DAYLIGHTING IN BUILDINGS IN ICELAND

WHAT EVALUATION METHODS ARE SUITABLE FOR NORDIC DAYLIGHT?

ANALYZING THE NEED FOR REQUIREMENT UPDATES IN ICELANDIC BUILDING REGULATIONS

by

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Abstract:

As cities expand, become more populous and dense, buildings become taller, and building materials constantly evolve, it is crucial to ensure the sustainability of the environment. Daylight is critical in buildings, as it affects people's health and well-being. Evaluation of daylight in buildings is done according to the standards, regulations and sustainability certifications of every country. It is important that countries have an informed regulatory process, and that the regulations used are sufficient to ensure good daylighting, keeping building occupants happy and healthy, and energy costs down.

The aim of this thesis is to review methods used to evaluate daylighting in buildings, and their suitability to the unique Nordic daylight in Iceland, as well as reviewing whether or not there is a need to update the current building regulations in Iceland, which are lacking in setting standards for good daylighting. This is done through a literature review on the geographical location of Iceland, the history of architecture and urban planning in Iceland's capital city, Reykjavík, an analysis on evaluation methods for daylighting, as well as a review on building regulations in Iceland and Norway, along with two internationally recognized sustainability certifications. Qualitative interviews with lighting designers and architects were conducted in order to get an understanding of the knowledge that professionals possess, as well as their thoughts and concerns on the matter.

The evaluation method thought to be most suited for Nordic daylight was Climate Based Daylight Modeling, nevertheless, through qualitative interviews it was concluded to be a technique too new and advanced to implement yet as a standard method in the small industry that exist in Iceland today. The hypothesis was confirmed, the building regulations in Iceland are generally considered not to date, especially in regards to the increased availability of technology to design for good daylighting, as well as construction techniques.

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Tinna Kristín Þórðardóttir

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2 INTRODUCTION

Daylighting, or natural lighting is well known as a desirable factor in buildings. It is believed to have a profound effect on human health, both physically and mentally, as well as being energy efficient. Ensuring sufficient daylight in buildings is therefore an important factor in the design process, and it is necessary that methods to evaluate daylight in buildings are useful for the environments they are applied to. Daylight evaluations are performed according to standards, regulations and sustainability certifications in every country. It is critical that every country has an informed regulatory process and insures that the regulations used are sufficient to assure good daylighting, keeping building occupants happy and healthy, and energy costs down.

2.1 PURPOSE OF THE RESEARCH

In the past century, interest in the effects of daylighting on human health has increased. With increasing knowledge, studies and enthusiasm, researchers distinguished the importance of receiving adequate daylight in buildings. Most people spend the majority of their lives inside the walls of their homes and workplaces, making the need to ensure good daylighting absolutely essential.

Reykjavík, along with a few other Nordic cities, have unique daylight scenarios which make the penetration of daylight into buildings different from cities in the southern areas of the Earth. The sun's position in the sky is considerably lower and the daylight hours vary greatly between seasons, making the evaluation of the daylight's potential in buildings crucial. While the world develops and changes, the urban environment does as well. The capital of Iceland, Reykjavík, has developed rapidly in the past century, evolving from a town to a city. The density of the city has increased drastically as well as higher buildings being built and new building materials implemented. However, the regulations regarding daylighting in buildings have not changed since 1965 (Construction adoption, 1965). A lack of research on the matter of evaluating daylight in buildings in Iceland is a fact, and therefore considered an important, and even necessary, research topic.

Designers' intentions should always strive to create the best possible daylighting conditions and it is crucial to utilize daylight to its maximum capacity, not only to reduce the energy consumption but also to increase the quality of space, and how the building is perceived. But do the requirements set forth in Iceland's building regulations compel designers to do so? Should the urban development of Reykjavík affect the requirements? What are the methods that are available to evaluate daylighting in buildings and how suitable are they for the design phase of a building located in Iceland?

2.2 RESEARCH QUESTION

Based on the issue of urban development and a lack of changes to Icelandic building regulations, the following research question was formulated;

> "What methods are available to professionals to evaluate daylight in buildings in Iceland, during the design phase?
>
> - A review of methods and their suitability for Nordic daylight during the design phase of a building
> - Is there a need to update the current regulations in Iceland, in order to secure good daylighting design in buildings?"

A hypothesis is set forth that the building regulations in Iceland are currently lacking, and intend to prove that through reviewing different methods of daylight evaluation available to industry professionals today, as well as comparing Icelandic building regulations to Norway's regulations, and juxtaposing those regulations to internationally recognized sustainability certification processes.

2.3 STRUCTURE OF THE THESIS

The thesis will begin with a comprehensive and detailed literature review chapter, which touches on the following subjects: Iceland's geographical location and the uniqueness of Nordic daylight, the history of architecture and urban planning in Reykjavík, Iceland's capital city, a review of the methods that are available to evaluate daylight in buildings and a look into building regulations and sustainability certifications. Thereafter is a chapter which consists of interviews with professionals in Iceland, in order to get a clearer understanding of the knowledge that the specialists in the field possess, as well as their understanding of the current regulations. Finally a conclusion is reached, where the final outcome of the research is discussed.

3 LITERATURE REVIEW

This literature review will cover four aspects of research related to daylight evaluation in Iceland.

The review will begin with a sub-chapter covering Iceland's geographical location. It is important to analyze the location of Iceland's capital, Reykjavík, in order to better understand the uniqueness of daylighting in cities in the northernmost part of the Earth. Reykjavík will be compared with another Nordic city with a similar geographical location, in order to compare similarities, and a city in a southern region of the world, in order to show the opposites.

Next the history of Icelandic architecture and urban planning will be touched on. This chapter gives an insight into the development of the city, and how architects have perceived daylight in the past.

This is followed by a detailed review of methods used to analyze daylight in buildings. The methods selected are considered to be the most recognized and used. Each method will be discussed and the advantages and disadvantages, in relations to Iceland, reviewed.

The fourth and final subject of the literature review is a review of building regulations in both Iceland and Norway, as well as a review of two sustainability certifications, LEED and BREEAM, in regards to daylighting.

3.1 ICELAND'S GEOGRAPHICAL POSITION

In order to get a better understanding of the daylighting conditions in a country in the northernmost part of the world, and how to evaluate them, one must know the geographical position of it and how the location effects the daylight that the inhabitants receive.

Is the daylight in Iceland different from daylight in other regions of the world? What characterizes the natural light in the Nordic cities?

This chapter will review the similarities of the daylight in Reykjavík, Iceland and another Nordic city, Trondheim, Norway as well as showing the drastic difference to a country in a southern region of the world, Sierra Leone, Africa.

The geographical alignment of Iceland's capital city is latitude of 64°10'N and longitude of 21°57'W. The northernmost point is at 67°98'N and 18°41'W (Kolbeinsey) and southernmost point at 63°17'N and 20°35'W (Surtsey).

Iceland can therefore be categorized with Nordic cities like Helsinki, Finland (60°10'N, 4°56'W), Copenhagen, Denmark (55°40'N, 12,34W), Stockholm, Sweden (59°19'N) and Trondheim, Norway (63°26'N, 10°24'W), (Matusiak M. , 2013) when looking at solar angles and daylight hours. Sierra Leone, (8°29'N, 13°13'W), is located in another continent, Africa, closer to the equator, resulting in a different relationship to the sun due to it's geographical location.

Figure 1: A world map, showing the placement of the three locations to be analyzed, Reykjavík, Trondheim and Sierra Leone, each marked with a red circle

3.1.1 REYKJAVÍK IN COMPARISON TO TRONDHEIM AND SIERRA LEONE

Two Nordic cities, Reykjavík, Iceland (64°10'N, 21°57'W) and Trondheim, Norway (63°26'N, 10°24'W) as well as Sierra Leone, Africa (8°29'N, 13°13'W) were compared, using a software called *Solar Beam*, which was developed by Martin Matusiak for the Norwegian University of Science and Technology. The three locations were compared to demonstrate both daylight hours and solar angles.

Firstly, the solar angles of all locations were compared. Solar angle is the altitude of the sun in the sky, in degrees down from the zenith, the imaginary point directly above a particular location. The data of solar angles is retrieved from SolarBeam, where solar angle of each city, on the 21st of each month at 13:00 is obtained. When analyzing the solar angles, the difference is evident. The solar angle is always considerably higher in Sierra Leone compared to Trondheim and Reykjavík. The solar angle in Sierra Lion stays consistent, as well as high, throughout the months of the year, with a variation of only 17.14°, from 55.76 at its lowest, to 72.9 at its highest. The variation in solar angle between months in both Reykjavík and Trondheim is much more drastic. For Reykjavík, the range between the lowest and highest angle is a staggering 44.33°, from 1.19° at its lowest, to 45.52° at its highest. The solar angle is as well exceedingly lower in large parts of the year compared to Sierra Leone. This is demonstrated in the graph in figure 2.

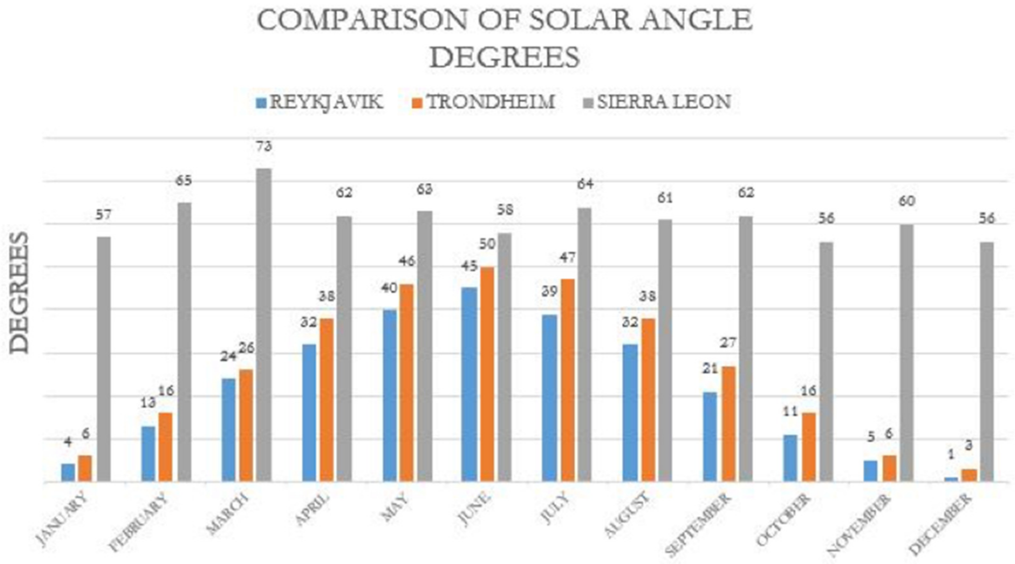


Figure 2: Comparison of solar angles in Reykjavík, Trondheim and Sierra Leone. The information of the solar angle is taken on 21st of each month, at 13:00. The graph was made in Excel.

Secondly, the daylight hours of all locations were compared. Using the website www.timeanddate.com, a monthly average of all daylight hours was obtained. A calculator from www.sunearthtools.com was used for verification of data. The monthly average for total daylight hours was retrieved for all locations for a whole year, and combined in a graph, month by month, in order to receive a better understanding of the data.

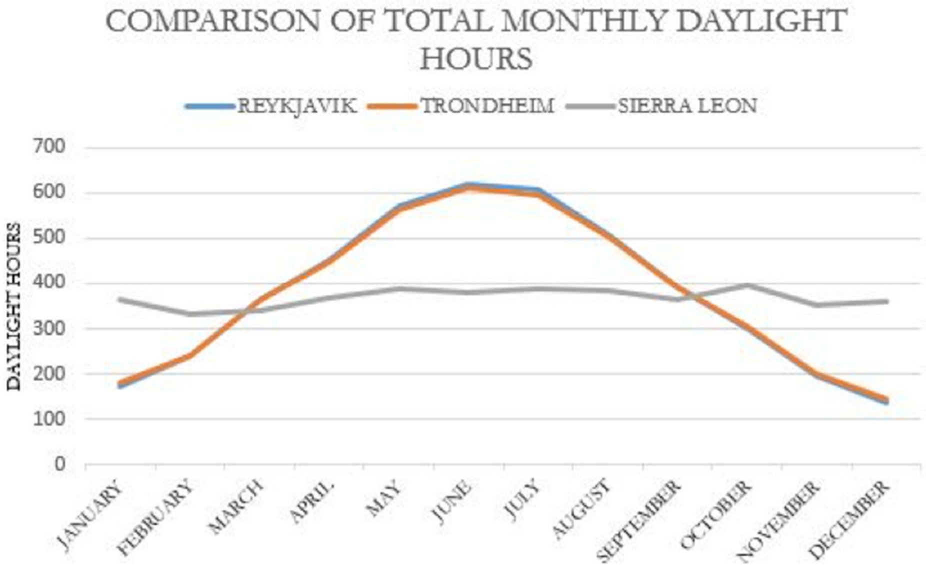
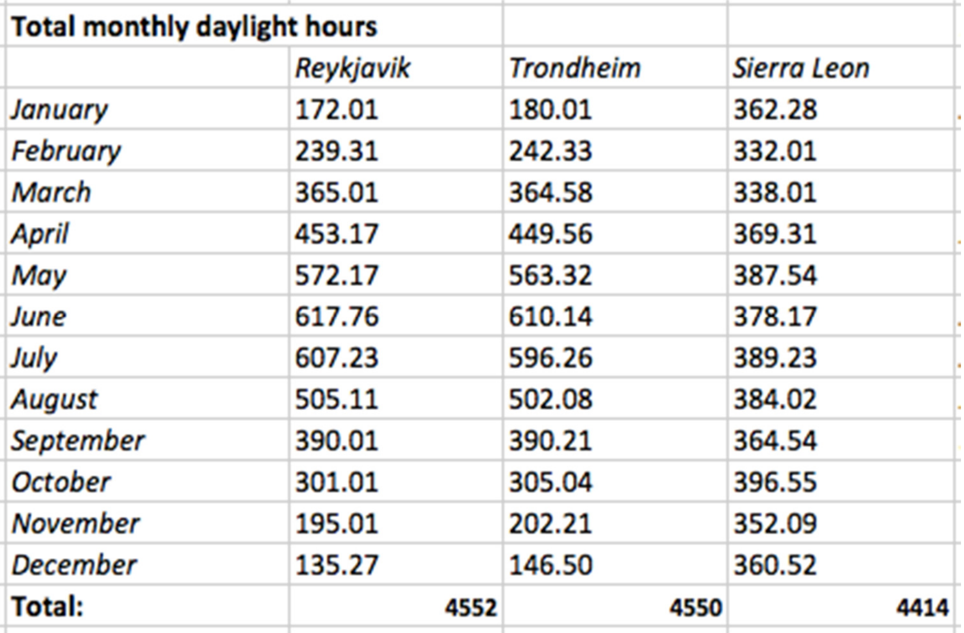


Figure 3:Comparison of daylight hours in Reykjavík, Trondheim and Sierra Leone, information obtained from www timeanddata.com and graph made in Excel.

The graph shown in figure 3 demonstrates daylight hours of the three locations every month of the year.

The total amount of daylight hours in all three locations is roughly the same, nevertheless, the difference lies, as with the solar angles, in the variation between months. The daylight hours in Sierra Leone are consistent throughout the year. There is a variation of 57 hours between months, from the lowest of 332 hours in February to the highest of 389 hours in July. In Trondheim and Reykjavík, the variation is drastic, where it goes from the lowest of around 145 daylight hours in December, to the highest of around 615 in June, a variation of 470 hours between months.



Total monthly daylight hours			
	Reykjavik	*Trondheim*	*Sierra Leon*
January	172.01	180.01	362.28
February	239.31	242.33	332.01
March	365.01	364.58	338.01
April	453.17	449.56	369.31
May	572.17	563.32	387.54
June	617.76	610.14	378.17
July	607.23	596.26	389.23
August	505.11	502.08	384.02
September	390.01	390.21	364.54
October	301.01	305.04	396.55
November	195.01	202.21	352.09
December	135.27	146.50	360.52
Total:	**4552**	**4550**	**4414**

Figure 4:Table showing the monthly daylight hours in Reykjavík, Trondheim and Sierra Leone. Information obtained from www.timeanddate.com, graph made in Excel

With these two analyses of the solar angle, and the daylight hours in the three locations, it is evident that Trondheim, Norway and Reykjavík, Iceland, with their similar geographical positions, are very similar when it comes to both daylight and solar angles. Comparing those two Nordic cities to Sierra Leonee, a large discrepancies in solar angles is seen, as well as daylight variation between months. Sierra Leonee is consistent throughout the year, both when looking at solar angles, as well as daylight hours between months. Trondheim and Reykjavík consist of more drastic scenes, where the daylight hours vary greatly between months, as well as a large shift in solar angle between months.

DISCUSSION ON ICELAND’S GEOGRAPHICAL POSITION

One main differentiation was identified when comparing the two Nordic cities in question, to Sierra Leone. In Sierra Leone, both factors, daylight hours as well as the solar angles, are consistent. The monthly daylight hours are roughly the same throughout the year, with the lowest amount of daylight hours in February, or around 330 daylight hours, and the highest amount of daylight hours in the month of July, or around 390 daylight hours. That is a variation of roughly 60 hours between months throughout the year. The solar angle is very consistent as well, with the lowest solar angle in December at 55.76° and the highest solar angle in March of 72.9°, which gives a variation of 17.14°. In the Nordic cities these factors are not at all consistent, with high degrees of variation between lowest and highest months on both parameters. Residents of these cities go from receiving only about 135 daylight hours in the month of December, to having about 617 daylight hours in June. That is a variation of roughly 480 hours between months. In addition the solar angles see a drastic change as well, from the lowest of 1.19° in the month of December, to 45.52° in the month of June. That is a variation of 44.33° between months.

The average solar angle in Sierra Leone throughout the year is 61.41°, while the average in Reykjavík is 29.75°.

But what does this mean? How do the solar angle and amount of daylight hours affect how daylight enters a building?

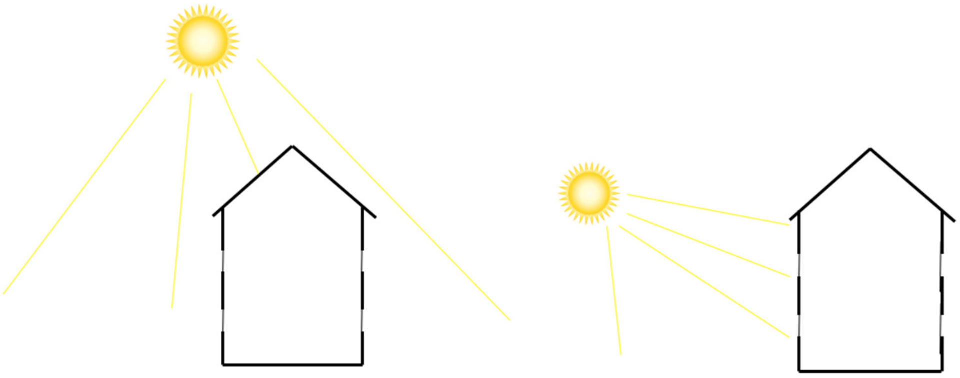


Figure 5: Illustration showing the difference in sunlight, from a high solar angle to a low solar angle.

The Nordic light is often said to be unique. The low position of the sun results in long shadows, and therefore, buildings and the urban environments are affected by the sun's position and directions. The low solar angle results as well in a low penetration of daylight into buildings, that is, when the sun is present, it shines its light directly in to buildings, resulting in discomfort, glare, and the reaction will be that occupants pull down the window's curtains, and turn on the artificial lighting. This can be seen in the illustration in figure 5. The left image shows how the sunlight distributes from a high solar angle, in locations such as Sierra Leone. The right image shows the distribution of sunlight from a low position of the sun, in Nordic countries such as Iceland.

The residents of the cities in the northernmost regions receive daylight from a low angle, that is, the solar angle is drastically lower a majority of the year, compared to cities in the southern parts of the world. Those low solar angles result in long shadows, that cast darkness over the buildings surrounding them. In these cities, daylighting evaluation in buildings is undoubtedly important, as these previously mentioned conditions make the daylight even more valuable to its inhabitants.

Figure 6: Low position of the sun over Reykjavík, Iceland

But how has the daylight affected the architecture and the urban planning throughout the years in the capital city, Reykjavík? Has the growing density of the city changed how daylight is perceived in buildings?

3.2 ARCHITECTURE AND URBAN PLANNING IN REYKJAVÍK

When looking at daylighting in buildings one inevitably has to look at the history of architecture and urban planning, and how it has developed over the years.
This chapter will in few words summarize the history of daylighting in buildings and urban planning in Reykjavík, Iceland. This is done in order to gain a better understanding of the needs of daylighting in buildings and how the architecture and urban planning has developed through the years.

Turf houses were the first habitats Icelanders lived in. They developed and were prominent from the settlement of Iceland in the second half of the ninth century, until the early nineteenth century. Turf houses are dwellings that are covered with soil, on which plants are allowed to grow on. These constructions were most common in northern latitudes (Zhai & Previtali, 2010).

Daylight was very limited in these habitats, as glass was an expensive material, as well as the fact that having windows would let out valuable heat from the houses. Windows in turf houses became common in the mid 18th century, with usually one window in each house. The window was positioned deep into the wall, shielded from the weather, and usually too small to let any considerable amounts of daylight in (Jóhannsdóttir, 2014).

Figure 7: Traditional Icelandic turf house (Iceland, 2016)

In the early 18th century, with increased imports of timber, wooden houses became popular. In regards to daylight, the wooden houses were a drastic improvement compared to the turf houses, but, their windows remained small and positioned low on the walls, which restricted daylight from fully penetrating the building (Jóhannsdóttir, 2014).

The capital of Iceland, Reykjavík, developed from a town to a city in the early 19th century when people migrated in masses from the countryside of Iceland to the capital, in hopes of a better live, and construction of larger buildings began. It is a young city which has developed rapidly. With more density, the buildings grew closer together, which meant daylight only penetrated the building from two sides (Ármannsson, 2001).

With these rapid changes, one might say that Icelanders went straight from turf houses to modern architecture (Jóhannsdóttir, 2014).

Modernism in architecture was implemented in Iceland around the 1940's, where daylight was one of the key elements of the design. The building was designed around the light that enters it, that is, windows were positioned to ensure the best usage of daylight, and living rooms were placed with windows facing south and west. This was a new way of thinking; the daylight playing a valuable role in the design.

One of the best examples of modernism in Icelandic architecture is considered to be Ægisíða 80, a single family house designed by Sigvaldur Thordarson in 1958. The building has large windows and a living room facing south while the bedrooms where placed on the north side of the building (Gylfadóttir , Gunnarsdottir, & Ármannsson , 2005).

Figure 8: Ægisíða 80, a building well known for its modernist architecture. Shown here are the large, south facing living room windows (Gylfadóttir , Gunnarsdottir, & Ármannsson , 2005).

Figure 9: Ægisíða 80, a building well known for its modernism architecture. The north facing side of the house holds the bedrooms (Gylfadóttir , Gunnarsdottir, & Ármannsson , 2005).

In the book, *Dagsbirta sem vistvænn birtugjafi* (or "Daylight as a sustainable light source"), Jóhannsdóttir talks about the Nordic modernism; "It is often said that the Nordic modernism in architecture has a certain uniqueness that mostly involves how the architect handles daylight,." (Jóhannsdóttir, 2014) where she referes to the new way of thinking in the manmade environment.

In Nordic locations, where the winters are long with very limited daylight hours during the darkest months, and the summer characterized by long days, architects are required to handle the daylight with care.

The daylight plays a valuable part in urban planning as well as architecture. Jóhannsdóttir says in her previously mentioned book that; *"daylight is a powerful force in urban planning in terms of location of buildings in the country, shaping the city spaces and recreational areas"* (2014).

The way that daylight can affect urban planning is when looking at the shadows that a building produces. A low sun position means that the shadows a building casts are greater than in countries where the sun rises higher, as mentioned in chapter 3.3. Tall buildings therefore cast long shadows, which causes dark and cold environments for the surrounding buildings.

Figure 10 examines and compares the shadow cast by a building in Reykjavík on the equinox and summer solstice.

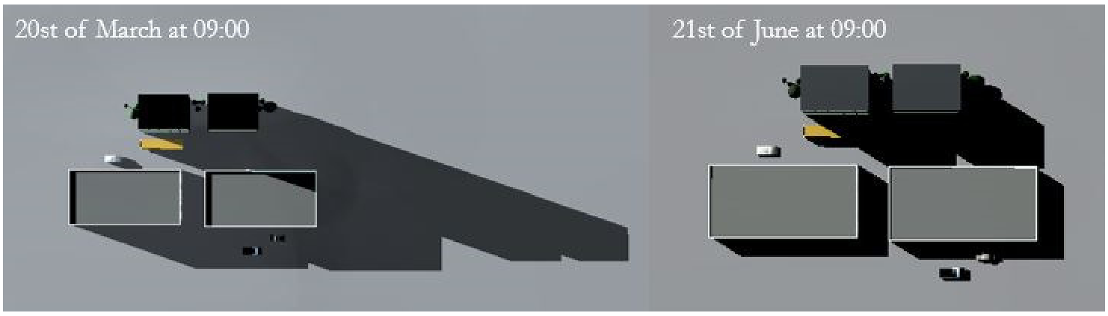


Figure 10: Shadows of the same building at different times of the year. Image made using Dialux.

The picture on the left shows the shadows of a building with the sun angle at around 26°, on the equinox (20st of March at 9:00) while the picture on the right shows the shadows of the same building with the sun angle at around 46° on summer solstice (21st of June).

The long shadows are evident, as well as their possible effects on the surrounding buildings.

As the image in figure 10 demonstrates, countries where the solar angle never goes lower than 40° do not have the concern of buildings casting those long shadows.

DISCUSSION

The city has undergone a large transition over the past century and is still developing. The density of the city gets greater, with taller buildings being built, new technology in building methods and materials, and the population increases.

One might assume that it is crucial for the future of the city to have regulations that keep up with the pace that the city is developing at, both in regards of daylighting, as well as sustainable development. It is important for designers to not let hasty expansion and economical thinking get in the way of the importance of creating a sustainable environment. The regional plan for 2001-2024 covering all the municipalities in Reykjavík declares sustainable development as one of their goals

(Svæðisskipulag höfuðborgarsvæðisins 2001-2024, 2013). A change has also been proposed to the building regulations in Iceland, which are expected to be developed further in regards to daylighting in buildings, raising standards and requiring improvements. The changes to the building regulations will be further reviewed in chapter 3.4.3.

Having reviewed the geographical location of Iceland in comparison to a city with a similar coordinates and a country in a different region of the world, as well as shortly reviewing the history of architecture and urban planning of the capital city of Iceland, methods of evaluating daylight in buildings will now be analyzed.

3.3 EVALUATION METHODS

To get a better understanding of the procedure of evaluating daylight in buildings in Iceland, this chapter will analyze and review methods that have through the years been used to evaluate daylight, starting with the earlier procedures, and leading on to more recent methods. This review is performed to get a better understanding of the methods that are available, and how they are suited to the Nordic daylighting in Iceland, during the design phase of a building. The methods chosen are believed to be the methods that are best known and commonly used in the industry.

To evaluate daylight in buildings in Iceland, there are few factors that need consideration. Due to the sun's position throughout the year in Iceland, it is important to look at surrounding buildings to the building analyzed in each case. It is important to look at how the building should be orientated, as it will influence the building's daylighting. It is essential to view how its windows are positioned, as well as their sizes. The location's climate is an important factor too, therefore weather data is a helpful tool. The method chosen to evaluate daylight in Iceland must factor in all these considerations to give the most thorough analysis available, as well as being functional in the design phase of the building. Now methods that currently are used by professionals in the industry will be reviewed, using these predetermined considerations to assess their applicability to be utilized as evaluation methods in Iceland.

The scientific study of daylighting in the buildings is fairly recent, according to J.W.T Walsh (1951) its initiation started in 1895 with measurements of outdoor illumination. The measurements were mainly performed with illumination photometers. A variety of daylight availability metrics based on rules of thumb and computer simulations have been proposed since then. The first methods were primarily graphical in nature, and later scientist developed empirical methods to calculate and evaluate the performance of daylight in buildings. Methods were developed into more comprehensive computer software which is able to perform daylight analyses. The development continues, as the lighting industry develops and the knowledge expands (Kota & Haberl, 2007).

3.3.1 WALDRAM DIAGRAM

One of the earliest methods in evaluating daylight is the *Waldram Diagram*. It is mostly used in cases of *"Right to light"* matters in the United Kingdom, and in cases of urban planning. The method is well known by practitioners worldwide.

The "Right to light" is a form of easement in English law, that gives a long-standing owner of a building with windows a right to maintain the level of illumination, when adjacent constructions are made, and was established in the 1920's (Kerr, 1865). Having received the same illumination by daylight for twenty years or more, the building owner has the right to plead the Right to light in order to affect the construction being made. It is a civil matter that has to be considered even if planning permission has been granted (Littlefair P. J., 2009)

The usual way of calculating the loss of light is to compute the sky factor at a series of points of the working plane. In dwellings, the working plane height is usually set at 0.85 m. The sky factor is the ratio of the illuminance directly received from a uniform sky at the point indoors, to the illuminance outdoors under an unobstructed hemisphere of this sky. No allowance is made for loss of light through glass, blocked by glazed bars and window frames; nor is reflected light included, either from interior surfaces or from obstructions outside (Littlefair P. J., 2009). The sky factor is usually calculated using a Waldram diagram.

The Waldram diagram determines the sky factor for an interior space. It shows the value of light from the spherical sky represented on a flat piece of paper, where a room is considered adequately lit if the working plane (85 cm from floor) receives 1/500th of the total illuminance provided by the sky. That value equals 10 lx, a sky factor of 0.2% (RICS, 2010).

The diagram consists of a grid of squares, each of which represents a portion of sky factor. This is demonstrated in figure 11.

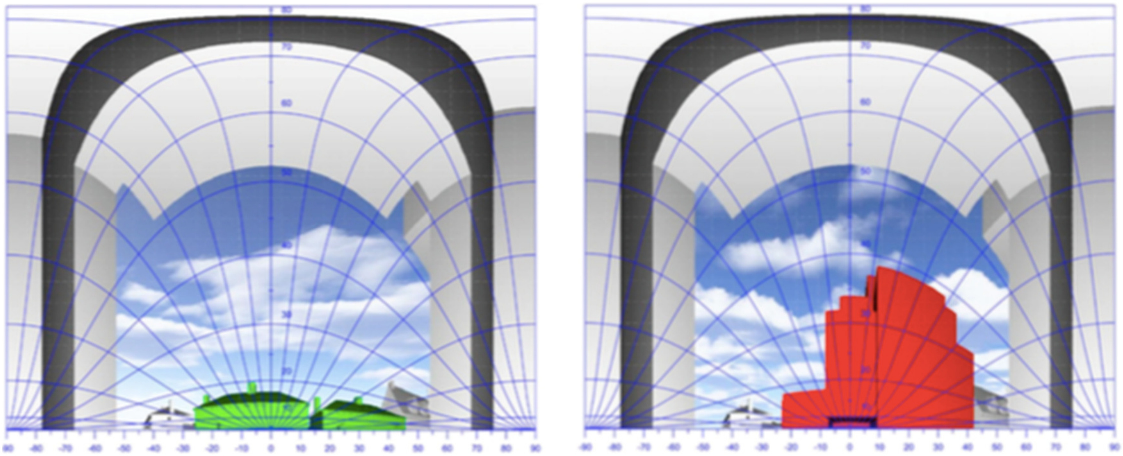


Figure 11: The Waldram Diagram shows the adequacy of light before and after a proposed development (RICS, 2010).

CONCLUSION ON THE WALDRAM DIAGRAM

- Can the method be used in the design phase? Yes
- Does the method consider window size and position? Yes
- Does it take surrounding buildings into account? Yes
- Does it consider the buildings orientation? No
- Does the method consider the location's climate? No

It can therefore be conclude that for the purposes of this research, the Waldram diagram method is not considered to be suitable for evaluating daylight in buildings in Iceland.

DISCUSSION ON THE WALDRAM DIAGRAM

Even though the Waldram diagram is a well known and considerably easy method in theory, it is not considered to be an adequate method for evaluating daylight in Iceland, as it does not consider an handful of valuable factors. It has also been the target of recent ciritcism and its applicability has raised many questions and doubts amongst practitioners (Defoe & Frame, 2007).

The method can be used during the design phase, but is not considered to be a very practical method to do so. It does take surrounding buildings into account, as it is designed to evaluate the daylight in buildings by looking at the surrounding buildings. However, it does not take the adjacent building's material into account. The window size and placement is considered in some cases, meaning, if the method is used to evaluate a room's daylight before a new, adjacent construction that could potentially block the room's daylight, is built, the window size and placement is considered, but if the method is used during a design phase of a new construction, it cannot take the buildings size or orientation into account. The orientation of the building, in regards to the sun's position is not considered. The method uses no weather data for its evaluation. These factors resulted in the method not being considered as a suitable method for daylight evaluation in Iceland.

3.3.2 DAYLIGHT FACTOR (DF)

With cities becoming larger and more populous, their building density increased, which resulted in lack of daylight in buildings. With more knowledge and understanding of daylight, and its benefits, the interest of it increased, which resulted in the formulation of the *daylight factor* (Mardaljevic J. , 2012).

James A. Love stated in 1992 that the daylight factor (DF) was first proposed in 1895 by Alexander Pelham Trotter (Love, 1992). The DF was designed to be a measurement of daylights potential in a building and could be used during the design phase of a building.

DF is the ratio that represents the amount of illumination available indoors relative to the illumination present outdoors at the same time, under CIE (Commission Internationale de l´Eclairage, or the International Commission on Illumination) sky. DF is calculated by dividing the horizontal work plane illumination indoors by the horizontal illumination on the roof of the building being tested, and then multiplying by 100 and is expressed as a percentage:

$$DF = \frac{E_{ind}}{E_{out}} \times 100\%$$

Where E_{ind} is the indoor illuminance at a fixed point and E_{out} is the outdoor illuminance under an overcast (CIE) sky.

Light can reach an analysis point inside a room through glazed windows in three possible ways:

- Light from the patch of sky visible at the analysis point, expressed as *Sky component (SC)*
- Light reflected from opposing exterior surfaces and then reaching the point, expressed as *Exterior Reflectance Component (ERC)*
- Light entering through a window but reaching the point only after reflection from the internal surfaces, expressed as *Interior Reflectance Component (IRC)*

The arithmetic sum of these three components give the DF.

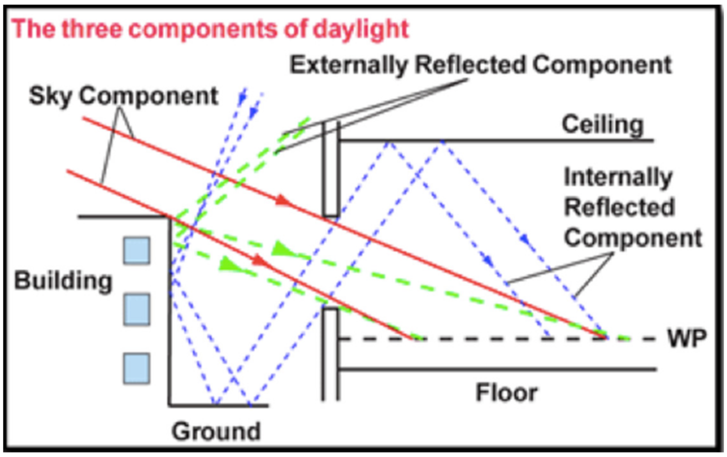


Figure 12:Diagrammatical representation of DF=SC+ERC+IRC (College, 2015)

CONCLUSION ON DAYLIGHT FACTOR

- Can the method be used in the design phase? Yes
- Does the method consider window size and position? Yes
- Does it take surrounding buildings into account? No
- Does it consider the buildings orientation? No
- Does the method consider the location's climate? No

It is therefore concluded that for the purposes of this research, the Daylight Factor method is not considered to be suitable for evaluating daylight in buildings in Iceland.

DISCUSSION ON DAYLIGHT FACTOR

Daylight factor is a known method for evaluating daylight worldwide. It is used as a benchmark in building regulations, e.g. in Danish and Norwegian regulations, and environmental assessment methods, and it can be assumed that the method's simplicity is the reason behind is popularity (Authority., 2010), (Development, 2010).
DF is recommended by the CIE, and can be calculated using free computer software such as Dialux, Relux, Radiance or Daylight Visualizer.

It cannot however be considered as an applicable method for daylight evaluations in Iceland, for a number of reasons. First, there are important factors that are not considered using the DF method, such as the surrounding buildings, the building's orientation and the local climate. As an example, a building that is evaluated with DF would get the same results for a building located in Africa, with windows facing south with no adjacent buildings, as it would get with a building located in Iceland, with windows facing north with multiple surrounding buildings.

As well as missing important factors, the method also is open to game-playing, as John Mardaljevic mentions in his chapter in the book "Nordic light and color", where factors such as reflection of walls, floors and ceilings, as well as the calculation grid of the surface are manipulated in order to receive the desired outcome (2012). While the DF is calculated during the design phase of a building, some factors are hard to control. When the building is calculated during the design phase, factors such as furniture, colors and materials of the building are not considered, which can greatly affect the daylight perceived in the building.

While the importance of good daylighting has gained interest, the execution of it is often lacking, if not counterproductive, meaning it can result in a worse rather than better daylight performance. This happens when good daylighting is mistaken by more daylight, or a higher DF (Mardaljevic J. , Nordic light and color, 2012).
The need for an updated method is well recognized, as Kevin Van Den Wymelenberg said; "Practitioners are beginning to realize that additional metrics are necessary to adequately describe daylight in all its complexity," (Daylight Dialect, 2008).

3.3.3 “RULES OF THUMB”

While there are various methods to evaluate daylight in buildings, so called “rules of thumb” have also been developed over the years. This sub-chapter will shortly cover three diverse rules of thumb, those are the *“25-degree rule”*, the *“45-degree rule”* and *“glass to floor ratio”*.

The 25-degree rule, and the 45-degree rule were set by BRE (Building Research Establishment) and are used to determine whether or not further detailed daylight and sunlight tests are required, when completing a building application in the United Kingdom, in areas where there are surrounding and adjacent buildings.

The third rule of thumb introduced is a common rule used to rate daylight availability in a side-lit space, the glass to floor ratio rule, which is used in building regulations in countries such as Iceland, Denmark and Norway (Mannvirkjastofun, 2012), (Authority., 2010), (Development, 2010).

3.3.3.1 25-DEGREE RULE OF THUMB

This rule of thumb examines the distance from the analyzed building to its adjacent buildings, that is, the building’s height has to be in a certain ratio to the distance of a nearby building. To carry out this rule, a section of the building is drawn, with adjacent buildings as well. A reference height of two meters is given, that corresponds to the top part of ground floor windows.

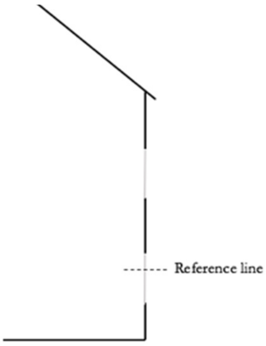


Figure 13: Reference line of two meters

If the obstructing (adjacent) building does not subtend an angle of 25 ° to the horizontal reference line, there is good potential for acceptable daylighting in the building.

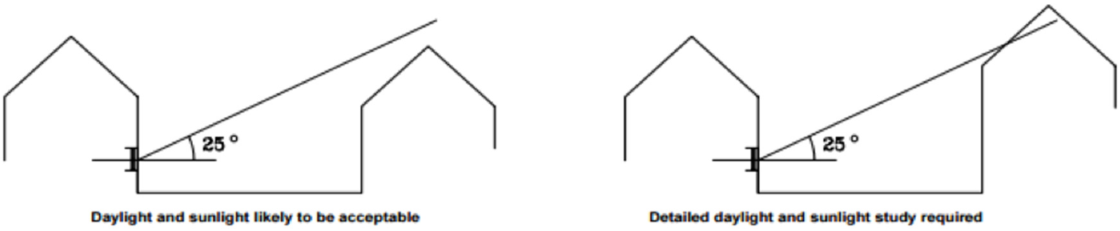


Figure 14: 25° rule of thumb (Marston, 2013)

If the angle subtends 25°, there is a need for more detailed checks on daylight and sunlight. When further daylight analysis is needed, it is suggested by BRE to use one of following detailed tests; calculate the Vertical sky components, using the Skylight indicator, Waldram Diagram, calculating the average DF, or Annual Probable Sunlight hours

CONCLUSION ON THE 25° RULE OF THUMB

- Can the method be used in the design phase? Yes
- Does the method consider window size and position? No
- Does it take surrounding buildings into account? Yes
- Does it consider the buildings orientation? No
- Does the method consider the location's climate? No

It is therefore concluded that for the purposes of this research, the 25° rule of thumb method is not considered to be suitable for evaluating daylight in buildings in Iceland.

3.3.3.2 45-DEGREE RULE OF THUMB

In courtyards or L-shaped buildings, it often occurs that the sky component changes rapidly along the façade. Therefore, if the windows are situated close to these corners, levels of daylight will be poor. This also occurs where an extension to the building has been built. The 45° rule can be used to check how far from an internal corner windows need to be situated to receive enough daylight.

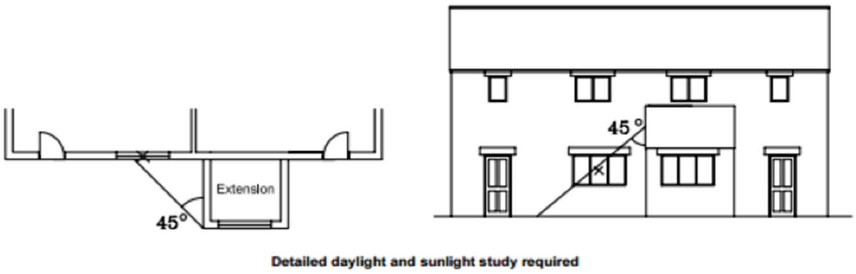


Figure 15: 45° rule of thumb (Marston, 2013)

If the center of the window lies on the extension side of both of the 45° lines (on plan and elevation), then there is a need for further analysis. Otherwise, daylight and sunlight levels are unlikely to be adversely affected because light will continue to be received either over the roof or beyond the end of the extension. In the example in figure 15, the extension has a sloping roof. In this situation the BRE guide states that the height of the extension should be taken half way along the slope of the roof (Marston, 2013).

CONCLUSION ON THE 45° RULE OF THUMB

- Can the method be used in the design phase? Yes
- Does the method consider window size and position? Yes
- Does it take surrounding buildings into account? No
- Does it consider the buildings orientation? No
- Does the method consider the location's climate? No

It is therefore concluded that for the purposes of this research, the 45° rule of thumb method is not considered to be suitable for evaluating daylight in buildings in Iceland.

3.3.3.3 GLASS TO FLOOR RATIO

This rule of thumb is regarding the ratio between the area of a window and the floor area of a room. The glass shall not be smaller than the equivalent of 1:10th of the floor area. It is used to determine optimum areas of fenestration in relation to the floor area of a room, and can be used as a starting point for a design, or as a verification that the potentials of daylight in buildings are good at the end of the design.

As mentioned previously, this is a common rule of thumb in building regulations in many countries, such as Iceland, Denmark and Norway (Mannvirkjastofun, 2012) (Authority., 2010) (Development, 2010).

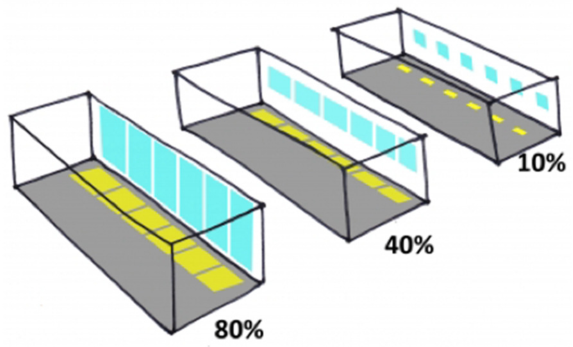


Figure 16: Different window to floor ratios and the resulting illumination (Autodesk, 2015)

CONCLUSION ON GLASS TO FLOOR RATIO

- Can the method be used in the design phase? Yes
- Does the method consider window size and position? No
- Does it take surrounding buildings into account? No
- Does it consider the building's orientation? No
- Does the method consider the location's climate? No

Due to the factors that it does not encompass, one can conclude that for the purposes of this research, the glass to floor ratio method is not considered to be suitable for evaluating daylight in buildings in Iceland.

DISCUSSION ON RULES OF THUMB

The benefits from the rules of thumb are that they are rather simple procedures, and do not require a specialist to perform them. It does not require any special calculation tools, and it is difficult to intend to cheat with this method. The disadvantage of this method is that it does not take into account the surrounding environment and the location's climate. These rules of thumb, could be combined together, and improved, in order to make them usable for the design phases of buildings in Iceland. The methods are missing better guidelines, that is, in cases of buildings with shade structures, overhangs and in spaces with more complex window placement, it would be beneficial for this method to have accessible tables and even simple calculators, to implement for example surrounding buildings, overhangs, and shade structures, which would improve the utilization and outcome of the methods

3.3.4 CLIMATE BASED DAYLIGHT MODELING (CBDM)

The accurate prediction of daylight in buildings under realistic sun and sky conditions, hourly for a full year, was first demonstrated in the late 1990s, introduced as Climate Based Daylight Modeling (CBDM). It gradually gained traction, first within the community of researchers, followed with practitioners within the field (Mardaljevic J. , 2015).

John Mardaljevic, who first introduced CBDM, has written many articles, reports and papers bout CBDM and therefore has on many occasions described the method as follows:

> Climate Based Daylight Modeling (CBDM) is the prediction of various radiant or luminous quantities (e.g. irradiance, illuminance, radiance and luminance) using sun and sky conditions that are derived from standard meteorological datasets. Climate-based modeling delivers predictions of absolute quantities (e.g. illuminance) that are dependent both on the locale (i.e. geographically-specific climate data is used) and the building orientation (i.e. the illumination effect of the sun and non-overcast sky conditions are included), in addition to the building's composition and configuration (Climate based daylight modelling , 2013), (Nordic light and color, 2012), (Climate based daylight analysis, 2008).

There are two principal analysis methods:

Cumulative analysis is the prediction of some aggregate measure of daylight (total annual illuminance) founded on the cumulative luminance effect of (hourly) sky and sun conditions derived from the climate dataset. Determined over the period of a

year, season or a month. Shorter than a month is not recommended, although analysis may be restricted to those hours in the day that cover the time that a particular building is in use.
Cumulative analyses are used for predicting the micro climate and solar access in urban environments, long term exposure of art work to daylight and the determination of seasonal dynamics of daylight and/or shading at the early design stage.
The cumulative approach has the potential to influence the design of the building from the very early stages of conception, and becoming a valuable tool to help guide the design of the building from the initial conception onwards.

Time series analysis is predicting instantaneous measures (illuminance) based on all the hourly values in the annual climate dataset. Time series analysis is used to evaluate the overall daylighting potential of the building, occurrence of excessive illuminance or luminance, inputs to behavioral models for light switches and/or blind usages, and in assessing the performance of daylight responsive lighting controls.

The most common methods of CBDM today are *Useful Daylight Illuminance (UDI)* and *Daylight Autonomy.* The methods make use of hourly annual simulations of daylight illuminance, using a typical mean year weather file for daylight illuminance for each specific location. These methods will be described in the next two sub–chapters.

3.3.4.1 USEFUL DAYLIGHT ILLUMINANCE (UDI)

The first publication about Useful Daylight Illuminance (UDI) was in 2005, by A.Nabil and J.Mardaljevic in their article "Useful Daylight Illuminance: A New Paradigm for Assessing Daylight in Buildings".

UDI's objective is to reduce and formulate easier information from the climate based simulation without missing the valuable information from the raw data. Rather than to analyze a huge amount of info, the rationale behind UDI was to approach the data first from a human factor perspective, and then reduce it to compact meters.

Any metric that is designed with the aim of taking a measure of realistic time varying daylight illuminance must accommodate in some way the huge range in levels that occur, that can be achieved by abandoning the concept of a target illuminance, e.g 500 lux, and instead, determining the occurrence of a range illuminance (Mardaljevic & Nabil, 2005).

Achieved UDI is defined as the annual occurrence of illuminance across the work plane that are within a range considered "useful" by occupants. The range that is considered useful is based on a survey of reports of occupant preferences and behavior in daylight offices with user-operated shading devices (Mardaljevic & Nabil, 2005).
UDI achieved is defined as the annual occurrence of daylight illuminances that are between 100-3000 lux. Subdivided into two ranges:

UDI-Supplementary: Occurrence of daylight illuminances in the range 100-300 lx. For the levels of illuminance, additional artificial lighting may be needed to supplement the daylight for common tasks such as reading.
UDI-Autonomous: Gives the occurrence of daylight illuminance in the range 300-3000 lx were additional artificial lighting will most likely not be needed.

UDI-SCHEME:

- Illuminance less than 100 = UDI "fell short" (UDI-f)
- Illuminance greater than 100 and less than 300 lx = UDI supplementary (UDI-s)
- Illuminance is greater than 300 and less than 3000 lx = UDI autonomous (UDI-a)
- Illuminance is greater than 3000 lx = UDI exceeded (UDI-e) (Mardaljevic J. , Climate based daylight modelling , 2013)

Where the illuminance falls below the useful illuminance levels, it means that it does not contribute in any useful way to either the perception of the visual environment, or to carry out any visual tasks. Where the illuminance is greater than the useful level, it may produce visual or thermal discomfort, causing the occupants to use the blinds, and therefore blocking out all daylight (Mardaljevic & Nabil, 2005).

UDI keeps much of the analytical simplicity of the familiar DF approach, but unlike DF, the UDI metrics are based on absolute values of time varying daylight illumination for a period of a full year. The range that is used to identify the limits of UDI is based on the latest data from field studies of occupant behavior under daylit conditions, thus it offers an extensive step towards interpretive framework for daylighting that is founded both on realistic measures of absolute illuminance and on realistic models for occupant behavior.

3.3.4.2 DAYLIGHT AUTONOMY (DA)

Daylight Autonomy (DA) was first proposed by Association Suisse des Electriciens in 1989 and was improved by Christoph Reinhart between 2001-2004.
CBDM calculations are used to determine how much of the illuminance of the annual daylight hours exceed a given value in a field of activity (Lutron, 2013).
It considers the given geographical location's specific weather information on an annual basis. A variant of DA that is commonly used, is *Spatial Daylight Autonomy (SDA*), which is used alongside *Annual Sunlight Exposure (ASE)*

The aim of SDA is to estimate the dynamic qualities of daylit spaces, to better the predictive performance and define a steady calculation methodology to compare multiple design alternatives (Protzman, 2013). It is defined as a percentage of a workplane, where the illuminance exceeds 300lx at least half of the usage time. This is an accepted method of the *Illuminating engineering society of the United States of America, IES,* to evaluate daylight in office buildings and other places of work.

While SDA's goal is to receive adequate daylight inside the building, there is a need to balance the daylight, to avoid too much direct sunlight, which can cause visual discomfort or increase the cooling loads for the building. The method of ASE is therefore combined with SDA and has the aim of measuring the percentage of the floor area that is receiving too much sunlight, over 1000 lux for at least 250 occupied hours per year. The ASE is necessary as the SDA does not have a upper limit for the illuminance level, and ASE therefor creates the balance that is needed for SDA.

It is a commonly used method in the United States of America. The coordinates shows that the latitude of USA goes from 20°N to just under 50°N (MapXL, 2013) and is considered suitable for that location (Logadottir, Johnsen , Markvart, & Fontoynont, 2016).

CONCLUSION ON CLIMATE BASED DAYLIGHT MODELING

- Can the method be used in the design phase? Yes
- Does the method consider window size and position? Yes
- Does it take surrounding buildings into account? Yes
- Does it consider the buildings orientation? Yes
- Does the method consider the location's climate? Yes

It is therefore concluded that for the purposes of this research, the CBDM method is considered to be suitable for evaluating daylight in buildings in Iceland.

DISCUSSION ON CLIMATE BASED DAYLIGHT MODELING

In conclusion, CBDM could definitely be implemented for use in Iceland. CBDM's flaws cannot be overlooked though. The method has the same factors that can be manipulated as DF does, which are the reflection factor of walls, ceiling and floors, as well as the calculation grid of the calculation surface, and can therefore be manipulated in order to receive a desireable outcome.

By doing a CBDM calculation, the results are expected to be a complete truth of the expected daylight conditions, though CBDM has only hourly weather data, and for Nordic cities, the weather can change drastically over the course of an hour. Therefore, in Nordic cities, that must be taken into account when receiving the results.

Another flaw within CBDM is that the method does take shading into account, but the market offers shade structures that can both increase or reduce the usage of daylight, and those factors cannot be included in CBDM.

DISCUSSION ON EVALUATION METHODS

Having reviewed several methods that aim to evaluate daylight in buildings, a better understanding has been reached. The reviewed methods were; Waldram diagram, Daylight Factor, 45° rule of thumb, 25° rule of thumb, glass to floor ratio and finally Climate Based Daylight Modeling (including Useful Daylight Illuminance and Daylight Autonomy).

In the beginning of the chapter, it is made clear what factors need to be present for the method so that it can be used to get optimal results in Iceland. Those were the surrounding buildings, the building's orientation, the window position and size, the local climate, and if the method can be used during the design phase of a building

By reviewing each method with those factors in mind, the conclusion was that CBDM included all of the factors mentioned. But even though the method meets the set requirements, it must be taken into account that this is a new method and it can be assumed that architects and lighting designers do not have a lot of experience with the method as well as there are still flaws within the method which can result in 'game playing', as there are factors within the method that can be manipulated.

In order to be of direct use for design evaluations, daylight availability metrics are usually coupled with benchmarks or cutoff levels, above which a point in a space is defined to be *daylit*. The usefulness of benchmarks is that a space can be divided into a daylit and non-daylit area. These benchmarks and cutoff levels are implemented in building regulations and sustainability certifications.

Having reviewed the methods, it is important to see where those methods are being used. What methods are professionals in neighboring countries of Iceland using? What methods do sustainability certification procedures require? This will be reviewed in the following chapter.

3.4 REGULATIONS AND SUSTAINABILITY CERTIFICATIONS

In today's society a tremendous effort is placed all over the world, in order to achieve sustainable development in the construction industry. The aim is reducing energy consumption in construction, as well as management of buildings, and therefore limiting its consequences on the local and global environment (Roderick, McEwan, Wheatley, & Alonso, 2009). This development led to the formation of environmental schemes and regulations for buildings, with the aim of measuring the performance of buildings.

This chapter will review building regulations in Iceland and in Norway, as well as two different sustainability certifications, where previously reviewed analysis methods are brought to use.

The rationale behind reviewing Norway's building regulations rather than another Nordic country is that the two countries, Iceland and Norway, have previously been

compared due to their geographical similarities, which was covered in Chapter 3.1, and thus considered reasonable to compare regulations between the two countries.
The two sustainability certifications which will be discussed are LEED (Leadership in Energy and Environmental Design) and BREEAM (Building Research Establishment Environmental Assessment Methodology). Those certifications were chosen to be reviewed due to their recognition in the building industry.

LEED originates in the United States, and BREEAM was developed in the United Kingdom. LEED and BREEAM are rigorous third-party commissioning processes, which offer compelling proof to the contractor, the architect, the client and the public that the building achieves its environmental goals and is performing as designed.

3.4.1 LEED

LEED is the recognized standard for measuring building sustainability, and originated in the USA in 1994. LEED has four ratings, Certified, Silver, Gold and Platinum, which are earned depending on how many points are achieved throughout the evaluation process.
The book "LEED for Building Design and Construction" states that LEED provides a framework for building a holistic green building, creating a healthy, resource-efficient, cost-effective building – one that enhances the lives and experiences of everyone that walks through its doors (Council U. G., 2016).

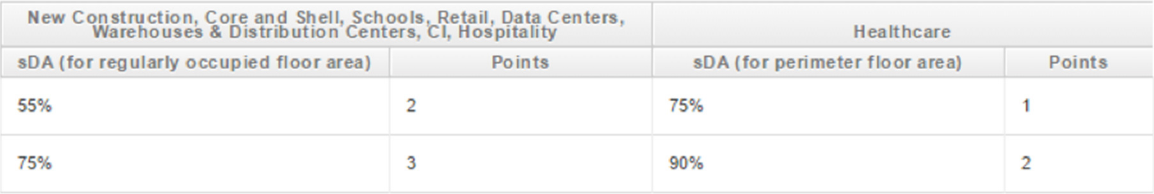
LEED for Building Design and Construction (LEED BD+C) covers the matter of daylight in chapter LEED BD+C: Schools / v4 – LEED v4, where there are a total of three points a building could possibly earn. The intent is "to connect building occupants with the outdoors, reinforce circadian rhythms, and reduce the use of electrical lighting by introducing daylight into the space" (Council U. G., 2016).

It offers three different approaches of receiving the points, where option one includes SDA and ASE, methods that have previously been reviewed in Chapter 3.3.4.2. Option two offers illuminance calculations, and option three revolves around physical measurements. These options will be described further in this chapter.

<u>Option 1:</u>
Simulation methods of SDA and ASE are required in option one. This is done through computer modeling.

SDA describes how much of a space receives satisfactory daylight. Lighting is considered satisfactory when the illuminance exceeds 300 lux over at least half of the usage time.

LEED rewards points based on how much percentage of annual daylight hours receives this pre-stated satisfactory lighting, this option offers one to three points, where two points are given when 55% of annual daylight hours receive 300 lux or more, and three points if the percentage is 75% or above. In healthcare buildings the demand is higher, where one point is rewarded if the space receives 300 lux or more for 75% of the annual daylight hours, and two points if the percentage is 90%, as demonstrated in figure 17.



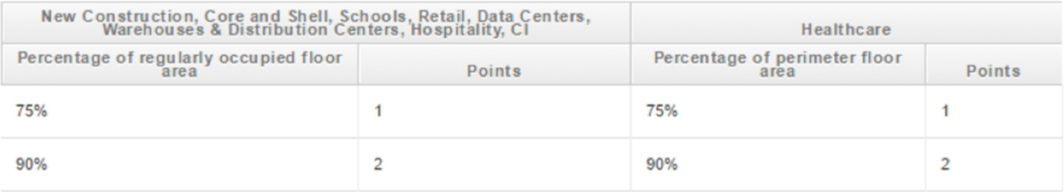
New Construction, Core and Shell, Schools, Retail, Data Centers, Warehouses & Distribution Centers, CI, Hospitality		Healthcare	
sDA (for regularly occupied floor area)	Points	sDA (for perimeter floor area)	Points
55%	2	75%	1
75%	3	90%	2

Figure 17: Points for daylit floor area: Spatial daylight autonomy (Council G. B., 2016)

ASE is also required if option one is chosen. The method describes how much space receives too much direct sunlight. As previously covered in Chapter 3.3.4.2 on DA, ASE measures the percentage of the floor area that is receiving too much sunlight, or over 1000 lux for at least 250 occupied hours per year.
LEED requires that no more than 10% of the considered floor area receives over 1000 lux for 250 occupied hours per year.
Buildings and new construction are categorized into two categories, as shown in the table in figure 17, where healthcare buildings have higher requirements, and shows the points given according to categories.

The calculation grid should be no more than 0.18 m^2 (2 square feet) and laid out across the regularly occupied area at a work plane height of 76 cm (30 inches) above finished floor.

<u>Option 2:</u>
The requirements for option two is a simulation illuminance calculation, demonstrated through computer modeling with weather data. Calculations are done on two separate days of the year, on the equinoxes, 21st of March and 21st of September, at two different times, at 9:00 and 15:00, and are made to demonstrate that the given space receives illuminance of 300-3000 lux. Option two offers one to two points, where one point is given to a building that shows that 75% of the occupied floor receives the required lux level, and two points are given to a building that receives the required lux level on 90% of the occupied floor area.



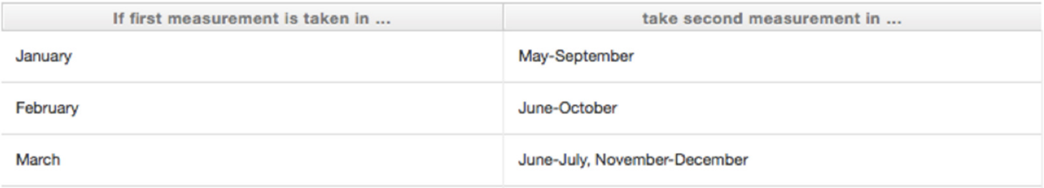
New Construction, Core and Shell, Schools, Retail, Data Centers, Warehouses & Distribution Centers, Hospitality, CI		Healthcare	
Percentage of regularly occupied floor area	Points	Percentage of perimeter floor area	Points
75%	1	75%	1
90%	2	90%	2

Figure 18: Illuminance calculation: points for daylit floor area (Council G. B., 2016)

In both option one and two, blinds, shades and movable furniture should be excluded from the model.

Option 3:

For option three, the requirements are to achieve illuminance levels between 300 lux and 3000 lux by physical measurements. Two measurements have to be taken. The first one is taken at any hour between 9:00 and 15:00 on a regularly occupied month.

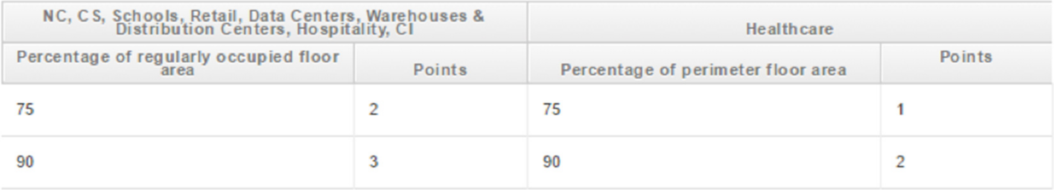


If first measurement is taken in ...	take second measurement in ...
January	May-September
February	June-October
March	June-July, November-December

Figure 19: Instruction showing what month is required for second measurement. (Council G. B., 2016)

The second one is taken in a month opposite to the month previously measured. Guidelines on what month to measure are given by LEED, an example can be seen in figure 19.

One to three points are given for option 3, where two points are rewarded if required measurements are fulfilled for 75% of the regularly occupied floor are, and three points if the percentage is 90%. Healthcare buildings offer one point if 75% of the occupied floor is receiving the required lux levels, and two points if the percentage is 90%, as seen in figure 20.



NC, CS, Schools, Retail, Data Centers, Warehouses & Distribution Centers, Hospitality, CI		Healthcare	
Percentage of regularly occupied floor area	Points	Percentage of perimeter floor area	Points
75	2	75	1
90	3	90	2

Figure 20: Measurements: points for daylit floor area. (Council G. B., 2016)

DISCUSSION ON LEED

LEED offers three different options to reach points for daylighting in buildings. Option 1 offers the rather new method of DA, where SDA and ASE are required. That method has proven well in climates where the sun rises high in the sky (latitude of 30-50°N) and is considered quite reliable.

Option 2 requires lux measurements under clear sky through computer modeling, a method which John Mardaljevic and Jens Christoffersen described as a "…flawed if not actually unsound…" method, (A roadmap for upgrading national/EU standards for daylight in buildings, 2015) where they for example criticize the default value being an extremely coarse approximation, with no basis of local, prevailing climate conditions or there being any mention of what the sun's luminance should be. Option 3 requires physical measurements once the building has been constructed. That gives a clear indication of the daylight in the space, where there is no avoiding the reflection of walls, the obstruction of daylight in the surrounding buildings, effects from furniture, color and atmosphere in the space, and therefore gives a reliable result.

Out of the three options available to achieve LEED certification, Option 1 would be the most applicable to use during the design phase of a project, since it utilizes SDA combined with ASE. Option 2 has been criticized for being flawed and Option 3 can only be applied after the building has already been constructed, they are therefore not considered the most feasible options for the purposes of providing guidelines to achieve desirable daylighting.

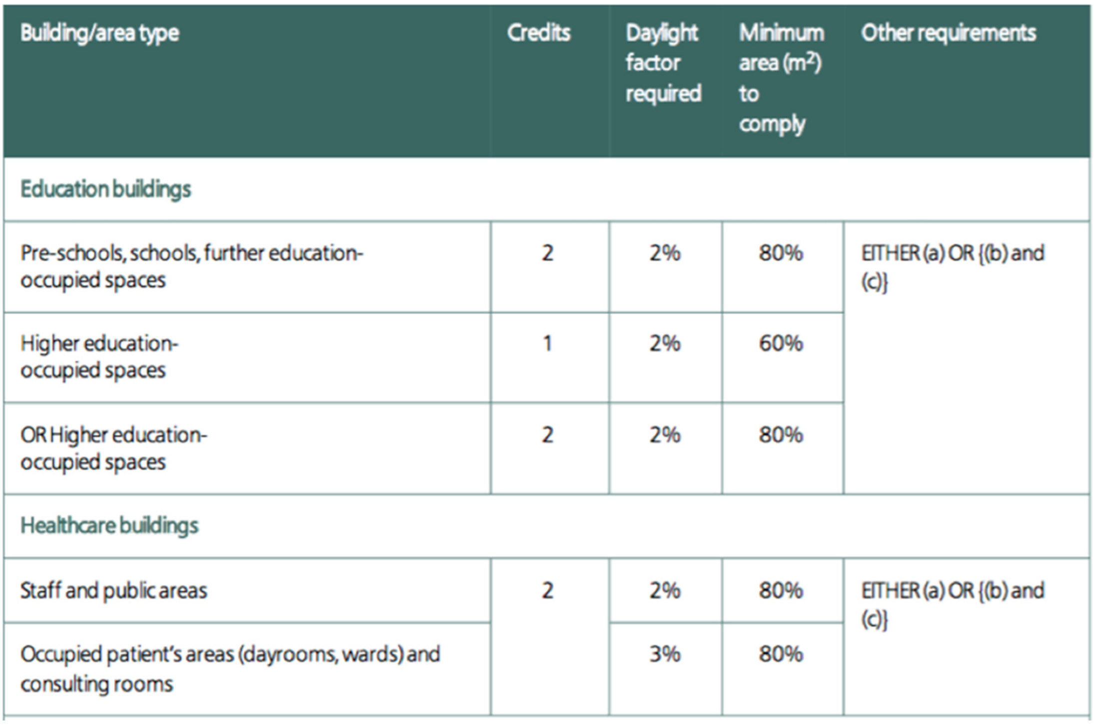
3.4.2 BREEAM

BREEAM was founded in 1990, making it the world's first sustainability assessment method for buildings. It is used in over seventy countries worldwide and is adaptable to local and climate conditions (Establishment, 2015). BREEAM is the most widely used building environmental rating scheme in the U.K. (Roderick, McEwan, Wheatley, & Alonso, 2009).

BREEAM is a point system which results in a grade that is given to the building. When a target is reached, credits are awarded. The chapter that refers to daylighting is "HEA1 – Visual Comfort". It covers daylight, as well as glare control, and artificial lighting. The aim of chapter HEA1 is the following: "*To ensure daylighting, artificial lighting and occupant controls are considered at the design stage to ensure best practice visual performance and comfort for building occupants.*"

This review will cover the part that refers to daylighting. One to three credits can be achieved for daylighting, depending on the building type. There are two options for receiving these credits, one involves the previously mentioned DF, and the other illuminance requirements.

In the DF option, the requirement is a minimum value of an average DF of 1.5% - 3%, in 35% – 80% of the occupied floor area. This is dependent on the building type, as seen in figure 21, where an example of two categories is given. The categories are the following: education buildings, healthcare buildings, retail buildings, prison buildings and courts, industrial, office buildings and all other building types.



Building/area type	Credits	Daylight factor required	Minimum area (m²) to comply	Other requirements
Education buildings				
Pre-schools, schools, further education-occupied spaces	2	2%	80%	EITHER (a) OR {(b) and (c)}
Higher education-occupied spaces	1	2%	60%	
OR Higher education-occupied spaces	2	2%	80%	
Healthcare buildings				
Staff and public areas	2	2%	80%	EITHER (a) OR {(b) and (c)}
Occupied patient's areas (dayrooms, wards) and consulting rooms		3%	80%	

Figure 21:Examples of minimum values of average DF required

Along with having a requirement of an average DF, all building types have an additional requirement, depending on their operation. This can be seen in the column "Other requirements" in figure 21.

An example of an educational building is given:
A preschool building has a requirement of a 2% DF in 80% of occupied spaces of the building. When talking about "occupied" spaces, it refers to spaces that are in use for no less than 30 minutes per day. In addition, there is a requirement for either fulfilling option (a) or (b) and (c).
These options, (a), (b) and (c) are explained on page 61 in the BREEAM technical manual:

(a) A uniformity ratio of at least 0.3 or a minimum point DF of at least 0.3 times the relevant average DF value in table 9. Spaces with glazed roofs, such as atria, must achieve a uniformity ratio of at least 0.7 or a minimum point DF of at least 0.7 times the relevant average DF value in table 9.
(b) At least 80% of the room has a view of sky from desk or table top height (0.85m in multi-residential buildings, 0.7m in other buildings)
(c) The room depth criterion $d/w + d/HW<2/(1-RB)$ is satisfied
d = room depth
w = room width
HW = window head height from floor level
RB = average reflectance of surfaces in the rear half of the room (Global, 2014).

The latter option to acquire BREEAM points for daylighting is an illuminance requirement. It requires an average illuminance and a minimum point illuminance. An average daylight illuminance of 100-300 lux for 2000-3150 hours per year is required for 35-80% of occupied spaces, depending on the building's type, as seen in figure 22. For this critera, the UDI method which was reviewed in chapter 3.3.4.1 can be used.

Area type	Credits	Minimum area to comply	Average daylight illuminance (averaged over entire space)	Minimum daylight illuminance at worst lit point
Education buildings				
Pre-schools, schools, further education - occupied spaces	2	80%	At least 300 lux for 2000 hours per year or more	At least 90 lux for 2000 hours per year or more
Higher education - occupied spaces	1	60%		
OR Higher education - occupied spaces	2	80%		
Healthcare buildings				
Staff and public areas	2	80%	At least 300 lux for 2000 hours per year or more	At least 90 lux for 2000 hours per year or more
Occupied patient's areas (dayrooms, wards) and consulting rooms		80%	At least 300 lux for 2650 hours per year or more	At least 300 lux for 2650 hours per year or more

Figure 22: Illuminance requirements

There is a demand for delivering compelling evidence that these requirements are met. That includes calculations from computer software, where calculations for each applicable room are delivered, floor plans of the building indicating rooms that were calculated, and a site plan proving that no adjacent buildings are blocking daylight exposure to the building.

DISCUSSION ON BREEAM

A wide discussion in regards of the credibility of BREEAM's daylighting chapter has occurred among lighting experts. John Mardaljevic stated in his chapter in the book "Nordic Light and Color" that;

> "Even with something as seemingly straight forward as an average daylight factor specification, the results are open both to interpretation and "gameplaying". The average can be quite a misleading quantity when applied to daylight distribution, especially for spaces illuminated from vertical glazing on one wall where the very high DF close to the windows can significantly

influence the average DF. In lighting guide 5 it is recommended to have a 0.5m border from glazing, but not in BREEAM.

Where Madaljevic talks about "game-playing", it can be assumed that he is referring to altering the factors required to calculate the DF in the computer software, which is known to be done. BREEAM states that it is adaptable to local and climate conditions. However, BREEAM relies, amongst another methods, on DF, which is insensitive to both the building's orientation and the intended locale.
It is the author's opinion that the daylight section in BREEAM, HEA1 – Visual comfort is flawed in some aspects and is likely to require an update in the near future.

3.4.3 ICELANDIC BUILDING REGULATIONS

Having reviewed sustainability certifications and what methods are being used in those processes, it is important to look at the countries' regulations, as those are the rules that all buildings are required to follow, whereas sustainability certifications are, at least for now, optional. First, the building regulations of Iceland will be reviewed.

The following regulations are taken from the 2012 Icelandic building regulations, chapters 6.7.6 and 10.4.1 which refer to daylighting.

"Article 6.7.6, ceiling height and lighting conditions" states:

- Ceiling height should be at least 2.5 meters in all residential spaces.
- All apartments shall have windows on two sides of the residence, in the exception of apartments smaller than 55 m^2, where the requirement is windows on one side, if that side of the apartment is facing south.
- The combined window aperture of each room shall not be less than the equivalent of 1/10 of floor area, although never less than 1 m^2.

The last code refers to the glass *to floor ratio method,* which was reviewed in chapter *3.4.7.*

"Article 10.4.1, brightness and lighting" states:

- Structures must be designed and constructed in a way that all lighting conditions and brightness is fully consistent with the activities carried out by or within the structure, without resulting in unduly temperature or abnormal glare. When assessing the normal lighting conditions the needs of all age groups should be taken into account (Mannvirkjastofun, 2012).

Building regulation Article 10.4.1 states: *"Lighting of workplaces must meet the minimum requirements of the standard ÍST - EN 12464-1 for workplaces indoors"*

The standard ÍST EN 12464-1 is as follows:

> Where people will be working by natural light, the workspace should be designed to make the light distribute well and be as even as possible. Windows on the walls shall normally be at least 10% of the floor area. This ratio should

be increased if daylight is impaired due to bad conditions, such as structures that are close to workspace's window (Vinnueftirlitið, 1995).

During the writing of this thesis, on the third of May 2016, proposed changes to the Icelandic building regulations were accepted. Those changes aimed towards reducing the construction cost of residential buildings. No changes were made to Article 10.4.1. The changes made in Article 6.7.6. are as follows:

- Ceiling height in residential spaces can be 2.2 m if one third of the space has the average ceiling height of 2.5 m.
- Requirements regarding windows on two sides of the building in apartments larger than 55 m^2, and for at least a single south-facing window on one side in apartments smaller than 55 m^2, have been removed. (Mannvirkjastofnun, 2016)

In summary, the changes did not affect the clause regarding glass to floor ratio, the ceiling height requirements were reduced from 2.5 m to 2.2 m, and apartments are no longer required to have windows on two sides of the residence, neither are they required to have at least one south facing window.

3.4.4 NORWEGIAN BUILDING REGULATIONS

The following regulations are taken from the 2010 Norwegian building regulations, from the chapter that relates to daylighting.

"Article 13-12 – Light" states;

(1) Rooms shall have adequate access to light without an uncomfortable heat load.

Lighting is of great importance for human health and well-being, as well as crucial for how quickly and surely we can perform an operation. Daylight is the form of lighting that is generally perceived as the best and most appropriate level of light. To maintain activities when daylight is not present, we need to have artificial lighting.

(2) Rooms designed for constant occupation shall have a window that provides adequate access to daylight, unless the activity indicates otherwise (Development, 2010).

Incoming natural light is determined by the window area and location, shielding from terrain, other buildings, the room height and depth and reflection characteristics of the various surfaces in the room. Requirements for daylight can be verified either by calculation confirming that average DF in the room is a minimum of 2% or the room's glass surface represents at least 10% of the floor area. Using the average DF value, a good basis for satisfactory natural lighting is achieved in the room, regardless of size (Development, 2010).

DISCUSSION

Reviewing the two sustainability certification processes LEED and BREEAM, it is found that the most common methods used to calculate daylight are Daylight Factor, Useful Daylight Illuminance, Spatial Daylight Autonomy as well as physical measurements of illuminance.

A comparison of Norwegian regulations to Iceland's regulations was performed due to the geographical similarities of the two countries. Sierra Leone building regulations were meant to be reviewed, but could not be obtained at the time of this study.

The reviewed building regulations of Iceland and Norway state that methods to be used are glass to floor ratio, in both regulations, as well as the DF method in the Norwegian building regulations.

An employee of the Icelandic Construction Authority (appendix 8) stated in an interview that Iceland's neighboring countries' building regulations are used as a precedent for Iceland's regulations.

When reviewing the building regulations of Iceland and Norway in regards to daylight, it is clear that Iceland's regulations are lacking as they have not been updated like their precedents. Iceland has not updated their building regulations in over 50 years, but on the contrary, the neighboring countries update their building regulations regularly. The way daylight is implemented into the regulations of the neighboring countries could still be debated.

4 INTERVIEWS

After conducting a detailed review on Iceland's geographical location, the history of how daylight is perceived in architecture and urban planning in Iceland, and a thorough literature review of methods of evaluating daylight in buildings, as well as sustainability certification processes and building regulations, the need to interview experts in the industry was considered crucial. To get a broader view of the matter, seeking assessments from specialists in the field of architecture and lighting design in Iceland was the next step. In order to reach a conclusion, a few more aspects are looked into. What is the knowledge of previously mentioned methods among experts in Iceland? What is the most common used method amongst practitioners? What is the knowledge, and what opinions do professionals hold, in regards to Iceland's current building regulations and their requirements on daylight? What are the experts' opinions on what method(s) would be suitable to implement as baselines, if the building regulations were to be updated? The following is a summary of answers to these questions.

4.1 METHODOLOGY

Research methods are either qualitative or quantitative, or even both. What characterizes quantitative research is that it is based on figures, what can be counted and measured. Quantitative research is often presented as a hypothesis with the aim of proving or disproving statistically by collecting data from a large number of participants.

However, qualitative research is based on the experiences of individuals who are considered to have a deeper understanding of certain issues (Abawi, 2008).

Considering this, qualitative interviews were conducted for this particular study. This was done by reaching out to professionals with questions and getting their input and answers to the aforementioned questions.

4.2 DATA COLLECTION

The interviews taken were both structured and unstructured. A short and structured questionnaire was delivered to six professionals. In addition, an unstructured, in-depth interview was performed with one of the professionals, as well as an unstructured interview that was performed with a government employee, who preferred to remain anonymous.

By having short and structured questionnaires answered by professionals, the aim was to receive input in order to answer the research question set forth at the initiation of this study. After receiving answers from all participants, one of the interviewees was contacted and asked for an unstructured, in-depth interview. The in-depth interview was performed with a participant that, based on the answers of the questionnaires, possessed the best knowledge of the matter, and it was therefore considered helpful to perform a deeper interview. The interview was unstructured, in order to give the interviewee a chance to express herself freely. The interview had to have a considerable frame, in order to include all matters that were believed to be relevant. That frame was decided prior to the interview, where the aim was to know more of the projects that the interviewee had worked on in regards to daylighting and to get the interviewee's opinion on the recent update to Iceland's building regulations, as the update was published after the questionnaires were sent out to the experts. Them aim was as well to gain the interviewee's opinion on whether or not the regulations are in need of an update, and in what way.

4.3 SELECTION OF INTERVIEWEES

Interviewees were selected in accordance to the structure of this study, using *purposive sampling,* where the interviewees were chosen based on the knowledge that they are known to possess (Dudovskiy, 2011). Professionals that had worked with daylight analysis and calculations were sought. Information on these professionals was obtained by contacting both the Association of Icelandic Architects and The Icelandic Illumination Engineering Society, as well as receiving information from Verkís Consulting Engineers. The following is a list of the professionals chosen to participate in the survey. Eight people were contacted in total, two of whom were unable to participate.

- Andri Reynisson, B.Arch, MSc. in Lighting Design, 2 years professional experience.
- Anna Sigríður Jóhannsdóttir, M.Arch, Architect with over 19 years of experience.
- Ágúst Gunnlaugsson, electrician and a lighting designer, with 10 years experience as a lighting designer.
- Björn Guðbrandsson, M.arch, Architect and BREEAM assessor, with 14 years experience.
- Kristján Kristjánsson, lighting designer, with 12 years of experience.
- Rósa Dögg Þorsteinsdóttir, lighting designer with nine years professional experience in the field.

4.4 ANALYSIS OF DATA

The interviews were both structured and unstructured. The structured aspect of the interviews was in the form of a questionnaire that the participants answered. The unstructured, in-depth interview was recorded, and afterwards transcribed.

Once the data had obtained, the information was catagorized, in order to structure the results. The following sub-chapters are therefore as follows;

- General knowledge on daylighting
- What methods of daylight evaluation are currently being used in the industry
- Discussion regarding current building regulations, and possibilities for revision of those regulations

4.4.1 GENERAL KNOWLEDGE

The beginning of the questionnaire sought to gain an understanding of the knowledge that the interviewee possesses on the subject of methods of evaluating daylight in buildings.

The interviewees have between two and nineteen years of experience within the field of architecture and/or lighting design, with an average of eleven years. This was considered satisfactory evidence of their competence in the field. The questioned were aimed in particular towards the methods discussed in this study. The interviewees were asked to name a method that they were familiar with for evaluating daylight in buildings.

All of the interviewees first mention *DF*, or a computer software that uses DF. Two of the interviewees mention *glass to floor ratio*. Other methods mentioned are geometric algorithms, sun path studies and view of sky.

The rationale behind this question was to get a better understanding of the knowledge of other methods than the method required in the building regulations, to determine if the professionals in the field are aware of the variety of methods being used worldwide, as well as if the professionals themselves saw a need to go above and beyond the minimum requirements.

4.4.2 WHAT METHODS ARE BEING USED?

The interviewees where asked what method they most commonly used in their work to evaluate daylight adequateness in buildings. Are experts using glass to floor ratio, the current requirement for the building regulations, solely? If using other methods, in what purpose?

As previously mentioned, six people were asked to fill out a questionnaire. Two of those people are architects, while four are lighting designers. The answers received for this particular question are slightly divided between these groups, as the lighting designers answered differently than architects.

Both architects, Björn Guðbrandsson, and Anna Sigríður Jóhannsdóttir, answered this question similarly: “Glass to floor ratio. If I need to hand in any calculations or evidence, I will seek expert advice from a lighting designer “(A.S. Jóhannsdóttir, interview, May 4th 2016).

This shows that if there is a requirement for showing evidence of daylight adequateness in building, for example if a building is aiming for a BREEAM qualification, the architects seek consultation with a lighting professional. They rely on the glass to floor ratio, and do so early on in the design process. But apart from using the rule of thumb for glass to floor ratio, the architect undoubtedly examines each design individually:

> "Architects look at the site that the building will be built on, they look at surrounding buildings, see where the shadows will fall, where the adjacent street is, and the building will be designed with the aim of using the daylight as well as possible" (A.S. Jóhannsdóttir, interview, May 4th 2016).

The four lighting designers all stated that their preferred method of evaluating daylighting is 3D modeling of some sort, which uses DF. Only one lighting designer has worked with a different method than DF, where the designer used UDI on a particular project in Norway (R.D. Þorsteinsdóttir, interview, May 12th 2016).

According to these results, architects are more likely to use glass to floor ratio and professionals educated specifically in lighting, like lighting designers, are more likely to use DF.

4.4.3 ICELAND'S CURRENT BUILDING REGULATIONS

This question's aim was to review the interviewees' knowledge of the current building regulations regarding daylight in Iceland. It must be noted that the questionnaires were sent out prior to the changes in regulations that were passed during the performance of this study, as was reviewed in Chapter 3.4.3.

The question was formulated as an additional question to the questionnaire, as it was not directly related to the content of the interview, where the interviewee was asked; "Are you aware of what regulations are valid in Iceland, regarding daylighting in buildings?"

All interviewees except for one were familiar with the building regulations regarding daylighting in buildings. Three of the interviewees added that there is a lack of requirements in the building regulations. (Á.Gunnlaugsson, interview, May 7th 2016) (A.G.Reynisson, interview, May 5th 2016) (R.D. Þorsteinsdóttir, interview, May 12th 2016).

Another interviewee answered:

> "Yes, the building regulations only speak to glazing area and floor area ratio. There is on the other hand, no regulations that I know of regarding minimum regulations on how much daylight should be in buildings" (R.D. Þorsteinsdóttir, interview, May 1st 2016).

Here it must be stressed that the formulation of the question was solely to examine the interviewees' knowledge of the regulations, not to seek their opinion regarding the regulation. Regardless, half of the interviewees felt it was important to stress the regulations' shortcomings. This conforms to the study's initial speculation that the regulations are in need of an update to keep up with current building industry sustainability certifications as well as increased knowledge in the field of daylighting and its positive effects on manmade environments.

4.4.4 THOUGHTS REGARDING UPDATING CURRENT REGULATIONS

The questionnaire was not built around reaching a yes or a no answer regarding if there is a need for an update to the regulations. The aim was rather to review the current knowledge, both in regards to methods, as well as the regulations. Participants were however asked what they believed was the ideal method to evaluate daylight in buildings.

As mentioned above, the lighting designers are all used to working with DF, but when asked, only one believed that DF was the ideal method to evaluate daylighting in buildings. One interviewee stated that CBDM would be the method most suitable.

As mentioned above, architects tend to seek out an expert's opinion when more intricate daylight evaluation is necessary, as Björn Guðbrandsson says: "I rely on experts to find the best methods" (B. Guðbrandsson, interview, May 6th 2016) where he is referring to getting advice from a lighting designer.

The other architect interviewed had a different opinion on the matter:

> "I want simple procedures; rules of thumbs are always good. Methods that are too complicated might scare off architects, who do although, have a lot of experience with designing with daylight and have done so for many years," (A.S. Jóhannsdóttir, interview, May 4th 2016).

It is interesting to see that even though DF was the method most commonly used, only one interviewee stated that it was the most optimal method for evaluating daylighting in buildings.

4.5 RESULTS AND DISCUSSION

These qualitative interviews were performed in order to shine a light on the general thoughts and knowledge of the experts in the industry. The participants were chosen due to their experience, their knowledge, education and occupations. The questions were formulated to gain some insight into whether or not the industry reflects the standards that are set as baselines elsewhere in the world.

5 DISCUSSION

The interest in the effects of daylighting on human health has increased greatly over the years, and the need to utilize daylighting in buildings becomes greater as the cities become larger and denser. Many methods to evaluate daylighting in buildings have been produced, each one made with the intention of finding a way to best evaluate the daylighting in buildings. Whilst the message regarding “good daylighting” is being noticed, the implementation is often poor if not actually counterproductive. That is, it could result in worse rather than better daylighting performance. In part, this occurs because “good daylighting” is often taken to mean more daylighting. Evaluation methods have to be reviewed critically before they are implemented into regulations and sustainability certification processes. Each country has to look at the methods contingent on its location, building style and materials that characterizes the country’s infrastructure, as well as it’s climate.

The geographical location of Iceland, in comparison to two other locations, was made. That was done in order to evaluate the differences in solar angles and daylight hours due to different coordinates of the locations and how that affects the daylight perceived. These results show that the residents of the cities in the northernmost regions receive daylight from a low angle, that is, the solar angle is drastically lower for the majority of the year, compared to cities in southern parts of the world. Those low solar angles result in long shadows, that cast darkness over surrounding buildings and therefore block potential daylight entering other buildings, and can affect the urban planning of the cities. Receiving sunlight from a low solar angle can effect the building’s occupants, where direct sunlight can cause glare and discomfort, resulting in usage of blinds, and increased use of artificial lighting. All three locations have similar annual daylight hours, but what differs is the variation between months. Nordic cities are characterized by long days in the summer and short days in the winter, whereas the daylight hours are roughly the same throughout the year in southern locations of world. In Nordic cities, daylighting evaluation in buildings is undoubtedly important, where special considerations have to be made on how the building is oriented, the adjacent buildings, and the size and positioning of windows, more so than in countries where the solar angle holds steady, and considerately high throughout the year.

Architecture and urban planning in Reykjavík has changed drastically over the years, and reviewing those changes was considered helpful to get a fuller understanding of that development. While looking into the history of architecture and urban planning in Reykjavik, one finds that designers did not put a lot of consideration into designing with daylight until the 1940s when modernism made its way to Iceland. The urban environment of Iceland has rapidly changed, evolving from a town to a city. The city is denser, the buildings are taller and building materials constantly change and evolve, and these changes are nowhere near coming to a standstill. It is therefore important for designers to not let the hasty expansion of the city and economical thinking get in the way of the importance of creating a comfortable and a sustainable environment.

Sustainability certifications and building regulations were reviewed in order to see their requirements and methods being used. The sustainability certifications were two, LEED and BREEAM. LEED offers the user three different evaluation methods, DA, illuminance calculations under a clear sky condition through computer modeling, and finally physical measurements, once the building has been constructed. BREEAM offers two different methods, the DF method, and the UDI method. Both LEED and BREEAM are well known and recognized, but as has been pointed out, have flaws that might need reconsideration.

A comparison was conducted of the parts of Iceland's and Norway's building regulations that pertain to daylight. It can be stated that the requirements for the Norwegian regulations are considerably higher, as they require DF to be used. Iceland on the other hand has recently lowered the requirements for daylighting in buildings, a requirement that had not been changed since 1965. It is safe to say that Iceland is behind its neighboring countries when it comes to daylighting requirements, nevertheless, Norway, Denmark and Sweden are all performing daylight analyses using DF, a method that was, during the conduction of this study, discovered to hold fatal flaws.

Methods to evaluate daylight's potential were reviewed, with the aim of seeing what methods could be suitable for the Nordic daylight in Iceland. Several methods were analyzed, including the Waldram diagram, Daylight Factor, Climate Based Daylight Modeling, Useful Daylight Illuminance and Daylight Autonomy, and finally, three different rules of thumb used in design phases of buildings.

This study concluded that CBDM was the method best suited to Iceland's daylight scenario and urban environment.

Questionnaires were delivered to eight professionals in the field in Iceland, both architects and lighting designers, and six people responded. The main findings of the interviews were that DF is the method commonly used if there is a need for calculated results of daylighting, but when asked, only one of the experts claimed that DF was the optimal method to use to evaluate daylighting in buildings. As well only one participant claimed that CBDM was a suitable method to be implemented in Iceland, in contrast to the results from the previous literature review. Another interesting find was that half of the interviewees stated unprompted, that the requirements in the Icelandic building regulations were lacking.

6 CONCLUSION

Literature review and qualitative interviews were performed with the aim of answering the research question. The geographical location of Iceland and its unique daylight scenario was reviewed, the history of architecture and urban planning in Reykjavík, Iceland was analyzed, a detailed review of multiple daylight evaluation methods was performed as well as reviewing building regulations and sustainability certifications.

At the conception of this study, a research question and hypothesis were formulated and were as follows;

> "What methods are available to professionals to evaluate daylight in buildings in Iceland, during the design phase?
> - A review of methods and their suitability for Nordic daylight during the design phase of a building
> - Is there a need to update the current regulations in Iceland, in order to secure good daylighting design in buildings?"

Due to the lack of research done on this topic in Iceland, a research question covering these factors was thought to be important and necessary.

First, the question regarding the methods available to evaluate daylight in buildings and their suitability for Iceland is answered.

The results from the literature review demonstrated that climate based daylight modeling or CBDM was the method that would be most suitable for Iceland, in regards to the daylight scenarios and urban environment. There are still factors in the method that raise concerns, as there is a possibility to manipulate the outcome of the calculations.

The results of the qualitative interviews resulted in an interesting finding. The interviewees referred to DF as the most frequently used method, nevertheless, only one interviewee considered DF to be an optimal method to evaluate daylighting in buildings. However, only one interviewee stated that CBDM was the optimal method to evaluate daylight in buildings. These answers raised concerns. Based on the parameters of this study, CBDM was concluded to be the most feasible option to use for daylight evaluation in Iceland. According to the interviews conducted, it can be assumed that there is currently not enough knowledge on CBDM in the small industry of Iceland, to make it an industry standard.

Based on these interviews, CBDM can not be implemented as an industry standard in Iceland yet. The method is certainly the future of evaluating daylight in buildings, but there are still factors that need to be reconsidered within the method.

As an alternative, there is a possibility to better the current method used, the glass to floor ratio, with simple tables and calculators that are easy to use, for all professionals, architects and lighting designers. The method is easy to use, can be used during the design phase of a building, and does not require being performed by specialis. The factors that would need an update are that the method does not take surrounding buildings or the building orientation into account, as well as not considering window size and position. The bettering of the method can be considered as future work.

Secondly, the research aimed to answer if there is considered a need to update the current regulations in Iceland, in order to secure good daylighting design in Iceland. The hypothesis that was set forth aimed to conclude that the current building regulations in Iceland (the ones valid before the proposed change was accepted on May 3rd, 2016) were outdated and needed to be updated in order to keep up with the technology available today as far as daylight evaluation goes (and its capability of helping designers design sustainably from the beginning) as well as coming closer to meeting the standards of certain internationally acclaimed sustainability certification procedures. Unfortunately, the proposed changes that were accepted while this study was still ongoing, affected the regulations in a contradictory was to this study's hypothesis and findings believe as the design requirements were loosened further. When asked, an employee from the Construction Authority in Iceland said that there were no future plans relating to an update to the daylight chapter in the building regulations, as seen in Appendix 8. (Employee from the Construction authority, interview, 9th of May, 2016)

It is the author's hope that this study of evaluation methods for daylighting, and their suitability for Nordic conditions, can be of use when taking a step forward to a more sustainable environment.

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8 APPENDICES

APPENDIX 1: Questionnaire answered by Andri Garðar Reynisson

Name: *Andri Garðar Reynisson*
Age: *31*
Education: *Bachelor of Architecture, M.Sc. Architectural Lighting Design and Health*
Profession: *Lighting Designer*
For how long have you been working within your profession: *around 2 years*

1. Are you aware of methods to evaluate daylight adequateness in buildings? If so, please name those methods.

   Everything from physical modelling to computer software such as Ecotect, AGI32, GBS, Velux Visualizer and others.

2. Have you been involved in projects where daylight design was considered? If your answer is yes, please continue with this interview. If your answer is no, I thank you for your time.
   Yes.

3. What was the scope of your task?
   To evaluate the presence of daylight and the risk of overexposure.

4. Can you explain the process?
   Through 3D modelling I was able to evaluate the risks from 4 separate dates of the year, so average exposure could be evaluated.

5. During the process and the method(s) you chose to work with, were there any complications?
   An overexposure was recorded.

6. If you have one, please write down your most common method to evaluate daylight in buildings.
   Physical modelling combined with 3D modelling to confirm my findings.
7. In your expert opinion, what do you consider to be the best method to evaluate daylight in buildings?

Additional question: Are you aware of what regulations are in Iceland, regarding daylighting in buildings?
Somewhat or the lack of them.

APPENDIX 2: Questionnaire Answered by Anna Sigríður Jóhannsdóttir

Name: *Anna Sigríður Jóhannsdóttir*
Age: *52*
Education: *M.arch.*
Profession: *Architect*
For how long have you been working within your profession: *19 years*

1. Are you aware of methods to evaluate daylight adequateness in buildings? If so, please name those methods.
   Daylight factor and glass to floor ratio.

2. Have you been involved in projects where daylight design was considered?
   If your answer is yes, please continue with this interview. If your answer is no, I thank you for your time.
   All project need a lot consideration when it comes to daylighting. In nursing homes for example it is crucial to have sufficient daylight, but office buildings are not easier, whereas it is important that daylight is spread into the building, but not too much. There is not better to have large windows, which will just result in people pulling down the blinds and turning on the artificial lights. There you want to work more with the reflection of daylight, in order to have it well spread within the building.

3. What was the scope of your task?
   The daylight studies are early in the process.

4. Can you explain the process?
   Architects look at the site that the building will be built on, they look at surrounding buildings, where shadows will fall, where the street is, and design the building with the aim of using the daylight as well as possible.

5. During the process and the method(s) you chose to work with, were there any complications?
   no

6. If you have one, please write down your most common method to evaluate daylight in buildings.
   Glass to floor ratio. If I need to hand in any calculations or evidence, I will seek expert advice from a lighting designer.

7. In your expert opinion, what do you consider to be the best method to evaluate daylight in buildings?
   Simple procedures, rules of thumb are always good. Too complicated methods might scare of architects, who have though a lot of experience with designing with daylight and have done so for many years.

Additional question: Are you aware of what regulations are in Iceland, regarding daylighting in buildings?

Yes. But have not looked into the updated regulations.

Comment: the author explained the changes in the regulations and after that the author and Anna had a short talk about it.

"I think this is dangerous to allow this to happen. Architects do not have absolute power when it comes to decision making of the design. The client has the final answer on what he wants to build, the architect is hired to give advices and solutions, but the client has the final saying. In terms of energy conservation this is a step backwards and is not a positive thing."

Additional notes from the conversation:

- In the recent years/decades there have been build a lot of buildings which are made out of glass, but the daylight is not usable because it creates discomfort (glare) and people pull down the blinds and turn on the lights.

APPENDIX 3: Questionnaire answered by Ágúst Gunnlaugsson

Name: *Ágúst Gunnlaugsson*
Age: *47*
Education: *Electrician and a lighting designer*
Profession: *Lighting designer*
For how long have you been working within your profession: *10 years as a lighting designer, and previously as an electrician*

1. Are you aware of methods to evaluate daylight adequateness in buildings? If so, please name those methods.
   Yes. Daylight factor used in Dialux

2. Have you been involved in projects where daylight design was considered?
   If your answer is yes, please continue with this interview. If your answer is no, I thank you for your time.
   Yes

3. What was the scope of your task?
   Daylight calculations for BREEAM

4. Can you explain the process?
   According to the BREEAM requirements.

5. During the process and the method(s) you chose to work with, were there any complications? *Not*

6. If you have one, please write down your most common method to evaluate daylight in buildings. *Daylight factor*

7. In your expert opinion, what do you consider to be the best method to evaluate daylight in buildings?

   Daylight factor

Additional question: Are you aware of what regulations are in Iceland, regarding daylighting in buildings?
There is a lack of requirements in the building regulations

APPENDIX 4: Questionnaire answered by Björn Guðbrandsson

Name: *Björn Guðbrandsson*
Age: *42*
Education: *Master of Architecture*
Profession: *Architect*
For how long have you been working within your profession: *14 years*

1. Are you aware of methods to evaluate daylight adequateness in buildings? If so, please name those methods.
   Yes. For example software such as Dialux and 3ds max

2. Have you been involved in projects where daylight design was considered?
   If your answer is yes, please continue with this interview. If your answer is no, I thank you for your time.
   Yes, several times

3. What was the scope of your task?
   Architect, sometimes Breeam accessor

4. Can you explain the process?
   More or less according to the Breeam requirements.

5. During the process and the method(s) you chose to work with, were there any complications? *Not particularly with the methods*

6. If you have one, please write down your most common method to evaluate daylight in buildings. *I seek external expert advice on the matter.*

7. In your expert opinion, what do you consider to be the best method to evaluate daylight in buildings?

   Again, I rely on experts to find the best method.

Additional question: Are you aware of what regulations are in Iceland, regarding daylighting in buildings?
Minimum requirements of the building regulation.

APPENDIX 5: Questionnaire answered by Kristján Kristjánsson

Name: *Kristjan Kristjansson*

Age: *38*

Education: *Diploma Lighting Design*

Profession: *Lighting Designer*

For how long have you been working within your profession: *12 years*

1. Are you aware of methods to evaluate daylight adequateness in buildings? If so, please name those methods.

   Yes in Iceland i have been using Dialux CIE 110-1994

   In the UK Geometric algorithms and Sun path studies

2. Have you been involved in projects where daylight design was considered? Yes

   If your answer is yes, please continue with this interview. If your answer is no, I thank you for your time.

   Yes

3. What was the scope of your task?

   In Iceland daylight calculation for energy efficiency like breeam and LENI

   in the UK daylight and sunbeam calculations for better use of daylight and problematic harsh sunbeams in buildings.

4. Can you explain the process?

   Calculations Softwares like Dialux for energy efficiency and daylight factors.

   Sun calculating and sunbeam real video laps on location for long period of time using the information in 3D model do study the sun path in the building

5. During the process and the method(s) you chose to work with, were there any complications? *Yes budget*

6. If you have one, please write down your most common method to evaluate daylight in buildings. *I use Dialux alot (CIE 110-1994) for quick and simple daylight studies*

7. In your expert opinion, what do you consider to be the best method to evaluate daylight in buildings?

8. *Surveying the locations if possible using real data to compare with calculated values.*

Additional question: Are you aware of what regulations are in Iceland, regarding daylighting in buildings?

No i'm not a aware if there in regulations, there in the EU standards and ISO standards

APPENDIX 6: Questionnaire answered by Rósa Dögg Þorsteinsdóttir

Name: *Rósa Dögg Þorsteinsdóttir*
Age: *34*
Education: *Interior- and lighting designer*
Profession: *Lighting Designer*
For how long have you been working within your profession: *9 years*

1. Are you aware of methods to evaluate daylight adequateness in buildings? If so, please name those methods.
Yes, daylight factor, glazing area to floor area ratio, view of sky, glare/solar control evaluation, scale model study with heliodon.

2. Have you been involved in projects where daylight design was considered?
If your answer is yes, please continue with this interview. If your answer is no, I thank you for your time.
Yes.

3. What was the scope of your task?
Daylight calculation for evaluation of Breeam standard in buildings and Passivhus standard in Norway.

4. Can you explain the process?
For Breeam evaluation we studied the daylight factor, point DF, average DF. For us to do that we transferred BIM Revit model into Dialux and 3D studioMAX using gbXML model. After that we clean the model with bugs and insert daylight scenario, then calculate each room. For Passivhus we needed to calculate minimum lux on a surface, where we needed to maintain a certain illuminance but couldn't exceed 15 kWh/m2 per year.

5. During the process and the method(s) you chose to work with, were there any complications?
Yes. In 3D studioMAX are only square calculation surfaces and when rounded spaces need to be calculated it can be tricky! Sometimes the models have too many errors to import into evaluation programs and the architect needs to correct the BIM model for it to work properly, asking the architect to do these changes to the model only because we need it for evaluation is sometimes hard. The exact method of how to do the daylight calculation in a computer model is not very clear and sometimes its different between countries.

6. If you have one, please write down your most common method to evaluate daylight in buildings.
Daylight factor.

7. In your expert opinion, what do you consider to be the best method to evaluate daylight in buildings?
Climate based daylight calculation method.

Additional question: Are you aware of what regulations are in Iceland, regarding daylighting in buildings?
Yes, in the building regulation there is only glazing area and floor area ratio and some unclear recommendation on in what spaces windows should be and view out. There is on the other hand non that I know of any minimum regulation on how much daylight should be in buildings.

APPENDIX 7: Interview with Rósa Dögg Þorsteinsdóttir, Lighting Designer, 12th of May, 2016, 12:00 – 12:50.

A short conversation was had prior to the questions asked, to inform the interviewee of the topic of the thesis. That part was not documented as it was not considered to be relevant.

T: Are you familiar with more methods that DF and glass to floor ratio
R: Yes, for example Useful Daylight Illuminance
T: Have you then worked with other methods besides Daylight factor?
R: Yes, I was involved with a project in Norway, a swimming pool that needed to reach the requirements for Passivhus. There we used UDI.
T: Are you familiar with the building regulations, that is, how they were before the changes that came in the beginning of May?
R: Yes, I know them.
T: Do you have any thoughts or consirns of the building regulations? Anything you would like to share with me?
R: No, not really, I would say that the only times that a lighting designer is considering daylight is when the project has the requirement of BREEAM. Otherwise, it is the architects job to make sure that the building is according to regulations.

T: Have you reviewed the updated version to the regulations?
R: Yes
T: What are your thoughts and considerations?
R: I think it's questionable. Architects in the past have studied daylight, they have learned to design the building in a way were daylight is presented in the best way possible. "Lowering"
In a way, the regulations might decrease the interest of architects, and architect students of daylight, and slowly the responsibility of daylight moves from architects to lighting designers. By that I mean, that It might lead to the architect putting the responsibility of the daylight in the hands of a lighting designer. To be honest, I am a little bit afraid of this development.
In the regards of lowering the requirements of the ceiling height, I'm skeptical of that. Look at houses in Sweden for example. A lot of them are really bright and beautiful. That's maybe not because of the window size, but the ceiling height! Also looking at buildings in Milano. Many of them are built in a "box", whereas it is built around a courtyard. Those apartments only have on window side of the apartment, but are still bright, since the ceiling height is high. This is what matters. If the window is placed higher on a wall, the daylight penetrates the spaces deeper. It think this updated version is clearly a step back.
T: Through the years, Iceland has always looked to Sweden, Norway and Denmark when it comes to building regulations. But in the matters of daylight, we have not updated ours in regards of what is happening in our neighboring countries. What are

your thoughts? Do you believe that it is necessary to update them in accordance to N, S and D?
R: It's a tough question. Icelanders have always designed accordance to "rules of thumbs", whereas we know that the living room window should face south, the bedrooms face north, the ideal window size, and usually you don't have to think about adjacent buildings blocking the view, since there hasn't been a lot of tall buildings. There has been a lot of "common sense" when it comes to designing buildings.
T: But if we look at how the urban environment in Iceland is developing, this is changing. There are actually tall buildings in Reykjavik.
R: That's the thing, now the city has changed. As well are we more inside of buildings, we are in office buildings 8 hours a day. It makes it more important to have enough daylight inside of buildings.
T: What do you think of that now there are no requirements of how many sides of the apartment has windows and which direction that window is facing?
R: I think it is awful to be honest. As I said previously, in Italy you have those buildings, with only windows on one side, but those buildings have a ceiling height of maybe 3.5 meters, and of course you have to look at how the sun is positioned! Those are completely different conditions!

T: Would you want to see DF implemented as a building regulations, like it is in Denmark and Norway for example?
R: I'm not sure. There are a lot of "errors" in regards of DF. There are a lot that needs to be considered. For example, I believe that what BREEAM uses, where you are required to have a "view of sky" and consider the room depth in compliance to the window head height and the reflection of a wall, is a very effective way, and a good method.
Requirement inserted by author;

(d) *(At least 80% of the room has a view of sky from desk or table top height (0.85m in multi-residential buildings, 0.7m in other buildings)*
(e) *The room depth criterion* $d/w + d/HW < 2/(1-RB)$ *is satisfied*

d = *room depth*
w = *room width*
HW = *window head height from floor level*
RB = *average reflectance of surfaces in the rear half of the room*

I think that in a way the study of daylighting is being taken away from the architects if we implement a complicated method. But where does the knowledge go then? Who takes it over then? If the considerations of daylight moves over to engineers and lighting designers, isn't there something that gets lost in the middle, that is, from the designing of the building?

"A lot of people agree that LEED is better than BREEAM when it comes to the daylight chapter"

APPENDIX 8: Notes from an interview taken on the 9th of May, 2016 with an employee of the Construction Authority of Iceland, who wished to remain anonymous.

- The updates to the building regulations were done in the sole purpose of lowering the construction cost.
- We trust that designers can evaluate the daylight, and ensure that there is sufficient daylight in buildings.
- If the contractor is eager to build a building, that is seriously lacking when it comes to daylighting, we expect that the designer resigns from the project, that is, if the designer is not satisfied with the requirements from the contractor.
- Iceland looks to Norway, Sweden and Denmark, when it comes to all building regulations.
- There are no plans on developing the chapter that relates to daylighting.