30 x 2 cm

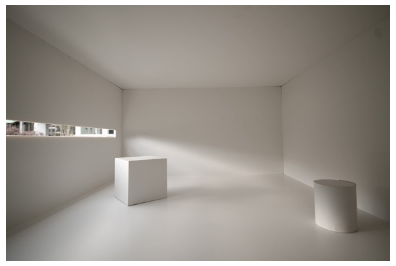
10. 34 x 2 cm



11. 38 x 2 cm

12. 42 x 2 cm

13. 46 x 2 cm



14. 50 x 2 cm

15. 54 x 2 cm

1.2| Square

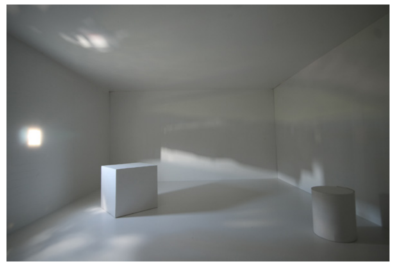
The small window creates a dramatic impression with sharp shadows and fields of light. Here the cube stands out thanks to the strong contrasts between the light sides facing the window and the darker one facing the room. In the first picture the surrounding is projected as an upside-down image on the walls making it hard to distinguish the light entering directly into the model. Light is also bouncing into the model from below creating a clear illuminated square in the ceiling with the shape of the window. In the first picture the difference of weather becomes visible. Compared to the first picture of the previous test which has the same window dimensions the room is significantly lighter.

The perceived level of light increases quite fast as the window grows in size due to light becoming more evenly distributed. The dramatic light transfers into a calm diffuse light and the room is experienced as pleasant. There are less contrasts further away from the window making the objects placed here blend with the walls. Shadows and highlights blur out, almost disappearing with the largest windows. This effect is also due to the light being indirect, creating a soft light.

Throughout the test walls floors and ceiling have in general quite similar tones. The darkest areas can be found on the window wall. Beneath the window there is also a sharp dark shadow where the wall meets the floor. Helping the depth perception are the light fields landing on different surfaces. The floor in front of the window and the left part of the front wall belong to the lightest parts of the room. Light also hits the wall opposite of the window, but lower down towards the floor.

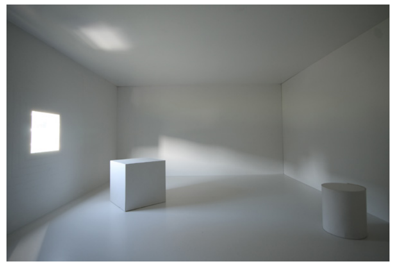
The cylinder remains vague throughout the test with tones similar to those of the background. The cube on the other hand appears clearly with monotone fields. Therefore this kind of window can create a good three-dimensional perception of objects depending on where they are placed and how big the window is.

Date: 2020.02.24
Time: 12:30–13:50
Orientation: North



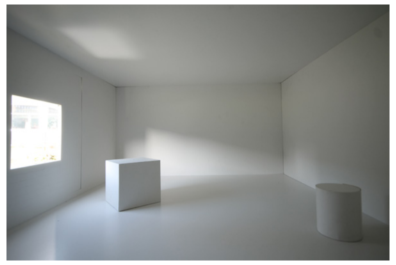
1. 2 x 2 cm

2. 4 x 4 cm

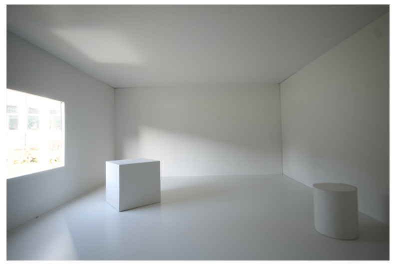


3. 6 x 6 cm

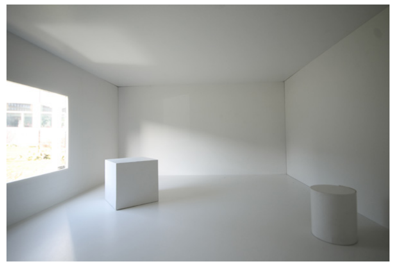
4. 8 x 8 cm



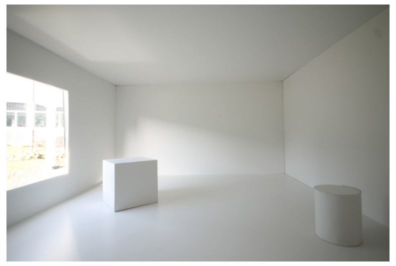
5. 10 x 10 cm



6. 12 x 12 cm



7. 14 x 14 cm



8. 16 x 16 cm

9. 18 x 18 cm

10. 20 x 20 cm

11. 22 x 22 cm

12. 24 x 24 cm

Sunny

1.3| Vertical

A clear image of the surrounding is not visible inside the room as seen in the previous test. The lower part of the front and right wall are light. The floor is divided into several fields. The experience is claustrophobic. The eyes are searching for the window, the shadows are pointing at it. The cylinder shadow is very sharp, the wall behind it is lit. The first half of the cube shadow is sharp then it blurs out. The top surface of the cube is dark.

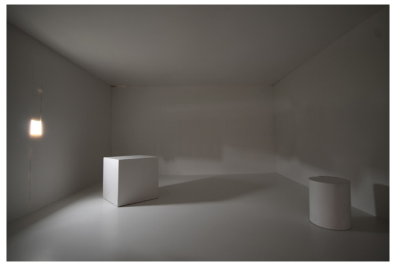
Throughout the test the side of the cube towards the window is perceived as very bright. The surface of the cube reflects light back on the wall of the window. In the second picture the field of light on the floor is lighter and the field contrast becomes clearer. At this stage the window is perceived as comfortable. The space is not experienced as particularly light. The shadows in general are sharp. Overall the walls and ceiling are even in tone. The light in the room is experienced as central, a directed light. The cylinder is varied from light to dark with a highlight and a clearly defined shadow behind it.

In the 5th picture the window is starting to create an intimate atmosphere. The strongest fields of light are centred around the window and the eyes are drawn towards it, giving an almost sacral impression. The window is reflected on the floor towards the spot where you observe. The window is experienced as narrow. The front and right wall have more variations within them. In general the three-dimensional comprehension is good. The window wall is light and the lightest area is around the window. The light in the space has a quite good scattering.

The area on the floor under the window is lighter and it is very close to the wall. As the window grows all of the noticed characteristics are enhanced. The front left corner is dark. Vertical surfaces facing the window are lighter, while horizontal surfaces are less illuminated.

In the last couple of pictures the light is central in the space. The scattering of light on the right wall is pleasing. The wall of the window is dark. The left part of the room has a dramatic light. The right part is less defined but still not monotone. The light field on the floor below the window reaches the wall. The cylinder shadow is blurred vertically. The sides of the cubes are rather monotone throughout the test.

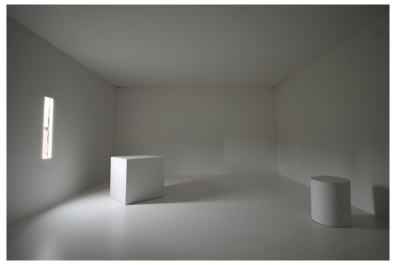
Date: 2020.03.03
Time: 14:30–15:30
Orientation: North


1. 2 x 2 cm


2. 4 x 2 cm

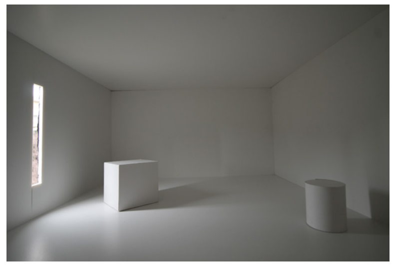

3. 6 x 2 cm


4. 8 x 2 cm


5. 10 x 2 cm

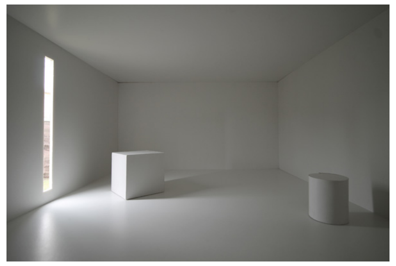

6. 12 x 2 cm

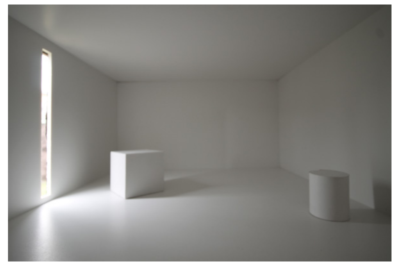

7. 14 x 2 cm


8. 16 x 2 cm


9. 18 x 2 cm

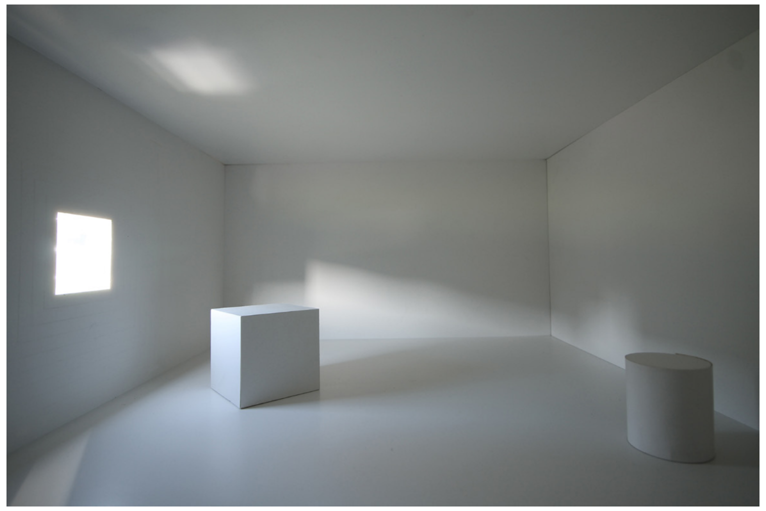

10. 20 x 2 cm


11. 22 x 2 cm


12. 24 x 2 cm


Cloudy

Horizontal
180 x 20 cm
1,2 % of floor area



Square
60 x 60 cm
1,2 % of floor area

Vertical
20 x 180 cm
1,2 % of floor area

Reflections | Conclusions

Horizontal

To conclude we found the horizontal rectangle to give a compressed feeling to the space. Both light and view have a narrow horizontal character, creating a sense of pressure from above. The window defines the height of the light which is directed with strong contrasts from dark to light fields, even during cloudy days. A dramatic light.

Square

The square creates a more airy feeling. The light is calm and diffuse. The larger windows distribute the light more evenly, making shadows and highlights blur. The darker side of the room is monotone but there is a good three-dimensional perception of objects close to window.

Vertical

For the vertical window the atmosphere is experienced as intimate, sometimes sacral. The light in the room is perceived as directed. Shadows blur vertically but are sharp horizontally. The three-dimensional perception is good, also of objects further away from the window. The small narrow windows create a directed three-dimensional light and experience. They probably need to be combined with other solutions for the space to be perceived as well lit.

For the whole test

The wall of the window and the area beneath is usually very dark compared to the window itself and the fields of light in the room. These contrasts can be used to create more dramatic impressions in spaces with less need for good visual performance. In spaces where detailed vision is important this can be experienced as problematic since high contrasts are troublesome for the eye.

The smaller windows give a claustrophobic feeling. As the window becomes bigger this feeling decreases and the room becomes more inviting.

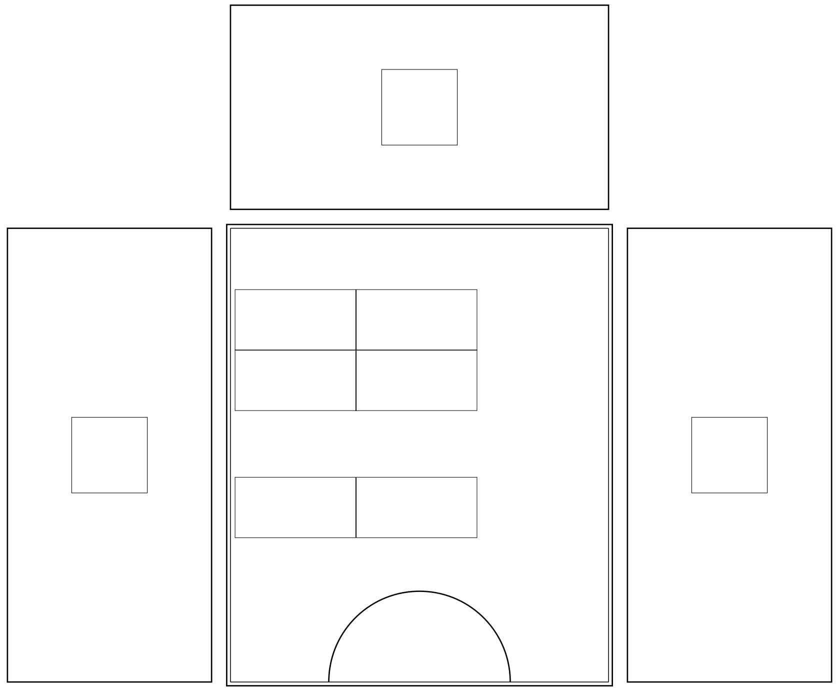
Weather affects the colour and level of light greatly. The cloudy sky gives a dark cold space while the clear sky creates a much lighter and slightly warmer room. We also noticed how the surrounding affected the light inside the model, further showing how site specific light is.

Window area

In general we experience the space to become comfortably lit early in the tests when the windows are still quite small. The exception would be for tasks that require detailed vision. The square which reaches ten percent in the 9th picture seen on page 39, is experienced as comfortably lit well before this point in the test. That test was performed in sunny weather, but looking at the light distribution we believe the experience would be the same on a cloudy day.

Another aspect to consider is adaptation. When we entered the model to experience the light we came from the much brighter outside. Since it takes time for the eyes to go through adaptation the new light situation will appear exaggerated. This means that we experienced the room to be darker than it actually was.

Test 2



Model seen from above with 6 desks. The three walls with a central square window are folded out.

2| Intro

In the second test the program workspace is added. The decision is made with the aim to be able to apply light to a specific activity and create a direction for the investigations. Many people spend their day at work which makes the workspace an important place for daylight. According to Dubois et. al. (2019) the expectations of a space influence the experience of it, therefore a specific use makes it easier to discuss and evaluate the light.

An aim to create a calm atmosphere is chosen with focus on the program. The choice of the window shape is made from the reflections in the previous test where the square window provided a calm feeling. The test is performed in a room with the same sized windows on three of the walls. This provides the possibility to see light coming in from several orientations simultaneously and an expectation is that the setting will provide an even light distribution. The area of the squares are altogether ten percent of the floor area, which according to Arbetsmiljöverket should provide sufficient daylight (Arbetsmiljöverkets författningssamling (AFS), 2009:2).

The room is set up with a common arrangement of desks towards one side of the room. The setting is tested during three different times of the day: morning, noon and afternoon. In addition to this it was done during two different weathers, cloudy and sunny.

Aim related to workspace

- **Good overall light** – Achieve “good overall light” during regular work hours defined as: experienced as sufficient, comfortable and with variety throughout the day.
- **View** – To create an area where your eyes can rest and a connection to the community outside.
- **Equal conditions** – Create equivalent circumstances for all desks to avoid hierarchy.
- **Avoid obstructing aspects** – The aim is as well for the light not to obstruct work. Obstructing aspects can be various fields with distinct contrasts on working tables or disturbing reflections that could cause glare.
- **Atmosphere** – A calm and spacious atmosphere.

Workspace - Cloudy

| Date: 2020.03.03

South

10:20 An airy and spacious feeling, likely because light enters from several directions which the shadows reveal. Only the work surfaces close to the windows are well lit. Walls and ceiling are similar in tone with the two lower corners of the front wall as the darkest areas in the room. The floor is the lightest surface with varying light fields.

12:20 Very similar to the previous test, possibly the shadows are less sharp. The lower part of the corners are quite dark.

16:30 The room is much darker and with a colder light, mostly due to the clouds being thicker. Apart from this the light is very similar to previous tests. Reflections are very apparent on the desks.

West

10:20 Very similar to facing south. The lower parts of the two corners are slightly darker and the shadows from the legs of the tables are slightly less sharp.

12:20 Most light comes from the south window and least from the north. Reflections are less dominant but the most visible ones seem to come from south and the sun behind the clouds. The shadows on the left wall are quite sharp. Tiny light spots in the ceiling above the windows appear. They are reflections from the surface outside the model.

16:30 The room is darker and has a colder temperature. Reflections are a little bit less apparent.

North

10:20 It is lighter under the front window. The shadows of the table legs are sharper, most of all the ones to the left. Floor and walls are monotone. The table furthest back to the left is the darkest one.

12:20 Reflections are very obvious. Still the floor surface is showing most variations in brightness.

16:30 Darker and with a colder temperature. Reflections are less apparent than in the test towards the west.

East

10:20 Very similar to the other cardinal directions during the same hour. The shadows from the tables have a slightly different direction. The lower part of the two corners towards the front wall are quite dark. Shadows of the table legs on the left wall are blurred.

12:20 Reflections are again a bit less apparent, otherwise very similar to the previous test.

16:30 Darker and with a colder temperature. A little darker than the other directions at this time. Reflections are least apparent here.

10.20–10.50 12.20–12.40 16.30–16.50

South

West

North

East

Cloudy

Cloudy

Cloudy

Workspace - Sunny

Date: 2020.03.06
Time: 08:50–09:45

Sunny

South

08:50 Direct light enters from south and east and lands on the table next to the window and the floor. The strong direct light makes the light in the rest of the room appear even with less subtle light fields. Work surfaces have the same tone as the surfaces of the room. A diffuse light comes in from the west direction and creates soft shadows of the tables on the left wall.

Southwest

09:00 Direct light is coming in from one side, touching the tables slightly and lands on the floor and wall. It gives a calm impression. The light is reflected on the floor making the light come from beneath the tables and casting shadows upwards the left wall. Overall the light is experienced as calm and hazy.

West

09.10 Direct light enters from the south window and lands on the four work surfaces furthest away. A soft light field is reflected onto the front wall. Light is perceived to bounce around in the room, giving a more illuminated feeling. It is quite easy to define both dark and light areas. The reflections make the room vivid with more varying light, like a forest.

Northwest

09:20 No direct light is entering which makes the light cold and diffuse. It is experienced as much darker with a quite husky and calm atmosphere. Overall the upper part of the room is homogeneous while the lower walls and floor have varying light patterns. There are light fields arriving from south west and north east. They are experienced as more distinct compared to the tests in cloudy weather.

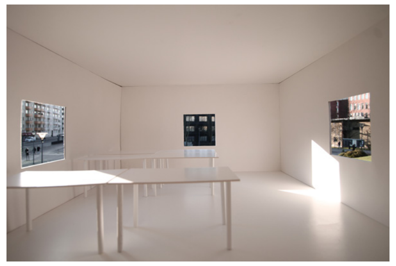
North

09.30 Direct light comes in from east and falls low on the front wall. Diffuse light is spreading upwards and makes it the lightest surface of the room. The light bounces up under the tables, casts shadows upwards on the right wall. The rest of the shadows are blurred. Your eyes are drawn to the central field with direct light. Besides the field of direct light the light in the room is pleasant.

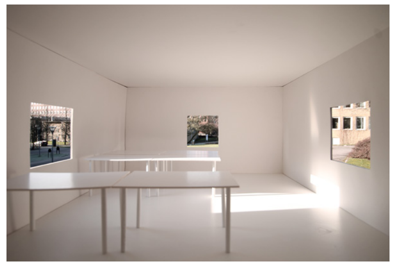
North east

09:35 The light is similar to the south and southwest facing tests. Direct light enters from southeast, landing mainly under the tables which gives a hint of the low position of the sun. Apart from the direct light the room has an even brightness.

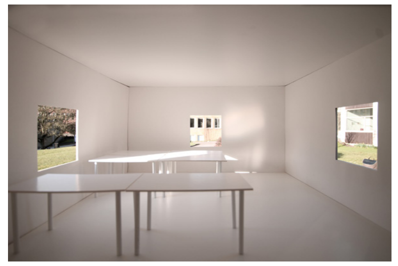
South



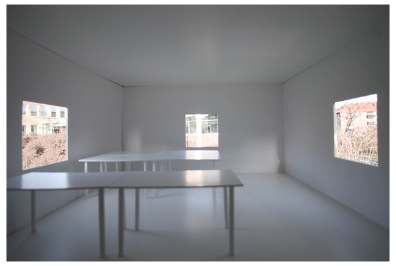
Southwest



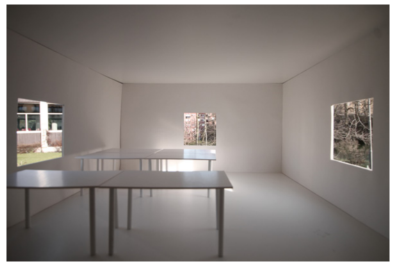
West



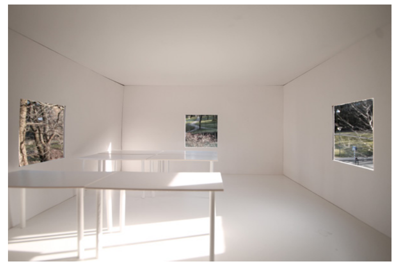
Northwest



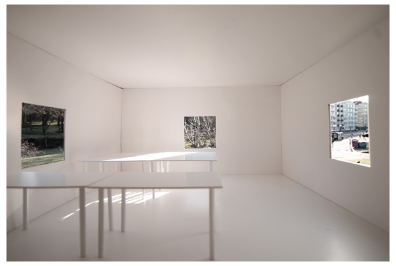
North



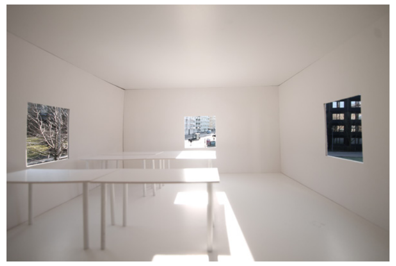
Northeast



East



Southeast



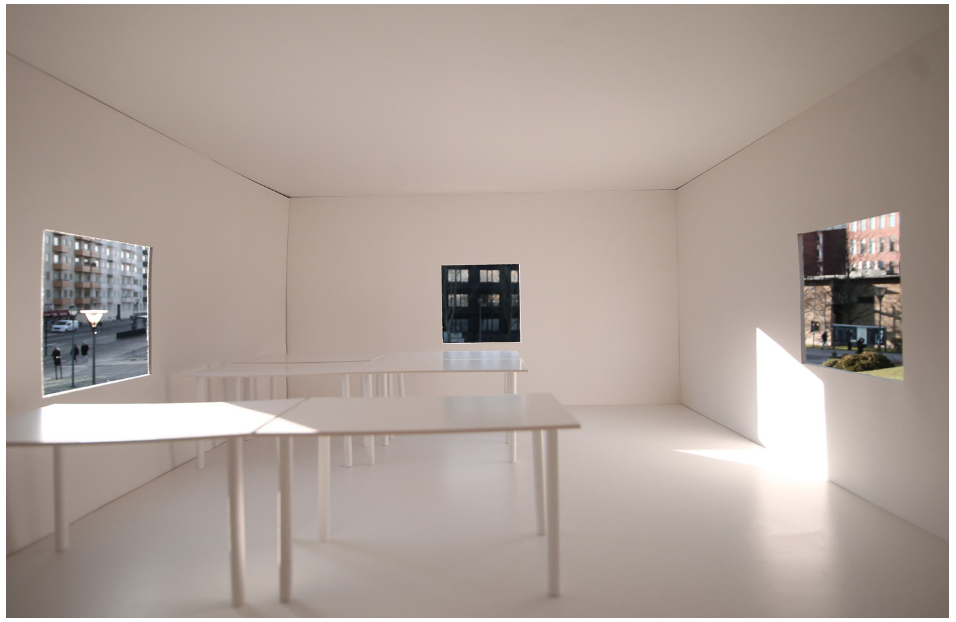
East

09:40 Direct light is entering from east and south, partially covering the tables in the cluster of four. The right side of the room is experienced as darker than the left. The room is evenly illuminated apart from the fields of direct light.

South east

09:45 The first impression of the space is spiritual. Direct light which appears dramatic enters from the southeast window and falls straight and far into the room. On its left side there is a soft light play and to the right it is monotone. The dramatic light is a distraction to the rest of the space. The sides of the room are forgotten including the diffuse light from the side windows. There is a soft light field in the ceiling reflected from tables. The front wall is darkest in the corners and lighter in the middle by the window. Other surfaces have an even brightness and the shadows from the tables are barely visible.


Cloudy | South


Sunny | South

Reflections | Conclusions

Cloudy sky

An airy and spacious feeling is created when light enters from three directions. Most light enters from the south, in this test with soft light. The floor is the most illuminated surface, while the rest of the room has similar tones.

Weather impacts the light more than the orientation during cloudy days. Both the light level and the temperature of light is greatly affected. During cloudy days, it is hard to create a feeling and understanding of cardinal direction and time of day.

Sunny sky

Direct light makes the room significantly brighter and warmer. Since it is moving in the room it creates variation over the day and year. In sunny weather we perceive more light bouncing on objects outside the model, creating reflected fields of light.

Fields of strong direct light make the tones of the rest of the room appear even. The subtle fields disappear, in comparison to a cloudy sky. In the northwest with only diffuse light entering the room we experience more light fields compared to the tests in cloudy weather.

More light than expected is hitting the surface under the tables. We imagined it to be more dark and in shadow. We experience direct light coming into a room as more similar to an electric light source.

Direct light is disturbing when landing on work surfaces. We observe that a change between warm and cold light will appear throughout the working day and wonder if this might be disturbing. Direct morning light has an important quality, it can help you feel alert when you arrive to work.

Common

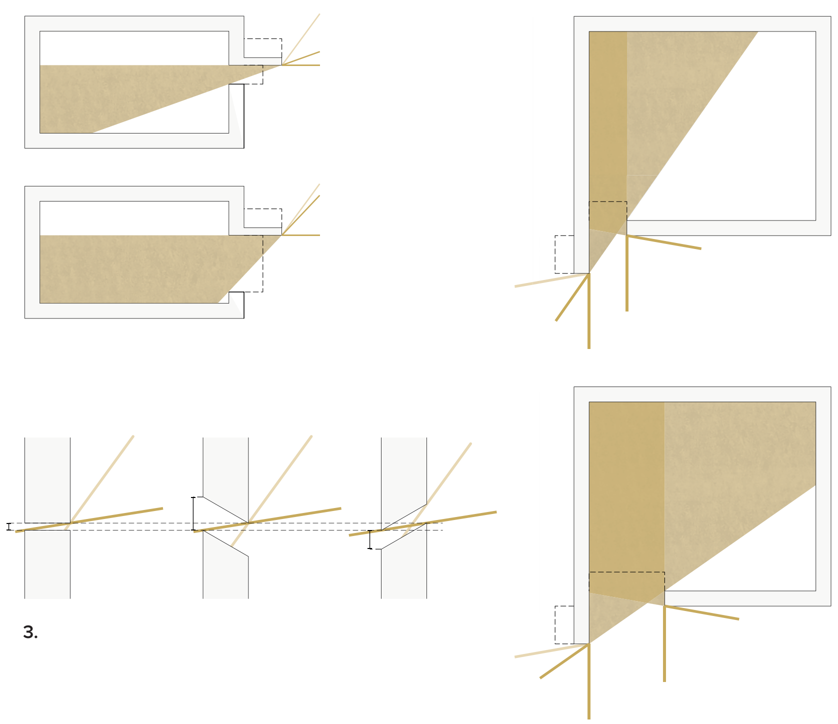
Windows in south are challenging, going towards north gives you a gradual increase of possibilities. Limiting yourself to north you risk a dim atmosphere and a montone light distribution. With direct light you risk a very dramatic atmosphere with focus on a specific area in the space which can appear chaotic. As Liljefors (2000) writes, both a monotone and a chaotic impression can be troublesome for the ability to experience a space.

Work surfaces have similar tones to the surrounding, which makes them blend in. The light in the room should therefore be elevated to illuminate the work surfaces better. Direct light is disturbing when landing on work surfaces, now it is important for us to investigate how direct light can be an asset. Additionally, a view out should be placed so that it feels accessible for everybody in the room.

Test 3

1.

2.



3.

3I Intro

From the evaluation of the previous round of tests it becomes clear that direct light is the most challenging part in a workspace. Diagram studies have shown that two perimeters that are very crucial to control direct light by ruling out some of the solar angles is the width of the window and the length of an extended element (diagram2). Studies in section, diagram 1, show that important aspects are the height of the window and the length of an extended element. Even if the height of the window is very limited some direct light will reach inside since the cardinal directions, with north as exception, are reached by very low angled sun altitudes.

Diagrams show that larger windows can be created by angling the niches of the window (diagram 3). Model tests will further investigate how different configurations of angled niches affect the light in a space. The perimeter of a fixed thickness of the wall is added, 0,4 meters, since the thickness will have an impact on how light enters the room.

3.1 Designing indirect light

For the first three configurations, picture 1-3 with a low angled niche of 30° in the top of the window the room is experienced as dark. Light is concentrated to the window, the niche is very light while the rest of the space is not. There is a clear division between inside and outside.

As the window grows into the ceiling because of a steeper top niche, so does the light and it reaches further into the room. These windows give an impression of a taller ceiling height. The darker field above the window decreases and disappears throughout the test.

As the bottom niche gets a steeper angle the light field in the ceiling gets sharper. As seen when comparing picture 1 and 3 a less angled bottom niche spreads out the light more which makes the room appear lighter. In the second half of the test the general level of light is good. Light is reflected down on the desk surfaces, which are perceived as light.

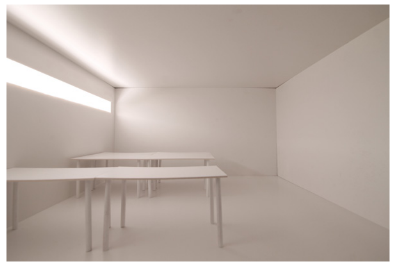
The surfaces of the room are quite similar throughout the tests. The wall of the window is the darkest, with some light reflected up from the tables. The front wall is average in illumination but with some variations coming from the window. The right wall is the lightest and is monotone throughout the tests. All surfaces have clear fields. The floor has variations in gradients, highlights and shadows which make the experience of it vivid. There are few clear fields on the floor, only from the legs of the tables. In the ceiling the light is centred above the window while the other side of it belongs to the darker tones of the room.

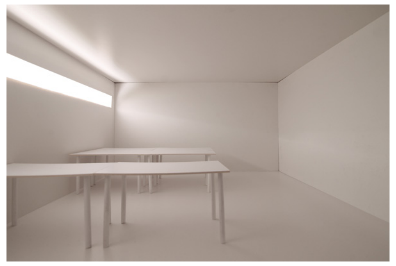
Reflections | Conclusions

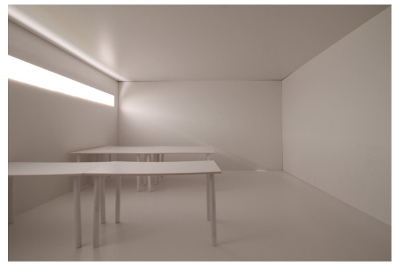
For the first three configurations in test 3.1 the room is experienced as too dark, light is not as spread out as expected. There is a clear indication of inside and outside and a feeling that the light does not reach in. Where the window meets the ceiling there is a feeling of the sky continuing into the room, which gives an impression of a taller ceiling height. The atmosphere is airy. The less angled bottom niches make the room appear lighter. In the second half of the test the general level of light is perceived as surprisingly good.

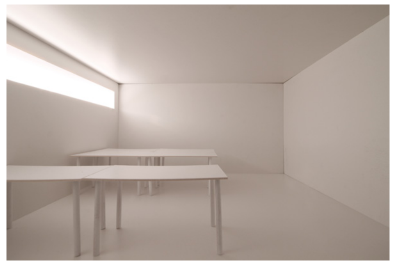
We clearly see differences between what we have experienced and what the pictures show. For instance the experience of light not reaching into the room in picture 1-3.

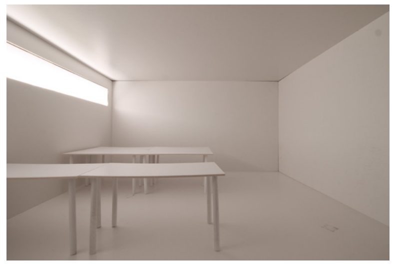
A reflection is made regarding rooms such as workspaces that are not used very early mornings or late evenings. In our context it is often the winter sun with late sunrise and early sunset that causes problems since the solar angles are flat and reach far into spaces. These solar rays are the ones that can not be ruled out by limiting the size of windows or adding extruding elements.

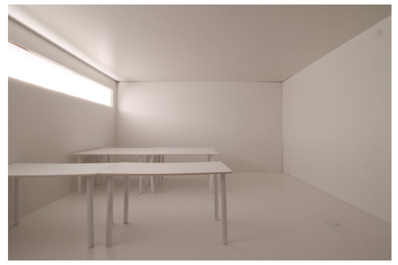

1. 30°/30°

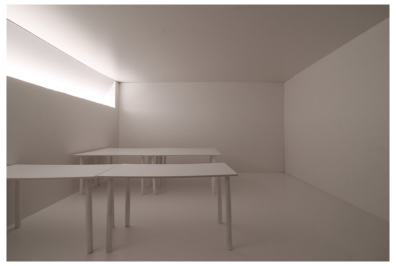

2. 30°/45°

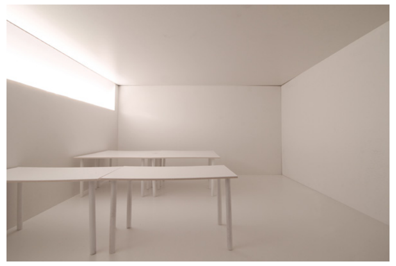

3. 30°/60°

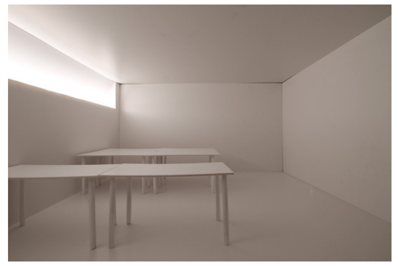

4. 45°/30°


5. 45°/45°

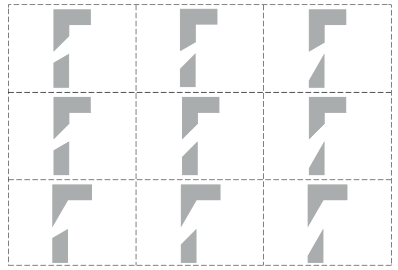

6. 45°/60°


7. 60°/30°


8. 60°/45°


9. 60°/60°

Top niche/bottom niche
Date: 2020.03.23
Time: 15:30–16:30
Orientation: West



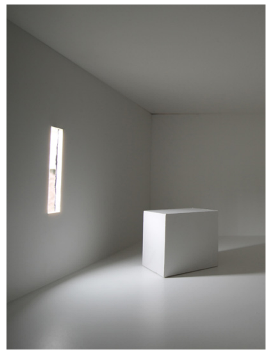

Sunny

Test 4

Scale 1:2000 | The site is located next to Chalmers University.

Wall material

Floor material



Window shape

4| Intro

In the fourth test the room is shaped into a more detailed workspace, aimed towards the program of an architecture office and designed for a specific site. It is imagined as part of a new office building where the focus is on the room design.

Site and Orientation

The site is located next to Chalmers University where development of this type of program is realistic. As part of a building, it is more probable to have only one wall with windows. This test investigates facing the room in two directions: 64° Northeast which follows the existing buildings, and 90° East to compare with a straight cardinal direction.

Room set-up

The room is designed for work hours between 08:00 and 18:00. The work is computer based which demands direct light and glare to be avoided on the screens. In tests performed in scale 1:1 the best placement for screens was found to be opposite each other, perpendicular to the window wall. In terms of materials a darker floor material and a matt texture on the northern wall was added to decrease glare.

A vertical window shape was chosen since it was found to create an intimate and calm atmosphere in test one. It also provides a view both from a sitting and standing position.

Angled niches are tested since they were found to distribute the light more and make transitions smoother in test three. The left window niches are straight to block direct light, while the right niches are angled to spread the light and increase the view. A diagram of this can be seen on page 58. The bottom part is not angled since test three shows that this spreads the light better. A comparison between a niche and a window reaching the ceiling is performed.

Investigation

This test investigates window size, proportion, placement and niches in combination with desk placements and shading elements, trying to meet the following criteria:

- **Atmosphere** should be calm and spacious to give a peaceful work environment.
- **Daylight** should be the main source of light throughout most of the year, to the extent it is possible and with a variation throughout the day.
- **Direct sunlight** should enter the room without creating discomfort by falling directly on work surfaces or creating disturbing reflections.
- **Glare** should be avoided on computer screens and work surfaces.
- **Sun shading** should be functional and not rely on automatic sun shading like curtains, since that will block qualities of light from entering the room.
- **View** should be equally accessible from all the workspaces to avoid a hierarchy between the tables.

Date: 2020.04.21
Time: 09:45–09:55

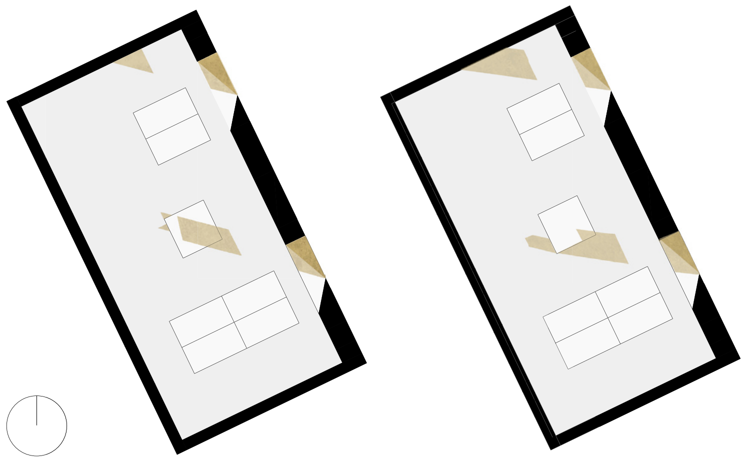
Northeast 64°

4.1| Niches

Desks are placed under the windows to avoid direct light, which enters diagonally in this orientation. The light level is experienced as pleasant and the floor has great variety in light fields. The right wall is lit up by the niche.

4.2| Pillar

Vertical pillars in this orientation can narrow or remove the long stripes of direct light. They are blocked sideways and therefore the pillars need to be wide to have an effect. The interior pillars split the window wall into separate fields, the right side is darker and the left lighter. This is experienced as negative, giving a messy impression.



22 of January 09:00
22 of April 09:00
22 of October 09:00
22 of July 09:00

Direct light studies

The decision on what room configurations to develop further partly origins from studies of direct light in the digital tool Sketchup. The diagram shows the room found to be most beneficial regarding direct light. This configuration is not chosen since the conclusion is made that the large size of the room is not worth the gains of avoiding all direct light on the desks. In this room direct light only falls on a common table.

East 90°

Date: 2020.04.21
Time: 09:40–09:45

4.3| Straight niches

Desks are placed between the windows to avoid the direct light in this direction. It enters more straight and further inside the room, creating longer fields of light. The straight niches limit the view and there is a sharp contrast between niche and wall. The right part of the room is experienced as dark.

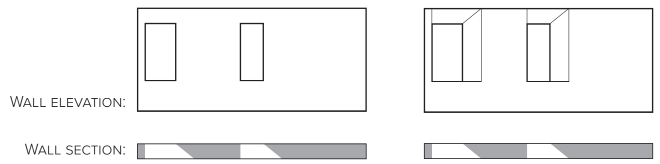
4.4| Angled niches

The angled niches are spreading the light. They also ease the contrast between inside and outside and the window wall appears less dark. The desks are reflecting some light upon the window wall.

The top niches are bringing more light to the ceiling, but are not increasing the general level of light in the room. Overall the niches create a slightly softer atmosphere and increase the amount of view without letting more direct light in.

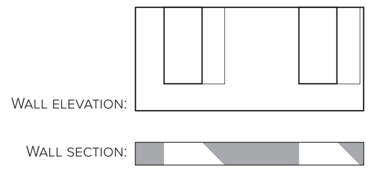
E 90°

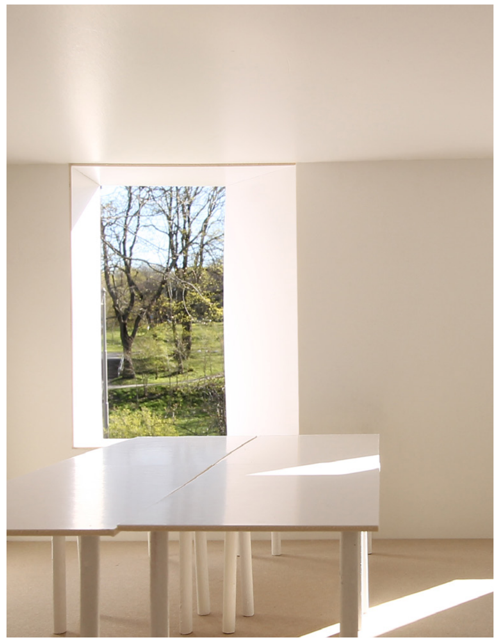
Window: 80 x 150 cm, 60 x 150 cm
Side niche: 50 cm
Top niche: 40 cm
Wall thickness: 50 cm.

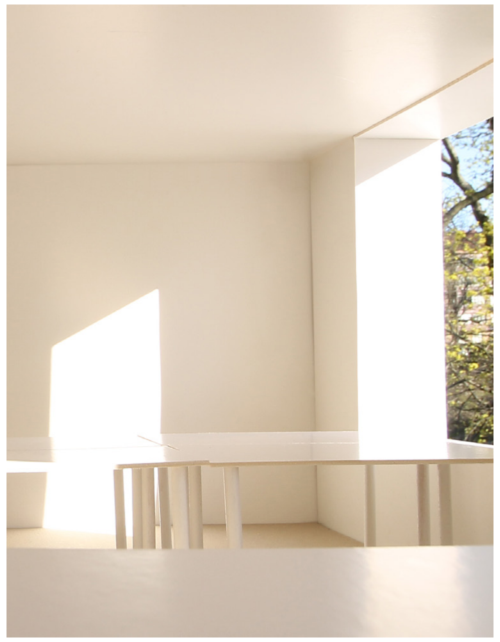


NE 64°

Window: 100 x 200 cm
Niche length: 60 cm
Wall thickness: 60 cm




Window wall
Contrasts


Northern wall
Direct light

Reflections | Conclusions

The window wall is quite dark in contrast to the windows which we experience as problematic since high contrasts are troublesome for the eye. Niches are making this transition softer, but are not solving the problem completely.

The direct light falling on the desks would be disturbing for detailed work. The design should be changed so that this problem is removed or limited to a short amount of time each day where temporary shading could be used.

The northern wall seen in the top right picture is reached by direct light and can be problematic. The light fields create very sharp contrasts and having it behind a screen could possibly lead to glare. In the model we do not experience it as problematic looking towards the direct light. The matt wall texture has a positive impact, just as the floor in reducing reflections and glare.

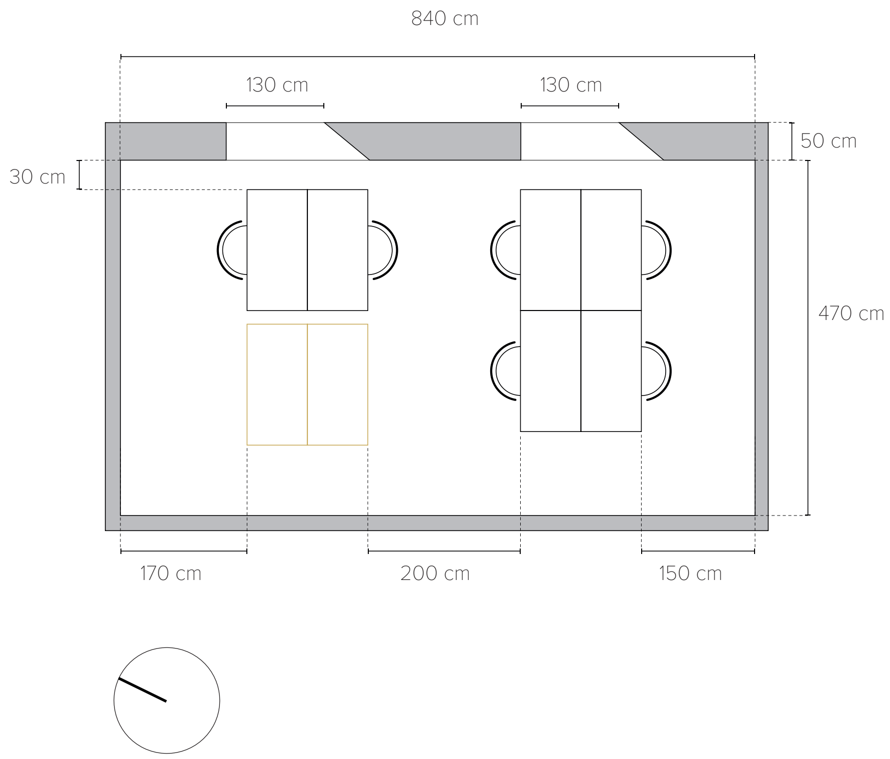
In the photographs the information of the highlights are less defined which makes the fields of direct light perceived as slightly more disturbing. The eyes are grasping the texture we have added on the wall which the camera does not. In general the eye makes the experience more convenient. This is something to reflect upon and highlight the importance of assessing the light as experienced in the model rather than in the photographs.

General Conclusions

After performing the tests we decided to continue with the orientation Northeast, following the grid of the existing buildings on site. Because of the Nordic context both orientations will receive direct morning light during the whole year. This makes the difference between facing the room 90° East and 64° Northeast marginal.

The desks should be placed close to the windows where the light level generally is better. A benefit of placing desks close to the windows is that the room can be quite shallow which creates better circumstances to succeed with the daylight. We find it negative that we do not place the desk straight under the windows which feels natural. A benefit of not doing it is that it reduces the amount of direct light on the desks which will decrease the time when shading is needed. This provides more hours with good daylight levels and view. With two windows of the width 1,3 meters we can manage the direct light from our criteria.

Test 5



Scale 1:100

Plan drawing of the workspace.

5| Intro

This test is an iteration of the previous, trying to improve light conditions by decreasing contrast between the bright windows and the darker window wall. The test explores how ceiling shape affects the distribution of light. This is a strategy used by many architects and inspiration was taken from ceiling designs of Alvar Aalto, Jørn Utzon and Kristian Gullichsen. Pictures of some of their works can be found in the book by Plummer (2012), Nordic Light: Modern Scandinavian Architecture. The niches are also altered, to see if they can have a positive impact on contrasts and the overall light.

Room set-up

The measurements of the workspace are defined following the recommendations of Arbetsmiljöverket (2009) and the aim to manage direct light. The room is made wider to provide enough room for the direct light to move between the desks most of the time. The depth of the room is slightly decreased, providing better possibilities for the space to be well lit.

As the program is specified to an architecture office there is a need for a more flexible table for drawings. Since this table is used temporarily more direct light can be allowed to fall here.

Window width is from the previous test defined to 1,3 meters, a balance between providing a good view while limiting the direct light. The windows are going all the way up to the ceiling to bring more light in. The angles of the right niches are defined from the previous test.

Wall thickness is set to 0,5 meters since it is a probable thickness that still allows good control of direct sunlight.

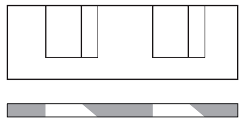
Date: 2020.04.22
Time: 10:00
Orientation: Northeast 64°

Direct Light

Direct Light

Direct light will typically fall into the room in this way, moving diagonally between the tables and on the northern wall. The direct light is not experienced as disturbing. However, there is still a big contrast between the niches and window wall.

Wall elevation:
Wall section:



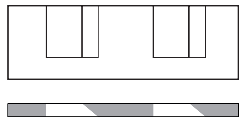
Niche Contrast

Date: 2020.04.22
Time: 10:00
Orientation: West, for indirect light

Colour

A light grey colour is decreasing the brightness of the niche and so decreasing the contrast to the wall. The gradient within the niche is also decreased and it becomes very dark in the top corner. The straight side of the niche which is the brightest, is experienced to function well with a decreased contrast to the window wall.

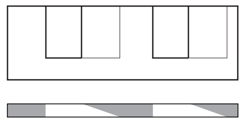
Wall elevation:
Wall section:



Width

In the wider niche the transition from light to dark is spread over a greater surface, making the contrast to the wall less strong.

Wall elevation:
Wall section:

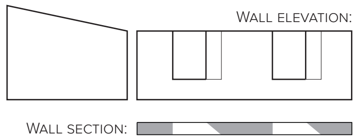


Date: 2020.04.22
Time: 09:45–11:30
Orientation: West, for indirect light

Ceiling shape

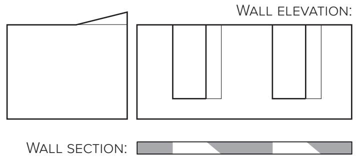
5.1

Angling the ceiling towards the inside wall spread the light in the ceiling better, making it reach further inside the room. The window wall is still experienced as too dark.



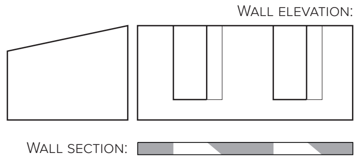
5.2

Having niches in the ceiling created a feeling of more light above the desks, but the light appeared to stay more in the niches instead of spreading over the ceiling.



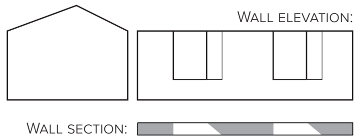
5.3

Angling the ceiling towards the window wall reflects the light back at it and is making it lighter, which we experience as positive. The room is well lit furthest in.



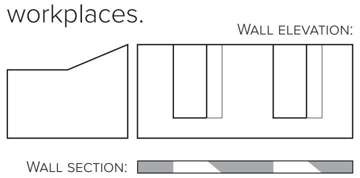
5.4

The saddle shaped ceiling creates a play of light in the ceiling which is very bright where the break is. Light reaches quite far in the ceiling which makes the room appear a bit brighter.



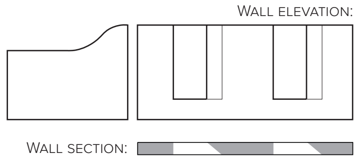
5.5

Breaking the slanted ceiling creates a varied light play where the shape is changing, giving a more living atmosphere. Light is also more varied on the angled part of the ceiling compared to the flat. The angled part illuminates the window wall and creates a more even light environment by the workplaces.



5.6

With a concave angled ceiling the top of the window wall is slightly lighter and the transition in the middle of the ceiling is smoother. The inner wall gets a little variation in brightness. A horizontal shadow from the ceiling is seen on this wall.

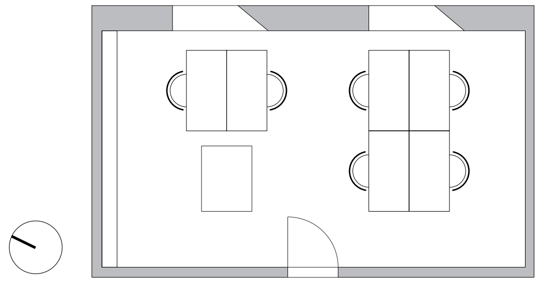


5.2 Final Design

For the final iteration, ceiling 5.5 from the previous test was chosen as it distributes the light towards the window wall and creates a varied light play in the ceiling. The break of the ceiling is moved closer to the inner wall to create a more coherent light above the desks. By the northern wall which receives direct light a bookshelf is placed to break up the light and decrease discomfort.

Date: 2020.05.12
Time: 15:20
Orientation: Northeast 64°

Scale 1:150



Date: 2020.05.12
Time: 15:20

Date: 2020.05.07
Time: 09:00

Direct light
This curtain set up blocks the disturbing direct light in the summertime.

Direct light
One curtain can be used to block the winter-sun on the affected desk.

Reflections | Conclusions

Conclusion design

With this design we fulfil the demands of Arbetsmiljöverket (Arbetsmiljöverkets författningssamling {AFS}, 2009:2) (Arbetsmiljöverket, 2020) and beyond this the design shows other qualities in the light environment. As Arbetsmiljöverket requires, the window area is larger than ten percent of the floor area. The depth of the room is less than six to eight meters. There is a view outwards and no screens are facing a window. The light varies over the day and with the common drawing table you can switch position and thereby vary your view outwards. The room has access to direct daylight, while disturbing direct light and glare is avoided.

Now qualities beyond the daylight regulations created in this design are described. The atmosphere is as we perceive it calm and spacious. We experience a comfortable light level. We believe we have been able to create similar conditions for the desks. Of course the same amount of daylight will not reach these two inner desks, but they are still well lit. On the other hand three of the other desks have the possibly disturbing factor of some limited direct light. All workplaces have good access to a view.

The shape of the ceiling creates a light play and thereby variation in the light environment. When shaping the roof we were able to make more light reach the inner wall. That area is quite even in tone but together with the desk area that is more lively the room feels balanced and as Liljefors (2000) describes this is beneficial for the surround vision.

We have carefully studied direct light and thereby created a result with limited distinct contrast on working tables. A dark window wall which creates contrasts is avoided by using window niches to create gradients together with shaping the roof in a beneficial way. The wall struck by direct light has received a texture and furniture to split up the large light field. Daylight regulations will be further discussed on page 76.

Direct light

Two of the workplaces next to the windows will have disturbing direct light approximately between the first of April and the first of October, for one and a half hours in the morning at the longest. One table will have a small stripe of direct light in the morning on some days during winter. This will be shadowed by temporary curtains, easily controlled from each workspace affected.

The master studio at Chalmers has the same orientation as the designed workspace. The studio has windows all along the facade with no interspace. The strategy to provide shadow is automatic curtains covering the whole window surface. What is noticed from spending time in the studio is that the curtains are often covering the windows until lunch. They do prevent direct light from entering, but they also take away the view and the room becomes unnecessarily dark. Sometimes it is helpful, but sometimes the curtains are redundant, as when they cover the windows although the sky is cloudy. This project uses a preferable strategy where shading is limited due to the window placement and controlled by the person affected by direct light.

Date: 2020.05.05
Time: 10:40

Chalmers Studio, NE 64°
Automatic curtains

Our design
Ventilation placed inside ceiling

Chalmers Studio
Ventilation placed openly in ceiling

Square window
Room depth 5 m

Angled ceiling
Room depth 4,7 m

Ceiling shape

The ceiling shape used might seem as an unnecessary expense when designing a workspace with a limited budget. However, today many technical systems such as ventilation are placed openly in the ceiling disturbing the distribution of light. This shape of the ceiling creates a space for these systems, leaving the ceiling free to better spread the light.

Room depth

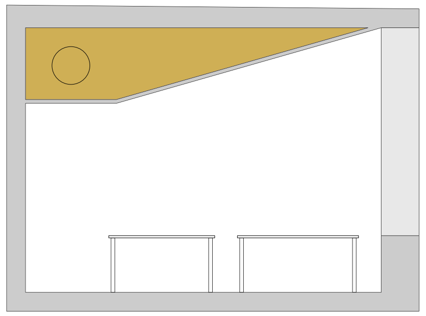
For rooms with one window wall to be well lit by daylight Arbetsmiljöverket (Arbetsmiljöverkets författningssamling (AFS), 2009:2) recommends a room depth of six to eight meters. From our investigation we conclude that suitable room depth varies. Size and proportion of windows as well as ceiling shape distributes the light in different ways.

In our first model, with a facade wall with the length of six meters and a room depth of five meters, we think that the room should not be any deeper than five meters to be experienced as well lit. Even in the first tests with a big square window the innermost part of the room was quite dark.

In the fifth test we noticed that shaping the ceiling can distribute the light further into the room. This means it would be possible to increase the depth of the room and that shaping the ceiling could be a strategy to make deeper rooms more well lit.

The building as entirety

The designed workspace is a shallow room with a long wall towards a facade. This affects the entirety of the building as this shape of room indicates a building that would not have to be particularly deep. This has not been elaborated further in this thesis since it is not part of the scope. Future investigations on the topic could produce knowledge on spatial distribution and qualitative daylighting of the program that is combined with the workspaces. We recommend further research on this topic.



Ceiling shape
Space for technical systems

05 Discussion

Daylight regulations

Boverket and Arbetsmiljöverket both mention qualities of daylight they aim for in the built environment such as light distribution and awareness of glare (BBR, BFS 2011:6) (Arbetsmiljöverket, 2020). The methods they refer to regarding evaluating daylight are daylight factor and window glass area. We argue that there is a discrepancy between the qualities aimed for and the tools of evaluation.

Daylight factor and especially the average or median daylight factor can be helpful to get a basic understanding of the measured light level. But it is clear that it is a narrow tool that only reveals the quantity of daylight. It only shows the median, average or the quantity measured in a single point among all the aspects daylight provides a space.

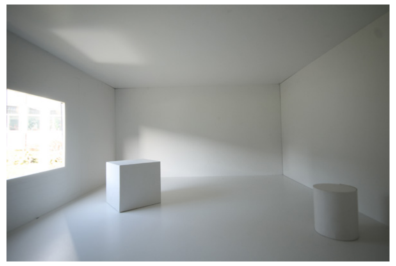
Both authorities use the expression satisfying light conditions (Arbetsmiljöverkets författningssamling {AFS}, 2009:2) (BBR, BFS 2011:6) to describe daylight conditions aimed for. This is vague, especially in the sense of being satisfying to a specific program of a space. We request other methods to evaluate a building design which should include all qualitative daylight aspects important for the specific program. We would argue that for the program workspace important qualitative aspects among others are: a substantial amount of daylight which will provide variety in light level and colour of light together with a balanced light distribution that is experienced as vivid.

There are regulations that deal with qualities but they are unspecific in their description. For instance Arbetsmiljöverket (2020) brings up the importance of the light environment to be adapted to the specific task. By being specific in the quantitative aspects such as ten percent window area or daylight factor one percent and vague in the description of qualities a hierarchy is indicated. The quantitative measurements must be fulfilled but it is not as clear how we evaluate that the qualitative are. Our conviction is that this undermines the focus on designing qualitative light environments.

Since qualities of daylight are subtle, the evaluation method needs to reflect that. This demands a certain knowledge of the person performing the evaluation. It would be appropriate to use an architect with experience in the field of qualitative daylight. The architect stands out in the building sector with a comprehensive view in projects. The diagram on page 58 can be used as an example. It showed a good solution for the aspect of direct light in this project but was not chosen as final design since the sketch had floor surface that did not benefit the program. We believe that the capacity to synthesize makes the architect suitable to make nuanced evaluations.

Window size

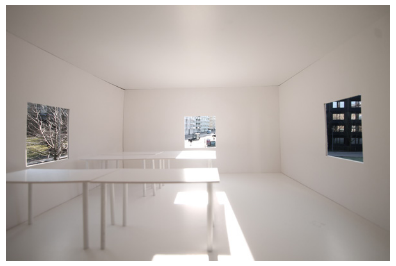
In this project we have found that a space can be experienced to have a comfortable light level with glass areas well beneath ten percent (picture 1). In test one a picture shows a space with a square window which is ten percent of the floor area (picture 2). The level of light is experienced as pleasant. Another observation is that the three-dimensional perceptions is vague in the darker half of the space.



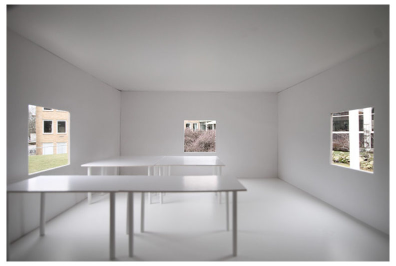
Picture 1: 4,8 % of floor area

Picture 2: 10 % of floor area

In the third test ten percent window area is used throughout the test. Since the configurations in this test all have windows in three walls light is overall experienced as evenly distributed in the space. We experience how problematic direct light can be for programs such as workspaces (picture 3) and how dim the atmosphere becomes in the test under a cloudy sky (picture 4). These are aspects not considered in the regulation. Looking at picture two we also find an issue that the regulation does not consider. If desks would be placed in the darker half of this room the lack of three-dimensional perception would be disturbing.



Picture 3: direct light



Picture 4: cloudy sky

Our investigations show that a ten percent window area can create a great variation of light in spaces. Our conclusion is that the regulation of a ten percent window glass area is unspecific regarding use of space and should be removed.

Nowadays office buildings are often built with glazed facades. From our studies we can claim that having a glazed facade will surely provide a light level that is higher than necessary. The question is if the facade can be justified in comparison to what daylight qualities it provides. As we see it, the most problematic aspects in terms of qualitative daylight in this case are disturbing glare and reflections. These aspects can be enhanced by direct light which as well create sharp contrasts. External shading is commonly used, depending on sort it can have a negative impact on light level and view. Other important aspects to evaluate in this kind of building design are the spatial distribution and the building depth, a deep building or walls that block the daylight would be contradictory to the facade. This project showcases another window design method where the possible issues of daylight in buildings are carefully studied and controlled by conscious shape and placement of windows.

Method

The model placed on the site, seen from Northwest.

There are differences in studies 1:1 and 1:10. We have been able to observe inside the model, but only from one point of view. We have not been able to move around in the space, to sit by the desks and look out of the windows to see how the view changes. Therefore some aspects are not included. One example as Alenius (2018) writes is that glare can change when you move in a space. On the other hand 1:10 is a relatively manageable scale to work with in terms of costs of material and the mobility of the model, which allowed us to move the model more easily to the site for testing.

This project focused on the process of using physical models, still we did combine it with a digital tool. This to be able to grasp the great variation of daylight angles over the year, most of all regarding direct light. This was very helpful in the process of choosing model tests and made it possible to reach further in our investigations.

Performing tests outdoors is quite tricky. You need to find a day when the weather conditions are what you aim for. A model 1:10 easily becomes quite big and heavy. These are aspects that are troublesome in a project where time is limited. But to be able to study light qualities we think being outdoors is crucial.

A part of our investigations has been to control direct light and bring it into a space as a quality, since our design is located on a relatively open site. We believe this context is probable, but it is worth to mention that an opposite situation also is common. For offices placed in dense areas the lack of direct light might be a bigger issue.

We have been able to be free in the shape of the room, there has not been a defined program in terms of square meters per person etc. It is probably rare to have this possibility, a building design is more about the totality and designing different spaces simultaneously. With that being said, our design is reasonable and we have chosen to work with common measurements of the room and furniture.

Site specificity in this project have been used in terms of local solar angles and weather conditions. The method does not include detailed studies of the surrounding in terms of buildings, objects and materiality. These aspects impact the light inside the model to a great extent and would be interesting to study further.

The project was conducted in Sweden, which means that observations and reflections relate to the cultural expectations and view on light in this region. In other contexts the experience of the light and atmosphere might be different.

Reflection on tests

In the first test the window was increased step by step. This provided an understanding of the qualities created by different window shapes and sizes. Choosing quite extreme shapes enhanced these qualities and made them easier to detect. Increasing the size, we could observe when the light started to be experienced as comfortable in relation to the window proportion.

The downside of starting with less common window proportions is that they are harder to apply to programs that have more specific demands for visual performance. These windows have to be altered or

Model test performed outside on the site, facing the wanted orientation.

combined which will change the light and atmosphere in the space. Still, we found it helpful to start with a more open exploration and add the program later. This meant that we could be more free in our observations of the light.

As Dubois et. al. (2019) writes, the expectations of a space are crucial when designing light. Defining the room as a workspace added certain expectations on light and atmosphere. It gave us a more clear direction for the tests and made it possible to evaluate the light towards specific needs. The later tests are aimed towards the program workspace, but we believe that many of the conclusions made here can be transferred to other buildings programs.

Daylight is relevant to almost all building programs. When starting a design project we therefore recommend:

- To obtain a basic understanding of the local daylight and in what cardinal directions for daylight intake a program is more or less suitable.
- To study the light conditions of the site in terms of topography, objects, materiality, colours and reflections.
- To perform tests outdoors, on the site of the project or a site with similar light conditions.
- To study the light in physical models, in 1:10 or other scale suitable for the specific program that makes it possible to experience the space.
- To perform model studies parallel with design of facade and window placement.
- To include materiality from the start or make it part of the experiments.
- To use digital tools as a complement, to understand how the light conditions change over the day and year.

Top: **Photograph of final design**
Date: 2020.05.07
Time: 09:14
Orientation: Northeast 64°

Bottom: **Rendering of final design**
Date: 2020.05.07
Time: 09:00
Orientation: Northeast 64°

Representation

We would like to address representation of architecture. During the design process a project is often communicated through renderings and in the built stage often through photography. In this project we have observed differences in how we experience spaces and what we can see in photographs of them. We will give an example of a photograph of our design, a rendering and our observations from the model.

Already in the transition from the model to the photograph we feel that aspects experienced in the model are lost. In the model the fields of direct light were not experienced as uncomfortable to look at. The eyes grasped the texture of the wall which softened their appearance. In the photographs this information is lost. The information of the highlights are less defined which makes the fields of direct light more disturbing. In general the eye makes the experience more convenient.

In the rendering even more information disappears. There are less variations within the different fields. Comparing the rendering to the photograph you can see how the ceiling and the wall with the bookshelf have much less variation in light and shadows. The window wall is also considerably darker in the rendering. The angled ceiling was found to light up this wall, but in the rendering it seems to have lost this illuminating effect.

It is quite complex to render a realistic image. It requires the correct textures, colours and reflectance values. The surrounding needs to be included and the specific weather needs to be simulated etc. The rendering seen here could have been done more precise, for example we have not included the surrounding in the rendering. Even though the rendering appears to create a realistic light for an architect with less experience in qualitative daylight, subtle qualities of light are lost.

Transferring the atmosphere as experienced in the model to a two-dimensional image is quite hard. We believe our photographs together with the observations give a fair understanding of the atmosphere. Still, the experience in the model is stronger and more vivid. In photographs we see the space mostly through our detailed vision. In the model we are enclosed by the space and experience it through our whole visual field. A much stronger sensation of the atmosphere is created.

Conclusion

This shows the importance of assessing the light as experienced in space rather than in photographs or renderings. To be able to do this in the design process, we see the use of model studies as crucial to fully grasp the qualities of daylight.

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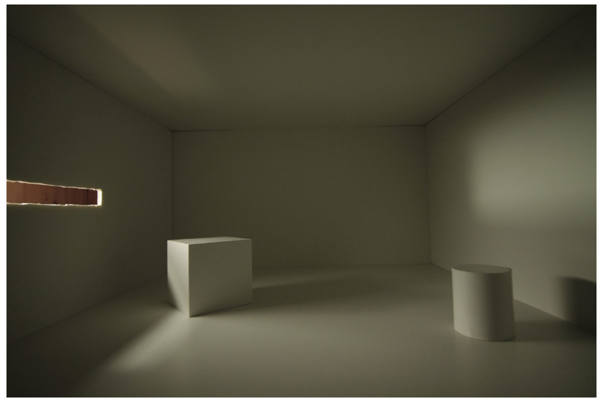
Outside
18 x 2 cm



Inside
18 x 2 cm

Outside
54 x 2 cm

Inside
54 x 2 cm

Inside | Outside

To compare the differences between real daylight and simulated daylight the same windows were documented indoor and outdoor. The aim is to see whether performing the investigation outdoors is important, or if indoor studies with artificial light can give a true understanding of the qualities of daylight.

Top images

Indoors light mainly enters from one direction which creates stronger contrasts and shadows. You can see this in the more defined shadows of the left wall and fields of light on the floor in front of the window. Outdoors on the other hand, light is noticed from many directions. Due to this the experience is of a more diffuse light overall together with smoother transitions of fields seen in the top picture.

The light falls over the cube differently. Inside it creates gradients, as example you can see the lightest surface of the cube towards the window shifting in different tones. Outdoors the sides of the cube are more homogenous. The light also reaches further into the model indoors hitting the wall inside higher and creating a light image of the window. This also makes the light much more centred in the room indoors than outdoors, where the right part of the room is darker.

Bottom images

The shadow from the cube becomes less apparent outdoors where the light entering is more diffuse from the cloudy sky. Indoors the shadow is much more defined. You can also see more of a highlight in the ceiling above the window which could be the light from the sky reflecting on the floor or the niche.

The darkest area in both images is under the window. It is even darker indoors because of light entering from one direction. In general there are smooth transitions between shadow and light in the outdoor tests, while contrasts are stronger indoors.

Conclusions

In the indoor test the light is much easier to predict, but it also lacks the variation of real daylight. Outside, the surrounding affects the light inside the model and the weather is constantly changing. This can be a problem when comparing results from different tests, but to fully grasp the qualities of daylight we find it crucial to include these variations by performing the investigation outdoors. The natural variations will make the tests less compatible with something made in a computer. Hopefully this will lead to an appreciation and a focus of this as an important quality of daylight.