*Article*

# Optimalization of Window Design for Daylight and Thermal Comfort in Cold Climate Conditions

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**Abstract:** Window design affects the overall performance of the building. It is important to include window design during the initial stages of the project since it influences the performance of daylight, thermal comfort as well as energy demand for heating and cooling. The Norwegian building code facilitates two alternative methods for achieving sufficient daylight, and guidelines for adequate indoor thermal comfort. In this study, a typical Norwegian residential building has been modelled in IDA ICE to investigate how well the criteria and methods facilitate consistent and good performances through different scenario changes. Furthermore how the national regulations compare to European standards. A better insulated building has usually a lower annual heating demand, with only a marginal decrease in the daylight performance. At the same time, a tighter construction increases the risk of overheating even in cold climates. A revision of window design increases the overall performance of the building, which highlights the importance of good window design. The pursuit of lower energy demand should not be at expense of the indoor thermal comfort considering the anticipated future weather conditions. There should be paid more attention to which criteria that are reliable and should be used for daylight calculate, as this study indicate that the criteria in the national regulations and the European standards are not consistent.

**Keywords:** Energy optimization; Daylight; Thermal comfort; IDA ICE

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## 1. Introduction

Window design is an important aspect for the overall performance of the building. A unfortunate window design can overturn a high performance building to a building with poor performance. How this design is planned affects the energy efficiency in terms of both annual heating demand and cooling demand and the need for artificial lighting. The amount of solar radiation transmitting through the fenestration also affects the indoor thermal environment. Having sufficient daylight provision influences the visual comfort of the occupants. A good daylight design provides stimulating and well-lit indoor environments.

The solar radiation that hits the earth is equivalent to 15.000 times the total annual energy consumption for the entire earth. This solar energy can be utilized either in a passive or active form. Using the solar heat gains through windows for space heating, and the solar radiation as substitute for artificial lighting are examples of passive utilization [1]. Principles for active utilization could be solar thermal collectors that directly uses the solar energy to heat water that circuits the building for space heating and domestic hot water. Conversion of the solar energy to electricity in form of solar panels is also an example of active utilization [2]. Since Norway is an elongated country with various topography, the solar radiation is very dependent on location and season. Figure 1 illustrates the variation of solar irradiation in Norway for winter and summer conditions.

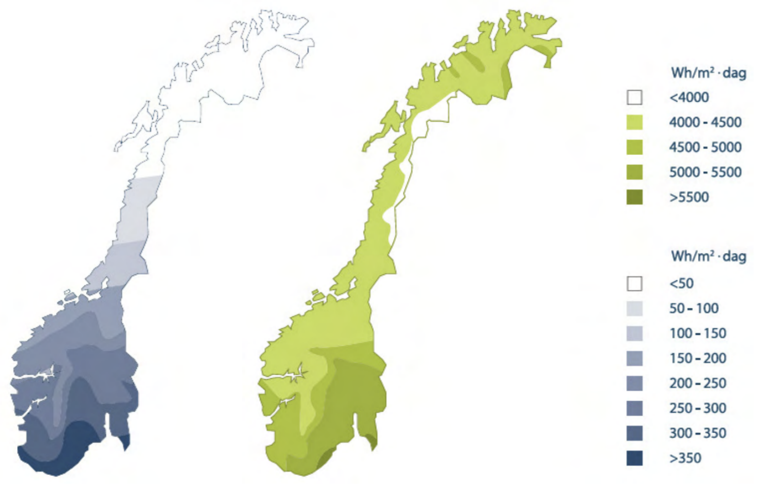


**Figure 1.** Daily solar irradiation on horizontal surface - January (left), July (right) [**?** ].

Daylight ensures many qualities both for the indoor environment and the psychological well-being. Daylight openings provides connection to the outside while also illuminating the indoor surfaces. Many studies found that daylight has a positive influence on the human health and well-being. When the human skin is exposed to sunlight, it produces vitamin D which is linked to several health benefits [6]. Lansdowne et al. [7] found that the body also produces serotonin that helps improving the mood. A recent study discovers that a photoreceptor in the eye is sensitive to the wavelengths in the blue spectrum which daylight naturally covers, and synchronizes our internal biological clock [8].

While numerous other European countries specifies a minimum hours amount of solar exposure, the Norwegian government has decided to withdraw the paragraph concerning sunlight from the building code in the latest upgrade of the Norwegian technical requirements, TEK17 [9]. It is therefore imperative that the regulations define sufficient minimal criteria for the daylight provision. In 2019, the European daylight in buildings standard EN 17037 was implemented as a Norwegian standard. The standard encourages building designers to focus on providing sufficient daylight spaces, and also categorizes target ambitions with respect to daylighting [10].

Thermal comfort is an important parameter in building design and affects how the occupants appreciate the indoor environment. The occupant behaviour may have a direct impact on the buildings energy consumption. A critical aspect of thermal comfort is the risk of overheating. Since thermal comfort is a subjective condition it is hard to tell at which exact temperature overheating occurs. With the anticipated increase in temperature due to climate change, buildings in cold climates stand in front of a future with an increased risk for overheating during summer. Norway experienced a set of extreme heat waves in the summer of 2018 and 2019 [11]. Li et al. [12] did a study of the indoor overheating risk for converted lofts in London. One of their findings was that passive adaptations were not sufficient enough to eliminate the overheating, and it is likely that by the 2080s active cooling is a necessity. Tian and Hrynyszyn [13] found in their study thata retrofitting to higher energy standards and improving the airtightness, increases the risk of overheating, even in cold climates. They highlight that overheating should be paid more attention to based on the expected future climate conditions. Lee et al. [14] investigated how light shelves with applied photovoltaics could help maximizing the buildings energy efficiency. Light shelves rotated 10 degrees towards the sun proved to be most efficient in terms of PV-production during the summer conditions.

Norwegian residential buildings are regulated by TEK17. It is therefore most relevant to use the given performance criteria for daylight and thermal comfort in this regulation as a scale of measure. The aim of this paper is to investigate how well the criteria and methods facilitate a consistent and good performance in terms of daylight and thermal comfort. And also how the national regulations compare to European standard. The methodology of this study examines a set of parameter changes to an original case building. Each case is simulated in IDA ICE, and the results indicate how to optimize the design of the case building in terms of daylight and thermal comfort performance.

## 2. Background

### *2.1. Norwegian regulation*

The Norwegian Building Regulations, TEK17, consist of a set of minimum properties and technical requirements that has to be satisfied in order to build legally. This building code defines functional regulations and performance criteria with attached pre-accepted performances which fulfill these requirements.

#### 2.1.1. Thermal comfort

For thermal comfort there are two functional requirements which are relevant for design of residential dwellings. The following paragraphs are cited in TEK17:

§13-4 (1):

> *The thermal indoor climate in rooms intended for continuous occupancy shall be regulated in a manner that promotes health and satisfactory comfort when the rooms are used as intended*

§13-4 (2):

> *In rooms for continuous occupancy it must be possible to open at least one external window or door*

#### 2.1.2. Daylight

TEK17 indicates two functional requirements that is considered to be relevant for building design. The following paragraphs are cited from TEK17[3].

§13-7 (1):

> *Construction works shall have adequate access to light*

§13-7 (2):

> *Rooms for continuous occupancy shall have adequate access to daylight*

The pre-accepted performances for §13-7 (2) give two methods for achieving required performance. The first method is based on the average daylight factor DF which has to be minimum 2.0% for the most critical rooms. Calculations with the use of simulations software have to validated according to CIE 171:2006 and the premises defined in NS-EN 12464-1:2011 chapter 4.4. The following equation needs to be fulfilled for selected rooms [3]:

$$\overline{DF} = 2.0\% \quad (1)$$

The premises from the European light standard NS-EN 12464-1:2011 describe how the grid systems shall be created. The maximum grid size is defined by the following equation [4]:

$$p = 0.2 \times 5^{log_{10}(d)} \tag{2}$$

Where:
p = Maximum grid size [m]
d = Longer dimension of the calculation area

Alternatively the daylight requirement can be achieved with a simplified simplified method [3]:

$$A_g \geq 0.07 \cdot A_{BRA} \cdot LT \tag{3}$$

Where:
$A_g$ = Glazing area [$m^2$]
$A_{BRA}$ = Usable floor space, including area of protruding building parts [$m^2$]
$LT$ = Light transmittance of the glass [%]

### *2.2. International regulations*

To compare the Norwegian regulations, a set of representative European standards are examined.

#### 2.2.1. Thermal comfort

NS-EN 16798-1:2019 states that for defining the thermal environment, the criteria shall be based on the indices PMV-PPD from EN ISO 7730. For buildings without mechanical cooling the criteria could either be specified by the default method from EN ISO 7730, or by using the adaptive method. The adaptive method also considers the adaptation effects for occupant behavior when experiencing thermal discomfort. This method applies to buildings with sedentary activities where the occupant can adapt to the thermal conditions by either ventilating through windows or change of clothing. The collected data material is based on studies conducted in office buildings, but the standard ensures that the method also is applicable for similar spaces, such as residential buildings.

$$\Theta_{rm} = (\Theta_{ed-1} + 0,8\Theta_{ed-2} + 0,6\Theta_{ed-3} + 0,5\Theta_{ed-4} + 0,4\Theta_{ed-5} + 0,3\Theta_{ed-6} + 0,2\Theta_{ed-7})/3,8 \tag{4}$$

Table 1: Adaptive comfort temperatures categories for free running buildings [15]

| | | |
|---|---|---|
| Category I | upper limit | $\Theta_o = 0,33\Theta_{rm} + 18,8 + 2$ |
| | lower limit | $\Theta_o = 0,33\Theta_{rm} + 18,8 - 3$ |
| Category II | upper limit | $\Theta_o = 0,33\Theta_{rm} + 18,8 + 3$ |
| | lower limit | $\Theta_o = 0,33\Theta_{rm} + 18,8 - 4$ |
| Category III | upper limit | $\Theta_o = 0,33\Theta_{rm} + 18,8 + 4$ |
| | lower limit | $\Theta_o = 0,33\Theta_{rm} + 18,8 - 5$ |

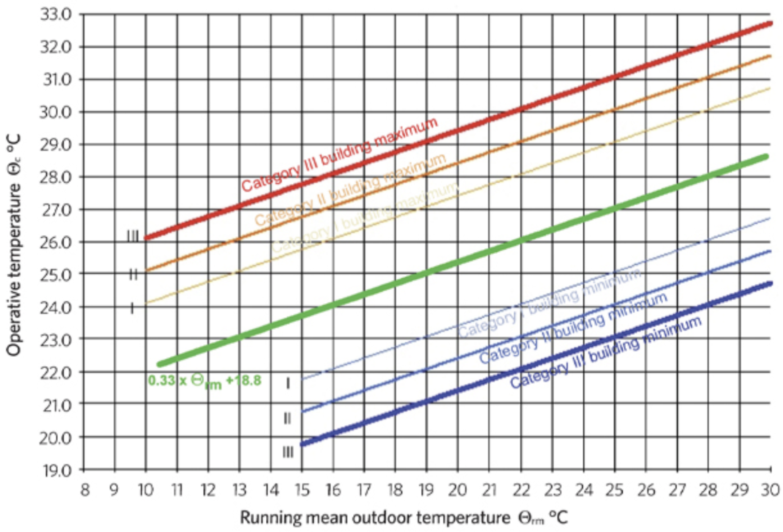


**Figure 2.** Acceptable operative temperature ranges based on temperatures from table 1 [16]

### 2.2.2. Daylight

The European standard for daylight in Buildings EN 17037:2018 is researched and prepared by Technical Committee CEN/TC 169 "Light and Lighting". The purpose of this paper is to facilitate a platform to secure adequate daylight provision in building design. The recommendations are categorized in different ambition levels as well as addressing challenging interfaces against view out, glare and exposure to sunlight. The standard was verified as a Norwegian Standard in February 2019. Since it has authority as a Norwegian Standard it will be referred to as NS-EN 17037:2018 further in this article.

**Table A.1 — Recommendations 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 3.** Recommended values for daylight provision

The table shown in figure 3 from the standard gives recommended values based on desired level of ambition. The values for measurement is expressed in terms of illuminance measured in lux. Table A.3 in figure 4 gives corresponding daylight factor values for respective CEN capital cities.

| **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 4.** Recommended values for daylight provision

## 3. Materials and Methods

### 3.1. Reference model

In this study a typical Norwegian residential building has been studied. Figure 5 displays a representative house model designed by Norgeshus. The total floor area is 140 $m^2$ over two floors. Common areas such as kitchen, dining area and living room are located on the ground floor, while bedrooms are situated on the first floor. See figure 6 for layout of the ground floor and figure 7 for the first floor.

**Figure 5.** Case building representing a typical residential building in Norway (Source: Norgeshus)

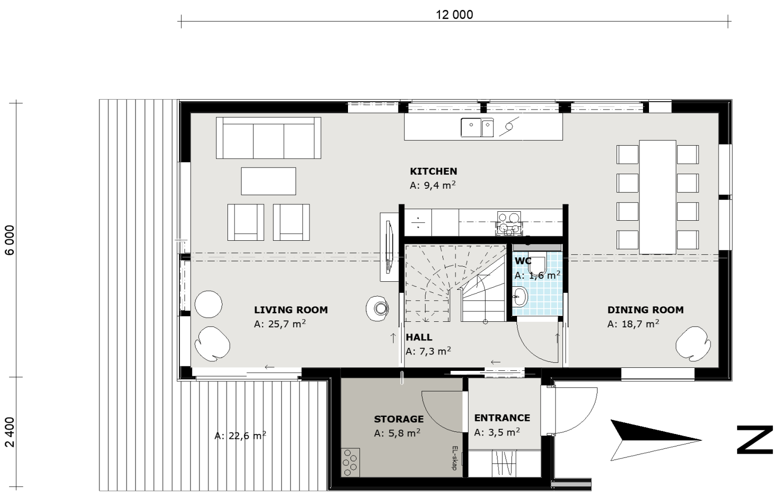


**Figure 6.** Ground floor layout (Source: Norgeshus)

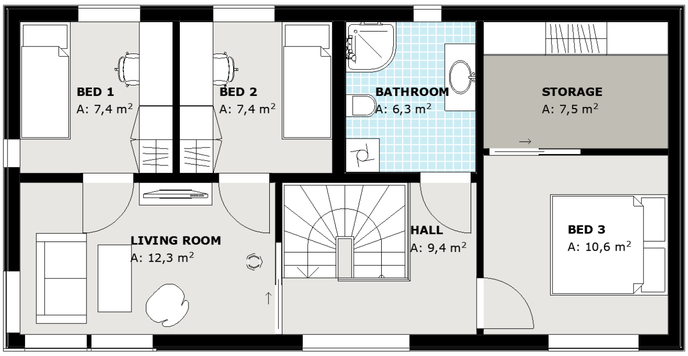


**Figure 7.** First floor layout (Source: Norgeshus)

The reference model is created with energy measures listed in table 2

Table 2: Input values regarding the building body for reference model

| Input parameter | Values for reference case |
|---|---|
| U-value exterior walls (200mm) | 0.198 $W/m^2K$ |
| U-value roof | 0.127 $W/m^2K$ |
| U-value floor | 0.094 $W/m^2K$ |
| U-value windows and doors | 0.900 $W/m^2K$ |
| Window and door ratio of usable space | 36 % |
| Temperature efficiency of heat recovery | 80 % |
| Air leakage rate per hour at 50 Pa pressure difference | 1.0 $h^{-1}$ |
| Normalized thermal bridge | 0.05 $W/m^2K$ |

Internal gains from occupants, equipments and lighting are defined according to the values set in the Norwegian technical standard, SN-NSPEK 3031:2020 [17].The deterministic occupancy schedule is based on schedules from Nord et al. [18] and adapted to fit the annual normalized values in the standard. By default, the reference model is applied with internal blinds that are PI-controlled with activation when operative indoor temperature reaches 23 °C. Windows open when operative temperature exceeds 25 °C.

### *3.2. Software*

The building performance simulations were conducted by using the software IDA-ICE [19]. For the case study, IFC-models from ArchiCAD were imported to IDA-ICE with slight modifications through SimpleBIM. SimpleBIM has an add-on which addresses compatibility issues with IDA-ICE and enables the possibility of modifying the model to be validated for usage in IDA-ICE.

The daylight calculations were executed with the integrated Radiance simulation tool [20]. In order to facilitate results which are easily comparable to both Norwegian regulations and European standards, only the Daylight Factor (DF) has been examined. The daylight factor presumes the illumination on a horizontal reference plane in the room expressed in percentage of the simultaneous illumination on an outdoor horizontal plane with no casting shadows [21]. This is a simpler approach than a dynamic, climate derived illuminance calculation. The DF method is calculated for a CIE overcast sky, and is therefore independent on window orientation. For this sky model the luminance changes with altitude and is three times as bright at zenith than near the horizon [22]. Even though this method does not comply with the actual daylight environment, it still represents the unfavourable case and will unlikely give results better than actual daylight performance [23].

As previously mentioned, TEK17 gives two functional requirements for thermal comfort. The guidance for fulfilment of the functional requirement states that the performance is adequate if the exceedance of highest temperature does not surpass 50 hours in a normal year. The acceptance criterion for NS 16798 is based on CIBSE TM52, where the limit of unacceptable hours is set to be 3% of occupancy hours [24]. In other words, based on used occupancy schedule this corresponds to a maximum of 86 hours for dayrooms and 125 hours for bedrooms.

### 3.3. Simulated cases

10 alternative cases are presented in table 3. Case 1 aims to investigate the effect of only changing the orientation of the building, which is relevant for a lot of building scenarios. This is done by orienting the longer facade to the south. A typical measure for pursuing better energy efficiency is improving the building envelope with more insulation. Thus, Case 2 investigates this scenario. Case 3 and 4 represents cases the boundary criteria that are allowed for the simplified method in §13-7(2) TEK17. Case 5, 6 and 8 investigates measures for solar control. Since the daylight factor is calculated for an overcast sky, the affect of having different shading strategies are neglected, since they don't influence the daylight calculation. A revised window design, case 7, aims to discover how strategically changing the window design affects the performance of the same building body. Case 9 and 10 investigate the effect of new technology based on discoveries from Lee et al. [14]. One of the findings was that an inclination of -10° have the most PV-production. Hence, the choice of two alternative cases for comparison. For each case alternative, only mentioned parameter changes have been applied. The remaining model is equivalent to the reference model.

Table 3: Overview of simulated cases

| Case nr | Case name | Case description |
|---|---|---|
| Case 0 | Reference model | Original model with default values |
| Case 1 | Oriented | Building model is rotated 90 degrees counter-clockwise |
| Case 2 | Thicker walls | Improving the building envelope. 350mm insulation in walls |
| Case 3 | Shading object | Maximum accepted obstruction angle in the horizon for the simplified method in TEK17 |
| Case 4 | Minimum glazing area | Minimum glazing criterion for the simplified method in TEK17 for each room |
| Case 5 | Low light transmittance | New glazing properties: LT = 27 and g-factor: 16 |
| Case 6 | Medium light transmittance | New glazing properties: LT = 61 and g-factor: 33 |
| Case 7 | Revised window design | Removal of windows facing north, and more windows facing south |
| Case 8 | Static external overhang | External overhang with depth of 1m |
| Case 9 | Light shelf with PV-module (horizontal) | Mounted on windows >1m wide |
| Case 10 | Light shelf with PV-module (-10° inclination) | Mounted on windows >1m wide. Rotated 10° towards the sun. |

## 4. Results

In the following section the simulation results are presented. Each case alternative is evaluated in terms of annual heating demand, daylight and thermal comfort. While energy is displayed collectively on a single table, daylight and thermal comfort are presented in representative tables and figures relevant for the studied rooms in the building.

### 4.1. Energy

The simulated heating demand is expressed as the total energy need for space heating including ventilation. As expected a more insulated wall in case 2 and reduction of window area in case 4, decreases the need for annual heating. A decrease of almost 27% for case 2 is a quite significant performance increase for the building. Just by optimizing the window design as in case 7, revised window design, there is a profit of 7.5 $kWh/m^2$ annually. The light shelves themselves does not influence the energy performance significantly, but there is an advantage in the production of electricity which can be utilized. The implementation of such an installment is rather based on a cost-benefit perspective.

Table 4: Heating demand for every case

| **Case number** | **Annual heating demand** $[kWh/m^2]$ |
|---|---|
| Case 0 | 43.9 |
| Case 1 | 42.9 |
| Case 2 | 32.2 |
| Case 3 | 55.1 |
| Case 4 | 36.2 |
| Case 5 | 59.6 |
| Case 6 | 50.7 |
| Case 7 | 36.4 |
| Case 8 | 45.4 |
| Case 9 | 42.6 - 3.7 PV-production |
| Case 10 | 43.7 - 4.8 PV-production |

### 4.2. Daylight

Based on the daylight results, bedroom 2 and 3 are the worst performing rooms. A possible reason for this can be that these rooms have a one-sided light transmittance, and the geometry of these rooms regulate how well the light is distributed. Case 4 and 5 have obvious issues with giving adequate daylight provision. Furthermore, it is worth noticing that case 4 is designed as a minimum defined by the simplified method in TEK17 and is not approved by any of the used criteria in this paper. A horizontal light shelf gets a slight decrease in daylight provision, but does not deviate from the reference case concerning criteria acceptance. The rotated light shelf, case 10, performs similar, but has more profit of PV-production.

The results for daylight are calculated for each individual room considered. The results are evaluated according to criteria set in TEK17 ($\overline{DF} = 2.0\%$) and NS-EN 17037(50 % of area $\geq D_T = 2.4\%$ and 95 % of area $\geq D_{TM} = 0.8\%$). The following figures display the results for each room with respect to mentioned criteria.

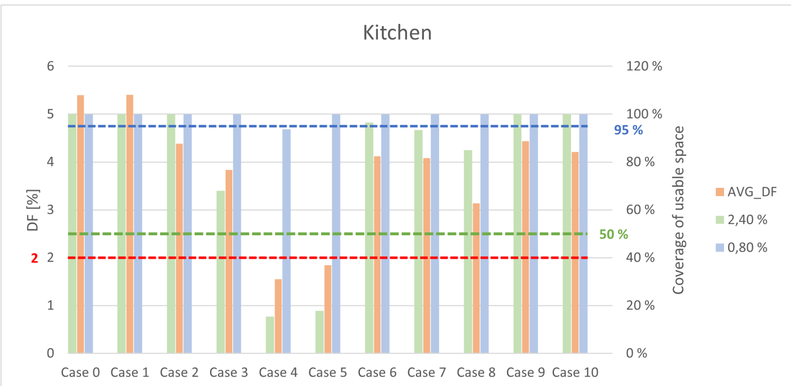


**Figure 8.** Simulation results for average daylight factor - Kitchen

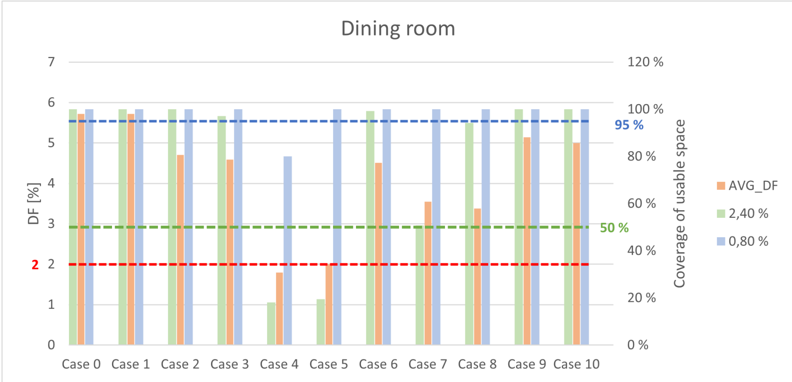


**Figure 9.** Simulation results for average daylight factor - Dining room

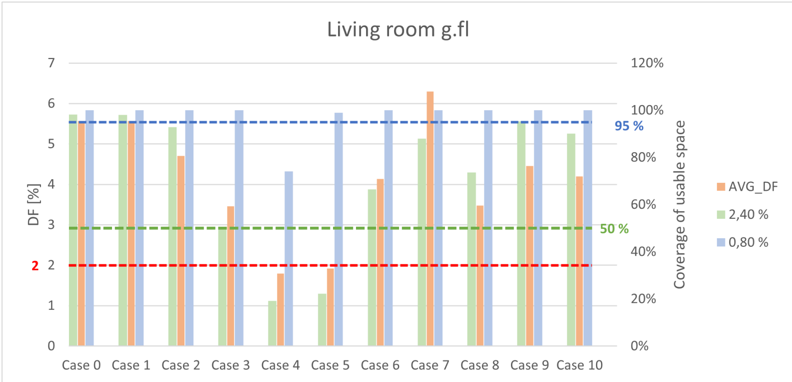


**Figure 10.** Simulation results for average daylight factor - Living room ground floor

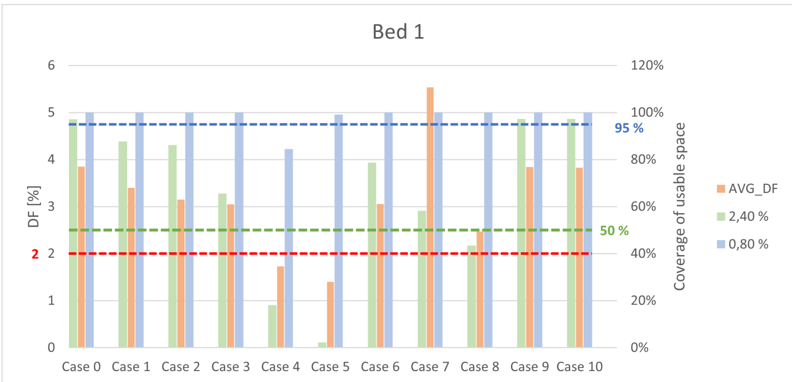


**Figure 11.** Simulation results for average daylight factor - Bed1

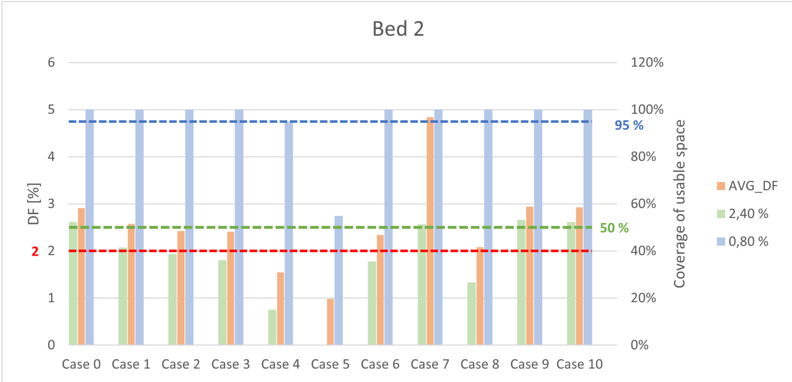


**Figure 12.** Simulation results for average daylight factor - Bed2

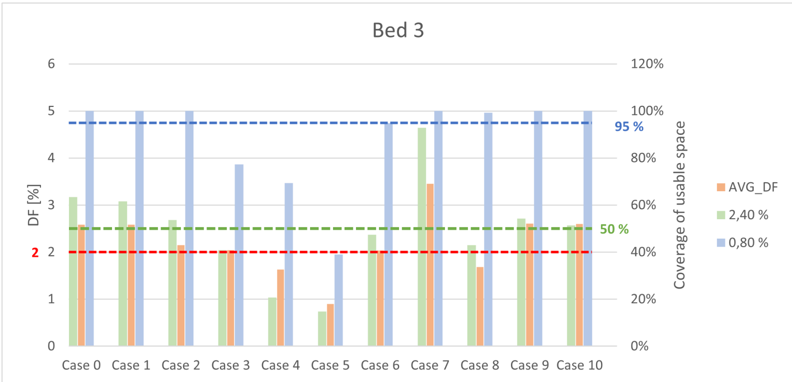


**Figure 13.** Simulation results for average daylight factor - Bed3

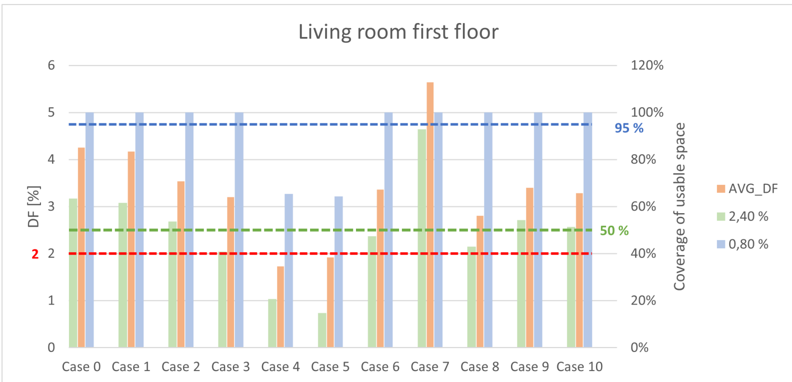


**Figure 14.** Simulation results for average daylight factor - Living room first floor

### *4.3. Thermal comfort*

By default, the reference model does not satisfy the expected performance regarding overheating hours in TEK17, see figure 4.3. In contrast to the significant improvement for energy in case 2, thicker walls leads to more severe overheating risk, as illustrated in figure 4.3. Reduction of glazing area, case 4, or improving glazing properties tends to be the most effective. Case 6, medium light transmittance, is a more reasonable measure than case 5, low light transmittance, since the latter has poor performance both for energy and daylight. The revised window design in case 7, revised window design, has a slight overall improvement, but still is not satisfactory for bedroom 2 and the living room on first floor. Table 13 for case 8, static external overhang, shows that static external shading gives good results, and the disapproved rooms fails by a small margin. The light shelves do not influence the thermal comfort performance very much. For most of the cases, there is a correlation between good energy performance and bad thermal comfort performance and vice versa.

**Case 0 - Reference model**

Table 5: Thermal comfort for case 0

| | IDA-ICE | |
|---|---|---|
| | Hours exceeding 26 °C [h] | Unacceptable hours (IV)[h] |
| Kitchen | 67 | 53 |
| Dining room | 69 | 38 |
| Living room g.fl | 54 | 67 |
| Bed 1 | 75 | 163 |
| Bed 2 | 78 | 172 |
| Bed 3 | 43 | 13 |
| Living room 1. fl | 61 | 79 |

**Case 1 - Rotated 90 degrees counter-clockwise**

Table 6: Thermal comfort for case 1

| | IDA-ICE | |
|---|---|---|
| | Hours exceeding 26 °C [h] | Unacceptable hours (IV)[h] |
| Kitchen | 61 | 44 |
| Dining room | 86 | 69 |
| Living room g.fl | 49 | 28 |
| Bed 1 | 55 | 65 |
| Bed 2 | 65 | 91 |
| Bed 3 | 35 | 10 |
| Living room 1. fl | 45 | 46 |

**Case 2 - Improved building envelope**

Table 7: Thermal comfort for case 2

| | IDA-ICE | |
| --- | --- | --- |
| | Hours exceeding 26 °C [h] | Unacceptable hours (IV)[h] |
| Kitchen | 77 | 64 |
| Dining room | 69 | 47 |
| Living room g.fl | 78 | 82 |
| Bed 1 | 75 | 167 |
| Bed 2 | 78 | 194 |
| Bed 3 | 43 | 18 |
| Living room 1. fl | 60 | 97 |

256 **Case 3 - Maximum accepted obstructing shading object TEK17**

Table 8: Thermal comfort for case 3

| | IDA-ICE | |
| --- | --- | --- |
| | Hours exceeding 26 °C [h] | Unacceptable hours (IV)[h] |
| Kitchen | 45 | 8 |
| Dining room | 46 | 6 |
| Living room g.fl | 47 | 19 |
| Bed 1 | 57 | 57 |
| Bed 2 | 59 | 57 |
| Bed 3 | 37 | 9 |
| Living room 1. fl | 53 | 36 |

257 **Case 4 - Minimum glazing criterion TEK17**

Table 9: Thermal comfort for case 4

| | IDA-ICE | |
|---|---|---|
| | Hours exceeding 26 °C [h] | Unacceptable hours (IV)[h] |
| Kitchen | 31 | 2 |
| Dining room | 29 | 2 |
| Living room g.fl | 32 | 2 |
| Bed 1 | 47 | 79 |
| Bed 2 | 58 | 117 |
| Bed 3 | 25 | 8 |
| Living room 1. fl | 44 | 31 |

258 **Case 5 - LT: 27 and g-factor: 16**

Table 10: Thermal comfort for case 5

| | IDA-ICE | |
|---|---|---|
| | Hours exceeding 26 °C [h] | Unacceptable hours (IV)[h] |
| Kitchen | 26 | 0 |
| Dining room | 24 | 0 |
| Living room g.fl | 25 | 0 |
| Bed 1 | 37 | 19 |
| Bed 2 | 39 | 20 |
| Bed 3 | 20 | 4 |
| Living room 1. fl | 31 | 12 |

259 **Case 6 - LT: 61 and g-factor: 33**

Table 11: Thermal comfort for case 6

| | IDA-ICE | |
|---|---|---|
| | Hours exceeding 26 °C [h] | Unacceptable hours (IV)[h] |
| Kitchen | 43 | 12 |
| Dining room | 42 | 7 |
| Living room g.fl | 40 | 13 |
| Bed 1 | 52 | 67 |
| Bed 2 | 52 | 73 |
| Bed 3 | 29 | 7 |
| Living room 1. fl | 44 | 33 |

260 **Case 7 - Revised window design**

Table 12: Thermal comfort for case 7

| | IDA-ICE | |
|---|---|---|
| | Hours exceeding 26 °C [h] | Unacceptable hours (IV)[h] |
| Kitchen | 55 | 26 |
| Dining room | 47 | 14 |
| Living room g.fl | 56 | 61 |
| Bed 1 | 45 | 79 |
| Bed 2 | 63 | 136 |
| Bed 3 | 33 | 11 |
| Living room 1. fl | 86 | 131 |

261 **Case 8 - Static external overhang**

Table 13: Thermal comfort for case 8

| | IDA-ICE | |
|---|---|---|
| | Hours exceeding 26 °C [h] | Unacceptable hours (IV)[h] |
| Kitchen | 56 | 26 |
| Dining room | 53 | 21 |
| Living room g.fl | 50 | 43 |
| Bed 1 | 60 | 129 |
| Bed 2 | 64 | 122 |
| Bed 3 | 32 | 10 |
| Living room 1. fl | 46 | 54 |

262 4.3.1. **Case 9 - Light shelf (horizontal)**

Table 14: Thermal comfort for case 9

| | IDA-ICE | |
|---|---|---|
| | Hours over 26 °C [h] | Unacceptable hours (IV) [h] |
| Kitchen | 62 | 33 |
| Dining room | 66 | 32 |
| Living room g.fl | 50 | 48 |
| Bed 1 | 74 | 155 |
| Bed 2 | 77 | 164 |
| Bed 3 | 43 | 14 |
| Living room 1. fl | 56 | 71 |

263 **Case 10 - Light shelf (Rotated 10 degrees towards the sun)**

Table 15: Thermal comfort for case 10

| | IDA-ICE | |
|---|---|---|
| | Hours over 26 °C [h] | Unacceptable hours (IV) [h] |
| Kitchen | 55 | 34 |
| Dining room | 63 | 32 |
| Living room g.fl | 47 | 50 |
| Bed 1 | 74 | 155 |
| Bed 2 | 77 | 166 |
| Bed 3 | 43 | 14 |
| Living room 1. fl | 62 | 70 |

## 5. Conclusions

Improving the building envelope is a recommended measure since it results in lower annual heating demand, and only has marginal loss in daylight performance. In terms of thermal comfort this scenario gives too large overheating risk, but in combination with either change of glazing properties or external shading has proved to be efficient. This highlights that well-insulated buildings has a risk of overheating even in cold climates, which further confirms the findings by Tian and Hrynyszyn [13]. The pursuit of lower energy demand should not be at expense of the indoor thermal comfort for the anticipated future weather conditions.

By performing a revision of the window design, the overall performance of the building improved. This indicates that daylight should be considered holistic already from the initial stages. By having window design in mind for the initial stages of planning, it can result, not only in better daylight provision, but also improved energy and thermal comfort performance, because they tie together.

There should be paid more attention to which criteria that are being used for daylight calculation, as the criteria are not consistent. According to the simulated results presented in this paper, the simplified method in TEK17 gives acceptance of a criteria which neither the average daylight factor or criteria in NS-EN 17037 approves. And a theoretical combination with case 3, maximum accepted obstruction, that also is accepted by the simplified method, would give an even worse daylight performance. A simplified method should be the most conservative alternative and give the oversized alternative while the advanced method should optimize closer to acceptable limit.

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