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Room Indicators in Miljöbyggnad
A Comparative Study of Simplified and Detailed Methods and Their Influencing Parameters

Master's Thesis in the Master's Programme Structural Engineering and Building Technology

ANNA GÖRANSSON
SUSANN GÖTHARSON

Department of Civil and Environmental Engineering
Division of Building Technology
Building Physics
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Department of Civil and Environmental Engineering
Division of Building Technology
Building Physics
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone: + 46 (0)31-772 1000

Cover:
A fictive representative living room and dining area, one of the objects studied with regards to the room indicators of Miljöbyggnad as a basis for a comparative study between simplified models and more detailed simulations.

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ABSTRACT

Miljöbyggnad is a building certification system adapted to Swedish regulations and design practice with focus on energy, indoor environment and materials. The building is assessed according to certain indicators and the resulting grade is based on a four-point scale GOLD, SILVER, BRONZE and CLASSIFIED, where GOLD is the highest grade and CLASSIFIED means that some performance requirements are not fulfilled. Some of the indicators are defined on room level; *solar heat load*, *thermal climate* and *daylight*. They can be assessed through simplified or detailed methods, where the simplified methods are based on simple formulae including a few parameters. The intention is to encourage the use of detailed methods by criteria formulated so that higher grades are more easily reached. However, the detailed methods are generally more time consuming due to simulations. Thus, the aim of this study is to determine the conformity between the two methods for the room indicators. Additionally, key parameters are defined in order to pinpoint the most important input data regarding both methods.

In order to evaluate the room indicators three building types with fictive representative room units are defined; a dwelling, an office and a hospital. For those, the room indicators are evaluated by simplified calculations and detailed simulations, the latter using IDA ICE and VELUX Daylight Visualizer. Then a parameter study of 17 parameters is performed. The results are divided into two parts; the results from the parameter analysis and the results regarding conformity between the two methods respectively.

The study concludes that the two methods converge very well regarding the solar heat load. Concerning the thermal climate indicators, the detailed simulations are found to be less sensitive to varied parameters than the simplified due to the compensation of installed heating and cooling power as well as ventilation and airing. For the daylight indicator the detailed simulations are favourable.

Key words: Environmental assessment method, certification system, Miljöbyggnad, solar heat load, thermal climate, daylight, IDA ICE, VELUX Daylight Visualizer

Rumsindikatorerna i Miljöbyggnad
En jämförande studie av förenklade och detaljerade metoder samt inverkande parametrar

Examensarbete inom masterprogrammet Structural Engineering and Building Technology

ANNA GÖRANSSON
SUSANN GÖTHARSON
Institutionen för bygg- och miljöteknik
Avdelningen för Byggnadsteknologi
Byggnadsfysik
Chalmers tekniska högskola

SAMMANFATTNING

Miljöbyggnad är ett certifieringssystem som är anpassat till svenska förhållanden och krav med fokus på energi, innemiljö och material i byggnader. Byggnaden bedöms enligt vissa indikatorer och det slutgiltiga betyget är baserat på en fyrgradig skala GULD, SILVER, BRONS och KLASSAD, där GULD är toppbetyget och KLASSAD betyder att de ställda kraven inte är uppfyllda. Vissa av indikatorerna bedöms på rumsnivå; *solvärmelast*, *termiskt klimat* och *dagsljus*. De kan bedömas antingen genom förenklade beräkningar eller mer detaljerade simuleringar. Användningen av detaljerade metoderna uppmuntras genom att de relaterade bedömningskriterierna generellt är formulerade så att höga betyg är lättare att nå. De detaljerade metoderna är dock ofta mer tidskrävande. Syftet med den här studien är att avgöra konformiteten mellan de förenklade och detaljerade metoderna för indikatorerna bedömda på rumsnivå. Dessutom fastställs vilka parametrar som är avgörande när indata ska definieras för de två metoderna.

För att kunna granska rumsindikatorerna skapas tre typer av fiktiva representativa rumsenheter; en bostad, ett kontor och ett vårdrum. För dessa bedöms rumsindikatorerna genom förenklade beräkningar och detaljerade simuleringar. För simuleringar används programmen IDA ICE och VELUX Daylight Visualizer. Sedan genomförs en parameterstudie med 17 parametrar. Alla resultat sammanställs och delas upp i två delar; en del gällande parameteranalysen och en del gällande konformiteten mellan metoderna.

Studien visar att resultaten för de två metoderna gällande solvärmelast stämmer väl överens. För termiskt klimat är de detaljerade simuleringarna mindre känsliga i parameteranalysen vilket beror på installerad kyl- och värmeeffekt samt ventilation och vädring som kompenserar. För dagsljus är de detaljerade simuleringarna överlägsna.

Nyckelord: Certifieringssystem, Miljöbyggnad, solvärmelast, termiskt klimat, dagsljus, IDA ICE, VELUX Daylight Visualizer

Contents

Preface

This Master's Thesis treats Miljöbyggnad and its room indicators and has been performed as a comparative study. The project was carried out from January to June 2015 at Chalmers University of Technology, Department of Civil and Environmental Engineering, Division of Building Technology within the Master's Programme Structural Engineering and Building Technology. The work was implemented at and in cooperation with the group of Energy and Environment at Sweco Systems.

Anna has been responsible for theory aiming to introduce the study and the topic as well as for identifying representative study objects and determining appropriate technical input data. Furthermore, she has been in charge of all IDA ICE models. Susann has done research about the background to Miljöbyggnad and its indicators. She has been responsible for establishing tools for simplified calculations and for VELUX Daylight Visualizer models. Additionally, she has compiled all results and presented them graphically.

A special thanks to our supervisor and examiner Angela Sasic Kalagasidis, Associate Professor at Chalmers, and our supervisor Magnus Österbring, PhD Student at Chalmers, for pushing us in the right direction. A big thank you also to our supervisor Sofia Rehn, energy engineer at Sweco Systems, for guiding us within the field and helping us to stay connected to the reality. Furthermore, a warm thanks to our opponents Emma Brycke and Jannicke Nilssen for meaningful and rewarding discussions. Finally, thank you all at Sweco Systems for welcoming us and providing such a pleasant atmosphere.

Göteborg, June 2015

Anna Göransson
Susann Götharson

Notations

Roman upper case letters

AF	[%],	window share
$AF_{façade}$	[-],	window share of façade
$A_{façade}$	[m^2],	façade area
A_{floor}	[m^2],	floor area, including area underneath furnishings, e.g. closets
A_{glass}	[m^2],	glass area of windows and doors, excluding frame and sash
$A_{glass.S.or.E.or.W}$	[m^2],	glass area of windows and doors, facing south, east or west
A_{temp}	[m^2],	heated floor area, see Vocabulary below
A_{window}	[m^2],	window area, including glass, frame, and sash
DF	[%],	daylight factor
LT	[-],	light transmission of visible light
PMV	[-],	predicted mean vote
PPD	[%],	predicted percentage dissatisfied
SVF	[-],	solar heat factor
SVL	[W/m^2],	solar heat load
T_a	[K] or [°C],	the air temperature
TF	[W/m^{2}K],	transmission factor
T_f	[-],	transmission factor used in *Bygga med glas* to obtain the SVF
T_{op}	[K] or [°C],	operative temperature
T_r	[K] or [°C],	the mean radiative temperature
$T_{setpo\,\mathrm{int}\,s}$	[K] or [°C],	setpoints for min and max temperatures allowed in a zone
$T_{\mathrm{sup}\,ply}$	[K] or [°C],	temperature of controlled air supplied to a room
U_{glass}	[W/m^{2}K],	U-value in the middle of the window glass

Roman lower case letters

$d_{insulation}$	[m],	insulation thickness
g	[-],	solar factor of the window
g_{syst}	[-],	solar factor of the window and any shading

Greek upper case letters

ΔP	[Pa],	pressure difference

Greek lower case letters

α_c	[W/m^{2}K],	the convective heat transfer coefficient
α_r	[W/m^{2}K],	radiative heat transfer coefficient

Vocabulary

Heated floor area	- area within the outer walls heated to more than 10 °C

1 Introduction

Buildings are complex systems with several parameters influencing the performance. Generally, the performance can be categorized into energy, construction accuracy and indoor environment. Thus by optimizing the performance, the environmental resources can be conserved and the indoor comfort can be improved.

To systemize the parameters several environmental assessment methods have been developed worldwide, covering one or more of the influencing parameters. *Miljöbyggnad* is a certification system adapted to Swedish conditions and requirements and is valid for existing and new buildings of all sizes. The certification system contains indicators with focus on different aspects of the building covering energy, indoor environment and materials and aims to secure quality of buildings.

People involved in the Miljöbyggnad certification process evaluate the building according to certain indicators and some of the indicators can be assessed through simplified calculations or detailed simulations. The simplified methods are developed to simplify the certification work and reduce the costs and these are often used in an early stage to estimate the building performance. To encourage the use of detailed methods, the idea is that the corresponding criteria are formulated so that higher grades are more easily reached. For some of the indicators, detailed simulations are required when aiming for a high certification grade.

However, the detailed methods are generally more time consuming due to the need of detailed models. This applies to the indicators assessed on building level as well as on room level. There is a lack of knowledge about the key parameters that significantly influence the results of the simplified and detailed methods. Finding the key parameters would help in order to pinpoint the most important input data. By evaluating indicators according to the two methods, significant differences can be determined and conclusions regarding accuracy can be drawn which would be useful to the involved professions. It would be of interest to determine for which indicators and building types the simplified results are comparable to the detailed results.

1.1 Objectives

The purpose of the study is to compare the indicator results in Miljöbyggnad when using two different approaches; simplified methods provided by Miljöbyggnad itself and detailed simulations. Additionally, the indicators and rooms for which the differences are significant are determined.

The study answers the following questions:

- With respect to the surroundings, the performance of the building envelope, typical occupational activities and technical installations, which are the key parameters and how large influence do they have?
- How do the indicator results differ when using simplified and detailed methods?

1.2 Limitations

The Miljöbyggnad system contains in total 16 indicators. For new buildings, 15 of those are applied. This study focuses on the four indicators assessed on room level; *solar heat load*, *thermal climate winter*, *thermal climate summer* and *daylight*. Thus, only room models need to be created which enables an efficient work. Additionally, this study focuses on new residential buildings, office buildings and hospital buildings only.

The latest version of the Miljöbyggnad manual, version 2.2, is followed when the calculations and simulations for the different indicators are performed, although older versions are still in use. Most of the projects under evaluation today are still done according to version 2.0 and 2.1 since version 2.2 was published only last autumn. Using version 2.2 ensures that the results and conclusions of this project will not be outdated too soon.

1.3 Method

Initially, the indicators included in Miljöbyggnad were reviewed and the four room indicators were chosen for the study. Those indicators are the only indicators which may be assessed by simplified and detailed methods. Then the background to the Miljöbyggnad manuals was investigated by literature studies of former manual versions and the reports used to establish the system. A review of the sources on which the current simplified calculation methods are based was performed. Additionally, the chosen indicators were all assessed on room level which enables productive comparisons of results.

A wider perspective was used to identify the environmental aspect of buildings in general and the usefulness of controlling the performance of a building. Discussions with supervisors started regarding which building types to include in the study and resulted in the following; a residential building, an office building and a hospital building. The aim was to cover at least three different buildings with different activities and technical solutions. For those buildings, representative fictive rooms were identified and defined regarding dimensions, activity and thermal properties amongst others. The identification of those rooms was done by reviewing similar recent buildings built in or close to Göteborg and by interviewing employees at Sweco Systems. A more detailed description of the procedure can be found in chapter 6.

When the input data for the reference rooms was set, simulation models in the software products IDA ICE and VELUX Daylight Visualizer were created as well as calculation tools for simplified analyses. Numerical comparative analyses using Miljöbyggnad tools and the simulation models were performed and a parameter analysis was prepared by identifying interesting parameters regarding building envelope, dimensions, occupation and technical systems. 17 such parameters were defined, influencing either both of the two methods or the simulations only. Initially, the parameters were varied between realistic extreme values in order to identify the impact of that certain parameter. If large variations were found in the result, a finer scale of variation was implemented.

The results from the simplified and detailed calculations as well as the parameter analysis were compiled. In order to be able to compare the results from simplified calculations and detailed simulations despite different units, a new generalised grading scale was created. The grade system BRONZE, SILVER and GOLD used in assessments today was translated into a numeric system which was created using the linearity of the grade limits. By using a grade system based on numbers instead of letters results in between the limits can be determined and evaluated.

Finally, the results from the analyses were presented graphically in order to discover interesting findings. The results were divided into two parts; firstly the results from the parameter analysis and secondly a comparison of the simplified and detailed methods.

2 Environmental Aspects of Buildings

Environmental impacts and indoor environment both significantly affects the sustainability of buildings. In order to ensure and encourage sustainability, visions and methods have been developed and are applicable to different levels of urban planning. This chapter gives an introduction to indoor climate through the history and introduces the Swedish national vision regarding sustainable building. Finally it gives a brief description of common environmental assessment methods to give a better understanding of Miljöbyggnad.

2.1 Indoor environment and its importance

Today it is known that the indoor environment has a significant impact on the human health since the majority of the time is spent indoors. The building design, installations and used materials all affect the indoor environment as does the use and maintenance of the building (Naturvårdsverket, 2013). Indoor climate is a wide term including comfort aspects for people in contact with the indoor environment. Those aspects regard thermal comfort, hygienic comfort, light comfort and sound comfort and the perception of the comfort differs from person to person depending on clothing, activity and age amongst others (Warfvinge & Dahlblom, 2012).

2.2 Building performance through the years

Through history, Swedish buildings have been built using old and traditional methods with local materials. The countryside did and does still house traditional wooden houses except for the most southern parts where half-timbered and brick houses were common. In the cities, mortared houses were dominating. Already from the 1940s and earlier, builders were aware of the importance of the location of the building to create favourable climate conditions and minimised losses of energy (Bülow, 2015).

The existing buildings from the 1940s and earlier have, in general, simple building structures with few different components and materials. The construction work was laborious and those buildings are far from fulfilling modern requirements on thermal insulation and air tightness. Heat losses and air leakages were compensated by increasing the internal heating (Abel & Elmroth, 2006).

More efficient building concepts were developed after World War II when urbanisation and industrialisation were influencing the society. The need for dwellings and facilities soared and a rationalisation of building principles was necessary in order to meet the needs. Still, energy efficiency was not of importance (Abel & Elmroth, 2006).

In the 1970s, when oil prices soared, thermally insulated and air tight building envelopes were crucial in order to control the energy use. Nowadays, the energy needed to compensate for heat losses through the building envelope is not the dominating part thanks to deep understanding of air tightness (Abel & Elmroth, 2006).

However, although there has been a lot of improvement in terms of building performance there is still some way to go until a sustainable society may be reached. Already in 1998 the Swedish government commissioned an advisory group to investigate industries with heavy environmental impact, one being the construction industry, and what goals of improvement may be realistically achieved in only a couple of decades (Kumar, 2008).

2.3 National environmental visions

The Swedish Government decided in 2011 to let the *National Board of Housing, Building and Planning* (Boverket) work out a plan of where Sweden should be the year 2025 in order to meet the vision of a sustainable society in 2050. The plan is called *Vision for Sweden 2025* and it is based on about one hundred national goals related to physical social planning in some way. The Vision for Sweden 2025 is aiming to encourage measures for a sustainable social development both locally and nationally (Boverket, 2014).

The Vision for Sweden 2025 is divided into twelve objectives handling different aspects. The *Building Sustainability* objective contains the vision regarding new and existing buildings and the following quotation states what preconditions, according to the *National Board of Housing, Building and Planning*, that need to be fulfilled:

> “Building and management is eco-sensitive through the efficient use of resources and the phasing out of hazardous substances. Energy efficiencies and changes are implemented with great attention paid to a comfortable indoor environment and accessibility, as well as the conservation of aesthetic, cultural and historical values.” (Boverket, 2014)

2.4 Environmental assessment methods

Environmental assessment methods for buildings are developed and used in Sweden as well as worldwide. The methods differ in extent but they all have in common that they systemise environmental aspects and improve the environmental performance of a building. By improving the performance, tenants and users as well as the environment are favoured. Better energy efficiency, improved indoor environment and reduced use of chemical substances are all positive consequences of careful control and assessment. The assessment methods can be used to determine potential for improvement regarding the performance. This is favourable for property owners and users as well as for the environment (SP, 2015b).

There are a number of national and international assessment methods and certification systems used in Sweden. The most used are the American method LEED (Leadership in Energy and Environmental Design), the British method BREEAM (BRE Environmental Assessment Method) and the Swedish method Miljöbyggnad. Miljöbyggnad is adapted to Swedish regulations and design practice and is the object of this study.

3 Miljöbyggnad

Miljöbyggnad is a Swedish certification system considering energy use, indoor climate and materials in new as well as existing buildings. The system is developed by researchers and companies in the building sector and it aims to cover areas affecting human health and the environment (SGBC, 2011). The following building qualities are rewarded (SGBC, 2014c):

- Low energy use
- Good indoor environment regarding sound, air quality, thermal climate and daylight
- Quality and knowledge of occurring building materials

3.1 History of Miljöbyggnad

The rather short but intense history of Miljöbyggnad can be said to have started as the Swedish Government in 1998 commissioned *Miljövårdsberedningen* to investigate environmental stressors, the construction industry being one of them. The strategy chosen was to engage the Government, several municipalities and 43 companies from the construction sector in a dialogue called *Bygga-Bo-dialogen*, roughly translated to Building-Living Dialogue. One of the commitments the participants of *Bygga-Bo-dialogen* agreed upon was to establish a system for certifying buildings on building related aspects influencing human health and the environment (Kumar, 2008). The system was to be scientifically grounded, easy to understand and unambiguous (Sundkvist, et al., 2006). Having a building being certified was not to be compulsory but a voluntary choice of property developers and owners. Financial incentives provided by the government, insurance companies, banks, etc. were also discussed (Carlson & Erlandsson, 2006).

Working towards this, three research projects were initiated. One project was to investigate existing national and international systems for classifying buildings to identity which aspects may be of interest to include in the new system. Other tasks in the project were to map what motivates property developers and property owners to evaluate their existing and planned buildings as well as investigate potential incentive providers (Sundkvist, et al., 2006). The aim of the other two projects was to develop and propose a set of aspects and indicators of the new classification system and test them on real planned and existing buildings (Carlson & Erlandsson, 2006).

The findings and conclusions drawn by these projects were compiled into a final report in spring 2008. In the report a complete system with chosen indicators, their respective methods and criteria for different grades, as well as a system for the steps of aggregating the results was presented. The intention of the system was to verify the actual performance of a building and therefore assessments were not possible until 12 months after the building was taken into use. The final report however provided instruction on how to design to be able to achieve different grades after completion. The possibility of having units with additional indicators added to the original 15 for the benefit of different target groups was also discussed. For instance indicators essential to providers of financial incentives could be gathered into one module (Glaumann, et al., 2008).

Since there had been some changes of significance and repackaging of the evaluation system, a general wish to test the latest draft to verify if it works in practice was voiced. This was done accordingly with feedback ranging from the individual indicators to the naming of the grades as a result (Carlson & Wintzell, 2008).

After some additional processing of the manual and setting up the administration for certification the secretariat of *Bygga-Bo-dialogen* was discontinued at the end of 2009. Instead the organisation *Miljöklassad Byggnad* took over and launched *Miljöklassad byggnad version 2.0* in spring 2010 (Kumar, et al., 2010). The Swedish Green Building Council, SGBC, took over the administration less than a year later and as Miljöbyggnad version 2.1 was released in 2012 the name was changed (SGBC, 2012b). The latest version available is *Miljöbyggnad version 2.2* which is applicable to all buildings registered for certification from 1 October 2014 (SGBC, 2014c).

The intension of grading the actual performance of a building is still a key in Miljöbyggnad, but right from the commercial start with version 2.0 it is possible to receive a preliminary grade which can be used in marketing. However, SGBC demands a verification of the grade in the second year since the building was taken into use (Kumar, et al., 2010).

3.2 Structure of Miljöbyggnad

Miljöbyggnad as classification system has been developed from only being valid for existing residential buildings, office buildings and schools to the current version which is valid for a significantly larger variety of buildings. Today, both new and existing residential buildings and commercial buildings housing for instance offices, schools, nurseries, hotels, health care and restaurants can be certified according to the system (SGBC, 2014c).

Buildings certified according to Miljöbyggnad version 2.2 are reviewed by 16 indicators. 15 of those are applied on new buildings; indicator 1 to 15. For existing buildings 14 indicators are applied; indicator 1 to 13 and 16. Those indicators are categorised in 11 aspects which are assessed and finally grouped into three areas; *Energy, Indoor environment* and *Materials.* The indicators, aspects and areas are presented in Table 3-1 below (SGBC, 2014c).

Table 3-1. The structure of the Miljöbyggnad system; indicators, aspects and areas.

Indicator		Aspect	Area	Building
1	Bought energy	Bought energy	Energy	Building
2	Heating power demand	Power demand		
3	Solar heat load			
4	Fraction of energy carriers	Fraction of energy carriers		
5	Noise protection	Noise protection	Indoor environment	
6	Radon content	Air quality		
7	Ventilation rates			
8	Nitrogen dioxide to indoor air			
9	Moisture prevention	Moisture safety		
10	Thermal climate winter	Thermal climate		
11	Thermal climate summer			
12	Daylight	Daylight		
13	Legionella	Legionella		
14	Documentation of materials	Documentation of building materials	Materials	
15	Absence of hazardous substances	Absence of hazardous substances		
16	Sanitation of hazardous substances	Sanitation of hazardous substances		

3.2.1 The grading scale

The indicators are assessed individually according to criteria of four grade levels; GOLD, SILVER, BRONZE and CLASSIFIED. CLASSIFIED basically means that the indicator is rated but the fundamental requirements in Miljöbyggnad are not fulfilled. BRONZE indicates that requirements from the *National Board of Housing, Building and Planning* and other authorities are fulfilled. SILVER indicates higher ambitions and GOLD, finally, indicates that the most environmentally outstanding technique is applied (SGBC, 2014c). An illustration of the grading scale is presented in Table 3-2 and a summary of the criteria for all indicators can be found in Appendix A.

Table 3-2. The grading scale starting from CLASSIFIED up to GOLD and descriptions of what can be expected of each grade.

GOLD	Outstanding technique
SILVER	Higher ambitions
BRONZE	National requirements fulfilled
CLASSIFIED	National requirements NOT fulfilled

Some of the indicators can be assessed either by using simplified methods, developed in the Miljöbyggnad system, or by using more detailed simulations. The simplified methods are intended to simplify the assessment and thus also reduce the costs of assessment. For the higher grades, however, simulations are often necessary (Glaumann, et al., 2008).

3.2.2 The aggregation of grades

The way the individually graded indicators contribute to the overall grade of the building may not be easy to grasp instantly. Therefore SGBC has provided a pedagogical and easy to use tool to facilitate the grade aggregation. A presentation of this tool can be found in Appendix B and the tool itself may be downloaded from SGBC's homepage (SGBC, 2014c).

The general idea behind the aggregation system is that bad results in any indicator cannot be covered up by top grades in other indicators, although some smaller exceptions do exist. The fact that all indicators matter and heavily influence the total grade of the building is hoped to work as an incentive to properly address even the more troublesome indicators (SGBC, 2014c).

The way the aggregation works is that the grades are combined level by level, starting by the indicators, then aspects, areas, finishing off with the building as a whole, just like moving left to right in Table 3-1.

Indicator → aspect
The grade of an aspect is the same as the lowest grade of the associated indicators. As an example see Table 3-3, how the grades of indicators 10 (GOLD) and 11 (BRONZE) give their aspect the grade BRONZE.

Aspect → area
The grade of each area is set by the lowest aspect grade. However, here is the exception. The area grade can be increased one step if at least half of the grades of the associated aspects are higher. Look at row 14 and 15 in Table 3-3 for an example.

Area → building
The overall grade of the building is determined by the lowest grade of all the three different areas.

Table 3-3. Example of grade aggregation in Miljöbyggnad.

Indicator		Aspect	Area	Building
1	BRONZE	BRONZE	BRONZE	BRONZE
2	BRONZE	BRONZE		
3	GOLD			
4	SILVER	SILVER		
5	BRONZE	BRONZE	BRONZE	
6	BRONZE	BRONZE		
7	GOLD			
8	SILVER			
9	GOLD	GOLD		
10	GOLD	BRONZE		
11	BRONZE			
12	BRONZE	BRONZE		
13	GOLD	GOLD		
14	GOLD	GOLD	GOLD	
15	SILVER	SILVER		

3.2.3 Rooms to be assessed

According to Miljöbyggnad, only rooms where people spend time more than temporarily and of those the most critical should be treated. In residential buildings the treated rooms are living rooms, bedrooms and kitchens. In commercial buildings such as offices and hospitals rooms with permanent workplaces shall be prioritized (SGBC, 2014c).

For each indicator specific rooms, floors or building parts are considered critical. Some of the indicators regard the performance of the entire building whereas some indicators are assessed on room level only. Room indicators need to be translated into indicator level. This means that one or more representative floor is selected and for each floor chosen, the most critical room where people spend time more than temporarily is evaluated and graded. The process is carried out for the second most critical rooms and further until 20 % of the heated floor area, A_{temp}, is covered (SGBC, 2014c). The recommendations regarding selection of critical rooms are presented for specific indicators in chapter 4.

4 Description of Studied Indicators in Miljöbyggnad

This study focuses on new buildings, which means that 15 indicators apply in total. Of those indicators, four are assessed on room level; *solar heat load*, *thermal climate winter*, *thermal climate summer* and *daylight*. The rest of the indicators are assessed on building level, which means that the entire building is considered.

The room indicators represent three different aspects. By evaluating room indicators, the findings are more easily applied on projects in general as the rooms can be considered as representative for the entire stock. Indicators considering the entire building are more limited regarding application. The chosen indicators and their aspect and area categories are presented in Table 4-1 below.

Table 4-1. The indicators assessed on room level.

	Indicator	**Aspect**	**Area**
3	Solar heat load	Power demand	Energy
10	Thermal climate winter	Thermal climate	Indoor environment
11	Thermal climate summer		
12	Daylight	Daylight	

The indicators can be assessed through simplified calculations or detailed simulations and not always do the unit of the result agree depending on the method. The different indicators and the specific assessment methodologies are presented in the following sections, so are the units related to the two methods for the different indicators.

4.1 Solar heat load

The solar heat can be a major part of the heat gains for a building. Through glazed building elements such as windows the solar gain forms a significant part of the heating but also high needs for comfort cooling and risk for overheating. By controlling the solar heat gains through careful design of glazing and shading properties, the need for cooling is reduced and the indoor climate is enhanced (SGBC, 2014b).

The solar heat load indicator aims to encourage a reduction of solar heat supplement during the warm season and thus reduce the need for comfort cooling. For this indicator, a room on an upper floor is considered as critical due to the exposure to the sun. A rule of thumb is to choose rooms with the largest window area in relation to floor area (SGBC, 2014c). The influence of the room orientation is also significant.

Table 4-2. The two methods to determine the solar heat load and the corresponding parameter units.

Method	Parameter	Unit
Simplified	Solar heat load	W/m^2
Detailed	Solar heat load	W/m^2

The expression in (4.1) below indicates if the building is well designed with regards to solar heat load where the window glass area is used, excluding frame and sash (Glaumann, et al., 2008).

$$\left(g \cdot \frac{A_{glass}}{A_{facade}} \right)_{\max} \tag{4.1}$$

The g-value is the solar factor of the window and describes the ratio of the solar heat gain through the glazing in relation to the solar irradiation on the glazing (Pilkington North America, 2013). A low g-value indicates a significant blocking of solar gains through the glazing. A value of 0.01 represents a well-designed shading system of efficient glazing and shading material whereas a value of 0.6 corresponds to a standard 3 pane window without any shading (Sveby, 2013).

The current simplified method of determining the solar heat load is based on the expression in (4.1). After adjusting the ratio so that it relates to the total floor area of a room instead of the façade and multiplying it with the maximum solar radiation on a vertical surface, expressions were obtained as a way to quantify the solar heat load.

Since the sun does not shine from all directions at once, the simplified calculations differ depending on the number of window orientations. The two equations are presented below and they are both valid for residential buildings and commercial buildings (SGBC, 2014b).

For rooms having windows in only one direction, equation (4.2) is used.

$$SVL = 800 \cdot g_{syst} \cdot \frac{A_{glass}}{A_{floor}} \tag{4.2}$$

For rooms with windows in more than one direction, the following expression is used.

$$SVL = \max \begin{cases} 560 \cdot g_{syst} \cdot \dfrac{A_{glass.S.or.E.or.W}}{A_{floor}} + 560 \cdot g_{syst} \cdot \dfrac{A_{glass.S.or.E.or.W}}{A_{floor}} \\ 800 \cdot g_{syst} \cdot \dfrac{A_{glass.}}{A_{floor}} \end{cases} \tag{4.3}$$

The maximum solar irradiation on a vertical surface is known to be about 800 W/m^2 throughout Sweden, which is inserted in the expressions above (Glaumann, et al., 2008). As mentioned before the sun cannot be in several places at once. And so, only 70 % of the maximum irradiation from each orientation, that is 560 W/m^2, may be taken into account (SGBC, 2014a). The g_{syst} -value used in the equations represents the g-value of the whole system, including both glazing and any shading materials.

Note that $A_{glass.S.or.E.or.W}$ means that the combination of windows facing *south and east* or *south and west* is considered. Thus, east and west can never be combined. Also, only windows towards south, east and west are treated since windows facing more towards north are considered negligible in the simplified method (SGBC, 2014d). However, in neither the Miljöbyggnad manual nor the interpretations by the technical council of the Swedish Green Building Council explicitly state how to handle a room with windows facing all three directions.

4.2 Thermal climate

Thermal comfort is achieved when a person is fully satisfied with the ambient temperature and neither warmer nor colder environment would be preferable. The perception of the ambient temperature depends on individual factors and thus it is impossible to satisfy everybody.

The thermal climate is assessed differently for the winter and summer cases respectively due to opposite climate conditions. The simplified methods are based on different parameters corresponding to the particular conditions. For the winter case the cooling effect of windows is considered while the solar heat contribution is considered in the summer case. The thermal climate in wintertime can be measured as a value of predicted percentage of dissatisfied, PPD, or as a transmission factor, TF. The thermal climate in summertime can be measured as a PPD value or as a solar heat factor, SVF, depending on whether the simplified or detailed method is used (SGBC, 2014b).

4.2.1 Simplified method - winter: Transmission factor, TF

The simplified method of determining the thermal climate during winter is assessed as a transmission factor and is valid for single-family houses only; otherwise the detailed method has to be used. The simplified method is not valid in order to reach GOLD, instead the detailed method is required (SGBC, 2014b). Rooms with the largest window area in relation to floor area are considered as most critical (SGBC, 2014c).

Table 4-3. The two methods to determine the thermal climate in the winter and the corresponding parameter units.

Method	Parameter	Unit
Simplified	Transmission factor	W/m^2K
Detailed	PPD	%

The transmission factor describes in a simple way the cooling effect of windows during the winter. It is based on the total window area of a room (including frame and sash) without differentiating between directions, the floor area and the U-value of the glass itself. The transmission factor is calculated according to (SGBC, 2014b):

$$TF = U_{glass} \cdot \frac{A_{window}}{A_{floor}} \tag{4.4}$$

According to manuals 2.1 and 2.2 the unit of the transmission factor is [W/m^2] but that is inconsistent with unit testing. Since the areas included all refer to different types of surfaces, either [Wm^2/(m^2·m^2)] or [W/m^{2}K] are possible candidates. In this report the latter has been chosen.

4.2.2 Simplified method - summer: Solar heat factor, SVF

The simplified measure of the thermal climate during summer is the solar heat factor. This simplified method is valid for single-family houses, residential buildings and school buildings. For the rest only the detailed methods are valid. The solar heat factor describes how the indoor climate is affected by the heat gain through windows (SGBC, 2014b). Again, rooms with the largest window area in relation to floor area are considered as critical.

Table 4-4. The two methods to determine the thermal climate in the summer and the corresponding parameter units.

Method	Parameter	Unit
Simplified	Solar heat factor	-
Detailed	PPD	%

The method and criteria used in Miljöbyggnad are based on the relation presented below and target values which both may be found in *Bygga med glas*, a handbook about glass in construction (Kumar, et al., 2010).

$$T_f = g \cdot \frac{A_{glass}}{A_{facade}} \tag{4.5}$$

This equation is applicable to façades facing east, south or west (Carlson, 2005). After modifying this model by using the ratio $A_{\text{façade}}/A_{floor} = 0.6$ the simplified method was obtained (Glaumann, et al., 2008):

$$SVF = 0.6 \cdot T_f = g_{syst} \cdot \frac{A_{glass}}{A_{facade}} \cdot \frac{A_{facade}}{A_{floor}} \tag{4.6}$$

Hence, the solar heat factor is calculated using

$$SVF = g_{syst} \cdot \frac{A_{glass}}{A_{floor}} \tag{4.7}$$

Important to notice is that g_{syst} relates to the total g-value including the effect of the glazing and any shading materials and A_{glass} is the area of the window glass, i.e. excluding frame and sash. A_{floor} is the total floor area, i.e. floor hidden underneath cupboards for example is also included (SGBC, 2014b).

For rooms with windows facing more directions than one the same principle as for the solar heat load is to be used, see section 4.1. The solar irradiation should be reduced to 70 % when adding the contributions from two directions, which is summarised as (SGBC, 2014a):

$$SVF = \max\begin{cases} 0.7 \cdot g_{syst} \cdot \dfrac{A_{glass.S.or.E.or.W}}{A_{floor}} + 0.7 \cdot g_{syst} \cdot \dfrac{A_{glass.S.or.E.or.W}}{A_{floor}} \\ g_{syst} \cdot \dfrac{A_{glass.}}{A_{floor}} \end{cases} \qquad (4.8)$$

where $A_{glass.S.or.E.or.W}$ indicates the glass area facing either south, east or west.

4.2.3 Detailed method - winter & summer: PPD & operative temperature

Due to the complexity of thermal comfort, Miljöbyggnad has developed the thermal climate indicators for the winter and summer cases respectively throughout the versions and different parameters have been used. The simplified methods offer a straight forward approach to the complex matter of indoor thermal climate by only taking into account physical aspects of the building.

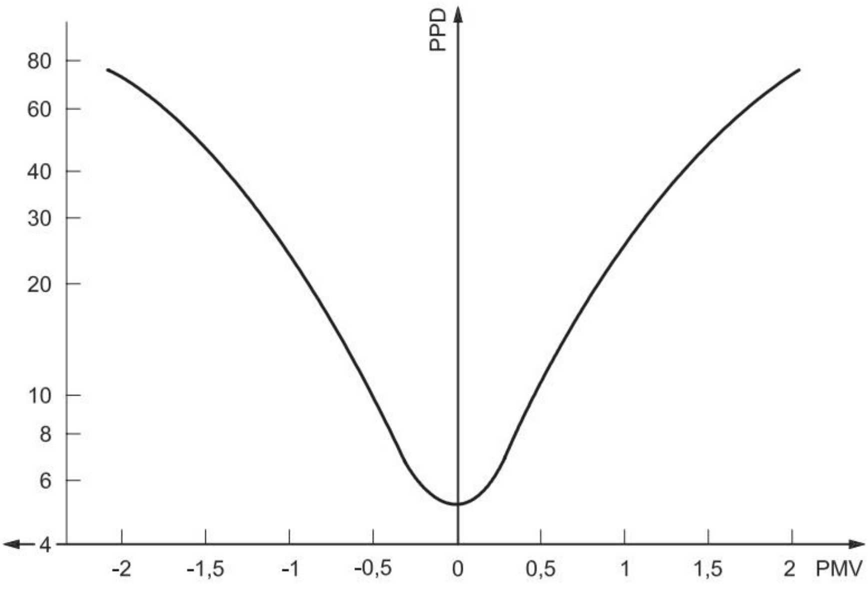
With start in version 2.1 the PPD index is used as the parameter for both winter and summer conditions and predicts the percentage of people that would be dissatisfied with the certain climate. This is described further later in this section. In addition to the PPD index requirement, 80 % of the responses from a survey to the occupants regarding the indoor comfort have to be “acceptable”, “good”, or “very good” to be able to receive GOLD (SGBC, 2012a). The same goes for version 2.2, but with the difference that while the criteria are written in PPD the comparison should be made in terms of operative temperature (SGBC, 2014b). Operative temperature is described in section 0.

By using *Fanger’s comfort index*, the number of people dissatisfied with a certain indoor climate can be predicted. Fanger was a Danish indoor climate researcher who studied the human perception of different combinations of certain indoor climate parameters. The predicted thermal comfort can be calculated using the PMV, Predicted Mean Vote. By using the PMV index, the predicted mean value of the votes of a large group of people exposed to the same environment can be determined on the seven point scale shown in Table 4-5 (SIS, 2006). The thermal climate is considered neutral when the PMV is at ±0.5.

Table 4-5.The PMV index which is used to predict the temperature experience of a large group of people (SIS, 2006).

PMV index	Perception
+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

Through the PMV the predicted share of people dissatisfied with a certain thermal climate can be determined. This index is defined as predicted percentage of dissatisfied, PPD, and predicts the percentage of people that would perceive the climate as uncomfortably warm or cold (SIS, 2006). Due to the individual factors that affect the perception, it is not possible to achieve a PPD lower than 5 %. This means that not more than 95 % of the people in a room can ever feel fully satisfied with the climate. Figure 4-1 below presents the relation between PMV and PPD, discovered by Fanger.



Key
PMV predicted mean vote
PPD predicted percentage dissatisfied, %

Figure 4-1 The relation between PMV and PPD (SIS, 2006).

The influencing parameters which are combined and defines the indoor thermal climate is *activity and clothing*, *air temperature*, *operative temperature*, *air velocity* and *air humidity* (Warfvinge & Dahlblom, 2012). Those parameters area described in sections below.

Activity level

The activity level, or metabolism, is measured in *met* where 1 met corresponds to a heat production of 60 W/m^2 skin surface. Examples of the heat production and metabolism at different activities are presented in Table 4-6 below (Warfvinge & Dahlblom, 2012).

Table 4-6. The heat production and metabolism at different activities (Warfvinge & Dahlblom, 2012).

Activity	Heat production [W]	Metabolism [met]
Sleeping	85	0.8
Sitting	105	1.0
Paperwork	125	1.2
Housework	180	1.8
Walking 5 km/h	320	3.2
Running 8.5 km/h	740	7.4

Clothing

The insulating ability of clothes is crucial in order to determine the thermal comfort. This ability is measured in *clo* where 1 clo corresponds to 0.155 m^{2}K/W and typical levels can be seen in Table 4-7 below.

Table 4-7. The insulating ability of different clothing levels (Warfvinge & Dahlblom, 2012).

Clothing	Insulating ability [clo]
Naked	0
Light summer clothing	0.5
Normal indoor clothing	1.0
Heavy indoor clothing	1.5
Polar clothing	4.0

Air temperature

The air temperature is easily determined but does not show the holistic picture of the thermal climate since influencing parameters such as radiation from surrounding surfaces and air movements are disregarded (Abel & Elmroth, 2006). Elderly people and sedentary people generally prefer higher air temperatures than others (Warfvinge & Dahlblom, 2012).

Operative temperature

The operative temperature is an average temperature of the air temperature and the mean radiative temperature and is a more accurate measure of the thermal comfort than the air temperature only (Abel & Elmroth, 2006). The impact of radiation may be most significant during the winter due to cold ambient surfaces, but the operative temperature must be considered all year around. In the summer, the solar irradiation heats glass surfaces and the air temperature needs to compensate in order to maintain a comfortable operative temperature (Warfvinge & Dahlblom, 2012).

The operative temperature is defined as

$$T_{op} = \frac{\alpha_c \cdot T_a + \alpha_r \cdot T_r}{\alpha_c + \alpha_r} \tag{4.9}$$

where α_c is the convective heat transfer coefficient between skin and air, α_r is the radiative heat transfer coefficient between ambient surfaces and skin. T_a is the air temperature and T_r is the mean radiative temperature.

Air velocity

When the air velocity exceeds 0.15 m/s more than temporarily and the operative temperature is between 20°C and 24°C, discomfort occurs. This discomfort is due to draught, which is defined as local cooling of the body and results in decreased skin temperature. High air velocities indoors can be derived from air leakages in the building envelope and glass surfaces with poor thermal properties. The air inlets for supply air might also cause draught problems (Warfvinge & Dahlblom, 2012).

Air humidity

The air humidity is the least influencing parameter when it comes to thermal comfort. The influence of high humidity is significant first in combination with high air temperatures (Warfvinge & Dahlblom, 2012).

4.3 Daylight

Daylight is the diffuse light from the sky and the light that is reflected from surrounding surfaces. The direct light is not included but defined as sunlight. Sunlight is varying during the day due to the position of the sun and shading obstacles whereas the daylight has a more uniform presence.

Light indoors can either be natural light through the windows or artificial light from luminaires. Irrespective of the light source, the light needs to fulfil some requirements in order to not result in discomfort indoors. The light level, direction, distribution and glare properties interact and result in appropriate or poor conditions. Too much light indoors results in glare and reflection problems causing difficulties to see (Löfberg, 1987).

The requirement of light is stated in the PBL, *Planning and Building Act*, published by the *National Board of Housing, Building and Planning* and regards both safety and health. In work environment as well as in domestic environment the level of light is of significance in order to ensure safety for all people regardless visual abilities. The access of light highly affects the psychological and medical health and helps to regulate the circadian rhythm (Boverket, 2014).

In Miljöbyggnad, the daylight indicator aims to reward buildings with good access to daylight. The daylight quantity is measured as a daylight factor, DF, or as a simplified measure called window share, AF (SGBC, 2014b). When evaluating the daylight indicator in a building, a floor located as low as possible is selected due to unfavourable shading conditions. Rooms with small window area in relation to floor area are considered as significantly critical (SGBC, 2014c). The parameters and units corresponding to the two evaluation methods can be found in Table 4-8.

Table 4-8. The two methods to determine the daylight properties and the corresponding parameter units.

Method	Parameter	Unit
Simplified	Window share	%
Detailed	Daylight factor	%

Whether or not daylight was to be included in Miljöbyggnad was thoroughly discussed in the early stages. On one hand it was argued that daylight is important to the human health and it is important to include since it is harder to assess and therefore easier to overlook. Without daylight as an indicator there would also be a risk that the size and numbers of windows would decrease to score better in the solar heat load indicator with darker rooms as a consequence. The other side argued that daylight is overrated and that there is no strong correlation between human health and daylight. In the first draft of Miljöbyggnad that was tested on real planned and existing buildings daylight was included as an indicator under an aspect called Thermal climate and daylight (Glaumann, et al., 2008). However, without any mentioning in the trial period report, daylight was given an aspect of its own as of Miljöbyggnad version 2.0 (Kumar, et al., 2010).

4.3.1 Simplified method: Window share, AF

Daylight indoors is influenced by several factors indoors and outdoors. Floor area, window properties, sky properties and shading obstacles outdoors all have an impact. Of all of these the glass area of the windows in relation to the floor area is the most determining factor and is hence used to calculate the window share as the simplified method for the daylight indicator (Glaumann, et al., 2008):

$$AF = \frac{A_{glass}}{A_{floor}} \cdot 100 \qquad (4.10)$$

If the daylight transmission, LT, of the windows are lower than 0.7, that is if less than 70 % of visible daylight passes through, its effect is influential enough that the detailed method has to be used instead (SGBC, 2014b).

For commercial buildings and buildings with workstations in large halls Miljöbyggnad version 2.2 offers complementing criteria in terms of a minimum view area (*utblicksarea*). The view area is a percentage of the total floor area that has at least a 5 degree view both horizontally and vertically of the outdoors without being obscured by permanent furnishings (SGBC, 2014b).

4.3.2 Detailed method: Daylight factor, DF

The illuminance, which might be described as the amount of light hitting a surface, varies from hundred thousands of lux in direct sunlight to only a few lux in twilight and dawn. When letting daylight into the building through windows and openings, one way to measure the resulting amount of light is by the daylight factor, DF (SP, 2015a). The daylight factor describes the share of illuminance in a point inside the room and the total illuminance on a horizontal surface outdoors. The daylight factor is defined using an overcast sky, why the orientation of the room has no impact, and it is expressed as a percentage. Having a daylight factor of 2.5 % in a point indoors means that the illuminance is 300 lux in that point when the illuminance outdoors is 12 000 lux (Löfberg, 1987).

The Daylight Factor is described in the Swedish standard SS 914201 from 1988 which is still applicable today. The standard states the exact spot to be assessed for daylight (0.8 m above the floor, 1 m from the darkest wall halfway into the room) as well as prescribing the calculation methods explained in *Räkna med dagsljus* from 1987 to be used (SIS, 1988). Miljöbyggnad version 2.2 refers to both these texts but recommends computer based simulation tools such as Radiance and VELUX Daylight Visualizer.

5 Description of Simulation Software Products

When assessing the four chosen indicators on a detailed level, different simulation software products are used. The choice of products shown in Table 5-1 below is not based on what is thought to be the most accurate tools but rather what is commonly used by practitioners. Short introductions to these simulation tools can be found in the following sections.

Table 5-1. The software products used to simulate the parameters corresponding to the room indicators.

Indicator	Solar heat load	PPD winter	PPD summer	Daylight factor
Software	IDA ICE	IDA ICE	IDA ICE	VELUX Daylight Visualizer

5.1 Structure of IDA ICE

IDA ICE is a simulation tool in which buildings and individual thermal zones are modelled with specified HVAC systems, building envelopes, site properties and internal gains. By running a simulation, data regarding energy performance, indoor climate and air flows as well as solar heat gains can be determined.

The simulated system consists of a building with one or more zones, a primary system containing hydronic components and one or more air handling units. Surrounding buildings or obstacles might shade the building and must be taken into account as site properties (EQUA, 2015c). The weather conditions on the site are defined by weather data files containing information of actual or synthetic weather.

IDA ICE is a detailed and complex software product with a wide range of possibilities to adjust and optimize the building properties. Two different types of models can be created; an energy model or a climate model. In this study the latter been used for simulations of solar heat load and thermal climate. The climate model is limited to rectangular zones only. Another feature that might be seen as a drawback is that all settings can be defined in a number of ways, why the output data is likely to extract wrongly due to the combination of settings.

5.1.1 Solar heat load simulation in IDA ICE

When evaluating the solar heat gain of a zone, the properties of the windows and any shading are crucial. Defining the properties of the window means that the glazing type, the window opening control, the frame properties and any window twists or tilts are determined. The shadings can be either integrated or external and the control of those can be defined.

The properties of the glazing are divided into shading coefficients and thermal coefficients. The g-value, known as solar heat gain coefficient or solar factor, describes the fraction of the irradiation through the window that heats the room. The algorithm takes into account both the radiation through the window directly and the radiation absorbed and later released to the zone, as convection and long-wave radiation. The solar transmittance, T-value, is the fraction of incident radiation that passes through the glazing as direct radiation (EQUA, 2015a).

The thermal properties of the window are defined as the glazing U-value and internal and external emissivity. The U-value is the heat transfer coefficient of the glazing with the frame disregarded. The internal emissivity represents the inwards longwave radiation whereas the external emissivity defines the outwards longwave radiation. The heat gain through external windows is based on long and short wave radiation as well as transmission through pane and frame (EQUA, 2015a).

5.1.2 Thermal climate simulation in IDA ICE

In IDA ICE simulations, the thermal comfort in each zone is presented as *Fanger's comfort indices* showing PMV and PPD. Those measures take into account air temperature, radiation, humidity, air velocity and occupant clothing and activity level which all are described in section 4.2.3. The thermal comfort is considered only for times when occupant loads are present (EQUA, 2015b).

The average of the air temperature and the radiative temperature is known as the operative temperature, which can be described as the temperature that a human perceive in the room. Operative temperature and perceived thermal comfort are also described more in detail in section 4.2.3. The algorithm calculates the operative temperature in a default position of an occupant, which is in the middle of the room at a height of 0.6 m above the floor. This represents the position of a sitting person (EQUA, 2015d). According to Miljöbyggnad, the position of the occupant is however recommended to be one meter from the largest window since that is considered the most critical position within the occupied zone.

Miljöbyggnad states that the thermal climate for summer is evaluated at the moment when the cooling power is at its maximum. This goes for buildings with installed cooling power and not for those that are cooled only by natural ventilation. The moment at which the cooling power reaches its maximum is assumed to be equal to the moment when the experienced indoor climate is warmest. Thus, for buildings with installed mechanical cooling, the summer PPD is found at the maximum PMV value.

5.2 Structure of VELUX Daylight Visualizer

VELUX Daylight Visualizer, henceforth written as Velux, is a simulation software product used for prediction and documentation of daylight levels in buildings. Daylight analyses are performed for 3D models with specified data corresponding to the actual case regarding geometry, surface properties and site properties amongst others. Available simulations outputs are luminance, illuminance, daylight factor and simulations of daylight and sunlight (VELUX, 2015).

VELUX is a rather basic and intuitive software product, hence there are some drawbacks. Creatable geometries within the program are limited to rectangles and right angles for almost everything. If more elaborate geometries or several storeys are to be modelled, the model has to be made outside of VELUX and then imported. An imported model, however, has to be complete with geometries, windows, and surfaces since neither can be modified in VELUX afterwards (VELUX , 2014).

Another disadvantage is that for a model made directly in VELUX all surfaces of the same type are given the same properties. For example, a balcony and high hedge would have the same reflectance (VELUX , 2014).

Other sources of errors in daylight simulations are first and foremost the human ones. Rather small deviations from a correct model with all the correct geometries, window positioning, exterior obstructions and surface properties can cause significant errors without immediate detection. Lack of experience in for example how to handle imported windows may also affect the simulation results (SBi, 2013:26).

5.2.1 Daylight factor simulation in VELUX Daylight Visualizer

There are different calculation methods that may be used to obtain the daylight factor for a room. There are those based on pre computer age calculation methods, some are finite element method based, and some are built upon ray tracing. The method used in VELUX is called photon mapping, which theoretically is split into two parts. In a first step rays from the sky outdoors are traced to and mapped on different surfaces within the room to see how much light reaches the surface. In the next step backward tracing is done from a view point, indicated by the eye in Figure 5-1 below. By combining both results the daylight levels may be obtained (SBi, 2013:26).

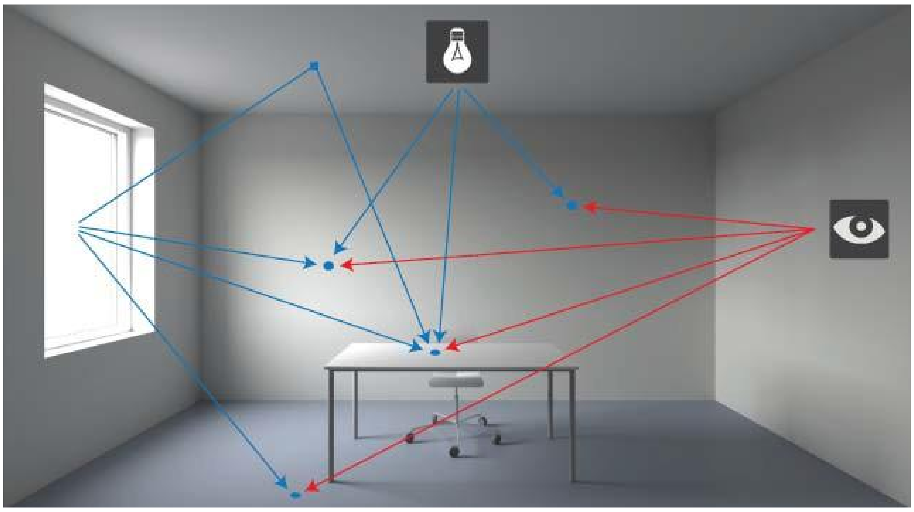


Figure 5-1 The ray path principle of the photon mapping method (SBi, 2013:26).

6 Representative Objects

In order to evaluate the room indicators, representative buildings and rooms need to be defined. Residential buildings, office buildings and hospital buildings generally diverge regarding number of floors, building envelope and building layout due to different applications. Thus, these three building types are treated separately when defining the representative objects. The ways in which the objects can be considered as representative are:

- Thermal properties
- Dimensions
- Internal gains
- Technical installations
- Room activities

To model entire buildings is time consuming and not always very helpful, especially if comparisons are to be made. In that case a simple reference model which can be compared to the results of a change in a parameter is more desirable. Removing unnecessary information to obtain a simple but representative model can be done by well justified assumptions.

First off there are already some assumptions prescribed in Miljöbyggnad, which have been summarised in Table 6-1. As a general rule the rooms to be investigated for the solar heat load and thermal climate indicators are the ones with the largest glass area to floor ratio since all these indicators are highly dependent on the size and properties of the windows. The same logic applies to the daylight indicator for which rooms with the smallest glass area to floor ratio are to be chosen (SGBC, 2014c).

Table 6-1 Guidelines for selecting critical rooms for each indicator.

Solar heat load	Large windows. Facing E, S or W
PPD winter	Large windows
PPD summer	Large windows
Daylight factor	Small windows

Secondly none of the Miljöbyggnad indicators on room level are directly height dependant. This may seem odd looking at the first assumptions but as already stated the first simplifications were due to the degree of shading and not the height itself. The differences in maximum solar irradiation on a vertical surface at the top or the bottom of a building are inconsequential. Therefore the same floor may be used to model both the top floor and the bottom floor by only changing the degree of shading.

For comparability, all objects are assumed to be located in the same area having equal climate properties. These are presented in Table 6-2.

Table 6-2 General climate data of the representative objects.

GENERAL CLIMATE DATA	
Location	Göteborg (Säve)
Climate	Gothenburg, Säve-1977
Winter external design air temperature	-14.6 °C (1 day)

6.1 Residential building

Representative residential buildings were identified by scanning the selection of apartments to be built by four different residential developers in the Göteborg region. The technical descriptions provided were studied and properties regarding layout, building envelope and surrounding buildings were identified. Finally, the obtained data was compiled and repetitive properties were considered as representative ones.

The concepts of residential buildings differ internationally and between urban and rural regions. In Göteborg, these buildings generally consist of ten apartments per storey, each with a size ranging from 40 to 140 m^2. Additionally, in the region of Göteborg, the modern residential buildings tend to be built as elongated buildings consisting of six to ten storeys.

There is a clear trend regarding the structure and building envelope of residential buildings in the studied region today. Slabs and interior walls are generally loadbearing and made of concrete whereas the exterior walls are non-loadbearing. The majority of the façades are built up by bricks but prefabricated concrete elements and plastered façades occur to some extent.

The layout of the apartment is generally open planned with no clear separation between the kitchen and the living room. The bedrooms are however clearly separated and a balcony is often attached to the living room or to a bedroom.

6.1.1 Representative building configuration

The residential building has a structure of concrete slabs and steel columns. The exterior walls are lightweight walls made of a steel stud structure covered by gypsum boards on the interior and weatherboards on the exterior with mineral wool in between. Due to an air gap between the exterior wall and the façade, the outer façade material has no impact on the thermal properties of the exterior walls. Thus, the façade material can remain undefined.

6.1.2 Representative room unit

Three representative rooms are defined; a bedroom, a kitchen and a living room. Due to the current trend, the kitchen and the living room are connected by large wall openings. The living room is the largest with a size of 5.2x6.6 m^2 and is connected to the kitchen with a size of 2.8x6.6 m^2. The separate bedroom is 3.6x4.0 m^2.

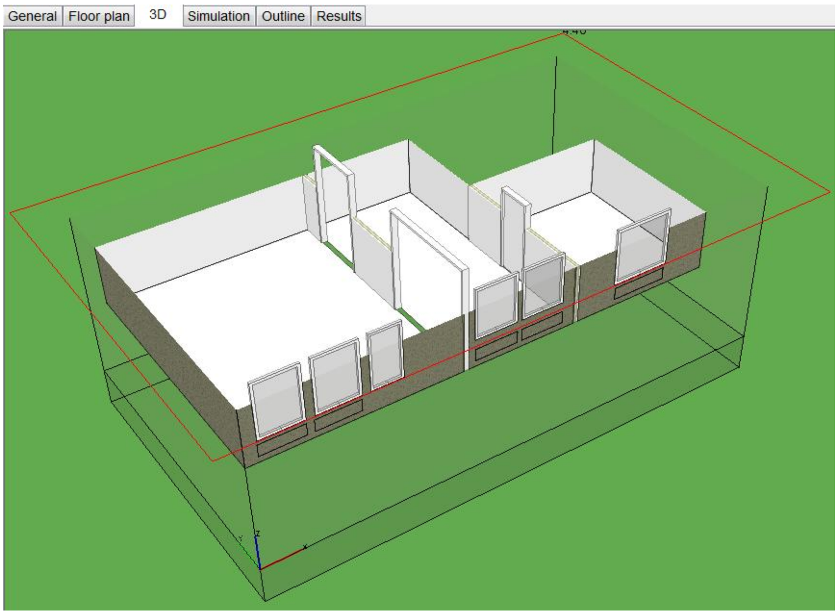


Figure 6-1 The IDE ICE model of the representative residential room unit containing a living room, a kitchen and a bedroom.

6.1.3 Input data for calculations

Below follows some of the most significant input data used in calculations. The rest can be found in Appendix C. The U-value of the wall corresponds to the actual wall with insulation thickness 225 mm and the U-, g- and LT-values of the window are retrieved from the manufacturer. The g-value of the shading corresponds to an internal blind and the total g-value is determined using the software product Parasol.

Table 6-3 Building performance of the representative residential building.

BUILDING PERFORMANCE	
Thermal bridges	20 %
External wall U-value	0.16 W/m^{2}K
Glazing U-value	1.0 W/m^{2}K (Pilkington Optitherm S3)
Window U-value	1.2 W/m^{2}K
Glazing g-value	0.55
Shading g-value	0.55
Total g-value, g_{syst}	0.305
Glazing LT-value	0.72

6.2 Office building

The concept of modern office buildings was identified by scanning the stock of newly built office buildings in Göteborg. Several buildings have been built recently and their properties regarding building layout and building envelope were determined by observing the buildings and corresponding drawings.

The office buildings that have been built recently tend to be high-rise buildings, detached to surrounding buildings. They have about 13 to 16 storeys and the floor area of each storey is generally 900 to 1200 m^2.

The concept of office buildings in the region is distinctly repetitive with concrete slabs, a loadbearing steel column system and lightweight exterior walls. Most of the buildings are covered by metal sheet façades apart from some exceptions made of prefabricated concrete elements.

Modern office buildings contain both private cell offices and larger shared areas defined as office landscapes. Generally, the cell office is used by one single employee whereas the office landscape has a people density of 10 m^2/person. The cell offices and office landscapes tend to be located along the exterior walls due to the need of daylight and the areas in the middle of the building are used for hygienic and storage purposes.

6.2.1 Representative building configuration

The office building has a structure of concrete slabs and steel columns. The exterior walls are lightweight walls made of a steel study structure covered by gypsum boards on the interior and weatherboards on the exterior with mineral wool in between. Due to an air gap between the exterior wall and the façade, the outer façade material has no impact on the thermal properties of the exterior walls. Thus, the façade material can remain undefined.

6.2.2 Representative room unit

Two representative office rooms are chosen; a cell office and an office landscape. The cell office is assumed to be used by one employee only while the office landscape is designed for a people density of 10 m^2/person. The sizes of the cell office and the office landscape are 2.6x3.5 m^2 and 7.9x10.5 m^2 respectively.

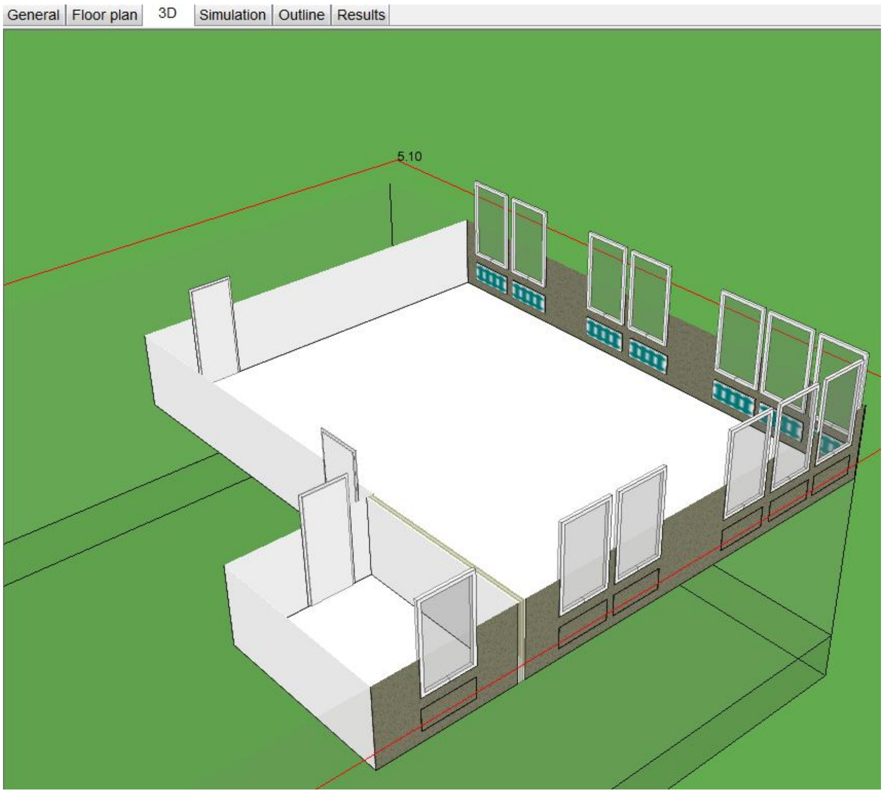


Figure 6-2 The IDE ICE model of the representative office room unit with a cell office connected to a larger office landscape located on the corner of the building.

6.2.3 Input data for calculations

Below follows some of the most significant input data used in calculations. The rest can be found in Appendix C. The U-value of the wall corresponds to the actual wall with insulation thickness 225 mm and the U-, g- and LT-values of the window is retrieved from the manufacturer. The g-value of the shading corresponds to an external blind and the total g-value is determined using the software product Parasol.

Table 6-4 Building performance of the representative office building.

BUILDING PERFORMANCE	
Thermal bridges	20 %
External wall U-value	0.16 W/m^2K
Glazing U-value	0.6 W/m^2K (Pilkington Suncool 70/40)
Window U-value	0.88 W/m^2K
Glazing g-value	0.38
Shading g-value	0.234
Total g-value of window, g_{syst}	0.089
Glazing LT-value	0.63

6.3 Hospital building

Identifying the concepts of modern hospital buildings is complex. Generally, hospitals are extended rather than newly built and thus the shape of the building is a bit limited. To scan the concepts of recently built hospitals, research was made covering not only the Göteborg region. The technical descriptions of such buildings provided by the developers were studied and by disregarding this defined region, it was shown that hospital buildings tend to be built as non-detached building bodies. These are connected by several glazed footbridges on one or more storeys which naturally create atriums between the building bodies.

The structure and building envelope of hospitals nowadays are repetitive and there is usually a structure of concrete slabs and loadbearing elements along the exterior walls, either by loadbearing concrete walls or by a steel column system. With a column system, the exterior walls are generally non-loadbearing. The façade is usually made of bricks, glass or metal sheets.

Hospitals host a number of different types of rooms for health professionals, the patients and their relatives. Except for patient rooms, operation theatres and examination rooms the health professionals have access to staff areas and workplaces. However, the patient rooms constitute the majority of the area and the design of these generally does not differ much in size or in layout. These rooms are also connected to private bathrooms.

6.3.1 Representative building configuration

The building has a structure of concrete slabs and loadbearing concrete exterior walls. Due to an air gap between the exterior wall and the façade, the outer façade material has no impact on the thermal properties of the exterior walls. Thus, the façade material can remain undefined.

6.3.2 Representative room unit

The representative room is a private patient room where the patient stays waiting for medical treatment as well as after treatment for monitoring. The room consists of one hospital bed and accommodation possibilities for one visitor.

The room unit is L-shaped with a rectangular patient room and the bathroom connected on one side. There is a door connection to the corridor and the exterior wall is largely constituted by windows. The patient room has a size of 4x4.2 m^2 and the bathroom is 2.2x2.2 m^2.

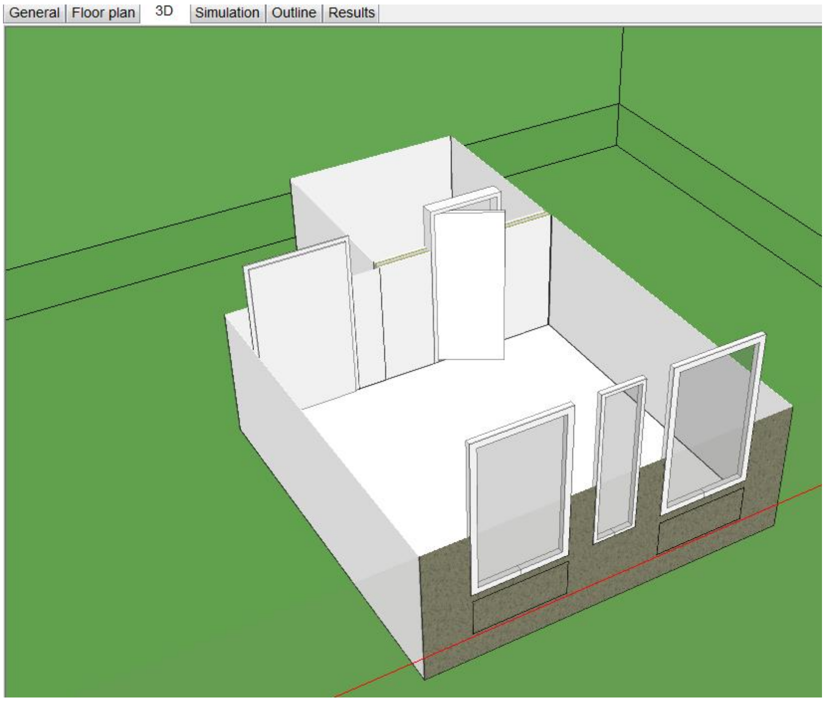


Figure 6-3 The IDE ICE model of the representative hospital room unit with a private room and a connecting private bathroom.

6.3.3 Input data for calculations

Below follows some of the most significant input data used in calculations. The rest can be found in Appendix C. The U-value of the wall corresponds to the actual wall with insulation thickness 250 mm and the U-, g- and LT-values of the window is retrieved from the manufacturer. The g-value of the shading corresponds to an external blind and the total g-value is determined using the software product Parasol.

Table 6-5 Building performance of the representative hospital building.

BUILDING PERFORMANCE	
Thermal bridges	20 %
External wall U-value	0.14 W/m^{2}K
Glazing U-value	0.6 W/m^{2}K (Pilkington Suncool 70/40)
Window U-value	0.88 W/m^{2}K
Glazing g-value	0.38
Shading g-value	0.232
Total g-value, g_{syst}	0.089
Glazing LT-value	0.63

7 Parameter Analysis

A number of parameters influence the indicators and their resulting grade. Some of the parameters are included in both the simplified and detailed methods while some are included in the detailed methods only, this due to their absence in the simplified expressions. Parameters possible to vary in the simplified methods are identified by scanning the simplified expressions, see chapter 4.

The structure of the analysis and the varied parameters related to both methods are presented in Table 7-1. The next part of the parameter analysis contains parameters influencing the detailed methods only. The structure of the analysis and the chosen parameters are presented in Table 7-2. Both tables are followed by a description of the involved parameters and their variations. Note that all parameters are varied one by one and no interdependencies are investigated, except regarding shading and shading orientation. The results from the parameter analyses for each representative object can be found in section 9.1.

Table 7-1 Varied parameters included in both simplifications and simulations for the four indicators.

	3. Solar heat load	**10. Thermal climate - winter**	**11. Thermal climate - summer**	**12. Daylight**
Floor area	x	x	x	x
Window share	x	x	x	x
g_{syst}	x	x	x	
Glazing U-value	x	x	x	
Orientation	x	x	x	x

Floor area, A_{floor}

To determine the impact of the floor area, the reference case floor area is decreased and increased by a factor of 0.5 and 2.0 respectively, meaning that the floor area is halved and doubled in size. This is done by keeping the width while the depth of the room was adjusted. The positions of the windows are fixed which in the case of the office landscape mean that some windows are excluded when the floor area is halved. Internal gains and ventilation flows are varied linearly due to the area dependency.

Window share, $AF_{façade}$

The window share is defined as a share of the façade area and the share is decreased by a factor of 0.5 and increased by a factor of 1.5. As far as possible the windows are treated as a unit with the unit centre matching the centre of the wall and a fixed height. For the halving of the window share this means that as the width decrease the space between the windows also decrease.

In the case of increased window share certain steps are followed to treat each case as equal as possible.

1. The height is fixed and the windows are treated as a unit with the unit centre matching the centre of the wall.
2. The space between the windows is removed.
3. The height of the windows is adjusted while the window to floor distance is kept.

As a consequence of varied window width, the radiator widths are changed so that the width of the radiator corresponds to the width of the window.

Solar factor, g_{syst}

The total solar factor, g-syst, of the window and its shading is varied to 0.1, 0.2, 0.4 and 0.6. The reference solar factors of the three objects are all in the lower region of 0.09 to 0.30.

Glazing U-value, U_{glass}

The U-value of the window glazing is varied to 0.6, 1.0 and 1.4 W/m^{2}K. The first value represents the reference case in the defined office and hospital buildings while the second value represents the reference case of the residential building.

Orientation

The orientation dependency is investigated by rotating the fixed room layout starting from the reference case facing south. The parameter analysis includes rotation towards west, north and east.

Table 7-2 Varied parameters included in the detailed simulations only for the four indicators.

	3. Solar heat load	10. Thermal climate - winter	11. Thermal climate - summer	12. Daylight
Shading	x	x	x	x
Shading orientation	x	x	x	x
Insulation thickness		x	x	
Supply air temp		x	x	
Temp setpoints		x	x	
Activity level		x	x	
Clothing		x	x	
Room height	x	x	x	x
Layout	x	x	x	x
Window level		x	x	x
Ground reflectance				x
Glazing LT-value				x

Shading

The influence of shading buildings and obstacles is studied adding a shading screen at three different combinations of height and distance from the building creating a shading angle of 29°, 40° and 55° respectively. The shading angle is defined as the angle between the horizontal plane starting from the middle of the window and the upper corner of the shading building, see Figure 7-1 below.

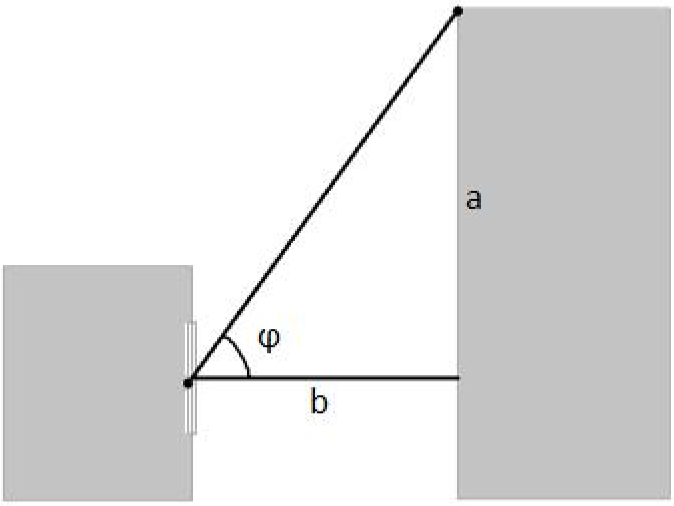


Figure 7-1 The definition of shading angle, seen in profile.

The length of the screen is defined as considerably longer than the studied building ensuring continuous shading. For the sake of the daylight simulations the screen is given a light grey painted finish (matte). The shading screen is applied to the reference orientation facing south.

Shading orientation

The shading screen shades the building differently depending on the orientation. Thus, the location of the building and the screen is fixed and this unit is rotated facing east and west. The two latter combinations of screen properties are chosen, both with a distance of 20 m from the building but with the height of 18 m and 30 m respectively.

Insulation thickness, $d_{insulation}$

The thermal property of the exterior wall is varied by changing the insulation thickness. Starting from the reference thickness of 215 mm, a thickness of 145 mm and 320 mm respectively was studied. Those thicknesses are chosen based on regular insulation board dimensions.

Supply air temperature, T_{supply}

In rooms with mechanical air supply, the supply temperature can be controlled by cooling or heating the air before supplying it to the room. In the defined residential building, the supply air temperature is equal to the outdoor temperature due to the absence of supply air conditioning. The air supply to the office and hospital rooms is however mechanical and the supply temperature is varied to 16 °C and 18 °C respectively, compared to the reference temperature of 17 °C .

Temperature setpoints, $T_{setpoints}$

The temperature setpoints define the minimum and maximum temperatures allowed in the zone. With sufficient heating and cooling equipment, those temperatures should be fulfilled. In the defined reference models, the setpoints are 23±2 °C. In the parameter analysis, those temperatures are changed to 23±1 °C and 23±3 °C respectively.

Activity level
The activity level of the occupants is related to room function and expected activities. The reference level of 1.2 met is changed to 1.0 and 1.4 met respectively.

Clothing
The clothing of the occupants is mostly related to the outdoor temperature; warmer clothing can usually be expected during winter than during summer and thus a span of clothing is defined. The reference clothing of 0.75±0.25 clo is decreased to 0.5±0.25 clo as well as increased to 1.0±0.25 clo.

Room height
The room height differs depending on the object; the lowest height is found in the residential building with 2.6 m and the largest height in the office with 3.4 m. The height is varied from 2.4 m, 2.7 m and 3.2 m to 3.8 m. The lowest height of 2.4 m is only applied in the residential building due to current regulations in commercial spaces.

Layout
When defining the layout of a unit of rooms connected to each other they can either be clearly separated by walls or connected by large openings or absence of walls. In residential buildings, the open layout between kitchen and living room is a common way of creating a welcoming and functional space. In an office, the layout commonly contains both cell offices and office landscapes. The private hospital room is clearly separated due to privacy and contagion risks.

The layout is varied for the residential building only, having either a continuous wall between kitchen and living room creating a closed layout or having two large openings creating an open landscape. The bedroom is left separated.

Window level
The window level is defined as the distance from the floor to the lower edge of the window. The residential building has a reference level of 0.55 m and 0.7 m in the different rooms. The office and hospital buildings have a reference level of 0.8 m. The level is varied to 1.0 m and 1.2 m.

Ground reflectance
The ground reflectance is a measure of the how much visible light that reflects off the ground. The reference value is 0.2 which is changed to 0.1, 0.3 and 0.8 respectively. The different values correspond to:

0.1 - grass, green vegetation, moist earth
0.2 - paving, dry earth
0.3 - sand
0.8 - snow (new)

Light transmission of the glazing, *LT*
The LT-value is the percentage of visible light passing through the glass. The reference value is defined as 0.72 for the residential building and 0.63 for the office and hospital buildings. The LT-value is varied between 0.4 and 0.8.

8 Comparison Method

Due to the diverging units of simplified and simulated methods comparisons are hard to perform, see Table 8-1. The methods may naturally be compared in terms of the reached indicator grade (GOLD, SILVER, BRONZE or CLASSIFIED), but such a comparison is rough and lacks distance to the grade limits. By translating the calculated results to a unitless scale, the results can be compared more accurately.

Table 8-1 The units of the simplified and detailed methods.

Indicator		Simplified	Detailed
3.	Solar heat load	SVL [W/m^2]	SVL [W/m^2]
10.	Thermal climate – winter	TF [W/m^{2}K]	PPD [%]
11.	Thermal climate – summer	SVF [-]	PPD [%]
12.	Daylight	AF [%]	DF [%]

Each indicator has its individual grade limits for the simplified method as well as for the detailed. To remove the unit dependency, the BRONZE-SILVER-GOLD system is directly translated into a numerical grade system:

Figure 8-1 The BRONZE-SILVER-GOLD system is translated into a numerical 1-2-3 system. CLASSIFIED corresponds to 0.

For both of the methods of each indicator Miljöbyggnad has clearly specified criteria for each grade. Using this together with the translated grades, linear equations can be determined. These equations are then used as tools to evaluate and compare results obtained from the methods. All the linearization equations can be found in Appendix D.

To illustrate the procedure an example is given. The criteria of the simplified method for indicator 10, *Thermal climate - winter*, can be found in Table 8-2. The criteria are illustrated in Figure 8-2 below and in the same figure it is shown how a TF-value of 0.35 W/m^{2}K is translated into a numerical grade of 1.5. This value of 1.5 means that a BRONZE grade has been obtained but also that it is halfway to a SILVER grade. With a grade system like this, comparing results from different methods regardless of units as well as evaluating the margins a grade was obtained with are possible. This translation of results into numeric grades has been done for the reference cases of the representative rooms, described in chapter 6, and the results can be found in Appendix E.

Table 8-2 The criteria for the transmission factor, according to Miljöbyggnad 2.2. This simplified method is not accepted for GOLD.

Grade	Transmission factor
BRONZE	< 0.4 W/m2K
SILVER	< 0.3 W/m2K
GOLD	-

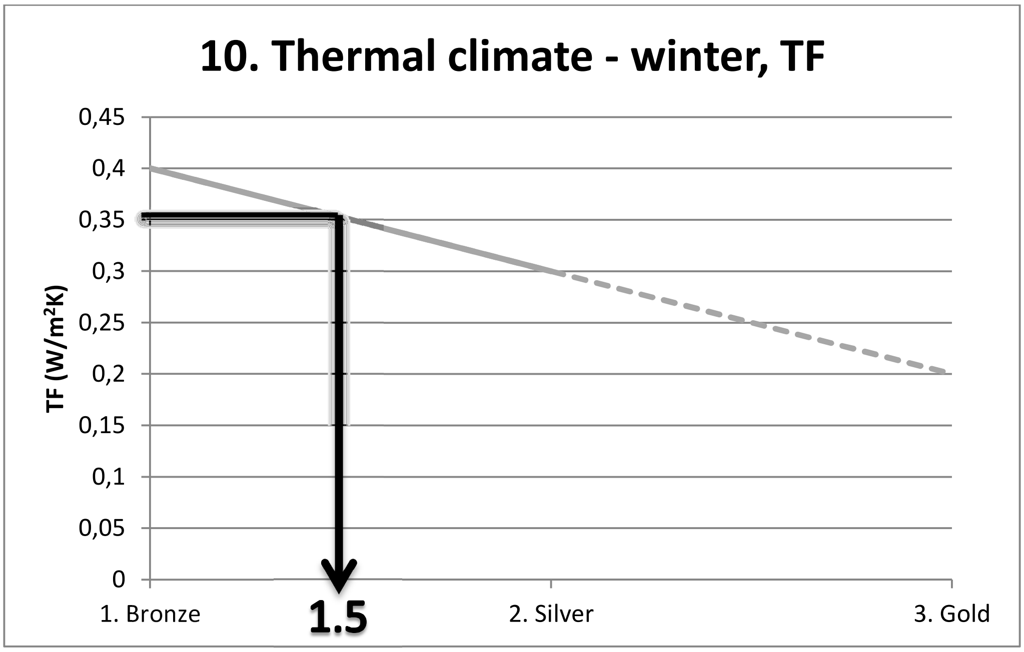


Figure 8-2 The linearization of the transmission factor criteria. An example of how a TF-value of 0.35 W/m^{2}K is translated into a numeric grade value of 1.5, meaning a grade BRONZE but being halfway to a grade SILVER. The dashed line indicates extrapolation since there is no GOLD criteria for TF.

Some simplifications are applied in order to create a generally applicable system. To start, linearity is always assumed for the relation between the indicator value and the resulting grade, although this does not always hold true. In most cases of semi linearity the reason is the criterion for the SILVER grade which is a rounded figure; hence the linear equation has been derived from the BRONZE and GOLD criteria where possible. The only two cases deviating significantly are the solar heat load criteria for commercial buildings and the daylight factor in general. In the first case the SILVER criterion is unexplainably 7.5 % easier to achieve than if linearity would have been applied when deciding on the criteria levels (43 W/m^2 instead of 40 W/m^2). The second case is illustrated in Figure 8-3 below.

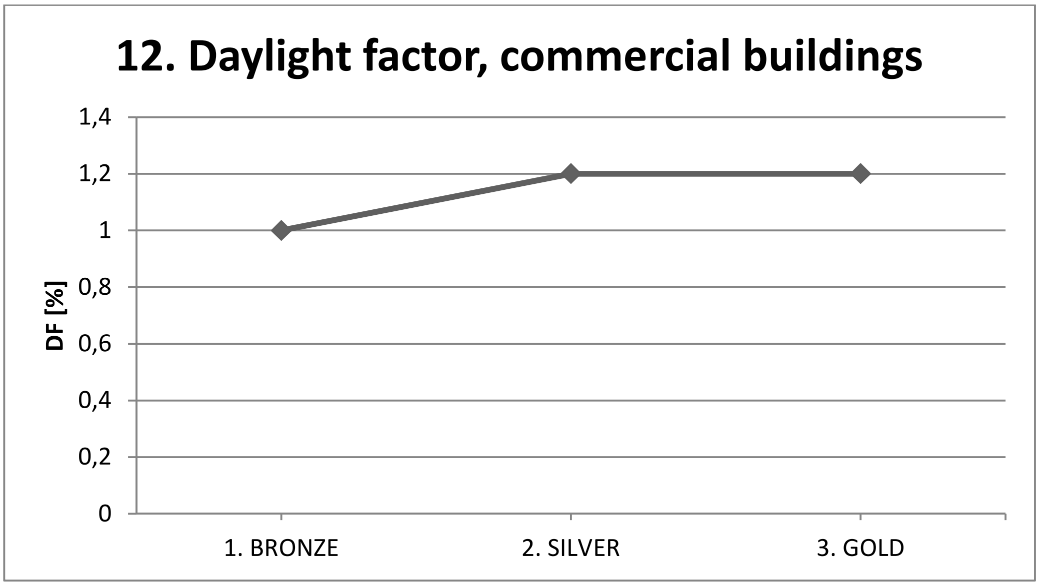


Figure 8-3 The criteria for the daylight factor are non-linear. The indicator instead relies heavily on the passing grade of the survey which is required to obtain GOLD.

As can be seen in the figure there is no difference between SILVER and GOLD criteria for the daylight factor, instead a survey is required. As for the linearization, with such small differences between BRONZE and SILVER the gradient becomes very large. This affects the grade system heavily, especially since daylight simulation results only can be obtained with the accuracy of one decimal. Large grades for daylight factor results should therefore be considered carefully before making comparisons with results from the other indictors.

As for the second simplification, for some indicators the simplified method is valid for certain objects or up to a certain grade only. For instance, for indicator 10, *Thermal climate – winter*, the simplified method is valid for single-family houses up to SILVER level only, otherwise the detailed method must be used. This limitation is indicated by the dashed line from SILVER to GOLD in Figure 8-2 above. However, since this system describes a methodology for comparison, such limitations are disregarded.

9 Results

This chapter presents the results from the study. It is divided into two sections; the first presenting the results from the parameter analysis and the second presenting the conformity between the simplified and detailed methods.

For clarity, results for each parameter is generally presented with the kitchen, bedroom and living room in one graph and the cell office, office landscape and patient room, which all have mechanical ventilation, in another. All in all there are 95 graphs illustrating the results, which all may be found in Appendix F. In this section however only graphs of interest are comprised, including some depicting no changes or relations contrary to expectations.

9.1 Parameter analysis

As described in chapter 7, a parameter analysis is performed concerning the chosen indicators. The degree of impact of the parameters is visualized by symbols, see Table 9-1 below.

Table 9-1 Symbols used to visualize the degree of impact of each parameter.

0	**No or negligible impact,**	< 0.25 grade units difference between the range limits
★	**Small impact**,	0.25 < ★< 0.75 grade units difference between the range limits, exception being indicator 12 where small changes in simulation results causes rapid increase in grades
★★	**Big impact,**	> 0.75 grade units difference between the range limits
-	**Not applicable**	

The studied parameters do either influence both simplified calculations and detailed simulations or only the latter. Thus, the results are divided into two parts which are shown in Table 9-2 and

Table 9-3. These tables give an overview of the degree of impact that each parameter (see the first column) has on the four different indicators (see the first row). Below the tables follow discussion regarding each parameter.

Table 9-2 The degree of impact that parameters affecting both simplified calculations and detailed simulations have on the four indicators.

	3. Solar heat load	**10. Thermal climate - winter**	**11. Thermal climate - summer**	**12. Daylight**
A **floor**	★★	★★	0 *(PPD)* ★★ *(SVF)*	★★
AF **façade**	★★	0 *(PPD),* ★★ *(TF)*	0 *(PPD)* ★★ *(SVF)*	★★
g **syst**	★★	0	★ *(dwelling)* ★★ *(office+patient)* ★★ *(SVF)*	-
U **glass**	★	0 *(PPD),* ★★ *(TF)*	0	-
Orientation	★	0	★ *(dwelling)* 0 *(office+patient)*	0

Table 9-3 The degree of impact that parameters affecting only the detailed simulations have on the four indicators.

	3. Solar heat load	**10. Thermal climate - winter**	**11. Thermal climate - summer**	**12. Daylight**
Shading angle	0 *(office landscape)* ★★ *(the others)*	0	0	★★
Shading orientations, 40°	0	0	0	0
Shading orientations, 55°	0 *(office landscape)* ★ *(the others)*	0	0	0
d $_{\textbf{insulation}}$	0	0	0	-
T $_{\textbf{supply}}$	-	0	0 *(dwelling)* ★ *(office+ patient)*	-
T $_{\textbf{setpoints}}$	-	★★	★★	-
Activity	-	★★	★★	-
Clothing	-	★★	★★	-
Room height	0	0	0	★
Layout	0	0	0	0 *(kitchen)* ★★ *(living room)*
Window level	0	0	0	★★
Reflectance	-	-	-	★★
LT	-	-	-	★★

Floor area, A_{floor}

The way the floor area affects the different indicators varies. Since all the simplified calculations include the floor area, significant influence was expected on the detailed simulations as well. This holds true for the solar heat load where the correlation is good (see Figures F-1 and F-2 in Appendix F) and the daylight for which the detailed simulations are sensitive even beyond expectations (see Figures F-31 and F-32 in Appendix F). However, it does not hold for thermal climate indicators, see Figure 9-1 below. The reason is believed to be the installed cooling and heating as well as ventilation an airing which compensate for the floor area differences, but causes increase in energy demand.

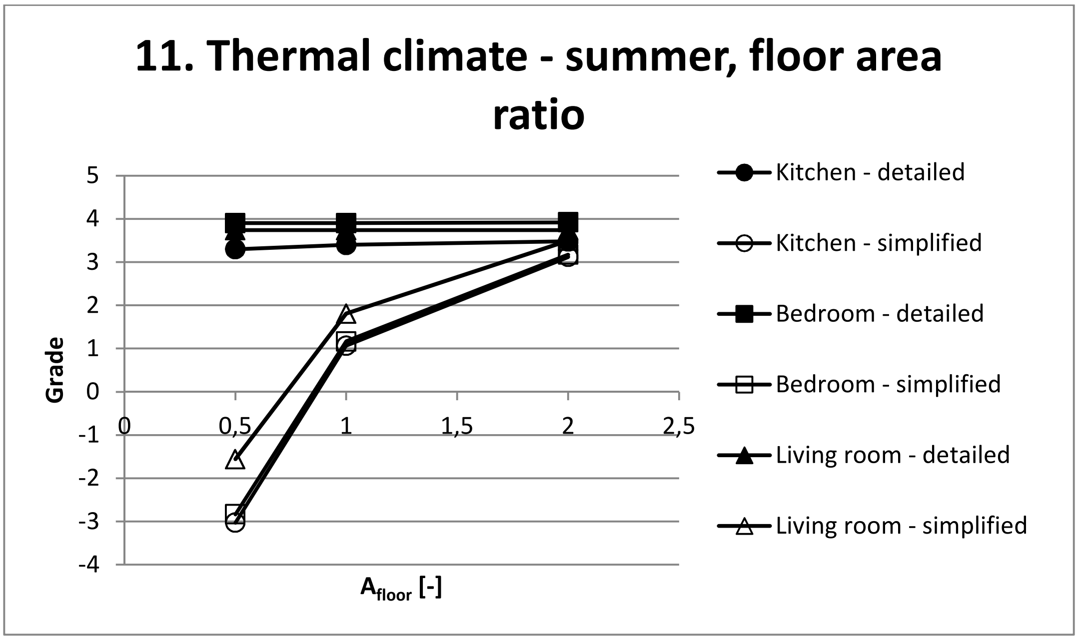


Figure 9-1 *Example showing the unexpected differences between the simplified calculations and the detailed simulations of the thermal climate.*

For the residential building the simulation results for the thermal climate winter case even show an inverted relation with the simplified calculations, which can be seen in Figure 9-2. This is thought to be due to how the ventilation is defined in the model. The air supplied to the rooms is proportional to the floor area. This is not the case for the radiators installed which consequently become undersized.

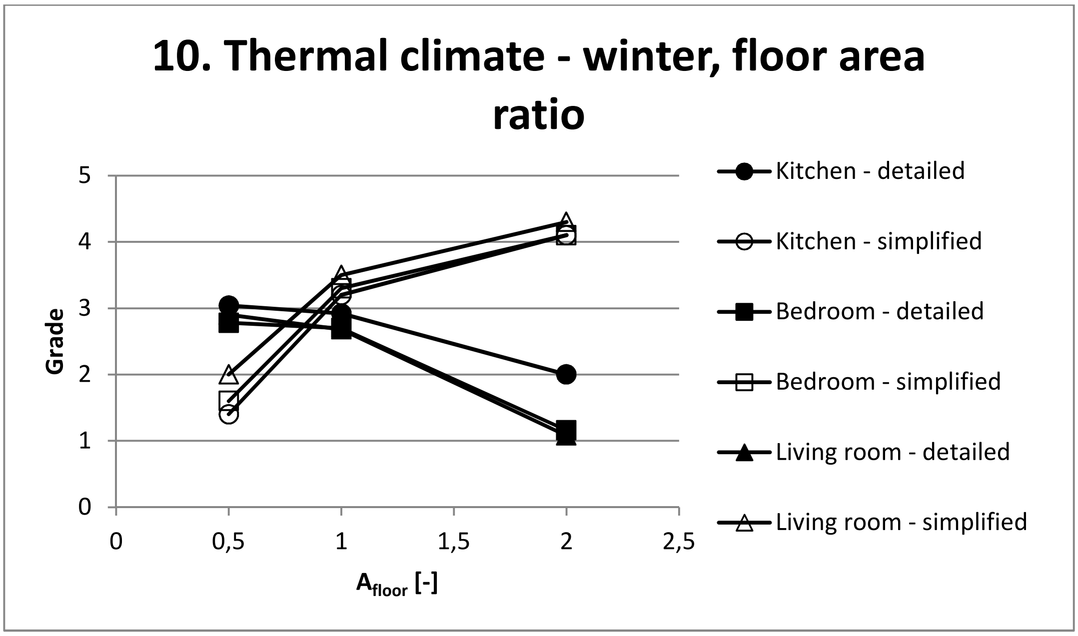


Figure 9-2 *The surprising inverse relation between the results of the simplified calculations and the detailed simulations for the thermal climate winter case of the residential building.*

Window share, $AF_{façade}$

Similarly to the floor area the window size is prominent in the simplified calculations of all the indicators included in this study. The results are also similar; the solar heat load results correlate well and the simulation results of the daylight are more sensitive than expected. The detailed simulations of the thermal climate indicators show an inverted pattern compared to their simplified counterparts, probably due to the heating and cooling which is taken into account in the former. The invertedness of the residential thermal climate winter case is hinted at in Figure 9-3 below.

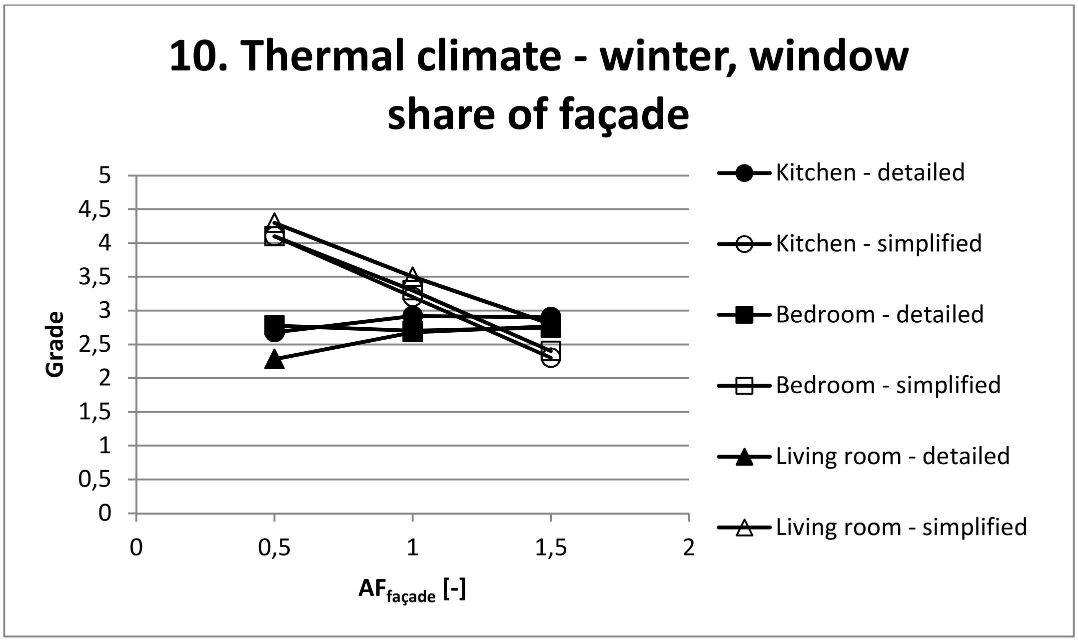


Figure 9-3 The relation between the indicator thermal climate winter and the window share of the façade.

Solar factor, g_{syst}

The total solar factor does not affect the winter thermal climate, which is not surprising. Neither is the fact that the solar heat load heavily depends on the g-value, with good correlation between the detailed simulations and the simplified models. However, for the thermal climate summer case the results are a bit more irregular. The overall trend is that the simplified method is more sensitive to an increasing g-value than the detailed method, which again is due to the presence of a compensating cooling system. This trend is clearly visualized in Figure 9-4 and Figure 9-5 below. For the residential rooms in the first figure, the airing works as cooling system and the result is comparable to the objects with mechanical cooling. The only room deviating from the pattern is the patient room, for which no satisfying explanation was found.

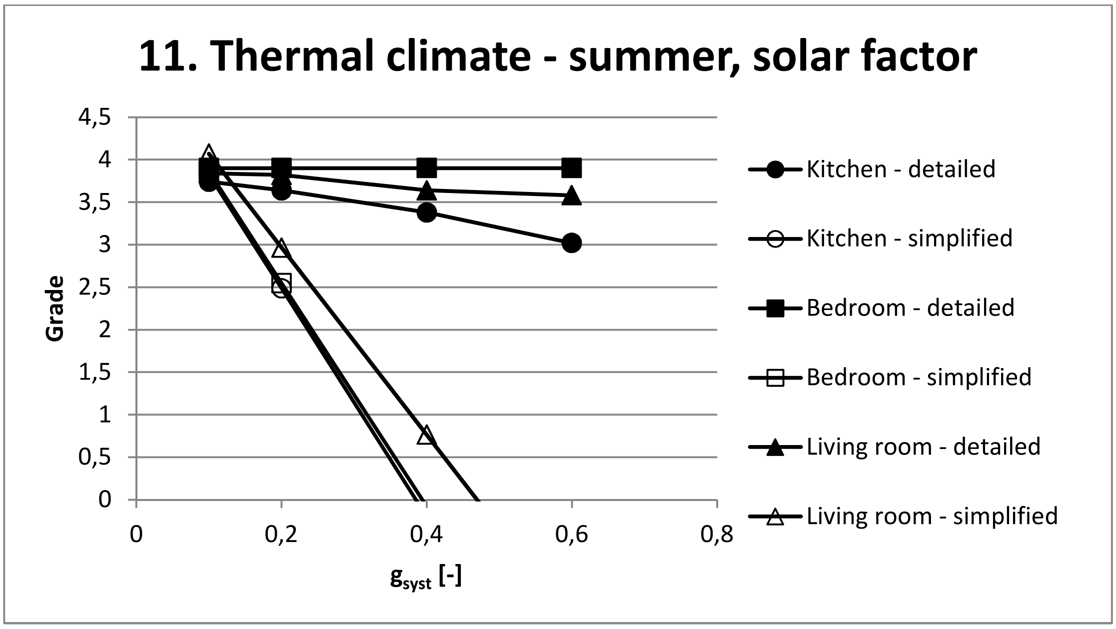


Figure 9-4 The simulations are not as sensitive to the g-value as the simplified model would have us believe. Reference case g_{syst}*=0.305.*

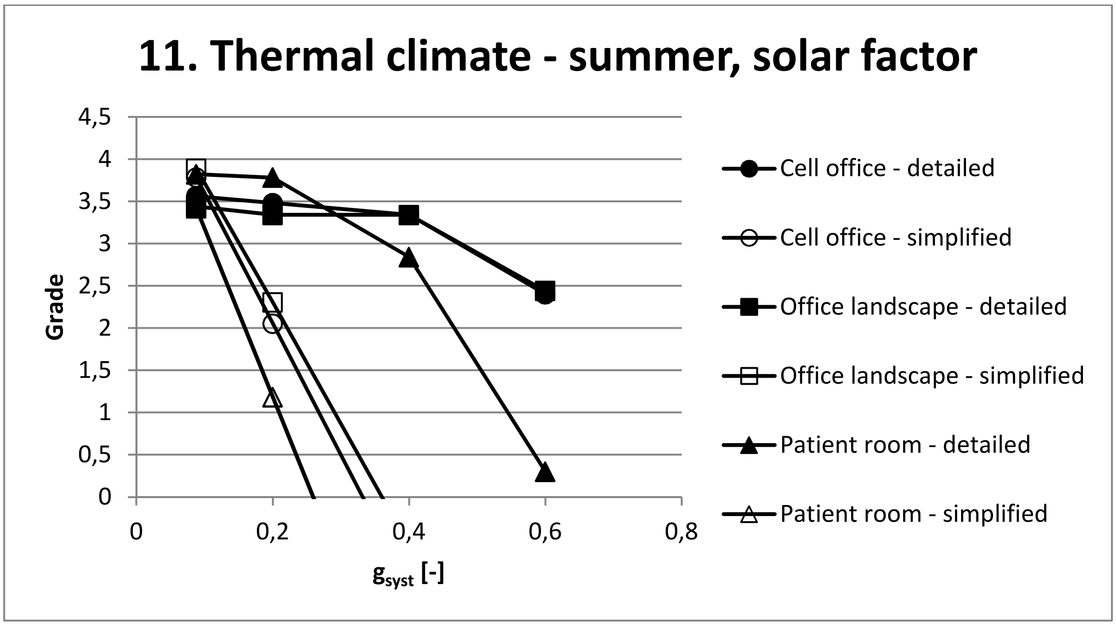


Figure 9-5 The simulated case for the patient room does not follow the pattern of the other simulated cases. Reference case: g_{syst}*=0.088 (offices),* g_{syst}*=0.089 (patient room)*

Glazing heat transfer coefficient, U_{glass}

The U-value was included in the study mainly for the benefit of the winter thermal climate where the simplified method is linearly dependent on U_{glass}. However, as seen before the thermal climate simulation results deviate from those produced by the simplified calculations as can be seen in Figure 9-6. The reason is probably the effect of the heating system present which compensates for heat losses by adjusting the indoor heating. Thus, for detailed simulations where the heating is taken into account, the grade is more or less independent of the U-value of the glass. However, for simplified calculations where no heating is considered the grade is clearly decreased by an increased U-value.

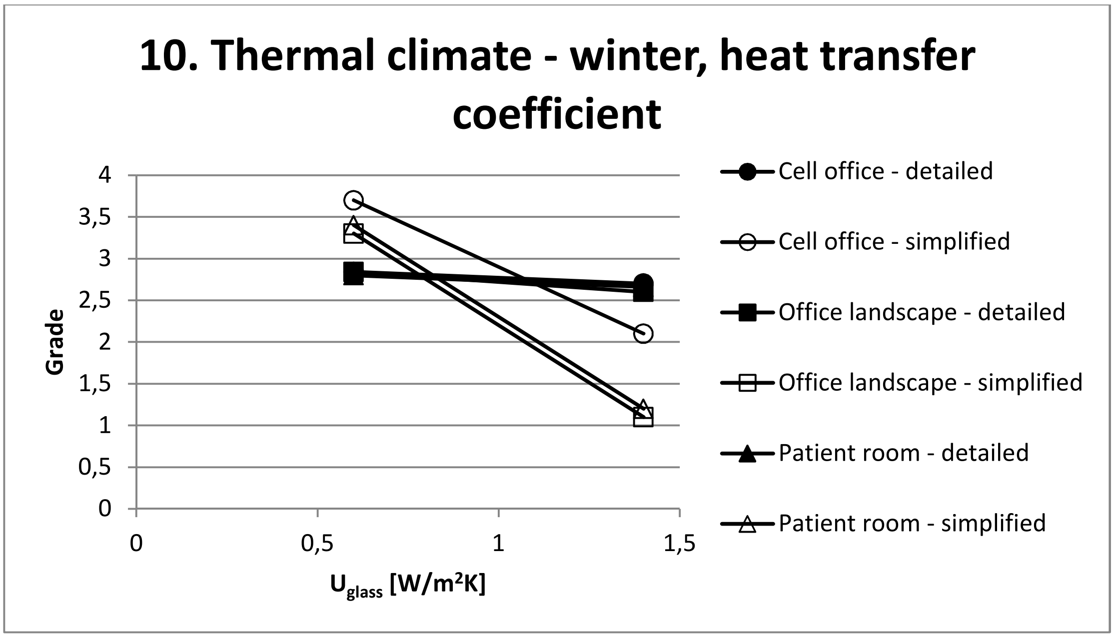


Figure 9-6 The relation between the indicator thermal climate winter and the U-value of the glazing, reference case = 0.6 W/m^{2}K.

Orientation

Since no solar heat gains may be taken into account in the thermal climate winter case and the effect of direct sunlight is not included in the daylight simulations it is not surprising that these two indicators are not affected by the orientation of the building. The detailed simulation results and the simplified calculation results for the solar heat load correlate well with each other, see Figure 9-7, even for the office landscape which has windows facing more than one direction. This means that the orientation of the building is mainly of interest in terms of if a room is facing north or not. There are only smaller differences between the east, south and west directions.

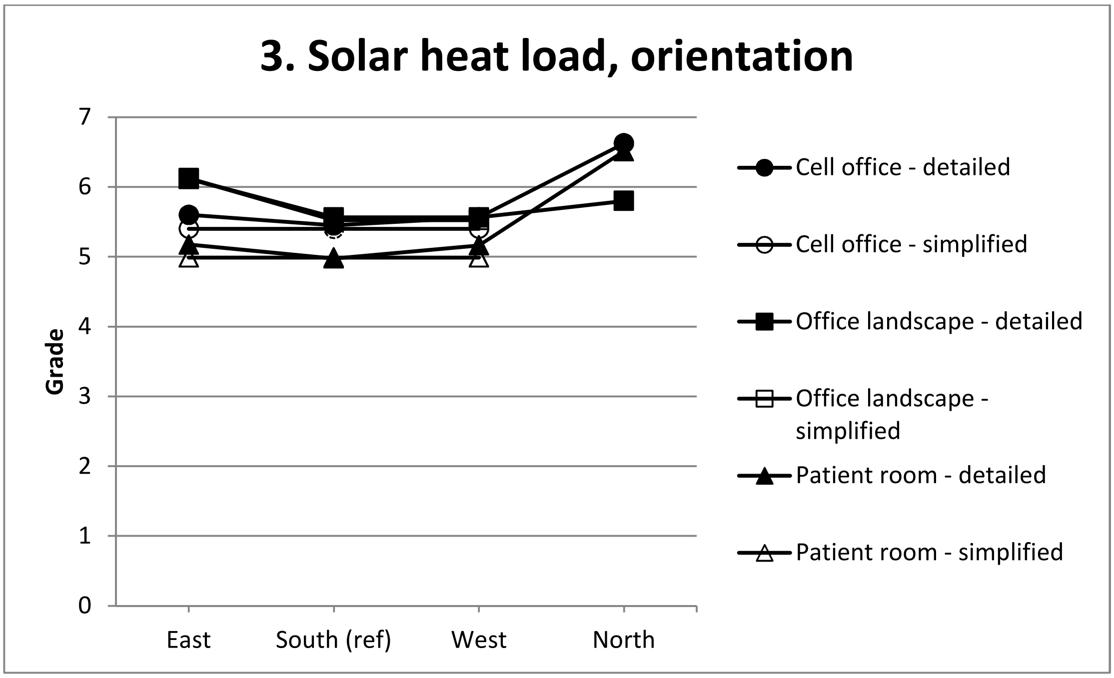


Figure 9-7 The detailed solar heat load simulation results of the office landscape correlate so well that the corresponding simplified calculation curve is not even visible in the figure.

Shading angle

Shading buildings and obstacles are expected to have an impact both by blocking direct sunlight as well as limiting the indirect light. By this it does not come as a surprise that the shading angle rather heavily influences both the solar heat load and the daylight, nor that the thermal winter climate remains unaffected. The thermal summer climate follows the trend of not fulfilling expectations and is not affected by the shading angle either.

Also worth mentioning is the relative independency of the office landscape with regards to shading angle noticed in Figure 9-8 and Figure 9-9. This is thought to be attributable to the significant depth of the room and the multiple window directions.

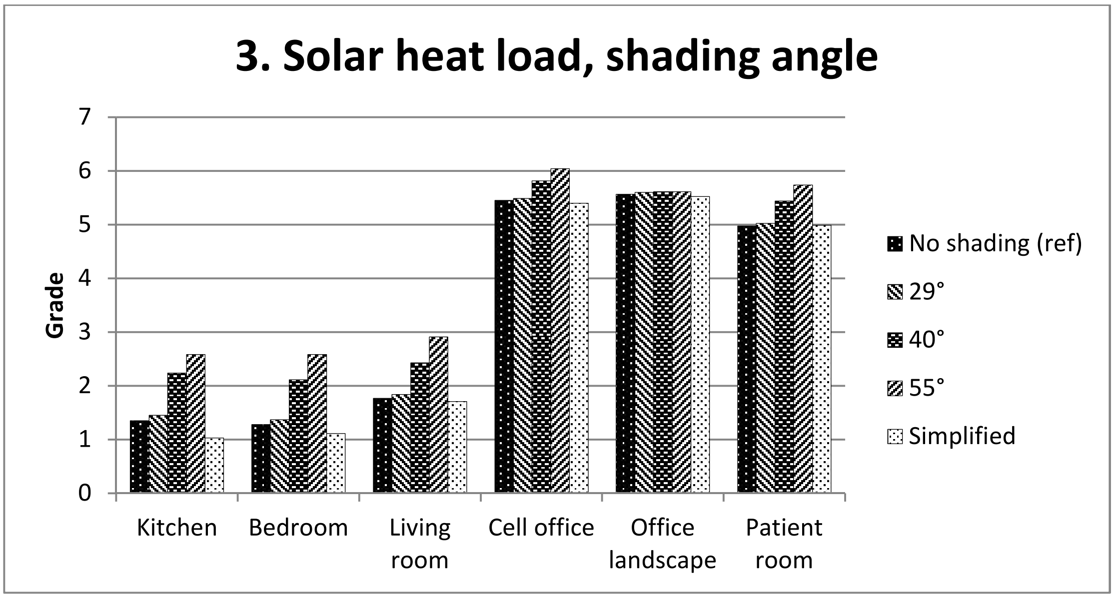


Figure 9-8 *By detailed simulations: the shading angle dependency with regards to solar heat load of all the standard rooms included in the study. Worth noticing is the independency of the office landscape.*

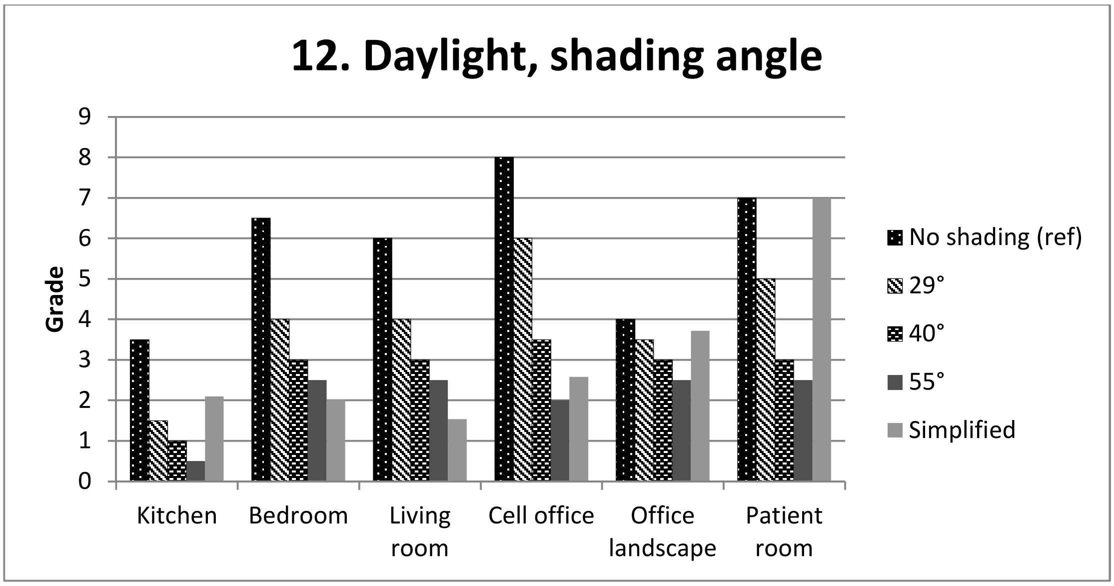


Figure 9-9 *By detailed simulations: the shading angle dependency with regards to the thermal winter climate of all the standard rooms included in the study. Worth noticing is the independency of the office landscape.*

Shading orientation

The shading in combination with different orientations does not give any synergy effects, as can be seen in Figure 9-10 where all the different curves have the same shape. The spacing between the curves is due to the different shading angles, which is covered in *Shading angle* above.

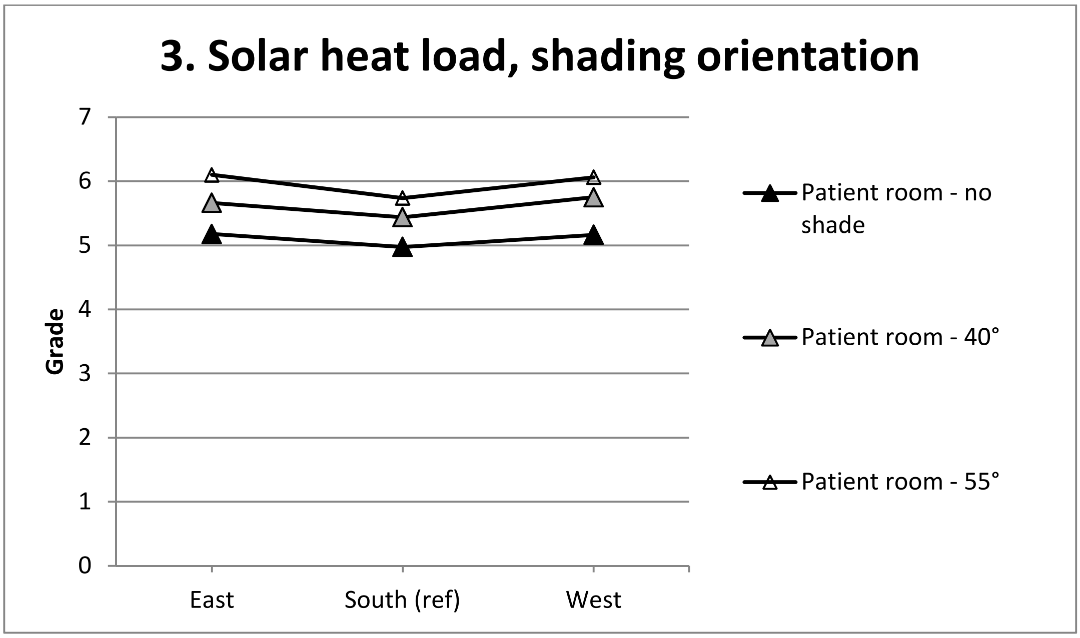


Figure 9-10 All the curves have the same shape, indicating that there are no synergies from combining different shading angles and orientations.

The only variations detectable are found for the summer thermal climate in the residential building, see *Figure 9-11*. Since there does not seem to be a pattern to the variations it is probable that these variations are due to how the possibility to ventilate by opening windows is defined in the detailed simulations.

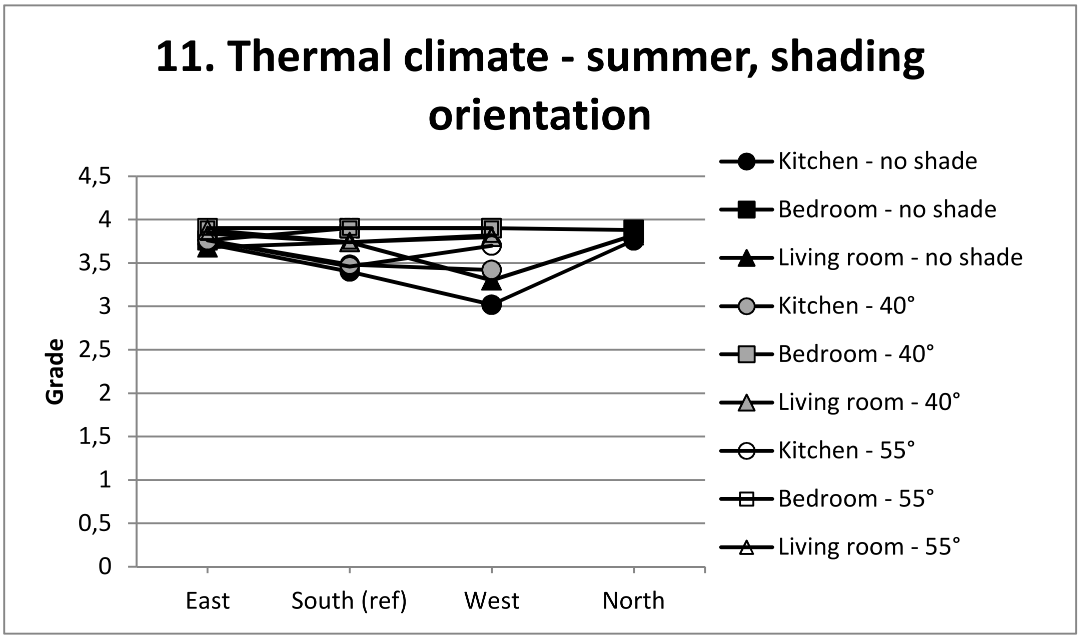


Figure 9-11 Deviations, seemingly without pattern, probably caused by how the possibility to ventilate by opening a window is treated in the detailed simulations.

Insulation thickness, $d_{insulation}$
Unexpectedly the insulation thickness does not seem to have an impact on either of the thermal climate cases. This is probably accounted for by extra heating and cooling, which results in higher energy demand.

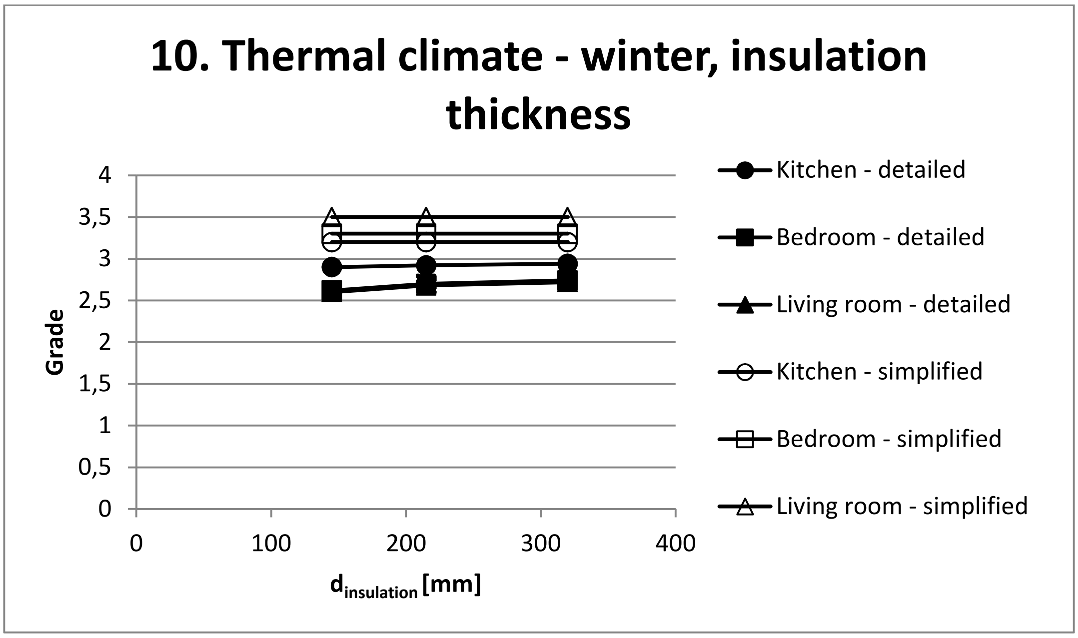


Figure 9-12 Example of how little the insulation thickness effects the thermal climate in different standard rooms, reference case = 225 m (dwelling).

Supply air temperature, T_{supply}
Unexpectedly the supply temperature does not affect the thermal climate, winter or summer case, noticeably, see Figure 9-13. The non-changing grades are most likely the result of room heating and cooling.

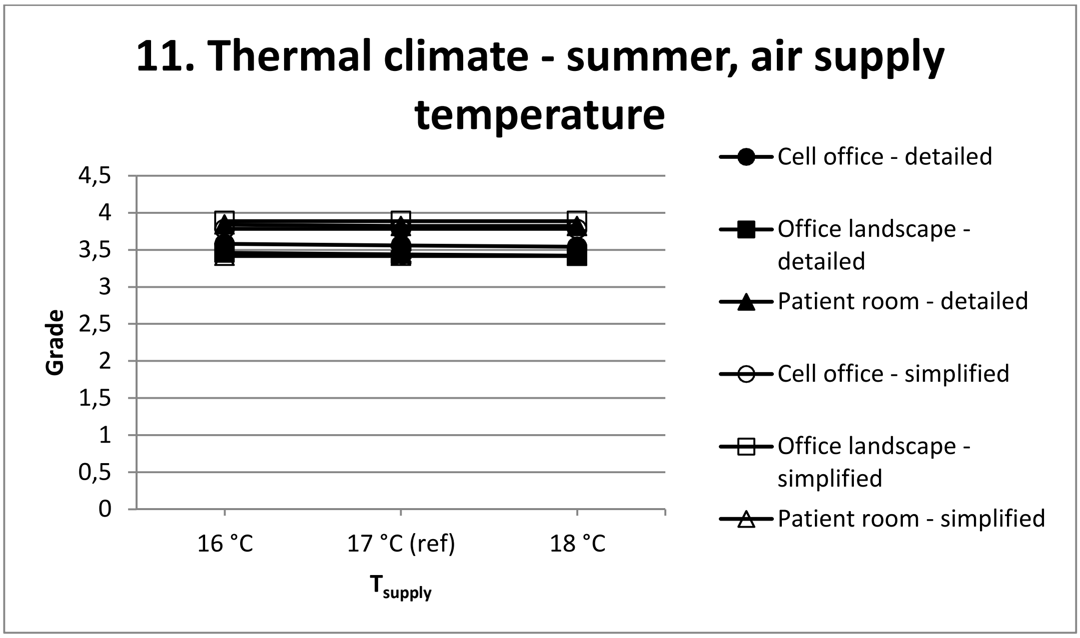


Figure 9-13 Contrary to expectations the supply air temperature does not influence the thermal climate indoors.

Temperature setpoints, $T_{setpoints}$

There is evident responsiveness of the detailed simulation results to the permitted variations in air temperature. The more the temperature in a room is allowed to vary the higher the PPD and the lower the grade for the thermal climate, as can be seen in Figure 9-14. Although such narrow spans can be kept, the increase in energy demand might not justify such a choice.

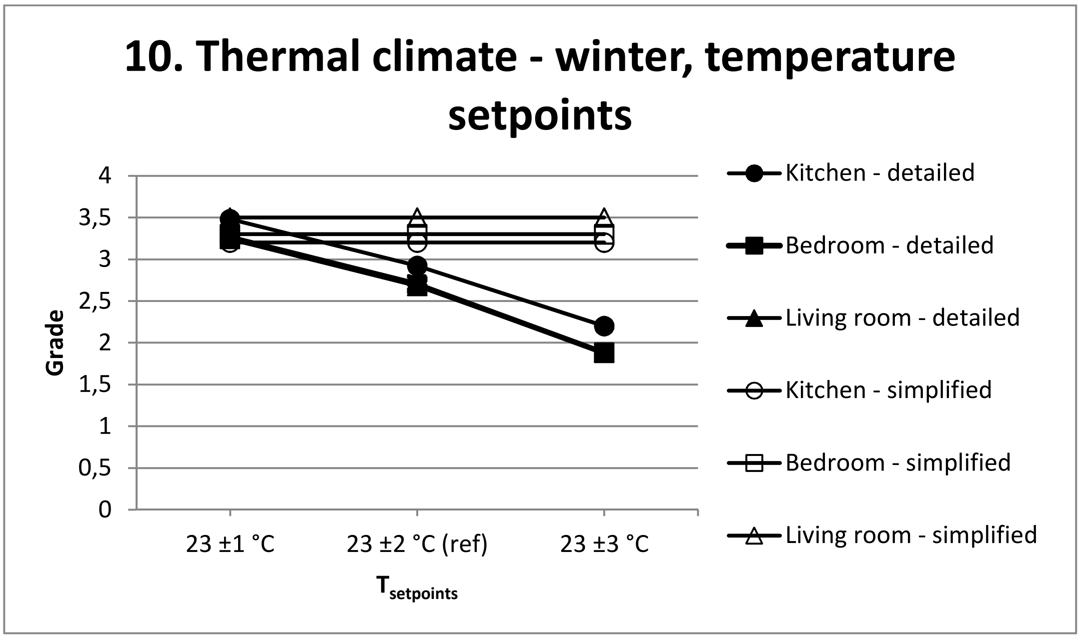


Figure 9-14 The thermal climate grades for temperature variations of 23°C ±1, ±2 and ±3.

Activity level
The PPD measure used for the thermal climate simulations is sensitive towards changes in the activity level of the occupants, rendering it important to make correct estimates. It also leaves an opening for tweaking the results since small changes in activity level can make the difference between a grade and another. Especially the winter case is extremely responsive to changes, see Figure 9-15, but the summer case cannot be disregarded either as can be seen in Figure 9-16 below. Too low activity level in the winter seems more critical than too high activity level in the summer.

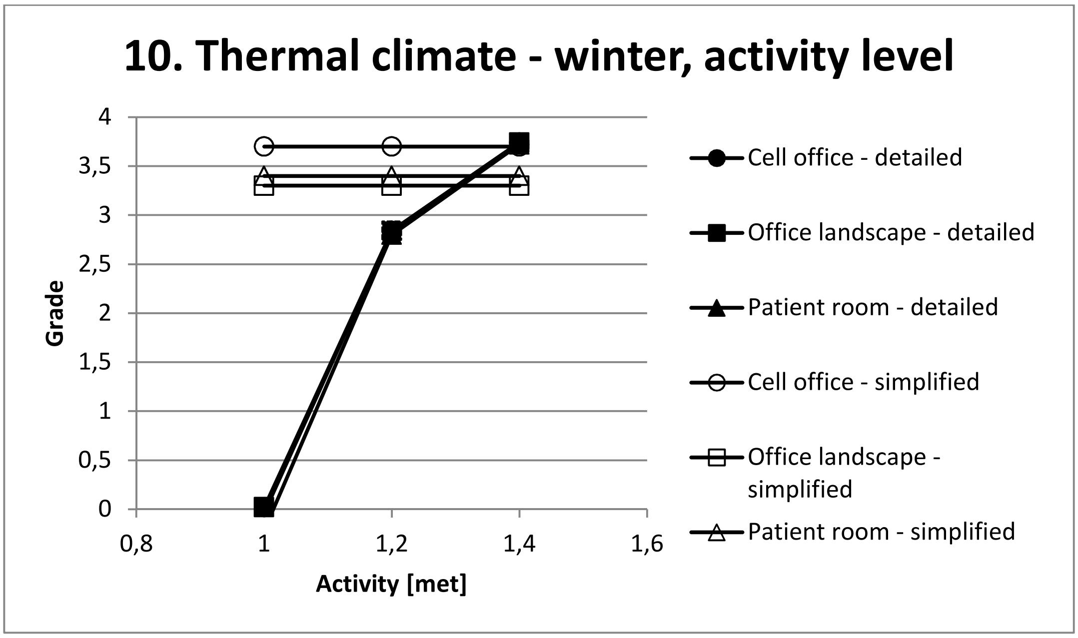


Figure 9-15 The winter thermal climate case is very sensitive to small changes in the activity level of the occupants.

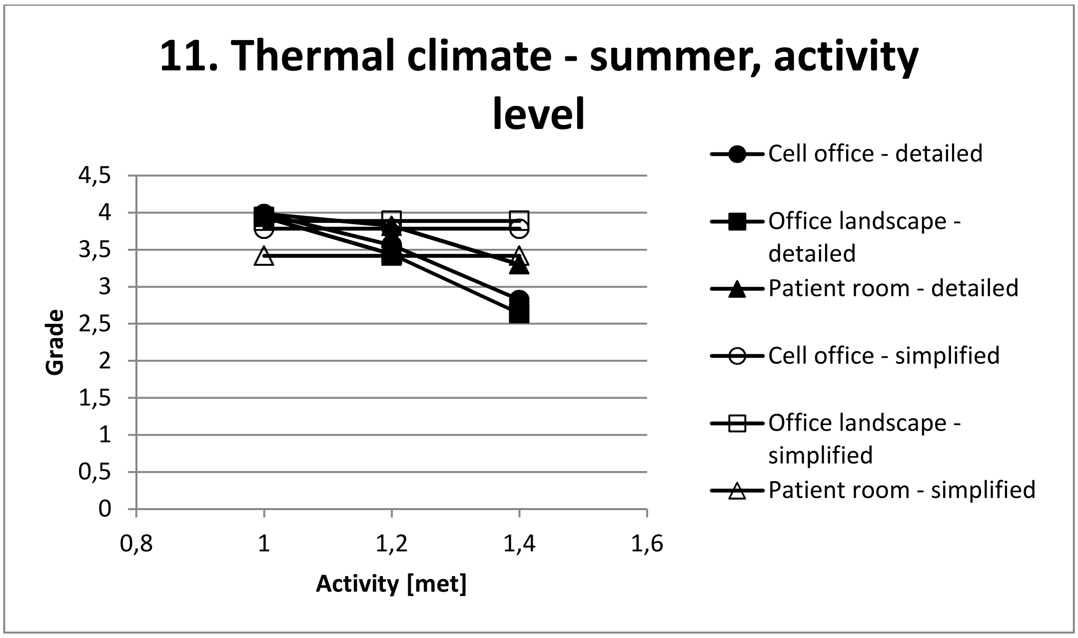


Figure 9-16 The summer thermal climate case is sensitive to changes in the activity level of the occupants, although not as extremely as in the winter case.

Clothing

Just like the activity level the clothing level heavily influences the PPD measure, bringing about the same need to make correct estimations and with the same risk for tweaked results. Increasing grades with increasing clothing levels for the winter case, see Figure 9-17, and vice versa for the summer case, see Figure 9-18, does not come as a surprise. If a person is hot he or she will take off a sweater, i.e. decrease the clothing level, and thereby feel more comfortable which increases the grade.

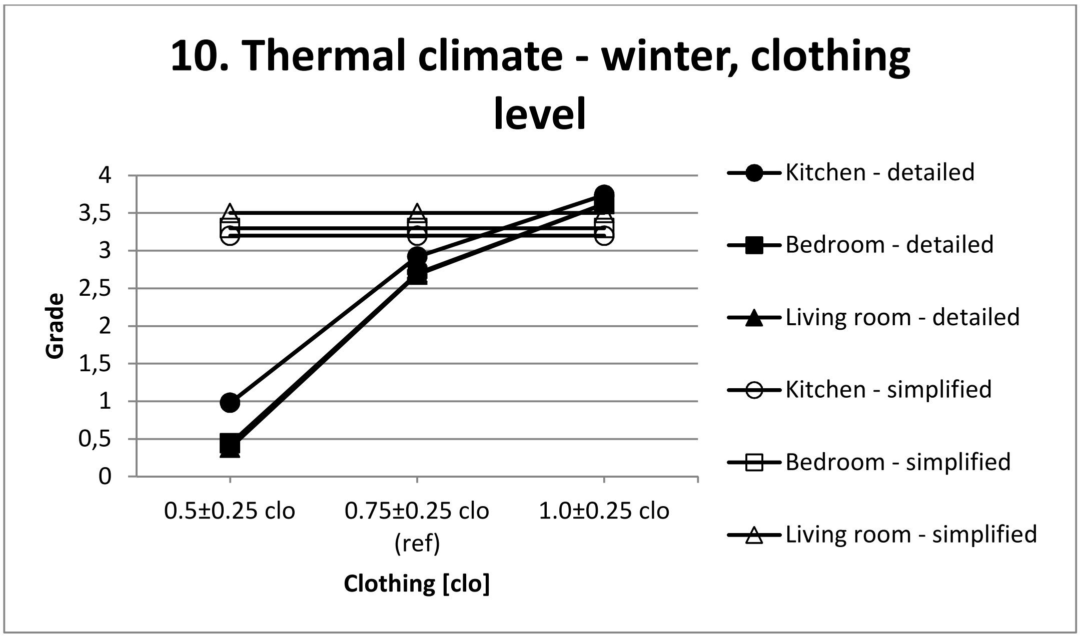


Figure 9-17 The grade for the winter thermal climate increases quite rapidly with small increases in clothing.

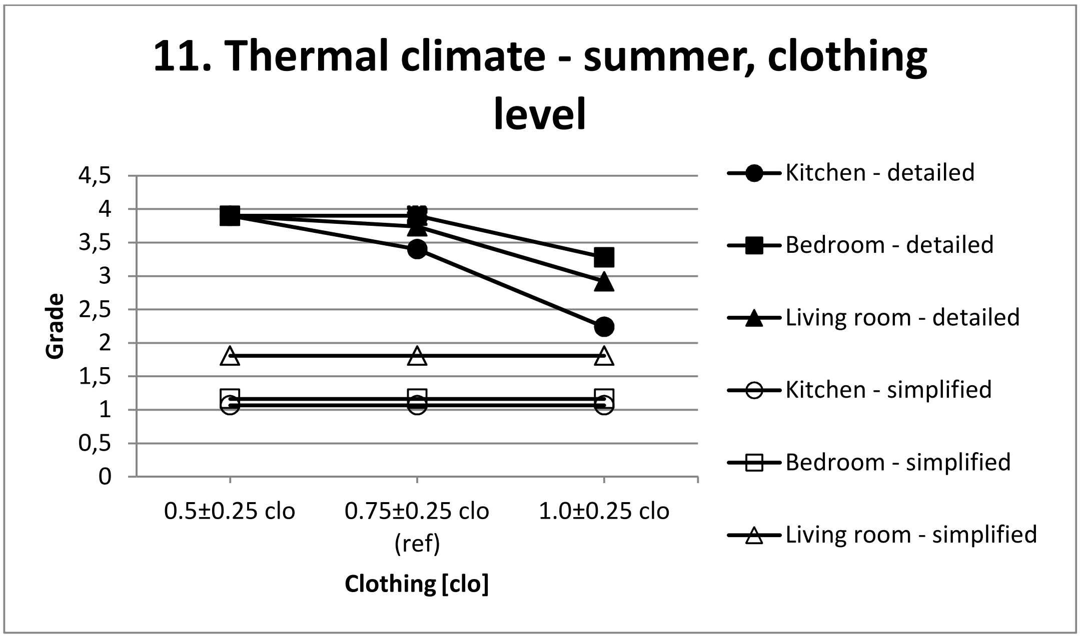


Figure 9-18 The grade for the summer thermal climate decreases quite rapidly with small increases in clothing.

Room height

Changing the height of the room does not alter the solar heat load or the thermal climate, but it does change the daylight indoors, see Figure 9-19 and Figure 9-20. This is most likely caused by the change in the paths of the light, especially considering the reflexions off the ceiling. Contrary to the smaller rooms the grade of the office landscape increases with increasing room height thanks to different reflexion angles suiting the larger room better. The differences are not as large as the figures might lead to believe, however, and any conclusions drawn from this should therefore be handled with care.

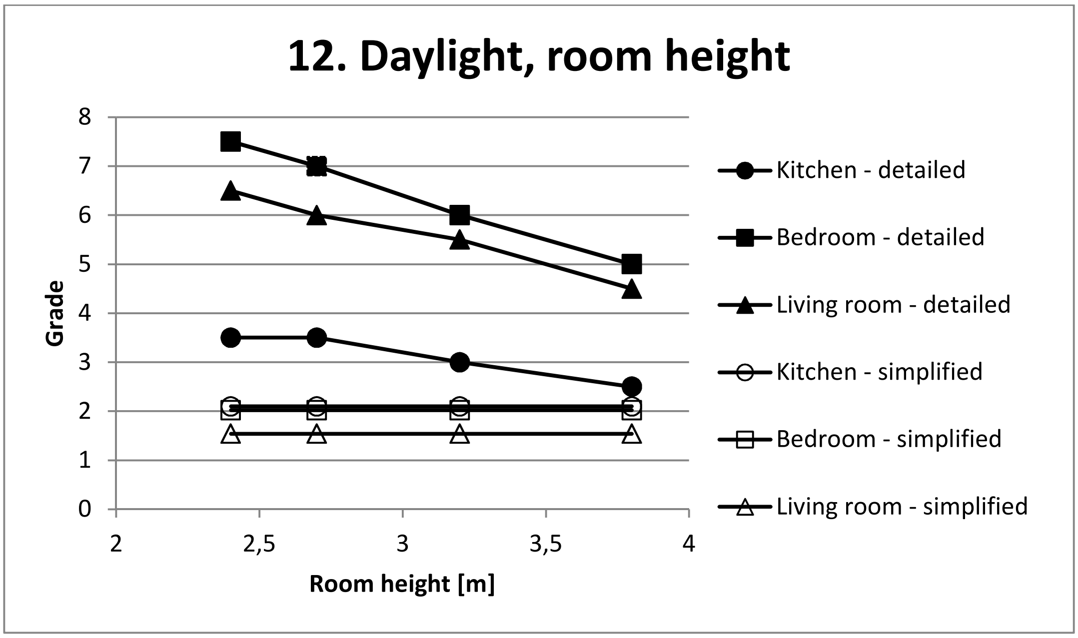


Figure 9-19 The daylight indoors decreases with increasing room height.

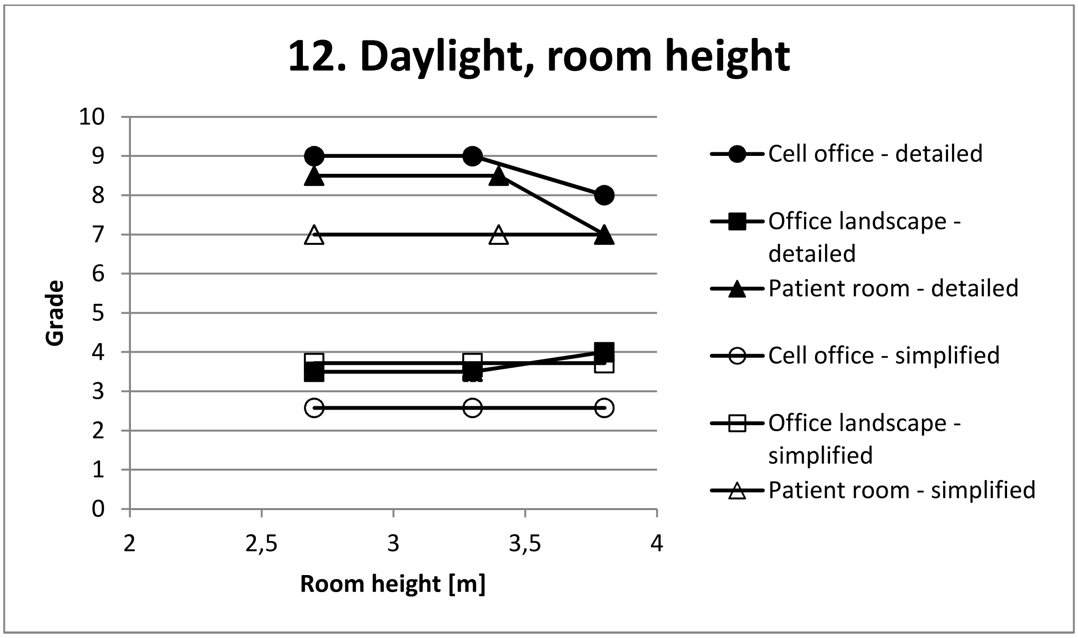


Figure 9-20 While the daylight indoors decreases for all the smaller rooms it increases for the office landscape.

Layout

Of the indicators treated in this study, having separate rooms instead of an open layout only influences the daylight significantly. Contrary to expectations only the living room shows any differences, while the kitchen seems indifferent, see Figure 9-21. This is probably owing to a small inner wall shielding the sensor point in the kitchen from the additional window of the living room while the sensor point in the living room has full view of the kitchen windows, as shown in Figure 9-22.

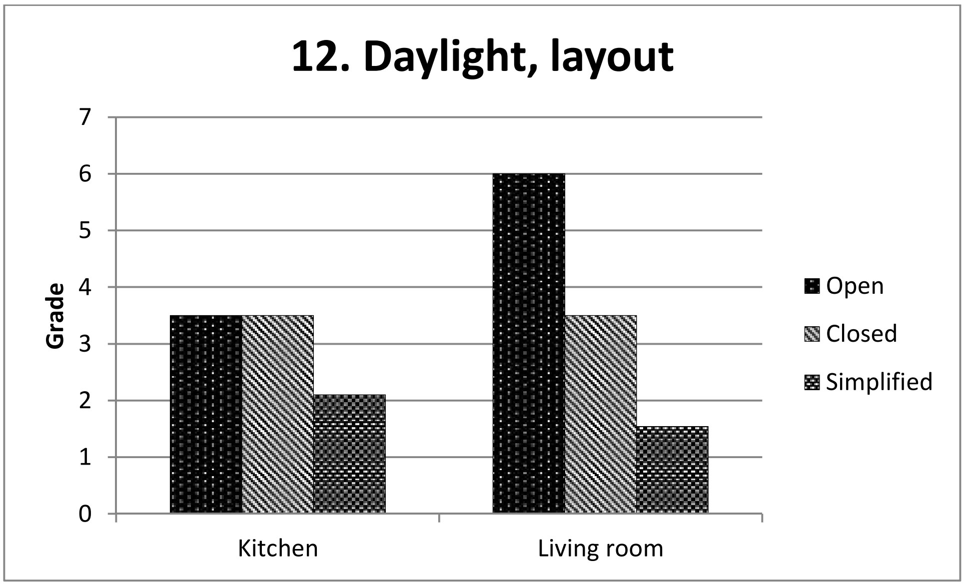


Figure 9-21 The differences in daylight depending on the layout of the apartment. The reference case used is the open layout in contrast with the solution of two separate rooms.

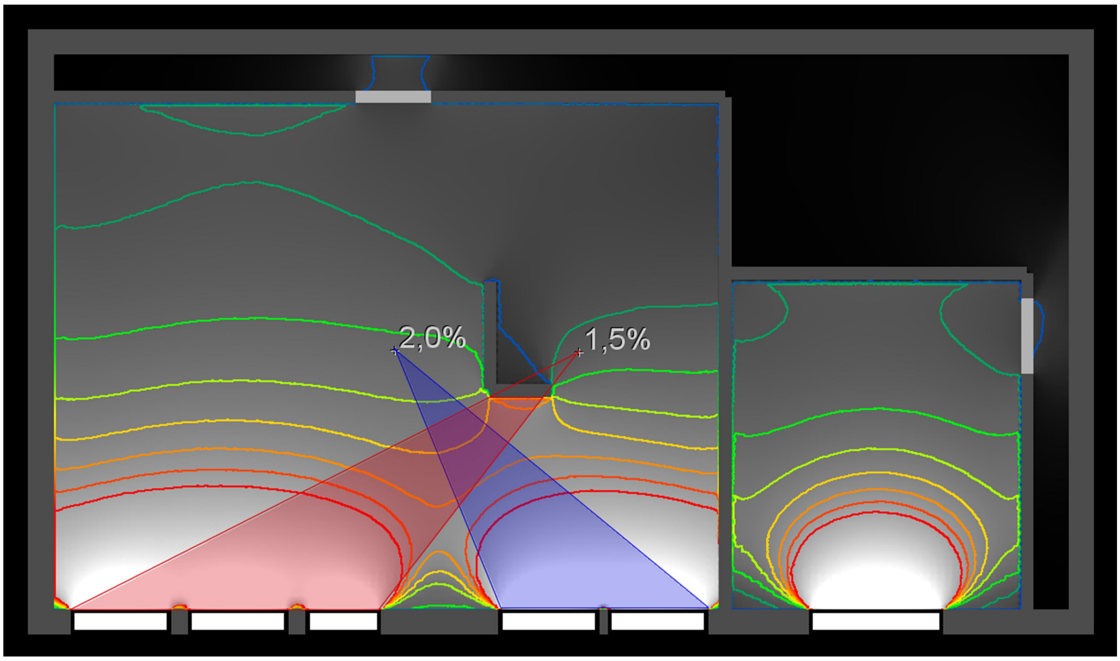


Figure 9-22 Simulation results of the open layout case, markings showing the view of additional windows seen by each sensor point. The red zone is obstructed by an inner wall.

Window level

Positioning the windows at different heights above the floor does not affect the solar heat load or any of the thermal climate cases. As expected, however, it does matter to the daylight. The daylight results do not vary linearly for any of the rooms, see Figure 9-23, and a possible explanation might be that they also depend on the floor height and how close to the ceiling the windows are positioned.

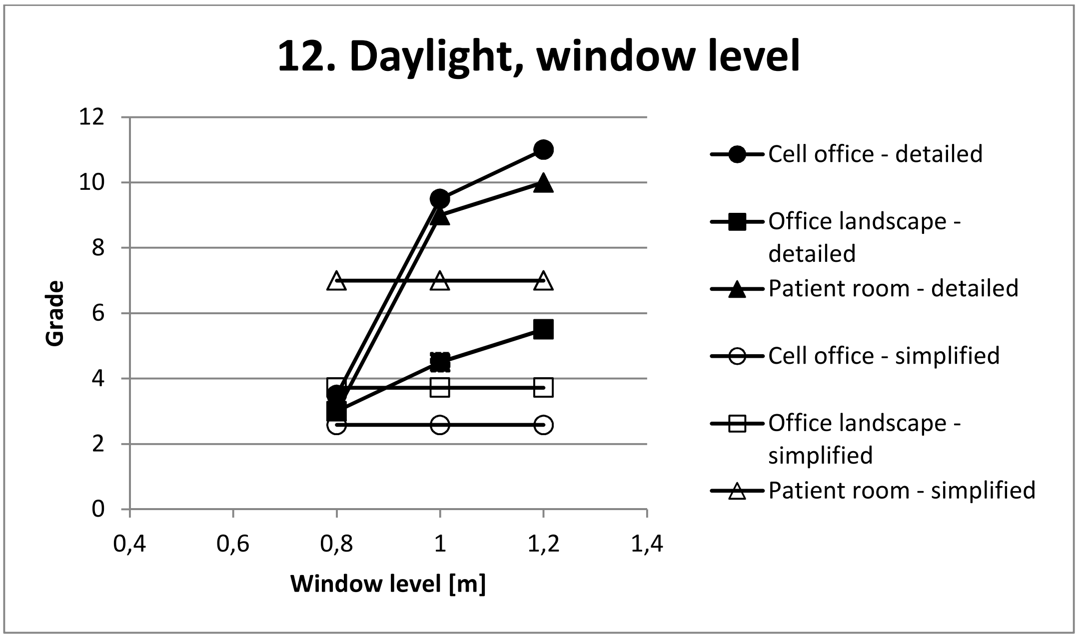


Figure 9-23 The daylight indoors depends on the positioning of the windows.

The simplified calculations for the daylight are only accepted in Miljöbyggnad under several conditions. One condition is that no window area below the height of 800 mm from the floor is to be taken into account. Since this paper aims to investigate the general applicability of the different methods this condition has not been heeded. The difference in grade due to this condition is not negligible which can be seen in Figure 9-24 below, since the bedroom and living room cases have their windows positioned at a level of 550 mm above the floor. Also observable in the figure is the huge differences in grades between the simplified calculations and the detailed simulations. Since the linearization of the daylight factor criteria (DF) is very sensitive it is hard to tell exactly how big the differences are and what might have caused them.

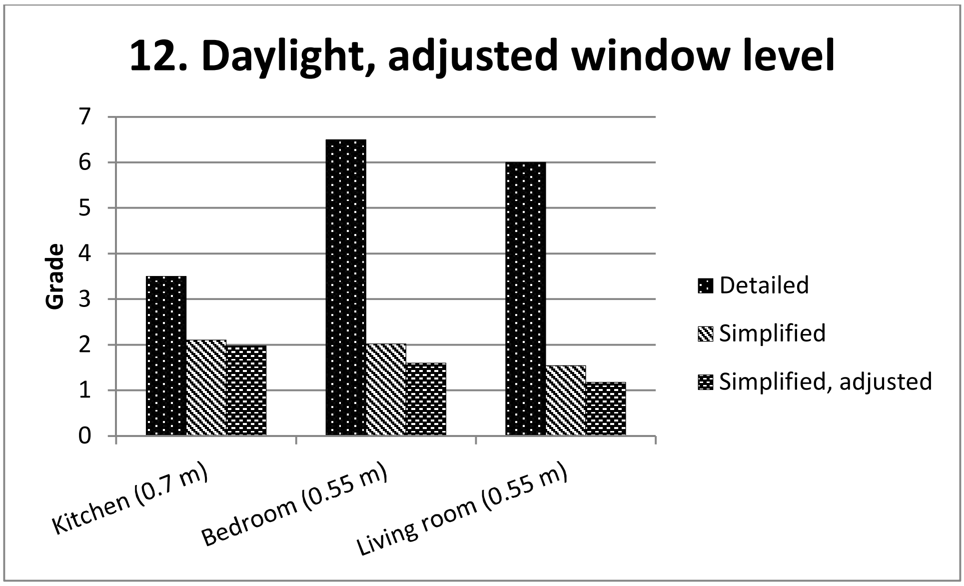


Figure 9-24 The reference cases for the individual rooms of a residential building. Results from detailed simulations, simplified calculations, and simplified

calculations where the window area has been adjusted following directives.

Ground reflectance

The reflectance of the ground affects how much light may enter a room or space. Since the darkest rooms often can be found on the first floors of a building the reflectance of the ground is of interest. As can be seen in Figure 9-25 the effect of the ground reflectance is considerable. Although the overly large differences in grades are due to the linearization problem explained in chapter 8 the influence the reflectance has is still quite substantial.

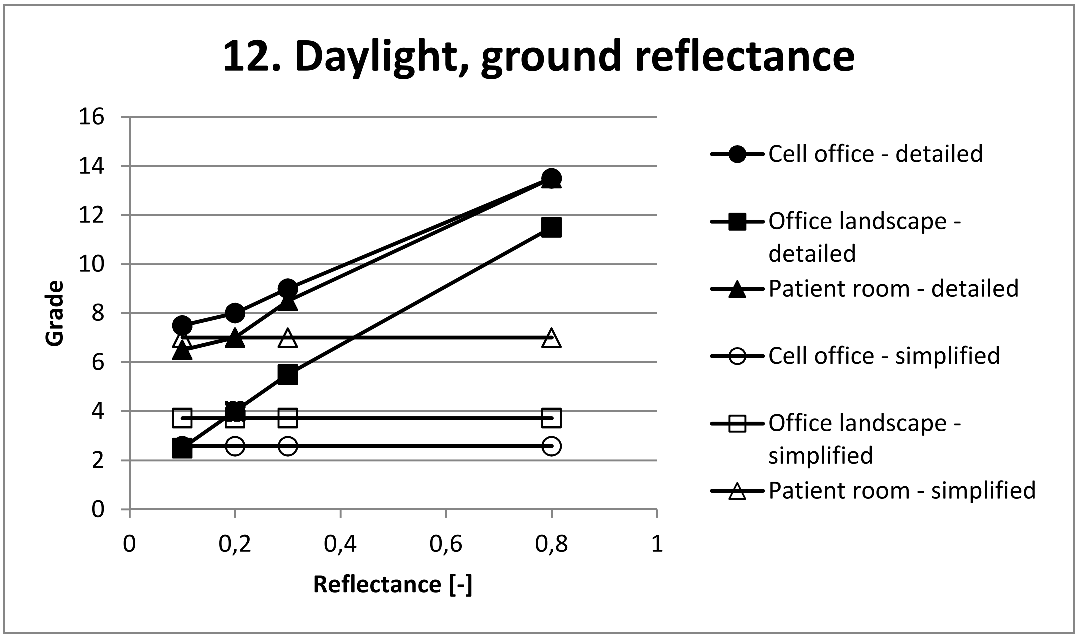


Figure 9-25 The effect of the reflectance of the ground on the daylight indoors, reference case = 0.2.

Keep in mind that the reference case for each room is an alone standing building without any obstructing buildings or objects close by. Possible synergies between ground reflectance and shading angles are not included in this study.

Light transmission of the glazing, *LT*

How much light that passes the window is of course of great importance to the daylight indoors, which Figure 9-26 confirms. That is why the simplified calculations may only be applied to windows with a LT-value higher than “approximately 0.7” as it is written in Miljöbyggnad 2.2.

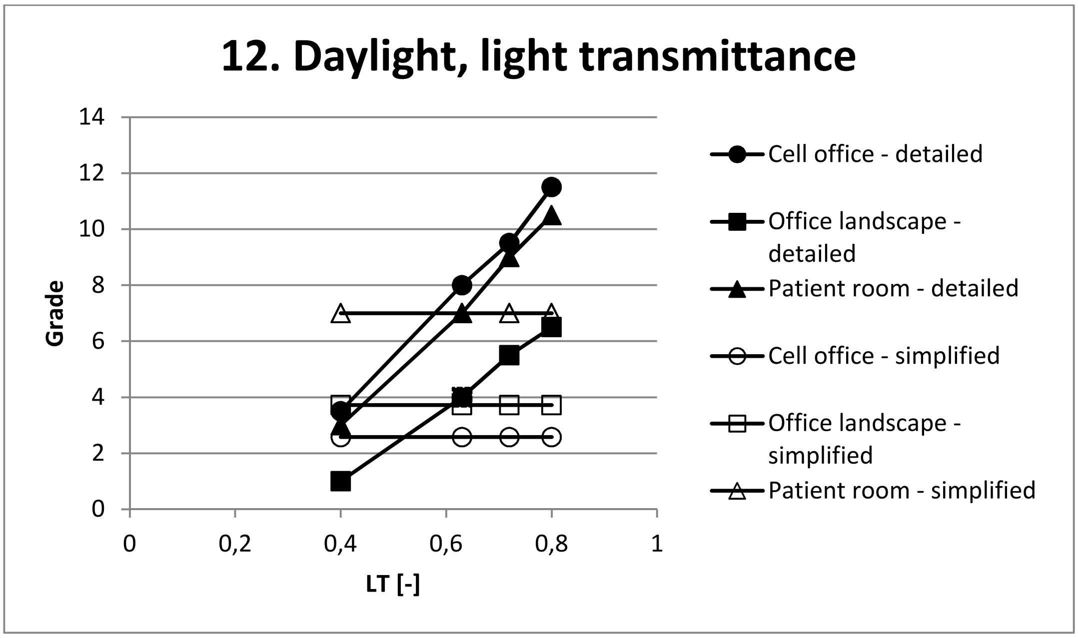


Figure 9-26 The light transmittance dependency of daylight indoors, reference case = 0.63.

9.2 Conformity between simplified and detailed methods

For some of the indicators, the simplified method and detailed method give similar results. This indicates a good correlation between the methods and the simplified method can be considered to, in an early stage, well predict the results from detailed simulations. Below follow the most important findings regarding converging and diverging results from the two methods. To visualize the findings, a system of symbols is defined. This system is shown in Table 9-4 and is then applied in Table 9-5, where an overview of the convergence between the results is presented.

Table 9-4 Symbols used to visualize the conformity of the results from the simplified and detailed methods.

x	**Converging** results
S	**Simplified** method is favourable
D	**Detailed** method is favourable
-	**Not applicable**

Table 9-5 The conformity of results from the simplified calculations and the detailed simulations. Res *indicates the results for the residential object and* Off+Hos *indicates the results for the office and hospital objects.*

	3. Solar heat load		**10. Thermal climate - winter**		**11. Thermal climate - summer**		**12. Daylight**	
	Res	*Off+ Hos*	*Res*	*Off+ Hos*	*Res*	*Off+ Hos*	*Res*	*Off+ Hos*
A $_{\textbf{floor}}$	x	x	<1: D, >1: S	<1: D, >1: S	D	<1: D, >1: S	D	D
AF $_{\textbf{façade}}$	x	x	S	S	D	<1: S, >1: D	D	D
g $_{\textbf{syst}}$	x	x	S	S	D	D	-	-
U $_{\textbf{glass}}$	x	x	S	S/D	D	x	-	-
Orientation	x	x	S	S	D	x	D	D

9.2.1 Converging results

Here follows a presentation of all findings from the parameter analysis where the results from the simplified and detailed methods converge.

Indicator 3. Solar heat load

The results show that the simplified method and detailed method for solar heat load correlate well to each other. This goes for all studied object types when varying the *floor area ratio*, the *window share of façade* and the *solar factor*, see Figure 9-27 to Figure 9-29. Thus, these parameters can be considered to be the most influential ones regarding solar heat load. Also, the solar irradiation of 800 W/m^2 can be assumed to well reflect the true solar irradiation.

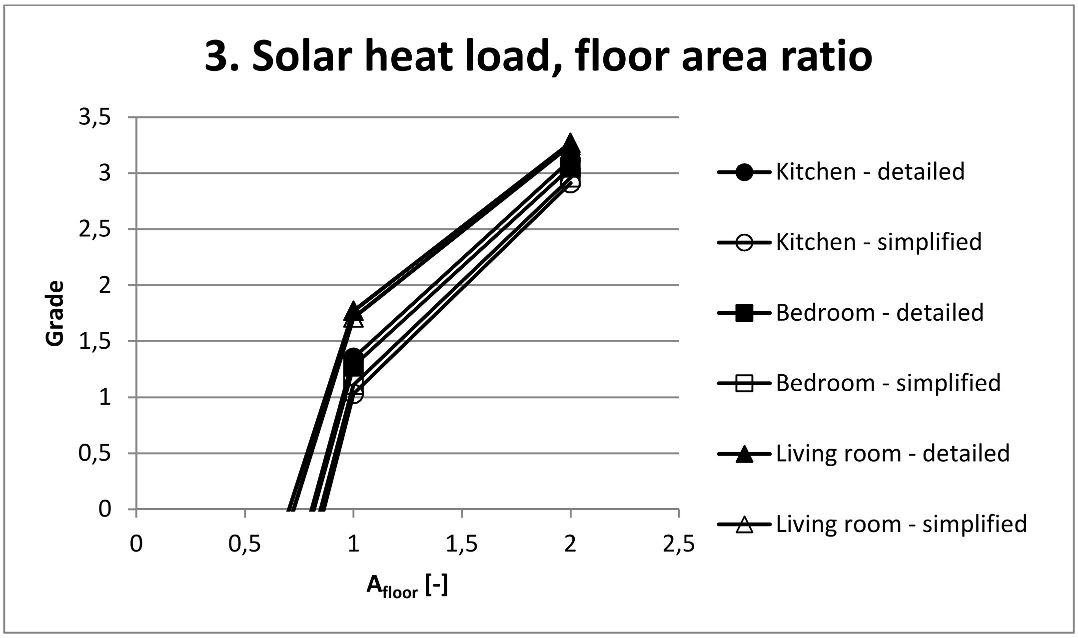


Figure 9-27 The convergent solar heat load results from simplified calculations and detailed simulations respectively when varying the floor area ratio.

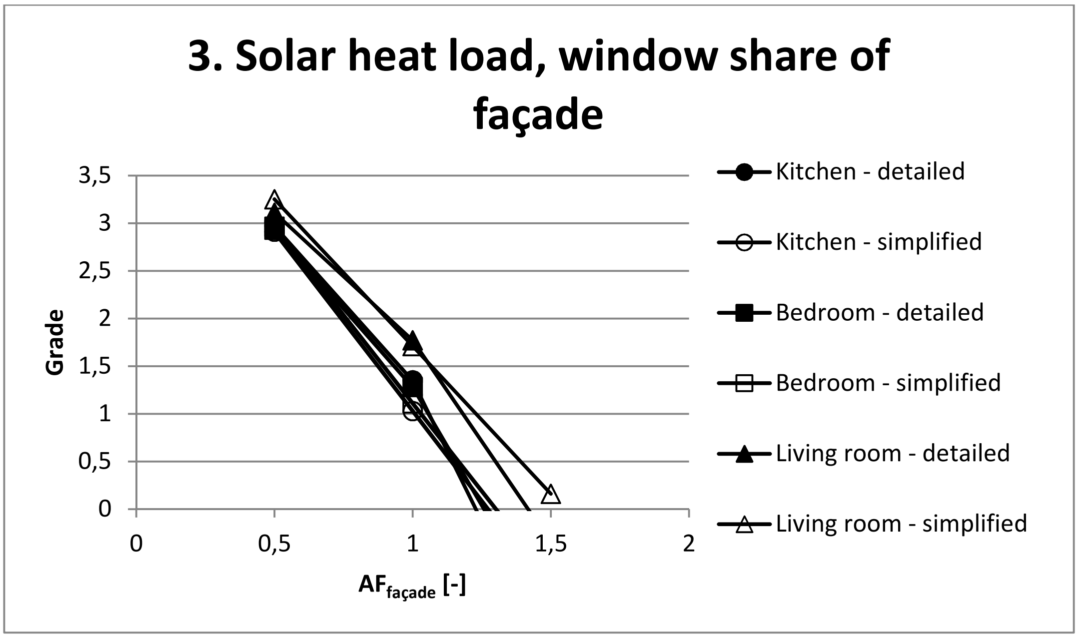


Figure 9-28 The convergent solar heat load results from simplified calculations and detailed simulations respectively when varying the window share of the façade.

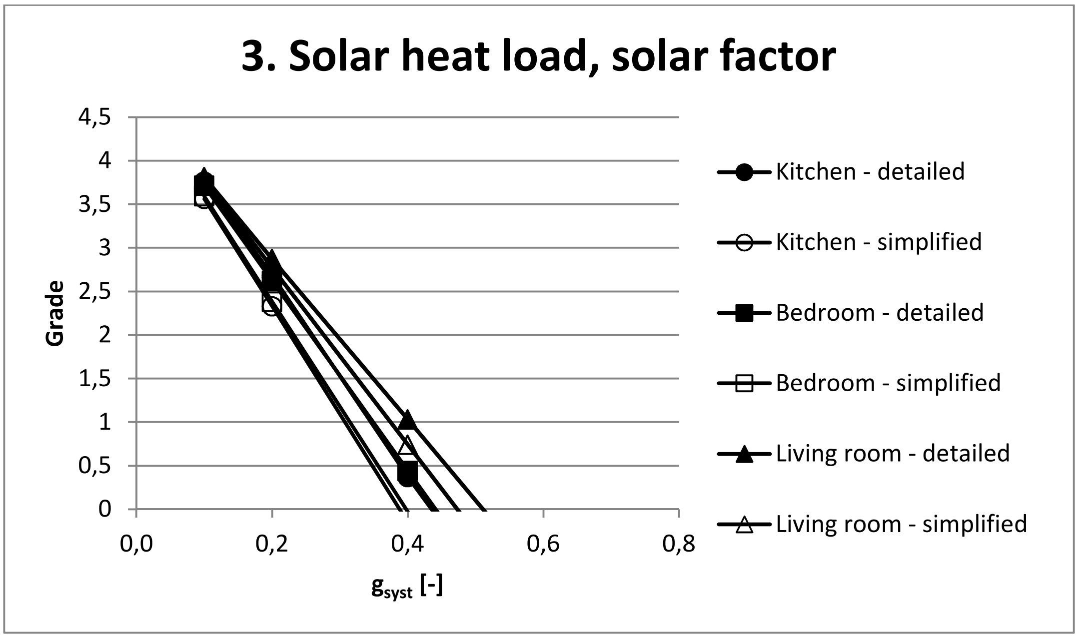


Figure 9-29 The convergent solar heat load results from simplified calculations and detailed simulations respectively when varying the solar factor of the window.

Indicator 11. Thermal climate – summer

Regarding indicator 11, thermal climate – summer, the results are converging only for the office and hospital buildings and for the two parameters *heat transfer coefficient* and *orientation*. The constant results regarding heat transfer coefficient, see Figure 9-30, is due do its insignificance for the summer thermal climate.

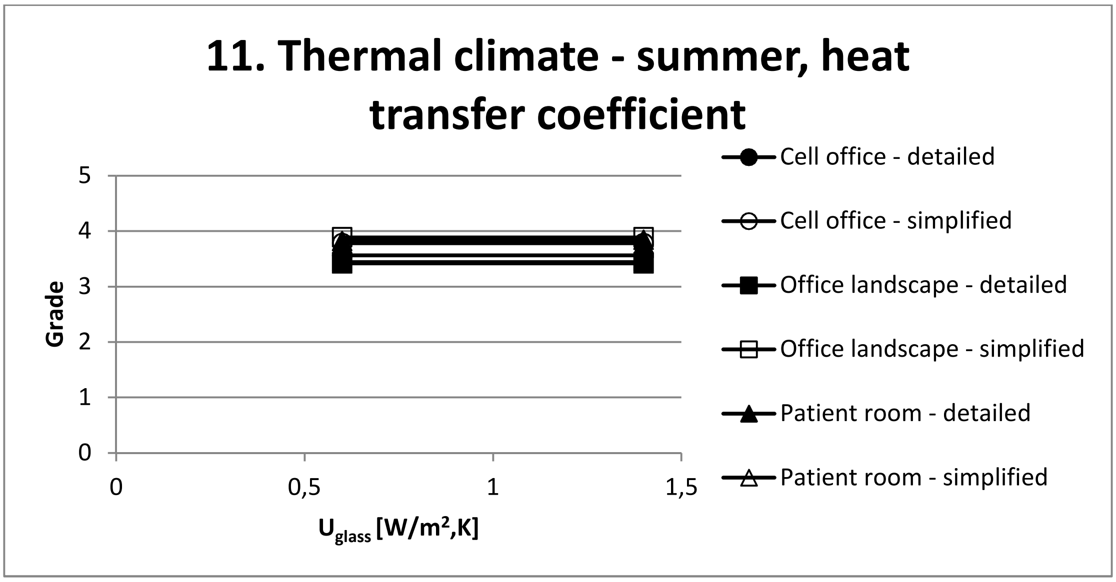


Figure 9-30 The convergent summer thermal climate results from simplified calculations and detailed simulations respectively when varying the heat transfer coefficient of the glazing.

The converging results from the *orientation* study indicate that the solar factor, the window area and the floor area ratio from the simplified expression are the most influential parameters for the summer thermal climate. The results are presented in Figure 9-31 below. The lower the solar factor, the better does the results converge from the two methods when varying the orientation. This is assumed by comparing the results for the office and hospital building with the residential building where the latter has substantially higher solar factor, see Figure 9-38.

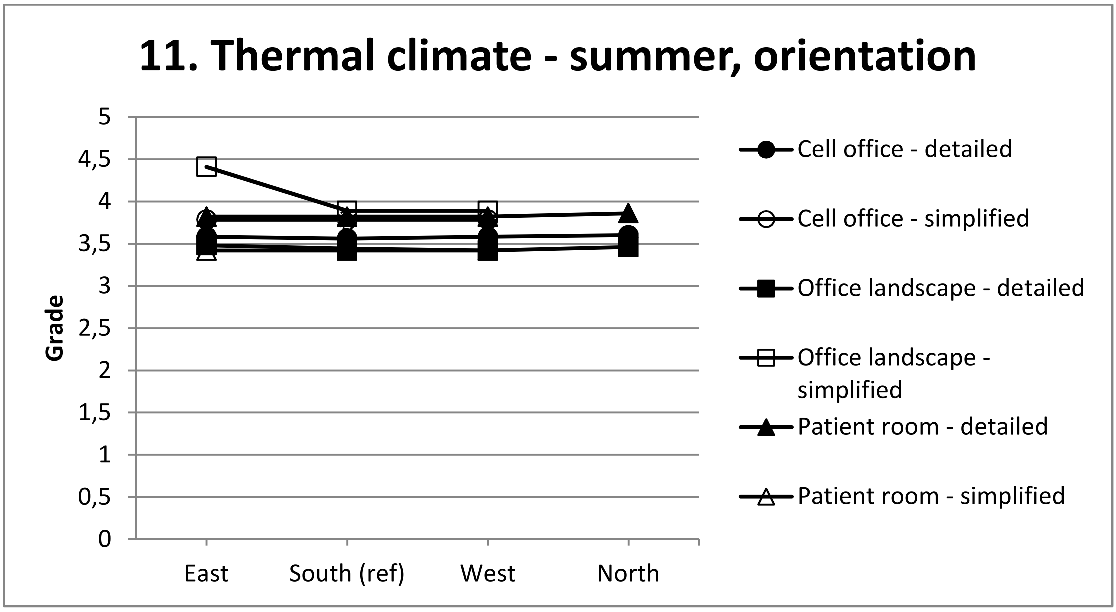


Figure 9-31 The convergent summer thermal climate results from simplified calculations and detailed simulations respectively when varying the orientation of the room.

9.2.2 Diverging results

Here follows a presentation of all findings from the parameter analysis where the results from the simplified and detailed methods diverge.

Indicator 10. Thermal climate - winter

The results regarding winter thermal climate and *floor area ratio* show that the simplified method is favourable when increasing the floor area ratio by a factor above 1, see Figure 9-32. Probably, this finding is due to the lack of heating power in the room which was kept constant while the ventilation flows were changed by the same factor as the floor area. The lack of radiators is not considered in the simplified calculations why these results are superior when increasing the floor area.

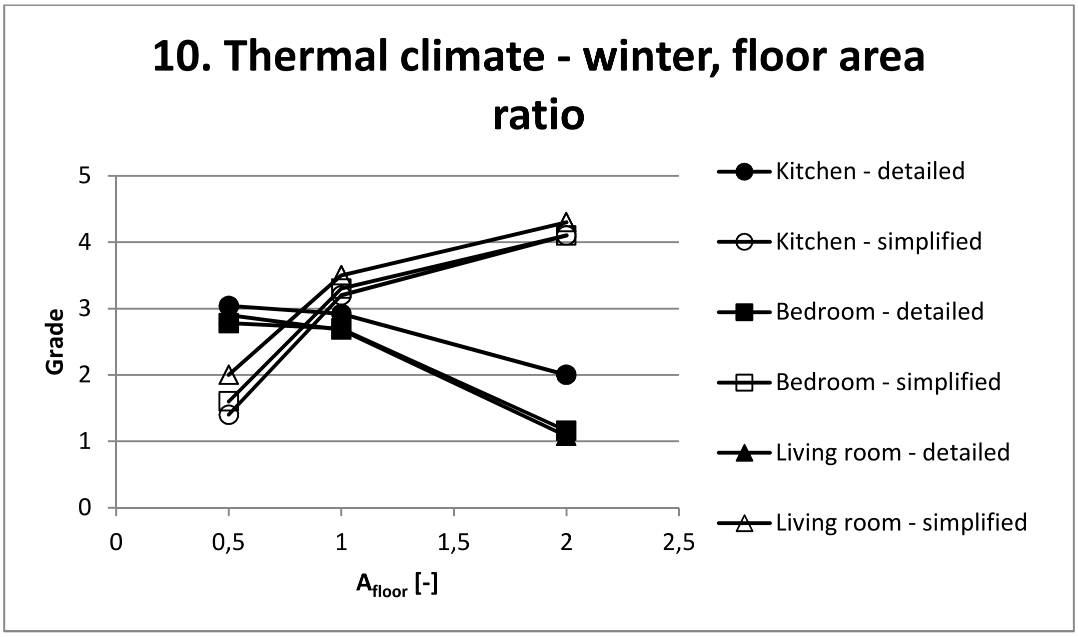


Figure 9-32 The divergent winter thermal climate results from simplified calculations and detailed simulations respectively for the residential building when varying the floor area ratio.

The winter thermal climate results show that the simplified method is sensitive to an increased *window share of the façade* while the result from the detailed method is more or less constant. This is due to the heating equipment which compensates for increased heat losses and is only taken into account in the detailed methods. The effect of varied *heat transfer coefficient*, U-value, is the same as when varying the window share of the façade; the heat losses through the window increases or decreases. Thus, the results from the window share of the façade shown in Figure 9-33 follow the same pattern as the results from the heat transfer coefficient in Figure 9-34.

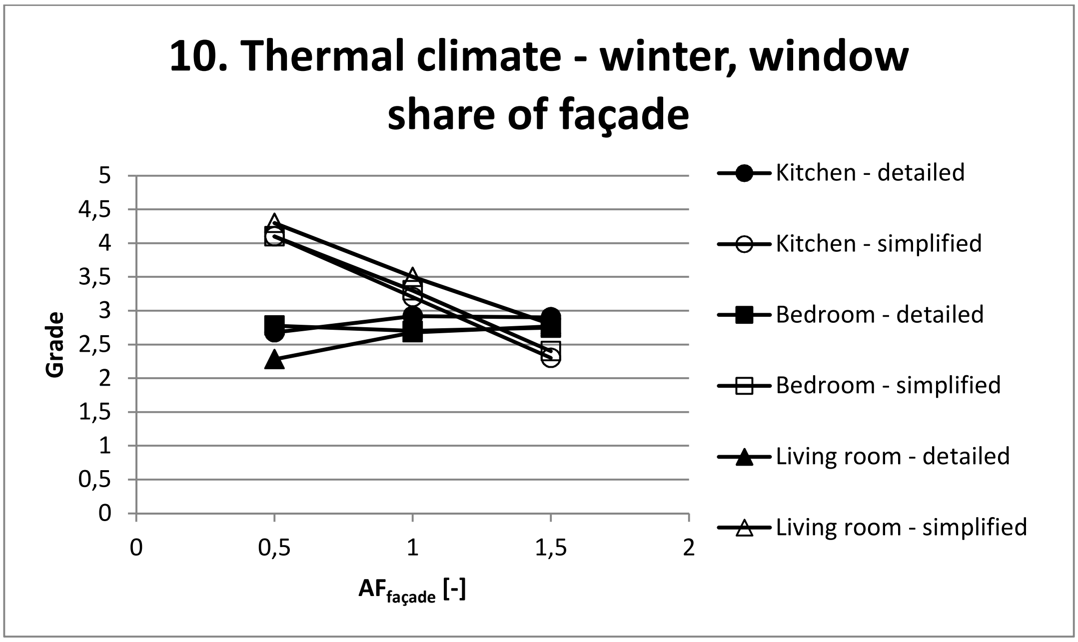


Figure 9-33 The divergent winter thermal climate results from simplified calculations and detailed simulations respectively when varying the window share of the façade.

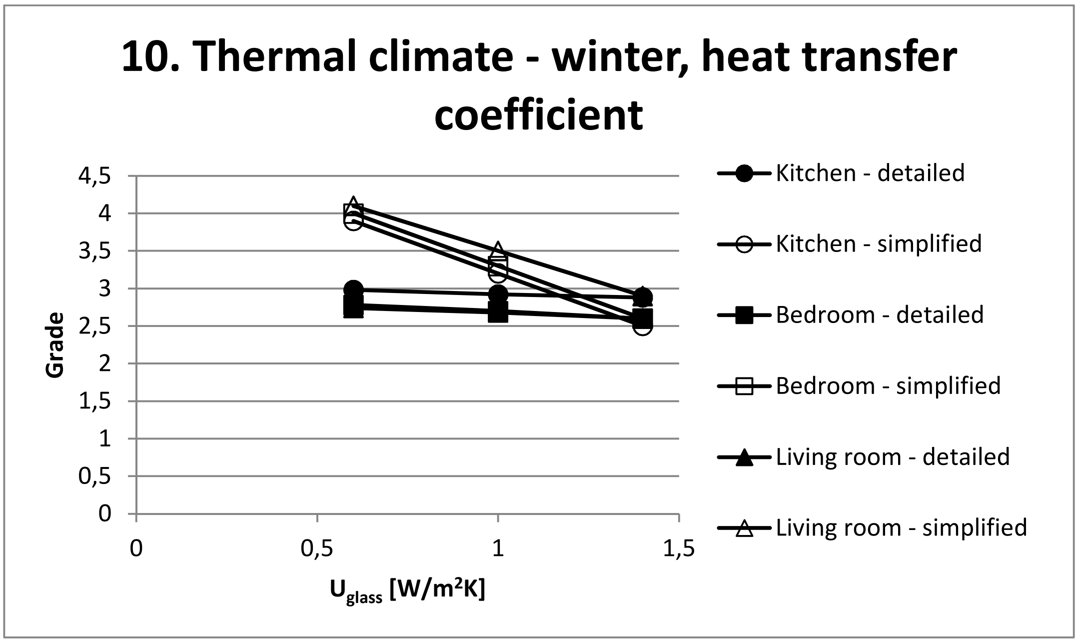


Figure 9-34 The divergent winter thermal climate results from simplified calculations and detailed simulations respectively when varying the heat transfer coefficient of the glazing.

Indicator 11. Thermal climate - summer

The simplified expression for summer thermal climate is dependent on the *floor area ratio*; the larger the floor area the lower the solar heat factor and the better is the grade. Thus, it is not surprising that the simplified calculation show that the grade increases with floor area, see Figure 9-35. However, the detailed method gives a constant result which is due to the ventilation and airing of the rooms. This compensates for changed floor area since the ventilation flow is defined per floor area.

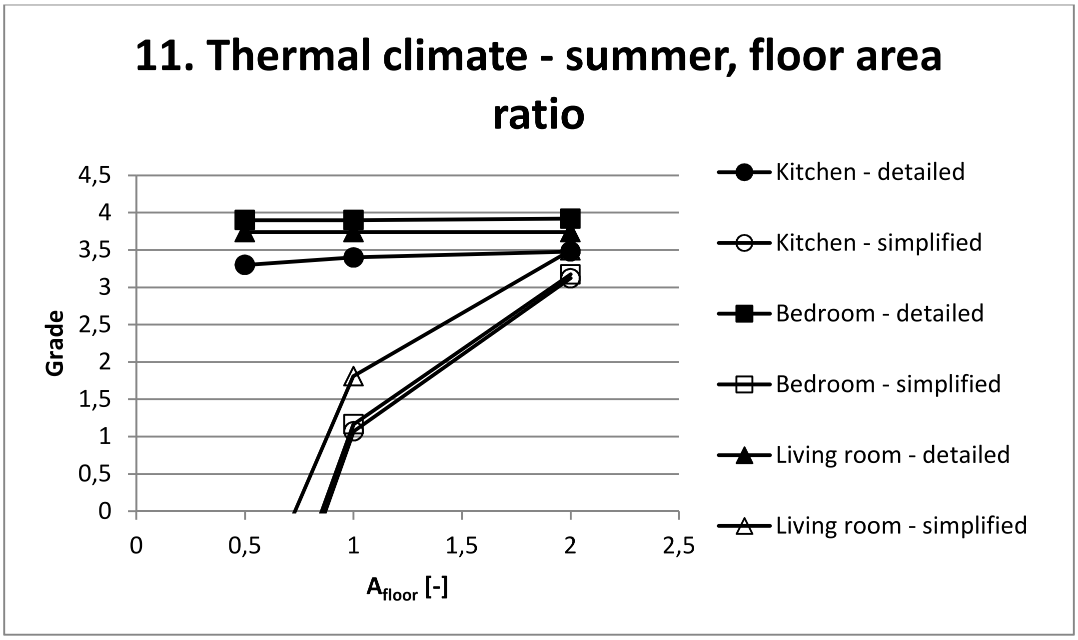


Figure 9-35 The divergent summer thermal climate results from simplified calculations and detailed simulations respectively when varying the floor area ratio.

The *window share of the façade* is highly influential for the summer thermal climate since it regulates the solar irradiation. The same does the solar factor of the window and its shading. Thus, the results from these studies are very similar, see Figure 9-36 and Figure 9-37. However, the results from the simplified calculations have a decreasing pattern with increased window share and solar factor whereas the results from the detailed simulations are more constant. Again, this is assumed to be due to the ventilation and airing.

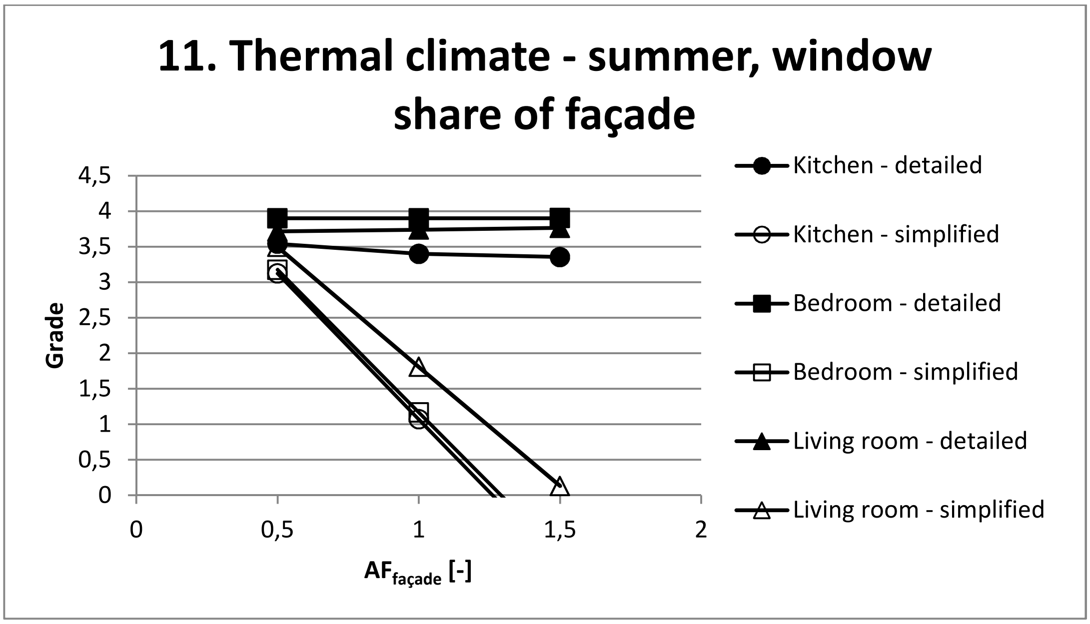


Figure 9-36 The divergent summer thermal climate results from simplified calculations and detailed simulations respectively when varying the window share of the façade.

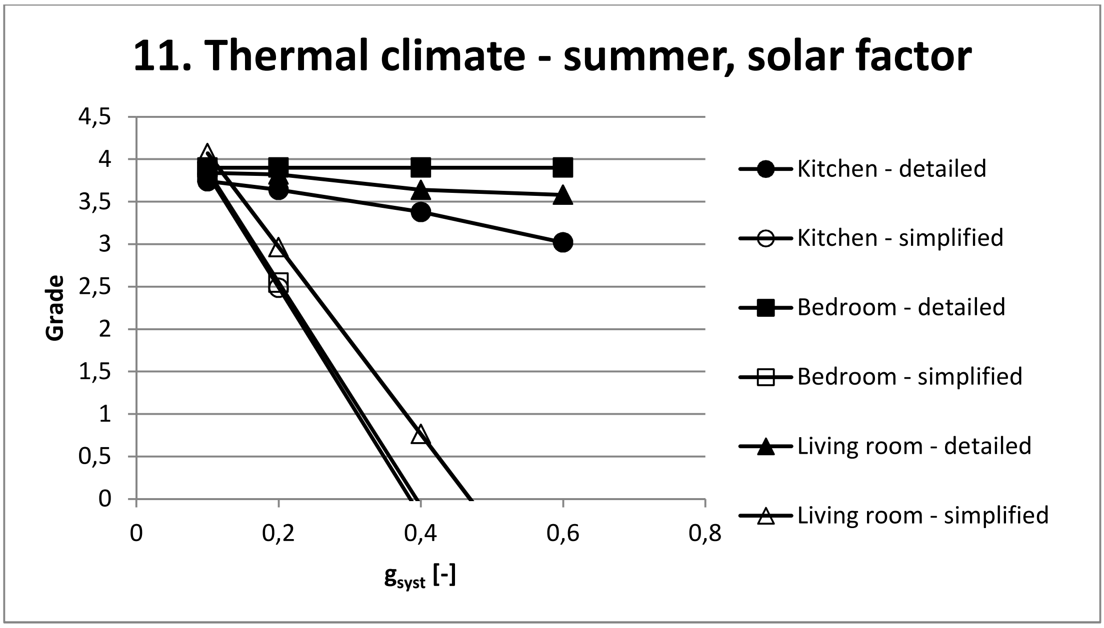


Figure 9-37 The divergent summer thermal climate results from simplified calculations and detailed simulations respectively when varying the solar factor of the window.

The influence of *orientation* regarding summer thermal climate is shown in the Figure 9-38 below. It can be seen that the detailed results are superior compared to the simplified. The latter results are constant and independent of the orientation, except for north which is excluded according to the definition. Once again, the detailed simulations are assumed to be favoured by the ventilation and airing which can be taken into account.

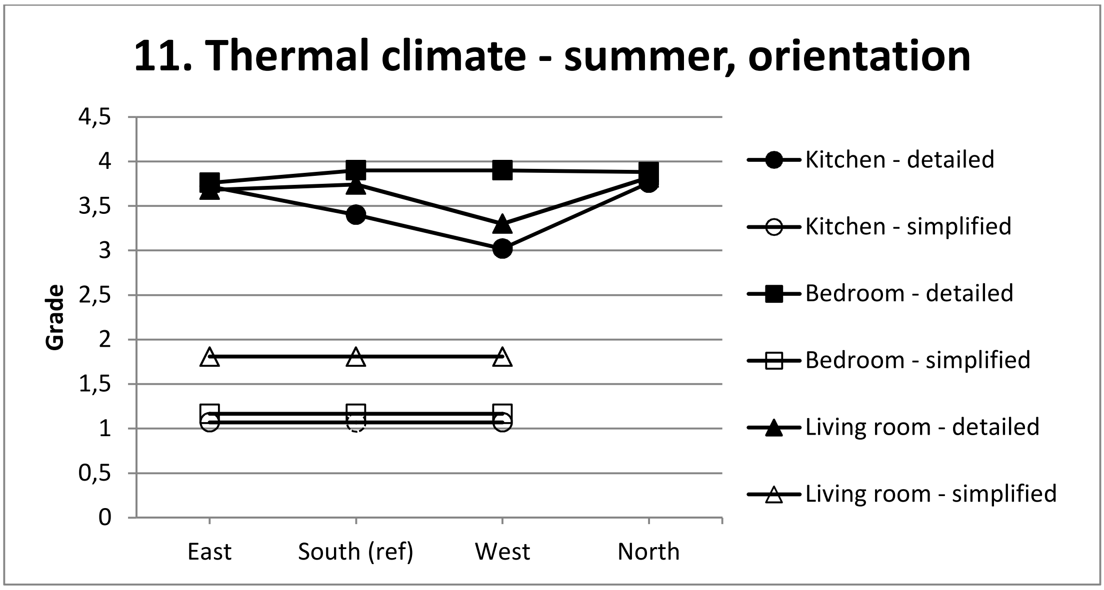


Figure 9-38 The divergent summer thermal climate results from simplified calculations and detailed simulations respectively when varying the orientation of the room.

Indicator 12. Daylight

The daylight indicator is clearly dependent on the *floor area ratio* according to the definition. So is the daylight factor received from detailed simulations, but it is defined in a point at the half depth of the room which basically means that the point for measuring is moved when changing the floor area. Also, the daylight factor is dependent on more parameters such as surrounding surfaces and the daylight transmission of the glazing, which is the reason why the detailed and simplified curves diverge, see Figure 9-39. However, they do follow the same pattern of decreased grade when increasing the floor area.

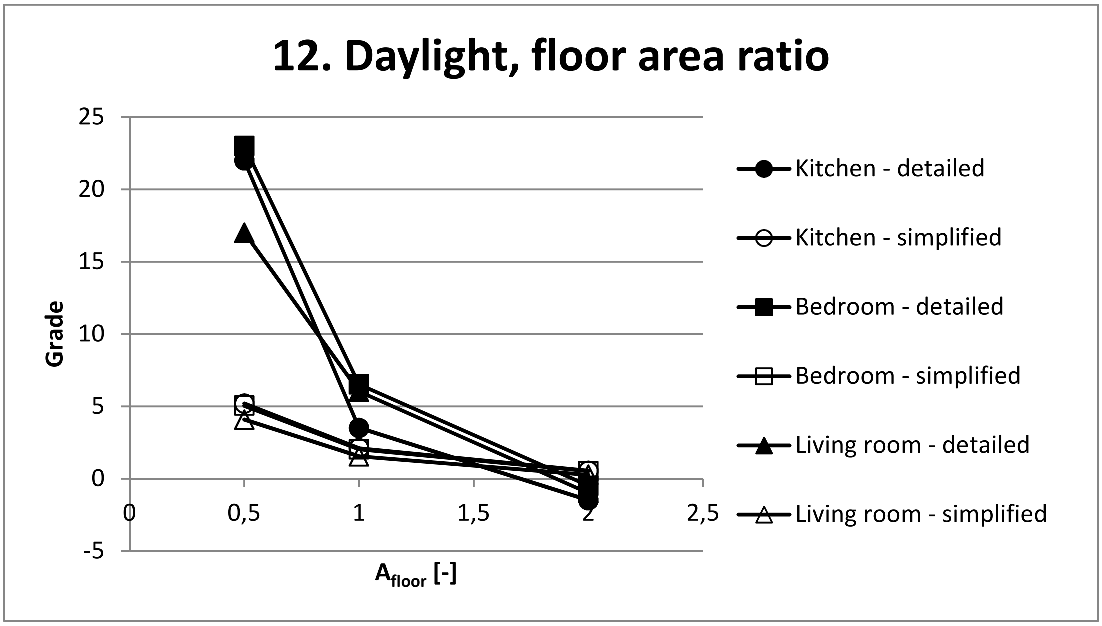


Figure 9-39 The divergent daylight results from simplified calculations and detailed simulations respectively when varying the floor area ratio.

The *window share of the façade* is highly affecting the daylight indoors; by increasing the window area the more daylight can reach the room. The two methods give slightly diverging results though they do show the same pattern of increased grade when increasing the window share, see Figure 9-40. The divergence is assumed to be due to the large number of influencing parameters taken into account in the detailed method.

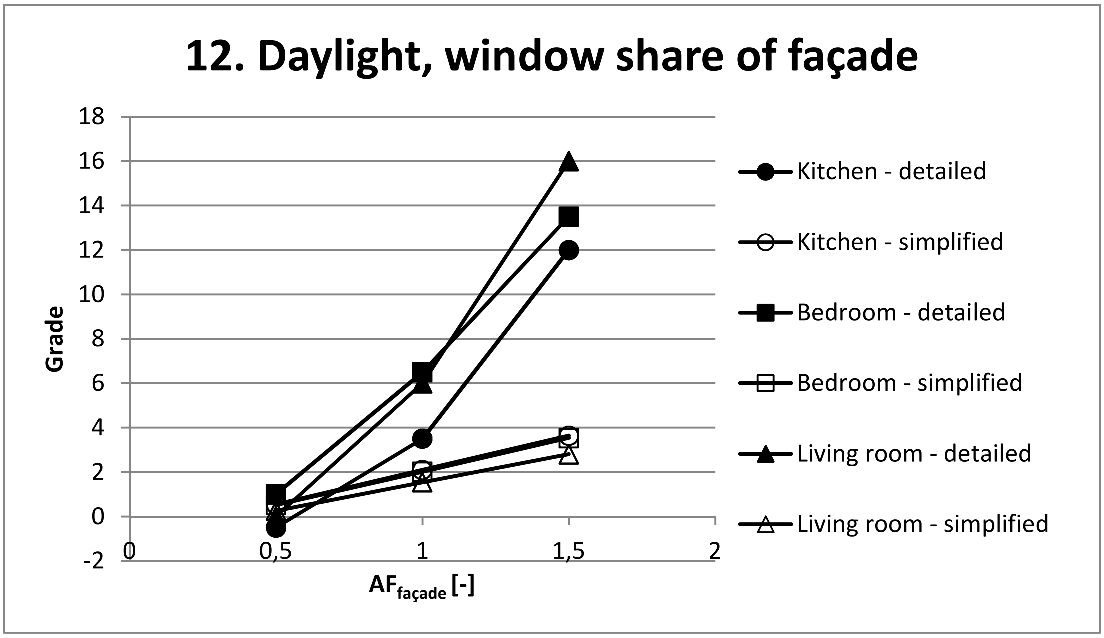


Figure 9-40 The divergent daylight results from simplified calculations and detailed simulations respectively when varying the window share of the façade.

As stated in section 4.3.2, the daylight indicator is independent of the orientation since the daylight is defined using an overcast sky. Thus, the constant result shown in

Figure 9-41 is not surprising. Again, the detailed simulations give better results than the simplified calculations, which is due to the favourable parameters such as daylight transmission and reflectance taken into account.

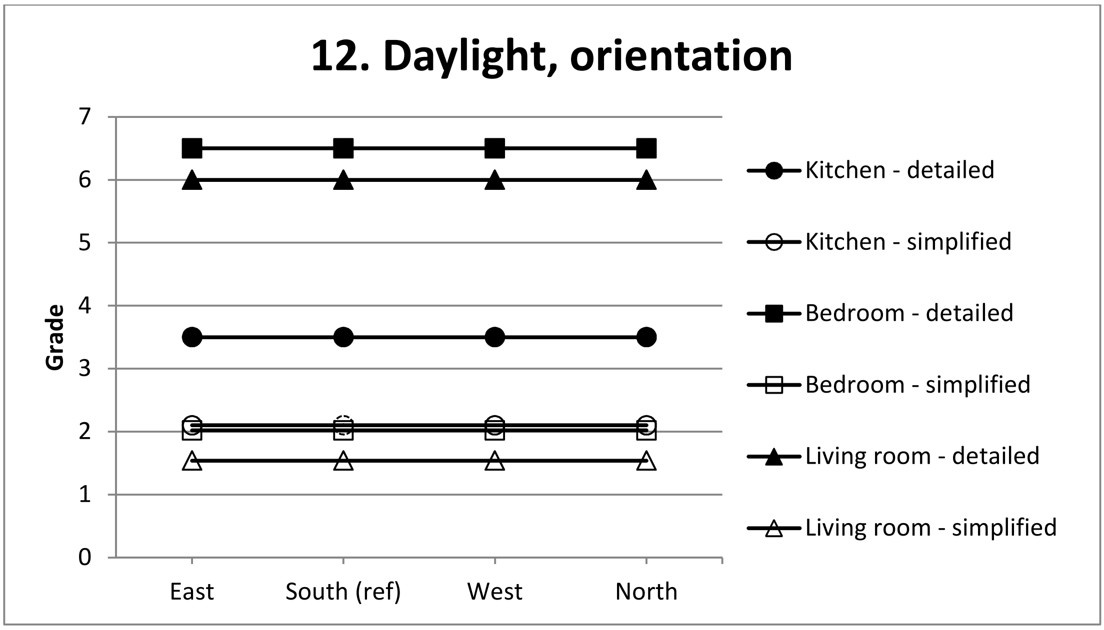


Figure 9-41 The divergent daylight results from simplified calculations and detailed simulations respectively when varying the orientation of the room.

10 Discussion of Applicability

All simulation models are based on input data established from qualified assumptions and recommendations. The aim has been to create representative models reflecting the reality as accurately as possible. Still, simulations are sensitive to what input data they are based on and the models can thus never be considered as completely general. However, all simulation models are matched with the simplified calculations in terms of input data so that the two methods can be regarded as comparable.

Concerning some of the indicators, the simplified methods are not valid continuously for the top grades. Additionally, the simplified methods are in some cases valid for certain objects only. In this study, this has been ignored and the grade limits have been extrapolated based on the lower grade limits assuming a linear relation. Thus, the results from this study can be considered as reflecting a scenario that is separated from the reality. However, the purpose of this study is to compare the simplified and detailed method in general and not only in the by Miljöbyggnad specified cases. The lack of grade limits has therefore not been considered.

In the parameter analysis, some of the parameters are related to the detailed simulations only and do not affect the simplified calculations. The key parameters in this category might cause deviations in the comparison of the results and can thus be the crucial part when trying to use the simplified method in early stages. The simplified method can still be a measure of the grade level when no parameter is varied and thus be a scale against which the simulated results can be compared.

Varying the properties of the surrounding environment in terms of shading and ground reflectance is not a matter of design; these parameters can rarely be affected in the design process. However, such parameters can be significant when comparing the results from simplified and detailed methods.

When simulating the objects with installed cooling, i.e. the office rooms and the patient room, the chilled beams are modelled by ideal coolers in IDA ICE. This can be considered as a simplification as these have no certain physical location and is completely stand-alone from the plant of the building. Thus, the thermal comfort issues related to the chilled beam, such as draft, are not considered and the comfort might be overestimated.

11 Final Remarks

This chapter is divided into three parts; the first and second presenting the most important findings from the parameter analysis and the comparison of the results from the simplified and detailed methods respectively. The third section suggests how the study can be developed further.

11.1 Conclusions regarding key parameters

In the following section the most important conclusions regarding the parameters and their influence on the indicators are presented. The first five parameters (*floor area* to *orientation*) concern both the simplified and detailed methods whereas the rest concern the detailed methods only.

Floor area, A_{floor}
The floor area is highly influential for both methods regarding all indicators except simulations of summer thermal climate where installed cooling power and airing is compensating.

Window share, $AF_{façade}$
The window share of the façade is highly influential for both methods regarding all indicators except simulations of winter and summer thermal climate where installed heating and cooling power is compensating.

Solar factor, g_{syst}
The solar factor is highly influential for both methods regarding solar heat load and summer thermal climate.

Glazing heat transfer coefficient, U_{glass}
The glazing heat transfer coefficient is highly influential for simplified calculations of winter thermal climate only. For detailed simulations, the U-value is less influential regarding thermal climate winter due to the compensating installed heating power.

Orientation
The orientation has small impact on all indicators. Regarding solar heat load, what is most influential is whether the room is facing north or not.

Shading angle
The shading angle is highly influential for solar heat load and daylight. Thermal climate is unaffected due to the installed cooling power and airing. The shading angle is less influential regarding solar heat load when a room has windows in multiple directions.

Shading orientation
The shading orientation has negligible impact on all indicators.

Insulation thickness, $d_{insulation}$
The insulation thickness has negligible impact on all indictors. Regarding thermal climate, it is of minor importance due to compensating technical installations. However, the thermal insulation might still be of importance regarding energy.

Supply air temperature, T_{supply}
The supply air temperature has negligible impact on all indicators. Regarding thermal climate, the air supply temperature to a room does not affect significantly which again is due to the compensating heating and cooling equipment in the room.

Temperature setpoints, $T_{setpoints}$
The temperature setpoints are highly influential for simulations of thermal climate, both winter and summer cases. The temperature setpoints of a room is more important than the supply temperature.

Activity level
The activity level of the occupants is highly influential for simulations of thermal climate, both winter and summer cases. However, too low activity level in the winter seems more critical than too high activity level in the summer.

Clothing
The clothing of the occupants is highly influential for simulations of thermal climate, both winter and summer cases.

Room height
The room height has negligible impact on all indicators except daylight, where the grade decreases with increasing room height due to enhanced area of reflecting surfaces.

Layout
The layout is influential for simulations of daylight only. The influence is significant in rooms where additional windows due to an open layout are fully visible from the sensor point. This is further explained in section 9.1 under *Layout*.

Window level
The window level is highly influential for simulations of daylight only.

Ground reflectance
The ground reflectance is highly influential for simulations of daylight due to the room location close to the ground.

Light transmission of the glazing, LT
The light transmission of the glazing is highly influential for simulations of daylight.

11.2 Conclusions regarding conformity

Here, the most important findings regarding the convergence between the simplified and detailed methods are presented. Generally, the simplified methods cannot be used to predict the outcome of the detailed simulations. The exception is indicator 3, *solar heat load*. Below follow the findings of each indicator.

Indicator 3. Solar heat load
The simplified and detailed methods converge very well.

Indicator 10. Thermal climate – winter
The simulated winter thermal climate is very sensitive to activity level and clothing. Additionally, it is sensitive to the installed heating power when varying the geometry of the room. However, the installed heating power compensates for enhanced heat losses due to increased window share or decreased U-value of the window.

Indicator 11. Thermal climate – summer
The detailed simulations are less affected by parameter variations due to the installed cooling power and airing taken into consideration, which compensates for heat gains. Thus, the detailed simulations are favourable when determining the summer thermal climate.

Indicator 12. Daylight
Detailed simulations of daylight are favourable due to the influential parameters being taken into account such as daylight transmission and reflectance. Also, open layouts are favourable when the sensor point in the room has full view of the additional windows.

11.3 Further investigations

In order to achieve comparability of the results from the simplified and detailed methods, only the room indicators have been included in this study. There is still a majority of indicators remaining and some of them are, as the indicators studied, evaluated by calculations. For those indicators, studies of the conformity between simplified and detailed methods can be implemented. Additionally, influencing parameters can be determined.

The parameters are all studied separately, one at a time. Thus, no synergies can be traced. By analysing the parameters in suitable units, their effect on each other can be found and a deeper understanding of their relation can be achieved. This should be useful in the design process when a large number of parameters need to be fixed.

Floor dimensions and total window area is evidently of importance since they are included in all of the simplified calculation for the indicators on room level. The approach used in this study, however, was not sufficient and no useful conclusions could be drawn from the results. A more detailed study centred on these parameters would benefit architects and engineers involved in the early stages of a project.

The comparison method developed for this study may be improved, especially for the daylight factor for which the linearization has a very steep gradient as previously mentioned. If a more moderate gradient could be obtained, the daylight factor grades would become comparable with the others and the method could become a useful tool for identifying which parameters are close to reaching the next level in Miljöbyggnad or in danger of not passing a level upon verification.

12 References

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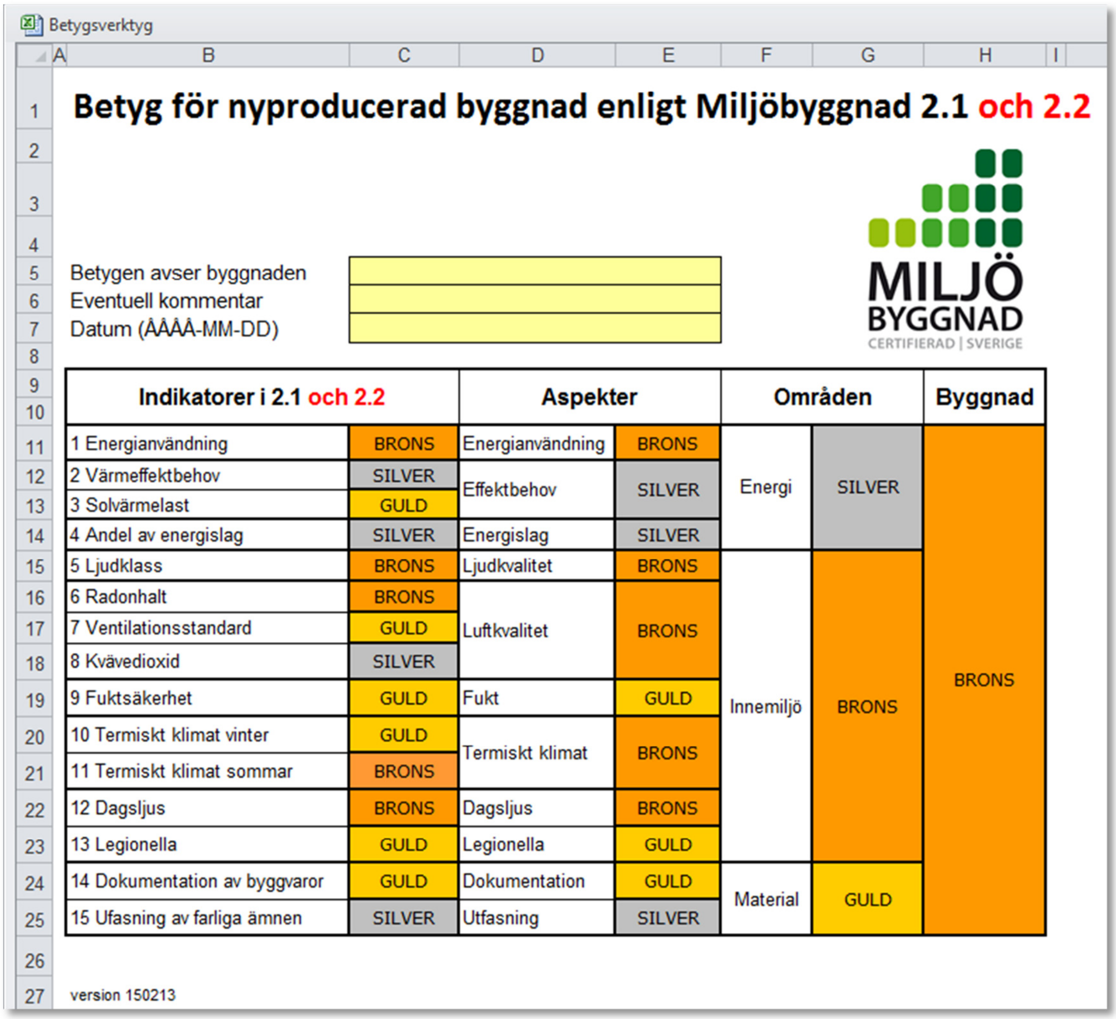
13 Appendices

Appendix A: Compilation of criteria in Miljöbyggnad for new constructions
Appendix B: Tool for aggregation of grades
Appendix C: Input data
Appendix D: Grade conversion equations
Appendix E: Grade conversion
Appendix F: Result diagrams

Appendix A – Compilation of criteria in Miljöbyggnad for new constructions

Indicator			BRONZE	SILVER	GOLD
3.	Solar heat load	*Commercial buildings*	SVL < 48 W/m^2 floor	SVL < 43 W/m^2 floor	SVL < 32 W/m^2 floor
		Dwellings	SVL < 38 W/m^2 floor	SVL < 29 W/m^2 floor	SVL < 18 W/m^2 floor
10.	Thermal climate - winter	*All buildings*	PPD ≤ 20 %	PPD ≤ 15 %	PPD ≤ 10 %, passing grade in survey
		Single family houses	TF < 0.4	TF < 0.3	-
		Dwellings	PPD ≤ 20 %, openable windows in dwellings and schools	PPD ≤ 15 %, openable windows in dwellings and schools	PPD ≤ 10 %, openable windows in dwellings and schools, passing grade in survey
		Commercial buildings			
11.	Thermal climate - summer	*Single family houses* *Residential buildings*	SVF < 0.048, openable windows	SVF < 0.036, openable windows	SVF < 0.025, openable windows, passing grade in survey
		Schools	SVF < 0.06, openable windows	SVF < 0.054, openable windows	-
12.	Daylight	*Dwellings* *Commercial buildings*	DF > 1.0 %	DF ≥ 1.2 %	DF ≥ 1.2 %, passing grade in survey
		Dwellings	AF ≥ 10 %	AF ≥ 15 %	-
		Commercial buildings	DF ≥ 1.0 % or view area ≥ 40 %	DF ≥ 1.2 % or view area ≥ 50 %	DF ≥ 1.2 % or view area ≥ 50 %, passing grade in survey

Appendix B - Tool for aggregation of grades



Betyg för nyproducerad byggnad enligt Miljöbyggnad 2.1 och 2.2

Betygen avser byggnaden
Eventuell kommentar
Datum (ÅÅÅÅ-MM-DD)

Indikatorer i 2.1 och 2.2		Aspekter		Områden		Byggnad
1 Energianvändning	BRONS	Energianvändning	BRONS	Energi	SILVER	BRONS
2 Värmeeffektbehov	SILVER	Effektbehov	SILVER			
3 Solvärmelast	GULD					
4 Andel av energislag	SILVER	Energislag	SILVER			
5 Ljudklass	BRONS	Ljudkvalitet	BRONS	Innemiljö	BRONS	
6 Radonhalt	BRONS	Luftkvalitet	BRONS			
7 Ventilationsstandard	GULD					
8 Kvävedioxid	SILVER					
9 Fuktsäkerhet	GULD	Fukt	GULD			
10 Termiskt klimat vinter	GULD	Termiskt klimat	BRONS			
11 Termiskt klimat sommar	BRONS					
12 Dagsljus	BRONS	Dagsljus	BRONS			
13 Legionella	GULD	Legionella	GULD			
14 Dokumentation av byggvaror	GULD	Dokumentation	GULD	Material	GULD	
15 Ufasning av farliga ämnen	SILVER	Utfasning	SILVER			

version 150213

Figure B- 1 Print screen of the grade aggregation tool for Miljöbyggnad.

This is a print screen of the tool the Swedish Green Building Council, SGBC, has developed to facilitate and illustrate how the aggregation of grades is to be done for Miljöbyggnad.

The way this tool works is that the grades for the different indicators on the left may be changed at will. After each change the corresponding grades for aspect, area and the overall building are adjusted according to the rules in Miljöbyggnad.

The tool is called *Betygsverktyg* and may be downloaded here: https://www.sgbc.se/dokument-och-manualer

To date this tool is only provided in Swedish.

Appendix C - Input data

C1 - Input data for residential building

Table C- 1

Occupancy data	**Bedroom**	**Living room**	**Kitchen**
Occupancy hours	Full occupancy 23.00-06.00	Full occupancy 7.00-8.00, 20.00-22.00	Full occupancy 6.30-7.30, 12.00-13.00, 17.00-20.00
People density	1 person		
Activity level	1.2 met (SGBC)		
Clothing level	0.75 ± 0.25 clo (SGBC)		

Table C- 2

HVAC data	Bedroom	Living room	Kitchen
Heating setpoint	21 °C		
Cooling setpoint	25 °C		
Supply air temp	Outdoor temp		
Principle for heating	Radiators		
Principle for cooling	Ventilation		
Supply air flow	5 l/s	12 l/s	-
Exhaust air flow	-	-	17 l/s
Ventilation operation hours	Always on		
Radiator power (55/40)	597 W	2x469 W	2x469 W

Table C- 3

Room properties	**Bedroom**	**Living room**	**Kitchen**
Floor area	14.4 m^2	34.3 m^2	18.5 m^2
Room width	3.6 m	5.2 m	2.8 m
Room length	4.0 m	6.6 m	6.6 m
Wall height	2.6 m	2.6 m	2.6 m
Exterior wall thickness	300 mm	300 mm	300 mm
Room orientation	Windows to the south	Windows to the south	Windows to the south
Total window area	2.5 m^2	5.1 m^2	3.4 m^2
Window width	1600 mm	900 mm or 1200 mm	1200 mm
Window height	1550 mm	1550 mm	1400 mm
Lining distance (inside wall to pane)	70 mm	70 mm	70 mm
Window height above floor	550 mm	550 mm	700 mm
Floor surface	Wooden floor 1	Wooden floor 1	Wooden floor 1
Exterior ground surface	Default (0.20)	Default (0.20)	Default (0.20)
Ceiling surface	White paint (matte)	White paint (matte)	White paint (matte)
Wall surface	White paint (matte)	White paint (matte)	White paint (matte)
Façade product surface	• Surface, frame: White polyurethane • Surface, lining: White paint (matte) • Surface, pane: 72 % transmittance	• Surface, frame: White polyurethane • Surface, lining: White paint (matte) • Surface, pane: 72 % transmittance	• Surface, frame: White polyurethane • Surface, lining: White paint (matte) • Surface, pane: 72 % transmittance

C2 - Input data for office building

Table C- 4

Occupancy data	**Cell office**	**Office landscape**
Occupancy hours	Weekdays 7.30-17.30	Weekdays 7.30-17.30
People density	1 pers/room	10 m^2/pers (Sveby, 2013)
Activity level	1.2 met (SGBC)	1.2 met (SGBC)
Clothing level	0.75 ± 0.25 clo (SGBC)	0.75 ± 0.25 clo (SGBC)
Lighting	10 W/m^2 (Sveby, 2013)	12 W/m^2 (Ljuskultur, 2013)
Equipment	125 W/pers (Sveby, 2013)	125 W/pers (Sveby, 2013)

Table C- 5

HVAC data	**Cell office**	**Office landscape**
Heating setpoint	21 °C	
Cooling setpoint	25 °C	
Supply air temp	17 °C	
Principle for heating	Radiators	
Principle for cooling	Chilled beams	
System type	VAV with temp. and CO_2 control	
Max VAV air supply	2 l/(s, m^2)	2 l/(s, m^2)
Max VAV air return	2 l/(s, m^2)	2 l/(s, m^2)
Ventilation operation hours	Weekdays 7.00-19.00 (Sveby, 2013)	
Radiator power (50/35)	407 W	12x407 W
Ideal cooler	400 W	4000 W

Table C- 6

Room properties	Cell office	Office landscape
Floor area	9.1 m^2	83.0 m^2
Room width	2.6 m	7.9 m
Room length	3.5 m	10.5 m
Wall height	3.3 m	3.3 m
Exterior wall thickness	300 mm	300 mm
Room orientation	Windows to the south	Windows to the south and east
Total window area	1.9 m^2	22.8 m^2
Façade product	Façade window, Vertical window system, Narrow window and walling system, Element without divisions	Façade window, Vertical window system, Narrow window and walling system, Element without divisions
Window width	1120 mm	1120 mm
Window height	1700 mm	1700 mm
Lining distance (inside wall to pane)	70 mm	70 mm
Window height above floor	800 mm	800 mm
Floor surface	Carpet 2 (grey)	Carpet 2 (grey)
Exterior ground surface	Default (0.20)	Default (0.20)
Ceiling surface	White paint (matte)	White paint (matte)
Wall surface	White paint (matte)	White paint (matte)
Façade product surface	• Surface, frame: White polyurethane • Surface, lining: White paint (matte) • Surface, pane: 63 % transmittance	• Surface, frame: White polyurethane • Surface, lining: White paint (matte) • Surface, pane: 63 % transmittance

C3 - Input data for hospital

Table C- 7

Occupancy data		
Occupants	Occupancy hours	40 % 8.00-20.00, 33 % otherwise
	People density	2 people/room
	Activity level	1.2 met (SGBC)
	Clothing level	0.75 ± 0.25 clo (SGBC)
Health professional	Occupancy hours	30 % 7.00-19.00, 5 % otherwise
	People density	1 pers/room
	Activity level	1.2 met (SGBC)
	Clothing level	0.75 ± 0.25 clo (SGBC)
Other	Lighting	75 W
	Equipment	• Monitoring equipment, 100 W • TV and DVD, 150 W • Monitor/terminal, IT, TV, 150 W
	Equipment operation hours	24 h/day, 365 days/year

Table C- 8

HVAC data	
Heating setpoint	21 °C
Cooling setpoint	25 °C
Supply air temp	17 °C
Principle for heating	Radiators
Principle for cooling	Chilled beams
System type	CAV
Supply air flow	25 l/s
Exhaust air flow	25 l/s
Ventilation operation hours	Always on
Radiator power (50/35)	2x270 W
Ideal cooler	400 W

Table C- 9

Room properties	
Floor area	16.8 m^2
Room width	4.0 m
Room length	4.2 m
Wall height	3.4 m
Exterior wall thickness	500 mm
Room orientation	Windows to the south
Total window area	4.6 m^2
Window width	470 mm or 1120 mm
Window height	1700 mm
Lining distance (inside wall to pane)	200 mm
Window height above floor	800 mm
Floor surface	Linoleum 1 (grey)
Exterior ground surface	Default (0.20)
Ceiling surface	White paint (matte)
Wall surface	White paint (matte)
Façade product surface	• Façade window, Vertical window system, Narrow window and walling system, Element without divisions • Surface, frame: White polyurethane • Surface, lining: White paint (matte) • Surface, pane: 63 % transmittance

C - References

Ljuskultur, 2013. *Ljus och rum: Riktlinjer för installerad effekt,* Stockholm: Ljuskultur.

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Appendix D – Grade conversion equations

The grade conversion equations, introduced in chapter 8, are here presented in full. For each set of criteria belonging to the different indicators there is a conversion equation. These are used to convert the results from the different calculations and simulations, which produce results of different units, into a unitless numerical scale.

x – The grade, expressed in the unitless numerical scale used in this project
y – The result, from simplified calculations <u>or</u> detailed simulations

3. Solar heat load

Dwellings

$$k = \frac{18-38}{3-1} = -10$$

$$m = 18 - (-10) * 3 = 48$$

$$SVL\ result = y = -10x + 48$$

$$\boxed{grade = x = \frac{y-48}{-10} = \frac{48-y}{10} = 4.8 - 0.1y}$$

Commercial buildings

$$k = \frac{32-48}{3-1} = -8$$

$$m = 32 - (-8) * 3 = 56$$

$$SVL\ result = y = -8x + 56$$

$$\boxed{grade = x = \frac{y-56}{-8} = \frac{56-y}{8} = 7 - 0.125y}$$

Note! The equation is approx. 8 % harsher for the SILVER criterion for commercial buildings than the manuals. This is due to unexplainable poor linearity in this specific case.

10. Thermal climate - winter

Transmissions factor, TF

Single-family houses

$$k = \frac{0.3 - 0.4}{2 - 1} = -0.1$$

$$m = 0.3 - (-0.1) \ast 2 = 0.5$$

$$TF\ result = y = -0.1x + 0.5$$

$$\boxed{grade = x = \frac{y - 0.5}{-0.1} = \frac{0.5 - y}{0.1} = 10 \ast (0.5 - y) = 5 - 10y}$$

Predicted percentage dissatisfied, PPD

Dwellings and commercial buildings

$$k = \frac{0.1 - 0.2}{3 - 1} = -0.05$$

$$m = 0.1 - (-0.05) \ast 3 = 0.25$$

$$PPD\ result = y = -0.05x + 0.25$$

$$\boxed{grade = x = \frac{y - 0.25}{-0.05} = \frac{20y - 5}{-1} = 5 - 20y}$$

11. Thermal climate - summer

Solar heat factor, SVF

Single-family houses and residential buildings

$$m = \frac{\frac{0.048}{1} - \frac{0.025}{3}}{\frac{3 - 1}{3 \ast 1}} = 0.0595$$

$$k = \frac{0.48 - 0.0595}{1} = -0.0115$$

$$SVF\ result = y = -0.0115x + 0.0595$$

$$\boxed{grade = \ x = \frac{119}{23} - \frac{y}{0.0115} = \frac{119}{23} - \frac{2000}{23}y}$$

Predicted percentage dissatisfied, PPD

Dwellings and commercial buildings

$$m = \frac{\frac{0.2}{1} - \frac{0.1}{3}}{\frac{3-1}{3}} = 0.25$$

$$k = \frac{0.2 - 0.25}{1} = -0.05$$

$$PPD\ result = y = -0.05x + 0.25$$

$$\boxed{grade = x = \frac{y - 0.05}{-0.05} = 5 - \frac{y}{0.05} = 5 - 20y}$$

12. Daylight

Window share, AF

Dwellings

$$m = \frac{\frac{0.15}{2} - \frac{0.1}{1}}{\frac{1-2}{1*2}} = 0.05$$

$$k = \frac{0.1 - 0.05}{1} = 0.05$$

$$AF\ result = y = 0.05x + 0.05$$

$$\boxed{grade = x = \frac{y - 0.05}{0.05} = -1 + \frac{y}{0.05} = 20y - 1}$$

Daylight factor, DF

Dwellings and commercial buildings

$$m = \frac{\frac{0.012}{2} - \frac{0.01}{1}}{\frac{1-2}{1*2}} = 0.008$$

$$k = \frac{0.01 - 0.008}{1} = 0.002$$

$$DF\ result = y = 0.002x + 0.008$$

$$\boxed{grade = x = \frac{y - 0.008}{0.002} = -4 + \frac{y}{0.002} = 500y - 4}$$

Appendix E – Grade conversion

3. Solar heat load

Table E-1

3. Solar heat load		1	2	3			
SVL [W/m2]	**Object**	**Bronze limit**	**Silver limit**	**Gold limit**	**Result**	**Grade**	**Abstract grade**
	Kitchen	38	29	18	37.7	BRONZE	1.0
	Bedroom	38	29	18	36.9	BRONZE	1.1
	Living room	38	29	18	30.9	BRONZE	1.7
	Cell office	48	43	32	12.8	GOLD	5.4
	Office landscape	48	43	32	11.8	GOLD	5.5
	Hospital room	48	43	32	16.1	GOLD	5.0
SVL [W/m2]	**Object**	**Bronze limit**	**Silver limit**	**Gold limit**	**Result**	**Grade**	**Abstract grade**
	Kitchen	38	29	18	34.5	BRONZE	1.4
	Bedroom	38	29	18	35.2	BRONZE	1.3
	Living room	38	29	18	30.3	BRONZE	1.8
	Cell office	48	43	32	12.4	GOLD	5.5
	Office landscape	48	43	32	11.5	GOLD	5.6
	Hospital room	48	43	32	16.2	GOLD	5.0

10. Thermal climate - winter

Table E-2

10. Thermal climate winter		1	2	3			
TF [W/m2]	**Object**	**Bronze limit**	**Silver limit**	**Gold limit**	**Result**	**Grade**	**Abstract grade**
	Kitchen	0.4	0.3	-	0.18	SILVER	3.20
	Bedroom	0.4	0.3	-	0.17	SILVER	3.30
	Living room	0.4	0.3	-	0.15	SILVER	3.50
	Cell office	0.4	0.3	-	0.13	SILVER	3.70
	Office landscape	0.4	0.3	-	0.17	SILVER	3.30
	Hospital room	0.4	0.3	-	0.16	SILVER	3.40
PPD [%]	**Object**	**Bronze limit**	**Silver limit**	**Gold limit**	**Result**	**Grade**	**Abstract grade**
	Kitchen	20.0%	15.0%	10.0%	10.4%	SILVER	2.92
	Bedroom	20.0%	15.0%	10.0%	11.5%	SILVER	2.70
	Living room	20.0%	15.0%	10.0%	11.6%	SILVER	2.68
	Cell office	20.0%	15.0%	10.0%	10.8%	SILVER	2.84
	Office landscape	20.0%	15.0%	10.0%	10.8%	SILVER	2.84
	Hospital room	20.0%	15.0%	10.0%	11.0%	SILVER	2.80

11. Thermal climate - summer

Table E-3

11. Thermal climate summer		1	2	3			
SVF [-]	**Object**	**Bronze limit**	**Silver limit**	**Gold limit**	**Result**	**Grade**	**Abstract grade**
	Kitchen	0.048	0.036	0.025	0.0472	BRONZE	1.1
	Bedroom	0.048	0.036	0.025	0.0461	BRONZE	1.2
	Living room	0.048	0.036	0.025	0.0387	BRONZE	1.8
	Cell office	0.048	0.036	0.025	0.016	GOLD	3.8
	Office landscape	0.048	0.036	0.025	0.0148	GOLD	3.9
	Hospital room	0.048	0.036	0.025	0.0202	GOLD	3.4
PPD [%]	**Object**	**Bronze limit**	**Silver limit**	**Gold limit**	**Result**	**Grade**	**Abstract grade**
	Kitchen	20.0%	15.0%	10.0%	8.0%	SILVER/ GOLD	3.4
	Bedroom	20.0%	15.0%	10.0%	5.5%	SILVER/ GOLD	3.9
	Living room	20.0%	15.0%	10.0%	6.3%	SILVER/ GOLD	3.7
	Cell office	20.0%	15.0%	10.0%	12.7%	SILVER	2.5
	Office landscape	20.0%	15.0%	10.0%	13.1%	SILVER	2.4
	Hospital room	20.0%	15.0%	10.0%	8.0%	SILVER/ GOLD	3.4

12. Daylight

Table E-4

12. Daylight		1	2	3			
AF[%]	**Object**	**Bronze limit**	**Silver limit**	**Gold limit**	**Result**	**Grade**	**Abstract grade**
	Kitchen	0.1	0.15	-	0.155	SILVER	2.1
	Bedroom	0.1	0.15	-	0.151	SILVER	2.0
	Living room	0.1	0.15	-	0.127	BRONZE	1.5
	Cell office	0.1	0.15	-	0.179	SILVER	2.6
	Office landscape	0.1	0.15	-	0.236	SILVER	3.7
	Hospital room	0.1	0.15	-	0.23	SILVER	3.6
DF [%]	**Object**	**Bronze limit**	**Silver limit**	**Gold limit**	**Result**	**Grade**	**Abstract grade**
	Kitchen	1.0%	1.2%	1.2%	1.5%	SILVER/ GOLD	3.5
	Bedroom	1.0%	1.2%	1.2%	2.1%	SILVER/ GOLD	6.5
	Living room	1.0%	1.2%	1.2%	2.0%	SILVER/ GOLD	6.0
	Cell office	1.0%	1.2%	1.2%	2.4%	SILVER/ GOLD	8.0
	Office landscape	1.0%	1.2%	1.2%	1.6%	SILVER/ GOLD	4.0
	Hospital room	1.0%	1.2%	1.2%	2.2%	SILVER/ GOLD	7.0

Appendix F – Result diagrams

F1 – Parameters concerning both simplified calculations and detailed simulations

F1a Indicator 3: Solar heat load

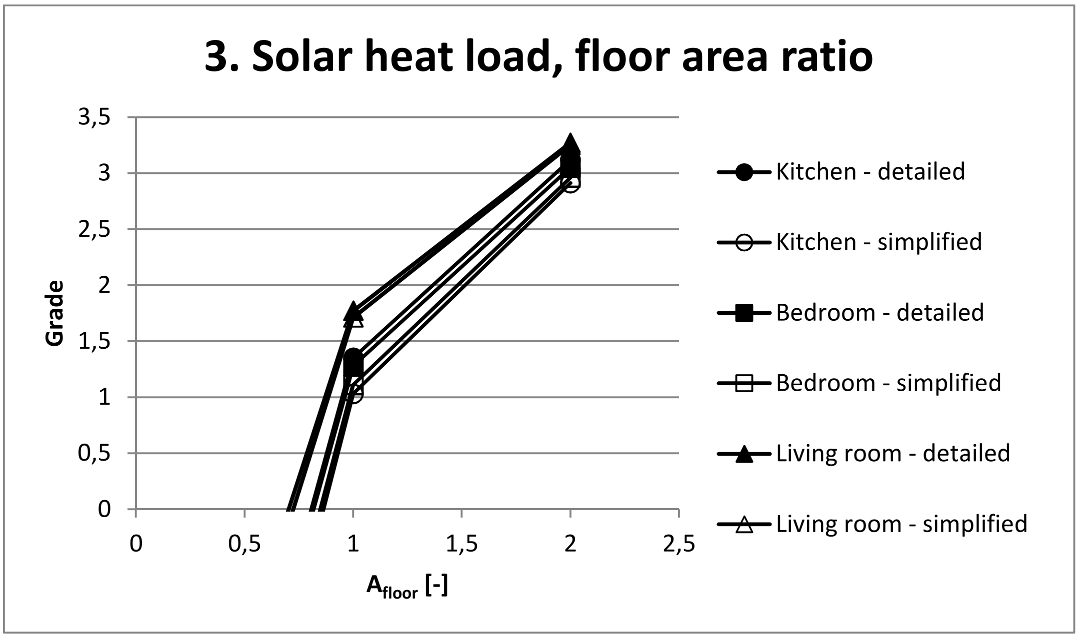

Figure F- 1

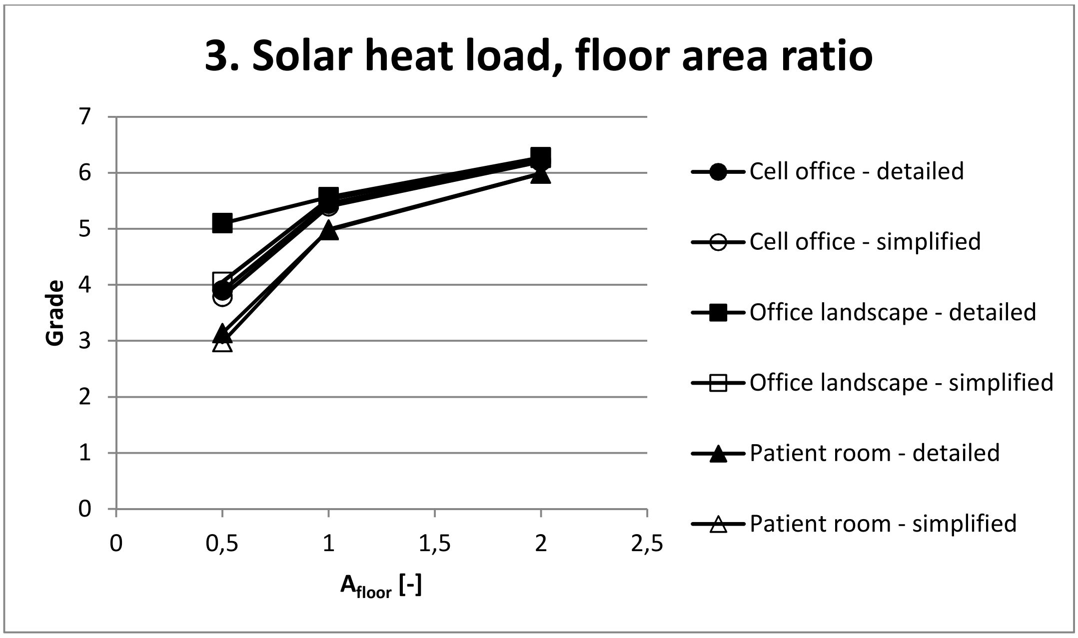

Figure F- 2

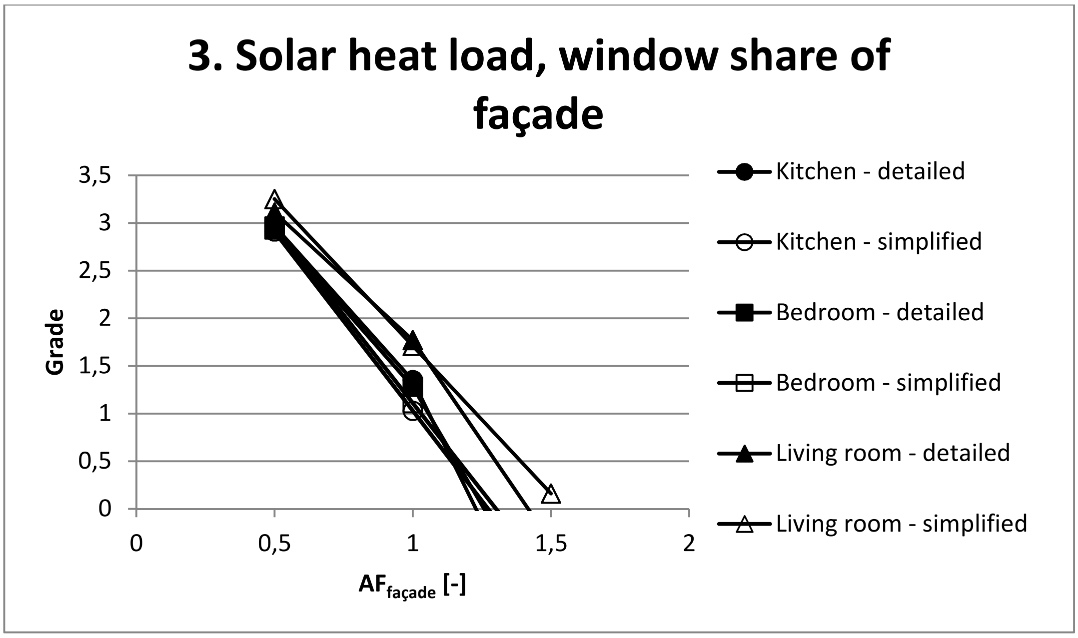

Figure F- 3

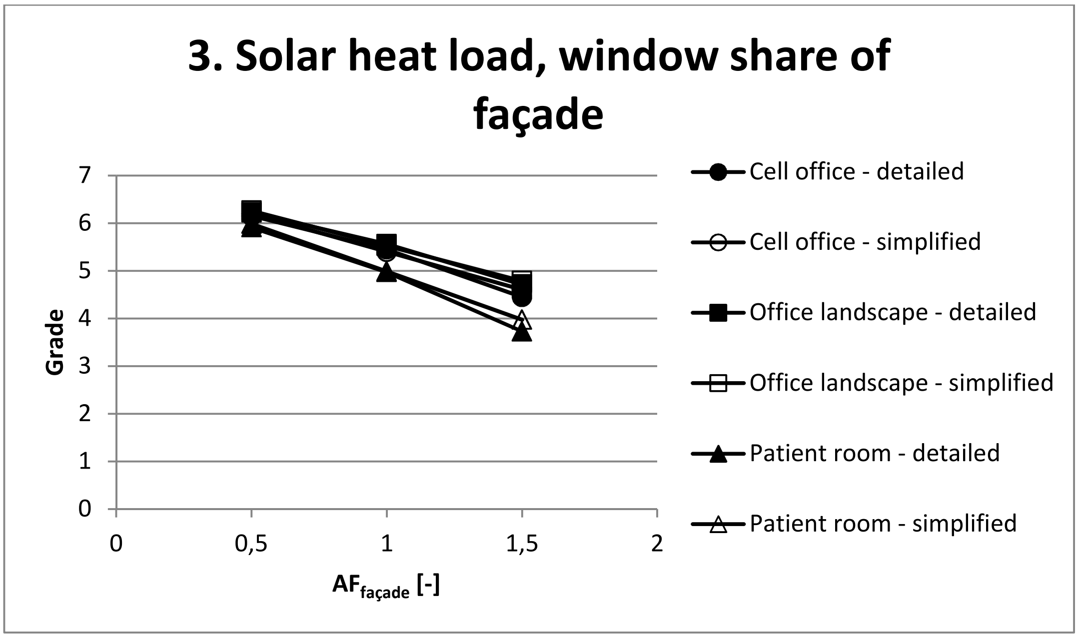

Figure F- 4

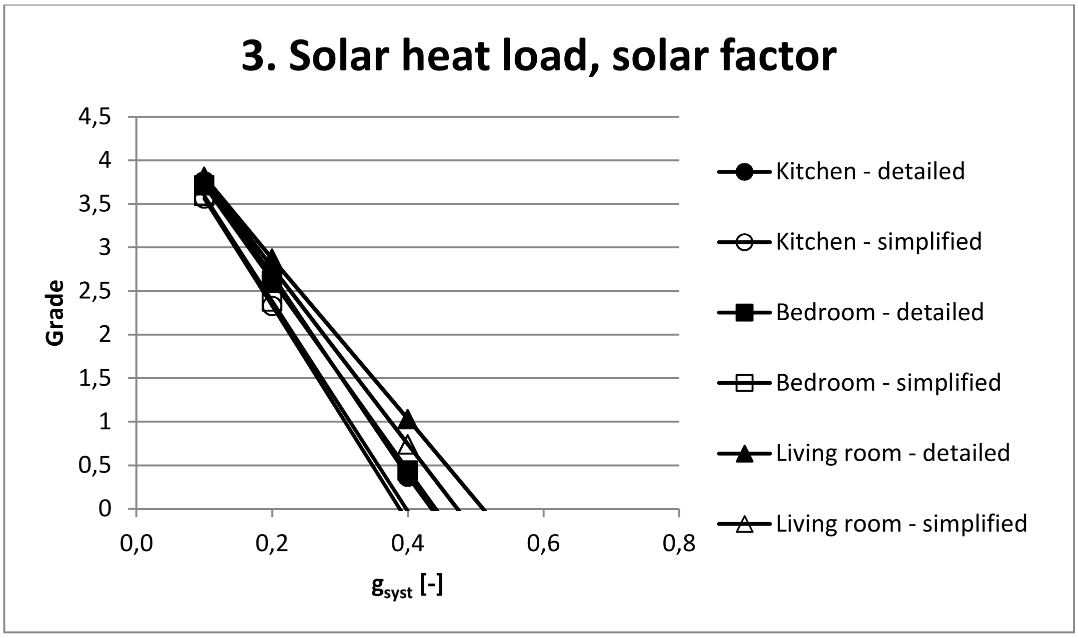

Figure F- 5

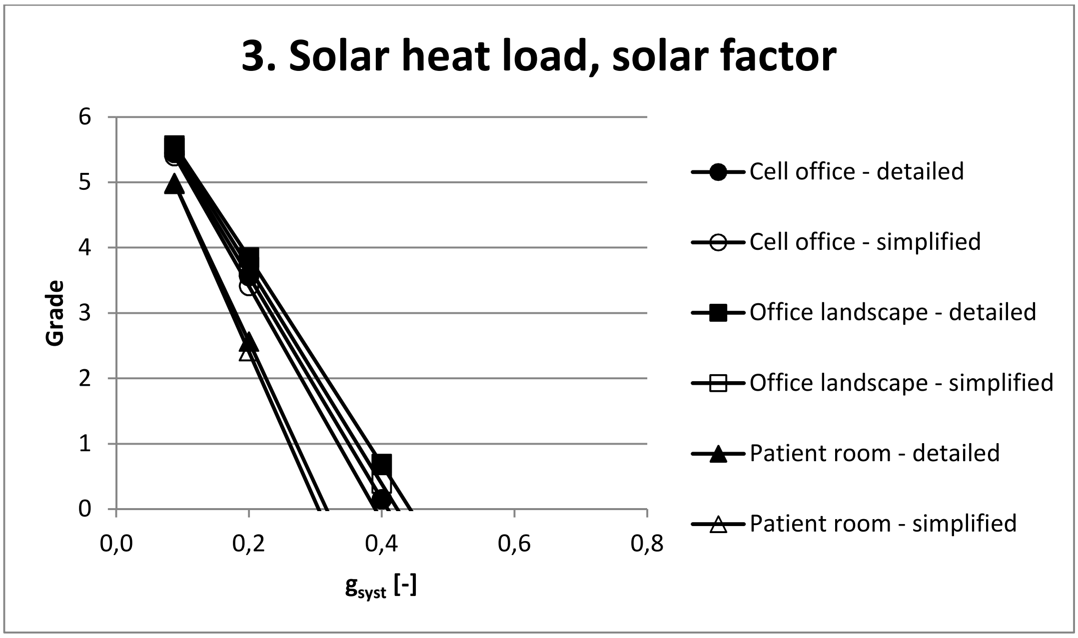

Figure F- 6

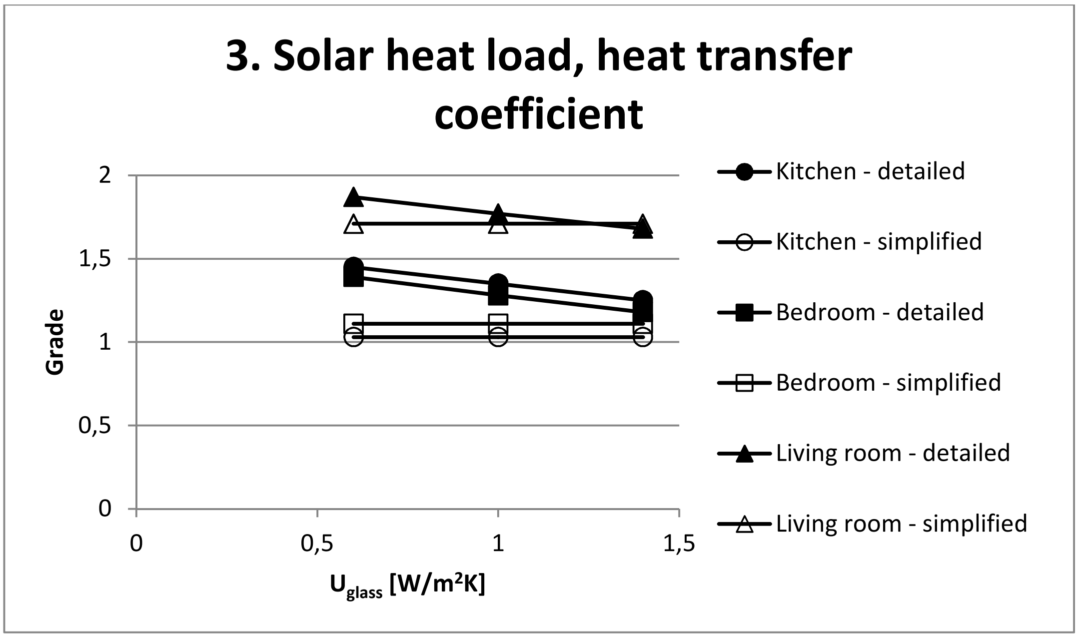

Figure F- 7

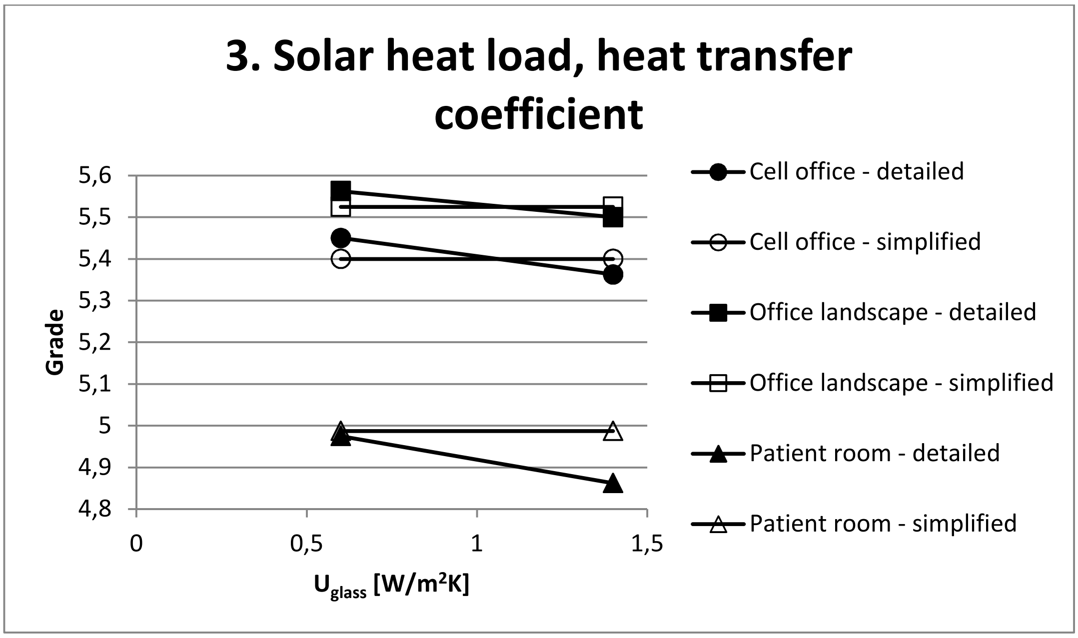

Figure F- 8

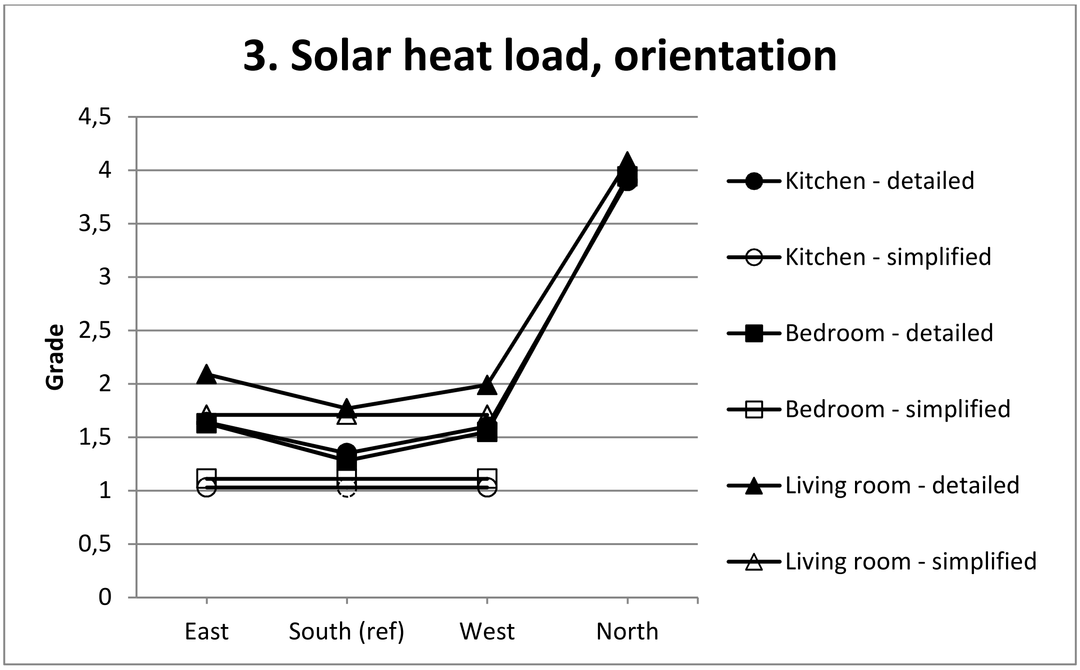

Figure F- 9

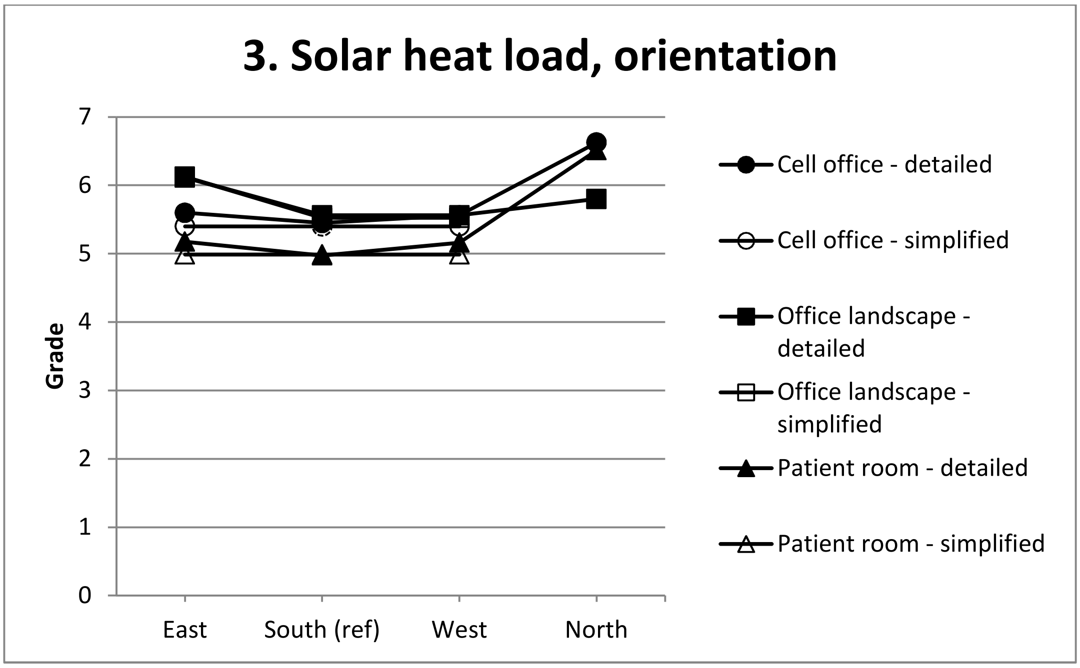

Figure F- 10

F1b Indicator 10: Thermal climate - winter

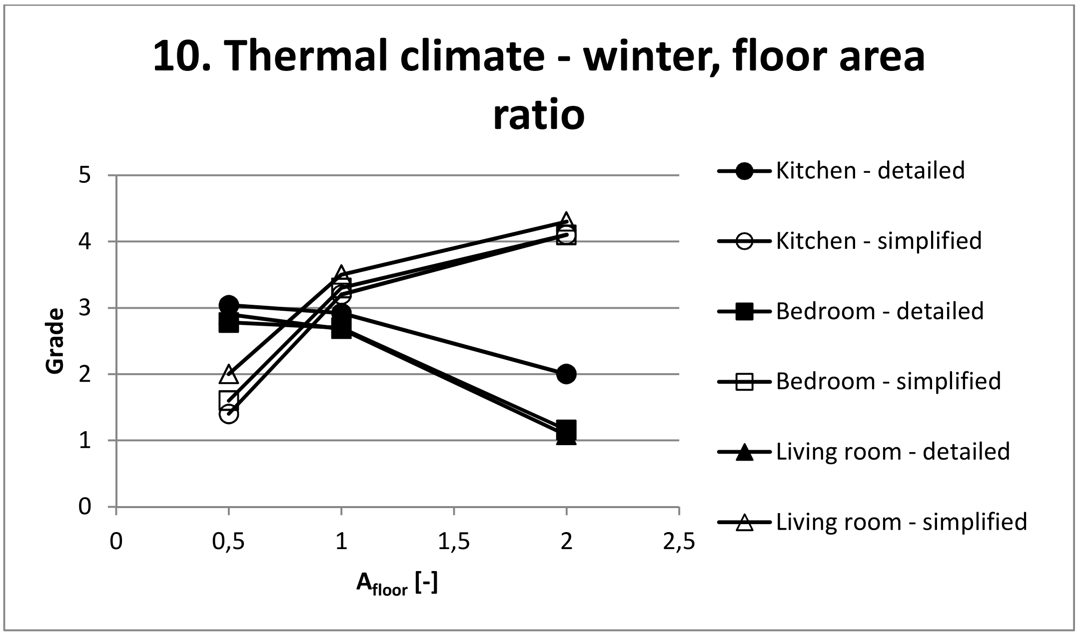

Figure F- 11

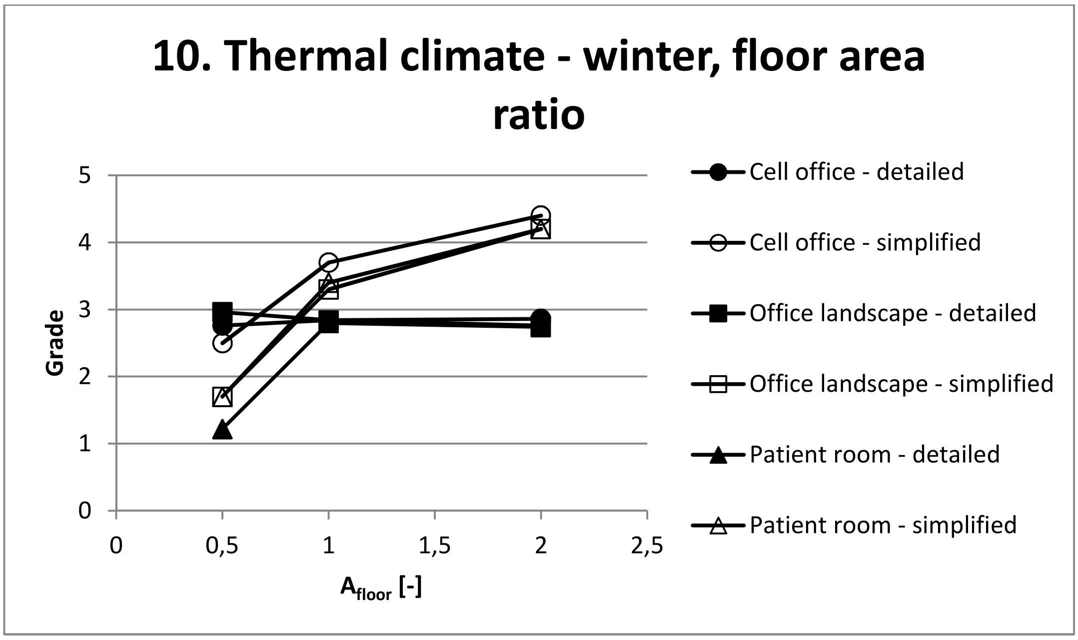

Figure F- 12

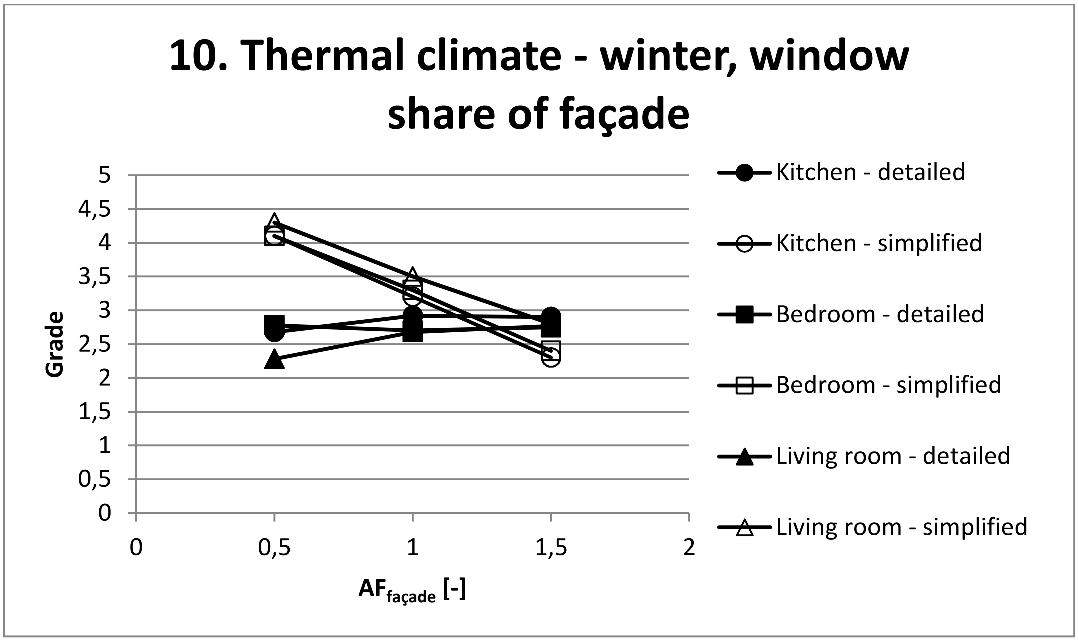

Figure F- 13

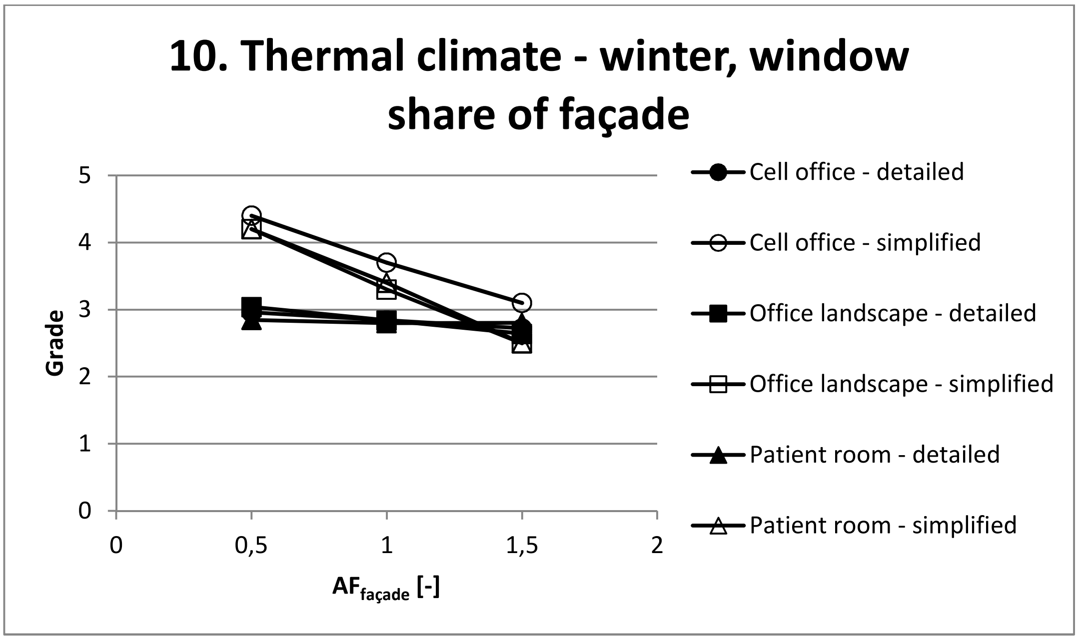

Figure F- 14

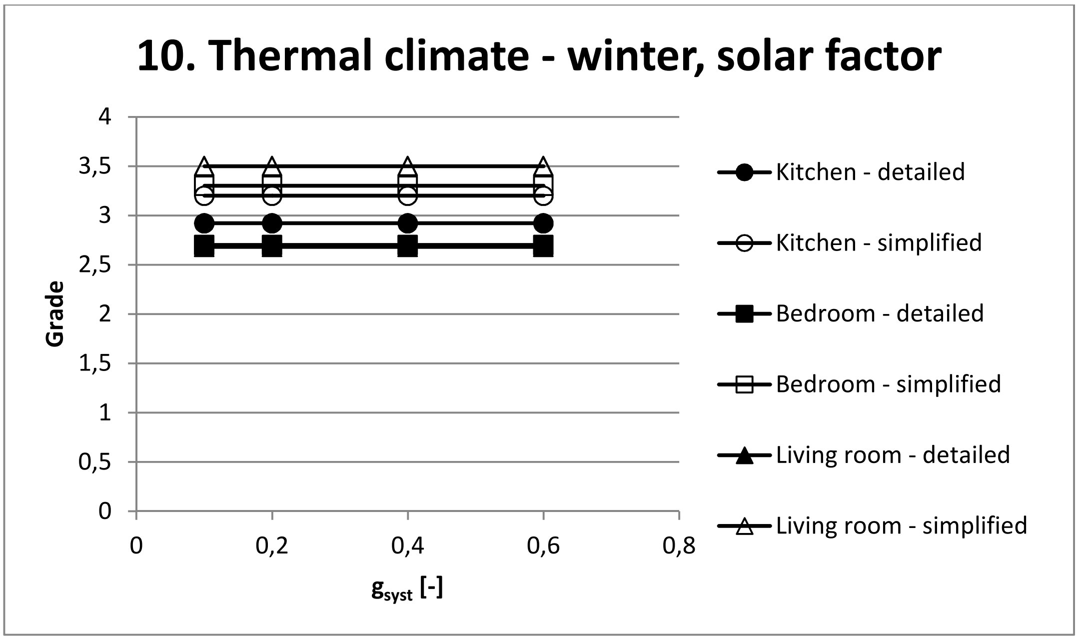

Figure F- 15

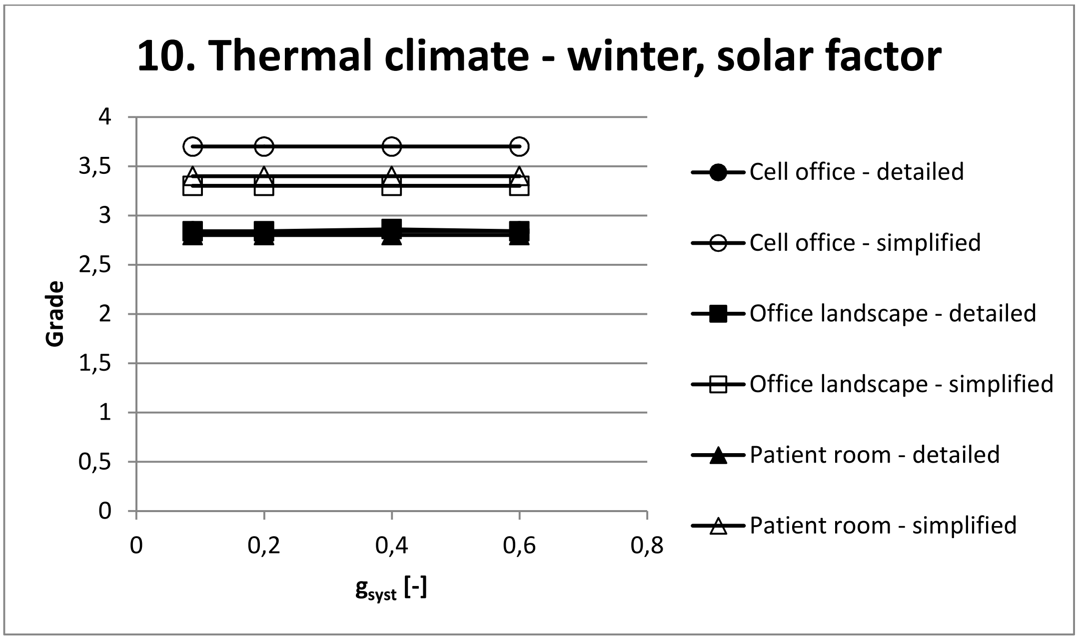

Figure F- 16

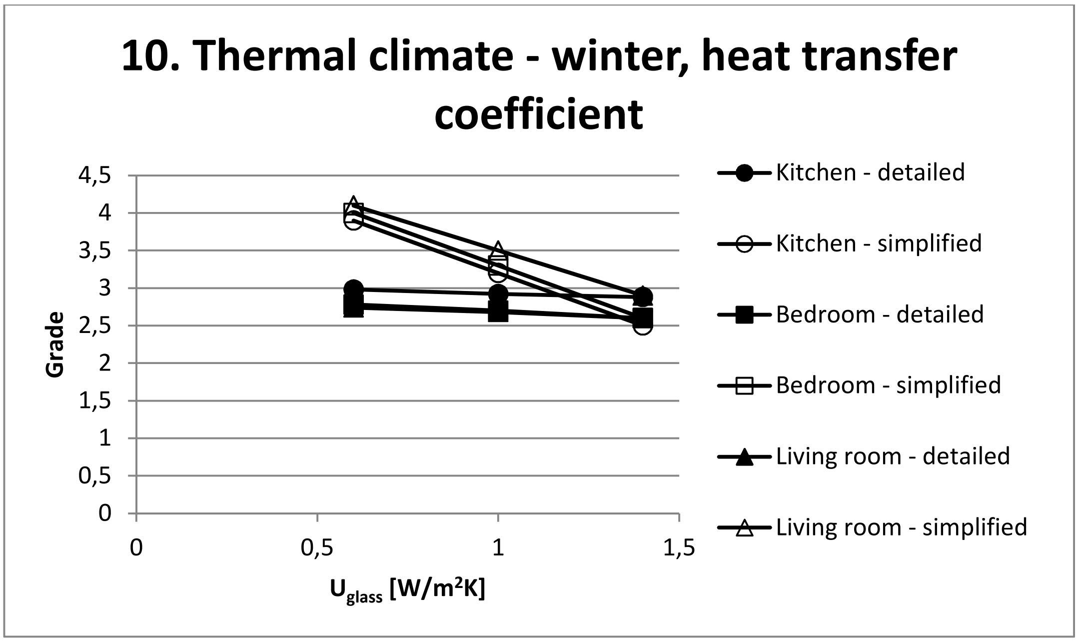

Figure F- 17

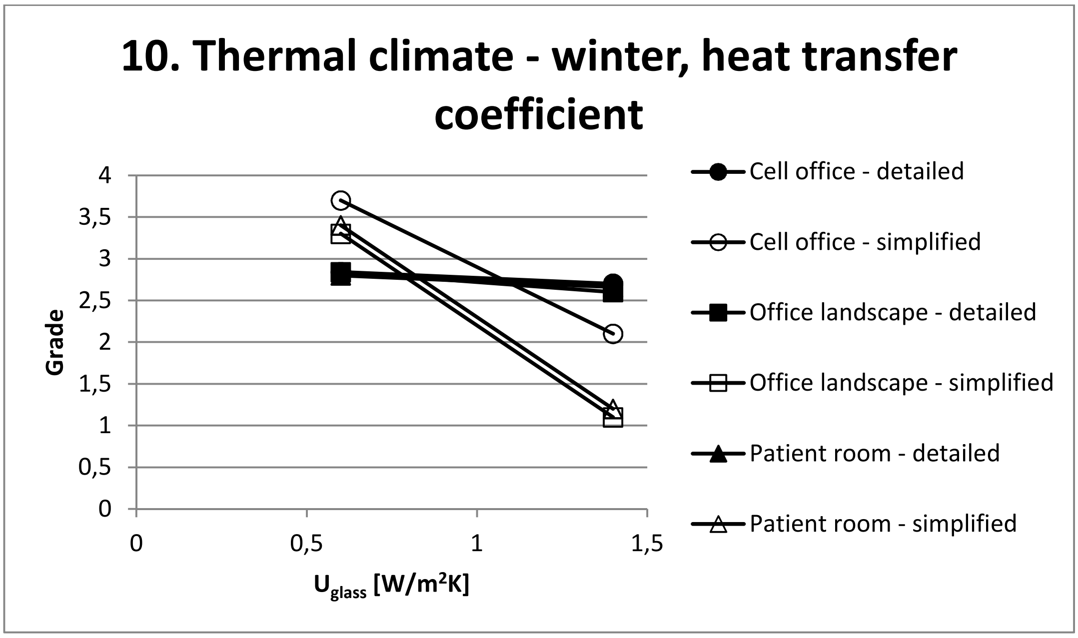

Figure F- 18

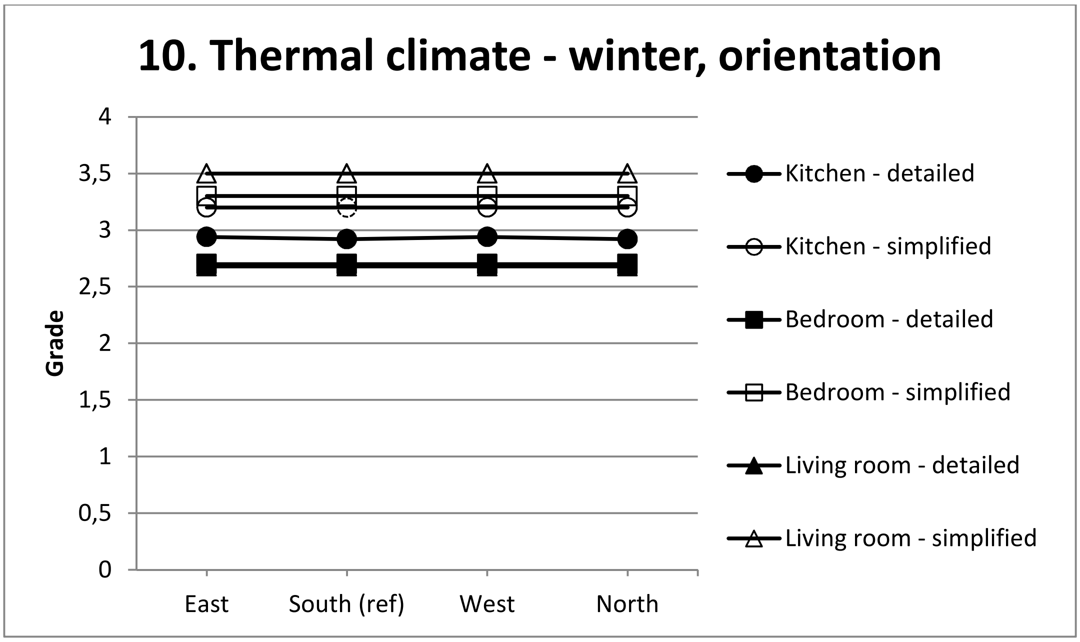

Figure F- 19

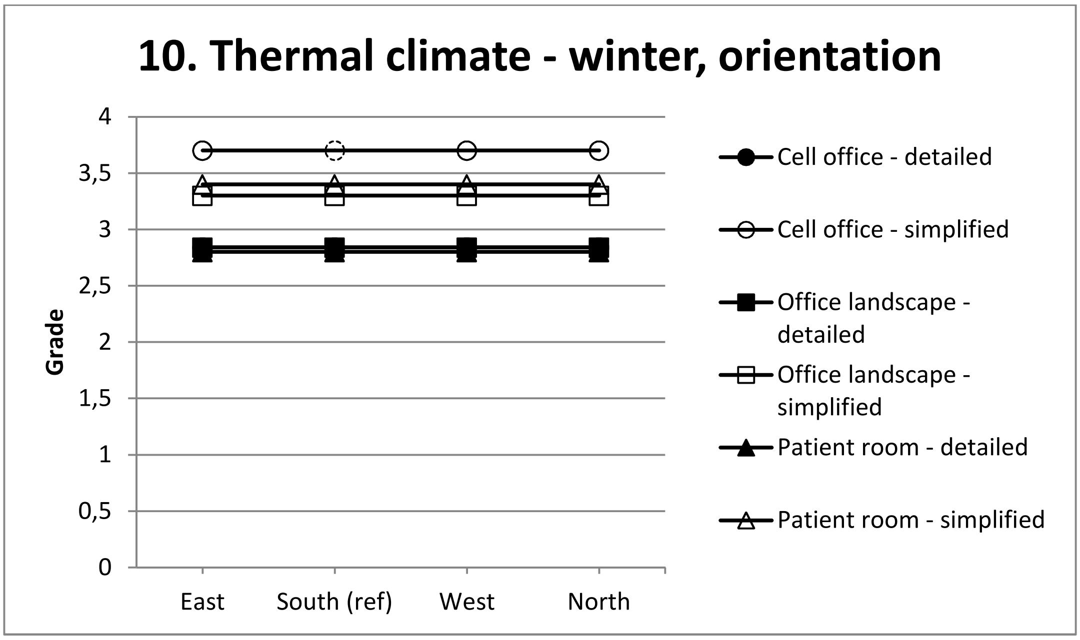

Figure F- 20

F1c Indicator 11: Thermal climate - summer

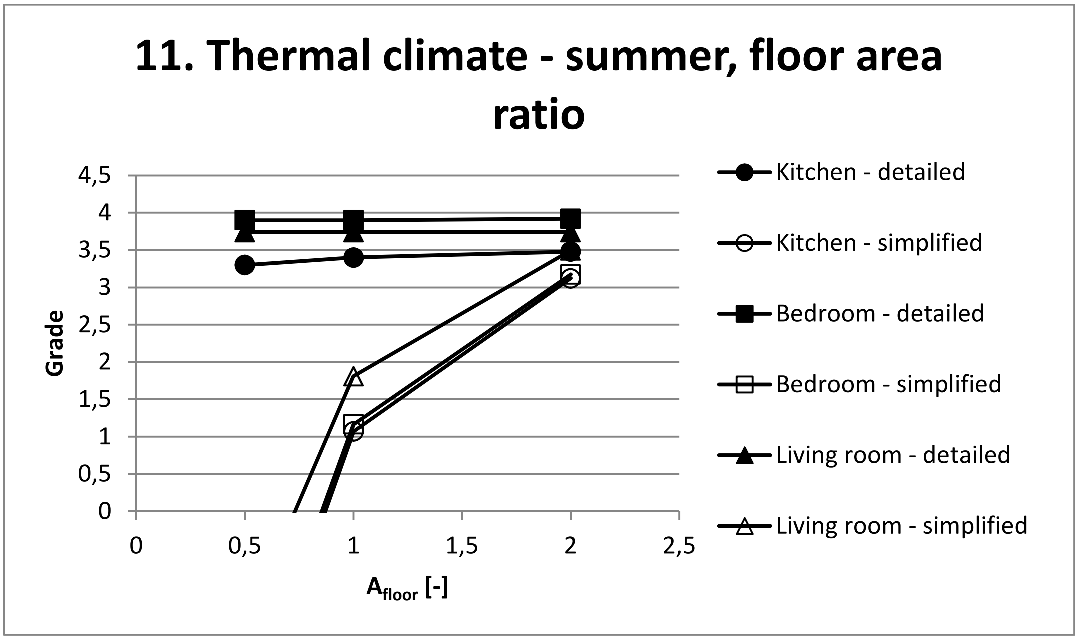

Figure F- 21

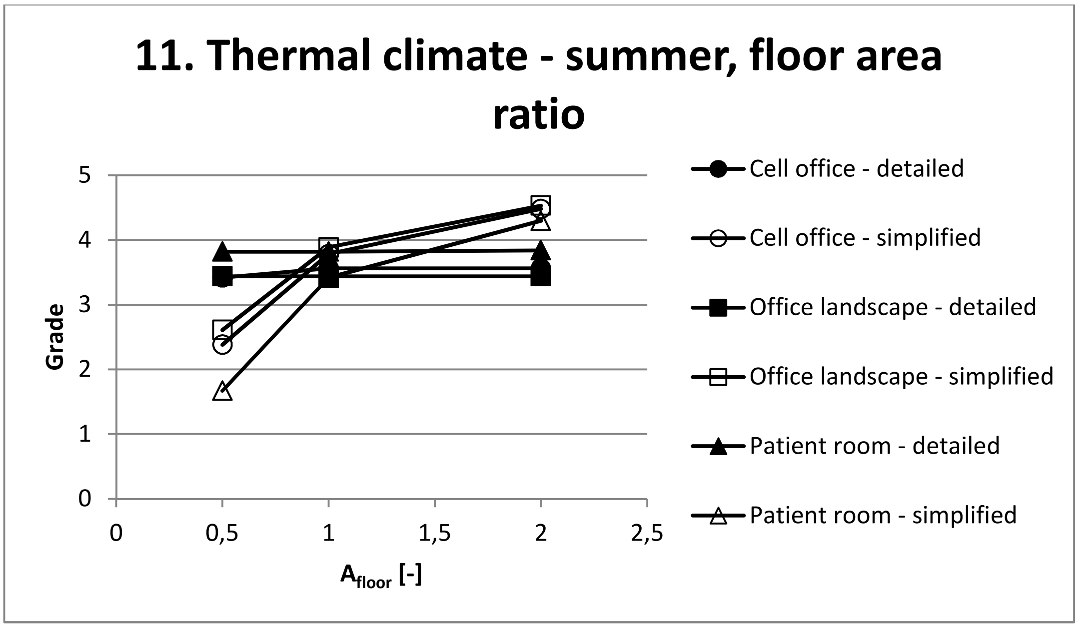

Figure F- 22

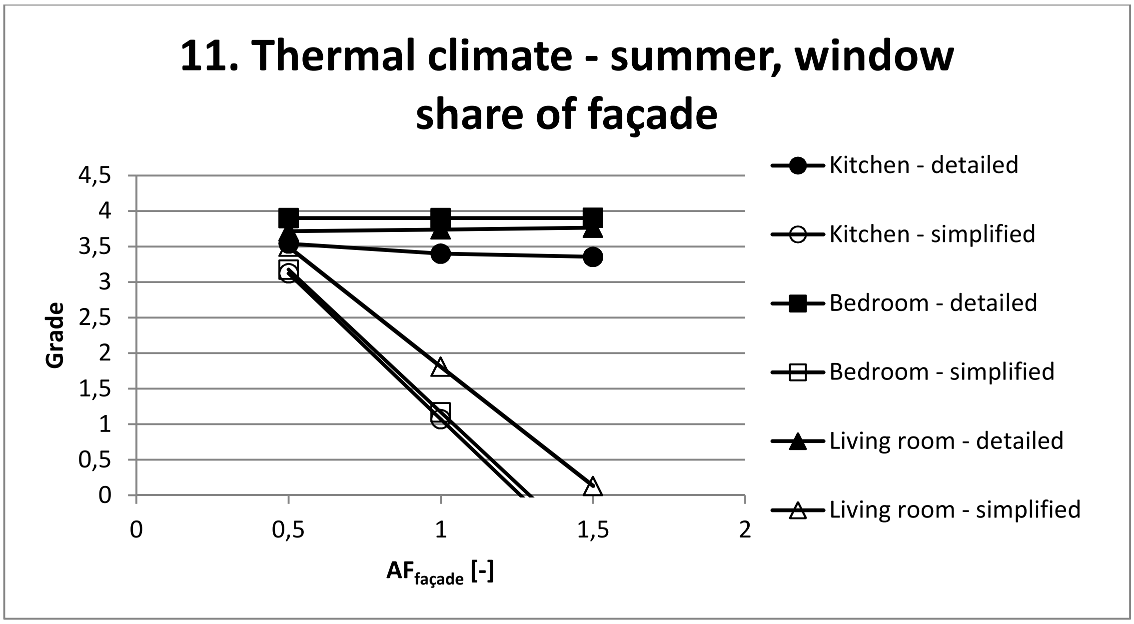

Figure F- 23

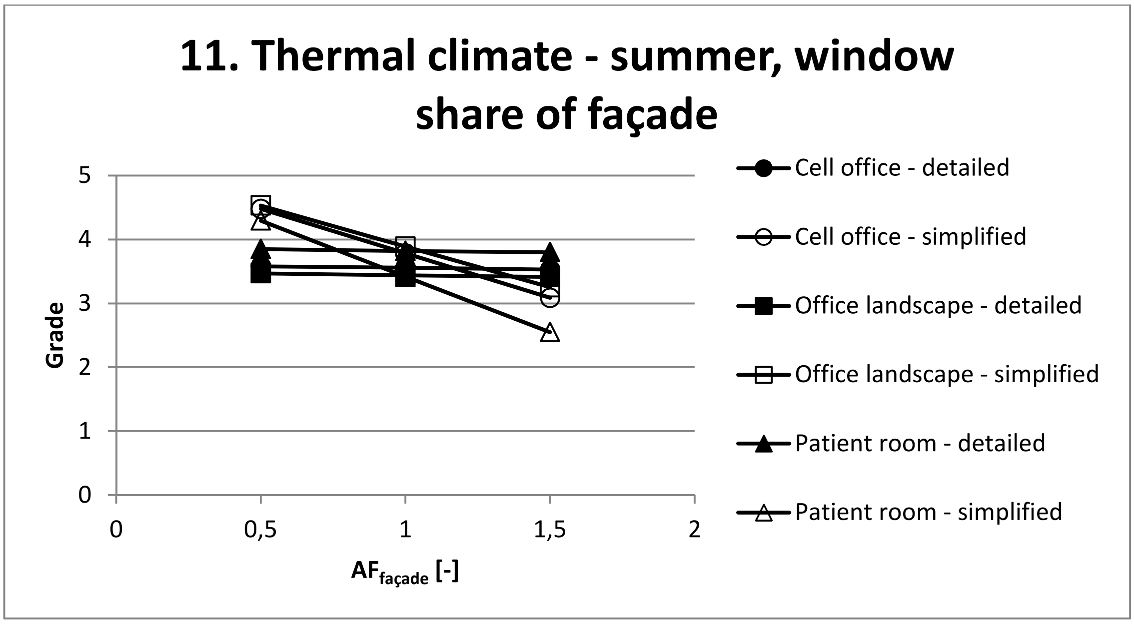

Figure F- 24

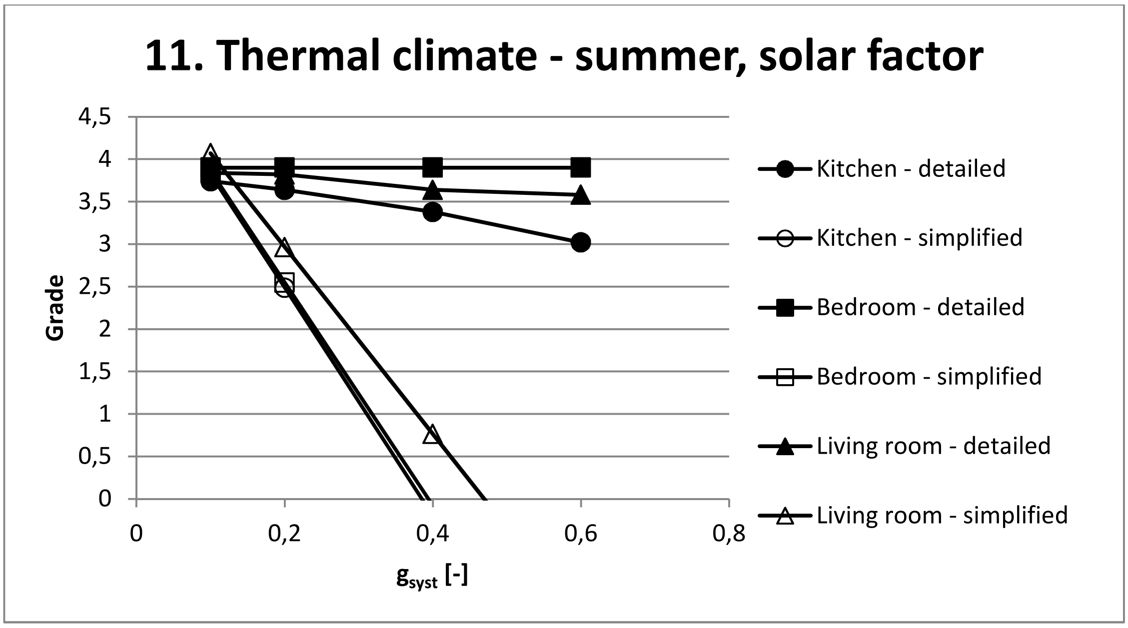

Figure F- 25

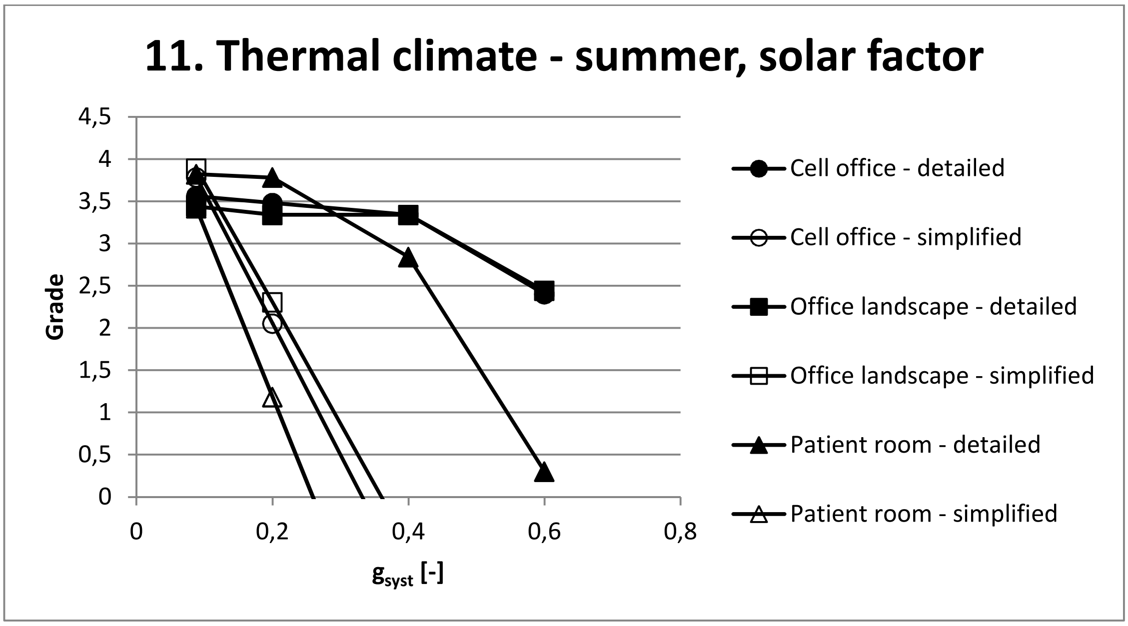

Figure F- 26

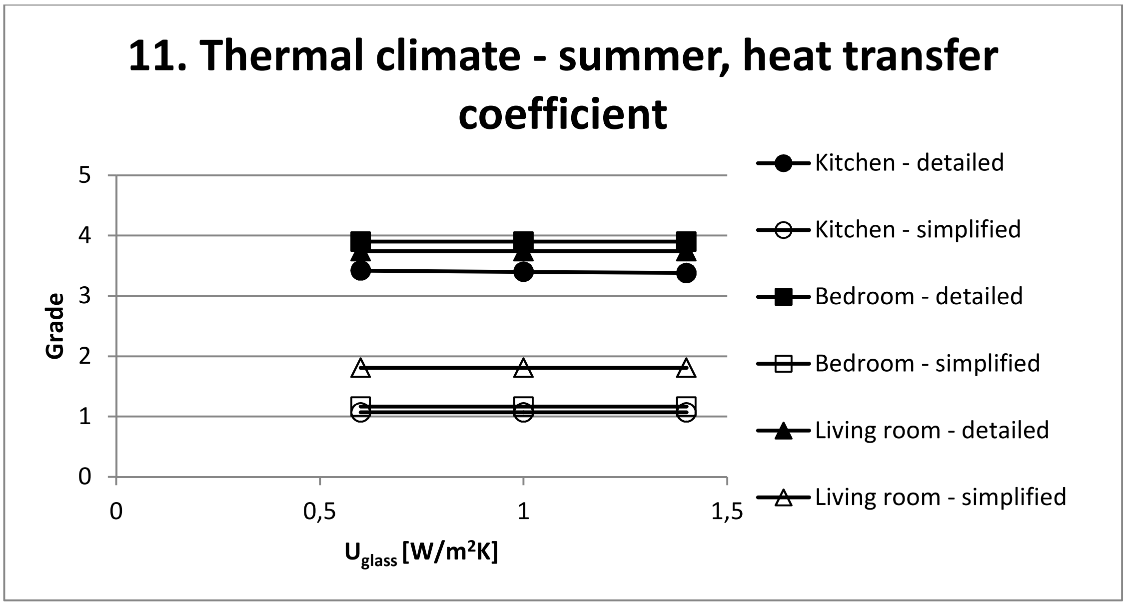

Figure F- 27

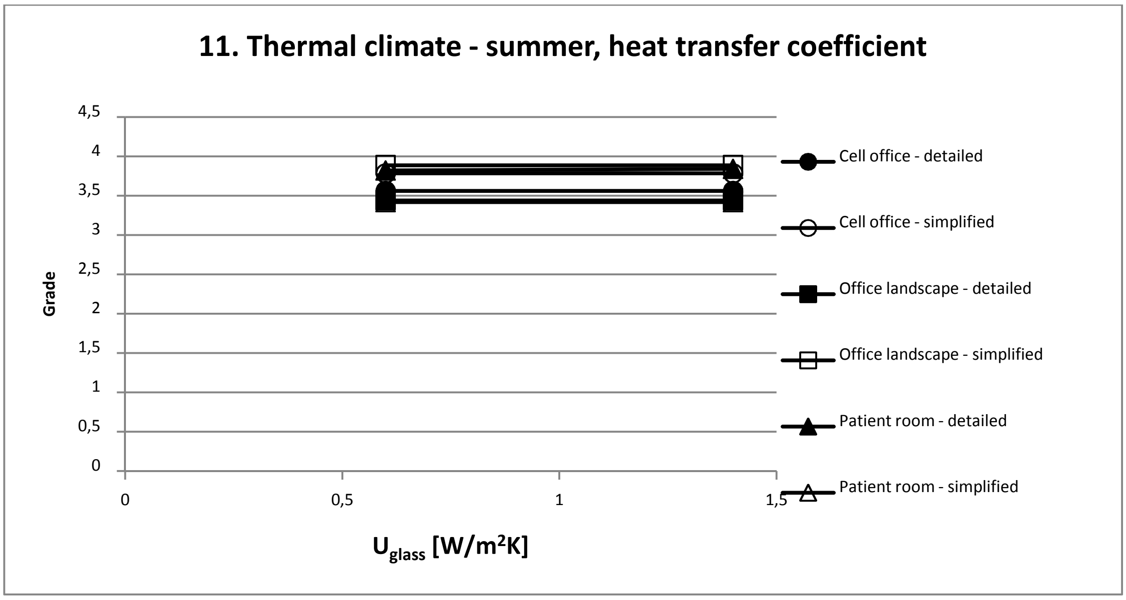

Figure F- 28

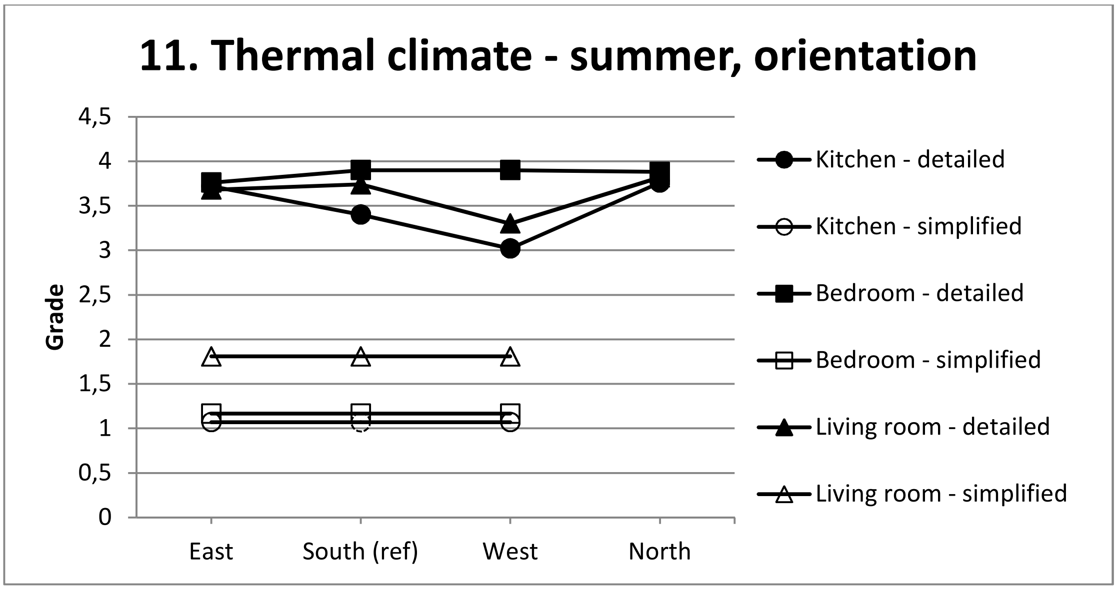

Figure F- 29

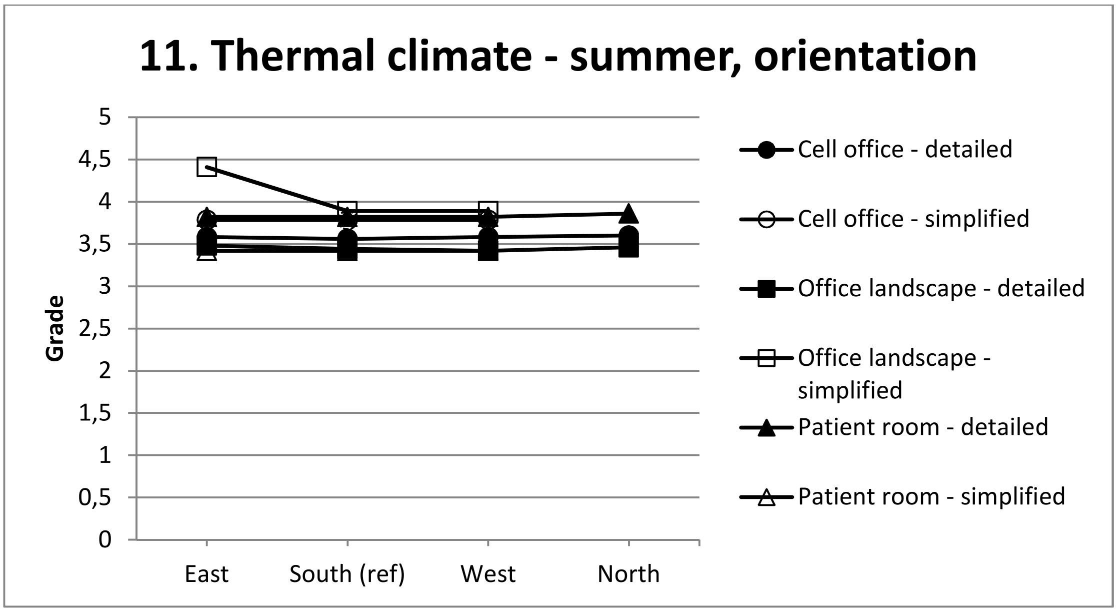

Figure F- 30

F1d Indicator 12: Daylight

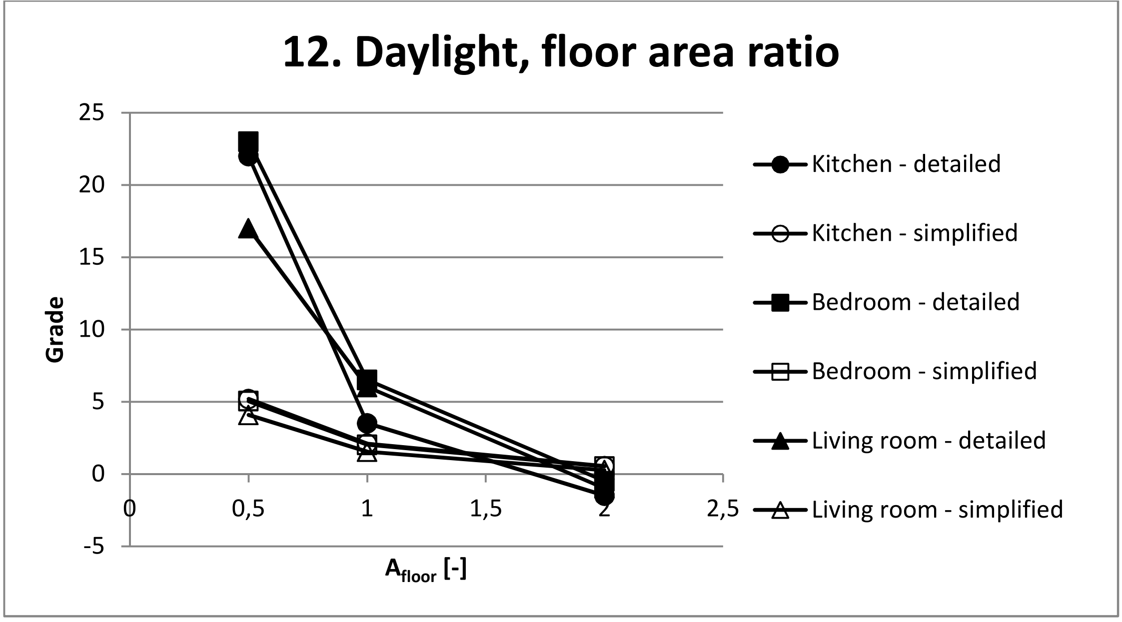

Figure F- 31

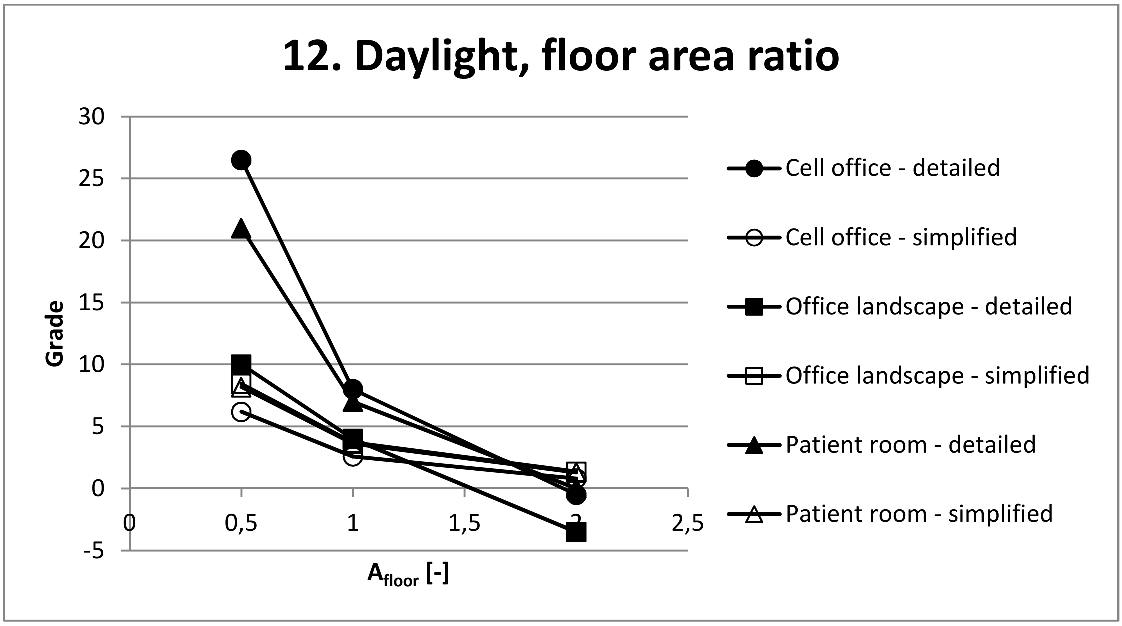

Figure F- 32

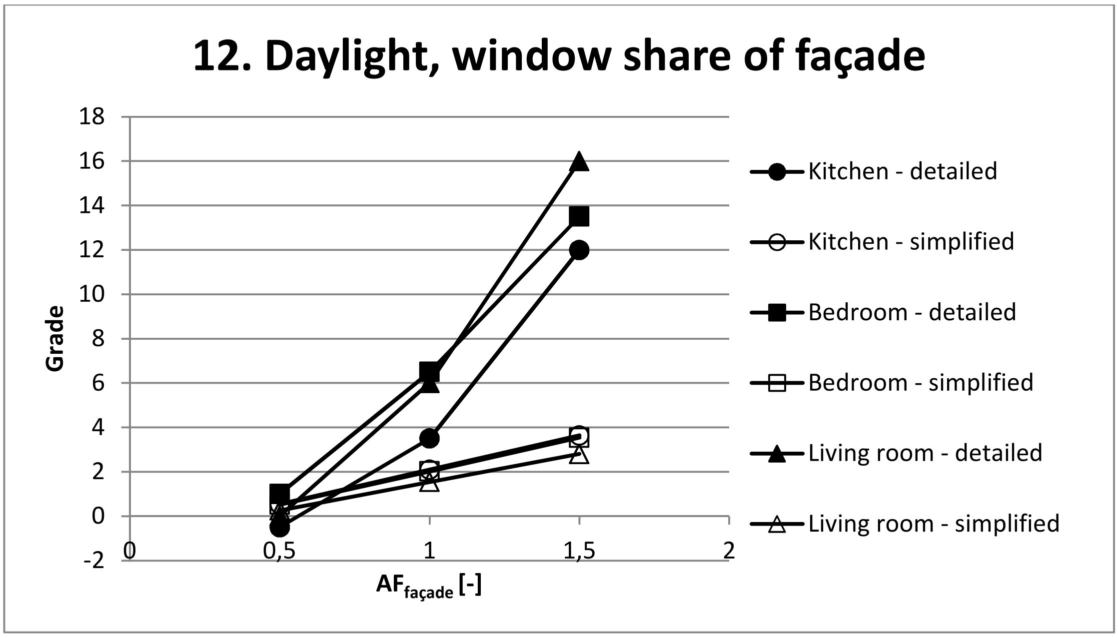

Figure F- 33

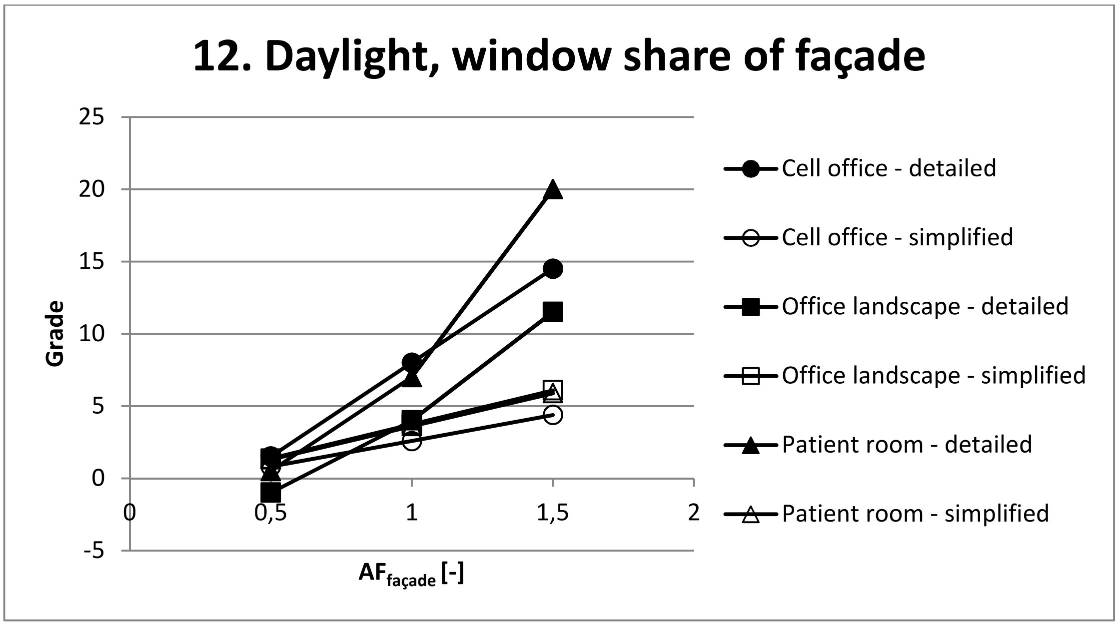

Figure F- 34

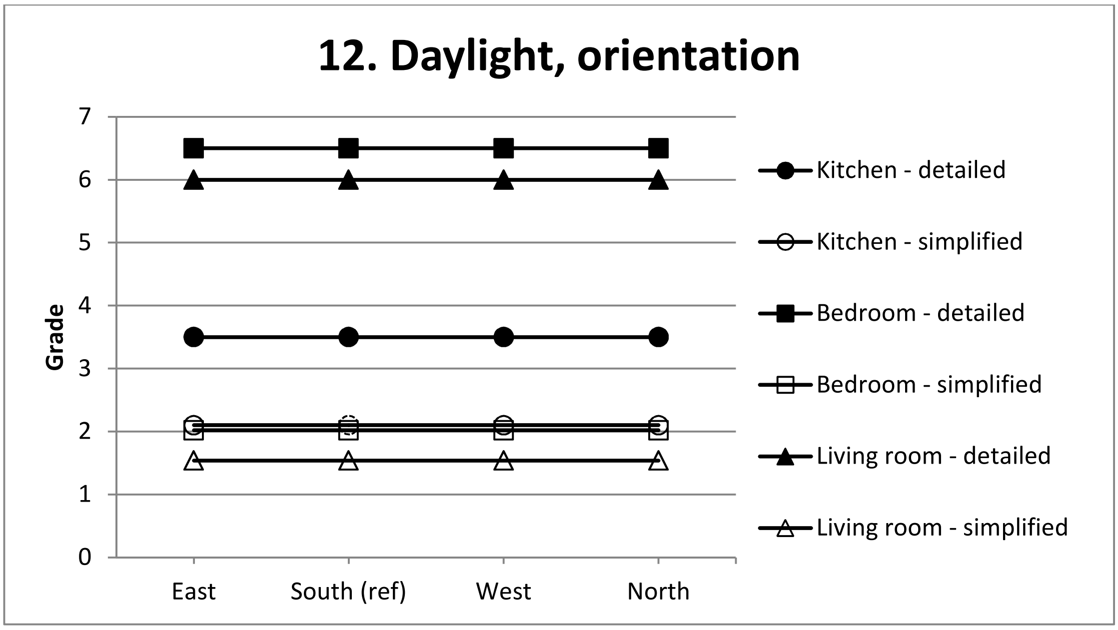

Figure F- 35

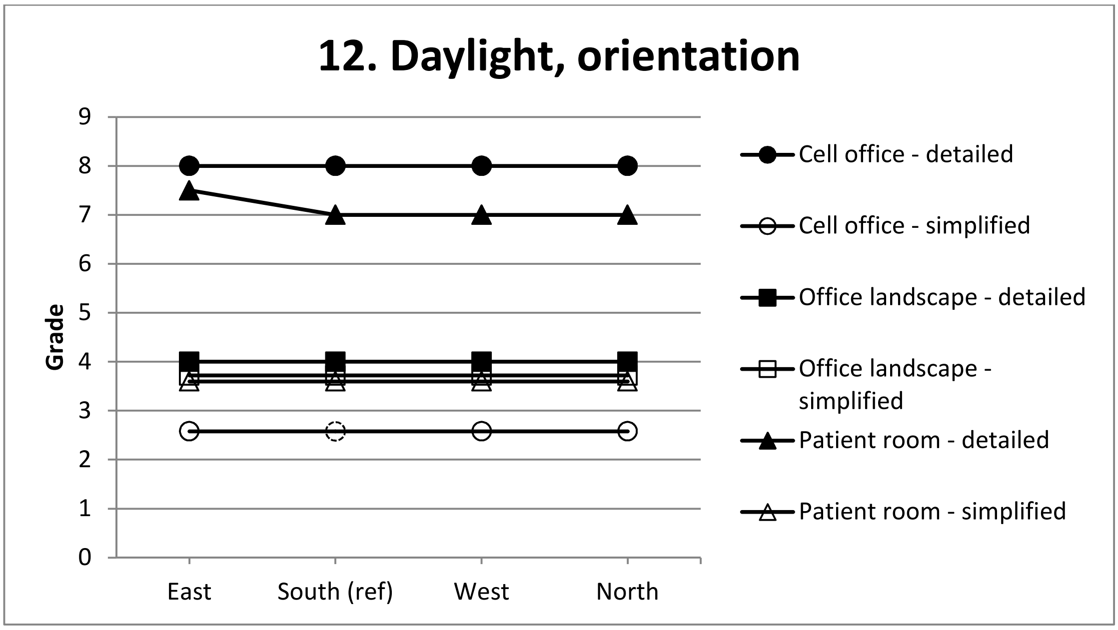

Figure F- 36

F2 – Parameters concerning only detailed simulations

F2a Indicator 3: Solar heat load

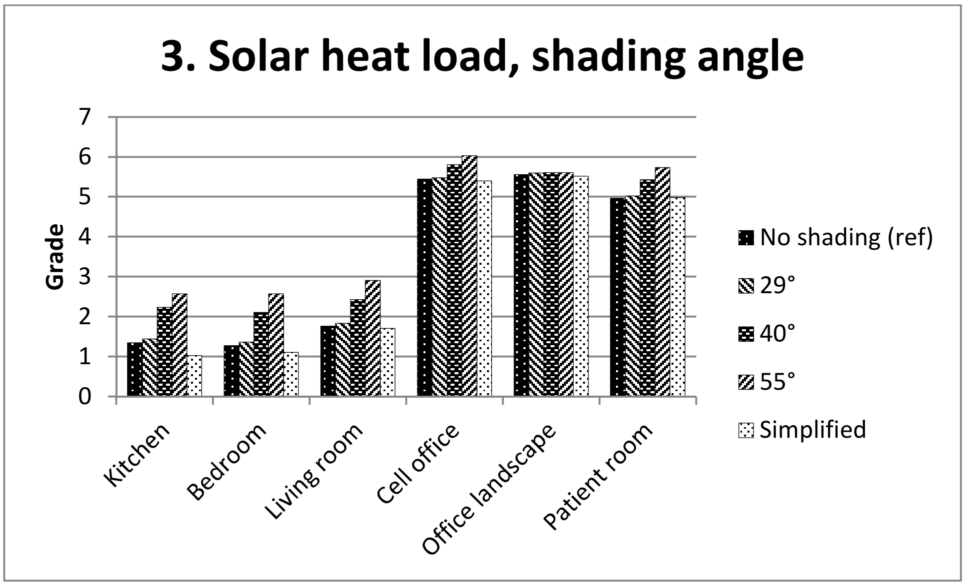

Figure F- 37

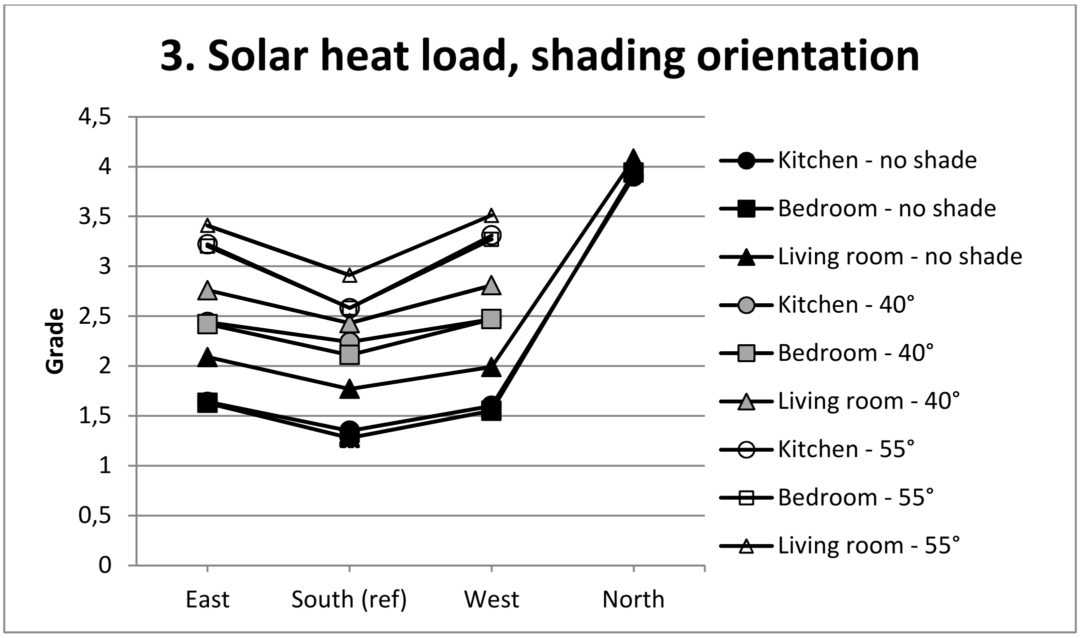

Figure F- 38

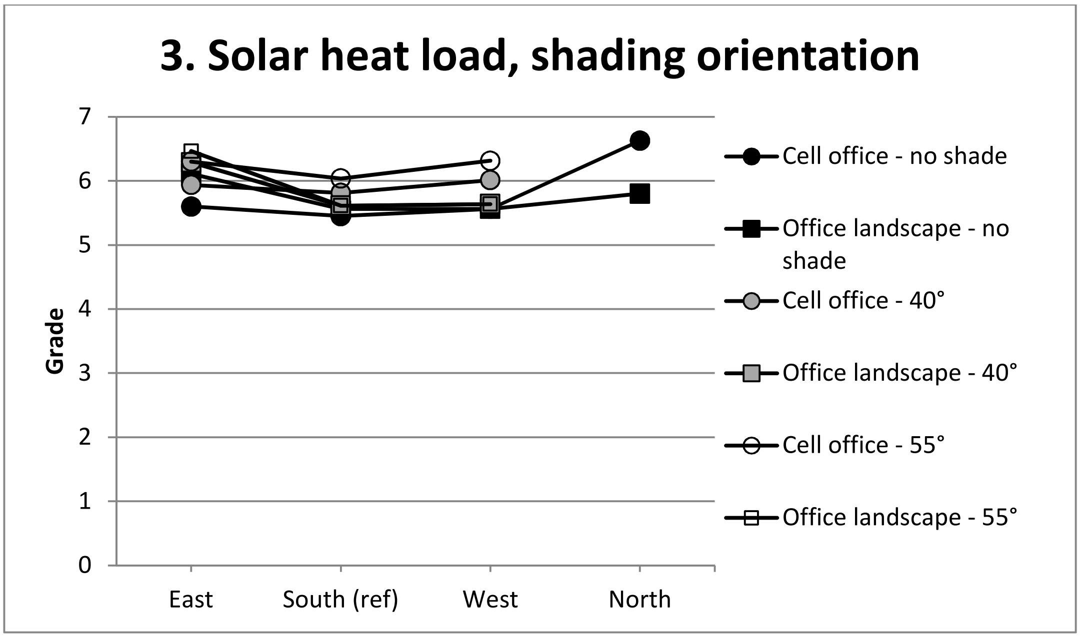

Figure F- 39

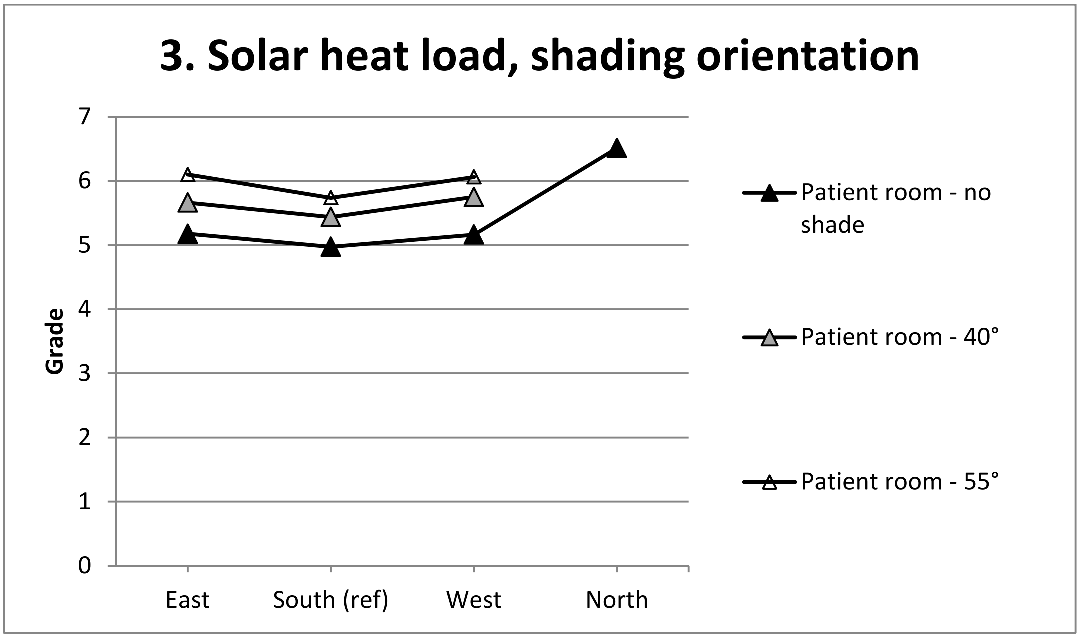

Figure F- 40

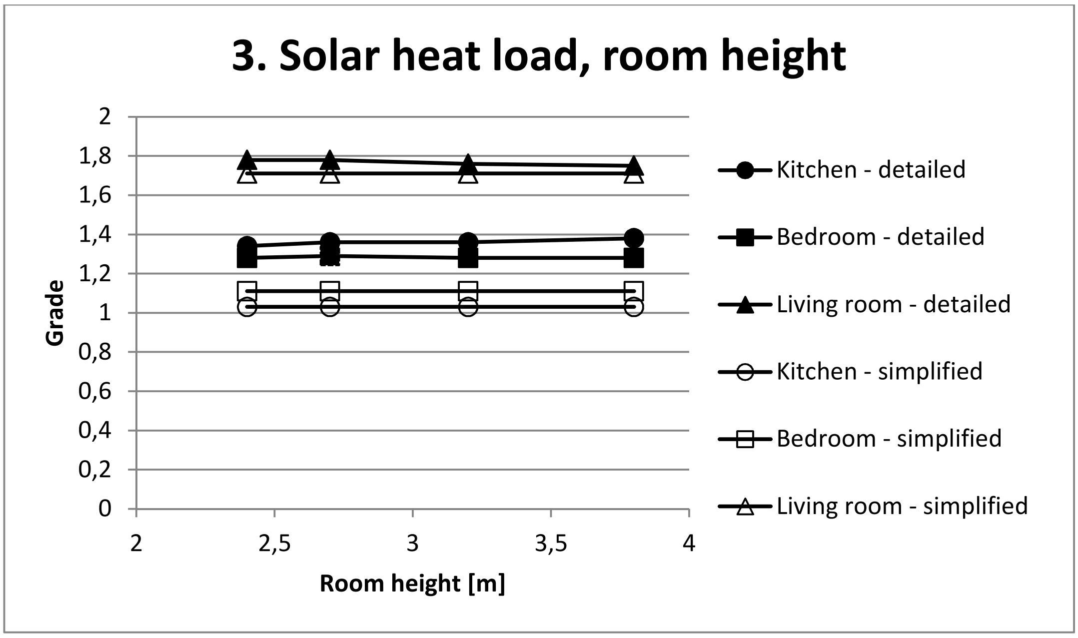

Figure F- 41

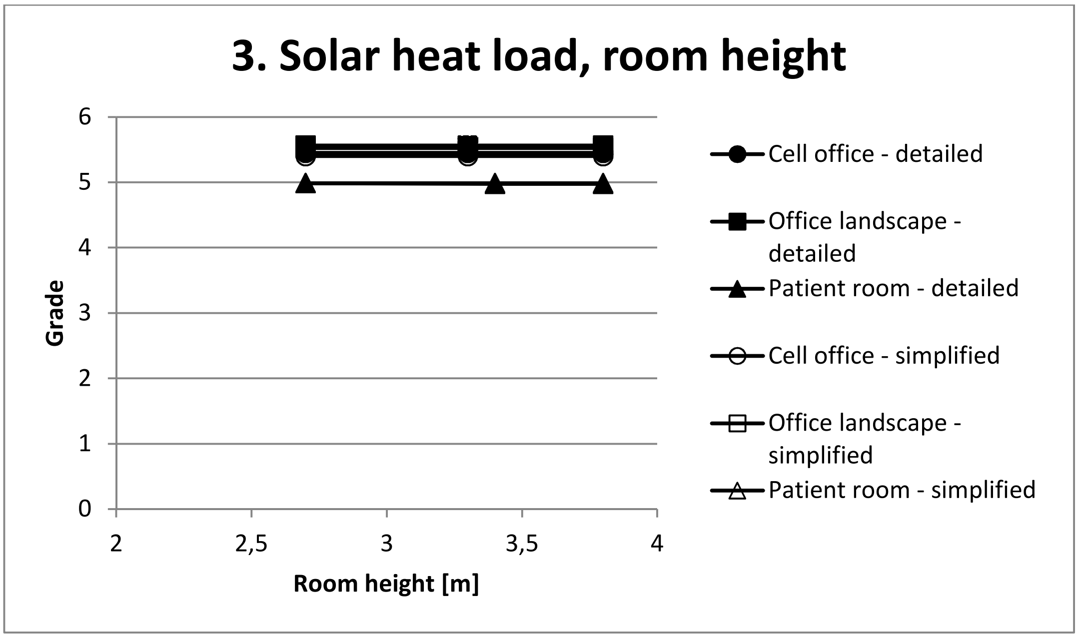

Figure F- 42

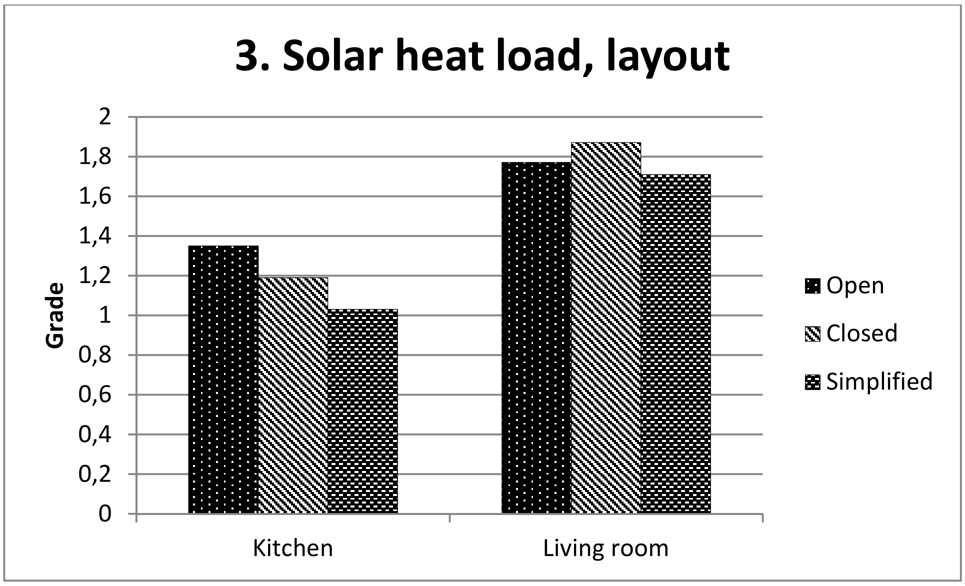
3. Solar heat load, layout
Grade
2
1,8
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
Kitchen
Living room
Open
Closed
Simplified

Figure F- 43

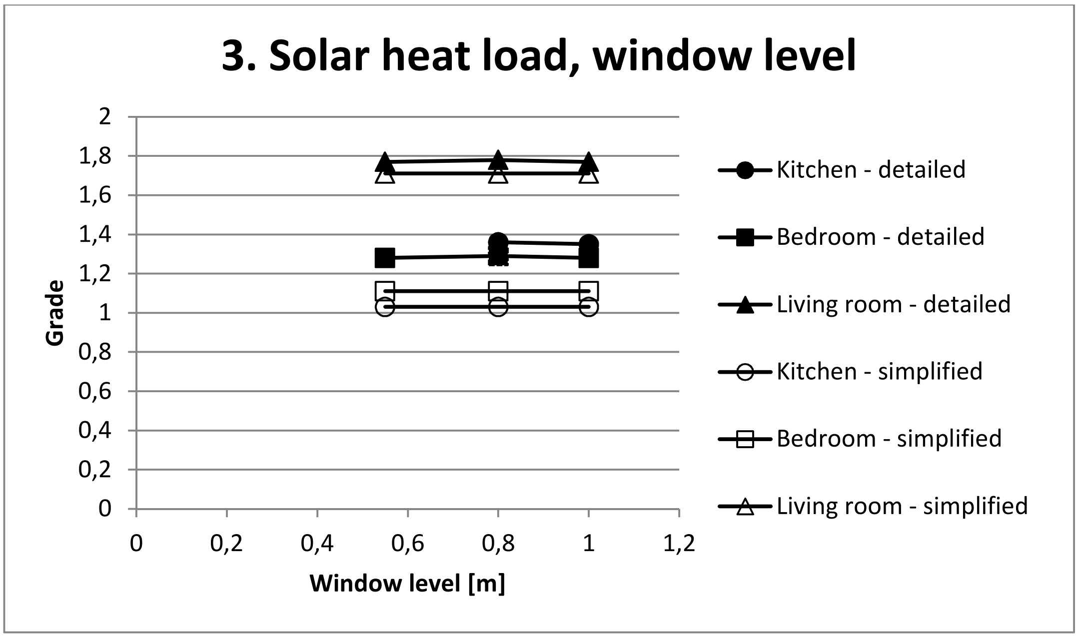

Figure F- 44

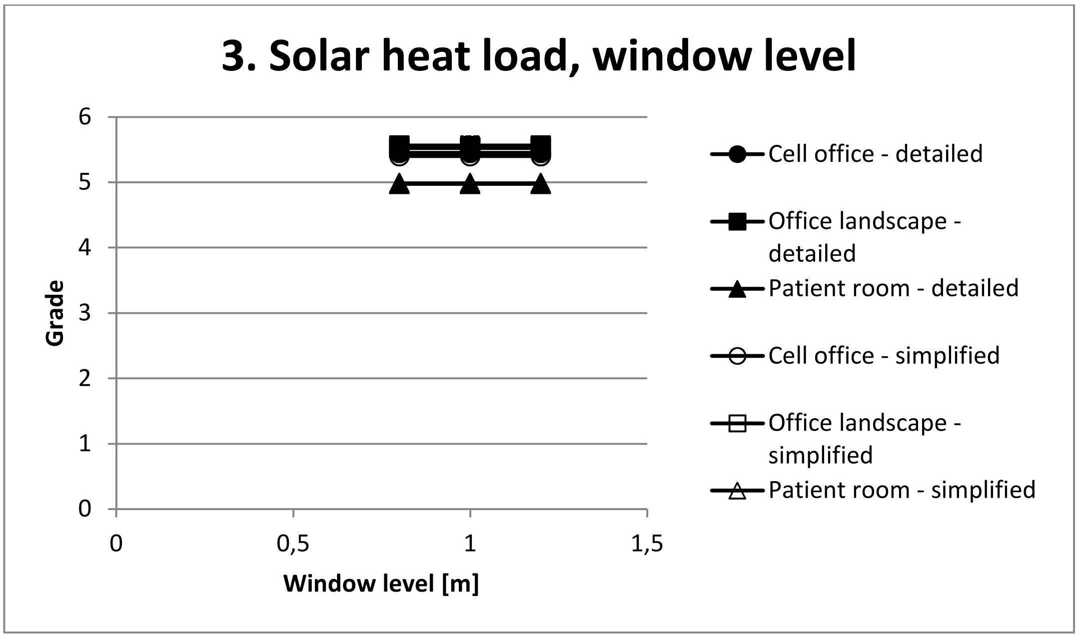

Figure F- 45

F2b Indicator 10: Thermal climate - winter

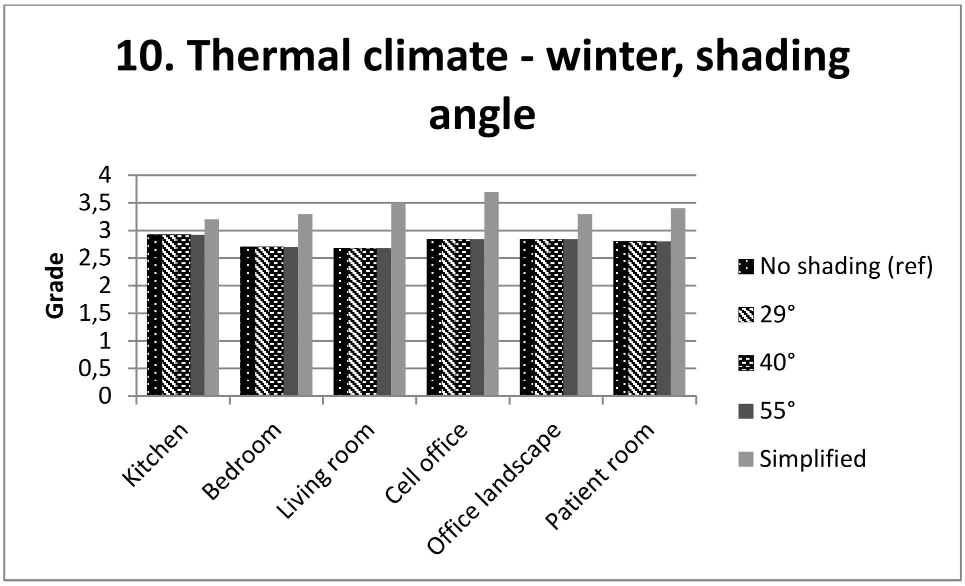

Figure F- 46

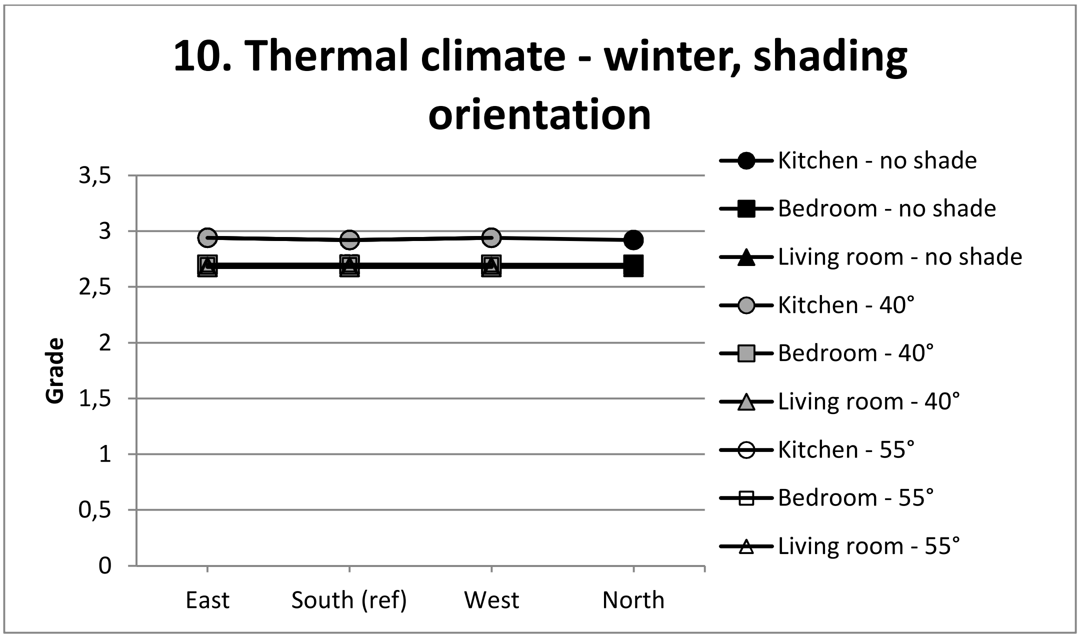

Figure F- 47

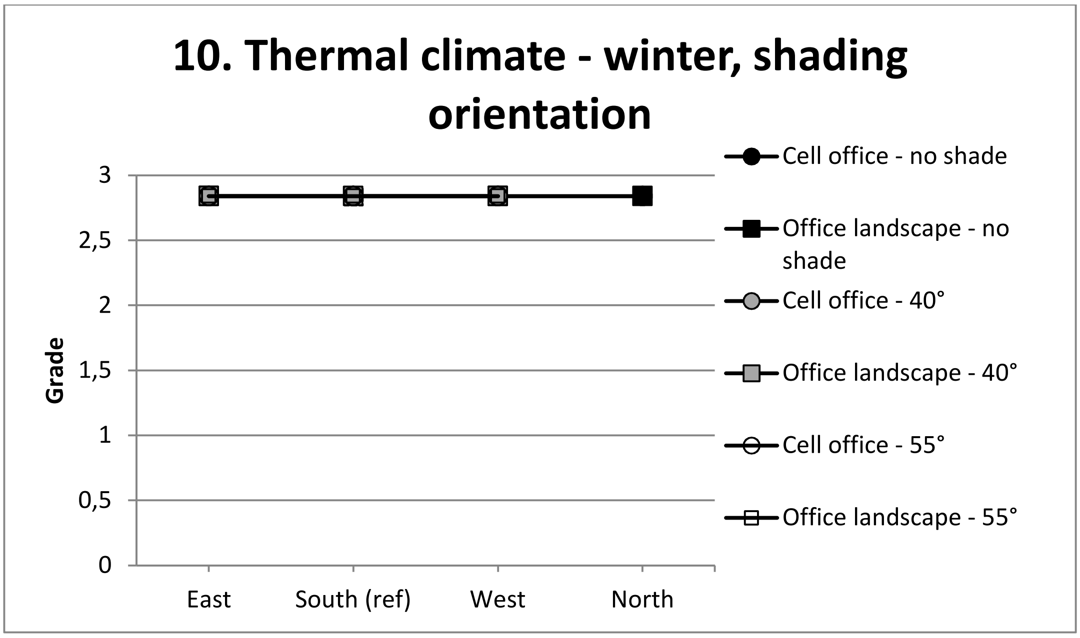

Figure F- 48

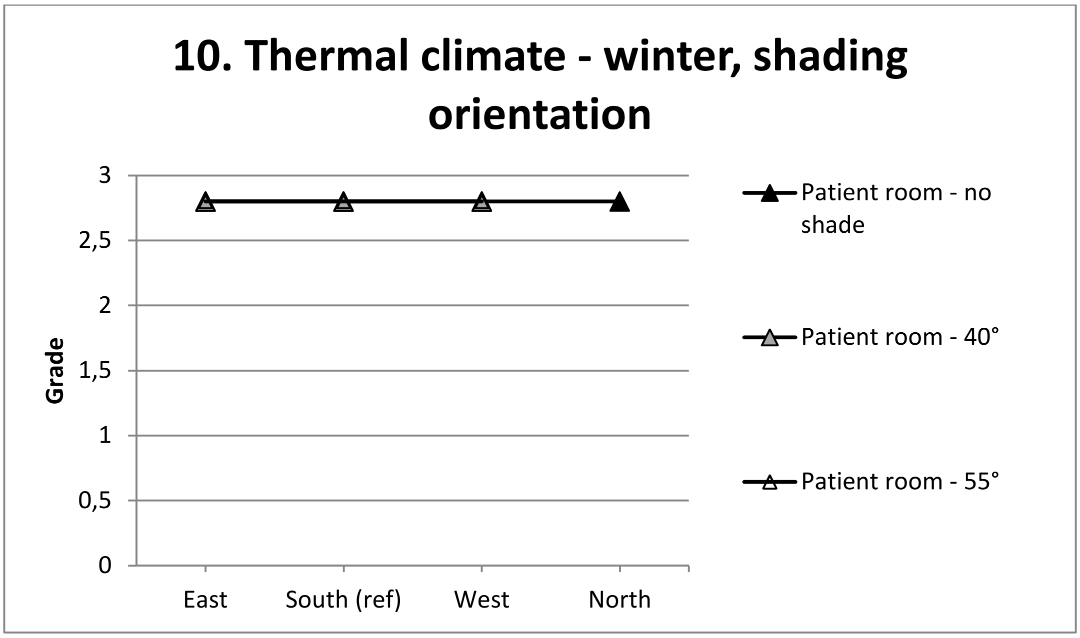

Figure F- 49

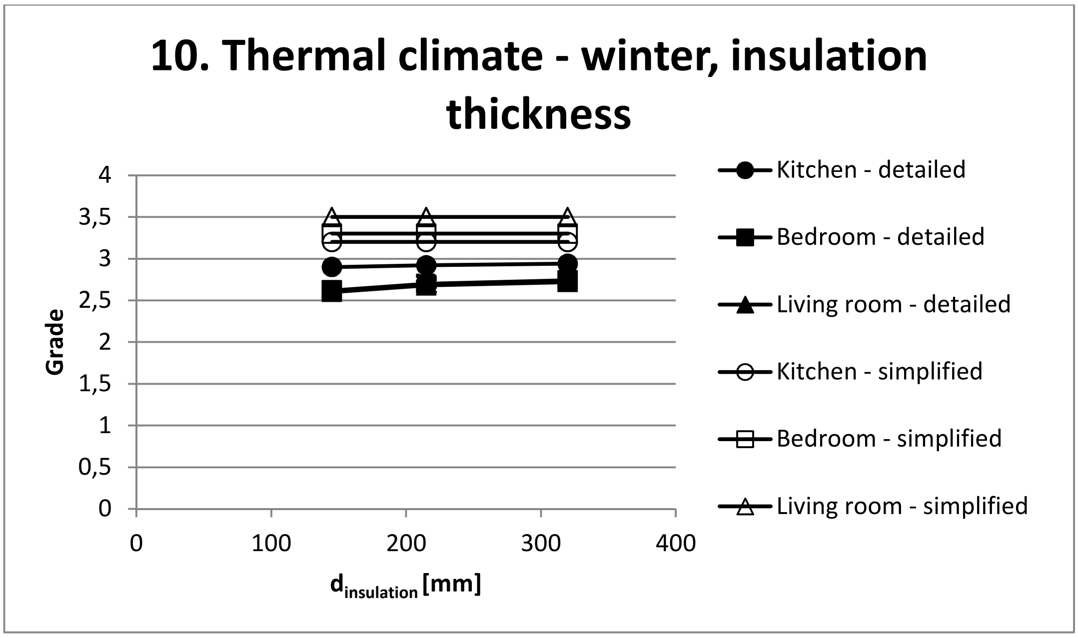

Figure F- 50

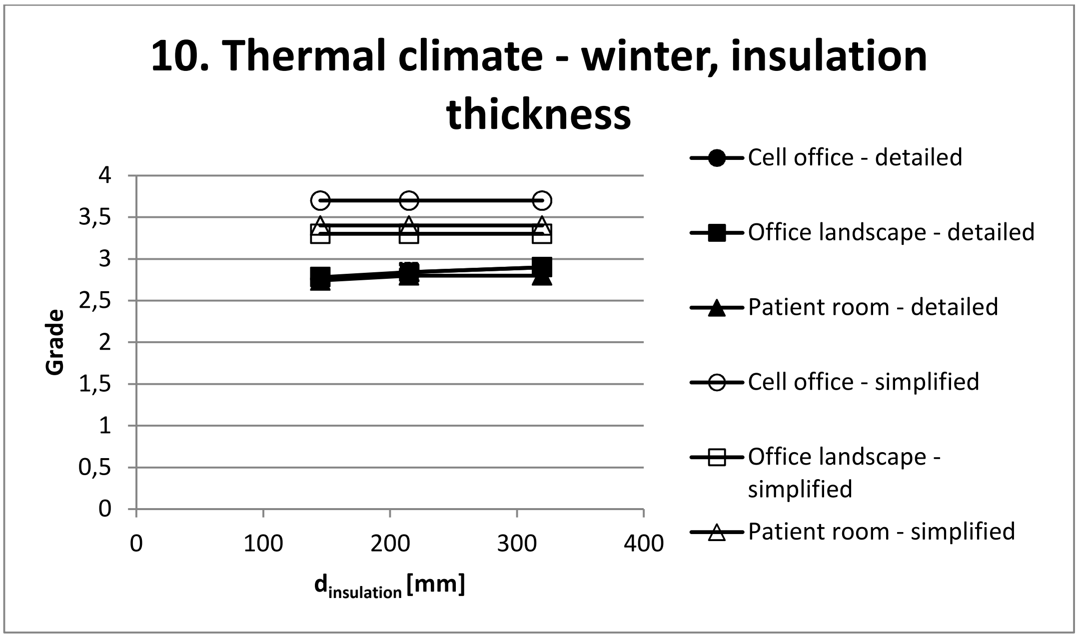

Figure F- 51

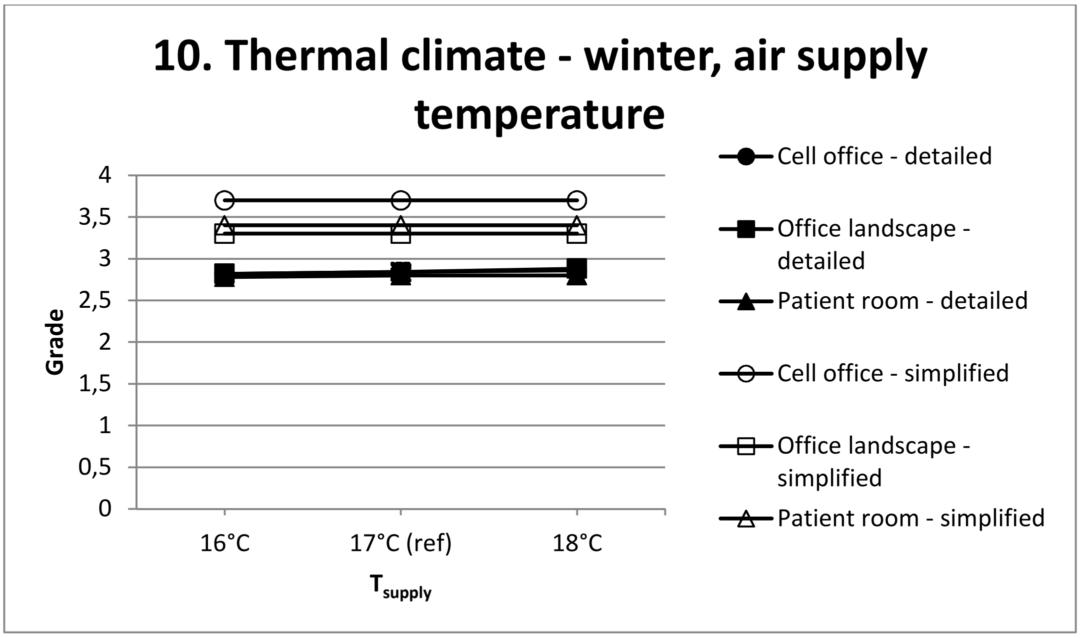
10. Thermal climate - winter, air supply temperature
Grade
4
3,5
3
2,5
2
1,5
1
0,5
0
16°C
17°C (ref)
18°C
T supply
Cell office - detailed
Office landscape - detailed
Patient room - detailed
Cell office - simplified
Office landscape - simplified
Patient room - simplified

Figure F- 52

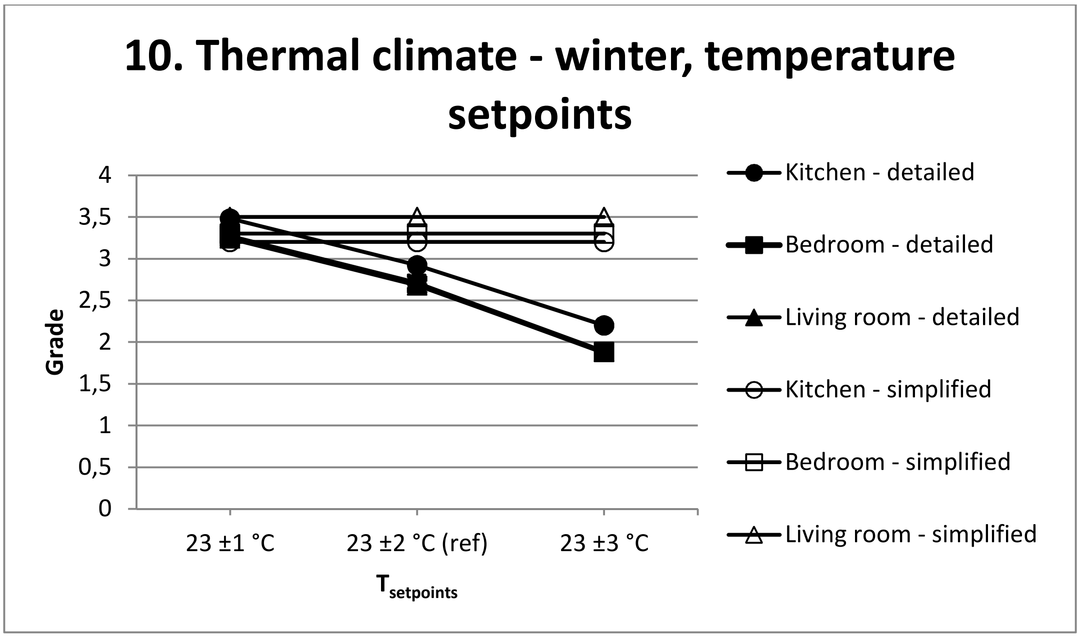

Figure F- 53

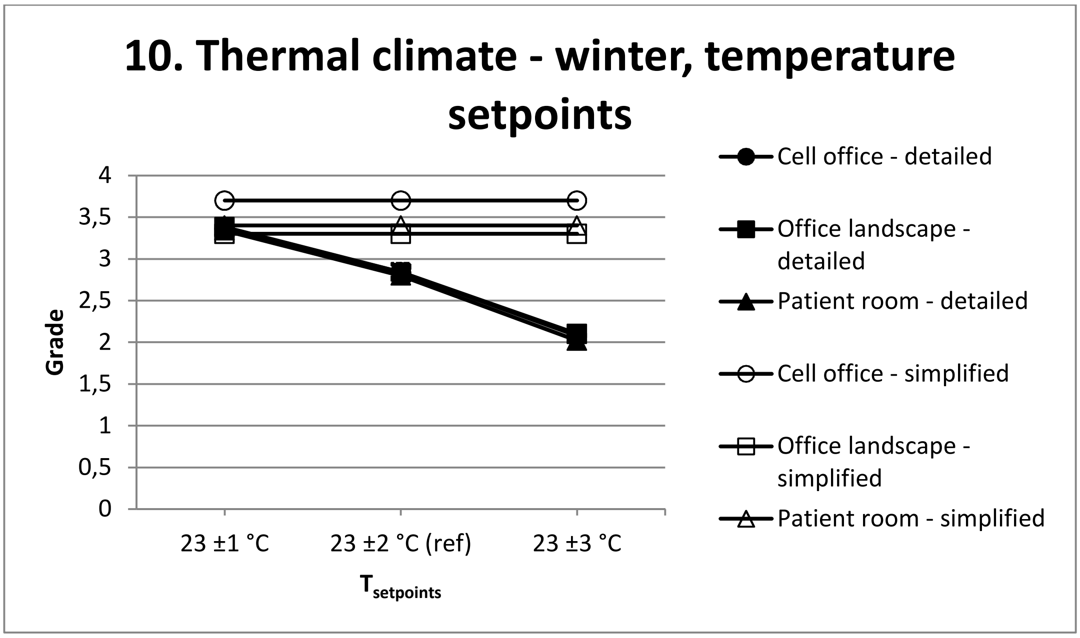

Figure F- 54

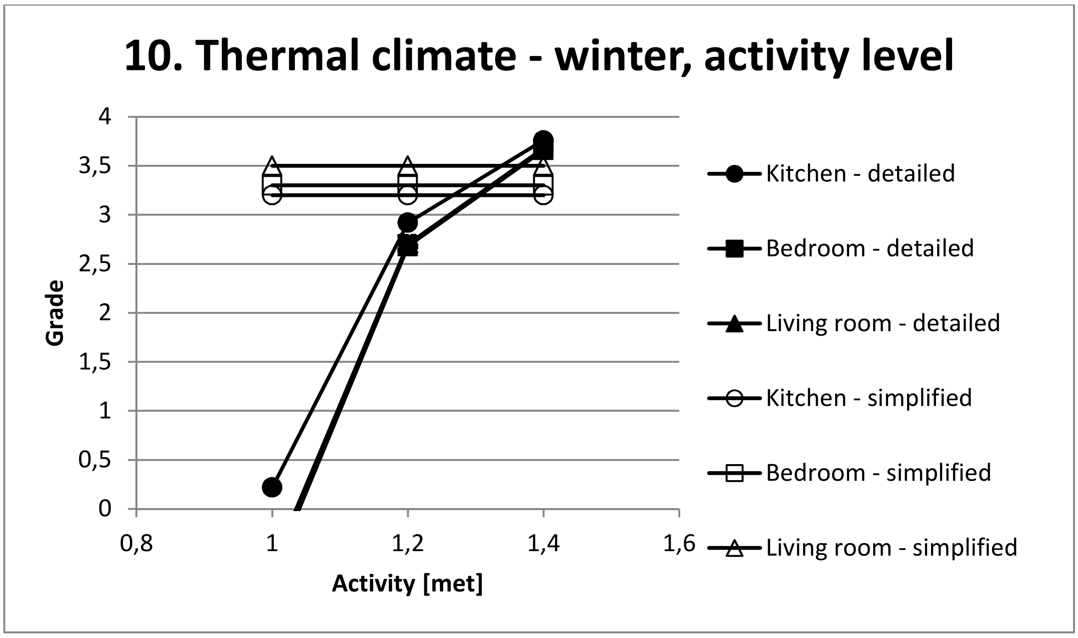

Figure F- 55

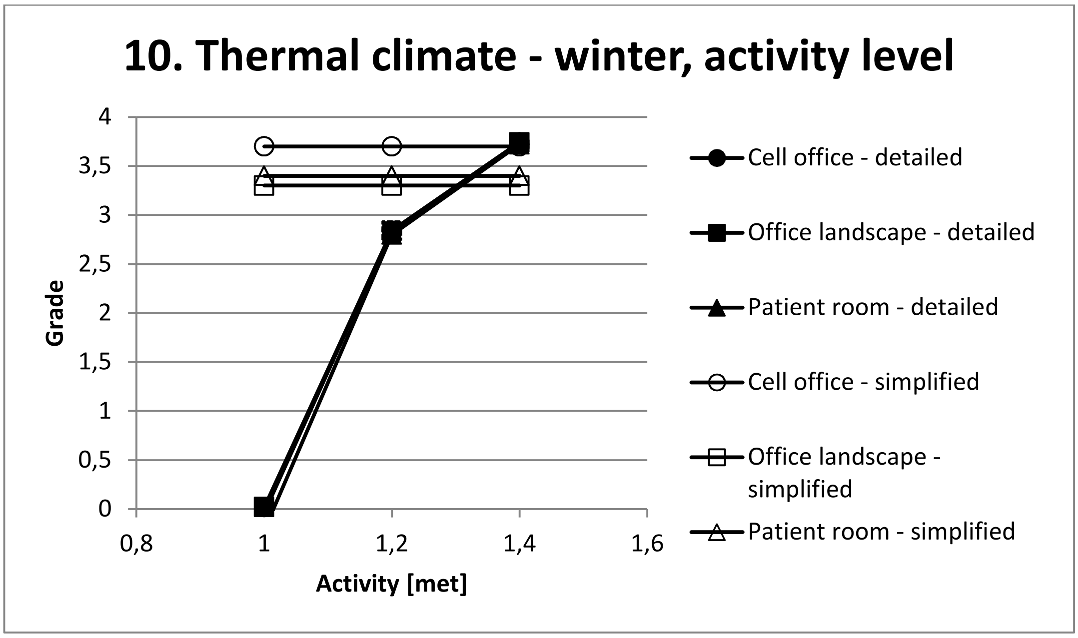

Figure F- 56

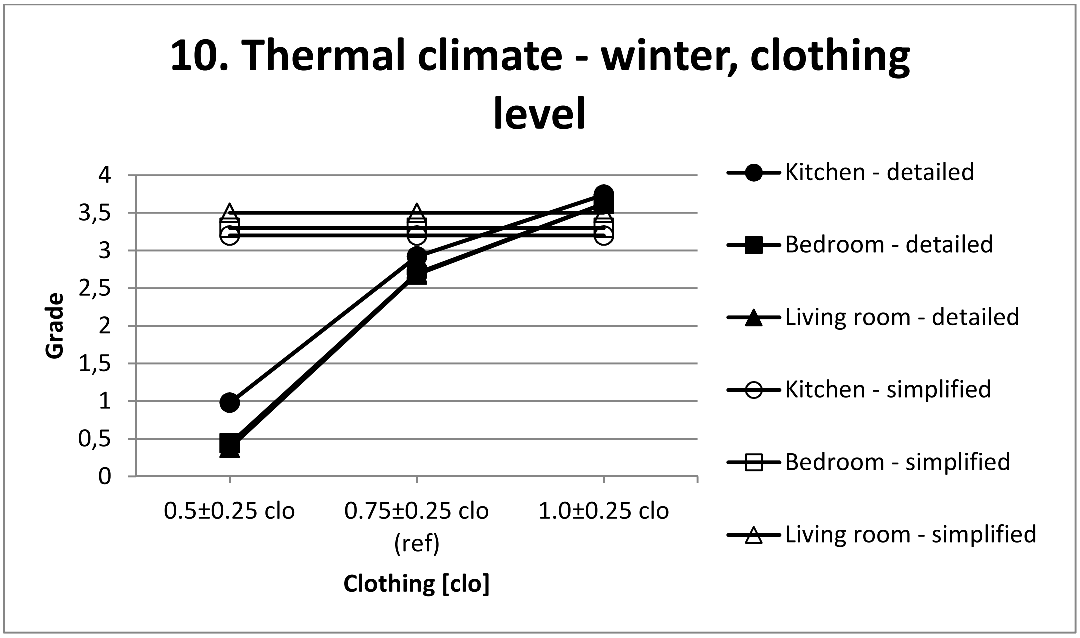

Figure F- 57

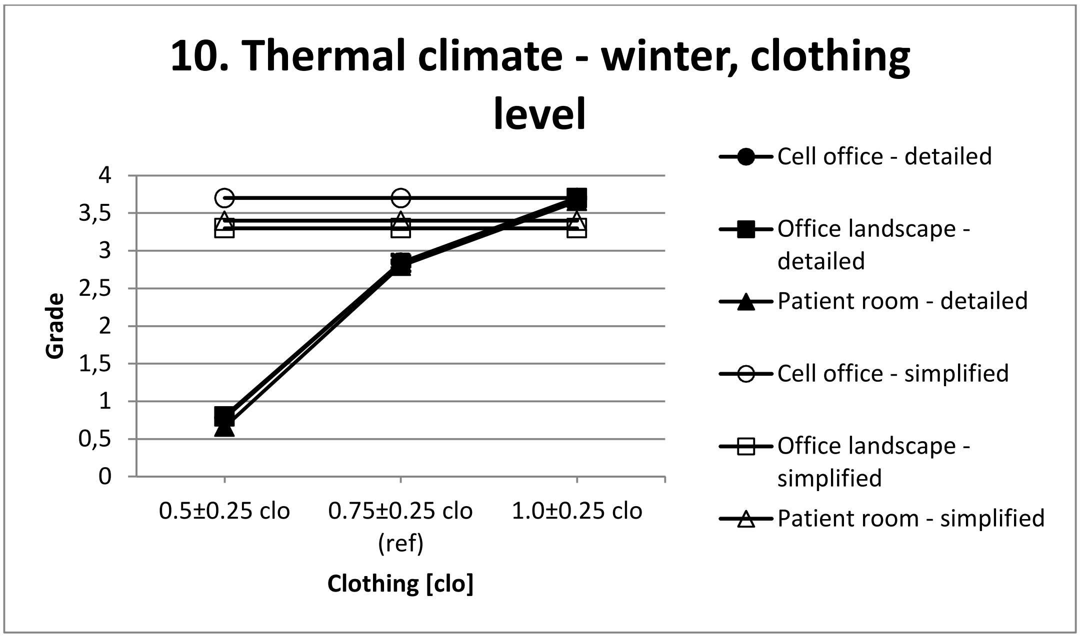

Figure F- 58

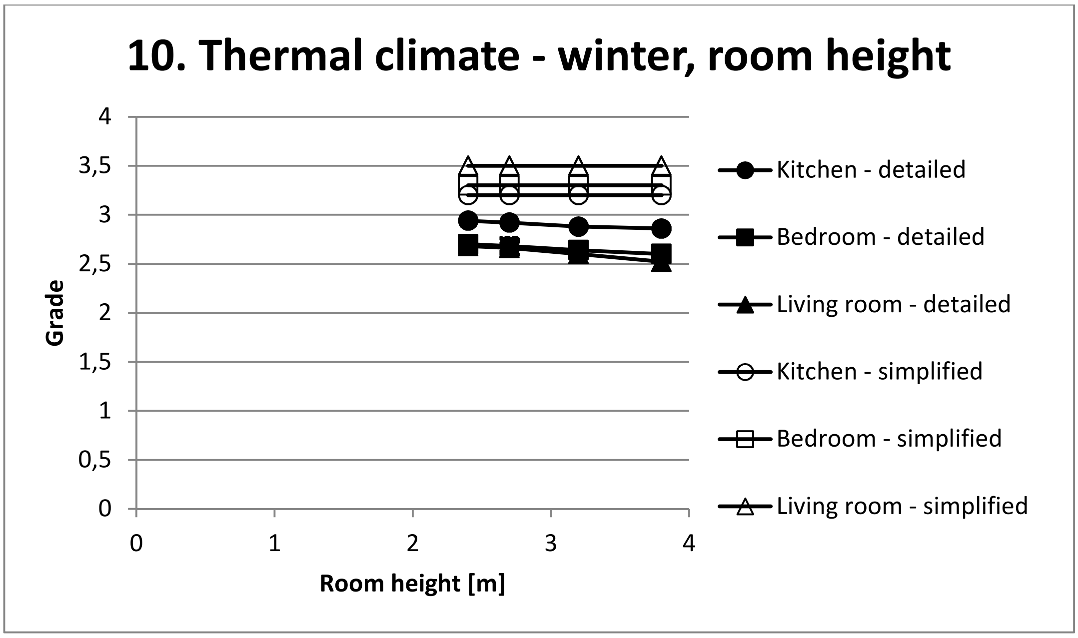

Figure F- 59

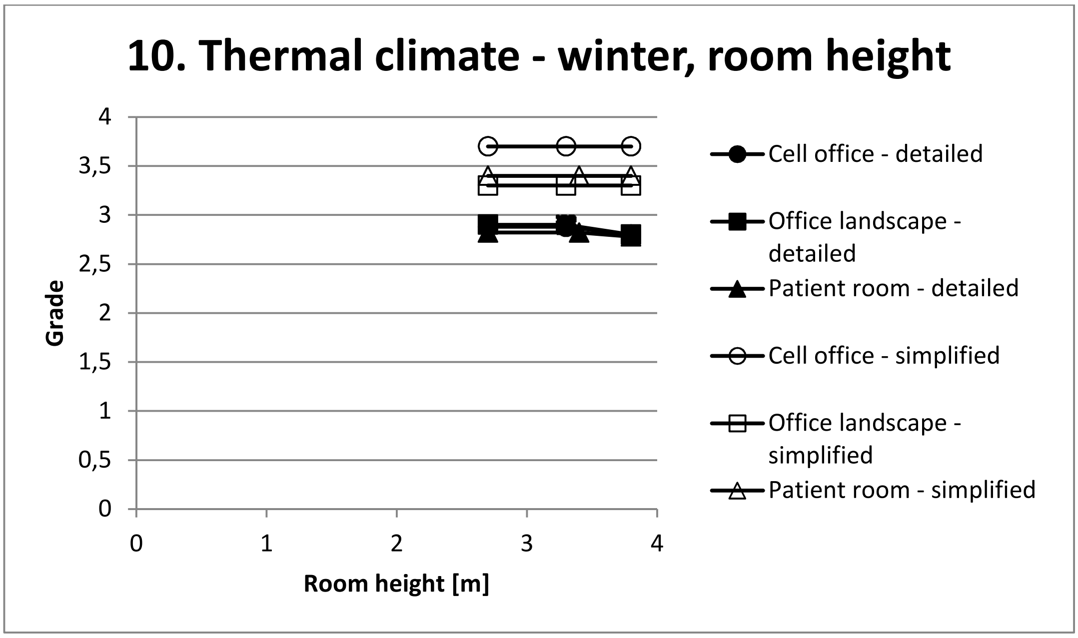

Figure F- 60

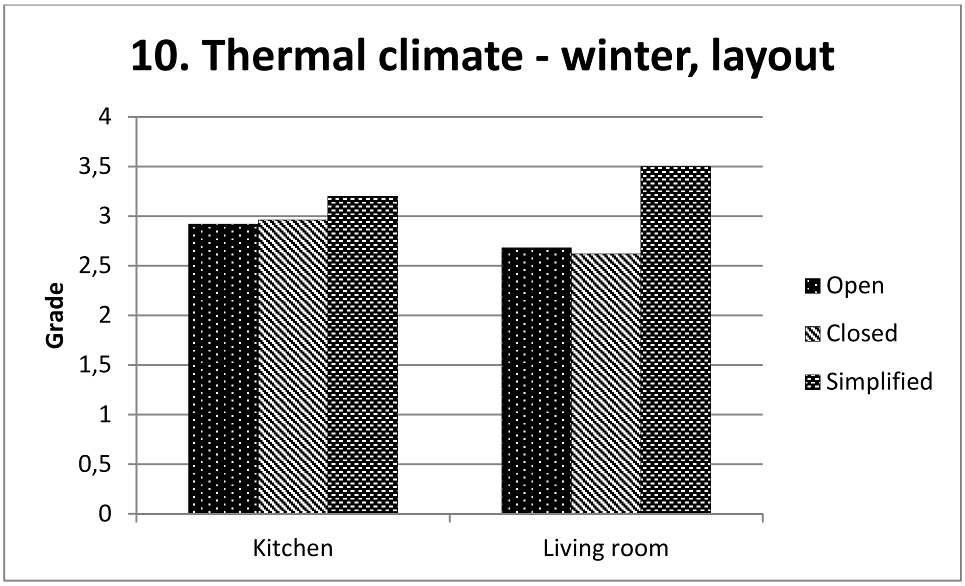
10. Thermal climate - winter, layout
Grade
4
3,5
3
2,5
2
1,5
1
0,5
0
Kitchen
Living room
Open
Closed
Simplified

Figure F- 61

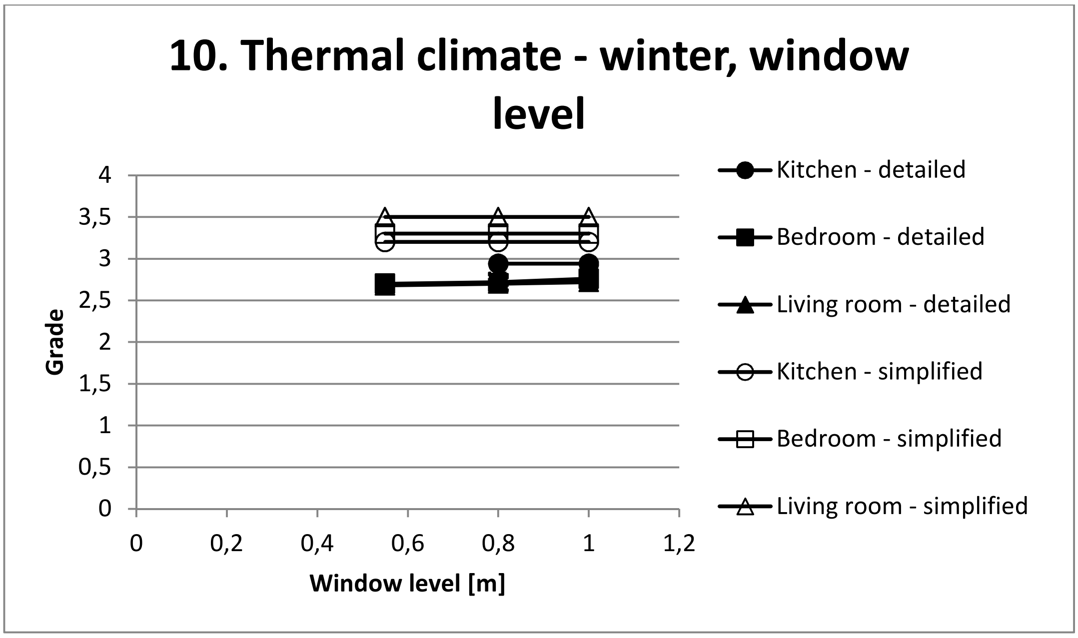

Figure F- 62

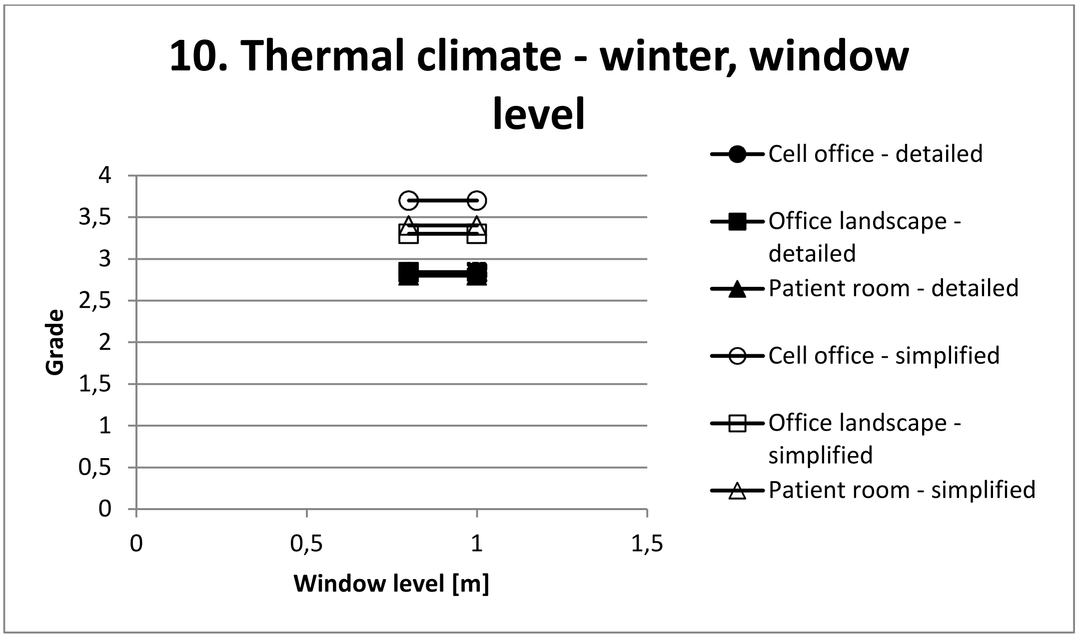

Figure F- 63

F2c Indicator 11: Thermal climate - summer

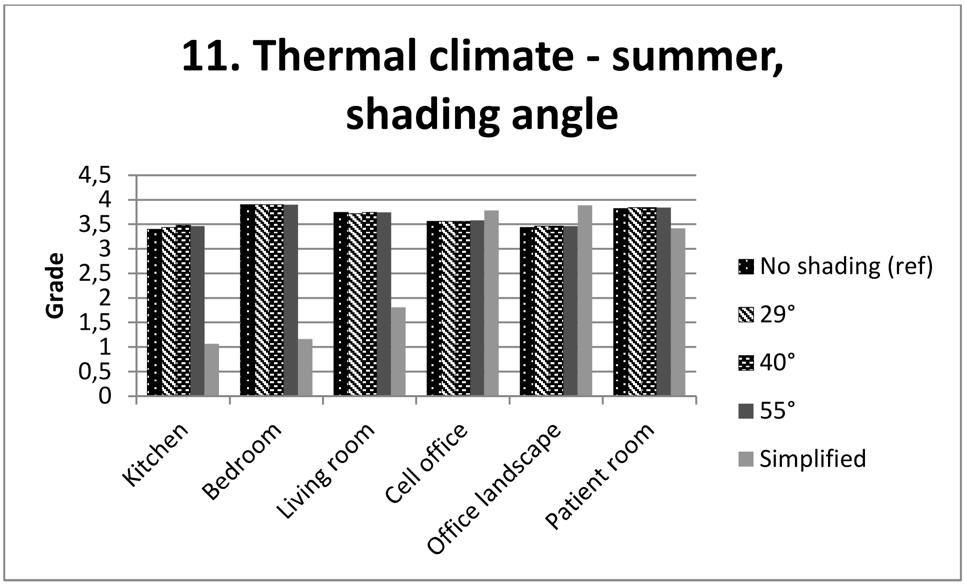

Figure F- 64

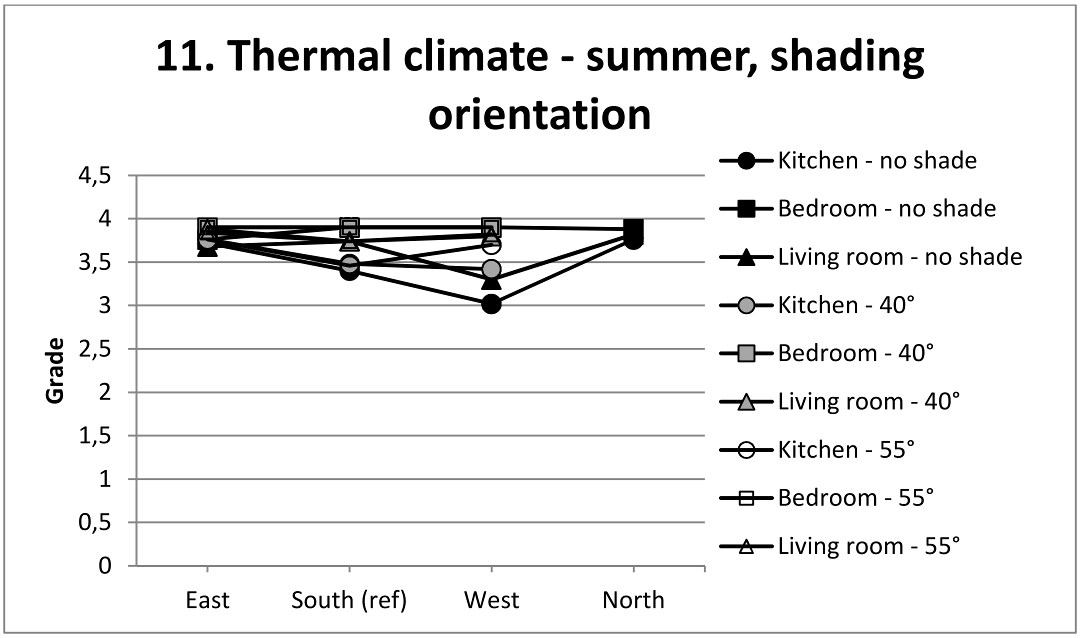

Figure F- 65

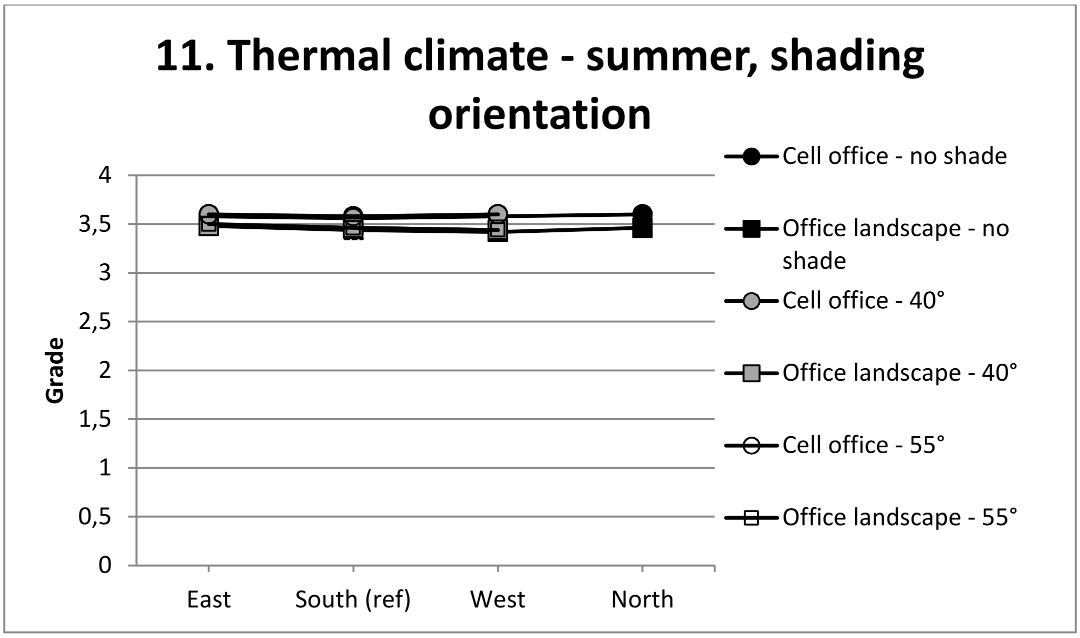

Figure F- 66

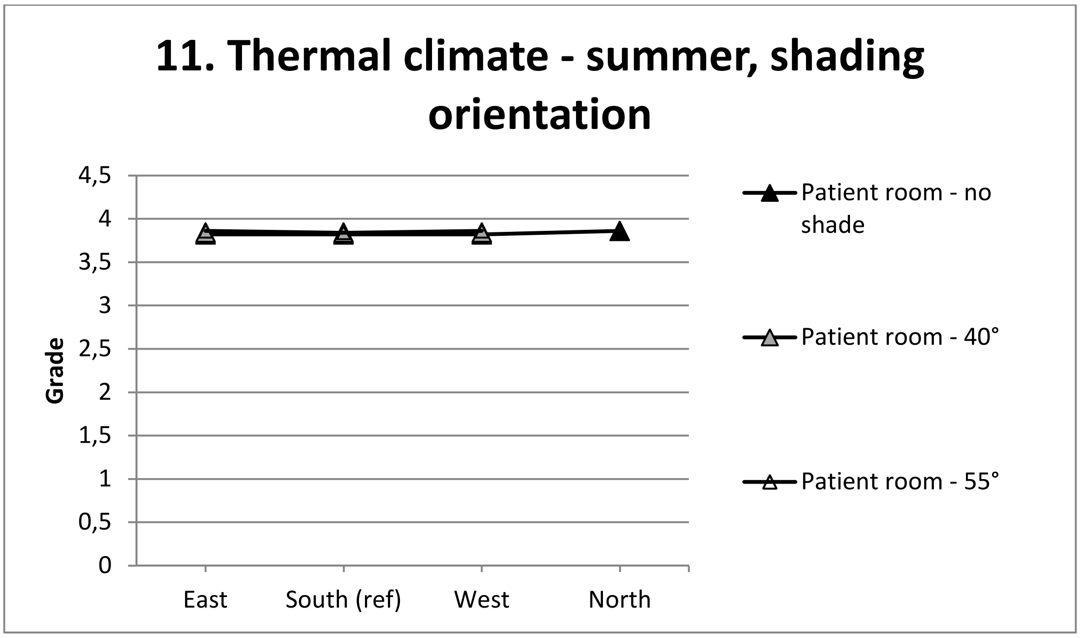

Figure F- 67

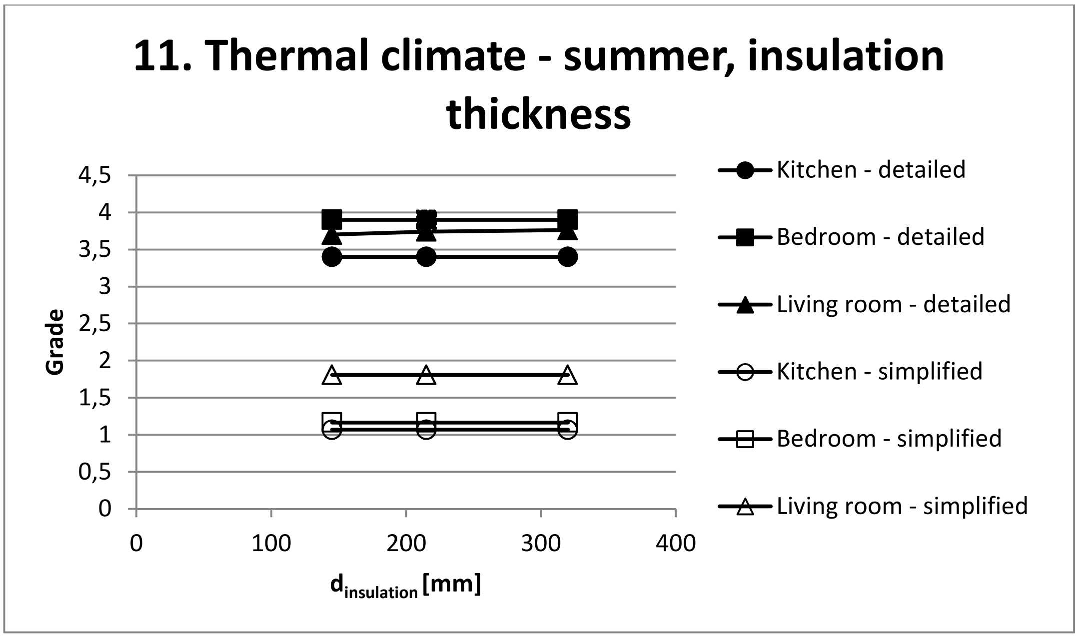

Figure F- 68

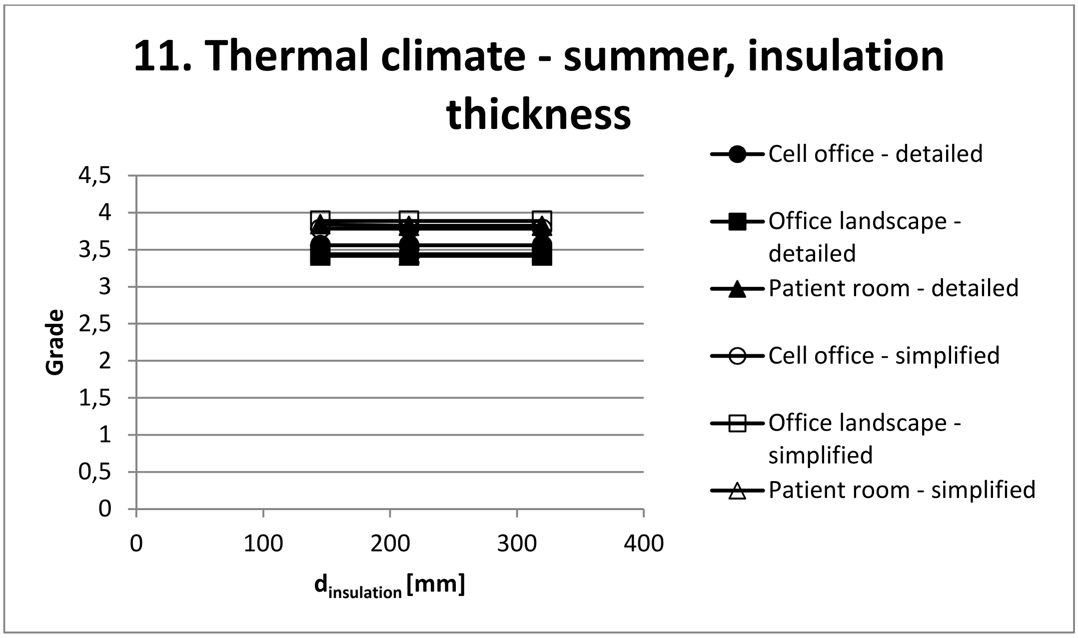

Figure F- 69

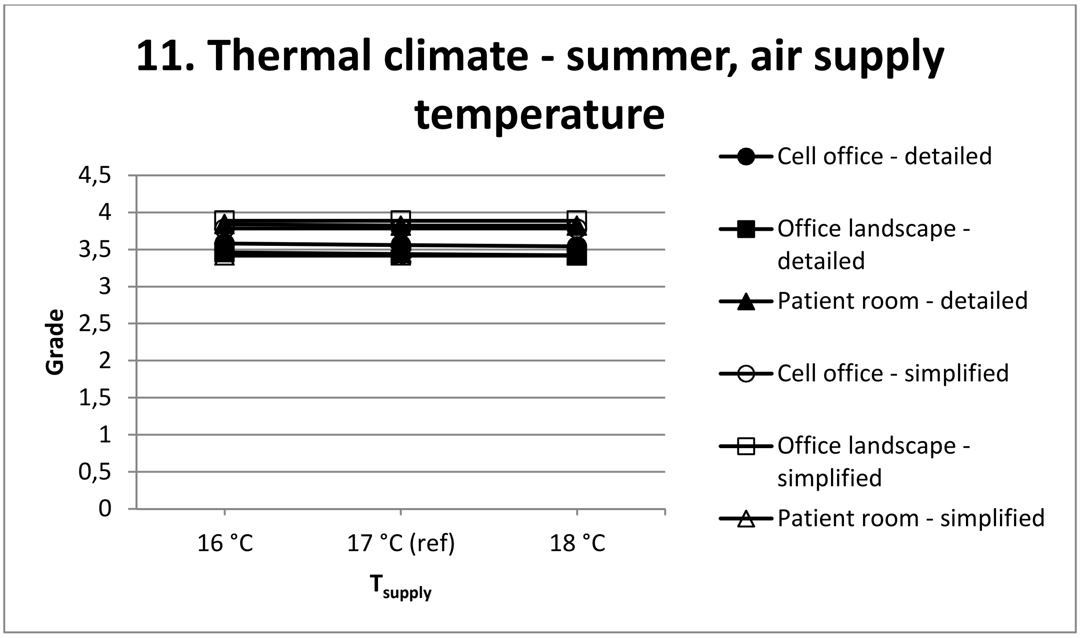
11. Thermal climate - summer, air supply temperature
Grade
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
16 °C
17 °C (ref)
18 °C
T_{supply}
Cell office - detailed
Office landscape - detailed
Patient room - detailed
Cell office - simplified
Office landscape - simplified
Patient room - simplified

Figure F- 70

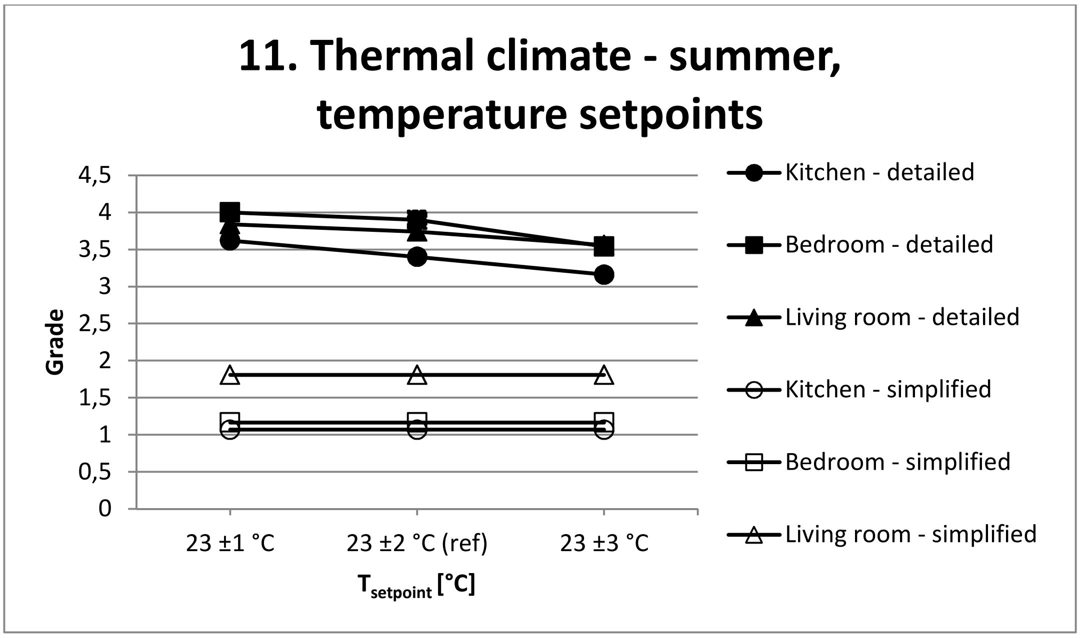

Figure F- 71

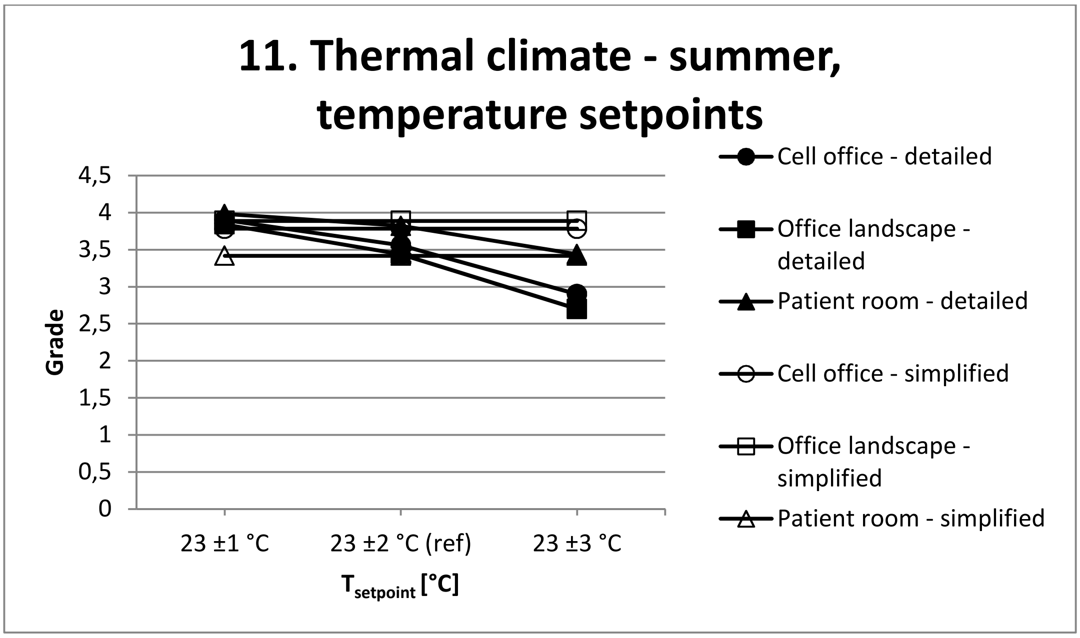

Figure F- 72

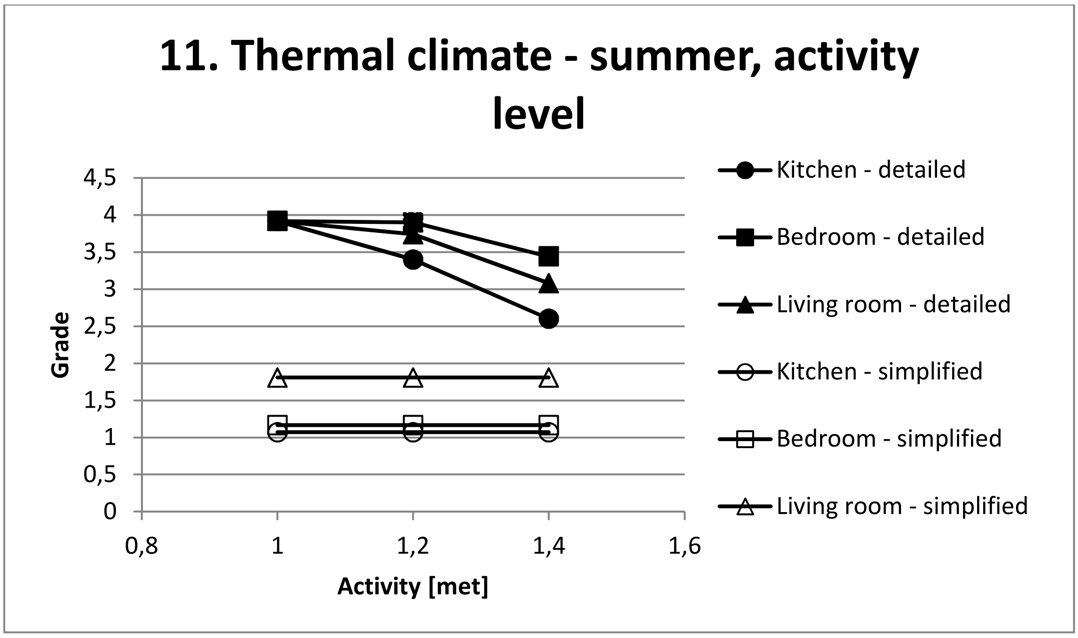

Figure F- 73

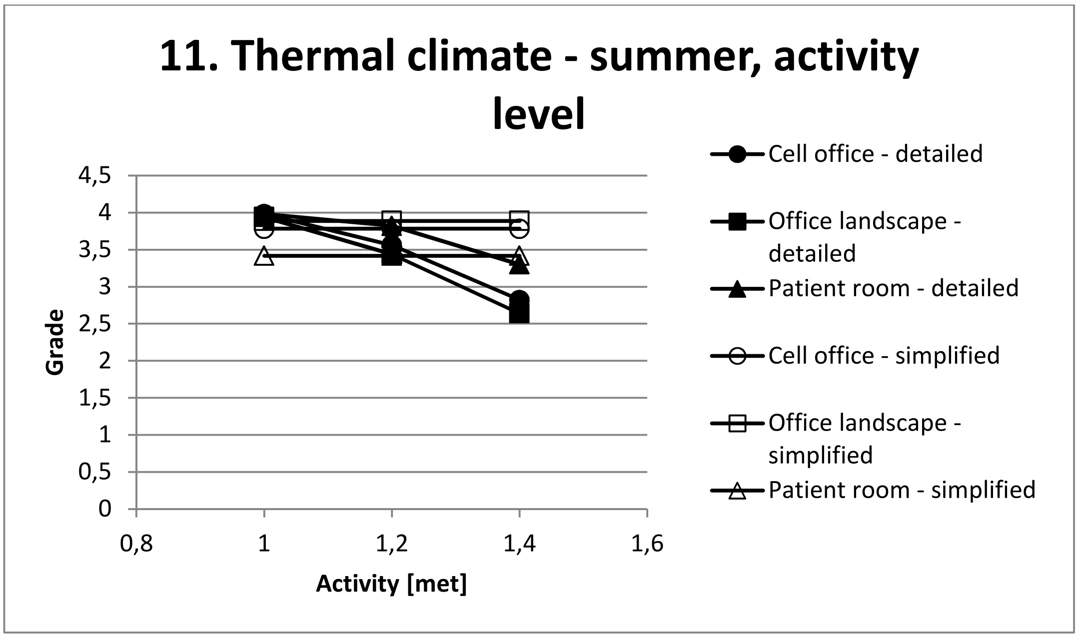

Figure F- 74

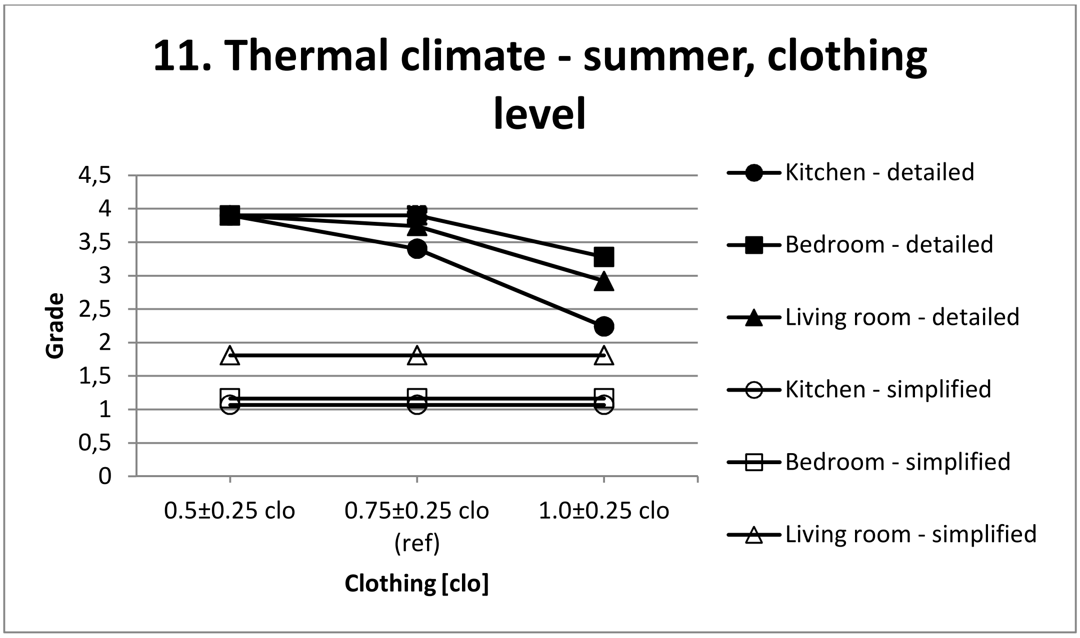

Figure F- 75

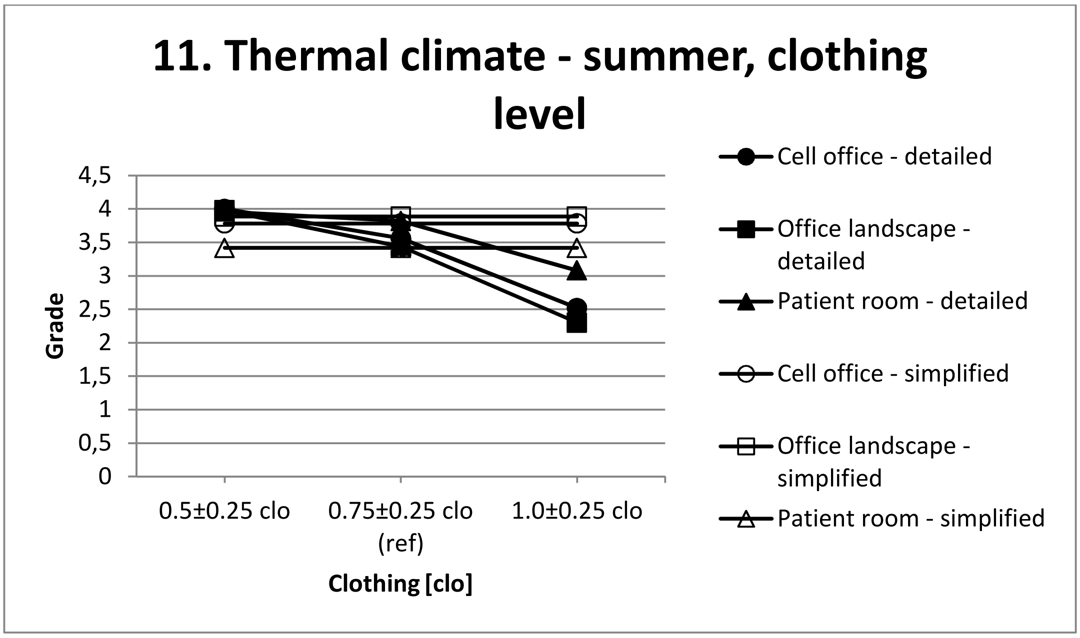

Figure F- 76

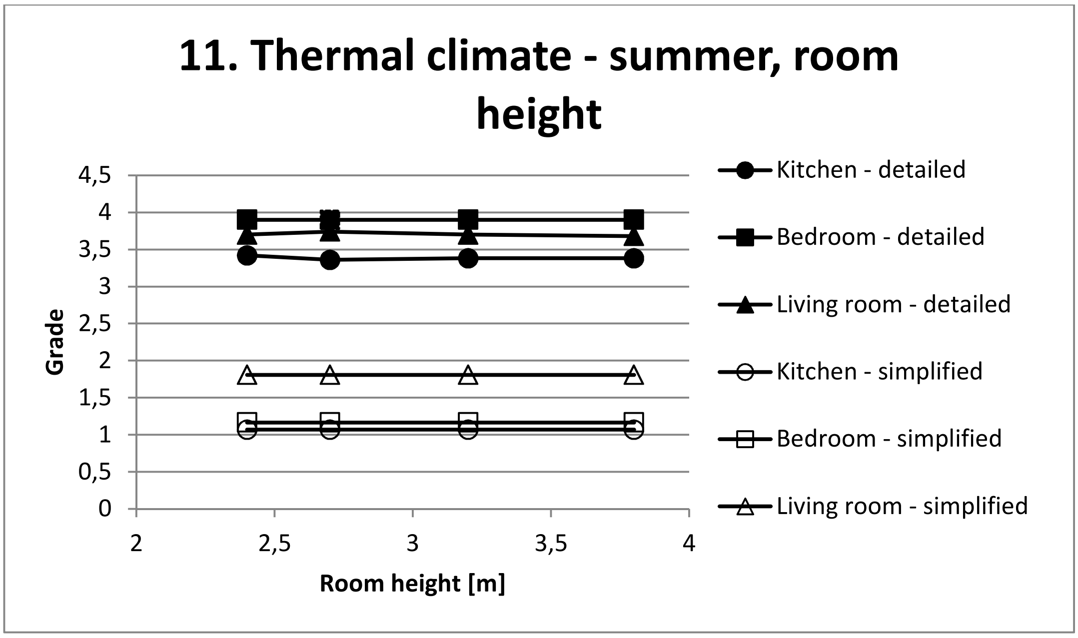

Figure F- 77

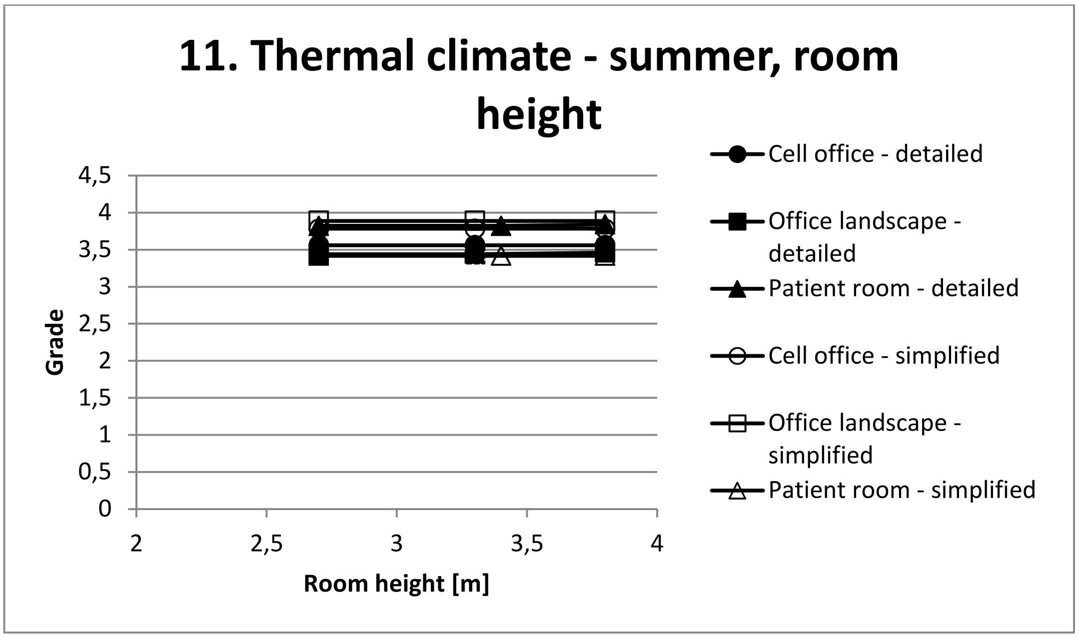

Figure F- 78

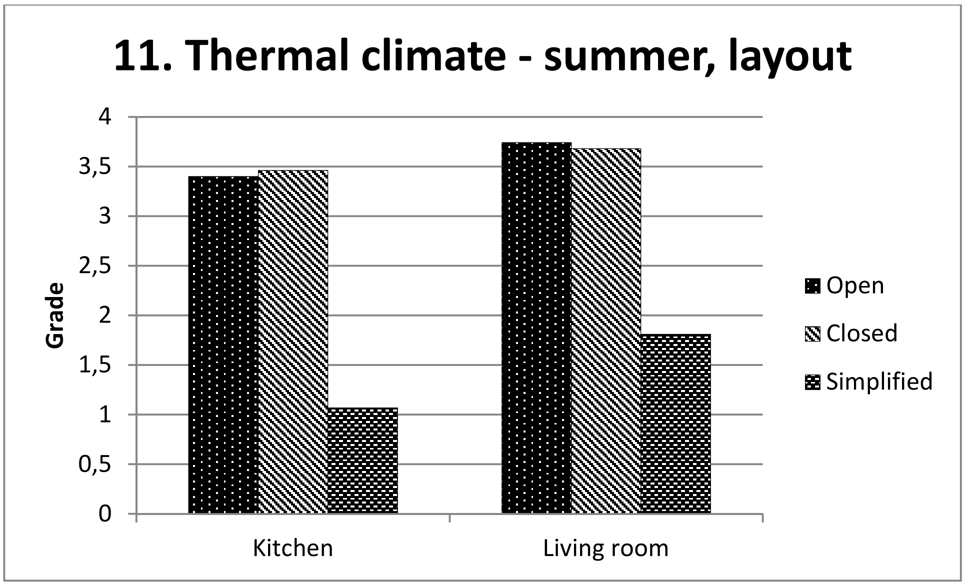
11. Thermal climate - summer, layout
Grade
4
3,5
3
2,5
2
1,5
1
0,5
0
Kitchen
Living room
Open
Closed
Simplified

Figure F- 79

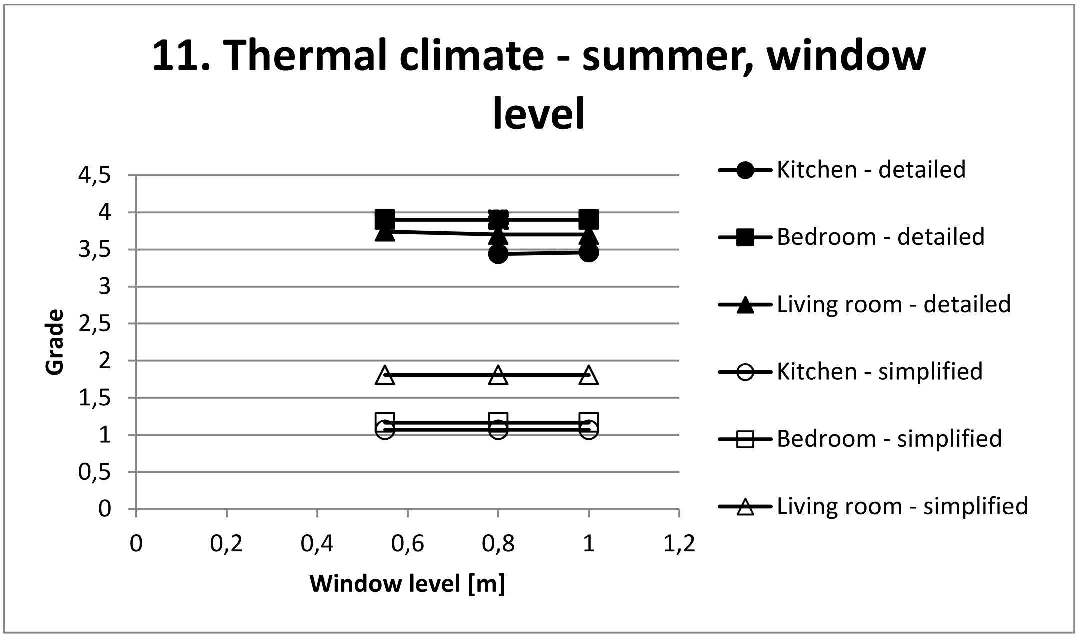

Figure F- 80

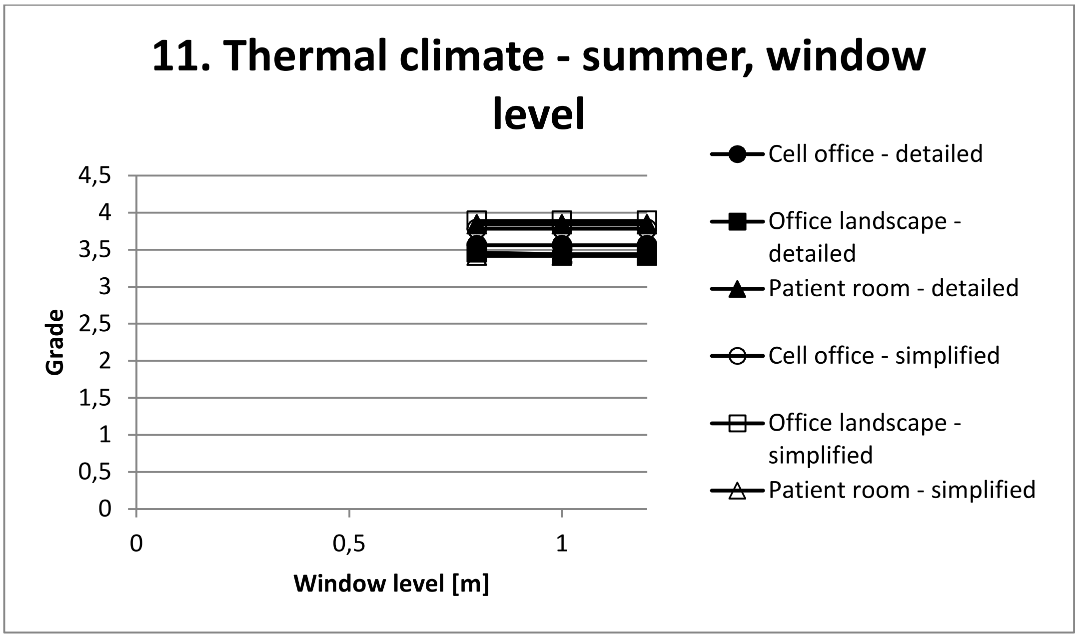

Figure F- 81

F2d Indicator 12: Daylight

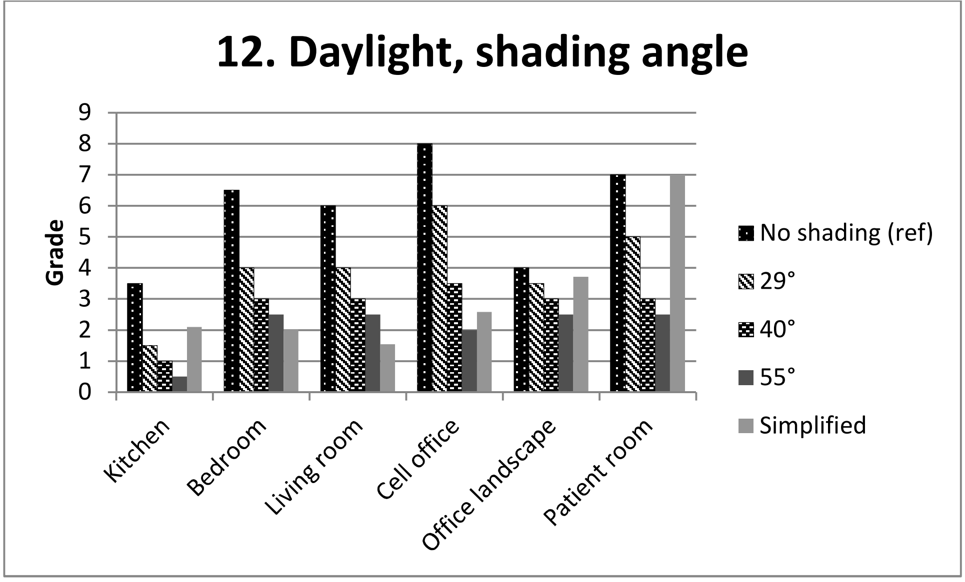

Figure F- 82

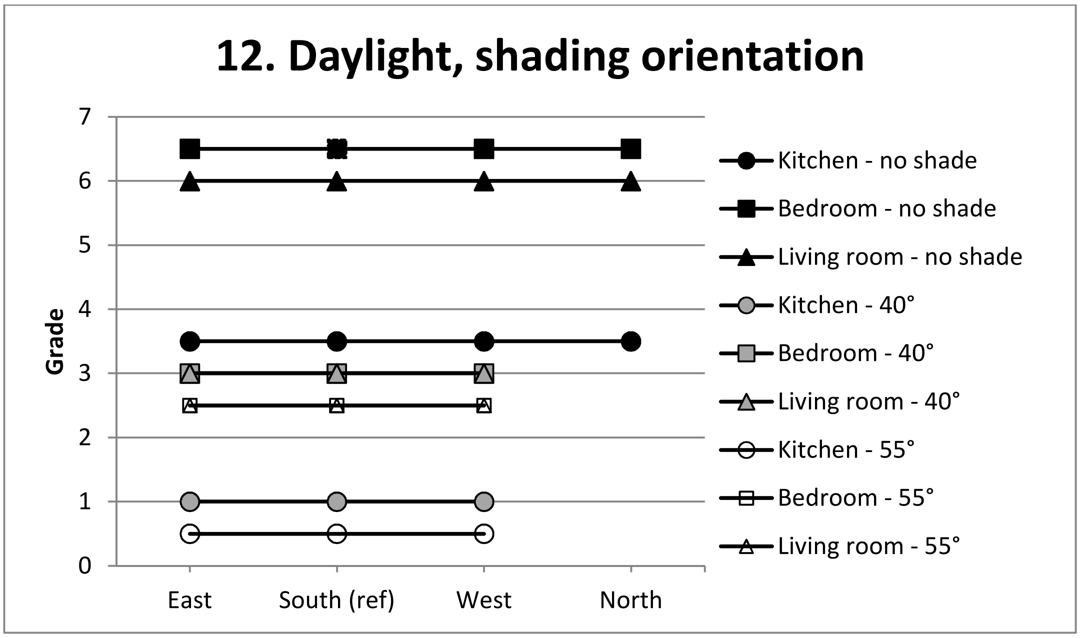

Figure F- 83

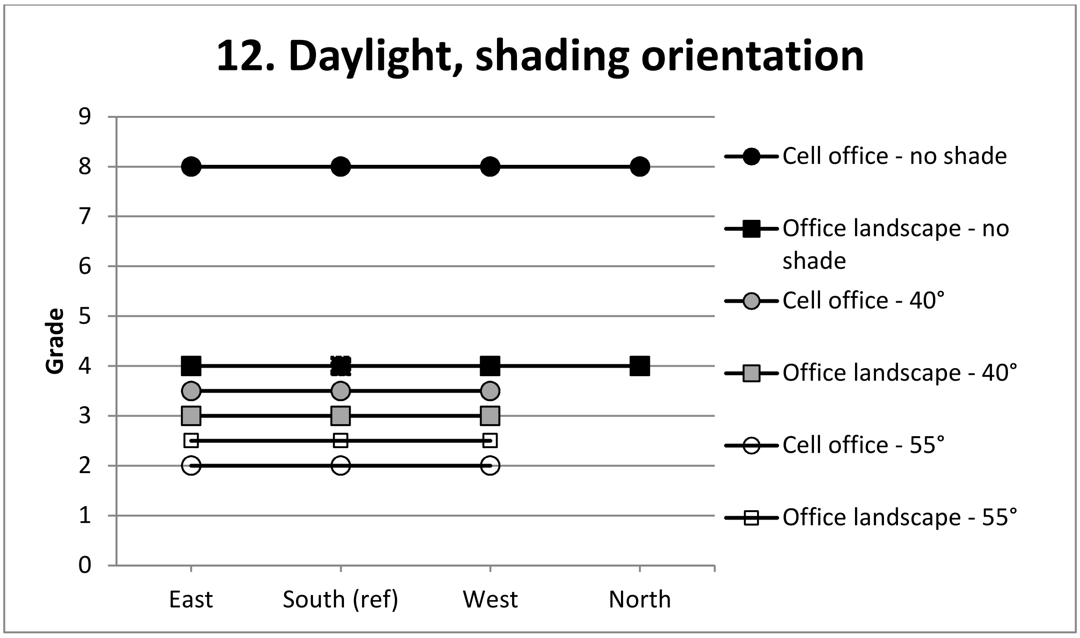

Figure F- 84

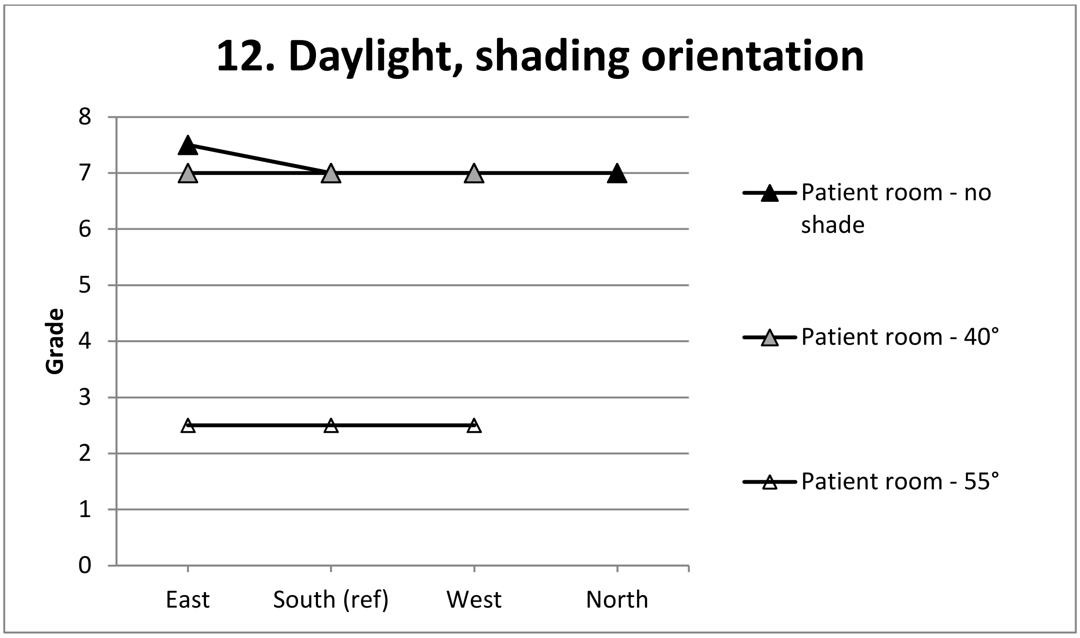

Figure F- 85

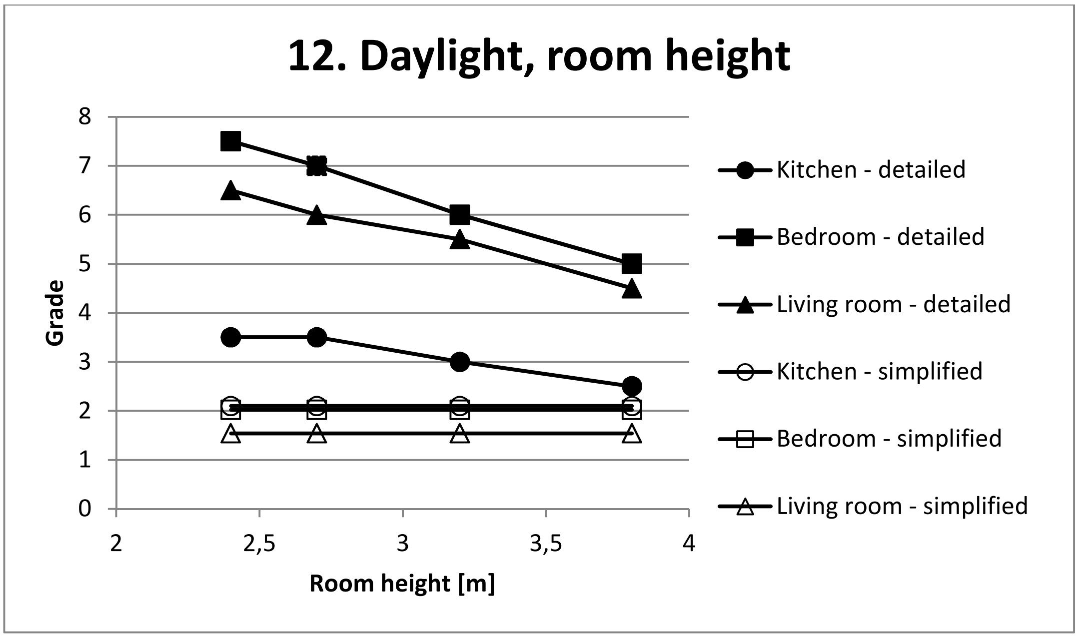

Figure F- 86

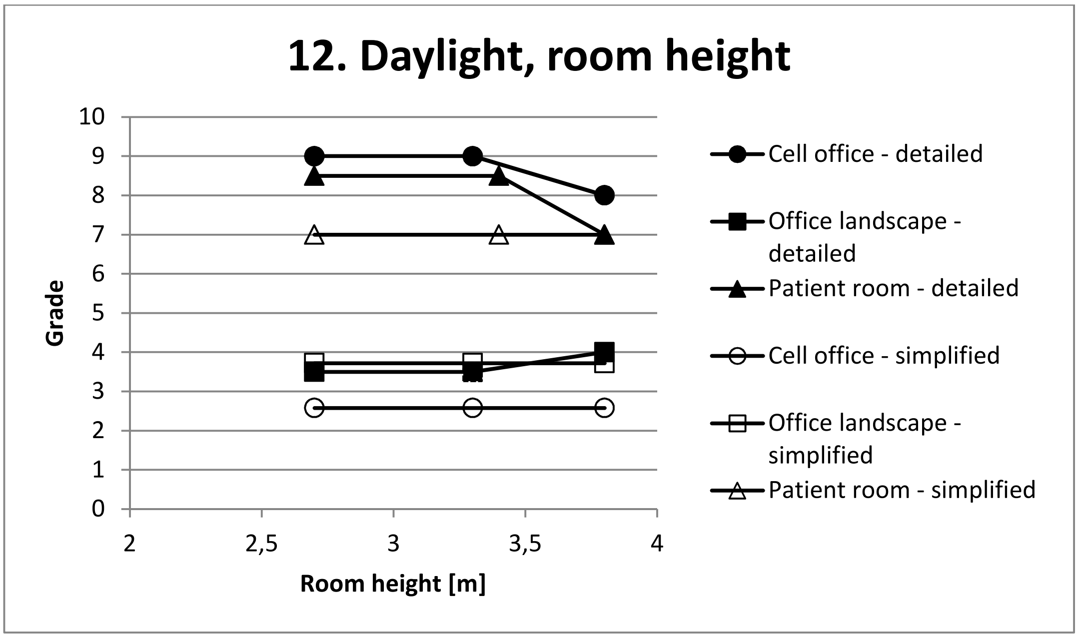

Figure F- 87

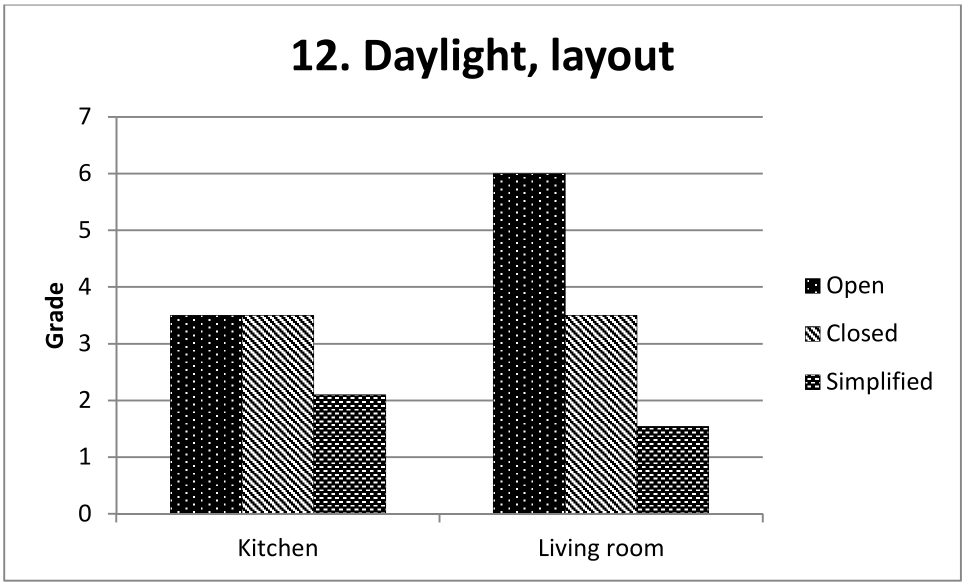
12. Daylight, layout
Grade
0
1
2
3
4
5
6
7
Kitchen
Living room
Open
Closed
Simplified

Figure F- 88

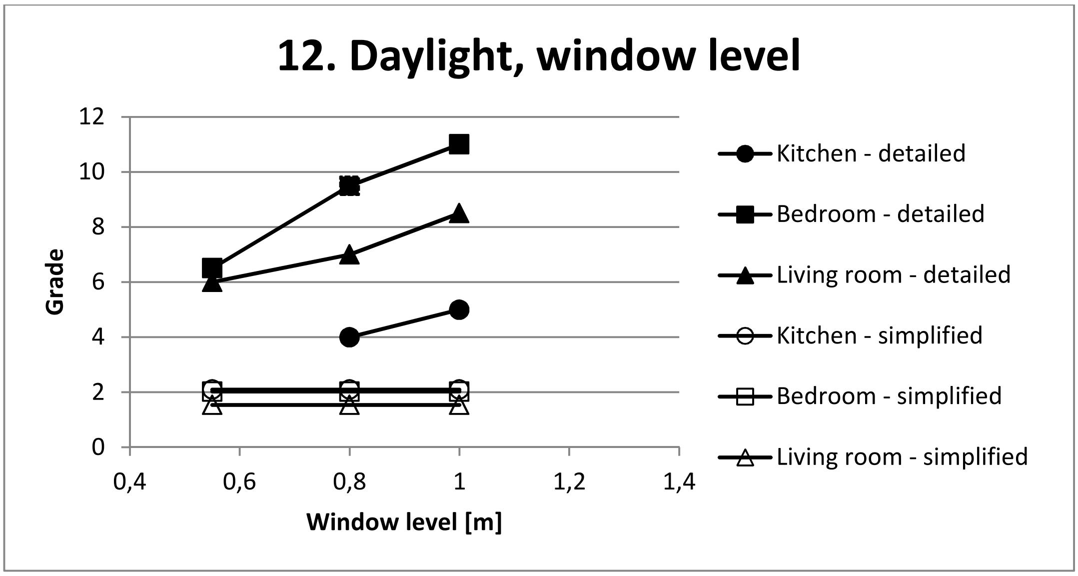

Figure F- 89

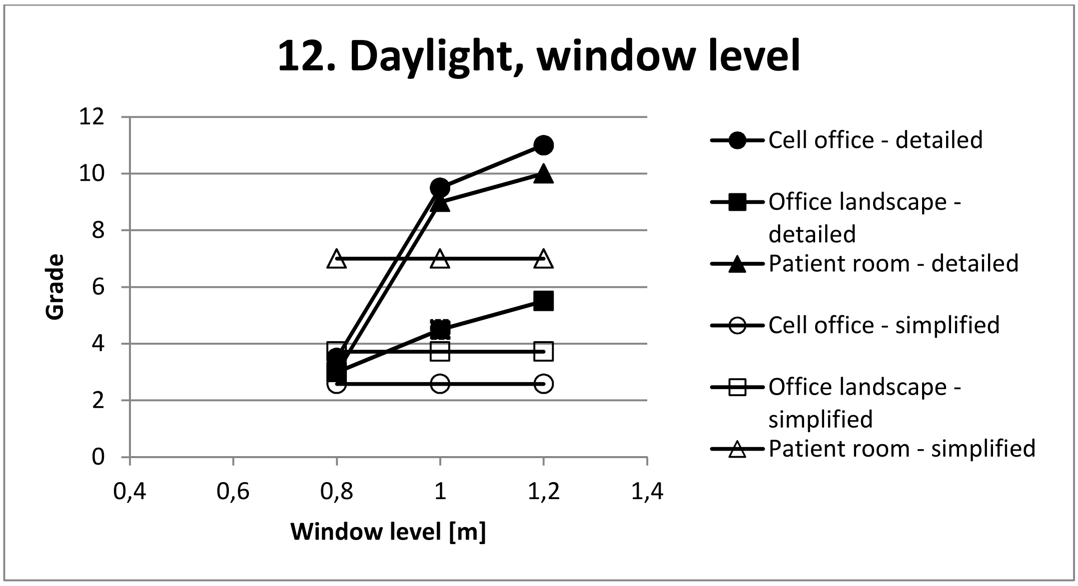

Figure F- 90

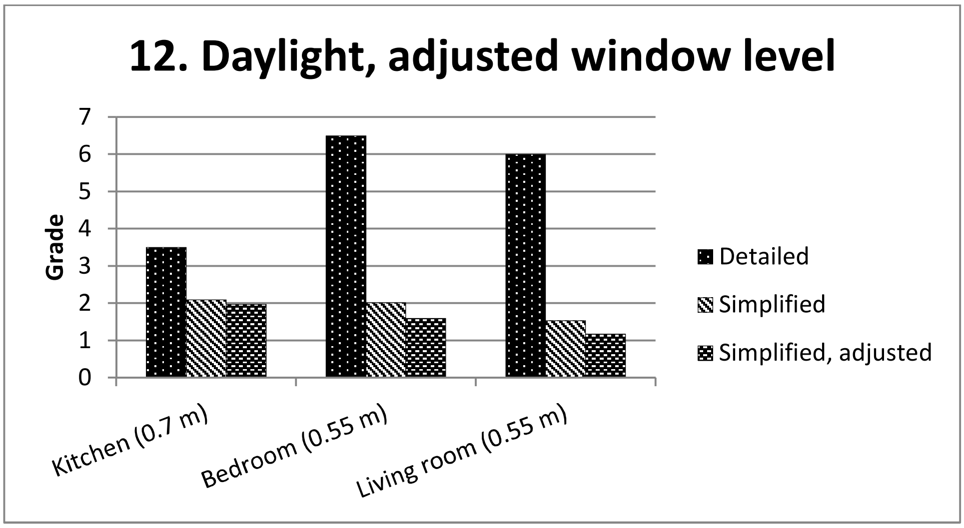

Figure F- 91

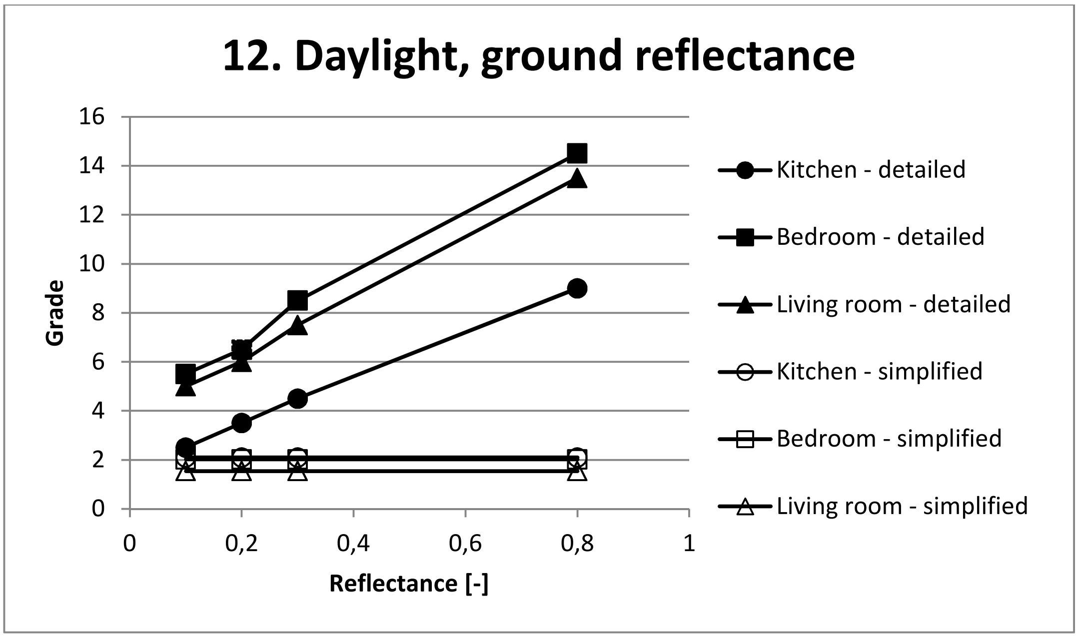

Figure F- 92

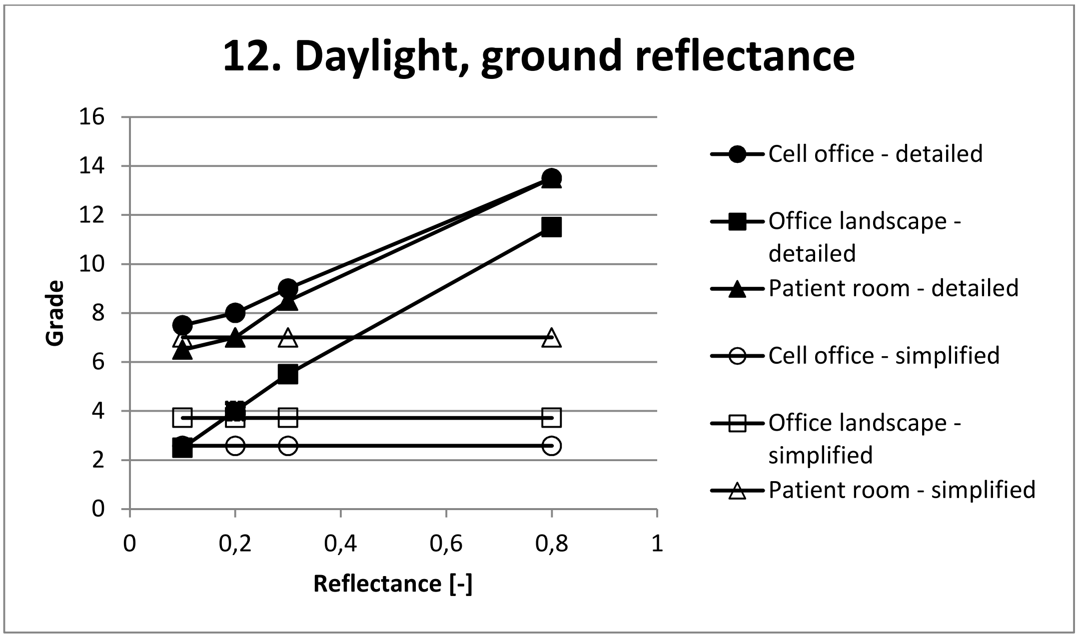

Figure F- 93

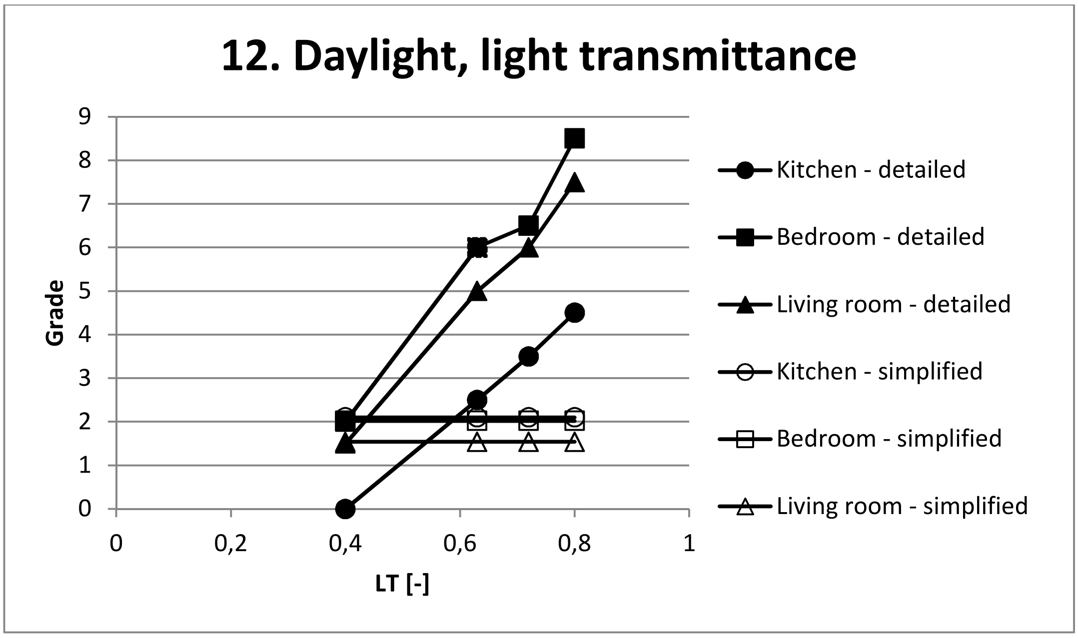

Figure F- 94

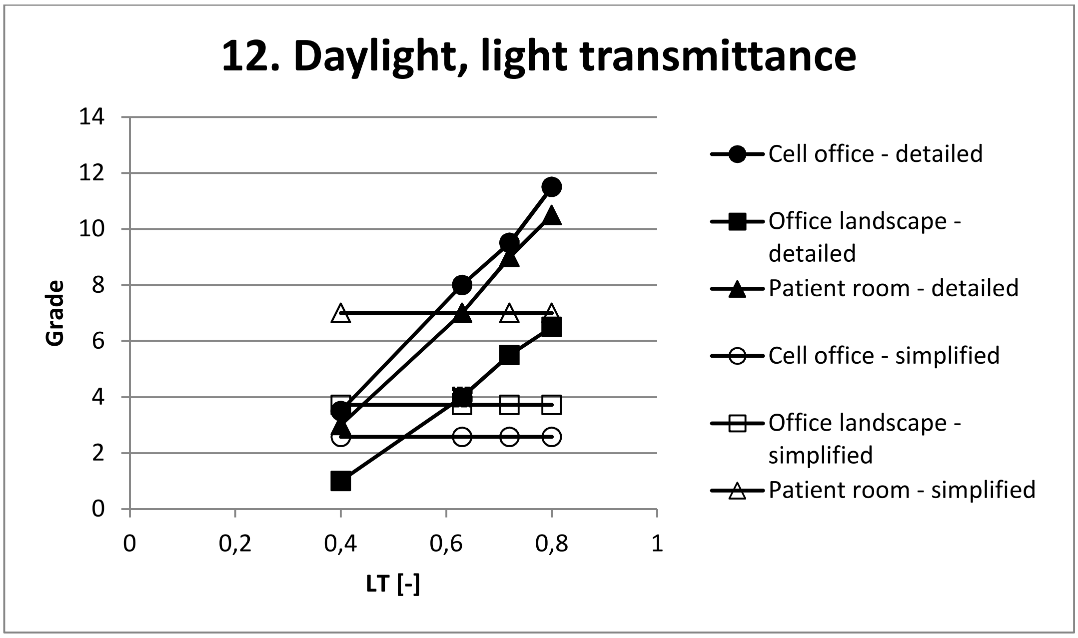

Figure F- 95