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# Daylight requirements in the Norwegian Regulations vs. the European Standard: A case study considering thermal performance

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# Daylight requirements in the Norwegian Regulations vs. the European Standard: A case study considering thermal performance

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# PREFACE

This is a master thesis within the specialization TBA4905 Building and Material Engineering in the study Civil and Environmental Engineering at the Norwegian University of Science and Technology. The thesis is a product of work performed during the fall of 2018 and completed January 2019.

My interest in building physics traces back to our first introduction to the theme in the course TBA4125 BM4 Design of buildings and structures, which led me to further choose courses within this specialization. After exchanging to the US for one year, I was unsure of which topic within building physics I wanted to specialize in, resulting in the decision to spend an extra semester taking additional courses related to the subject. One of the courses, AAR4850 Light and Lighting at NTNU with Professor Barbara Szybinska Matusiak awoke my interest and passion for daylight and became one of the reasons I chose to write about daylight in both my specialization project and later this master thesis. The second reason is my interest in architecture, thus the desire to move as close as possible to this interface.

I would like to thank my supervisor Associate Professor Mohamed Hamdy, who has been a great sparring partner, helping me sort, develop and perfect this thesis throughout the semester. His expertise within IDA ICE as well as contact with EUQA has been a great help. He has been very committed and provided guidance and encouragement when needed.

Furthermore, I would like to thank Multiconsult for the cooperation and for providing me with the necessary material to develop the case study. I am especially grateful to Cecilie Schmidt Overøye for project material and communication with the project owners, Vibecke Lea for guidance regarding thermal comfort and Ruth Marie Bottheim for excellent input and guidance regarding daylight simulations.

Finally, I would like to thank all my classmates for five amazing years at NTNU, leading up to this final thesis. A special thanks to my office partner Julie Sandli Danbolt, making this last semester memorable, and to my study partner Hanne Seeberg for company and encouragement, whom without this final month of the thesis would not have been possible.

Trondheim, January 2019

Helene Solvang

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# ABSTRACT

In this thesis, the Norwegian Building Regulation TEK17 and the European Daylight Standard FprEN17037 has been compared considering daylight performance, and the consequences of implementing their different criteria regarding thermal comfort and energy demand. The thesis consists of both an abstract and quantified comparison.

For the quantified comparison, a reference building from a construction project for residential building blocks at Løren in Oslo, called *Gartnerkvartalet* was used. Two critical rooms were chosen, regarding daylight and thermal comfort. These zones were then simulated in IDA ICE with different glazing areas and additional shading possibilities, in order to evaluate and compare their performance. 45 designs per zone were made, which again was given two locations, resulting in total 90 different models to simulate. The designs are combinations of five different glazing alternatives and 8 different additional shadings. The glazing areas are based on the different requirements in TEK17, FprEN17037 as well as including the glazing as designed for the project. The additional shadings consist different shading obstructions and window shadings. In order to create and manage all the different design combinations, a framework for the case management and simulation process was developed.

Comparing the Norwegian Building Regulations TEK17 and the European Daylight Standard FprEN17037, there is a difference in scope and approaches for evaluating daylight provision in buildings. TEK17 uses average daylight factor as a measure, while FprEN17037 uses target annual illuminance levels or target daylight factors. This results in the need of simulation software capable annual daylight simulations and more complex management of the daylight results for FprEN17037 than TEK17.

The results of the quantified comparison of TEK17 and FprEN17037 revealed a difference in the equivalent values for achieving their respective daylight criteria. This showed that fulfilling the criteria in FprEN17037 also will fulfil the criteria in TEK17, but not the other way around, meaning FprEN17037 ensures better daylight provision in buildings. When evaluating the performance of thermal comfort and energy demand, the results show that achieving the daylight criteria according to FprEN17037 require a large glazing area, which leads to a more hours of unacceptable thermal comfort and space heating demand compared to the glazing areas required in order to fulfill TEK17. Thus, considering thermal comfort and energy demand, TEK17 performs better than FprEN17037.

# SAMMENDRAG


I denne masteroppgaven er Norsk Byggteknisk Forskrift TEK17 og den Europeiske Standarden for Dagslys FprEN17037 blitt sammenlignet med hensyn på dagslys, samt hvilke konsekvenser for termisk komfort og energibehov de ulike kriteriene medfører. Oppgaven består både av en abstrakt og kvantifisert sammenligning.

For den kvantifiserte sammenligningen ble det benyttet et referansebygg fra et byggeprosjekt for boligblokker ved Løren i Oslo, kalt *Gartnerkvartalet.* To kritiske rom ble valgt med hensyn til dagslys og termisk komfort. Disse sonene ble deretter simulert i IDA ICE med forskjellige glassarealer og typer solskjerming, for å evaluere og sammenligne deres ytelse. 45 design per sone ble laget, som igjen ble gitt to lokasjoner, noe som resulterte i totalt 90 forskjellige modeller å simulere. Designene består av kombinasjoner av fem forskjellige alternativer for glassareal og 8 forskjellige typer for solskjerming. Vinduene er basert på de ulike kravene i TEK17, FprEN17037, samt vinduene slik de er designet for prosjektet. Solskjermingen består av skyggende nabobygg med ulik høyde og vindusskjerming. For å lage og håndtere alle designkombinasjonene, ble det utviklet et rammeverk for filhåndtering og simuleringsprosessen.

Ved å sammenligne Norsk Byggteknisk Forskrift TEK17 og den Europeiske Standarden for Dagslys FprEN17037, ser man en forskjell i omfang samt metoder for vurdering av dagslysforhold i bygninger. TEK17 bruker parameteren gjennomsnittlig dagslysfaktor, mens FprEN17037 benytter antall årlige timer med oppnådde illuminansnivåer eller dagslysfaktorer. Dette resulterer i et behov for simuleringsprogramvare kapabel til å gjennomføre årlige dynamiske dagslys-simuleringer og mer kompleks håndtering av dagslysresultatene for FprEN17037 enn TEK17.

Resultatene av den kvantifiserte sammenligningen av TEK17 og FprEN17037 viste en forskjell i deres ekvivalente verdier for å oppnå sine respektive dagslyskriterier. Ved å oppfylle kravene i FprEN17037, vil man også oppfylle kravene i TEK17, men ikke omvendt. Dette betyr at FprEN17037 sikrer bedre dagslysforhold i bygninger enn TEK17. Om man vurderer termisk komfort og energibehov, fører kritereien i FprEN17037 til et stort glassareal, som fører til flere timer med uakseptabel termisk komfort sant energibehov til oppvarming, sammenlignet med glassarealet som krever for å oppfylle kriteriene i TEK17. Dette betyr at TEK17 sikrer bedre bygningsdesign med hensyn på termisk komfort og energibruk, enn FprEN17037.

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# ABBREVIATIONS

| | |
|---|---|
| **BRA** | Bruksareal (in Norwegian); Usable area (in English) |
| **CIE** | Comission International de l'Eclairage |
| **CIE 171:2006** | International standard; *Test Cases to Assess the Accuracy of Lighting Computer Programs* |
| $\boldsymbol{D}$ | Daylight factor |
| $\boldsymbol{D_T}$ | Target daylight factor |
| $\boldsymbol{D_{TM}}$ | Minimum target daylight factor |
| **DIVA-for-Rhino** | Design Iterate Validation Adapt-for-Rhinoceros. A daylighting and energy plug-in for Rhino and Grasshopper. |
| $\boldsymbol{E}$ | Illuminance |
| $\boldsymbol{E_T}$ | Target illuminance |
| $\boldsymbol{E_{TM}}$ | Minimum target illuminance |
| **FprEN17037:2017** | European Standard; *Daylight of buildings* |
| $\boldsymbol{g_T}$ | Total solar heat gain coefficient |
| **IDA ICE 4.8** | IDA Indoor Climate and Energy. Building performance simulation software. Version 4.8 |
| **ISO** | International Organization for Standardization |
| **ISO 15469:2004** **(**CIE S 011/E:2003**)** | International Standard; *Spatial distribution of daylight – CIE standard general sky* |
| **NS-EN 12464-1:2011** | Norwegian/European Standard; *Light and lighting - Lighting of work places - Part 1: Indoor work places* |
| **NS-EN 15251:2007+NA:2014** | Norwegian/European Standard; *Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics* |
| **RIBfy** | Rådgivende Ingeniør Bygningsfysikk (in Norwegian); Consulting Engineer within Building Physics (in English) |
| **SP1** | Service Pack 1; newest update of IDA ICE 4.8 |
| $\boldsymbol{T_O}$ | Operative temperature |
| **TEK10** | The Norwegian Building Regulation – Edition from 2010 |
| **TEK17** | The Norwegian Building Regulation – Edition from 2017 |

# DEFINITIONS

The following terms are rapidly used in this thesis, thus are their definition presented.

**Illuminance**

‘’The luminous flux per unit area at any point on a surface exposed to incident light. It is measured in lux.’’ (Dictionary.com, n.d.)

**Daylight factor**

‘’Ratio of the illuminance at a point on a given plane due to the light received directly or indirectly from a sky of assumed or known luminance distribution, to the illuminance on a horizontal plane due to an unobstructed hemisphere of the sky, excluding the contribution of direct sunlight to both illuminances.’’ (CEN/TC 169, 2017 p.7)

# 1 INTRODUCTION

## 1.1 BACKGROUND

Daylight is an important factor to good health, as it has shown to have an impact on the circadian rhythm, mental health, vitamin D production etc.(WHO, n.d.) Good daylight provision often requires large glazing areas, which might contribute to overheating because of exposure to sun. It is also identified that overheating during summer for well insulated residential buildings even occurs in colder climates. (Persson et al., 2006) This means that the combination of large glazing areas and well insulated buildings may contribute to a poor thermal environment. The conflicting point of views focusing on good daylight provision and health or on thermal comfort and energy demand, illustrates the complexity of designing optimal buildings including all point of views.

As daylight, thermal comfort and energy are disciplines that are closely related and dependent of each other, it is important to know the extent of their correlation regarding a building's performance. Despite this, the trend is that daylight has traditionally been evaluated separately. With an arising focus on sustainable building design, this trend is changing, making it important to know their relations.

There are regulations concerning daylight in The Norwegian Building Regulations, but there has been discussions about a negative development of the criteria the last ten years, as an effect of other regulations becoming stricter. (RIF, 2017) This reflects the focus on daylight being down prioritized. In 2018 the first European Daylight Standard was released. Because of its new release, knowledge of the approach and criteria are still limited.

## 1.2 PURPOSE

The purpose of this master thesis is to compare the Norwegian Building Regulations (TEK17) and the European Daylight Standard (FprEN17037) considering daylight, and the consequences of implementing their different criteria regarding thermal comfort and energy demand. FprEN17037 is the first European standard for daylight, thus are the experience with the methods limited. The standard applies measures for adequate daylight conditions which are different from the ones used in TEK17. Based on this, are the following research questions formed in order to evaluate the possible differences and consequences of the two:

***Review***

- RQ1: Which one of the standards are easier to implement?

***Case Study***

- RQ2: What are the equivalent criteria for TEK17 and FprEN17037 according to their different approaches to daylight measures, and which one of the two provides a better building design for daylight availability?
- RQ3: What are the consequences of achieving the different levels of daylight, regarding thermal comfort and energy demand?

## 1.3 PROCEDURE

This master is divided into four parts, excluding the introduction. The first part is a review of relevant regulations, standards and papers regarding daylight, which will be used further in the thesis. This part also includes an overview of simulation software fit to perform daylight simulations.

The second part presents the method used when developing the thesis, divided in five steps. The first step is an abstract comparison of TEK17 and FprEN17037 related to the review and is the material used to answer the first research question. The following steps are related to the quantified comparison and case study, which explains the creation of cases, models and framework used to perform simulations.

The third part contains results and discussion. This part is sorted in four parts, according to the subjects being evaluated. These are lighting performance, thermal performance, indoor comfort and energy demand. The lighting performance includes all the results and evaluation of the daylight conditions, which are the material needed to answer the second research question. It also contains results for the artificial lighting demand and the relation of the two. Thermal performance presents the results for both thermal comfort and space heating demand. The two last parts contains the already presented results, processed and put in relation to one another, in order to being able to answer the third research question.

The final part is the conclusion of the thesis, presenting both the main findings and suggestions to future work.

# 2 REVIEW

The following review presents the relevant building codes, standards, theory, publications and other works used in this thesis. The chapters concerning daylight in the Norwegian Building Regulations TEK17 and the European Standard FprEN 17037 will be described more detailed, as these form the base of the thesis' comparison.

## 2.1 DAYLIGHT REQUIREMENTS IN NORWEGIAN REGULATIONS AND STANDARDS

The following Norwegian building regulations and standards are applied and further referred to in the thesis.

**Norwegian Building Regulation - TEK17**

The Norwegian Building Regulations consist of technical requirements and minimum properties a building must have in order to be legally built. The regulations are functional, but also interpreted to performance requirements, includes a guide with pre-accepted performances that meets these requirements. (TEK17, 2017a)

The following paragraphs are taken from TEK17 and contain functional requirements and criteria concerning daylight, with pre-accepted performance on how these can be achieved.

*''§ 13-7. Light: (2) Rooms for long term stay must have adequate access to daylight.*

''1. Pre-accepted performances:

a. Average daylight factor DF ⩾ 2,0% for most critical room regarding adequate daylight. The calculations must be performed in simulation programs validated according to CIE 171:2006 and with the assumptions given in NS-EN 12464-1:2011 chapter 4.4.

$$\overline{DF} \geq 2{,}0\% \quad [1]$$

b. For rooms in dwellings, the daylight requirement can alternatively be documented with the following method:

$$A_g \geq 0{,}07 * A_{BRA} * LT \quad [2]$$

$A_g = area\ of\ glass\ located\ minimum\ 0{,}8\ m\ above\ the\ floor$

$A_{BRA} = usable\ area\ of\ the\ room, included\ area\ under\ overhead\ balcony$

$$or\ other\ protruding\ building\ parts$$
$$LT = Light\ transmittance\ of\ the\ glass$$
$$\theta = 45°\ maximal\ shading\ angle\ measured\ from\ the\ horizontal\ plan''$$

(TEK17, 2017b)

**European light standard - NS-EN 12464-1:2011**

‘’Light and lighting - Lighting of workplaces - Part 1: Indoor work spaces’’

According to TEK17 §13-7, presented earlier in this chapter, should simulations for $\overline{DF}$ be performed with the assumptions from NS-EN12464-1:2011 chapter 4.4. These assumptions describe how grid systems should be created.  to form below.

‘’4.4 Illuminance grid

$$p = 0{,}2 * 5^{\log_{10}(d)} \quad , and\ \#\ grid\ points \geq {}^{d}/_{p} \qquad [3]$$

$$p: max.\,grid\ cell\ size$$
$$d: longer\ dimension\ of\ the\ calculation\ area$$
$${}^{d}/_{p}: nearest\ whole\ number - number\ of\ grid\ points\ in\ d''$$

(Standard Norge, 2011)

## 2.2 INTERNATIONAL REGULATIONS AND STANDARDS

The following international building regulations and standards are applied and further referred to in the thesis.

**European Daylight Standard - FprEN17037:2017**

‘’Daylight in buildings’’

The European standard for daylight prepared of the Technical Committee CEN/TC 169 ‘’Light and Lighting’’. The scope of the standard includes methods for achieving adequate daylight provision, and view out, as well as recommendations for exposure to sunlight and limit glare. For all the aspects, defined metrics, calculation methods and verification are given. The criteria are location specified. (CEN/TC 169, 2017) The following parts of the standard is used further in the thesis:

*’’A.2 Recommendations for daylight provision in space*

*Table A.1 give recommendations for daylight provision in a space. The table include levels of target illuminance $E_T$ (lx) and target minimum illuminance $E_{TM}$ (lx). A target illuminance $E_T$ level should be achieved across a specified fraction $F_{plane\%}$ of the reference plane within a space. For a space with vertical opening inclined daylight openings(s), a minimum target illuminance $E_{TM}$ (lx) should be achieved across the entire (i.e. 95%) fraction $F_{plane\%}$............ The recommendations in Table A.1 can be expressed in terms of a daylight factor $D$. Table A.3 provide the corresponding daylight factor (D) relative to recommended target illuminance $E_T$ (lx) and target minimum illuminance $E_{TM}$ (lx).''* (CEN/TC 169, 2017 p.15)

**Table A.1 — Recommendation of daylight provision by daylight openings in vertical and inclined surface**

| Level of recommendation for vertical and inclined daylight opening | Target illuminance $E_T$ lx | Fraction of space for target level $F_{plane,\%}$ | Minimum target illuminance $E_{TM}$ lx | Fraction of space for minimum target level $F_{plane,\%}$ | Fraction of daylight hours $F_{time,\%}$ |
|---|---|---|---|---|---|
| Minimum | 300 | 50 % | 100 | 95 % | 50 % |
| Medium | 500 | 50 % | 300 | 95 % | 50 % |
| High | 750 | 50 % | 500 | 95 % | 50 % |
| NOTE Table A.3 gives target daylight factor ($D_T$) and minimum target daylight factor ($D_{TM}$) corresponding to target illuminance level and minimum target illuminance, respectively, for the CEN capital cities. | | | | | |

*Figure 2-1 Table A.1 from FprEN17037 with recommended values for daylight provision (CEN/TC 169, 2017 p.15)*

**Table A.3 — Values of *D* for daylight openings to exceed an illuminance level of 100, 300, 500 or 750 lx for a fraction of daylight hours $F_{time,\%}$ = 50 % for 33 capitals of CEN national members**

| Nation | Capital [a] | Geographical latitude $\varphi$ [°] | Median External Diffuse Illuminance $E_{v,d,med}$ | *D* to exceed 100 lx | *D* to exceed 300 lx | *D* to exceed 500 lx | *D* to exceed 750 lx |
|---|---|---|---|---|---|---|---|
| Norway | Oslo | 59,90 | 12 400 | 0,8 % | 2,4 % | 4,0 % | 6,0 % |

*Figure 2-2 Table A.3 from FprEN17037 with corresponding values for daylight factor relative to the values given in Table A.1. (CEN/TC 169, 2017 p.16)*

**International Standard – ISO 15469:2004 (CIE S 011/E:2003)**
‘’Spatial distribution of daylight – CIE Standard General Sky’’

‘’This standard defines a set of outdoor daylight conditions on linking sunlight and skylight for theoretical and practical purposes.’’ (ISO 15469:2004, n.d.) ‘’Sets of luminance distributions defines different skies under a wide range of conditions. The standard can be used to both classify measured sky distributions and as a method in daylighting design for calculating sky luminance.’’ (CIE TC 3-15 “‘Sky Luminance Models,’” n.d.)

15 CIE sky types with attributes are presented in Figure B - 1 in Appendix B. CIE sky models. ‘’Overcast skies tend to be used for numerical work, which is aimed toward obtaining unambiguous quantities such as the daylight factor’’(Mardaljevic, 2003) The CIE standard overcast sky is used for calculating daylight factors. Its luminance changes with altitude, where the zenith is three times as bright as the horizon. (“Sky Types,” n.d.) See Figure B - 2 in Appendix B. CIE sky models, for details on this sky type.

**International standard – CIE 171:2006**
‘’Test cases to assess the accuracy of lighting computer programs’’

This standard is referred to in TEK17 §13-7 as well as FprEN17037 chapter B.3. The standard contains a validation approach and recommendations to test the accuracy of lighting computer programs. (TC 3-33, n.d.) The standard is not a list over approved software, but an approach to validate the software using test cases. (Ashdown, 2016)

## 2.3 BUILDING PERFORMANCE SIMULATION SOFTWARE

A simulation means mimicking an actual real life condition or scenario of assumed circumstances and factors, in order to find a cause of, or predict future events. (“What is a simulation,” n.d.) A building performance simulation integrates complex interactions between disciplines such as physics, mathematics, material science, biophysics, human behavioral, environmental and computational sciences in order to predict and evaluate the performance of a building. (Djunaedy et al., 2006) The level of simulation complexity varies, depending on the amount disciplines and time period evaluated. Simulations can be divided in the following three methods, dynamic being the most complex:

- Empirical – time frame: year, month
- Static – time frame: month, day

- Dynamic – time frame: day, hour, seconds (Haase, 2014)

Both TEK17 and FprEN17037 refers to CIE 171:2006 for software that should be used in simulations. Some of these are listed in Table 2-1. Two of the software are further presented.

*Table 2-1: Simulation software validated according to CIE 171:2006 (Geisler-Moroder and Dür, n.d.)*

| **Program** | **Manufacturer** |
|---|---|
| *3ds Max Design* | Autodesk |
| *APOLUX/LightTools* | |
| *DIALux/DIAL Eco* | DIAL GmbH |
| *Tas Daylight* | EDSL |
| ***Radiance*** | LBNL |
| *Agi32/ElumTools* | Lighting Analysts |
| *Lightscape* | Lightscape Technologies |
| *mental ray* | Mental Images |
| *iRay* | nVidia |
| *SPEOS* | Optis |
| ***Relux*** | Relux |
| *Daylight Visualiser* | Velux |

**Radiance**

Radiance is a lighting simulation software package that uses ray-tracing techniques to compute light levels and present the results both numerically and with rendered images. The package contains programs managing material properties, luminaire data, scene geometry and modeling. The simulation engine utilizes a hybrid approach of deterministic backward (back to source) ray tracing and Monte Carlo. (Radsite, 2013).

**Relux**

‘’Relux is a high-performance, intuitively-operated application for simulating artificial light and daylight.‘’ The software is capable of calculation of absolute values, supports national and international standards, as well as being compatible with CAD and BIM systems (ReluxNet, n.d.) The program has a comprehensive library of components used in artificial lighting design, making it a preferred tool for light designers. A report issued by SINTEF Byggforsk, investigated the most used simulation tool for daylighting simulations. The report revealed that Relux was the most widely used by 6 of 7 consulting companies. (Almås et al., 2016)

## 2.4 RELEVANT WORK

### Publications

The following listed publications contain relevant topics to this thesis. As FprEN17037 is the first European daylight standard and is newly released, there is not performed any comparing work like in this thesis. This results in the following publications not being used any further.

***Publication 1***

‘’The effect of dynamic solar shading on energy, daylight and thermal comfort in a nearly zero-energy loft room in Rome and Copenhagen’’ (Skarning et al., 2017)

This paper studied dynamic shading and its effect on the performance of daylight, thermal comfort and energy demand, by using climate-based daylighting metrics.

***Publication 2***

‘’Impact of façade window design on energy, daylighting and thermal comfort in nearly zero-energy houses’’ (Vanhoutteghem et al., 2015)

This paper is very relevant, and have investigated some topics similar to this thesis. It has analyzed window solutions for design of ‘nearly zero-energy’’ buildings in Denmark. The software EnergyPlus and Daysim was used.

***Publication 3***

‘’Thermal and Daylight Evaluation of Building Zones’’ (Altan et al., 2015)

This article analysis thermal balance and daylight in building residential zones, with the focus on the influence on reduction of solar gains and daylight by of the façade insulation layers and multi-pane windows. The software DesignBuilder was used. The results contained information about optimal façade design for energy efficiency and daylighting.

***Publication 4***

‘’Analysis of daylight metrics of side-lit room in Canton, South China: A comparison between daylight autonomy and daylight factor’’ (Bian and Ma, 2017)

This paper compares daylight factor and daylight autonomy using the simulation software Daysim. Daylight autonomy are based on climate-based-daylight modeling and are similar to the criteria in FprEN17037. This paper in relevant only for the daylight-part of this thesis.

# 3 METHODOLOGY

The methodology of this thesis consists of 5 steps, presented in Figure 3-1.

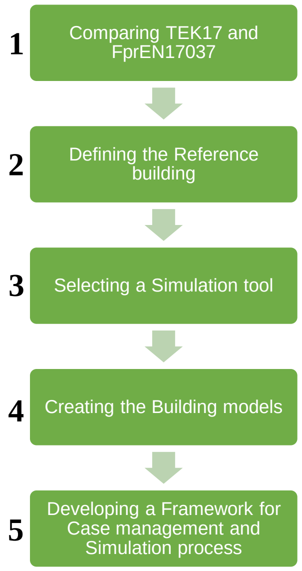



*Figure 3-1 Schematic diagram for the Thesis' methodology*

The first step is an abstract comparison of the TEK17 and FprEN17037 related to the review and is the material used to answer the first research question.

The second step is a presentation of the reference building, being based on a real building project for residential buildings in Oslo.

The third step presents simulation software relevant for thermal and energy simulations, and in combination with software suitable for daylight simulations, evaluates which tool should be used in the thesis.

The fourth step explains how the building model was made, by locating the two most critical zones regarding daylight and thermal comfort.

The fifth step contains the framework of the thesis. It is explained how the framework is developed and how it is used to perform the simulations.

## 3.1 COMPARING TEK17 AND FPREN17037

The following table Table 3-1 compares the scope, content and relevant methods for evaluating daylight provision according to TEK17 and FprEN17037. For the quantified comparison on the theses, only the chapters concerning daylight provision are evaluated, as these have comparable criteria. For this reason, these are presented in more detail than the other chapters for both TEK17 and FprEN17037.

TEK17 is the Norwegian regulations, thus must be applied and fulfilled in building design. FprEN17037 is a standard, which makes it optional to use. Still, standards often referred to for use in many of the regulations. For now, this is not the case in the daylight paragraph in TEK17.

The main difference in the evaluation of daylight provision, are the criteria. Both TEK17 and FprEN17037 allow two different methods and measures in order to be achieved, which in theory should be equivalently equal. None of the four criteria are in the same measure, making it difficult to evaluate which one has the higher requirements, without a quantified comparison.

The parameters in TEK17 are minimum glazing area and average daylight factor $\overline{DT}$, presented as a) and b) in the table. The minimum glazing is a calculated value, including the effect of the light transmission of the glazing and floor area. $\overline{DT}$ requires simulation in order to define the glazing area needed, thus making it a more realistic calculation with additional factors having an impact on the daylight provision. This evaluation requires a static simulation, as daylight factor is independent of time.

FprEN17037 uses target and minimum target illuminances $E_T$ and $E_{TM}$, or target and minimum target daylight factors, $D_T$ and $D_{TM}$. The illuminances are values that should be achieved av fraction of the area for more than 50% of the daylight hours in a year. This requires an annual dynamic simulation with site specific climate data, in order to perform hourly calculations for the illuminance. The daylight factors are stated to be the equivalent to the illuminance criteria and are defined to be achieved in the same fractions of area as the illuminances.

Table 3-2 is a presentation of the different the criteria which given a ‘’glazing alternative’’. These different glazing alternatives form is the base of the comparison between the different requirements. The alternatives are further explained in detail in 3.5.

*Table 3-1 Comparing overview of TEK17 and FprEN17037*

| | | TEK17 | | FprEN17037 | |
|---|---|---|---|---|---|
| Type of document | | Technical Regulations; must follow | | Standard; optional, can be used to document achieved criteria acc. to regul. | |
| Scope | | • **Daylight provision**<br>• View out | | • **Daylight provision**<br>• View out<br>• Exposure to sun<br>• Protection from glare | |
| Daylight provision | Measure | Minimum average daylight factor: $\overline{\boldsymbol{DF}}$ [%] | Minimum glazing area: $\boldsymbol{A_g}$ [$m^2$] | Target illuminance: $\boldsymbol{E_T}$ and minimum target illuminance: $\boldsymbol{E_{TM}}$ [lux] | Target daylight factor: $\boldsymbol{D_T}$ and minimum target daylight factor: $\boldsymbol{D_{TM}}$ [%] |
| | Criteria (Choose one of the two alternatives) | a) $\overline{DF} \geq 2\%$ | b) $A_g \geq 0{,}07 * \frac{A_{BRA}}{LT}$ | Method 1) $E_T \geq 300 lux,$ $50\%\ of\ BRA$ $and$ $E_{TM} \geq 100 lux,$ $95\%\ of\ BRA$ $for\ 50\%\ of\ daylit$ $hours\ per\ year$ | Method 2) $D_T \geq 2{,}4\%,$ $50\%\ of\ BRA$ $and$ $D_{TM} \geq 0{,}8\%,$ $95\%\ of\ BRA$ |
| | Boundary conditions | - | • Shading obstructions θ < 45°<br>• Placement height 0,8m<br>• Balconies and fixed overhangs; areas included in $A_{BRA}$ | Include correct space geometry;<br>• External obstructions<br>• Window shading<br>• Moveable shading devices – with control strategy | Include correct space geometry;<br>• External obstructions<br>• Window shading |
| | Reflection factors | - | - | Standard values; floor: 0,2; ceiling: 0,7; walls: 0,5 | |
| Simulation requirements | Validation | CIE 171:2006 | - | CIE 171:2006 | |
| | Type | Static | - | Annual dynamic | Static |
| | Data | Location | - | • Location<br>• Hourly climate and weather data | Location |
| | Sky conditions | - | - | Hourly sky and sun conditions from site specific climate data | ISO 15469:2004 Standard overcast sky (TYPE 1 or TYPE 16) |
| | Calculation grid | NS-EN 12464-1:2011 chapter 4.4: $p = \mathbf{0{,}2} * 5^{\log(d)}$ | - | $p = \mathbf{0{,}5} * 5^{\log(d)}$ | |

*Table 3-2: Design alternatives for glazing area*

| Standard | Paragraph/chapter | Formula/limit | Equation | Glazing alternative |
|---|---|---|---|---|
| TEK17 | §13-7. Light (2) a) | $A_g \Rightarrow \overline{DF} \geq 2\%$ | (1) | **B1** |
| | §13-7. Light (2) b) | $A_g \geq 0{,}07 * \frac{A_{BRA}}{LT}$ θ < 45° | (2) | **A1** |
| | §14-2. Requirements for energy efficiency (2)(energy measures) | $\frac{A_g}{A_{BRA}} \leq 25\%$ | (3) | **A2** |
| FprEN13037 | Annex A Chapter A.2 Table A.3 | $A_g \Rightarrow D_T \geq 2{,}4\%, 50\%\ of\ BRA\ and\ D_{TM} \geq 0{,}8\%, 95\%\ of\ BRA$ | (4) | **B2** |
| | Annex A Chapter A.2 Table A.1 | $A_g \Rightarrow E_T \geq 300lux, 50\%\ of\ BRA\ and\ E_{TM} \geq 100lux, 95\%\ of\ BRA\ for\ 50\%\ of\ daylight\ hours$ | - | - |
| Case project | As designed | - | - | **C** |

## 3.2 DEFINING THE REFERENCE BUILDING

The quantified comparison of TEK17 and FprEN17037 will be performed using a case study. The case is based on an apartment project called *Gartnerkvartalet* designed by Lillestrøm Architects AS and is currently being developed by OBOS and Veidekke ASA. The project consists of 7 different apartment buildings and is located at Løren in Oslo. In this case study, building number five will be used. Figure 3-2 presents the location of the project, the layout of all the buildings, and building five circled in red. The surrounding buildings and their location included in the study are presented in Figure 3-3, and Figure 3-4 as a 3-D overview of the site. Building five has 46 apartments spread over 8 floors and is shown in Figure 3-5. Multiconsult ASA has the planning responsibility for energy and building physics according to TEK10, revision 2016. Emphasizing changes from TEK10 to TEK17, the results in this thesis won't necessarily correspond with the already accepted evaluations. The goal of this thesis is not to consider whether the project is designed according to the TEK17, but to compare performance. Thus, will the results be analyzed relatively. The project and its specifications will mainly be used as a base model, in order to have a realistic project when performing the study.

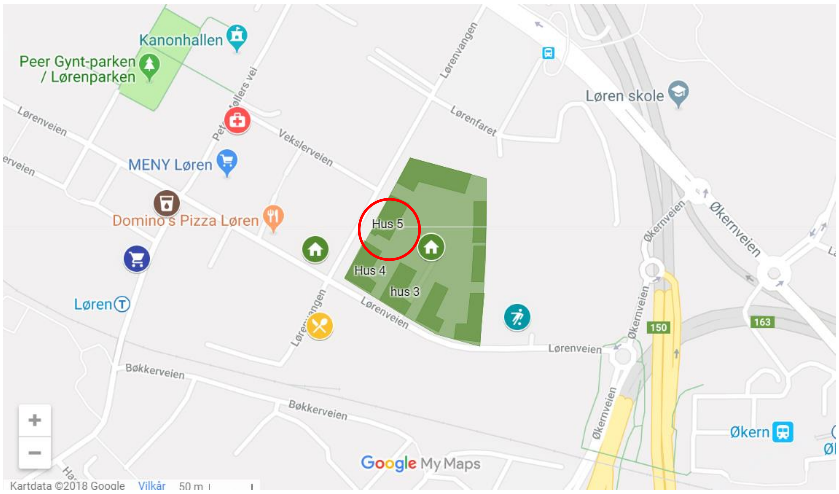



*Figure 3-2 Location and site layout of Gartnerkvartalet at Løren in Oslo (OBOS, n.d.)*

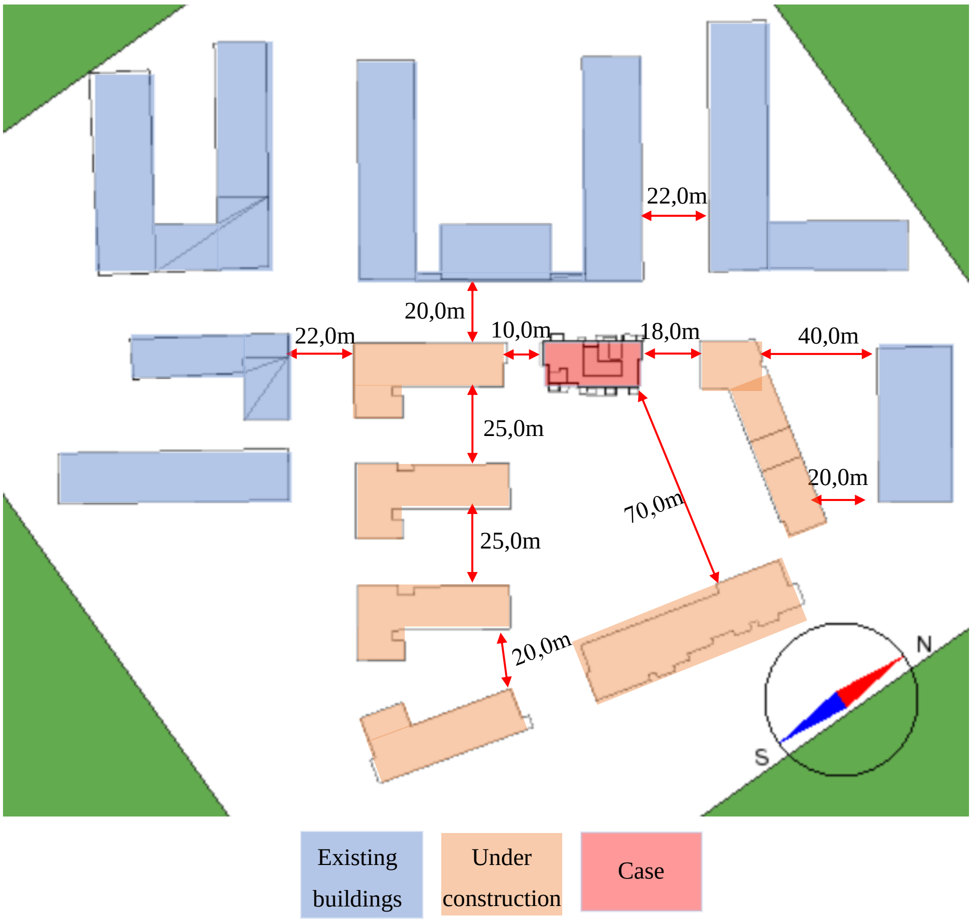



*Figure 3-3 Distances between buildings included in the case study*

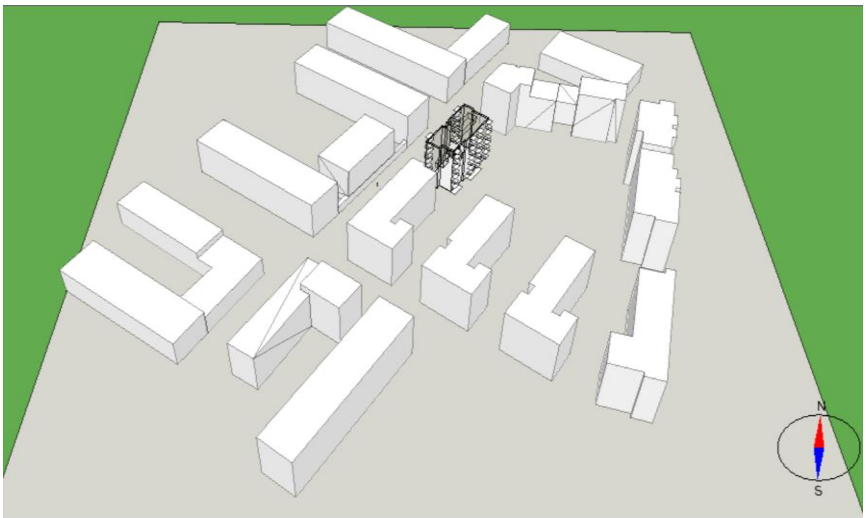
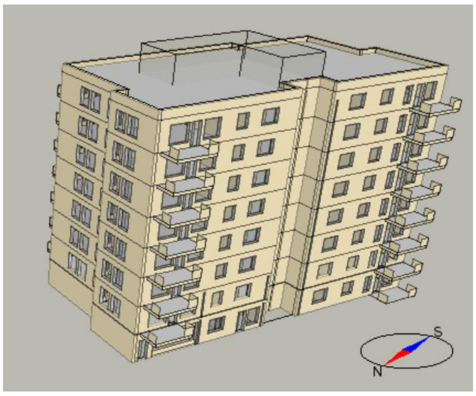



*Figure 3-4 Model of project site with building case (wireframe) and neighboring buildings (white) - 3D view in IDA ICE*

a) Realistic illustration of the building ("VR Visning - Gartnerkvartalet," n.d.)




b) IFC-model of the building (Lillestrøm Architects, 2018a)

*Figure 3-5 Building 5 from Gartnerkvartalet used in the case study*

### 3.2.1 Reference model

To fit the purpose of this study, the IFC-model presented in Figure 3-5b) has been further developed from an IDA ICE model created by Vilde Christine Hagen for her thesis ''Robustness Assessment Methods to Identify High-Performance Building Designs.'' The reference model is made following the energy measures presented in Table 3-3, and the premise note for the designed project from Multiconsult. (Multiconsult, 2018).

*Table 3-3 Energy measures for apartment building acc. to TEK17 §14-2. (2) (TEK17, 2017d)*

| **Energy measures** | **Values for apartment building** |
|---|---|
| U-value exterior walls | $\leq 0{,}18\ [W/_{m^2K}]$ |
| U-value roof | $\leq 0{,}13\ [W/_{m^2K}]$ |
| U-value floor | $\leq 0{,}10\ [W/_{m^2K}]$ |
| U value windows and doors | $\leq 0{,}80\ [W/_{m^2K}]$ |
| Window- and door-share of heated BRA | $\leq 25\ [\%]$ |
| Annual average temperature efficiency of heat recovery in ventilation systems | $\geq 80\ [\%]$ |
| Specific fan power in the ventilation system (SFP) | $\leq 1{,}5\ [kW/_{(m^3/_s)}]$ |
| Air leakage rate per hour at 50 Pa pressure difference (fixed) | $\leq 0{,}6\ [h^{-1}]$* |
| Normalized cold bridge value, where $m^2$ is specified as heated BRA | $\leq 0{,}07\ [W/_{m^2K}]$ |

*This parameter is set to 0,55 in the premise note from Multiconsult, and is the value used in the models.

***Adaptive thermal comfort approach***

The building is designed not to have any mechanical cooling. This requires a strategy to cool the building naturally, avoiding overheating. The adaptive thermal comfort criteria according to NS-EN15251:2007+NA:2014 is chosen. The adaptive thermal comfort model is based on the theory of the adaptive principle: ''if a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort.''(Nicol and Humphreys, 2002) People adapt to the thermal environment in different manners.

Figure 3-6 present the acceptable indoor operative temperatures during summer. The temperatures ranges apply when the occupants regulate the thermal conditions by opening and closing windows. (Standard Norge, 2014) The limits and calculation formulas are presented in Table 3-4, and their definition in Figure 3-7.

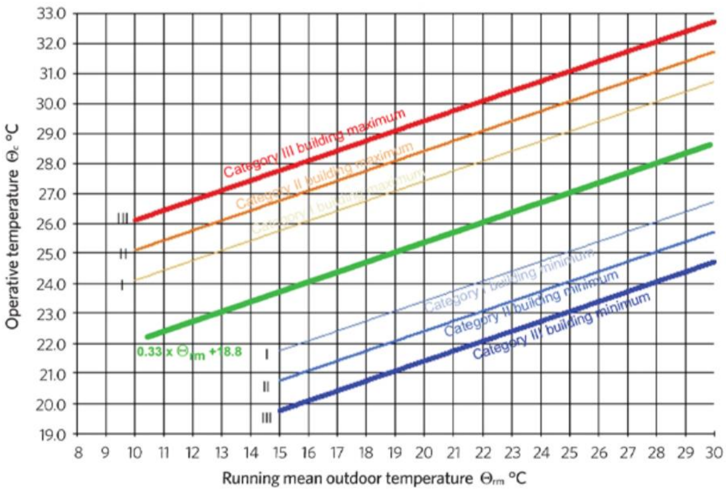



*Figure 3-6 Acceptable operative temperatures ranges for free-running, naturally conditioned spaces (Dwyer, 2017)*

*Table 3-4 Categories with temperature ranges used for designing buildings without mechanical cooling (Standard Norge, 2014)*

| Category | Limit | Formula |
|---|---|---|
| I | Upper | $\theta_{i\,max} = 0{,}33 * \theta_{rm} + 18{,}8 + 2$ |
| | Lower | $\theta_{i\,min} = 0{,}33 * \theta_{rm} + 18{,}8 - 2$ |
| II | Upper | $\theta_{i\,max} = 0{,}33 * \theta_{rm} + 18{,}8 + 3$ |
| | Lower | $\theta_{i\,min} = 0{,}33 * \theta_{rm} + 18{,}8 - 3$ |
| III | Upper | $\theta_{i\,max} = 0{,}33 * \theta_{rm} + 18{,}8 + 4$ |
| | Lower | $\theta_{i\,min} = 0{,}33 * \theta_{rm} + 18{,}8 - 4$ |

| Category | Explanation |
| --- | --- |
| I | High level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons |
| II | Normal level of expectation and should be used for new buildings and renovations |
| III | An acceptable, moderate level of expectation and may be used for existing buildings |
| IV | Values outside the criteria for the above categories. This category should only be accepted for a limited part of the year |

*Figure 3-7 Table with description of the applicability of the categorization for indoor environment (Standard Norge, 2014)*

## 3.3 SELECTING A SIMULATION TOOL

For the comparison of TEK17 and FprEN17037, simulations were performed. The use of simulations enables a high number of different model designs, thus a greater basis for comparison.

In order to answer the research questions, outputs within the subjects of daylight, thermal comfort and energy are needed. An overview of planned simulation outputs is presented in Table 3-5. The glazing alternatives and case designs will be presented in the chapter 3.4. To get the wanted outputs, an appropriate simulation software must be chosen. Fit for this thesis, some simulation programs were considered in addition to the ones validated for daylight simulations presented in 2.3.

*Table 3-5 Setup and explanation of simulation outputs*

| Glazing alternative | Additional shading | Daylight Availability | | | Thermal Comfort | | Annual Energy Demand | |
|---|---|---|---|---|---|---|---|---|
| | | $\overline{DF}$ [%] | $D_T$ [%] | $D_{TM}$ [%] | $T_{O,max}$ [°C] | Annual hours in category IV [h] | Heating $[kWh/m^2]$ | Artificial lighting $[kWh/m^2]$ |
| A1<br>A2<br>B1<br>B2<br>C | 0<br>..<br>..<br>..<br>..<br>..<br>..<br>..<br>n | Average daylight factor acc. to evaluate acc. to TEK17 | Fraction of area with daylight factor above target and minimum daylight factor acc. FprEN17037 | | Maximum operative temperature in zone for simulated year | Number of hours with unacceptable temperatures acc. to adaptive thermal comfort criteria | Annual energy demand for heating and lighting in simulated zone | |

### 3.3.1 EnergyPlus

EnergyPlus is a whole building energy simulation program used to model both energy consumption and water use in buildings as well as thermal calculations. Some of the features and capabilities also includes illuminance and glare calculations for reporting visual comfort and driving lighting controls. It is a console-based program and has a simple spreadsheet-like interface, which makes it not very user friendly. It does have functional Mockup interface for co-simulation with other engines, for example DIVA-for Rhino. (EnergyPlus, n.d.)

### 3.3.2 IDA ICE

IDA Indoor Climate and Energy, IDA ICE, is a ‘’whole-year detailed and dynamic multi-zone simulation application for study of thermal indoor climate as well as the energy consumption of an entire building.’’(EQUA, n.d.)

Daylight simulations became possible in version 4.7, as the software implemented Radiance. The possible outputs are daylight factor and illuminance presented in average, minimum, maximum and uniformity ratio. The calculations can be performed for zones or user defined measure planes, where the results can be visualized as percentage of area above or below a threshold value. IDA ICE does not yet have the function to perform annual (dynamic) daylight calculations. This will be introduced in the next version of IDA ICE 5.0. (Hellström, 2018a) See Appendix A. Consultation EQUA for forum post and consultation with EQUA concerning this matter.

**DIVA- for-Rhino**

‘’DIVA-for-Rhino is a highly optimized daylighting and energy modeling plug-in for the Rhinoceros-NURBS modeler.’’ The plug-in performs advanced calculations and simulations such as radiation maps, renderings, glare analysis, climate-based daylighting metrics and single thermal zone energy and load calculations. The calculation engines are Radiance and EnergyPlus, described earlier. (Solemma, n.d.) The Climate-Based Metrics are annual calculations for recorded climate data which simulates different outputs for daylight performance, such as autonomy, availability and useful illuminance. (Diva4Rhino., n.d.)

A weakness in DIVA-for-Rhino, is the capability of thermal simulations. The calculations do not include systems and control strategy and are only performed for one zone.

### 3.3.3 Choosing the correct simulation tool

Evaluating daylight and thermal comfort, there are several applicable software for this purpose. Based on this thesis’ focus on daylight, different software for daylight simulations are investigated. Secondly, are their capability for thermal and energy simulations considered.

Based on the review in 2.3 and the simulation software presented in this chapter, IDA ICE version 4.8 (later SP1) is chosen as the simulation tool for this thesis’ case study. IDA ICE is a verified simulations tool for energy and thermal conditions which has a user friendly interface compared to EnergyPlus. Radiance, presented in 2.3, was implemented in 2016, making it possible to perform daylight simulations. For running daylight simulations, the implementation of Radiance is relatively new. This results in IDA ICE not being the most widely used program for daylight simulations. DIVA-for Rhino which is capable of performing climate-based-metrics would have been a better program for running simulations according to FprEN17037. But because of its limitations regarding thermal comfort, it is not the most suitable for this study. In addition, does NTNU have license and expertise in IDA ICE, which also is an important factor in this decision.

### 3.3.4 Daylight simulations

The daylight simulations in IDA ICE are run in a separate simulation process than for energy and thermal environment. In the daylight simulation tab, it is possible to perform two types of simulations; either calculating the daylight factor or the illuminance. This calculation setting is shown in Figure 3-8 (1).

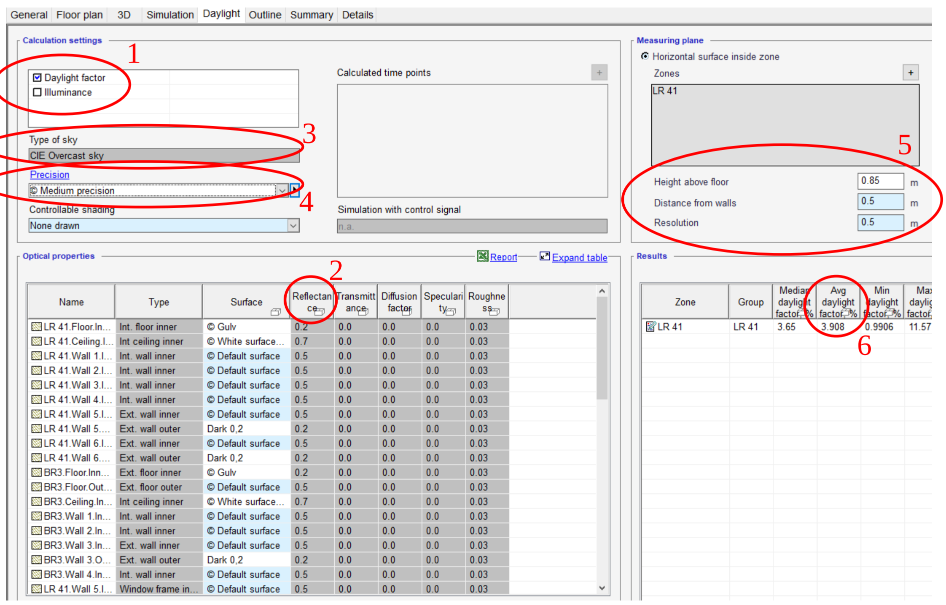



*Figure 3-8 Daylight simulations tab with relevant settings and inputs circled in red*

#### *Chosen calculation – Daylight factor*

As stated in 3.10, one of the criteria' for illuminances in FprEN17037 require dynamic simulations run over a year, with a defined calculation grid and fraction of the room area. IDA ICE can perform dynamic simulations for average illuminance in a room but does not have the function to define the calculation planes. This is only possible for a set of chosen calculation time points. Consulting with Mika Vuolle from EQUA and reading answers in their forum, this observation was confirmed, thus excluding the illuminance simulations from this thesis. See

Appendix A. Consultation EQUA for e-mail thread and forum post. The simulations for daylight factor are static and have a fixed running date and time set to March 21th at 12.00.

#### *Material surfaces*

The reflectance of surfaces has an impact on the daylight factor and illuminance in a room. All the surface reflectances are changed according to standard recommended default values in FprEN17037 Annex B, and are listed in Table 3-6. The surface-table where these inputs are changed according to component type is shown in Figure 3-8 (2).

*Table 3-6 Reflectance factors for material surfaces*

| Surface | Reflectance factor |
|---|---|
| Wall | 0,5 |
| Ceiling | 0,7 |
| Floor | 0,2 |
| Outside ground | 0,2 |

#### *Sky type*

Weather and climate are important factors in calculating daylight, thus the type of sky model used in the simulations. As presented in Definitions, daylight factor is calculated with an overcast sky. Figure 3-8 (3) show ''CIE Overcast sky'' for the setting for type of sky. Appendix B. CIE sky models, Figure B - 2 is an illustration of this specific sky model, with the distribution of highest luminance in zenith to lower luminance at the horizon.

#### *Precision level*

The precision level for the simulations are set to medium, shown in Figure 3-8 (4). The radiance parameters for this precision level are shown in Figure 3-9 a). EQUA recommend a precision level of high or super high in order to get most accurate results. These levels require either a strong computer or long simulation time. Because of the large number of simulations run for this thesis in combination with long simulation time, the simulations for daylight were run with medium precision. The main goal of the thesis is to compare different designs and scenarios, thus making the precision of each simulation less important, as they all are run with the same precision.

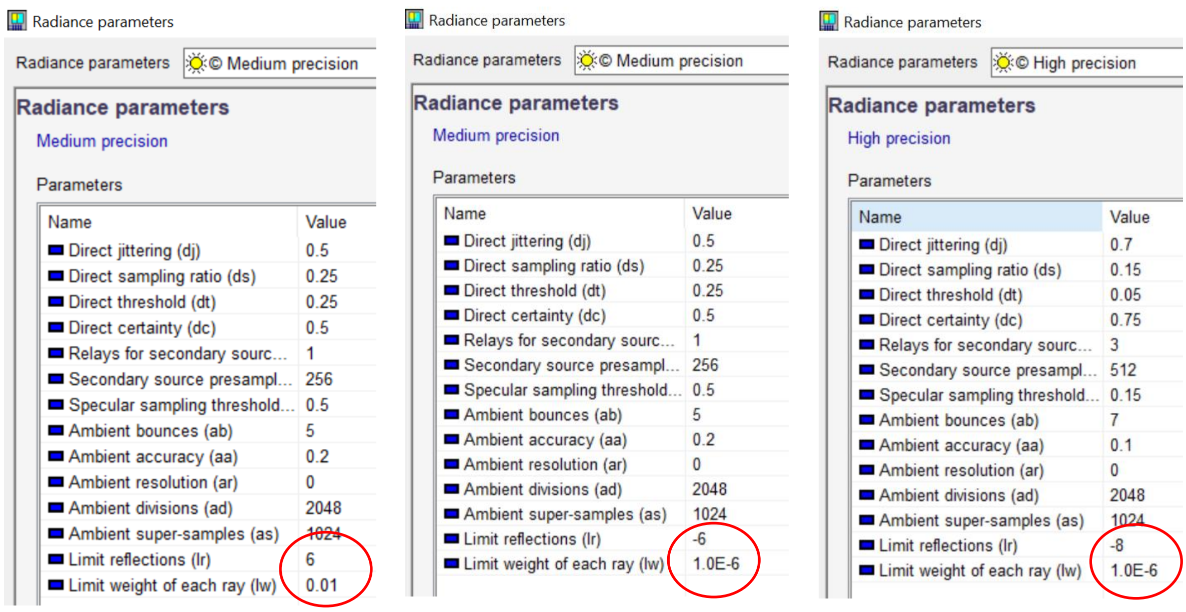
### Weakness and evaluation of precision level in daylight simulations in IDA ICE 4.8

In late November 2018, after all the daylight simulations had been run, EQUA posted a new update of the program. The new update SP1 (Service Pack 1), included changes of the input parameters for the daylight simulations. The changes were a result of some cases run with

''High precision'' that gave unexpectedly much lower daylight factor than ''Super high precision''. Parameter changes were done for all precision levels. The parameter ''lr'' was changed to a negative number, and ''lw'' was set to 1E-6, as shown in Figure 3-9 b) and c). The changes have the highest impact on the simulations run with ''High precision'', but will also have some effect on the simulations with ''Medium precision''. (Hellström, 2018b)

*In order to evaluate the effect of the accuracy of the different precision levels, several test where performed. The tests where run with glazing areas as designed and with site specific neighboring buildings. The simulations were run in both IDA ICE 4.8 and 4.8 SP1, with the precision levels medium and high. The simulation time for super high precision was too long to perform, and therefore not possible to include in the test.*

Table 3-7 contain the results for different precision levels in the two versions of IDA ICE. Two zones were investigated, one at the ground floor and one at the 8th floor. The changed parameters give different values for $\overline{DF}$, but when only including one decimal all the results are equal, except for medium precision on the top floor. Comparing the medium level for version 4.8 with high level in both version 4.8 and 4.8 SP1, the results are the same when only including one decimal. Since the planned outputs will be evaluated with one decimal and are simulated with version 4.8, this test of the precision levels supports the validation of the results.




*a) Medium precision in version 4.8* *b) Medium precision in version 4.8 SP1* *c) High precision in version 4.8 SP1*

*Figure 3-9 Radiance parameters for daylight simulations for two versions and precision levels in IDA ICE*

*Table 3-7 Precision test for daylight simulations in IDA ICE – comparing medium and high in version 4.8 and 4.8 SP1*

| Test zones at two levels in the case study | IDA ICE version | $\overline{DF}$ [%] | | | |
|---|---|---|---|---|---|
| | | Medium | Medium (1 decimal) | High | High (1 decimal) |
| Ground floor | 4.8 | 1,130 | 1,1 | 1,079 | 1,1 |
| | 4.8 SP1 | 1,088 | 1,1 | 1,080 | 1,1 |
| Top floor | 4.8 | 3,685 | 3,7 | 3,652 | 3,7 |
| | 4.8 SP1 | 3,777 | 3,8 | 3,740 | 3,7 |

***Measuring plane***

The input values for the measuring plane used in the calculation of daylight factor is shown in Figure 3-8 (5). The calculation grid is calculated according to FprEN17037, and set to have a resolution of 0,5m. Evaluating an example living room in the case study, the maximum grid size was calculated to be 1,67m with 4 grid points in depth. This evaluation is found in Appendix C. Calculation grid. For a more accurate representation of the distribution of daylight in the simulated zones, the resolutions were set to 0,5m, as this also were the default in IDA ICE. The measuring plane is set to height 0,85m with an excluded band of 0,5m from the walls, according to FprEn17037 Annex B. Normally this height is 0,8m in Norway. The plane is set to be 0,5m from the walls, as this is not considered as a useable area.

***Extracting results for daylight results***

The results needed for this thesis required two types of measures for the daylight factor. An average daylight factor for the whole zone, and specific daylight factors in grid points, as represented in Table 3-5. The average daylight factor, $\overline{DF}$, was extracted directly from the results table after each run of daylight simulations, shown in Figure 3-8 (6). After a daylight simulation has been performed, it is possible to animate the results of the daylight distribution according to the calculated grid points. This is presented as a color scale on the measuring plane in the zone. An example of this is shown in Figure 3-10. In order to evaluate the fraction of the area that has daylight factors above the two measures according to FprEN17037, $D_T$ and $D_{TM}$, the daylight factor scale must be handled manually. Figure 3-11 shows an example from a simulation where the animation of daylight factor has been set to separate the measure plane in values over and under the two limits. The percentage of the associated area is presented besides the scale. This operation was performed for all zones in each model if the thesis.

### Weakness of using IDA ICE for daylight simulations

It is not possible to incorporate the daylight simulations in the version management where the other simulations results are extracted (which will be described in 3.5) This is because Radiance is incorporated as an own tab in IDA ICE, which results in the simulations being run separate. This makes the process of simulating many cases time consuming and inefficient, as one must open each model to run the simulations manually.

The only way to extract the results for $D_T$ and $D_{TM}$ is in the daylight animation in 3D-view. The reason is that this is the only place where it is possible to view the daylight factors in a chosen area of the measure plane. In addition to this, the fraction of area viewed on the daylight factor scale in the animation in 3D-view represents simulated zones. When simulating two different zones, it is expected different results for the percentage of area with daylight factor above the set value. This is not the case in 3D-view, as it is not possible to select only one zone to perform operation on. In order to get valid values for the fraction of areas, daylight simulations must be run separately per zone simulated. This increases the time needed for each daylight simulation, since this must be done manually for each zone in each model.

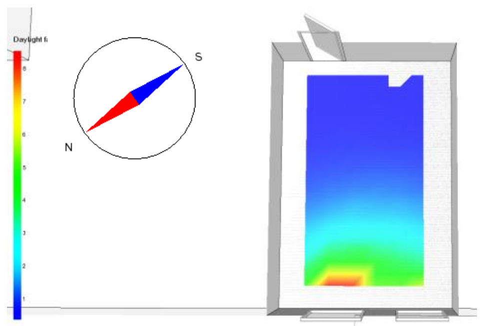
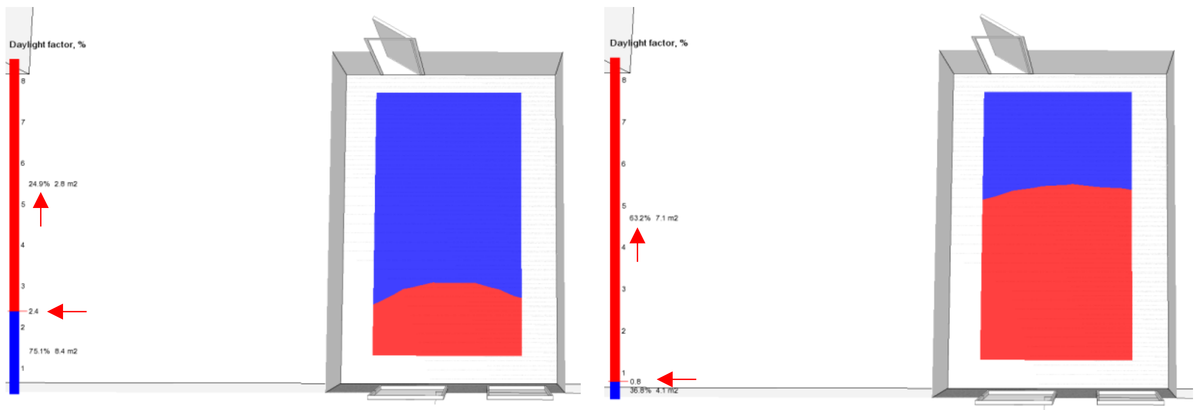



*Figure 3-10 Illustration of how the results for daylight factor is animated in IDA ICE*




*a)Target DF of 2,4% for 50% of the area (not achieved in this case)*

*b)Target DF 0f 0,8% for 95% of the area (not achieved in this case)*

*Figure 3-11 Illustration of how the fraction of area with daylight factors above the values acc. to FprEN17037 where found in IDA ICE*

### 3.3.5 Thermal comfort simulations

***Window opening strategy based on the Adaptive thermal comfort model***

The apartments are free-running, naturally conditioned. In order to avoid overheating, there must be a window opening strategy. It is chosen to use the adaptive thermal comfort model, described in 3.2. Hagen created an adaptive thermal control strategy for her thesis, shown in Figure 3-12. This opening control was implemented in this thesis, with a change of parameters in the p-controller input, circled in red. The values are calculated according to the base function for adaptive thermal comfort criteria from NS-EN 15251:2007+NA:2014 (Standard Norge, 2014), marked in green in Figure 3-6. These inputs in the opening control are shown in Figure 3-13. The windows are set to open 50% relative to width and height and has a Cd factor in flow of 0,65.

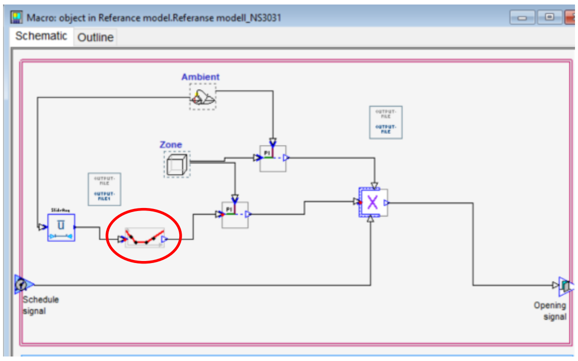
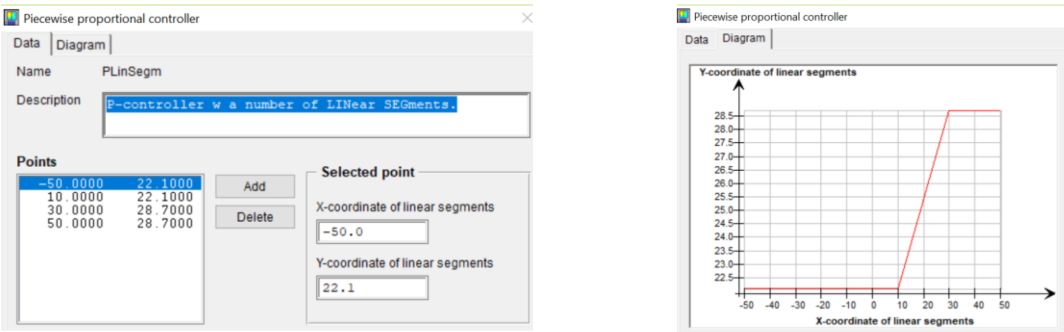



*Figure 3-12 Window opening control strategy (Hagen, 2017)*




*a)Steps in p-controller*

*b)Diagram illustrating the setpoints for the p-controller*

*Figure 3-13 Inputs for p-controller in window opening control acc. to adaptive thermal comfort model*

***Window shading strategy***

In some of the cases, the windows have external shadings. The shadings have a control strategy based on the radiation from the sun. This control is linked to system parameters in IDA ICE, shown in Figure 3-14. The inputs are default values and are not changed based on the statement in the yellow text box in the top right corner if the figure. The red circle marks the values relevant for the shading control, which are considered in relation to the amount of solar radiation that hits the window. When the solar radiation is $100 W/_{m^2}$, the shading is drawn.

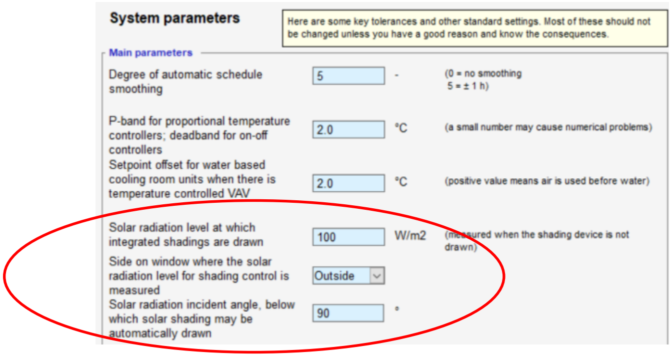



*Figure 3-14 System parameters for shading control strategy in IDA ICE*

### *Occupant behavior*

The occupants are set to always be present with an activity level of 1.0 MET and clothing varying from 0,6 to 1,1 CLO, as shown in Figure 3-15. These are default values from IDA ICE. As a simplification, the number of occupants per zone simulated are set to 1.

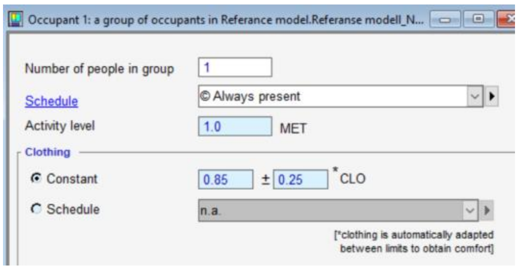



*Figure 3-15 Occupancy behavior*

### *Generating and extracting results for thermal comfort*

As presented in Table 3-5, the relevant outputs for thermal comfort in this thesis are the unacceptable hours, according to the adaptive thermal comfort criteria. In order to get the wanted outputs, they must be requested before performing the simulations. IDA ICE evaluates the thermal comfort for the zones, according to NS-EN 15251:2014 for buildings without cooling, as shown in Figure 3-16. These results are generated directly in the results table for in the version management and were extracted to excel without any editing.

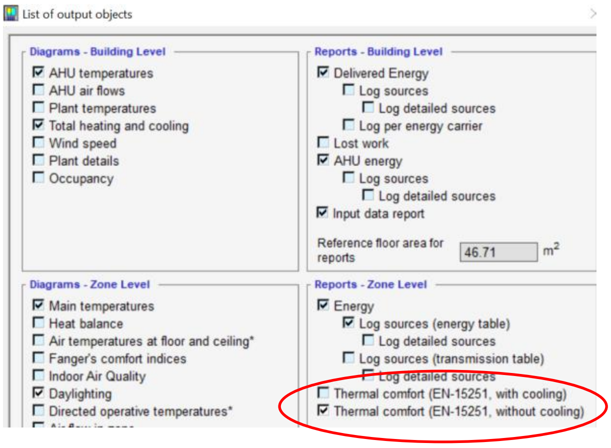



*Figure 3-16 Requested output setting for thermal comfort results*

### 3.3.6 Energy simulations

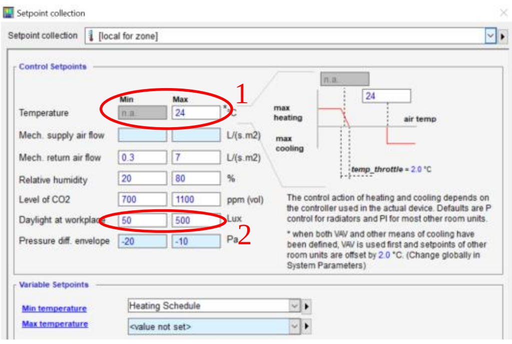
As the results for energy demand not are the focus of this thesis, the some of the inputs needed for the energy simulations are simplified. The energy system is based on an energy assessment performed by Multiconsult, which have evaluated the performance of the building according to TEK10. (Multiconsult, 2017)

***Heating, cooling and ventilation***

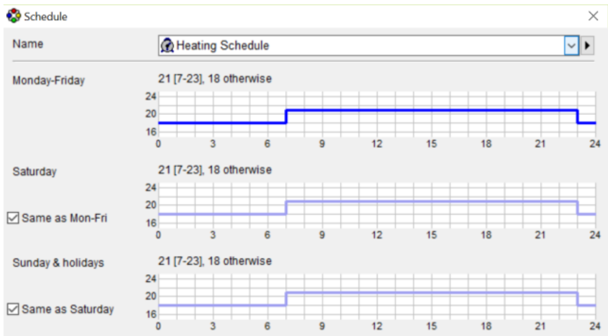
The apartments are designed with water-born heating systems and balanced ventilation, without cooling. (Multiconsult, 2017) In the IDA ICE model, the zones are set to be heated by electric radiators and have a CAV-system heated by an electric heating coil. The input values used are presented in Table 3-8. The heating control strategy are both linked to a setpoint for max. temperature and a heating schedule for min. temperature. These are presented in Figure 3-17. The setpoints are based on recommended temperatures for energy calculations in NS-EN 15251:2007+NA:2014 for residential buildings. (Standard Norge, 2014) The heating schedule is set to allow a lower temperature during the night, in order to save energy, and since the people in general have a higher tolerance for or crave lower temperatures when sleeping.

*Table 3-8 Input values used in IDA ICE for heating, ventilation and infiltration*

| Component | Input | Comment | |
|---|---|---|---|
| Power for Electric radiator | 2000 W | Default values from IDA ICE. Radiator dimensions: 0,5m x 1,0m. Proportional controller and air temp. sensor. | |
| Leakage number: Fixed infiltration at 50 Pa, $n_{50}$ | 0,55 $^{oms}/_{h}$ (ACH) | Input value acc. to Multiconsult. Value in TEK: 0,6$^{oms}/_{h}$ | TEK10 and Tek17 §14-2. (2) Energy measures. |
| $SFP_e$-factor for ventilation | 1,5 $^{kW}/_{m^3 s}$ | | |
| Annual average temperature efficiency for heat recovery in ventilation systems | ≥ 80% | Value from Multiconsult: 75% | |
| Supply and return air for CAV | 1,2 $^{m^3}/_{h * m^2}$ | Min. acc. TEK10 and TEK17. §13-2. Ventilation in residential building | |




*a)Control setpoints. (1)Temp. setpoints, connected to heating schedule*




*b)Schedule for min. temperature*

*Figure 3-17 Heating setpoints and schedule in IDA ICE*

### *Artificial lighting*

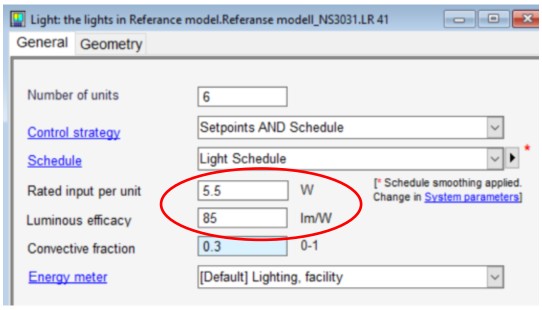
Evaluating the energy demand for artificial lighting in relation to the daylight availability, it is possible to consider the importance of daylight in apartments. As daylight is the core of this thesis, the simulation of artificial lighting is an important factor.

The energy demand varies greatly with the type of light source chosen. In order to simulate a realistic scenario, LED lights are chosen. The properties of the lights are based on a Philips LED light bulb (Philips, 2018), and are presented in Table 3-9. Based on the recommended amount of illuminance for a living room, the area and properties listed below, the number of light units needed in each zone simulated were calculated. Depending on the activity, illuminances between 50lux to 500lux are recommended for living rooms. (Panasonic Global, n.d.) An illuminance of 100lux was chosen for the calculation, as it lies between the amount of general light and the amount needed for reading.

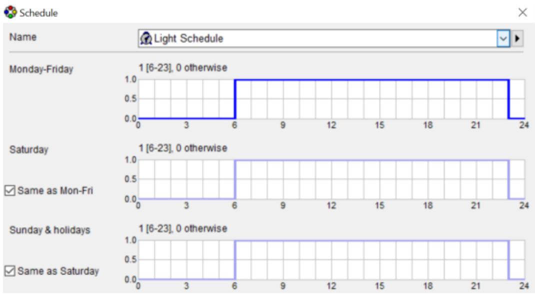
The control strategy for the artificial lighting are a combination of both a lighting schedule and setpoints of min. and max. amount of light in the zones. The lighting schedule are presented in Figure 3-18, where the light is always off during the night, and always on during the day. The schedule during the day is also linked to the setpoints for illuminances, meaning it might also be off during the day if the illuminance exceeds the limit. The min. and max. illuminances are set according to include all values recommended for living rooms, between 50lux and 500lux. (Panasonic Global, n.d.) The input of these setpoints in IDA ICE are shown in Figure 3-17( 2).

*Table 3-9 Properties of chosen artificial lighting - Philips LED light bulb*

| **Parameter** | **Value** |
|---|---|
| Power | 5,5 $W$ |
| Luminous efficacy | 85 $lm/W$ |
| Luminous flux | 470 $lumens$ |




*a)Power and luminous efficacy for artifial lifhting units*




*b) Schedule for artifical lighting*

*Figure 3-18 Inputs and schedule for artificial lighting in IDA ICE*

### *Extracting results for energy demand*

The wanted results for energy demand, presented in Table 3-5, are annual energy use per area. The results are generated in the simulations done in version management and appear in a combined results table for the whole project file. The results are then exported as an excel file.

#### Weakness of usability of version management regarding results for energy demand

The results for energy demand for heating and lighting generated in the version management table, are monthly. In this thesis, the total annual amount is relevant. In order to get the annual values, it must be collected manually from each model and per zone. With many models and projects, as in this thesis, this is a very time-consuming task. In addition, the values are not given per floor area, which is needed when comparing different zones. These numbers have to be calculated manually for all the extracted energy demands, which again requires more time.

### 3.3.7 Location and climatic input

It is chosen to run all the simulations for two locations, as the FprEN17037 standard is based on being adapted according to different latitudes. The chosen locations are Oslo and Alta, representing the site as designed located south, and one of the most northern cities with a higher latitude in the north of Norway. The two cities will illustrate the difference and impact of location, even though being in the same country following the same regulations.

These locations are chosen in IDA ICE, which have the inputs needed for both cities. The climate files are downloaded from EQUAs ‘’Climate data download center’’; ASHRAE IWEC 2 database for weather files. The files represent measurements from Oslo/Gardermoen Airport and Alta Airport.

One of the inputs in the climate files are the outside dry-bulb temperatures which are used in the calculation and evaluation of thermal comfort according to NS-EN 15251:2007. As the buildings are without mechanical cooling will overheating be the prime concern, thus the running mean outdoor temperature, calculated by the outside dry-bulb temperatures. These temperatures during the summer months are the most critical and are presented in the Table 3-10 below.

*Table 3-10 Outside dry-bulb temperatures from climatic files used for simulations in IDA ICE (ASHRAE IWEC 2)*

| | Outside dry-bulb temperature [°C] | | |
|---|---|---|---|
| | June | July | August |
| Oslo/Gardermoen | 13,2 | 15,6 | 14,8 |
| Alta | 11,5 | 13,4 | 12,6 |

## 3.4 CREATING THE BUILDING MODEL

With a goal to evaluate different daylight conditions and the resulting thermal comfort, there has been chosen 2 zones from the apartments presented in Figure 3-21 to simulate for this thesis. Figure 3-20 shows the location and layout of the 2 zones. The illustrations are from an IFC model in IDA ICE, and are based on the updated drawing from Lillestrøm Architects, presented in Appendix D. Site layout for Gartnerkvartalet. Both zones are living rooms in apartments on the ground floor and 8$^{th}$ (top) floor, as these are the most critical regarding daylight and potential overheating. A building body for the model as well as the two zones were generated from an IFC file provided by Multiconsult. Figure 3-19 shows the base model in IDA ICE with the building body marked as thin lines and the zones colored blue. On the outside of the building body, the white elements are simplified balconies.

### 3.4.1 Defining critical zones

When evaluating the most critical zones in the building, there are different indicators for daylight and thermal comfort. The most critical zone regarding daylight is not the same as the most critical zone for thermal comfort. In this thesis, both conditions are investigated, thus are 2 zones included.

***Daylight***

The living room in the apartment 5104 located on the ground floor were chosen as the most critical regarding daylight availability. There are several factors leading to this choice:

- **Lowest height above ground.**
  Being located at the ground floor, the light from the sun and the sky will enter the room with a steeper angle, thus have a shorter distribution into the room. Rooms on the ground floor will also be exposed to the largest shading angles of obstructions of the horizon, such as landscape and buildings. This also leads to less availability to daylight.
- **Closest adjacent buildings.**
  The zone is oriented northwest. This orientation has the closest neighboring buildings, 20 meters as shown in Figure 3-3. In combination with being located on the ground floor, this results in the largest shading angle for the apartments facing northwest. The two different angles used in the simulations are shown in Figure 3-22.
- **The effect of the orientation is insignificant.**

For simulations of daylight factor in IDA ICE, the sky model is fixed as ‘’overcast’’. This sky model behaves as an overcast sky, and the daylight simulations will not be depended on the orientation of the zone relative to the sun. (If the simulations had been done dynamically for illuminance, the orientation would have had an impact on the results. Because of the location in Norway, the high latitude generally results in north facing windows receiving the smallest amount of daylight.)

- **Depth of room.**

  Only having one façade with windows, the distribution of daylight into the room is often low. Considering the zones with only one façade and largest depth, the room with the closest neighboring buildings were chosen.

***Thermal comfort***

The living room in apartment 5802 located in the southern corner at the top floor were chosen as the most critical for thermal comfort. This conclusion was a result of the amount of sun exposed glazing and initial overheating simulations run for the top floor, where the living room at the top floor experienced the highest operative temperatures.

- **Orientation to the south – dynamic simulations**

  The thermal simulations run in IDA ICE are annual dynamic, and dependent of the location and climate data. The orientation of the zone is therefore important. Being located in Norway, the sun is moving at a relatively low altitude across on the southern part of the hemisphere, moving from the east to west. As the living room is located in the southern corner, its two facades are oriented southeast and southwest, and are exposed to the sun during the entire course of the day.
- **8th floor - large area sun exposed glazing**

  The windows for this zone, as designed for the project, have a glazing area of 9,5$m^2$ which equals a glazing-to-floor ratio of 37,6%. Being located at the 8th floor, the zone is not shaded by any neighboring buildings, thus are the glazing exposed to the sun.
- **Overheating simulations run to find the most critical at the top floor**

  Hagen concluded with one of the apartments on the top floor to be the most critical regarding overheating in her simulations in her master thesis.(Hagen, 2018) Using this as reference, an initial overheating simulation were run for the southern zones at the top floor. The zone with the highest number of hours above 27°C where chosen as the most critical regarding overheating.

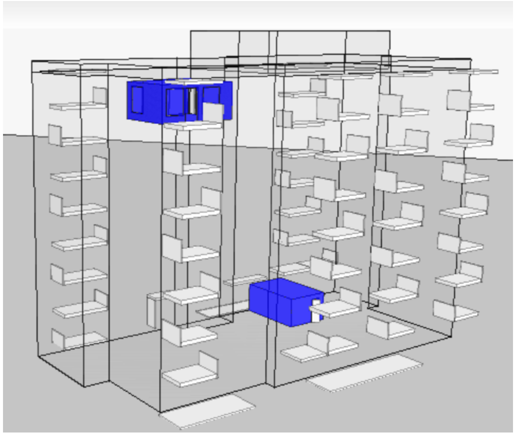
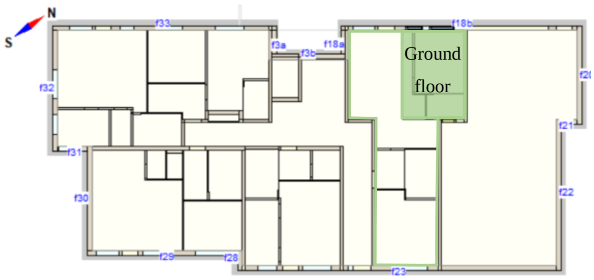
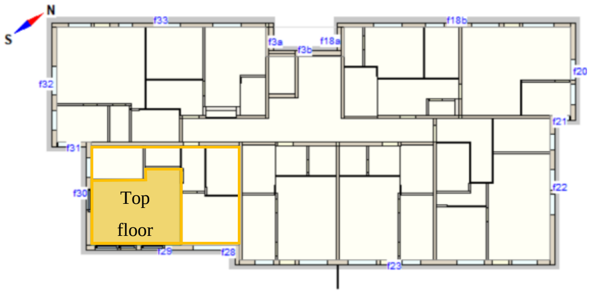


*Figure 3-19 IDA ICE model made for the case study, with critical zones marked in blue and balconies as white 3D-objects*



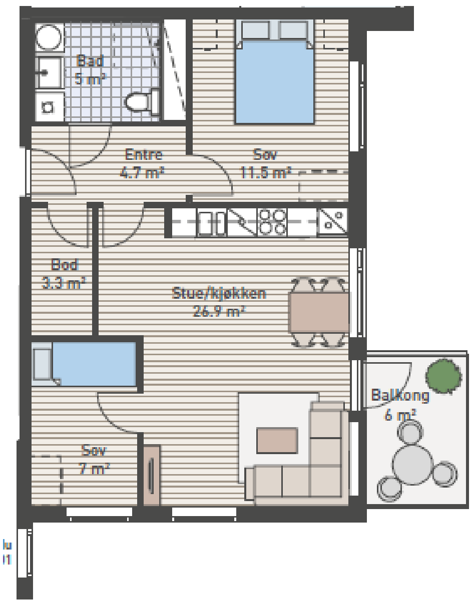

*a) Representative living room – ground floor*




*b) Representative living room – top floor*

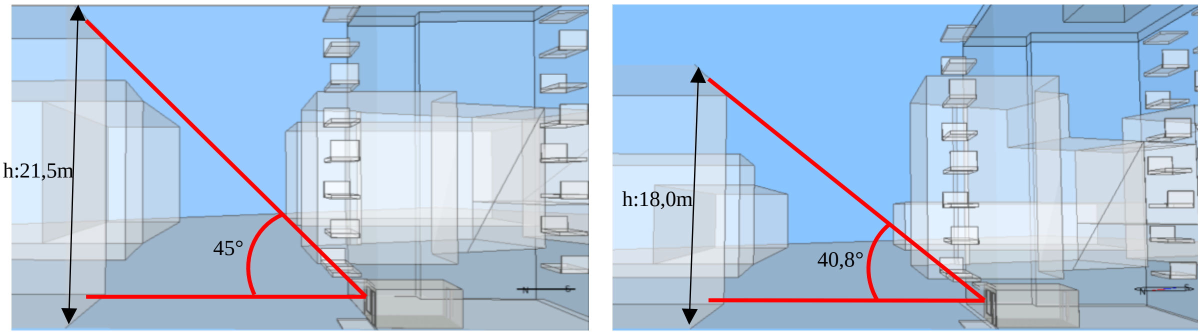
*Figure 3-20 Living rooms chosen to evaluate and made to zones in IDA ICE*


*a) Apartment 5104 (OBOS, n.d.)*




*b) Apartment 5802 (OBOS, n.d.)*

*Figure 3-21 Apartment layout for the two selected zones*




*a) Maximal shading angle acc. to preaccepted performances TEK17 - 45°*

*b) Site specific buildings – 41°*

*Figure 3-22 Shading angle from living room on ground floor to closest adjacent obstruction*

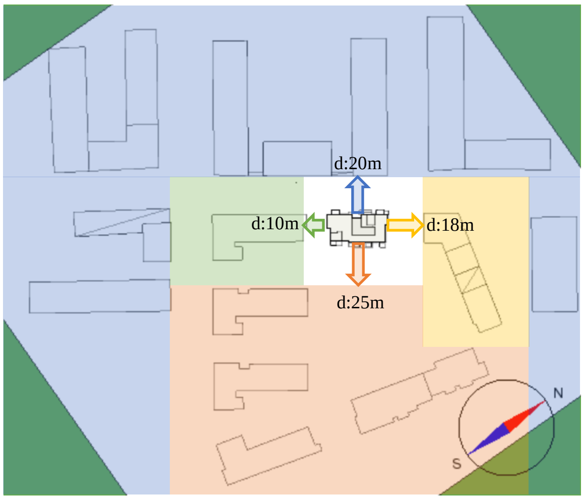
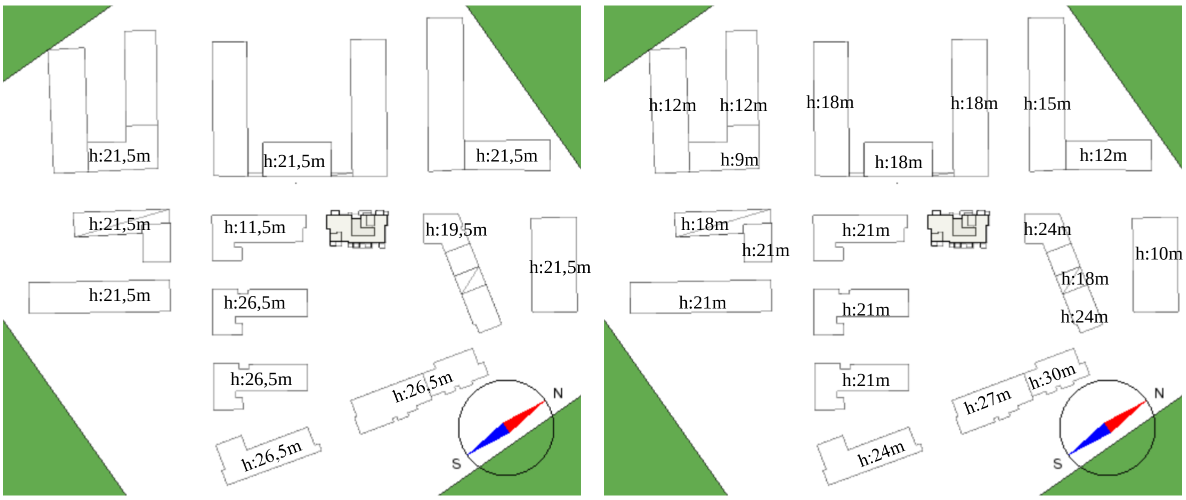



*Figure 3-23 Chosen areas for calculated building heights and the distances used to calculate them acc. 45°*




*a) Calculated acc. to 45° and distances shown in Figure 3-23*

*b) Site specific for existing buildings and as designed for buildings under construction*

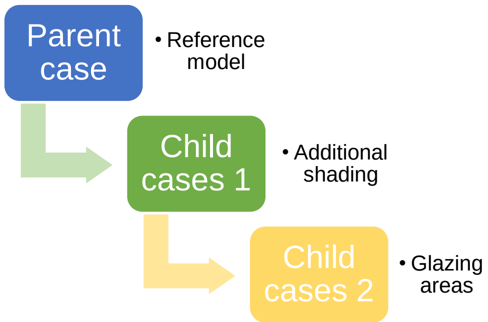
*Figure 3-24 Height of neighboring buildings for the 2 different scenarios*

## 3.5 DEVELOPING A FRAMEWORK OF CASE MANAGEMENT AND SIMULATION PROCESS

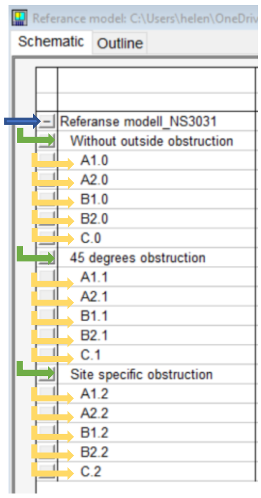
IDA ICE has a function called *Version management*, which simplifies the process of repeatedly changing parameters, rebuilding models, running simulations and comparing results. The system of version management consists of one or more root cases called parents, with depending branches called child cases. (EQUA, 2006) The child cases are versions of their parent cases. The version management where chosen to use in this thesis, as many model designs are being compared.

For this thesis the version projects only have one parent case, with three branches of child cases, which again has five child cases each. Thus, each project consists of three joints. The parent case is the reference model, the first set of child cases are the additional shading designs, while the second level of child cases are the different glazing alternatives. Figure 3-25 illustrates the principle of parent and child cases in version management, and how this is systemized in IDA ICE.

The 90 different models created using the project versions in IDA ICE are partitioned in six different files, or *projects*, containing 15 designs each. Figure 3-26 illustrates the structure of how the 90 models are created, combining different scenarios, locations and designs. Each box in the design column represent a project file like the one illustrated in Figure 3-25 b).




*a) Principle of parent and child cases*




*b) Illustration from IDA ICE*

*Figure 3-25 Version management*

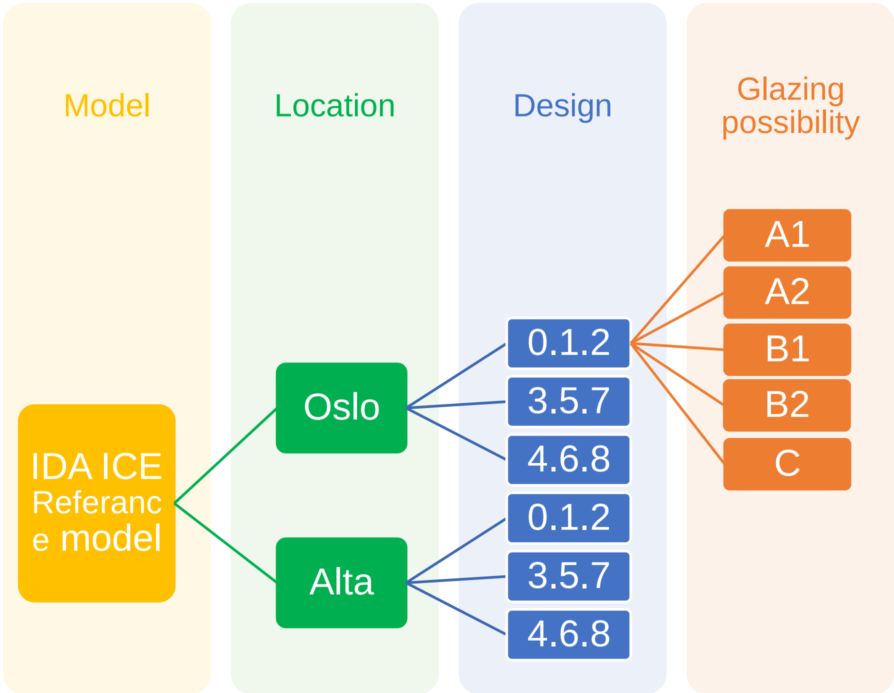



*Figure 3-26 Framework of the 90 project files and model combinations*

### 3.5.1 Models - defining glazing areas

As the goal of this thesis is to compare the performance of the two standards mainly regarding daylight, the different requirements for glazing area in TEK17 and FprEN17037 were the fundament for creating the models. Table 3-2 presents an overview over the relevant paragraphs and the respective requirements for glazing area according to Tek17 and FprEN17037, also described in 2.1 and 2.2.

The glazing areas are the base for five different case groups, labeled as a glazing alternative. These are presented in Table 3-11. The two glazing areas in case group A are based on formulas and does not need simulation to be determined. They are based on the minimum glazing area for adequate daylight and the maximum recommended area regarding energy efficiency in TEK17. Case group B consist of the glazing areas that are based on limits rather than formulas, thus resulting in the glazing areas to be found through an iterative simulation process. The two glazing areas in group B are based on the limits from both TEK17 and FprEN17037. Case group C is the glazing area as designed in the project and is therefore not calculated or based on a limit. This is included in the study in order to evaluate the standards with a realistic case of glazing area.

The number of windows, dimensions and placement for all the glazing areas in the different case groups are illustrated in Table 3-11. The original placement and number of windows as designed per zone were chosen to use as a base. The zone at the ground floor has one façade with glazing, consisting of one window and one door. The zone at the top floor is a corner apartment and has two facades with glazing. The wall oriented southwest have one window, while the other oriented southeast has two windows and a glazed door. This original design is shown in the table, and is represented as case group C. Neither of the dimensions for this group are changed.

For the rest of the glazing alternatives, it was chosen to have a fixed window height and placement above the floor, only changing the width of the windows according to the calculated glazing areas shown I Table 3-12. This was chosen in order to avoid another variable, as the dimensions and placement of a window has an impact on the daylight results. (Matusiak, 2017a) The height above the floor where set to be 0,8m, as this is one of the criteria according to TEK17 for the pre-accepted performance used for calculating A1. This height was also applied as a simplification of the door, which originally was glazed for its total height, as in case group C. All specific dimensions and placements of the windows for each zone and case group were decided according to the method described and the conditions presented in Table 3-11.

***Limitations of chosen glazing alternative A1 and B2***

Glazing area A1 were decided early in the thesis and calculated according to equation (2) in Table 3-2. At this stage in the process, not all model parameters were decided. A criterion for TEK17 when using the pre-accepted performance of calculating the glazing area using equation (2), is that $A_{BRA}$ should include the area if there are any overhangs. This will result in a larger glazing area, making up for the shade provided by the overhang. Later in the design phase of the thesis, of was decided to include the balconies as a part of the reference model. These are presented in the next sub-chapter 3.5.2. It was decided not to change the A1 glazing areas in the models, based on the comparison of glazing-to-floor-ratio for the glazing alternatives presented in Table 3-13. The new calculation of A1* still represent the smallest glazing area of all the alternatives, even though the glazing-to-floor ratio are a bit higher than for the initial A1. Since tis thesis is a comparing study, the results do not need to be correct. As long as A1 still are the smallest glazing area with the correct calculation, its relation to the others are intact, thus ok to use for the rest of the study. It is important to keep in mind that the results for glazing A1 regarding daylight may be somewhat lower than what they should have been acc. the criteria in TEK17.

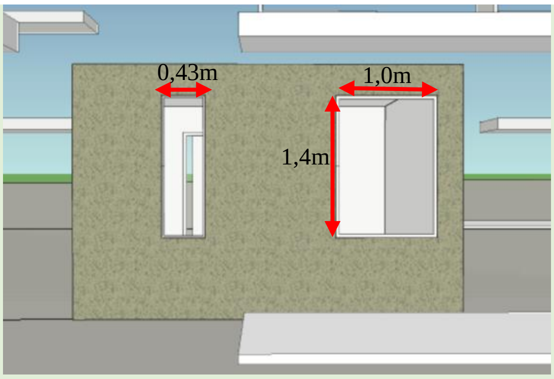
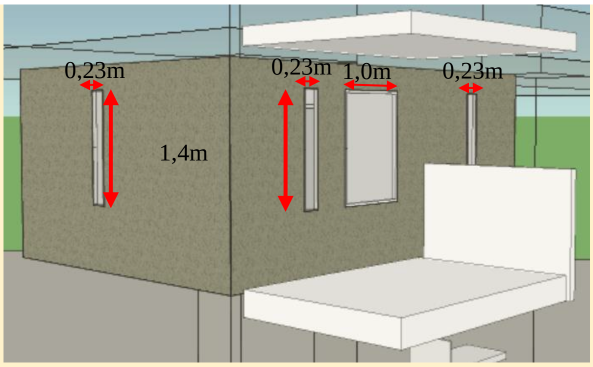
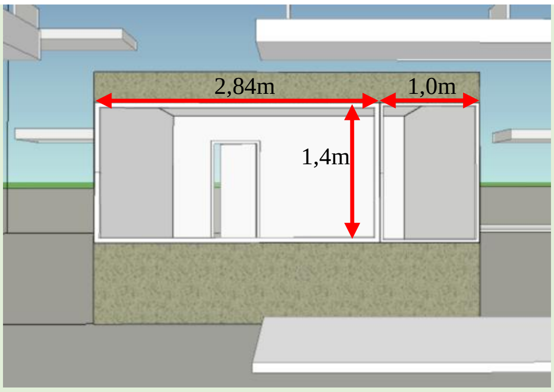
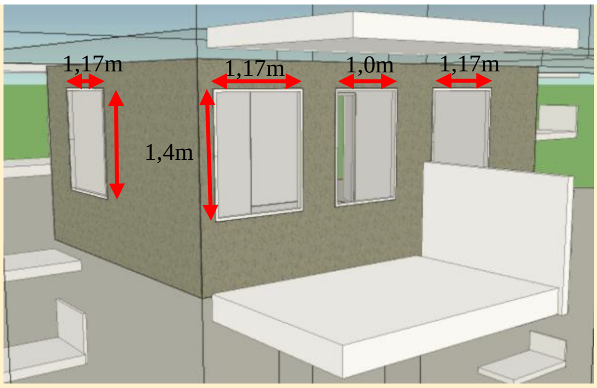
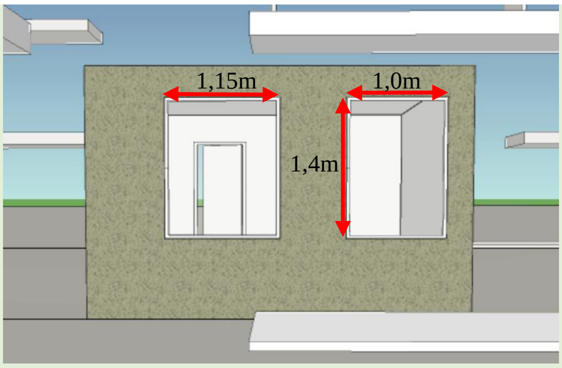
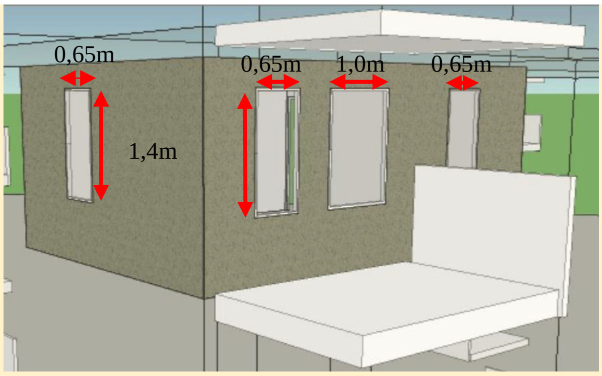
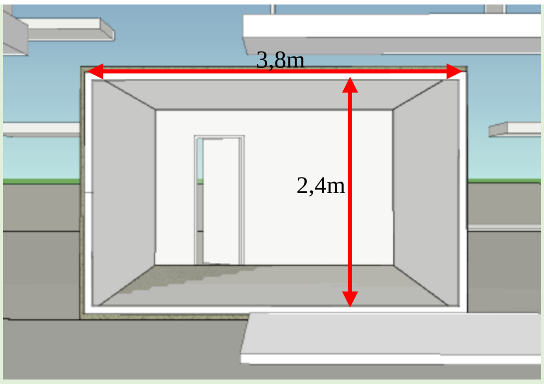
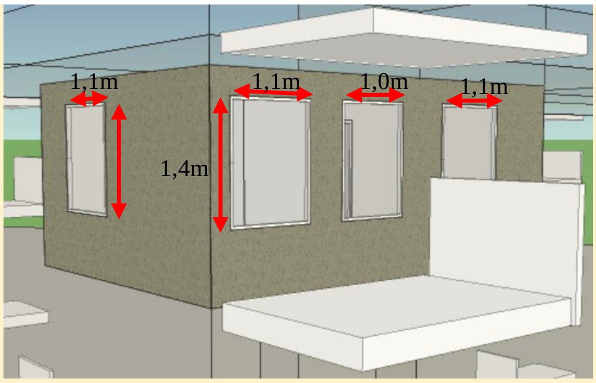
B.2 represent the area needed to achieve the criteria in FprEN17037. After several simulations were performed finding glazing area B2, it became clear that the fixed height would not result in adequate daylight conditions according to FprEN17037 for the ground floor. After maximizing both the width and the height of the window, the values were still not adequate. These glazing dimensions are not optimal for direct comparison of daylight results with the other glazing alternatives. Still the dimensions for B2 at the ground floor were kept and will give a measure for the maximum daylight results possible for this zone.

*Table 3-11: Case groups and glazing areas for the five main models*

| Case group | Glazing alternative | Formula for glazing area | Glazing area [$m^2$] | |
|---|---|---|---|---|
| | | | **5104** | **5802** |
| **A**<br><br>Min. and max. glazing areas based on TEK17<br><br>Simulation is not needed | **A1**<br>(Min. area for min. daylight base don TEK17) | $A_1 = 0,07 * \frac{A_{BRA}}{LT}$ | 2,0 | 2,37 |
| | **A2**<br>**(**Max. area for energy efficiency based on TEK17) | $A_2 = 0,25 * A_{BRA}$ | 5,38 | 6,31 |
| **B**<br><br>Simulation is needed | **B1**<br>(Min. area for min. daylight based on TEK17) | $A_3 \Rightarrow \overline{DF} = 2\%$ | 3,01<br><br>(4)* | 4,31<br><br>(4)* |
| | **B2**<br>(Min. area for min daylight based on FprEN17037) | $A_4 \Rightarrow D_T = 2{,}4\%,$<br>$50\%\ of\ BRA$<br>$and$<br>$D_{TM} = 0{,}8\%,$<br>$95\%\ of\ BRA$ | 9,12<br><br>(13)* | 6,02<br><br>(6)* |
| **C**<br><br>As designed | **C** | - | 4,37 | 9,50 |

*( ) minimum number of iterations required in order to find the glazing area ensuring daylight conditions over the limit.

*Table 3-12 Illustration of chosen glazing designs and dimensions for the simulated zones at ground and top floor*

<table>
<tr><th></th><th>Ground floor</th><th>Top floor</th></tr>
<tr><td>A1</td><td>
</td><td>
</td></tr>
<tr><td>A2</td><td>
</td><td>
</td></tr>
<tr><td>B1</td><td>
</td><td>
</td></tr>
<tr><td>B2</td><td>
</td><td>
</td></tr>
</table>

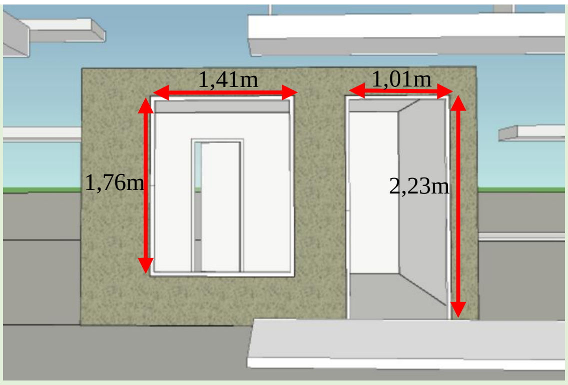
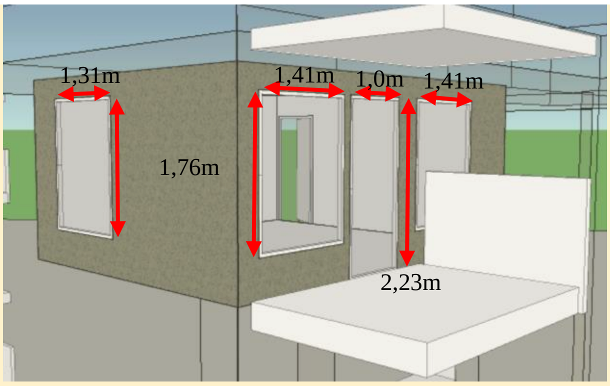
| | **Ground floor** | **Top floor** |
|---|---|---|
| **C** |  |  |
| **Fixed overhang** | depth: 1,0m, width:2,0m | depth: 2,0m, width:3,0m |

*Table 3-13 Glazing to floor ratio for glazing alternatives*

| | Ground floor | | Top floor | |
|---|---|---|---|---|
| | Area $[m^2]$ | Glazing to floor ratio [%] | Area $[m^2]$ | Glazing to floor ratio [%] |
| A1 | 2,0 | 9,3% | 2,37 | 9,4 |
| A2 | 5,38 | 25,0% | 6,31 | 25,0% |
| B1 | 3,01 | 14,0% | 4,31 | 16,4% |
| B2 | 9,12 | 42,5% | 6,02 | 23,9% |
| C | 4,37 | 22,0% | 9,5 | 37,6% |
| *A1 w/ fixed overhang | 2,22 | 10,0% | 2,95 | 11,7% |

*Table 3-14 Glazing width shaded by fixed overhangs visible in Table 3-12*

| | **Glazing width shaded by fixed overhang** | |
|---|---|---|
| | Ground floor | Top floor |
| A1 | 70% | 73% |
| A2 | 60% | 48% |
| B1 | 47% | 56% |
| B2 | 60% | 49% |
| C | 48% | 53% |

### 3.5.2 Balconies - interoperability between IDA ICE and IFC

The balconies, illustrated as withe 3D-elements on the façade in Figure 3-19, are a simplification made from the IFC-file. The red arrows in Figure 3-5 marks the difference in materials used on the balconies. The slab and one side of the railing are made of concrete, while the rest of the railing is made of glass. IDA ICE has a shading balcony object to use in models, but this object is fixed with only one material, as shown in Figure 3-27. The use of these balconies in the simulations for Gartnerkvartalet might therefor result in less daylight availability, as the balconies provide more shade than intended by the design. Still, it is important to include the balconies in the simulations, as they will have a shading effect on the zones. In order to model the balconies as correct as possible, they were imported into IDA ICE as a separate 3D vector graphic. The program SimpleBIM were used to extract the balcony elements from the IFC-file and then imported to SketchUp, shown in Figure 3-28. Making the balconies as a SketchUp-file made it possible to import them into IDA ICE as an object, which could be placed correctly on the building body of the model. The import also has the trait of being assigned a surface material and being included as shade in calculations done in the simulations, which is crucial for the daylight results. As a simplification of the balconies, the glass railing is excluded from the model, because of their high light transmission of 80-90%. After a consulting with a light designer in Multiconsult, Ruth Marie Bottheim, this assumption was made.

In this part of the modelling, a weakness of IDA ICE was revealed. The program will not include the IFC file as a shading element, even though the option is checked off. (“IDA ICE Daylight calculation,” n.d.) This error results in a time-consuming process of including an object into the model in order to be considered in the calculations, even though it technically is there already.

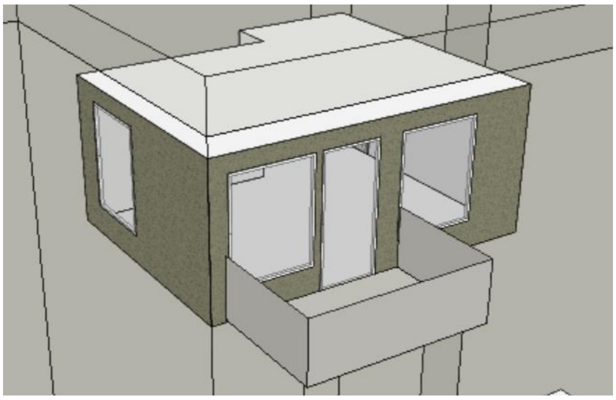


*Figure 3-27 Shading object: Balcony in IDA ICE*

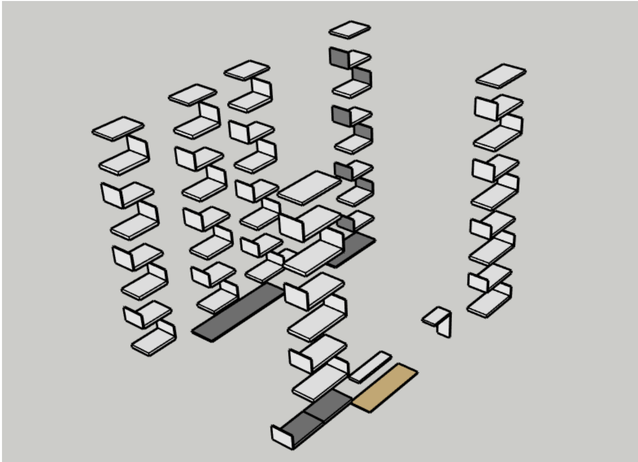


*Figure 3-28 Balconies extracted from IFC and imported to SkecthUp*

### 3.5.3 Additional shading variables

As presented in Table 3-15, there are four different additional shadings. Two versions of shading obstructions, being the neighboring buildings, and two versions of window shading.

*Table 3-15 Combinations of additional shading used in the comparing study*

| Design with additional shading | Shading | | | |
|---|---|---|---|---|
| | Outside obstruction (Figure 3-24) | | Window shading | |
| | TEK17 (θ = 45°) (a) | Site specific (b) | Drop arm awning | Additional coating (g=0,25) |
| 0 | Reference design without any special consideration | | | |
| 1 | x | | | |
| 2 | | x | | |
| 3 | | | x | |
| 4 | | | | x |
| 5 | x | | x | |
| 6 | x | | | x |
| 7 | | x | x | |
| 8 | | x | | x |

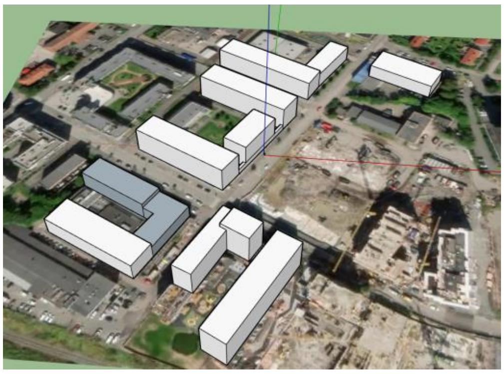
### *Shading obstructions*

The two shading obstructions both represent the same neighboring buildings, but with different heights. These are shown in the previous presented

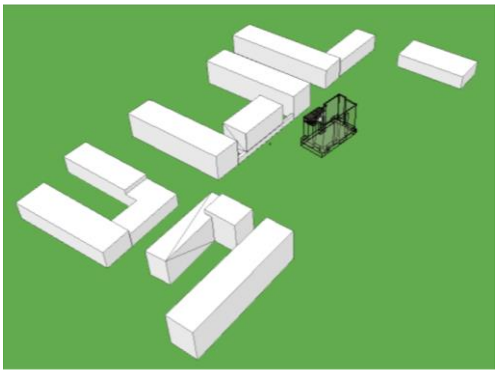
Figure 3-4 to Figure 3-24. They were created as four files in Sketchup before being imported as 3D object to IDA ICE, ensuring that the buildings are located correctly according to each other. The existing buildings were created by using a ‘’map function’’ in Sketchup, as shown in Figure 3-29 a). The imported 3D-object of the existing buildings in IDA ICE are shown in Figure 3-29 b). In the map function, the location of the project was found, before drawing simplified outlines of the buildings and assigning them heights. The other buildings that are a part of the project and are under construction were made the same way, but by using the DWG-file of the site layout provided by the architects.(Lillestrøm Architects, 2018b)

The first alternative for the shading obstructions are based on the heights being set by an angle of 45 degrees, which is the maximum shading angle in the one of the pre-accepted performances for daylight in TEK17. The neighboring buildings were sorted in different areas relative to the building used in this project, based on which direction they are located. Each area was given a height, calculated according 45 degrees from 1,55m above ground and the distances shown in Figure 3-23.

The second alternative represent the site-specific heights. The heights were assumed based on the number of floors of each building, found by using google maps street view. Each floor was estimated to have a height of 3 meters. The heights of the buildings under construction where also simplified to 3 meters per floor.



*a) SketchUp-model made by using ‘’map function’’*



*b) Imported SketchUp-file in IDA ICE*

*Figure 3-29 Creating shading obstructions of existing buildings*

### *Window shading – external drop arm awning*

One alternative window shading is an external drop arm awning. The properties and dimensions of the overhang are shown in Figure 3-30. These shadings are drawn according to the control strategy presented in 3.3.5. As a result of the fixed balconies and overhangs, some of the windows are already always shaded. Even though both elements serve as an overhang, there are some differences. The drop arm provides shade for a larger area of the window than the fixed overhang, as it is inclinedly drawn in front of the window. On the other hand, the drop arm material let 5% of visible light through, while the fixed overhang is completely opaque with no light transmittance. As mentioned above, the drop arms are only drawn when there is sun, while the fixed overhangs always are present. The drop arm will also shade the window for when the sun is at lower positions than the fixed shade. The fixed overhang only shade about 60% of the windows in all alternatives. The alternative with the drop arm awning is therefore an alternative that will provide a different scenario, even though the original model has some overhangs in all cases.

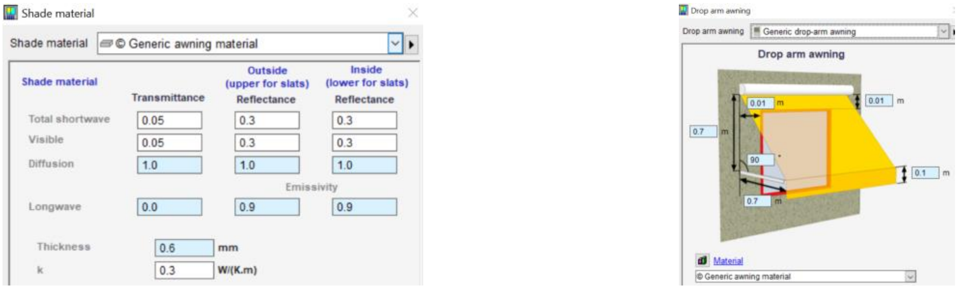



*Figure 3-30 Properties and dimensions of external window shading - drop arm awning*

### *Window shading – additional coating*

The second alternative for window shading is additional coating. This was done in IDA ICE by changing the window type to *Pilkington Suncool 50/25*, with properties as shown in Figure 3-31. The difference from the original window construction, is the outer glass changed to Suncool 50/25 and the cavities with argon are increased from 12mm to 15mm. The additional coating on the outer glass reduces the solar heat gain coefficient, transmittance and u-value of the window, which will influence both the daylight availability and the heat demand.

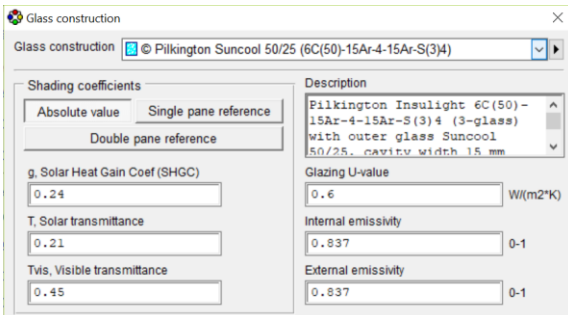



*Figure 3-31 Window properties for window with additional coating - Pilkington Suncool 50/25*

*Table 3-16 Overview of the glazing properties for the 3 different window shading alternatives*

| | Reference | Additional window shading | |
|---|---|---|---|
| | Pilkington Optitherm S3 | Pilkington Suncool 50/25 | Drop arm awning |
| Visible transmittance (LT) | 72,1% | 45% | 5% |
| Solar heat gain coefficient (g) | 0,55 | 0,24 | - |
| U-value | 1,0 | 0,6 | - |
| Emissivity | 0,837 | 0,837 | 0,9 |

# 4 RESULTS AND DISCUSSION

As this thesis consists of two main parts, are this chapter ordered accordingly. It is chosen to combine results and discussion in one chapter. There are two reasons for this. The abstract comparison requires an evaluation and discussion of TEK17 and FprEN17037, where the results mainly are the discussion. The case study is multi-dimensional and will be evaluated within and across several disciplines. These assessments are considered to be performed best when combining the presentation of results and the discussion of them.

The case study done in IDA ICE makes up the quantified comparison of TEK17 and FprEN17037 regarding daylight. In order to evaluate the effect of the different performances in its entirety, results for artificial light, thermal comfort and energy demand has also been extracted and considered. The following sub-chapters present the most important results, processed, evaluated and discussed in relation to one another. The complete set of results will be referred to through the chapter and is found in Appendix E and F. Table 4-1 illustrates the organization of the result tables being presented in the following chapters. The numbers 0-8 represent the shading designs presented in Table 3-15.

*Table 4-1 Illustration of the results table for simulations done for thermal comfort and energy demand. Number 0-8 represent the design combination.*

| | Glazing area | No outside obstruction | | 45° shading obstruction | | Site specific obstruction | |
|---|---|---|---|---|---|---|---|
| | | Thermal comfort | Energy | Thermal comfort | Energy | Thermal comfort | Energy |
| No window shading | A1<br>A2<br>B1<br>B2<br>C | 0 | | 1 | | 2 | |
| External blinds | A1<br>A2<br>B1<br>B2<br>C | 3 | | 5 | | 7 | |
| Additional coating | A1<br>A2<br>B1<br>B2<br>C | 4 | | 6 | | 8 | |

## 4.1 LIGHT PERFORMANCE

Light performances can be evaluated regarding natural daylight and/or artificial lighting. The main goal of this thesis is to evaluate performance based on natural daylight availability. Access to, and good distribution of daylight may result in a smaller need for artificial lighting, thus a smaller energy demand. For this reason, it is interesting to consider the effect of the different models on artificial lighting in relation to the performance of daylight. All results for lighting simulations can be found in Appendix E. Lighting results. The most relevant results are further presented in this chapter.

**Daylight**

The daylight performance is evaluated according to two different criteria, presented in 3.1. TEK17 uses average daylight factor as a measure, while FprEN17037 uses achieved daylight factors in a fraction of the area simulated. These criteria are listed in Table 4-2 below.

*Table 4-2 Daylight factor criteria in TEK17 and FprEN17037*

| | TEK17 | FprEN17037 | |
|---|---|---|---|
| **Criteria** | $\overline{DF} \geq 2{,}0\%$ | $DF \geq D_T = 2{,}4\%$ for 50% of the area | $DF \geq D_{TM} = 0{,}8\%$ for 95% of the area |

Table 4-3 presents the quantitative daylight results for all 45 models containing 2 zones, simulated in Oslo. The daylight results for Alta are presented in annex E.1 Daylight simulation. The results marked green is above the TEK17 criteria, while the results marked in red are above the FprEN17037 criteria.

***Location and its effect on the daylight results***

Reviewing the simulation results for daylight performed for Oslo and Alta, there were very small to no difference. For this reason, it is chosen to use only the values from Oslo when evaluating the results further. Evaluating the results for the two locations up against one another, gives no indication of trend for the small differences in results. Based on the knowledge of different altitude and exposure to sun for the two locations, it was expected to get bigger differences in the results. One explanation may be the overcast sky type used for the daylight simulations in IDA ICE, and whether the location input effects the radiation values.

Secondly, are the daylight simulations static and the daylight factor independent of time. The differences to daylight conditions vary over the year for the two locations, which means that the differences in the results might only be visible when performing a dynamic annual illuminance simulation, climatic-daylight metric. Since FprEN17037 is based on giving different limits adapted according to the latitude of the location investigated, the small difference between Oslo and Alta might be a result of a simplified evaluation of the daylight conditions. This is a limitation of using IDA ICE, which only can perform static simulations for daylight. For this reason, the use of another simulation software capable of annual dynamic simulations such as DIVA-for Rhino, might have given a more accurate illustration of the difference in daylight for the two locations.

***Daylight results per glazing alternative with respect to their reference design***

**A1** is calculated according to the pre-accepted performance in TEK17 and is the smallest of the glazing alternatives, representing the minimum recommended are. The two reference designs for this glazing is 0 and 1. Design 0 are the most simplified, thus are the results for daylight availability the best for this design. Comparing it to the other pre-accepted performance of TEK17, $\overline{DF}$ above 2,0%, reflects the poor performance of $\overline{DF}$ 1,1% and 0,9% for this glazing area. The pre-accepted performance from TEK17 sets a limit of 45° shading obstruction for this glazing area, which is represented with design 1. The effect of this design is worst for the ground floor, with the reduction of $\overline{DF}$ to 0,3%. Compared to the intended equivalent value of 2,0%, this is a big difference. The top floor is only reduced to 0,8% $\overline{DF}$. This illustrates the effect of the shading obstruction on the ground floor, which was one of the reasons the ground floor was chosen as a critical zone regarding daylight. It is important to keep in mind that 70% of tis glazing alternative's width is shaded by a fixed overhang, meaning that the results would have been higher with no fixed overhang. Even so, is this a more realistic representation of the reality, as many building blocks today are built with fixed overhangs.

**A2** represents the maximum recommended glazing area in relation to the floor area in respect to energy efficiency. Design 0 with no obstructions or additional window shadings result in above 3,0%, which is above the pre-accepted performance of acc. to TEK17. These results are with 60% of the glazing shaded by the fixed overhangs at the ground floor, and 48% shaded at the top floor. Even though the ground floor achieves a $\overline{DF}$ high above the TEK17 criteria, it only fulfils the criteria for $D_{TM}$ in FprEN17037, with 100% of the area. 42,4% of the area achieves $D_T$, which is below the target of 50%. Lower for top floor, but fulfills both the criteria for $D_T$ and $D_{TM}$.

**B1** illustrates the other pre-accepted performance acc. to TEK17 with $\overline{DF}$ above or equal to 2,0%. The glazing alternative is also a measure of what the criteria for daylight in TEK17 equals to, according to the measure of FprEN17037. For this alternative, 47% of the glazing width at the ground floor are covered by the fixed shading, and 56% at the top floor. The $\overline{DF}$ results for design 0 are 1,9% and 2,0% as intended. The ground floor only achieved a $\overline{DF}$ of 1,9% in the final simulations, as the iteration process done to decide the glazing area was performed in an early stage and with lower precision. The achieved TEK17 criteria equals achieved $D_T$ in 25,4% and 26,8% of the area for both ground and top floor. This is only half of the FprEN17037 criteria of 50%. For the area with achieved $D_{TM}$, there are a bigger difference between the two floors. The ground floor with 64,6% and the top floor with 89,1%. This may be a result of the shape of the room and placement of windows. The ground floor is deeper and only has windows on one wall, while the top floor is shallower and has windows on two walls, thus better distribution into the room. Still, neither one of the two zones achieve the minimum of 95% of the area with $D_{TM}$.

**B2** represent the glazing area required to fulfil the criteria in FprEN17037. Equal to B1, this is a measure of what the criteria in FprEN17037 equals according to the a $\overline{DF}$ measure in TEK17. As described in 3.1, does the standard specify that the calculations should be performed including all design and site-specific properties. Design 2 with site specific shading obstructions is therefore the reference design for this glazing alternative. The resulting large glazing area for the ground floor still only achieves $D_T$ in 22,5% of the area and $D_{TM}$ in 58,7% of the area. As this glazing area is maximized for the façade wall, are these the highest achievable values for this room layout. While this glazing alternative does not fulfil FprEN17037, does it achieve a of 1,9%, close to the criteria in TEK17. Considering design 0, which the other glazing areas has as a reference, are the results significantly higher and above both the criteria in TEK17 and FprEN17037. The top floor is not affected of the obstructions as the ground floor, resulting in the need for a lower glazing area while still being able to fulfill the criteria according to FprEN17037. 54,3% of the area achieves $D_T$ and 97,7% achieves $D_{TM}$, with a resulting $\overline{DF}$ of 2,9% which is above the TEK17 criteria. The results for design 0 are somewhat better, but very close to the results for design 2. This state the importance level in relation to neighboring buildings, evaluating the daylight availability.

**C** is the glazing area as designed. As explained in 3.5.1, are the dimensions of the glazing a bit different than for the other chosen glazing alternatives. While the others are set to have the same fixed height above 0,8m above the floor, are the windows in C higher and located closer to the ground. This might have some effect on the results, which is commented on later in this chapter. Evaluating design 0, both ground and top floor fulfil the $\overline{DF}$ criteria according to TEK17.Even though the $\overline{DF}$ 2,4%, it does not fulfil the criteria according to FprEN17037. The top floor has a very large glazing area, resulting in a $\overline{DF}$ of 4,0%. This glazing area does also fulfil the FprEN17037 criteria with $D_T$ in 76,3% of the area and $D_{TM}$ in 100% of the area.

***Glazing alternatives and shading designs achieving limits acc. TEK17 and FprEN17037***

Figure 4-1 illustrates the trends of the $\overline{DF}$ results according to the design combinations of shading obstructions and shading windows. Annex E.2 $\overline{\boldsymbol{DF}}$ in relation to fraction areas with $\boldsymbol{D_T}$ illustrates the results for $\overline{DF}$, $D_T$ and $D_{TM}$ in relation to the criteria and according to each glazing alternative.

*Ground floor*

The results for the ground floor, shown in Figure 4-1 a), have the same decreasing development for all glazing areas from the designs without shading obstruction to the designs with shading obstructions. Only glazing A2, B2 and C achieves a $\overline{DF}$ above the TEK17 criteria with design 0. The only glazing with a shading combination that is above the limit of 2,0%, is glazing B2 with design 4. B2 is maximized with a glazing area of 43,5% of the floor area, shown in Figure 4-2 a). Design 4 is additional coating on the windows, reducing the LT to 45%, but without any shading obstructions. Out of these glazing alternatives and designs, is it only B2 with design 0 that fulfil the criteria in FprEN17037.

From Figure 4-2 it is shown that in order to achieve TEK17 criteria, the glazing area must be above 22% of the floor area, and above 42,4% of the floor area to fulfil the FprEN17037 criteria, with design 0.

The shading obstruction of 45° is the one that results in the lowest values for $\overline{DF}$ as shown in Figure 4-1 a). As shown in Figure 3-24, the heights of the adjacent buildings for the ground floor is higher than for the site-specific obstructions. Lower values are therefor to expect. Of the additional window shading alternatives, does the drop arm awning result in the lowest values. Even though the shading is not drawn all the way down covering the windows, it’s low LT of 5% almost does not any light pass though for the area shaded. This results in these values being the lowest. Still, the results are not that much lower than for the additional coating, even though this window shading has a LT of 45%. The reason for this is that the rest of the window not shaded by the drop arm awning, has an LT of 72,1%, allowing more light to pass through this area, while the additional coating covers the whole glazing area.

Comparing glazing area A2 and C for the ground floor, they achieve the same $\overline{DF}$ for design 3,5,7 with drop arm awning even though A2 has a larger glazing area than C. This illustrates the effect of the window height in C, as well as the shading effect of the drop arm awning. The $\overline{DF}$ for both the designs with not window shading 0, 1,2 and the designs with additional coating 4, 6, 8, are lower in C than in A2, in line with the lower glazing area. This means that even though the drop arm awning shades the window and only has a LT of 5%, it does not shade the whole height of the window equally, allowing light in at the heights closer to the ground. This is the reason why the $\overline{DF}$ is the same as in A2, despite smaller glazing area for C.

*Top floor*

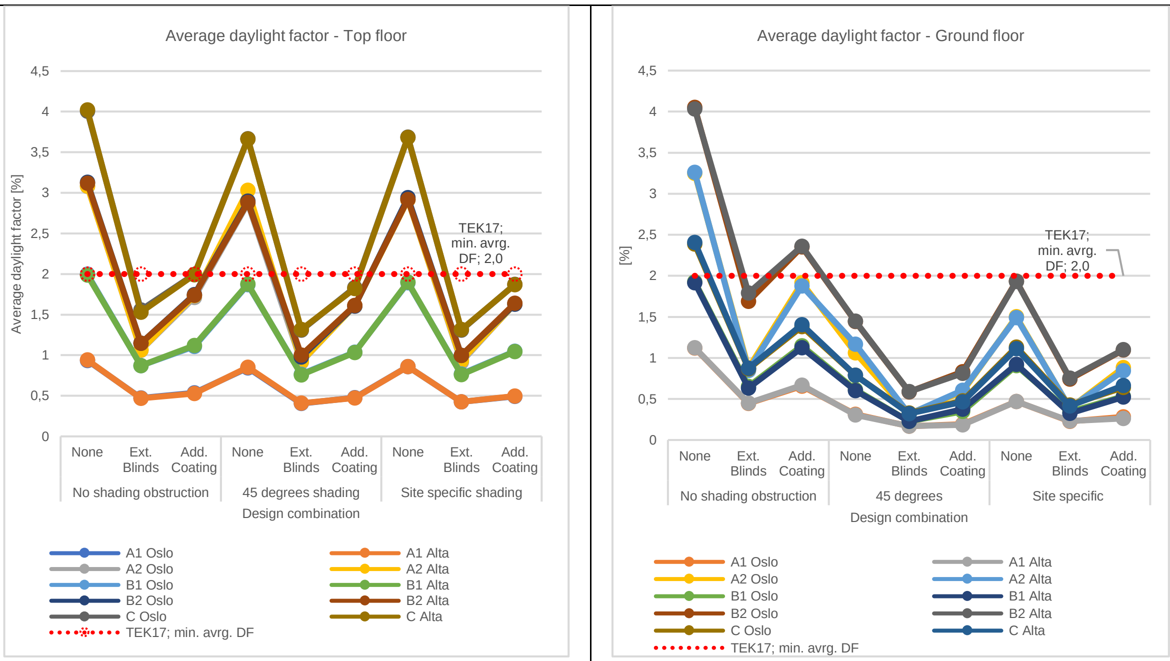
Figure 4-1 illustrates the trend of effect of the different design combinations for the different glazing areas. Comparing the different shading obstruction alternatives, there are almost no differences. This is a result of the high location of the top floor, not shaded by any of the neighboring buildings. The glazing areas achieving $\overline{DF}$ according to TEK17 criteria are A2, B1, B2 and C. A2 and B2 with all the shading obstruction alternatives, does get $\overline{DF}$ over 2,0%. The same applies for C, that in addition fulfils the criteria for design 4, additional coating. B1 only fulfills the criteria with design 0. A2, B2 and C for all shading obstructions without additional window shading achieves both the criteria for $D_T$ and $D_{TM}$ in FprEN17037. This might be a result of the hight of the floor unaffected by the obstructions, which gives a good distribution of the daylight into the room. However, glazing C with no shading obstruction, but additional coating, does not achieve the FprEN17037 criteria. The additional coating with lower LT reduces the $\overline{DF}$ from 4,0% to 2,0%. As seen in the discussion of results from B1, also here does a $\overline{DF}$ of 2,0% only achieve $D_T$ in 25,2% of the area and $D_{TM}$ in 88,0%.

From Figure 4-2 it is shown that in order to achieve TEK17 criteria, the glazing area for the top floor must approximately be above 16,4% of the floor area and above 23,9% of the floor area to fulfil the FprEN17037 criteria, with design 0, 1 and 2.

Also for the top floor, does the drop arm awning result in the lowest values of $\overline{DF}$. The reasons are the same as described for the ground floor.

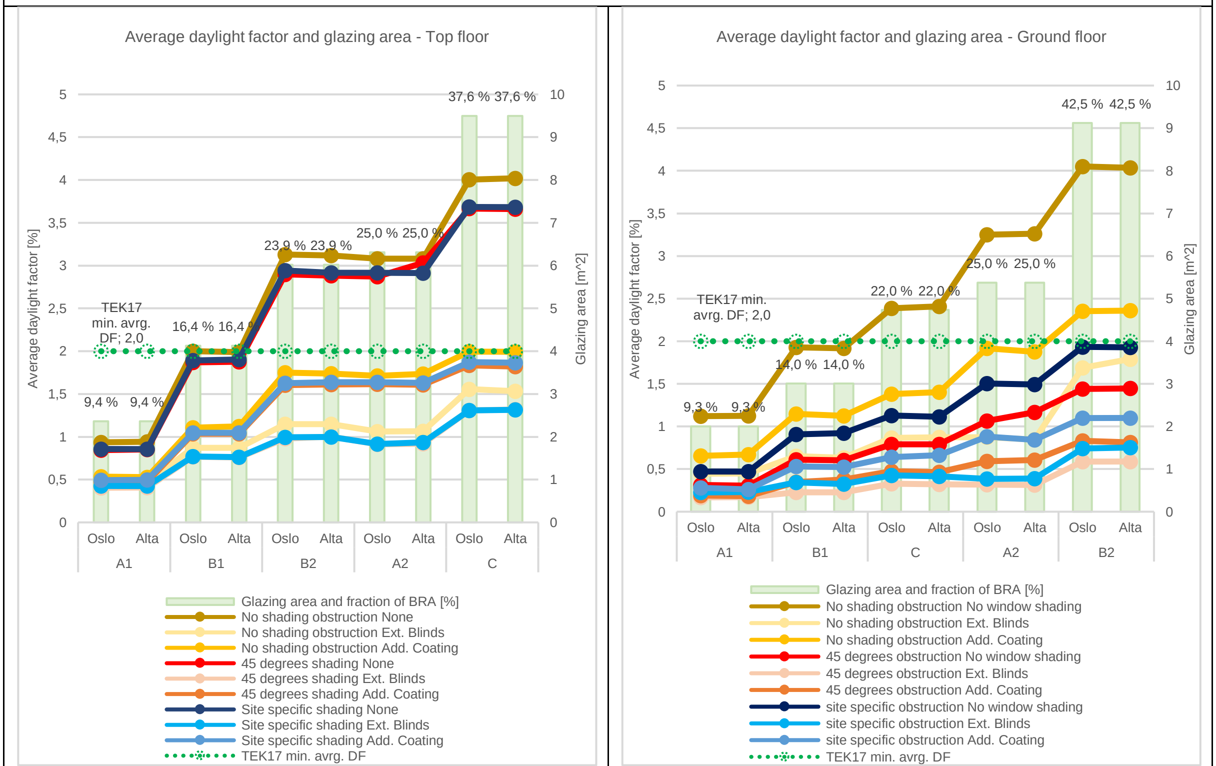
*Table 4-3 Numerical results from daylight simulations - Oslo*

| Glazing alternative | Additional shading design | TEK17 $\overline{DF}$ Ground fl. | TEK17 $\overline{DF}$ Top fl. | FprEN17037 % of area w/ DF > $D_T$ Ground fl. | FprEN17037 % of area w/ DF > $D_T$ Top fl. | FprEN17037 % of area w/ DF > $D_{TM}$ Ground fl. | FprEN17037 % of area w/ DF > $D_{TM}$ Top fl. |
|---|---|---|---|---|---|---|---|
| **A1** [2,00/2,34$m^2$ acc. to TEK17 §13-7b)] | 0 | 1,1 | 0,9 | 7,0 | 1,0 | 44,3 | 47,5 |
| | 1 | 0,3 | 0,8 | 0,0 | 0,7 | 5,9 | 40,2 |
| | 2 | 0,5 | 0,9 | 0,3 | 0,7 | 15,9 | 41,0 |
| | 3 | 0,4 | 0,5 | 0,1 | 0,0 | 13,4 | 8,7 |
| | 4 | 0,7 | 0,5 | 1,0 | 0,0 | 35,9 | 13,6 |
| | 5 | 0,2 | 0,4 | 0,0 | 0,0 | 0,6 | 6,0 |
| | 6 | 0,2 | 0,5 | 0,0 | 0,0 | 2,0 | 10,4 |
| | 7 | 0,2 | 0,4 | 0,0 | 0,0 | 0,9 | 6,6 |
| | 8 | 0,3 | 0,5 | 0,0 | 0,0 | 4,8 | 11,4 |
| **A2** [5,38/6,31$m^2$ acc. to TEK17 §14-2] | 0 | 3,2 | 3,1 | 42,4 | 57,2 | 100,0 | 98,7 |
| | 1 | 1,1 | 2,9 | 9,7 | 52,4 | 34,4 | 93,3 |
| | 2 | 1,5 | 2,9 | 16,7 | 53,0 | 43,8 | 95,3 |
| | 3 | 0,9 | 1,1 | 3,1 | 1,2 | 35,5 | 56,3 |
| | 4 | 1,9 | 1,7 | 25,3 | 14,3 | 66,2 | 82,3 |
| | 5 | 0,3 | 0,9 | 0,0 | 0,7 | 0,8 | 44,9 |
| | 6 | 0,6 | 1,6 | 1,6 | 12,2 | 19,6 | 78,0 |
| | 7 | 0,4 | 0,9 | 0,0 | 0,7 | 7,8 | 45,0 |
| | 8 | 0,9 | 1,6 | 7,7 | 12,5 | 28,5 | 79,3 |
| **B1** [3,01/4,13$m^2$ acc. to TEK17 §13-7a)] | 0 | 1,9 | 2,0 | 25,4 | 26,8 | 64,6 | 89,1 |
| | 1 | 0,6 | 1,9 | 3,6 | 20,8 | 19,9 | 84,7 |
| | 2 | 0,9 | 1,9 | 7,9 | 21,3 | 27,9 | 86,3 |
| | 3 | 0,7 | 0,9 | 1,1 | 0,0 | 24,2 | 44,3 |
| | 4 | 1,1 | 1,1 | 10,8 | 2,6 | 45,9 | 62,6 |
| | 5 | 0,2 | 0,8 | 0,0 | 0,0 | 1,0 | 37,2 |
| | 6 | 0,3 | 1,0 | 0,0 | 2,3 | 8,8 | 58,6 |
| | 7 | 0,3 | 0,8 | 0,0 | 0,0 | 4,9 | 36,0 |
| | 8 | 0,5 | 1,0 | 1,9 | 2,3 | 17,6 | 57,8 |
| **B2** [9,12/6,02$m^2$ acc. to FprEN17037] | 0 | 4,1 | 3,1 | 53,8 | 59,5 | 100,0 | 99,6 |
| | 1 | 1,4 | 2,9 | 16,9 | 54,0 | 49,6 | 95,7 |
| | 2 | 1,9 | 2,9 | 22,5 | 54,3 | 58,7 | 97,7 |
| | 3 | 1,7 | 1,1 | 20,3 | 1,2 | 71,3 | 64,9 |
| | 4 | 2,4 | 1,7 | 33,0 | 15,0 | 89,9 | 84,7 |
| | 5 | 0,6 | 1,0 | 0,0 | 0,7 | 21,9 | 50,5 |
| | 6 | 0,8 | 1,6 | 4,7 | 11,7 | 30,0 | 79,1 |
| | 7 | 0,7 | 1,0 | 0,0 | 0,7 | 32,0 | 51,6 |
| | 8 | 1,1 | 1,6 | 10,7 | 11,9 | 37,8 | 80,4 |
| **C** [4,73/9,50$m^2$ acc. as designed] | 0 | 2,4 | 4,0 | 31,8 | 76,3 | 81,5 | 100,0 |
| | 1 | 0,8 | 3,7 | 5,4 | 68,4 | 26,3 | 100,0 |
| | 2 | 1,1 | 3,7 | 11,4 | 69,5 | 35,5 | 100,0 |
| | 3 | 0,9 | 1,6 | 3,1 | 9,5 | 34,6 | 85,0 |
| | 4 | 1,4 | 2,0 | 15,9 | 25,2 | 53,6 | 88,0 |
| | 5 | 0,3 | 1,3 | 0,0 | 4,7 | 3,1 | 71,0 |
| | 6 | 0,5 | 1,8 | 0,5 | 20,5 | 14,9 | 82,9 |
| | 7 | 0,4 | 1,3 | 0,0 | 4,9 | 8,8 | 74,2 |
| | 8 | 0,6 | 1,9 | 3,0 | 21,7 | 22,3 | 84,9 |




*a) Top floor* *b) Ground floor*

*Figure 4-1 Illustration of results for average daylight factor for all design combinations - Oslo and Alta*




*a) Top floor* *b) Ground floor*

*Figure 4-2 Average daylight factor in relation to glazing area – Oslo and Alta*

***The equivalent criteria for TEK17 and FprEN17037***

The performed analysis of the results for the daylight simulations, makes it possible it possible to answer the first research question related to the case study.

Table 4-4 present an overview of the equivalent values of the criteria to daylight availability according to TEK17 and FprEN17037. The values are based on the results from all the glazing alternatives and designs in Table 4-3 achieving a result approximately the same as the criteria.

Evaluating the results for all the glazing and designs that achieves a $\overline{DF}$ of approximately 2,0% the following area reaching $D_T$ is around 25%, which equals half of what FprEN17037 has as a criterion. The areas achieving $D_{TM}$ vary more for the ground and top floor. For the ground floor, the resulting area with $D_T$ and $D_{TM}$ is approx. 63%, while for the top the area 87%. This may be a result of the shape of the room and placement of windows. The ground floor is deeper and only has windows on one wall, while the top floor is shallower and has windows on two walls.

Considering the glazing and designs which fulfil the criteria according to FprEN17037, there is a significant difference between ground and top floor. In order to achieve the FprEN17037 criteria, the $\overline{DF}$ must be 4,1% for the ground floor, while only 3,0% for the top floor. This is an interesting observation compared to the values for achieving a $\overline{DF}$ of 2,0% acc. to TEK17, where the equivalent FprEN17037 measures where closer in range for ground and top floor.

The overview show that when fulfilling the criteria according to FprEN17037, also the criteria according to TEK17 will be fulfilled. On the other hand, will fulfilling the criteria according to TEK17 lead to also fulfilling the FprEN17037 criteria. Thus, from a perspective of daylighting conditions, FprEN17037 provides better building design than TEK17.

Considering the results for B2 at the ground floor, the criteria in FprEN17037 may be evaluated as to strict and in some cases unachievable. One counterargument might be that this will force a change of room layout which avoids deep rooms. FprEN17037 will by this ensure better building design considering daylight.

*Table 4-4 Overview over the equivalent values of the criteria to daylight acc. to TEK17 and FprEN17037*

<table>
<tr><th colspan="3">Building regulation / Standard</th><th>TEK17<br>[$\overline{DF}$ ]</th><th colspan="2">FprEN17037<br>[area fraction w/ $D_T$ or $D_{TM}$ ]</th></tr>
<tr><td colspan="3">Criteria</td><td>$\overline{DF} \geq 2{,}0\%$</td><td>$DF \geq D_T =$ 2,4% for 50% of the area</td><td>$DF \geq D_{TM} =$ 0,8% for 95% of the area</td></tr>
<tr><td rowspan="4">Equivalent for all glazing alternatives that achieved the criteria (approximation)</td><td rowspan="2">With respect to TEK17</td><td>Top floor</td><td>2%</td><td>21-27%</td><td>85-90%</td></tr>
<tr><td>Ground floor</td><td>1%</td><td>22-25%</td><td>59-66%</td></tr>
<tr><td rowspan="2">With respect to FprEN17037</td><td>Top floor</td><td>3%</td><td>52-60%</td><td>95-100%</td></tr>
<tr><td>Ground floor</td><td>4%</td><td>54%</td><td>100%</td></tr>
</table>

**Artificial lighting**

The results for artificial light demand are presented in Table 4-5 and are illustrated with bar charts in Appendix E. Lighting results, E.3 Artificial lighting demand, for visual comparison.

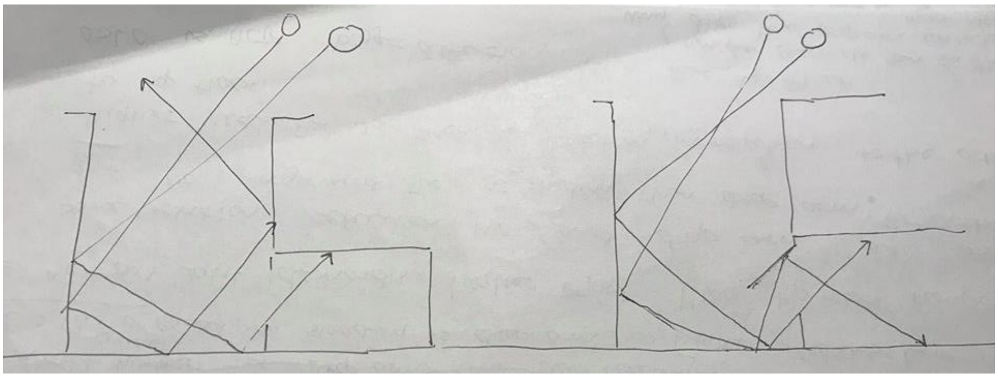
Evaluating the results viewed as bar charts, there is a visible trend of the smallest demand for artificial lighting for the designs with the largest glazing area, and the highest demand for the designs with the smallest glazing areas. At the top floor this is glazing alternative C and A1, and for the ground floor this is B2 and A1. All the designs, except the ones with glazing alternative C, with additional coating as window shading have the highest demand of artificial lighting. The additional coating provides a constant shading allowing less light pass because of the low LT (45%), thus the highest demand for artificial lighting. The drop arm awnings are controlled by the sun, meaning that they are not always drawn. This strategy in combination with the normal LT (72,1%), results in the annual demand for artificial light being lower than for additional coating. Comparing the Oslo and Alta, are all the demands a bit higher for the all the designs simulated for Alta. This is expected, because of the difference in altitude and climate.

The results for the top floor vary very little with the different shading obstructions. This indicates that they do not get effected by the height of the neighboring buildings in any significant degree, as the room is located in the 8th floor.

For the ground floor, designs with 45° shading obstructions results in somewhat higher demands for artificial lighting. This is because these adjacent buildings are the taller than the site-specific ones, providing more shade, thus a greater lighting demand. An interesting observation is that the designs with drop arm awnings in combinations with shading obstructions, require a smaller demand of artificial light compared to the designs without. One explanation of this might be the reflection of light from the adjacent buildings. When drawn, the drop arm awning ‘’catches’’ some of the light reflected via the ground from the adjacent buildings and reflects it into the room. As illustrated in Figure 4-3, the drop arm awning might catch some of the light that normally would not hit the glazing surface and enter the room. But this is only an assumption and should be investigated further.

*Table 4-5 Results for annual artificial lighting ground and top floor - Oslo and Alta*

| Ground and top floor | | Annual Artificial Lighting $[^{kWh}/_{m^2}]$ | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | No shading obstruction | | | | 45° shading obstruction | | | | Site specific shading | | | |
| Design | Glazing area | Ground floor | | Top floor | | Ground floor | | Top floor | | Ground floor | | Top floor | |
| | | Oslo | Alta | Oslo | Alta | Oslo | Alta | Oslo | Alta | Oslo | Alta | Oslo | Alta |
| No window shading | A1 | 5,50 | 5,69 | 4,45 | 5,01 | 7,48 | 7,63 | 4,67 | 5,10 | 7,01 | 7,30 | 4,53 | 5,05 |
| | A2 | 3,70 | 4,01 | 3,30 | 4,01 | 5,38 | 5,74 | 3,43 | 4,05 | 4,89 | 5,23 | 3,37 | 4,03 |
| | B1 | 4,58 | 4,76 | 3,63 | 4,30 | 6,76 | 7,08 | 3,79 | 4,34 | 6,04 | 6,46 | 3,71 | 4,32 |
| | B2 | 3,13 | 3,63 | 3,29 | 3,99 | 4,34 | 4,66 | 3,41 | 4,04 | 4,02 | 4,33 | 3,36 | 4,02 |
| | C | 3,85 | 4,12 | 3,00 | 3,73 | 5,60 | 5,98 | 3,10 | 3,77 | 5,12 | 5,43 | 3,06 | 3,75 |
| Drop arm awning | A1 | 6,12 | 6,26 | 4,94 | 5,46 | 7,35 | 7,43 | 5,16 | 5,58 | 7,02 | 7,26 | 5,03 | 5,51 |
| | A2 | 3,73 | 4,04 | 3,43 | 4,13 | 5,25 | 5,55 | 3,57 | 4,19 | 4,84 | 5,19 | 3,52 | 4,16 |
| | B1 | 4,96 | 5,20 | 3,85 | 4,50 | 6,60 | 6,82 | 4,02 | 4,57 | 6,04 | 6,40 | 3,94 | 4,53 |
| | B2 | 3,13 | 3,62 | 3,41 | 4,10 | 4,19 | 4,49 | 3,55 | 4,16 | 3,89 | 4,23 | 3,49 | 4,13 |
| | C | 3,86 | 4,12 | 3,03 | 3,75 | 5,41 | 5,71 | 3,13 | 3,79 | 4,99 | 5,28 | 3,11 | 3,77 |
| Additional coating | A1 | 6,62 | 8,02 | 5,41 | 5,85 | 7,83 | 9,43 | 5,66 | 5,97 | 7,54 | 9,24 | 5,51 | 5,90 |
| | A2 | 4,37 | 5,47 | 3,69 | 4,34 | 6,47 | 8,18 | 3,84 | 4,38 | 5,88 | 7,53 | 3,77 | 4,36 |
| | B1 | 5,67 | 7,00 | 4,15 | 4,72 | 7,52 | 9,18 | 4,34 | 4,79 | 7,02 | 8,72 | 4,23 | 4,75 |
| | B2 | 3,58 | 4,70 | 3,67 | 4,32 | 5,10 | 6,51 | 3,83 | 4,36 | 4,68 | 5,97 | 3,75 | 4,34 |
| | C | 4,58 | 5,70 | 3,27 | 3,99 | 6,70 | 8,41 | 3,41 | 4,03 | 6,14 | 7,81 | 3,36 | 4,01 |



*a) Without additional window shading* *b) With drop arm awning*

*Figure 4-3Illustration of the reflection of light for designs with shading obstructions*

**Daylight and artificial lighting**

An overview of the relation between the achieved $\overline{DF}$ and resulting saving of artificial lighting demand for the different models are illustrated as scattered diagrams in Figure 4-4 and Figure 4-5. The overall take away from the scattered diagrams is that the artificial light savings are greater for Oslo compared to Alta, and for the ground floor compared to the top floor.

*Top floor*

By evaluating the top floor, there is a difference in potential savings in artificial lighting demand for the two locations. The savings are somewhat larger for Oslo, as all the results are slightly shifted towards the right along the x-axis. The difference shows that the annual dynamic simulations takes the different climates and latitudes into account. As discussed in the daylight analysis in Location and its effect on the daylight results, doesn't the results from the daylight simulations show any significant difference for the two locations, thus are the designs placement along the y-axis unchanged.

Design C.0 which achieve the highest $\overline{DF}$ also achieves highest value for light saving. This correlation seems valid, as glazing alternative C has the largest area and design 0 does not have any additional window shading. Observing the other designs that are above the benchmark for TEK17, the difference in light savings are not very large even though they achieve lower values for $\overline{DF}$.

Design A1.6 does not result in any savings of artificial light demand and achieve the lowest results for $\overline{DF}$. The glazing alternative has the smallest glazing area and have both additional coating which reduces the amount of light passing through, as well as being shaded by a 45°

obstruction. Even though the shading obstruction does not have a large impact on the results for the top floor, are this this the worst design, mostly because of the additional coating.

*Ground floor*

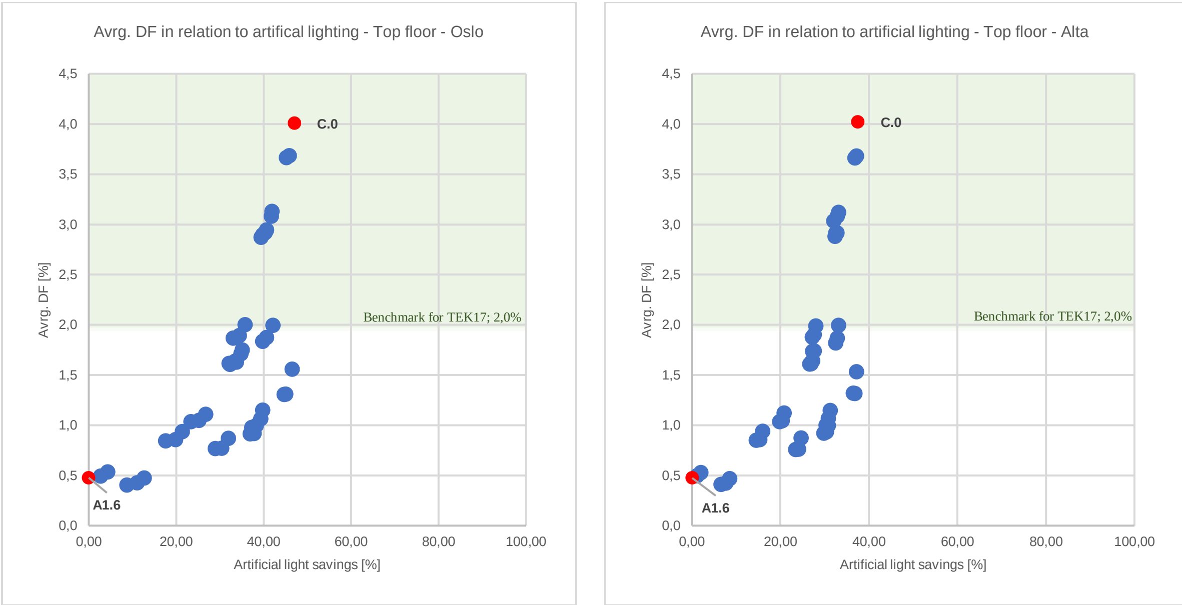
The results for the ground floor are more scattered than for the top floor. This is because the ground floor is more affected of shading by the adjacent buildings, which leads to higher demand for artificial lighting. This leads to a bigger difference between the model results, depending on whether it has a shading obstruction or not. Alta has more scattered results than Oslo, as the climate and latitude ensures lower daylight availability annually compared to Oslo.

B2.0 achieves the highest $\overline{DF}$ and has the largest saving for artificial lighting demand. This is the largest glazing area and the design does not have any additional shading. From the daylight analysis, it is known that this is the only design for the ground floor which fulfils the FprEN1703 criteria. As for the top floor, the difference in light savings compared to the other designs that are above the TEK17 benchmark are not very large.

Also, for the ground floor is design A1.6 the worst, with the smallest glazing area and design combination of additional coating and 45° shading obstruction.

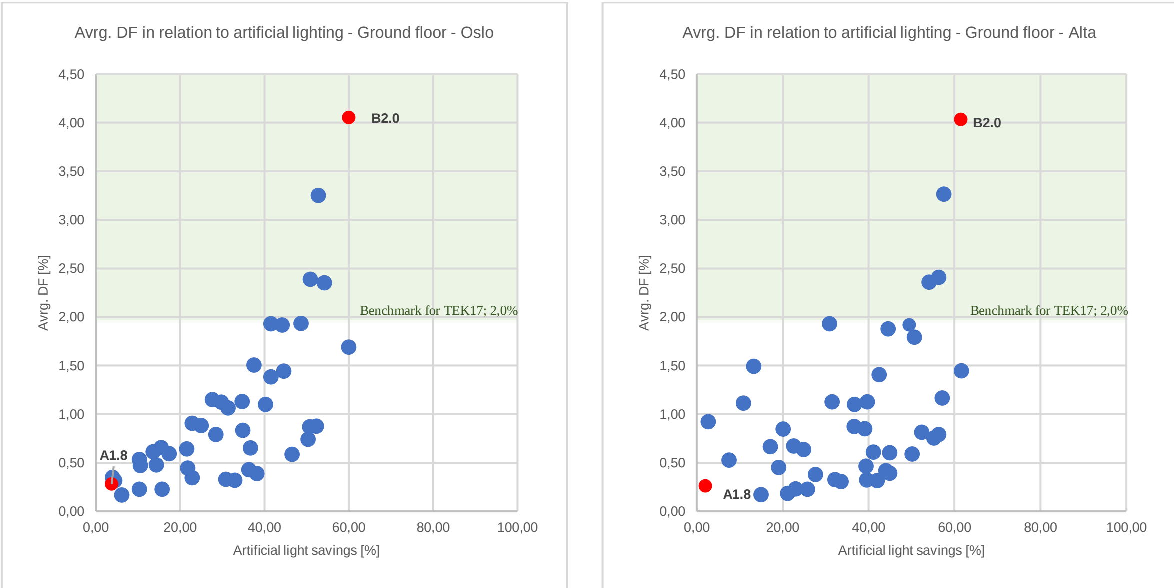
*Overall observation*

For the designs achieving the highest and lowest $\overline{DF}$ above the TEK17 benchmark in all the scattered diagrams, there is not a big difference in light savings. Observing the designs beneath the benchmark, the potential light savings are greater. The reason for this might be the set-points for the artificial lighting. As mentioned in Artificial lighting are the artificial lighting controlled by set-points linked to the illuminance levels in the room. The minimum set-point is 50lux, which means that whenever the illuminance values are below this value, the artificial lighting will be turned on. From the diagrams, it seems as an illuminance level of 50lux equals to a $\overline{DF}$ lower than 2,0%, thus are the difference bigger beneath the benchmark. This implies that by choosing a higher minimum set-point for the artificial lighting control strategy, the difference in light savings might have increased.




*a) Oslo* *b) Alta*

*Figure 4-4 Avrg. DF in relation to savings of artificial lighting demand - top floor*




*a) Oslo* *b) Alta*

*Figure 4-5 Avrg. DF in relation to saving of artificial lighting demand - ground floor*

*Note 1: Light savings are calculated according to the highest artificial lighting demand for the respective glazing alt.*

*Note 2: The labels present the glazing alternative from Table 3-11, followed by the design from Table 3-15.*

## 4.2 THERMAL PERFORMANCE

Evaluating the thermal performance, both the results for indoor thermal environment and space heating demand is important. The simulations are annual and dynamic, thus are the importance of location, weather and sun conditions greater than for the simulations performed for daylight factor.

**Thermal comfort**

The indoor thermal indoor environment for the case study evaluated according to NS-EN 15251:2007; Annex A.2, for buildings without mechanical cooling. This adaptive approach uses an hourly criterion as performance indicator, presenting the results as number of hours per category. The chosen output evaluating thermal comfort, are number of hours where the indoor operative temperatures are in category IV, labeled unacceptable. The results are shown in Table 4-6 and Table 4-7.

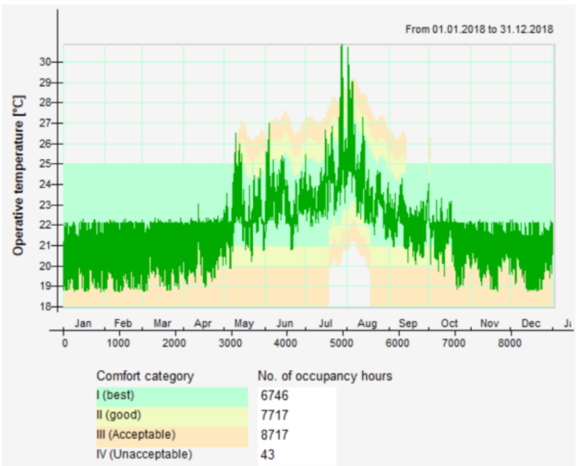
Comparing the results for the ground and top floor, the thermal comfort for the ground floor is better than for the top floor, as the majority of the models does not have any hours in category IV. There is also a difference between Oslo and Alta, where the models simulated for Oslo experience more hours in category IV than Alta. This applies to both the ground and top floor.

Looking at the maximum operative temperatures, there is not any huge differences between Oslo and Alta, or ground and top floor. This implies that the maximum operative temperatures might not be a representative measure of the overall thermal environment. As presented in 3.3.7, the outside dry bulb temperatures in the climatic files used in IDA ICE are different for the two locations. These temperatures are used in calculating the outdoor running mean temperature, as presented in Table 3-10, which again effects the adaptive thermal limits used in categorization of thermal comfort outputs. As the outside dry bulb temperatures during summer are higher for Oslo than Alta, should also the tolerance for higher temperatures in Oslo be higher. Even so are the number of unaccepted hours in Oslo higher than in Alta. An explanation of this might be the difference in latitude, resulting in Oslo being more exposed to the sun compared to Alta.

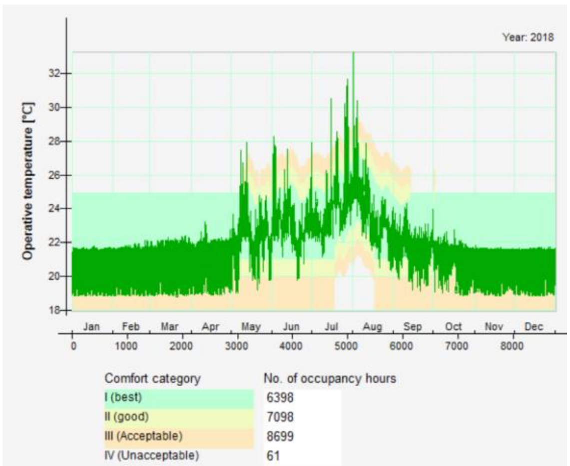
For the top floor, the model with the worst thermal environment is the largest glazing alternative C with no window shading and no shading obstructions, in Oslo. Looking at the temperatures in the thermal comfort diagram shown in Figure 4-6 a), the unacceptable hours occur in May, July and August. For the different shading obstructions, the results are not that affected, because of its location on the top floor. Of the window shadings, the additional coating achieves the fewest unacceptable hours, because of its g-factor of 0,24, which allows less radiation to pass though than the other window with g-factor of 0,6.

Glazing B2 with no window shading and no shading obstructions results in the worst thermal environment for the ground floor. As for the top floor, is this the largest glazing alternative. The unacceptable hours with too high temperatures occur in the May, June, July and August, shown in Figure 4-6 b). For the ground floor, the effect of the shading obstructions is bigger than for the top floor. This is illustrated though the reduced number of unacceptable hours for all the models with both 45° shading obstruction and site-specific shading obstruction.

Glazing A2 for the ground floor with no window shading or shading obstruction, experience a very high number of unacceptable hours, which does not match that pattern of the other results. Trying to discover the reason for this, without success, the conclusion is that this might be an error in the simulations. If there had been some days with extremely high outside temperatures in the weather file, this would also give an effect on the results for the other glazing areas as well, which it has not.




*a) Top floor, glazing alt. C with no window shading or shading obstructions, Oslo*




*b) Ground floor, glazing alt. B2 with no window shading or shading obstructions, Oslo*

*Figure 4-6 Thermal comfort results diagram acc. to NS-EN 15251:2007*

*Table 4-6 Results for thermal comfort top floor - Oslo and Alta*

| Top floor | | No shading obstruction | | | | 45° shading obstruction | | | | Site specific shading | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Design | Glazing area | max. $T_O$ [°C] | | hours with unacceptable temp. [h] | | max. $T_O$ [°C] | | hours with unacceptable temp. [h] | | max. $T_O$ [°C] | | hours with unacceptable temp. [h] | |
| | | Oslo | Alta | Oslo | Alta | Oslo | Alta | Oslo | Alta | Oslo | Alta | Oslo | Alta |
| No window shading | A1 | 28,75 | 29,00 | 14 | 7 | 28,64 | 28,89 | 8 | 6 | 28,66 | 28,92 | 9 | 6 |
| | A2 | 30,48 | 30,42 | 41 | 27 | 30,37 | 30,31 | 39 | 26 | 30,44 | 30,36 | 40 | 27 |
| | B1 | 29,63 | 29,72 | 29 | 18 | 29,57 | 29,65 | 28 | 17 | 29,56 | 29,64 | 25 | 17 |
| | B2 | 30,39 | 30,34 | 40 | 27 | 30,31 | 30,25 | 38 | 25 | 30,31 | 30,26 | 36 | 25 |
| | C | 30,89 | 30,66 | 43 | 30 | 30,78 | 30,57 | 39 | 29 | 30,84 | 30,62 | 42 | 30 |
| Drop arm awning | A1 | 28,30 | 28,44 | 5 | 3 | 28,28 | 28,32 | 4 | 2 | 28,30 | 28,34 | 5 | 2 |
| | A2 | 28,73 | 28,49 | 12 | 3 | 28,65 | 28,40 | 10 | 2 | 28,67 | 28,43 | 10 | 3 |
| | B1 | 28,52 | 28,51 | 10 | 3 | 28,48 | 28,40 | 5 | 3 | 28,51 | 28,43 | 5 | 3 |
| | B2 | 28,70 | 28,50 | 12 | 3 | 28,65 | 28,40 | 10 | 2 | 28,68 | 28,43 | 10 | 3 |
| | C | 29,31 | 29,01 | 19 | 8 | 29,23 | 28,91 | 18 | 5 | 29,25 | 28,94 | 18 | 6 |
| Additional coating | A1 | 28,02 | 28,02 | 3 | 0 | 28,00 | 28,00 | 3 | 0 | 27,99 | 27,94 | 0 | 0 |
| | A2 | 28,54 | 28,40 | 10 | 2 | 28,49 | 28,36 | 8 | 2 | 28,51 | 28,38 | 9 | 2 |
| | B1 | 28,28 | 28,18 | 5 | 0 | 28,28 | 28,15 | 5 | 0 | 28,29 | 28,12 | 4 | 0 |
| | B2 | 28,49 | 28,37 | 9 | 2 | 28,45 | 28,34 | 7 | 2 | 28,46 | 28,32 | 5 | 2 |
| | C | 28,79 | 28,43 | 13 | 2 | 28,74 | 28,38 | 11 | 2 | 28,77 | 28,41 | 12 | 2 |

*Table 4-7 Results for thermal comfort ground floor - Oslo and Alta*

| Ground floor | | No shading obstruction | | | | 45° shading obstruction | | | | Site specific shading | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Design | Glazing area | max. $T_O$ [°C] | | hours with unacceptable temp. [h] | | max. $T_O$ [°C] | | hours with unacceptable temp. [h] | | max. $T_O$ [°C] | | hours with unacceptable temp. [h] | |
| | | Oslo | Alta | Oslo | Alta | Oslo | Alta | Oslo | Alta | Oslo | Alta | Oslo | Alta |
| No window shading | A1 | 29,10 | 28,23 | 7 | 3 | 27,22 | 27,08 | 0 | 0 | 27,87 | 27,11 | 0 | 0 |
| | A2 | 31,76 | 31,90 | 43 | 59 | 27,84 | 27,44 | 0 | 0 | 29,40 | 27,81 | 14 | 0 |
| | B1 | 30,07 | 28,95 | 16 | 6 | 27,37 | 27,10 | 0 | 0 | 28,28 | 27,31 | 0 | 0 |
| | B2 | 33,28 | 31,29 | 61 | 18 | 28,66 | 27,25 | 3 | 0 | 29,97 | 27,90 | 16 | 0 |
| | C | 31,18 | 29,76 | 29 | 9 | 27,78 | 27,17 | 0 | 0 | 28,80 | 27,49 | 4 | 0 |
| Drop arm awning | A1 | 28,11 | 27,42 | 0 | 0 | 27,20 | 27,11 | 0 | 0 | 27,46 | 27,10 | 0 | 0 |
| | A2 | 29,60 | 28,65 | 13 | 4 | 27,58 | 27,44 | 0 | 0 | 28,13 | 27,54 | 0 | 0 |
| | B1 | 28,41 | 27,62 | 0 | 0 | 27,29 | 27,11 | 0 | 0 | 27,64 | 27,11 | 0 | 0 |
| | B2 | 31,34 | 29,66 | 27 | 7 | 28,42 | 27,27 | 4 | 0 | 29,12 | 27,45 | 9 | 0 |
| | C | 29,61 | 28,50 | 13 | 3 | 27,59 | 27,16 | 0 | 0 | 28,24 | 27,31 | 0 | 0 |
| Additional coating | A1 | 27,89 | 27,31 | 0 | 0 | 26,99 | 26,95 | 0 | 0 | 27,17 | 26,95 | 0 | 0 |
| | A2 | 29,26 | 28,36 | 9 | 3 | 27,09 | 27,02 | 0 | 0 | 27,76 | 27,08 | 0 | 0 |
| | B1 | 28,04 | 27,44 | 0 | 0 | 27,02 | 26,92 | 0 | 0 | 27,31 | 26,92 | 0 | 0 |
| | B2 | 29,67 | 28,46 | 13 | 3 | 27,32 | 27,02 | 0 | 0 | 28,18 | 27,21 | 0 | 0 |
| | C | 28,58 | 27,75 | 2 | 0 | 27,07 | 26,88 | 0 | 0 | 27,62 | 26,93 | 0 | 0 |

**Space heating**

Table 4-9 and Table 4-9 contains the results for space heating demand for all the performed simulations. The results are illustrated in Appendix F. Thermal performance results, F.1 Space heating demand bar charts, for visual comparison.  Reviewing all the charts, it is clear that the space heat demand is dependent of glazing to floor ratio. This is shown by the lowest heat demand for the smallest glazing areas A1, and highest for the largest glazing areas, C for the top floor and B2 for the ground floor.

Furthermore, does the designs with no window shading require the most heat demand in all cases. Second, are the designs with drop arm awning, and with the lowest heat demand are the designs with additional coating, which also has a lower u-value. These trends apply to both the ground and top floor and matches the theory of less heat loss the lower the u-value, thus are the space hating demand the lowest for these designs.

The heat demand for the designs with the drop arm awning are lower than without window shading. Normally, one would assume that the heat demand would be higher when having overhangs, as they shade the sun from providing heat to the room. The drop arm awnings used in the simulations have a control strategy to be drawn when exposed to the sun, as described in Window shading strategy. This means that the drop arms may shade the room from getting overheated by the sun. A window with no shading sometimes may lead to uncomfortable temperatures during the year for the occupants. The high temperatures lead to increased window opening by the occupants, which again can result in a higher heat demand as the heating system strive to be the set-point temperatures. The drop arm awnings decrease these heating ‘’tops’’, thus the window opening and resulting space heating demand.

For the top floor, the difference in heat demand are greater than for the ground floor. This also validates the assumption of increased window opening because of high sun exposure. For the top floor, being evaluated as the most critical regarding overheating, the occupants will open the windows more than at the ground floor. The top floor is oriented to the south, having both the window facades oriented southeast and southwest, which is where the sun is located during the day. The ground floor, being oriented with the windows northwest, does not get the same amount of sun exposure, thus less need for window opening and resulting higher heat demand. The A2 glazing areas have the same glazing to floor ratio of 25%, which makes these models suitable for comparing the heat demand for the ground and top floor. From the charts for A2 in appendix F.1 Space heating demand bar charts, the effect of the orientation is reflected by the difference in heat demand for the simulations done with no shading obstructions and no window shading, ground and top floor. The charts also show that the top floor only takes a small impact by the shading obstructions, as the results for these models almost have the same heat demand as the ones without shading obstructions. The difference in heat demand for the shading obstructions are also small for the ground floor. Even though the adjacent buildings provide shade to the ground floor, the northwest orientation initially is less to the sun, which leads to the little impact of the shading obstructions.

*Table 4-8 Results for annual space heating demand top floor - Oslo and Alta*

| Top floor | | Annual Space Heating $[kWh/m^2]$ | | | | | |
|---|---|---|---|---|---|---|---|
| Design | Glazing alternative | No shading obstruction | | 45° shading obstruction | | Site specific shading | |
| | | Oslo | Alta | Oslo | Alta | Oslo | Alta |
| No window shading | A1 | 74,99 | 75,60 | 78,28 | 85,17 | 89,16 | 86,60 |
| | A2 | 168,84 | 198,83 | 150,37 | 194,66 | 163,51 | 196,33 |
| | B1 | 129,76 | 153,25 | 112,43 | 145,55 | 141,30 | 160,42 |
| | B2 | 164,93 | 195,63 | 147,09 | 190,59 | 174,60 | 203,87 |
| | C | 208,37 | 237,46 | 187,44 | 234,98 | 202,90 | 236,43 |
| Drop arm awning | A1 | 46,56 | 50,68 | 50,43 | 73,64 | 55,47 | 74,34 |
| | A2 | 104,79 | 110,11 | 104,32 | 121,86 | 115,82 | 126,14 |
| | B1 | 85,57 | 84,95 | 81,84 | 102,18 | 93,42 | 102,48 |
| | B2 | 105,72 | 108,70 | 103,05 | 119,52 | 115,24 | 124,41 |
| | C | 165,88 | 188,60 | 156,86 | 196,27 | 169,42 | 201,31 |
| Additional coating | A1 | 27,44 | 39,57 | 27,52 | 39,46 | 48,37 | 66,41 |
| | A2 | 92,35 | 92,58 | 79,02 | 88,28 | 89,27 | 90,69 |
| | B1 | 52,87 | 60,65 | 46,29 | 58,77 | 64,21 | 80,02 |
| | B2 | 89,50 | 89,84 | 77,51 | 85,72 | 102,20 | 107,11 |
| | C | 128,58 | 135,03 | 112,45 | 128,75 | 125,60 | 131,88 |

*Table 4-9 Results for annual space heating ground floor - Oslo and Alta*

| Ground floor | | Annual Space Heating $[{}^{kWh}/_{m^2}]$ | | | | | |
|---|---|---|---|---|---|---|---|
| Design | Glazing alternative | No shading obstruction | | 45° shading obstruction | | Site specific shading | |
| | | Oslo | Alta | Oslo | Alta | Oslo | Alta |
| No window shading | A1 | 74,92 | 102,57 | 74,60 | 102,23 | 73,78 | 101,35 |
| | A2 | 108,93 | 126,45 | 88,49 | 119,74 | 86,90 | 118,73 |
| | B1 | 83,91 | 118,73 | 78,88 | 107,52 | 78,73 | 107,76 |
| | B2 | 151,04 | 212,93 | 108,69 | 144,97 | 111,92 | 149,57 |
| | C | 106,12 | 152,49 | 86,60 | 116,80 | 86,19 | 118,59 |
| Drop arm awning | A1 | 75,61 | 93,84 | 74,34 | 96,56 | 73,76 | 96,07 |
| | A2 | 88,52 | 109,88 | 87,92 | 113,48 | 86,79 | 112,57 |
| | B1 | 82,14 | 100,25 | 78,60 | 101,73 | 78,49 | 101,85 |
| | B2 | 137,66 | 182,96 | 106,37 | 138,43 | 108,55 | 141,15 |
| | C | 98,12 | 126,15 | 86,03 | 111,01 | 85,52 | 111,17 |
| Additional coating | A1 | 70,31 | 90,52 | 72,24 | 92,79 | 71,91 | 91,82 |
| | A2 | 79,23 | 101,97 | 82,06 | 105,09 | 81,20 | 104,27 |
| | B1 | 72,79 | 94,09 | 75,32 | 96,60 | 75,29 | 96,78 |
| | B2 | 102,07 | 138,30 | 94,10 | 120,06 | 92,99 | 119,02 |
| | C | 81,86 | 104,93 | 80,78 | 103,32 | 80,07 | 102,61 |

## 4.3 INDOOR COMFORT

Indoor comfort can be measured by several parameters. In this thesis it is chosen to investigate the interaction between performance of daylight and indoor thermal comfort. The two measures put in relation are:

- Average daylight factor $\overline{DF}$
- Hours of acceptable thermal comfort (category I, II, III)

Figure 4-7 and Figure 4-8 illustrates the relation between the simulation results for $\overline{DF}$ and hours with an acceptable thermal comfort for the top and ground floor, for the two locations simulated. Considering both floors, the diagrams shows that the simulated models have the same relations to each other for Oslo and Alta. However, the difference is that all the results for Alta har shifted towards the right. This is a result of better performance for thermal comfort presented in 0, with fewer hours of unaccepted temperatures. Some of the designs, evaluated as the extremes of the results and the overall best results are chosen to investigate further and marked in red.

**Top floor**

C.0 represent the best design considering daylight availability but are the worst regarding thermal comfort. This design has the largest glazing area, with no window shading or shading obstructions. As discussed in the daylight results, the large glazing area assures high result for $\overline{DF}$, which is twice the minimum criteria in TEK17. Without any window shading for he large glazing area, as well as having two facades two facades oriented south, does the design experience uncomfortable temperatures. The effect of this, not shown in the diagrams but discussed in space heating, is the largest space heating demand in addition.

The best design from a thermal comfort point of view is A1.8, which is the smallest glazing area with additional coating and shaded by site specific obstruction. For the top floor in Oslo, this is the only design that achieves zero hours with unacceptable thermal comfort. This glazing area is 9,4% in ratio to the floor, and as shown in methodology are the area divided on four very narrow windows. Even though this leads to an acceptable thermal comfort, both the resulting conditions for daylight and view out is extremely bad and not acceptable acc. to TEK17.

The analysis of the daylight results in 0, revealed that in order to achieve the criteria in FprEN17037 for the top floor, the $\overline{DF}$ had to be above 2,9%. Figure 4-7 shows that there are some of the designs that achieve this value. They are closely grouped together and have approximately the same results for thermal comfort, as they also have glazing areas close in size. Design B2.2, without additional window shading and with site specific obstructions are the one in the grouping that achieves the best thermal comfort. The number of unacceptable hours is 36, only 8 hours fewer than for than design C.4 presented in Table 4-6.

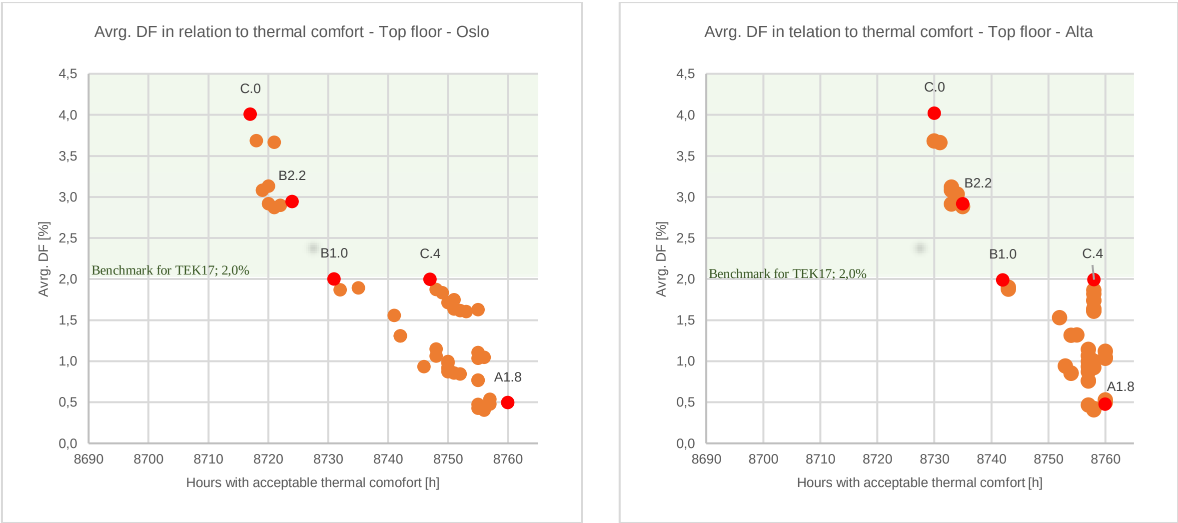
The top floor location provides optimal conditions for good daylight results, while having more risk of worse thermal conditions. B2.2 represent a compromise between the two subjects, with the focus on achieving the FprEN17037 criteria. This glazing design, whit the glazing to floor ratio of 23,9%, can only be an indicator for what is required in order to achieve FpreEN17037 for cases with the same conditions.

**Ground floor**

B2.0 is the best design considering the daylight availability at the ground floor and the worst for thermal comfort, as this extreme for the top floor. It is also the design that results in the most unacceptable hours of thermal comfort, considering both ground and top floor. The design achieves a high $\overline{DF}$, twice as big as the TEK17 criteria. From the analysis in 0, it was revealed that the ground floor would need to achieve a $\overline{DF}$ above 4,0% in order to also achieve the FprEN17037 criteria. This means that B2.0 is the only design for the ground floor that fulfills both criteria.

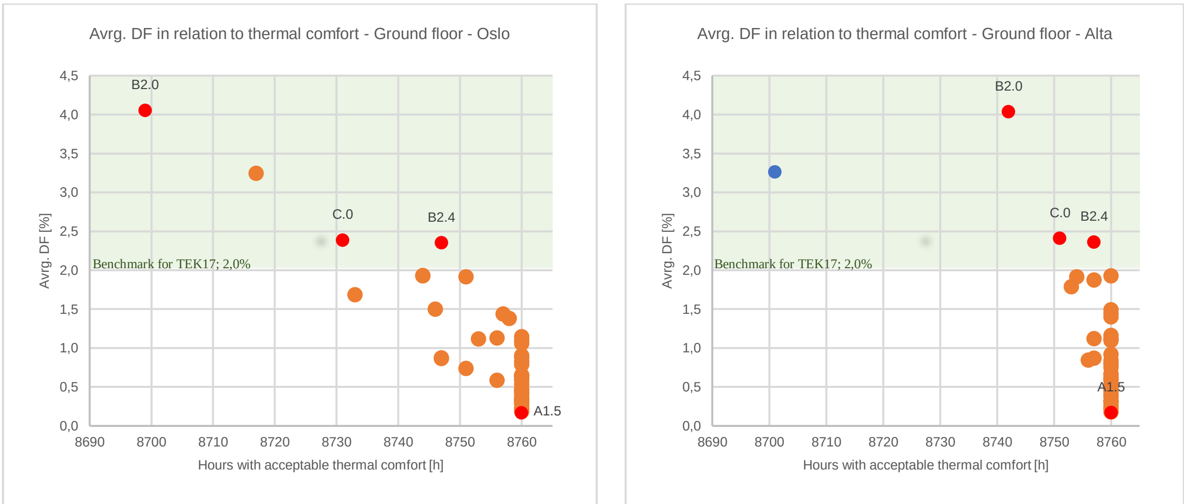
There are several designs that achieve 0 hours of unaccepted thermal comfort. These are shown as a vertical grouping to the right in Figure 4-8, with the A1 glazing alternatives having the lowest $\overline{DF}$ results. Design 5, 6 and 7 all have the exact same results for both $\overline{DF}$ and thermal comfort. Design 5 and 7 have drop arm awnings as additional window shading, while the design 6 have and have additional coating. All have shading obstructions, 5 and 6 with heights according to 45° and 7 with site specific. These extremes all have a design with two additional shadings, compare to the top floor where the respective design only had additional coating.

B2.4 are evaluated to be the compromise for the two fields, thus the most optimized. The design achieves a $\overline{DF}$ above the TEK17 criteria. Comparing B2.4 and C.0 which have the same results for $\overline{DF}$, B2.4 have a better thermal comfort. This is despite having larger glazing area than C.0. The reason for this that the window with additional coating also has a lower g-factor, thus allowing less solar radiation pass to heat the room. Comparing B2.0 with the highest result for $\overline{DF}$ and B2.4, the additional coating resulted in a reduction in $\overline{DF}$ from 4,1% to 2,4%. The hours with unacceptable thermal comfort was reduced by 48 hours.




*a) Top floor - Oslo* *b) Top floor – Alta*

*Figure 4-7 Scattered diagrams for indoor comfort - Top floor*




*a) Ground floor – Oslo* *b) Ground floor - Alta*

*Figure 4-8 Scattered diagram for indoor comfort - Ground floor*

*Note 1: The hours with acceptable temperatures are calculated by subtracting the number of hours with unacceptable thermal comfort (Table 4-6 and Table 4-7) from the total amount of hours in a year.*

*Note 2: The labels present the glazing alternative from Table 3-11, followed by the design from Table 3-15.*

## 4.4 ENERGY

There are two energy measures that have been considered when evaluating the case study. These are annual artificial lighting demand and annual space heating demand, presented in 0 and 0. The two measures have opposite relations to the performance of daylight. Higher values of $\overline{DF}$ result in a reduction in artificial lighting, because of larger glazing areas, while this increases the space heating demand because of the windows u-value and/or increased window opening for thermal comfort.

**Heat demand and artificial lighting**

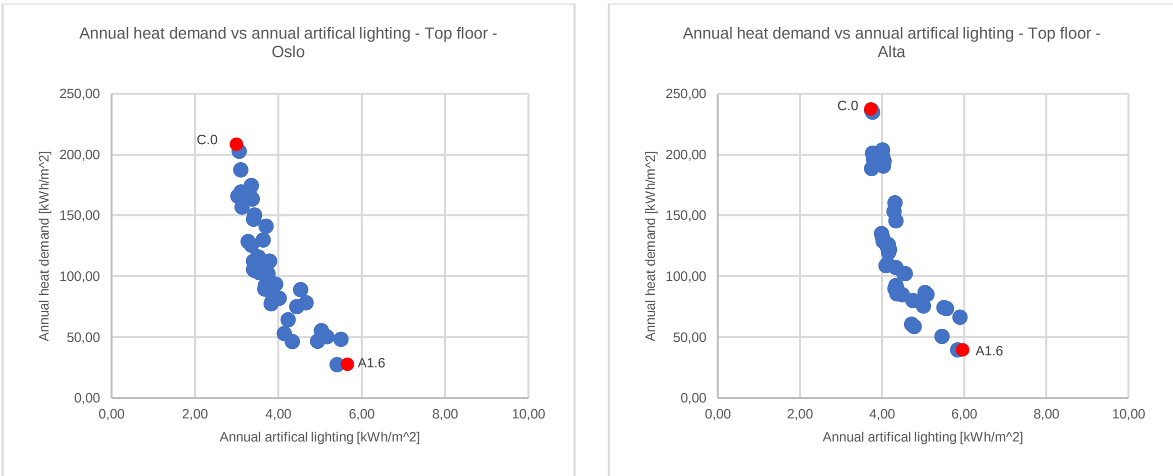
As the space hating demand and artificial lighting are opposite related to $\overline{DF}$, it is interesting to evaluate them in relation to each other. This is done with scattered diagrams, shown in Figure 4-9 and Figure 4-10.

Comparing the worst and best design for both the top and ground floor, the biggest differences in annual energy demand occur for the space heating demand at the top floor. This is shown in Table 4-10, as the possible energy saving of the designs are 86,6% and 83,4%. For the ground floor, the possible saving is only approximately 55%. This might be because the top floor has a higher space heating demand, as described in 0, thus more potential for reduction. Considering energy demand for artificial lighting, does the designs for the ground floor have more potential of energy savings, of 60%. This is also the maximal possible energy saving as a result of glazing area for the ground floor, since the best design B2.0 covers all the façade area.

By evaluating the extremes and the corresponding reduction in energy demand for artificial lighting or space heating, it shows that the amount of energy saved relative for lighting is significantly smaller than the savings for space heating demand. For the top floor, the difference in glazing area and daylight availability will only be able to be responsible of reducing the energy demand by 1,1-1,4% of the total energy demand. The possible energy saving for the ground floor is somewhat higher, but still only 4,6-5,6% of the total energy demand. A reason for the big differences in energy demand for lighting and space heating, might be the lighting properties. As presented in the methodology, are the lighting are set to be efficient LED, which results in a low energy demand compared to older light bulbs. Thus,are the annual energy demand for artificial lighting very low for the simulations. The lights are also linked to set-points, which means that the lighting only turns on when the illuminance levels are below 50lux. Had this set-point been given a higher value, would the energy demand for lighting increased.

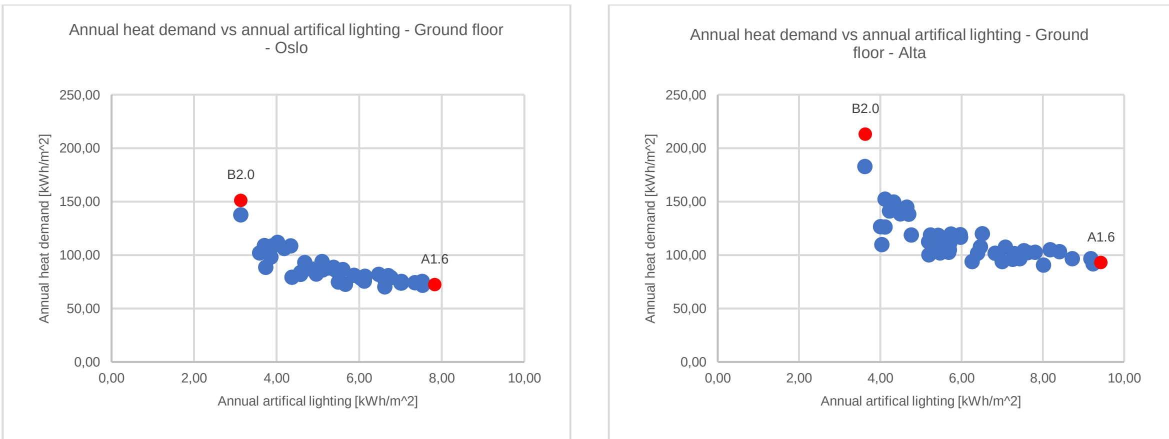
*Table 4-10 Comparison of the annual maximum energy savings for the worst and best designs*

| Annual maximum savings | | Artificial lighting | | Space heating | | Percentage of total annual savings | |
|---|---|---|---|---|---|---|---|
| | | kWh/m^2 | [%] | kWh/m^2 | [%] | Artificial lighting | Space heating |
| Top floor (Worst:A1.6 Best: C.0) | Oslo | 2,66 | 47 | 180,85 | 86,6 | 1,4% | 98,6% |
| | Alta | 2,24 | 37,5 | 198,0 | 83,4 | 1,1% | 98,9% |
| Ground floor (Worst:A1.6 Best: B2.0) | Oslo | 4,7 | 60 | 78,75 | 52,1 | 5,6% | 94,4% |
| | Alta | 5,8 | 61,5 | 120,12 | 56,4 | 4,6% | 95,4% |




*a) Oslo* *b) Alta*

*Figure 4-9 Annual space heating demand in relation to artificial light heating demand – top floor*




*a) Oslo* *b) Alta*

*Figure 4-10 Annual space heating demand in relation to artificial light heating demand - ground floor*

## 4.5 CLOSING DISCUSSION

Reviewing the different evaluations for the results from the case study, it is possible to draw some overall conclusions. Still, is important to keep in mind that the indoor comfort and energy demand of a building is complex and reliant of many different factors. Table 4-11 illustrates a comparison of best and worst designs and their performance in the different topics simulated in studies. In general, there is a clear correlation for the designs achieving the highest $\overline{DF}$, thus the lowest demand for artificial lighting, also being the same designs with the worst results regarding space heating demand and thermal comfort. This is because of their large glazing are without any shading. The same connection applies for the designs achieving the lowest $\overline{DF}$ , thus the highest demand for artificial lighting, as they have the best results regarding space heating demand and thermal comfort. They are the designs with the smallest glazing area and a combination of two additional shadings.

*Table 4-11 Comparing overview of the designs achieving the best and worst results in all topics evaluated*

| | Daylight | | Artificial lighting demand | | Space heating demand | | Thermal comfort | |
|---|---|---|---|---|---|---|---|---|
| | Top | Ground | Top | Ground | Top | Ground | Top | Ground |
| Best results | C.0 | B2.0 | C.0 | B2.0 | A1.6 | A1.6 | A1.8 | A1.5 |
| Worst results | A1.5 | A1.5 | A1.6 | A1.6 | C.0 | B2.0 | C.0 | B2.0 |

Table 4-12 and Table 4-13 show an overview of some extracted results chosen with respect to achieved $\overline{DF}$. The designs which were chosen to compare, are the ones evaluated in Indoor comfort marked in red in Figure 4-7 and Figure 4-8. The designs represent the best and worst in addition to the designs achieving the criteria in FprEN1703 and TEK17.

For the top floor, design C with no additional window shading or additional shading achieve the highest $\overline{DF}$. Glazing alternative C has the largest glazing area, and without any shading it also has the highest space heating demand. The large sun exposed glazing area leads to the highest number of unacceptable hours of thermal comfort, which again has an impact on the space heating demand, as the overheating leads to increased window opening. As a result of the largest glazing area, this design has the energy demand for artificial lighting. But, as discussed in earlier in Heat demand and artificial lighting, the amount of energy demand for artificial lighting is almost irrelevant in relation the space heating. In the other end of the scale is design A1 with both additional coating and site-specific shading. This design with the smallest area, only glazing-to-floor ratio of 9,4%, achieves the lowest $\overline{DF}$, unacceptable hours of thermal comfort, space heating demand, but the highest demand for artificial lighting.

As shown in Table 4-4, the equivalent $\overline{DF}$ in order to achieve FprEN17037 is~3%. The design achieving the FprEN17037 criteria at the top floor is represented by B2.2.

Comparing B1.0 and C.4 which both achieve the TEK17 criteria to daylight, the effect of the additional coating is clear. Glazing C with additional coating, results in almost half as many unacceptable hours for thermal comfort, even though the glazing area is over twice as big. The designs also have the same space heating demand, the big difference in glazing area. This means that by adding additional coating and doubling the glazing area, it is possible to improve the thermal comfort without reducing the $\overline{DF}$. This solution will lead to some change in the artificial lighting demand, but as stated earlier, this amount is insignificant compared to the space heating demand. From Table 4-13, the same relation when for the two designs achieving TEK17 occur when adding additional coating. Only for the ground floor, these designs are C.0 and B2.4, but they have the same relation in glazing areas, as the two designs compared for the top floor.

For the ground floor, the design achieving the best $\overline{DF}$ is B2 without any additional shading. This design is the only one for the ground floor achieving the FprEN17037 criteria, as shown in Table 4-4. This glazing area is the largest, and as stated in the methodology fills the whole façade area available. As a result of the large glazing are, the number of unacceptable hours is very high. Compared to the top floor, they are higher, even though the space heating demand is lower for the ground floor. This might indicate that there is less window opening for the ground floor, thus more unaccepted hours of thermal comfort, while also leading to less space heating demand. The reason for the less window opening at the ground floor might be that the glazing, being faced north, it less exposed to direct sun exposure, which again implies that the overheating in this zone might be less extreme than for the top floor. As for the top floor, does smallest glazing area A1, achieve the lowest values of $\overline{DF}$, unacceptable hours of thermal comfort and space heating demand, while the highest demand of artificial lighting. The worst design for the ground floor is the combination of drop arm awning and 45° shading obstruction, which is the highest of the two obstruction alternatives.

*Table 4-12 Overview of results for the different daylight levels marked red in Figure 4-7 – Top floor*

| Top floor Oslo | | Results | | | | Properties | | |
|---|---|---|---|---|---|---|---|---|
| | | Daylight | Thermal comfort | Energy (annual) | | | | |
| Ranking | Glazing alt.model | $\overline{DF}$ [%] | Unacc. hours of thermal comfort [h] | Space heating demand $[{kWh}/{m^2}]$ | Artificial lighting demand $[{kWh}/{m^2}]$ | Glazing area (glazing-to-floor ratio) $[m^2]$ | Window shading* | Shading obstructions |
| Best | C.0 | 4,0 | 43 | 208 | 3,0 | 9,5 (37,6%) | - | - |
| FprEN17037 | B2.2 | 2,9 | 36 | 175 | 3,4 | 6,02 (23,9%) | - | Site specific |
| TEK17 | B1.0 | 2,0 | 29 | 130 | 3,6 | 4,13 (16,4%) | - | - |
| TEK17 | C.4 | 2,0 | 13 | 129 | 3,3 | 9,5 (37,6%) | Add. coating | - |
| Worst | A1.8 | 0,5 | 0 | 66 | 5,5 | 2,34 (9,4%) | Add. coating | Site specific |

*Table 4-13 Overview of results for the different daylight levels marked red in Figure 4-8 – Ground floor*

| Ground floor Oslo | | Results | | | | Properties | | |
|---|---|---|---|---|---|---|---|---|
| | | Daylight | Thermal comfort | Energy (annual) | | | | |
| Ranking | Glazing alt.model | $\overline{DF}$ [%] | Unacc. hours of thermal comfort [h] | Space heating demand $[{kWh}/{m^2}]$ | Artificial lighting demand $[{kWh}/{m^2}]$ | Glazing area (glazing-to-floor ratio) $[m^2]$ | Window shading* | Shading obstructions |
| Best FprEN17037 | B2.0 | 4,1 | 61 | 151 | 3,1 | 9,12 (42,5%) | - | - |
| TEK17 | C.0 | 2,4 | 29 | 106 | 3,9 | 4,73 (22,0%) | - | - |
| TEK17 | B2.4 | 2,4 | 13 | 102 | 4,7 | 9,12 (42,5%) | Add. coating | - |
| Worst | A1.5 | 0,2 | 0 | 74 | 7,4 | 2,00 (9,3%) | Drop arm awning | 45° |

*Additional coating: g-factor reduced from 0,55 to 0,24

**Challenges discovered during thesis**

*Indoor comfort – criteria for thermal comfort*

One of the challenges when evaluating indoor comfort from the scattered diagrams, are the benchmark for thermal comfort. The category which the results represent are labeled ‘’unacceptable’’. This means that none of the designs are capable in achieving both the criteria for $\overline{DF}$ and accepted thermal comfort. Despite this, are the main purpose of this thesis to compare according to the criteria for daylight and look at the consequences for the other subjects. The models are not optimized to fulfil the criteria of thermal comfort, thus is it chosen not to define a new benchmark. An improvement of this evaluation, discovered in the aftermath of the analysis, could have been to decide a benchmark for the thermal comfort. This could have simplified the process by excluding some of the designs.

*Combination of results from static and dynamic simulations*

Another challenge discovered when analyzing the results in relation to each other, was the type of simulations the two factors are performed in. The $\overline{DF}$ is a result of a static simulation independent of time, while the results for the thermal comfort are found trough an annual dynamic simulation. The dynamic simulations use the climatic file for the chosen location, thus the shift to the right for thermal comfort in the Alta-diagrams. One would assume that this difference in climate would affect the daylight results more than they have, because of the difference in latitude. Because of the different criteria linked to latitude in FprEN17037, should the results for Alta have been lower. Even though the glazing designs B1 and B2 where decided through iterative simulations with Oslo as locations, are the results for Alta almost the same.

*Fixed overhang*

Furthermore, are the presence of the fixed overhangs an important factor. Since they are a part of the balcony-design which was decided to be a part of the reference model, they influence all the results. This means that in some of the created designs, there are a ‘’double set’’ of window shading. Presented earlier, 30%-60% of the window width, depending on the glazing alternative, always shaded by the fixed overhang. Thus, are design 0, 1 and 2 also somewhat affected by an additional window shading. This validates these designs in being truer to the daylight conditions that will occur in reality. If done again, a better option for the designs would have been to have a reference model without any balconies and fixed overhangs, instead having these as one of the additional window shadings. The drop arm awnings should have been changes with the balconies and fixed overhangs, as these provide somewhat similar shade. Then there would be a reference design representing a ‘’best-case-scenario’’ as well, suitable for comparing the other designs to what is possible. Another argument for this switch is that the fixed overhangs will always shade the windows, thus are the daylight results realistic. The drop arm awnings follow a control strategy, and to perform the simulations with these drawn does not represent the reality. This is because the $\overline{DF}$ are calculated for an overcast sky, where the drop arm awnings would not have been drawn.

In context to the previous described challenge of evaluating static and dynamic simulations in relation to one another, would the drop arm awnings have been more suitable if the daylight simulation had been dynamic. The actual effect of the sun-controlled shadings would have been measured, and not just for the times when they are drawn which represent the worst scenario for the daylight conditions

*Complexity of the thesis*

In afterthought of the analysis of the results and the process of developing the thesis, there was revealed several things elements that could have been done differently to perfect the simulation outcomes for better evaluation. The complexity of the thesis showed itself challenging to discuss and interpret in its entirety. The large number of models in combination with the four different subjects of outputs, made it hard to evaluate all the results. If done again, reducing the number of design combinations would have been an option, in order to take a closer look at the all the results.

# 5 CONCLUSION

Considering daylight, this thesis' comparison of the Norwegian Building Regulation TEK17 and the European Daylight Standard FprEN17037 should be adequate to answer the following research questions, as presented in the introduction:

***Review***

- RQ1: Which one of the standards are easier to implement?

***Case Study***

- RQ2: What are the equivalent criteria for TEK17 and FprEN17037 according to their different approaches to daylight measures, and which one of the two provides a better building design for daylight availability?
- RQ3: What are the consequences of achieving the different levels of daylight, regarding thermal comfort and energy demand?

## 5.1 MAIN FINDINGS

The comparing review shown in Table 3-1 reveal several differences between TEK17 and FprEN17037. As FprEN17037 is a standard, the scope is significantly greater than for TEK17, which is to be expected. FprEN17037 have defined methods and criteria, described in detail. TEK17 does not contain as many boundary conditions or explanations of how to evaluate the provision of daylight, making it more open for interpretation and simulations being performed differently. They each have two alternative criteria with different measures in order to achieve adequate daylight provision. The parameters in TEK17 are minimum glazing area and average daylight factor $\overline{DT}$, while FprEN17037 uses target and minimum target illuminances $E_T$ and $E_{TM}$, or target and minimum target daylight factors, $D_T$ and $D_{TM}$. The measures applying illuminances require annual dynamic simulations, as the criteria are set to be time dependent as well as requiring site specific climate data. This results in a high level of skills needed to perform this climate-based simulation approach, as well as a software capable of handling the output according to the definitions of the criteria. The criteria given in daylight factors only needs software capable of static daylight simulations, and are is the same unit at TEK17 criteria, making them comparable. Both criteria are defined to be fulfilled in a certain fraction of the area simulated, meaning that it must be possible to extract results for a given area, or show the percentage of area above of below a threshold value. IDA ICE, being the chosen software to use in this thesis, can show percentages above or below a threshold, but only in the animation view and for all the zones simulated in total. This makes the evaluation according to FprEN17037 a time-consuming task compared to direct outputs according to the $\overline{DF}$ parameter in TEK17. Thus, are the usability of FprEN17037 restricted by the simulation software. There is software capable of performing annual dynamic daylight simulations, but they may be limited regarding thermal and energy simulations. The conclusion is that FprEN17037 require more advanced software as well as skill to evaluate daylight in buildings than TEK17, while it contrarily contains detailed methods, making it less open for interpretation compared to TEK17.

The simulations performed in the case study revealed a difference in achieved daylight availability according to the criteria to daylight in TEK17 and FprEN17037. As the criteria are set according to different approaches and measures, the equivalent values had to be found. The findings, shown in Table 4-4, unveiled that the equivalent to achieving the criteria according to TEK17 of $\overline{DF}$ of 2%, only achieves half of the criteria related to $D_T$ in FprEN17037. This is the case for both ground and top floor. With respect to achieving FprEN17037, there occur a difference between the ground and top floor. The equivalent $\overline{DF}$ for achieving the criteria in FprEN1703 are 3% for the top floor, while 4% for the ground floor. This means that fulfilling the criteria according to FprEN17037, also the criteria according to TEK17 will be fulfilled. On the other hand, will fulfilling the criteria according to TEK17 not lead to fulfilling the FprEN17037 criteria. This leads to the conclusion is that FprEN17037 ensures better daylight availability then TEK17, thus a better building design considering daylight.

In general, the daylight results show that the daylight availability is better the larger the glazing area is. There is a clear correlation for the designs achieving the highest $\overline{DF}$, thus the lowest demand for artificial lighting, also being the same designs with the worst results regarding space heating demand and thermal comfort. While the opposite applies for small glazing areas and low $\overline{DF}$. The results show that achieving the daylight criteria according to FprEN17037 require a large glazing area, which leads to a more hours of unacceptable thermal comfort compared to the glazing areas required in order to fulfill TEK17. This also leads to a higher space heating demand. The large glazing areas according to FprEN17037 leads to a lower demand for artificial lighting in relation to TEK17. Still, the size of energy demand for artificial lighting is significantly low in relation to the energy demand for space heating. This means that considering daylight, FprEN17037 ensure a better building design, but considering thermal comfort and energy demand, TEK17 perform better.

## 5.2 FUTURE WORK

As a part of the process of this master thesis, developing cases and performing simulations, it was discovered several things that could have been done differently or which could have been interesting to investigate further with another approach. The following list presents some suggestions for future work:

- Using the framework made in this thesis to perform annual dynamic daylight simulations when IDA ICE 5.0 is released. It would be interesting to investigate the achieved illuminance results compared to the results for daylight factor in this thesis.
- Test another simulation software capable of performing climate-based-daylight metric and compare with achieved results.
- Include other types of external shading into the framework to evaluate their effect. In this thesis, external blinds were not included, because they were evaluated ‘’to similar’’ to the additional coating. When dynamic simulations are possible, the external blinds will give different results than the external coating, thus making it more relevant for these types of simulations.
- Further evaluate what changes of room layout that must be done for the ground floor living room in order to achieve FprEN17037 when shaded by adjacent buildings. Is it realistically possible?
- Optimization regarding both daylight and thermal comfort. With respect to fulfilling the illuminance criteria in FprEN17037 as well as acceptable thermal comfort, what building design is required?

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# APPENDICES

# APPENDIX A. CONSULTATION EQUA

Investigating the possibility of dynamic daylight simulations, it was performed both a search in EQUA's forum and discussed over email with an employee at EQUA. These two threads are presented in Figure A - 1 and Figure A - 2, both stating that the annual calculation of daylight is yet not available and won't be available until next version of IDA ICE.

For the next version (5) of IDA ICE we plan to introduce annual Radiance calculation of daylight. We hope then also to give the option of placing the measurement plane on any surface to obtain the solar radiation. Right now it is only possiible to get shaded solar radiation on windows and unshaded on facades.

answered **22 hours ago**
Bengt Hellström, EQUA Simulation AB 591

edit flag offensive delete link

Since it is not possible to be done in IDA-Ice, I would suggest using Rhino-Grasshopper for this task. It is fairly easy and there are thousands of scripts available from other users across the globe.

answered **Dec 14 '18**
Kaspar Bajars 1

edit flag offensive delete link

This is not possible and it it not easy to calculate it on building bodies either. It includes logging at advanced level, virtual windows to calculate shading, some clever scripts and editing prn-files for visualizing.

answered **May 14 '18**
Max Tillberg 1945

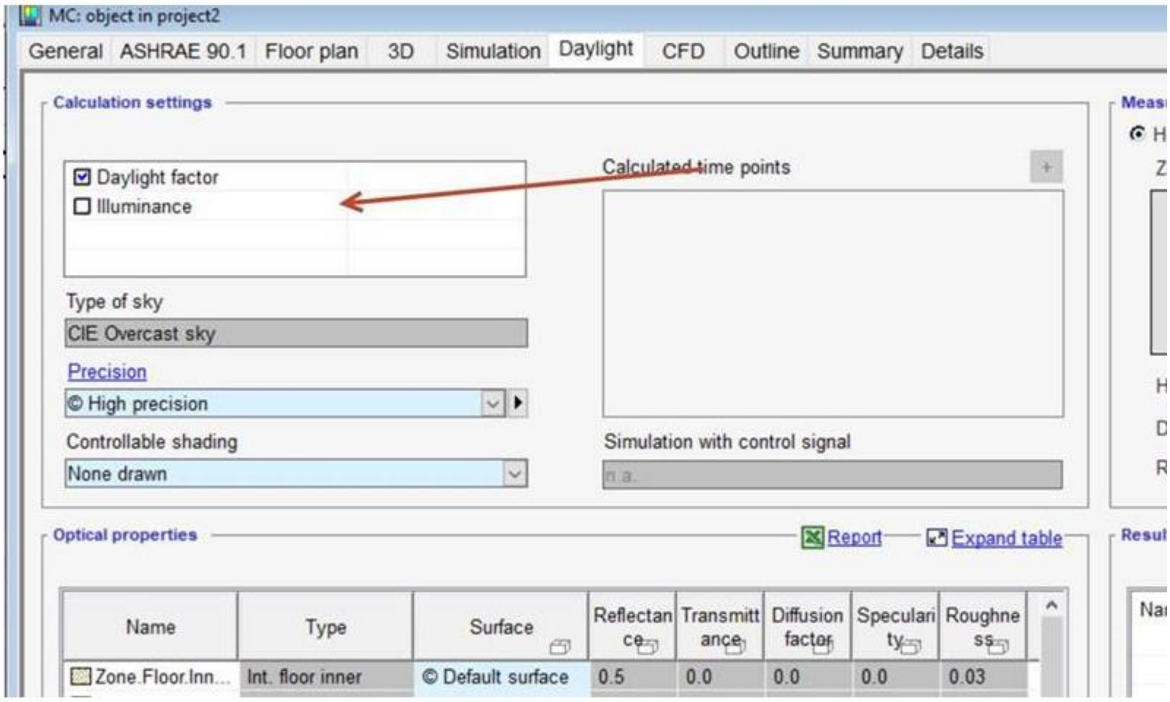
edit flag offensive delete link

*Figure A - 1 Forum post regarding annual daylight simulations in IDA ICE (Hellström, 2018b)*

**From:** Mika Vuolle <mika.vuolle@equa.fi>
**Sent:** Wednesday, November 21, 2018 7:20 AM
**To:** Mohamed Hamdy <mohamed.hamdy@ntnu.no>; Patrik Skogqvist <patrik.skogqvist@equa.se>
**Subject:** RE: Email for EQUA

Hi,

To get lux ou you have to select illuminanace instead og daylight




The question to get DF procent per zone, I cannot answer. Script perhaps needed

The annual daylight simulation is in the pipe line. Not published yet.

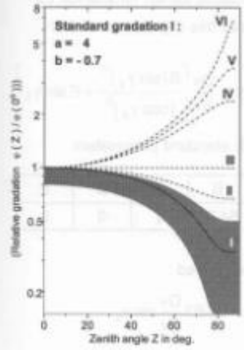
*Figure A - 2 An excerpt from e-mail thread with EQUA employee, 21.11.2018*

# APPENDIX B. CIE SKY MODELS

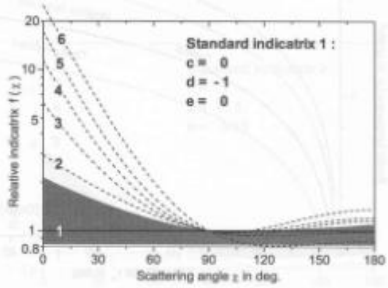
| Code | Type of sky | Recommended or standardised parameters: for gradation | for indicatrix | typical Dv/Ev | B | C | D | E | for Lz as F(Tv) | typical cases |
|---|---|---|---|---|---|---|---|---|---|---|
| I.1 | Overcast with the steep gradation and with azimuthal uniformity | a= 4<br>b= -0.7 | c= 0<br>d= -1<br>e= 0 | 0.10 | 54.63 | 1.00 | 0.00 | 0.00 | Because these sky standards are associated with no sunlight the relation Lz=F(Tv) is not valid | |
| I.2 | Overcast with the steep gradation and slight brightening toward sun | a= 4<br>b= -0.7 | c= 2<br>d= -1.5<br>e= 0.15 | 0.18 | 12.35 | 3.68 | 0.59 | 50.47 | | |
| II.1 | Overcast moderately graded with azimuthal uniformity | a= 1.1<br>b= -0.8 | c= 0<br>d= -1<br>e= 0 | 0.15 | 48.30 | 1.00 | 0.00 | 0.00 | | |
| II.2 | Overcast moderately graded and slight brightening toward sun | a= 1.1<br>b= -0.8 | c= 2<br>d= -1.5<br>e= 0.15 | 0.22 | 12.23 | 3.57 | 0.57 | 44.27 | | |
| III.1 | Overcast, foggy or cloudy with overall uniformity | a= 0<br>b= -1 | c= 0<br>d= -1<br>e= 0 | 0.20 | 42.59 | 1.00 | 0.00 | 0.00 | | |
| III.2 | Partly cloudy with a uniform gradation and slight brightening toward sun | a= 0<br>b= -1 | c= 2<br>d= -1.5<br>e= 0.15 | 0.38 | 11.84 | 3.53 | 0.55 | 38.78 | | |
| III.3 | Partly cloudy with a brighter circumsolar effect and uniform gradation | a= 0<br>b= -1 | c= 5<br>d= -2.5<br>e= 0.3 | 0.42 | 21.72 | 4.52 | 0.64 | 34.56 | A1=0.957<br>A2=1.790 | Tv=12.0<br>A=13.27 |
| III.4 | Partly cloudy, rather uniform with a clear solar corona | a= 0<br>b= -1 | c= 10<br>d= -3<br>e= 0.45 | 0.41 | 29.35 | 4.94 | 0.70 | 30.41 | A1=0.830<br>A2=2.030 | Tv=10.0<br>A=10.33 |
| IV.2 | Partly cloudy with a shaded sun position | a= -1<br>b= -0.55 | c= 2<br>d= -1.5<br>e= 0.15 | 0.40 | 10.34 | 3.45 | 0.50 | 27.47 | A1=0.600<br>A2=1.500 | Tv=12.0<br>A= 8.70 |
| IV.3 | Partly cloudy with brighter circumsolar effect | a= -1<br>b= -0.55 | c= 5<br>d= -2.5<br>e= 0.3 | 0.36 | 18.41 | 4.27 | 0.63 | 24.04 | A1=0.567<br>A2=2.610 | Tv=10.0<br>A= 8.28 |
| IV.4 | White - blue sky with a clear solar corona | a= -1<br>b= -0.55 | c= 10<br>d= -3<br>e= 0.45 | 0.23 | 24.41 | 4.60 | 0.72 | 20.76 | A1=1.440<br>A2=-0.75 | Tv= 4.0<br>A= 5.01 |
| V.4 | Very clear / unturbid with a clear solar corona | a= -1<br>b= -0.32 | c= 10<br>d= -3<br>e= 0.45 | 0.10 | 23.00 | 4.43 | 0.74 | 18.52 | A1=1.036<br>A2=0.710 | Tv= 2.5<br>A= 3.30 |
| V.5 | Cloudless polluted with a broader solar corona | a= -1<br>b= -0.32 | c= 16<br>d= -3<br>e= 0.3 | 0.28 | 27.45 | 4.61 | 0.76 | 16.59 | A1=1.244<br>A2=-0.84 | Tv= 4.5<br>A= 4.76 |
| VI.5 | Cloudless turbid with a broader solar corona | a= -1<br>b= -0.15 | c= 16<br>d= -3<br>e= 0.3 | 0.28 | 25.54 | 4.40 | 0.79 | 14.56 | A1=0.881<br>A2=0.453 | Tv= 5.0<br>A= 4.86 |
| VI.6 | White - blue turbid sky with a wide solar corona effect | a= -1<br>b= -0.15 | c= 24<br>d= -2.8<br>e= 0.15 | 0.30 | 28.08 | 4.13 | 0.79 | 13.00 | A1=0.418<br>A2=1.950 | Tv= 4.0<br>A= 3.62 |

*Figure B - 1 CIE Standard sky types: 15 CIE models (Matusiak, 2017b)*

# I.1




Place of sky type I.1 in the standard sky set :




Standard formula for relative luminance distribution :

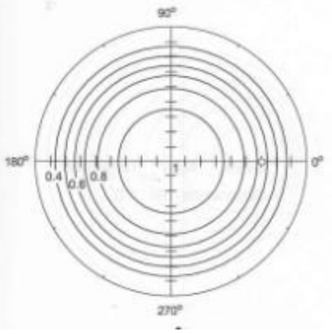
$$\frac{L_{ZZ}}{L_{ZS}} = \frac{1 + 4\exp(-0.7/\cos Z)}{2.986}$$

where Z is the zenith angle

Table of approximate range and auxiliary conditions

| Gradation scale zenith:horizon | Indicatrix scale | Frequent range Dv/Ev | Usual range Δ | Usual Tv range | Gradation range zenith:horizon | Indicatrix prolongation range | Probable range Lz/Dv*) |
|---|---|---|---|---|---|---|---|
| 1 : 0.33 | around 1 | 0.05-0.3 | 0.03-0.25 | over 20 | 1:0.1 - 1:0.5 | 0.8:1 - 1.2:1 | over 0.38 |
| Note : *) The Lz/Dv value for an ideal standard I.1 is 0.408 at every solar altitude | | | | | | | |

Example for Zs = 60°




Sky profile in solar meridian

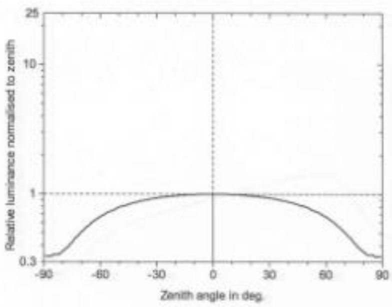



*Figure B - 2 CIE sky type I.1 Overcast with steep gradation and with azimuthal uniformity (Matusiak, 2017b)*

## APPENDIX C. CALCULATION GRID

Formulas for minimum dimensions for calculation grid:

- NS-EN 12464-1:2011 Chapter 4.4:

$$p = 0{,}2 * 5^{\log_{10}(d)} \; [1] \quad , and\ \#\ grid\ points \geq {}^{d}/_{p} \; [2]$$

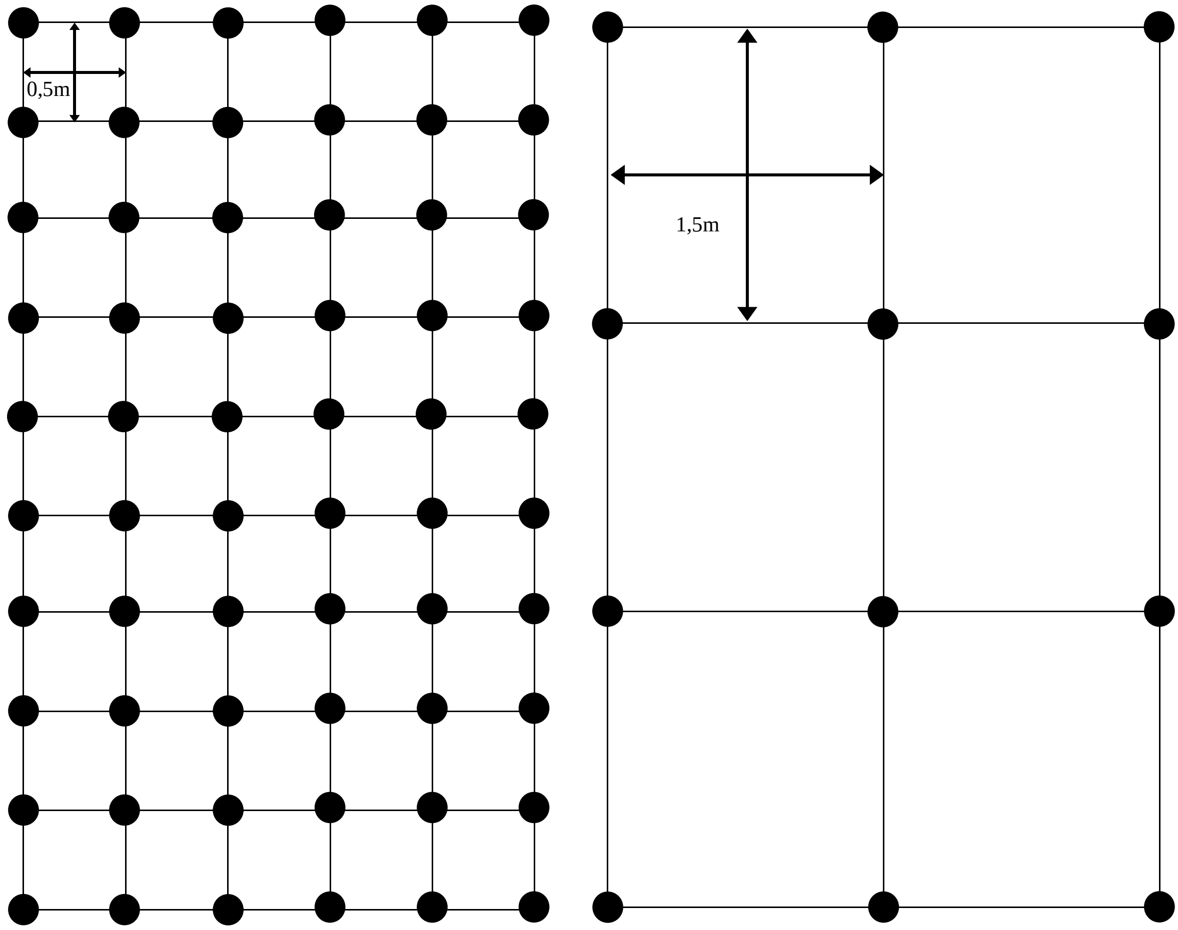
- FprEN17037:2017 Annex B, Chapter B.2:

$$p = 0{,}5 * 5^{\log_{10}(d)} \; [3] \quad , and\ \#\ grid\ points \geq {}^{d}/_{p} \; [4]$$

$p$: $max.\ grid\ cell\ size$

$d$: $longer\ dimension\ of\ the\ calculation\ area$

${}^{d}/_{p}$ : $nearest\ whole\ number - number\ of\ grid\ points\ in\ d$




*a)Min. resolution acc. to NS-EN 12464-1:2011 & default resolution in IDA ICE: 0,5m – 60 grid points*

*b)Min. resolution acc. FprEN 17037:2017: 1,5m – 12 grid points*

*Figure C - 1 Example of two calculation grids for a room with dimension 3,8m x 5,6m*

*Table C - 1 Minimum dimensions for calculation grid acc. NS-EN 12464:2011 and FprEN17037:2017*

| | **p [m]** | **d/p [calc. points in d]** | | **Resulting p [m]** | |
|---|---|---|---|---|---|
| **NS-EN 12464-1:2011** | Calculated acc. [1] | Calculated acc. [2] | Nearest greater whole number | d/nearest whole number | Nearest 0,5 interval |
| Ground floor | 0,67 | 8,36 | 9 | 0,62 | 0,5 |
| Top floor | 0,67 | 8,47 | 9 | 0,63 | 0,5 |
| **FprEN 17037:2017** | Calculated acc. [3] | Calculated acc. [4] | Nearest whole number | d/nearest whole number | Nearest 0,5 interval |
| Ground floor | 1,67 | 3,35 | 4 | 1,40 | 1,5 |
| Top floor | 1,68 | 3,38 | 4 | 1,42 | 1,5 |

# APPENDIX D. SITE LAYOUT FOR GARTNERKVARTALET


*Figure D - 1 Site layout for Gartnerkvartalet at Løren in Oslo (Lillestrøm Architects, 2018b)*

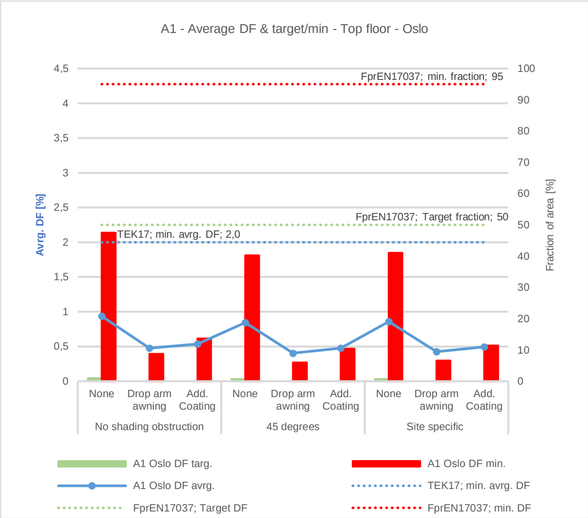
# Appendix E. Lighting results

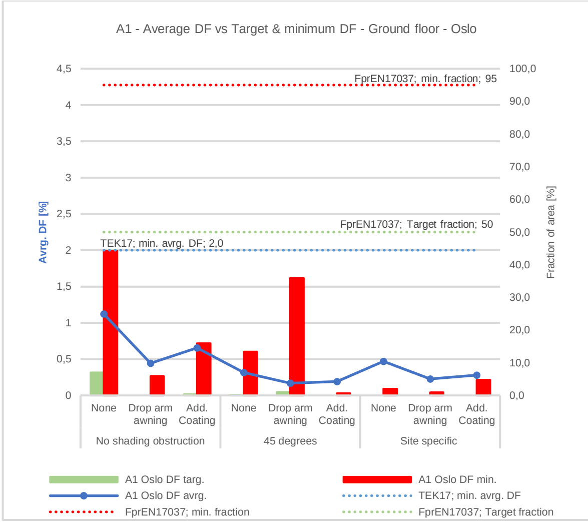
## E.1 Daylight simulation results

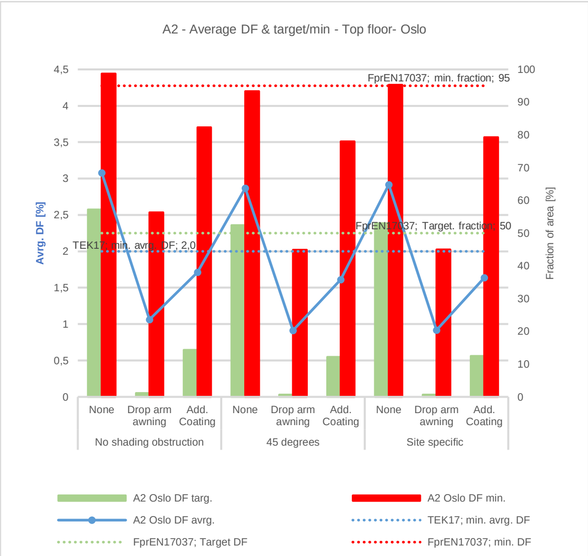
*Table E - 1 Result table daylight simulations - Alta*

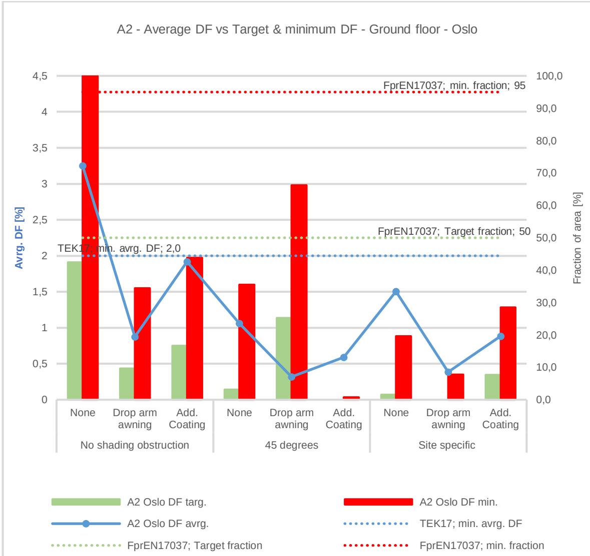
| Glazing alternative | Additional shading design | TEK17 | | FprEN17037 | | | |
|---|---|---|---|---|---|---|---|
| | | | | % of area w/ DF > | | % of area w/ DF > | |
| | | Ground fl. | Top fl. | Ground fl. | Top fl. | Ground fl. | Top fl. |
| **A1** [2,00/2,34$m^2$ acc. to TEK17 §13-7b)] | 0 | 1,1 | 0,9 | 7,0 | 1,1 | 44,8 | 47,8 |
| | 1 | 0,3 | 0,9 | 0,0 | 0,7 | 5,9 | 40,2 |
| | 2 | 0,5 | 0,9 | 0,3 | 0,7 | 15,6 | 42,2 |
| | 3 | 0,4 | 0,5 | 0,1 | 0,0 | 13,9 | 8,3 |
| | 4 | 0,7 | 0,5 | 1,0 | 0,0 | 26,2 | 13,1 |
| | 5 | 0,2 | 0,4 | 0,0 | 0,0 | 0,5 | 6,3 |
| | 6 | 0,2 | 0,5 | 0,0 | 0,0 | 1,8 | 10,5 |
| | 7 | 0,2 | 0,4 | 0,0 | 0,0 | 1,0 | 6,4 |
| | 8 | 0,3 | 0,5 | 0,0 | 0,0 | 4,4 | 11,4 |
| **A2** [5,38/6,31$m^2$ acc. to TEK17 §14-2] | 0 | 3,3 | 3,1 | 42,6 | 56,8 | 100,0 | 98,7 |
| | 1 | 1,2 | 3,0 | 10,4 | 56,3 | 39,9 | 96,7 |
| | 2 | 1,5 | 2,9 | 16,4 | 53,1 | 43,3 | 95,4 |
| | 3 | 0,8 | 1,1 | 2,7 | 1,3 | 33,7 | 55,9 |
| | 4 | 1,9 | 1,7 | 24,6 | 14,9 | 65,0 | 82,9 |
| | 5 | 0,3 | 0,9 | 0,0 | 0,8 | 0,8 | 45,4 |
| | 6 | 0,6 | 1,6 | 1,9 | 12,0 | 20,1 | 77,0 |
| | 7 | 0,4 | 0,9 | 0,0 | 0,7 | 8,1 | 46,4 |
| | 8 | 0,8 | 1,6 | 7,1 | 12,3 | 27,1 | 79,1 |
| **B1** [3,01/4,13$m^2$ acc. to TEK17 §13-7a)] | 0 | 1,9 | 2,0 | 25,2 | 26,3 | 64,1 | 89,0 |
| | 1 | 0,6 | 1,9 | 3,6 | 21,6 | 19,4 | 85,4 |
| | 2 | 0,9 | 1,9 | 8,4 | 21,7 | 28,1 | 87,5 |
| | 3 | 0,6 | 0,9 | 0,9 | 0,0 | 23,8 | 44,8 |
| | 4 | 1,1 | 1,1 | 10,3 | 2,7 | 43,8 | 63,5 |
| | 5 | 0,2 | 0,8 | 0,0 | 0,0 | 1,0 | 36,2 |
| | 6 | 0,4 | 1,0 | 0,0 | 2,3 | 9,8 | 58,1 |
| | 7 | 0,3 | 0,8 | 0,0 | 9,0 | 4,5 | 35,9 |
| | 8 | 0,5 | 1,0 | 2,0 | 2,3 | 17,2 | 58,3 |
| **B2** [9,12/6,02$m^2$ acc. to FprEN17037] | 0 | 4,0 | 3,1 | 54,0 | 59,1 | 100,0 | 99,8 |
| | 1 | 1,4 | 2,9 | 17,2 | 52,7 | 49,9 | 95,0 |
| | 2 | 1,9 | 2,9 | 22,6 | 53,8 | 58,8 | 97,4 |
| | 3 | 1,8 | 1,1 | 21,1 | 1,3 | 72,8 | 64,1 |
| | 4 | 2,4 | 1,7 | 33,2 | 14,7 | 91,0 | 84,8 |
| | 5 | 0,6 | 1,0 | 0,0 | 0,8 | 21,4 | 52,5 |
| | 6 | 0,8 | 1,6 | 4,4 | 11,9 | 28,8 | 79,9 |
| | 7 | 0,8 | 1,0 | 0,0 | 0,7 | 33,6 | 51,2 |
| | 8 | 1,1 | 1,6 | 10,7 | 12,3 | 37,9 | 81,2 |
| **C** [4,73/9,50$m^2$ acc. as designed] | 0 | 2,4 | 4,0 | 32,2 | 75,8 | 83,7 | 100,0 |
| | 1 | 0,8 | 3,7 | 5,4 | 68,3 | 26,2 | 100,0 |
| | 2 | 1,1 | 3,7 | 11,1 | 69,3 | 34,0 | 100,0 |
| | 3 | 0,9 | 1,5 | 3,0 | 8,9 | 35,5 | 84,2 |
| | 4 | 1,4 | 2,0 | 16,4 | 25,4 | 54,9 | 88,0 |
| | 5 | 0,3 | 1,3 | 0,0 | 4,8 | 2,6 | 73,8 |
| | 6 | 0,5 | 1,8 | 0,4 | 20,2 | 14,4 | 82,5 |
| | 7 | 0,4 | 1,3 | 0,0 | 5,0 | 8,3 | 73,2 |
| | 8 | 0,7 | 1,9 | 3,0 | 21,1 | 22,5 | 84,5 |

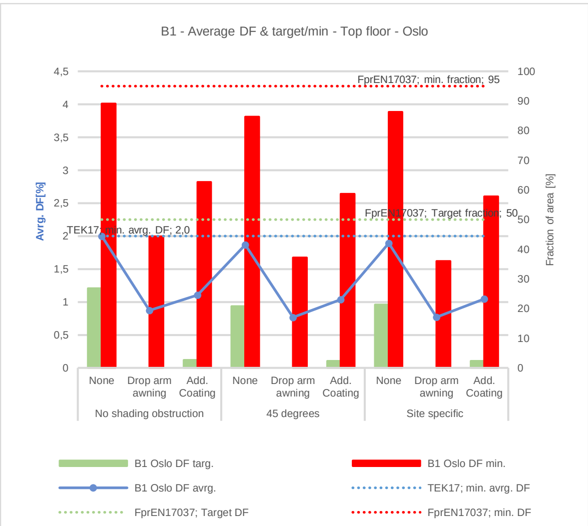
## E.2 $\overline{DF}$ in relation to fraction areas with $D_T$ and $D_{TM}$

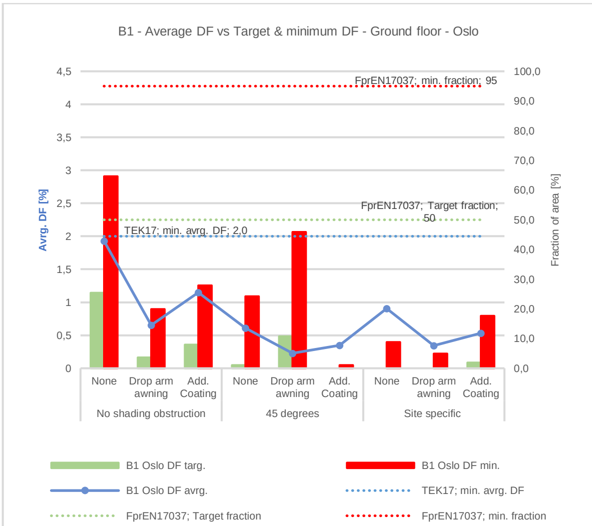


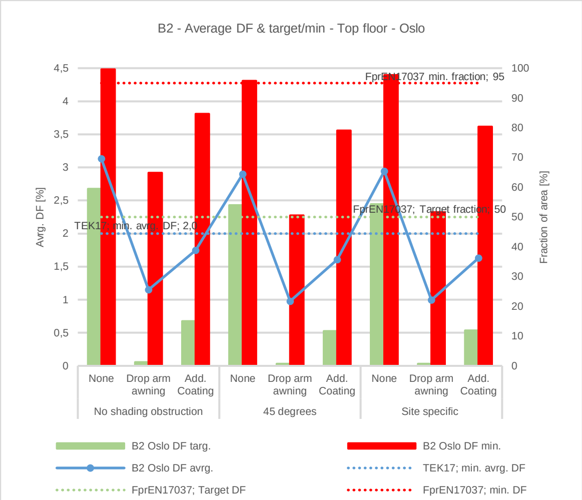



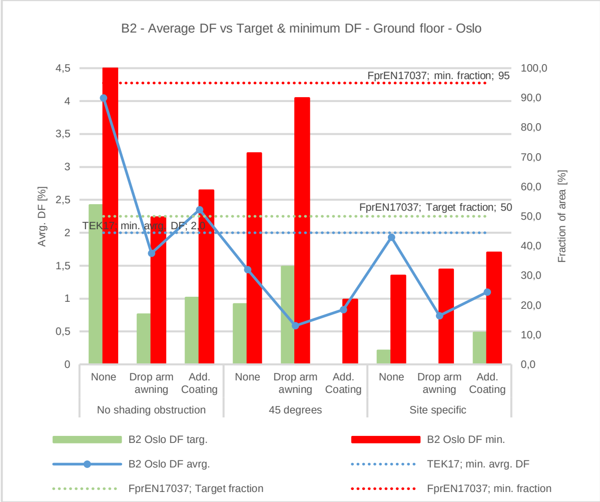



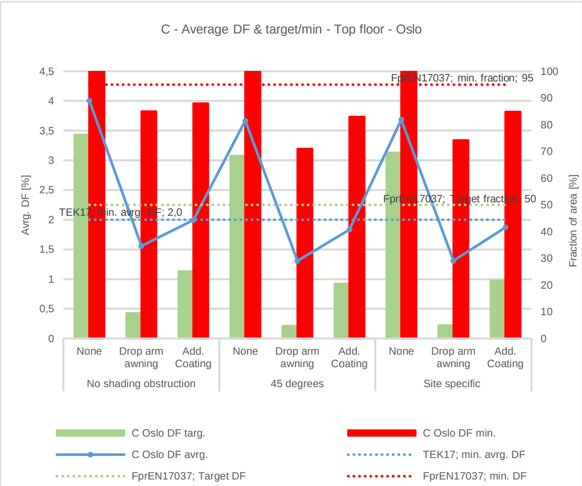



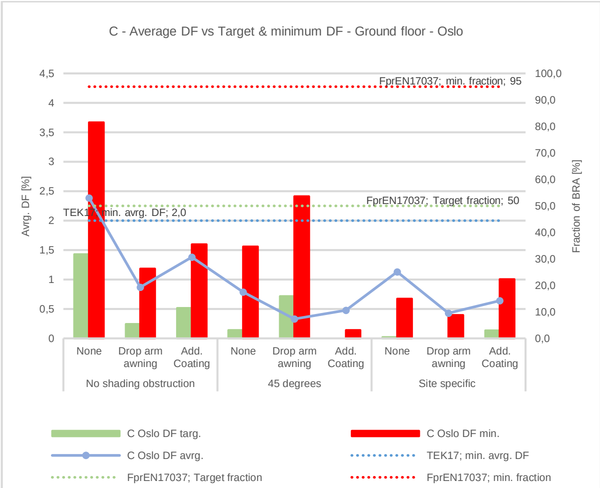



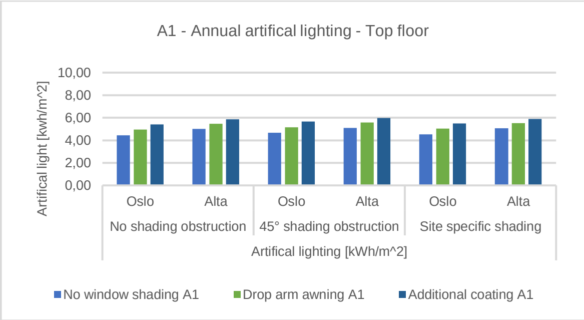

B2 - Average DF & target/min - Top floor - Oslo
Avrg. DF [%]
Fraction of area [%]
FprEN17037 min. fraction; 95
FprEN17037; Target fraction; 50
TEK17; min. avrg. DF; 2,0
None
Drop arm awning
Add. Coating
No shading obstruction
45 degrees
Site specific
B2 Oslo DF targ.
B2 Oslo DF min.
B2 Oslo DF avrg.
TEK17; min. avrg. DF
FprEN17037; Target DF
FprEN17037; min. DF

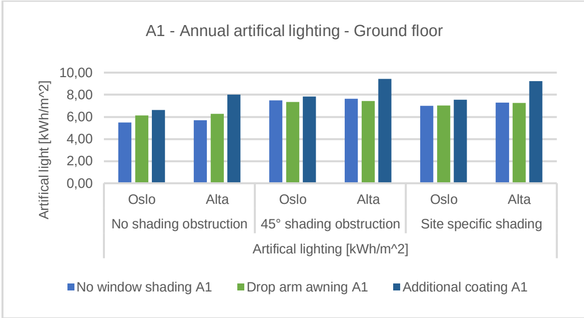

B2 - Average DF vs Target & minimum DF - Ground floor - Oslo
Avrg. DF [%]
Fraction of area [%]
FprEN17037; min. fraction; 95
FprEN17037; Target fraction; 50
TEK17; min. avrg. DF; 2,0
None
Drop arm awning
Add. Coating
No shading obstruction
45 degrees
Site specific
B2 Oslo DF targ.
B2 Oslo DF min.
B2 Oslo DF avrg.
TEK17; min. avrg. DF
FprEN17037; Target fraction
FprEN17037; min. fraction

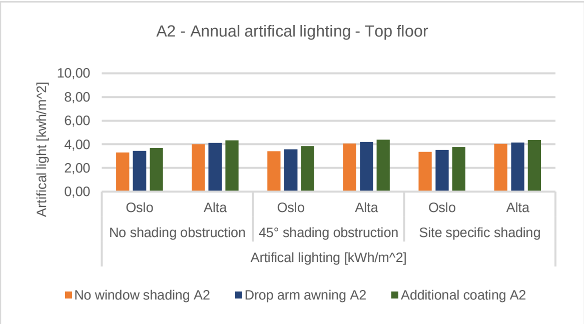

C - Average DF & target/min - Top floor - Oslo
Avrg. DF [%]
Fraction of area [%]
FprEN17037; min. fraction; 95
FprEN17037; Target fraction; 50
TEK17; min. avrg. DF; 2,0
None
Drop arm awning
Add. Coating
No shading obstruction
45 degrees
Site specific
C Oslo DF targ.
C Oslo DF min.
C Oslo DF avrg.
TEK17; min. avrg. DF
FprEN17037; Target DF
FprEN17037; min. DF

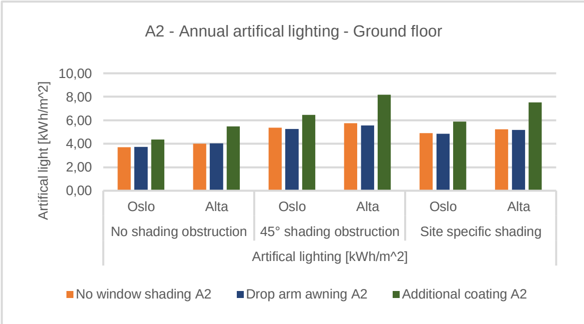

C - Average DF vs Target & minimum DF - Ground floor - Oslo
Avrg. DF [%]
Fraction of BRA [%]
FprEN17037; min. fraction; 95
FprEN17037; Target fraction; 50
TEK17; min. avrg. DF; 2,0
None
Drop arm awning
Add. Coating
No shading obstruction
45 degrees
Site specific
C Oslo DF targ.
C Oslo DF min.
C Oslo DF avrg.
TEK17; min. avrg. DF
FprEN17037; Target fraction
FprEN17037; min. fraction

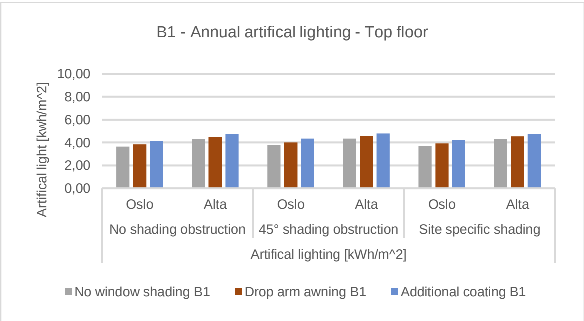
# E.3 Artificial lighting demand bar charts

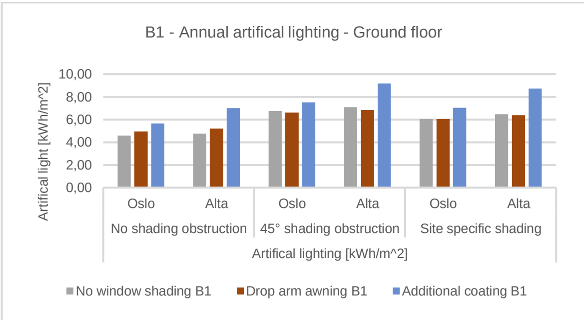


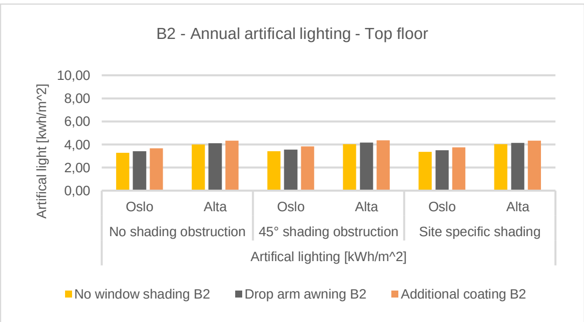



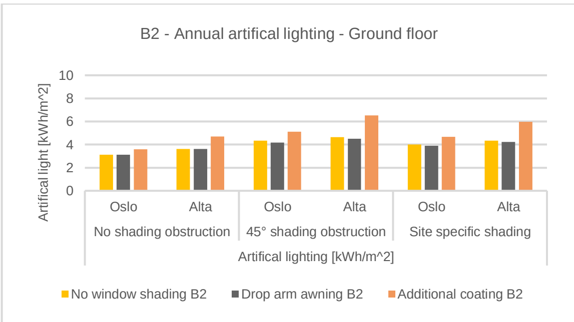



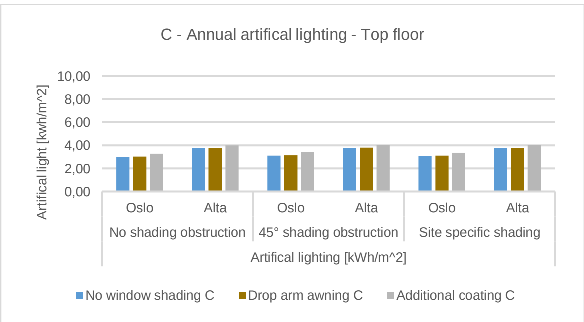



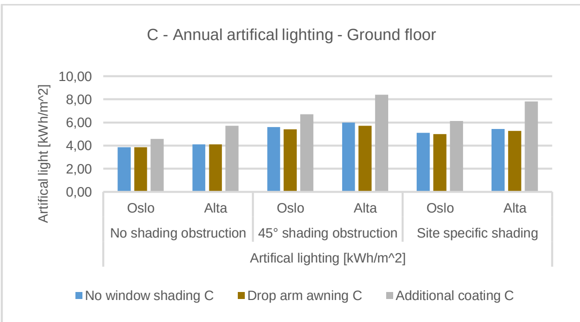



# Appendix F. Thermal performance results

## F.1 Space heating demand bar charts