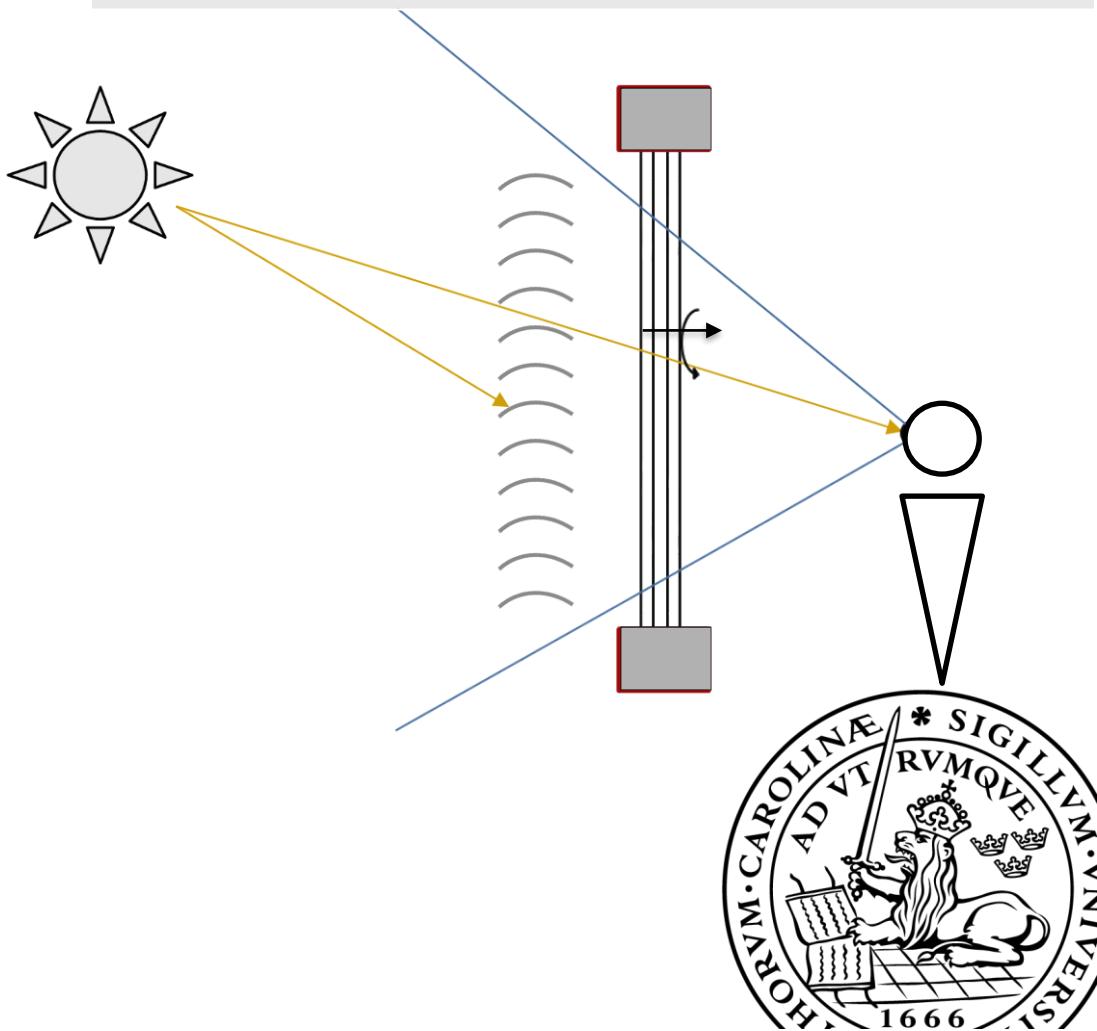


An early design tool/method for assessing the performance of complex fenestration systems

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Master thesis in Energy-efficient and Environmental Buildings
Faculty of Engineering | Lund University



Lund University

Lund University, with eight faculties and a number of research centres and specialized institutes, is the largest establishment for research and higher education in Scandinavia. The main part of the University is situated in the small city of Lund which has about 112 000 inhabitants. A number of departments for research and education are, however, located in Malmö. Lund University was founded in 1666 and has today a total staff of 6 000 employees and 47 000 students attending 280 degree programmes and 2 300 subject courses offered by 63 departments.

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The degree project is the final part of the master programme leading to a Master of Science (120 credits) in Energy-efficient and Environmental Buildings.

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Keywords: Design tool, Glazing, Shading use, User predictability, Solar gains, View

Thesis: EEBD – ‘15 / ‘17

Abstract

It is common knowledge that shading systems and solar control glasses are used to avoid glare and overheating at expenses of daylight. In Dynamic Thermal Modelling tools, there is no assessment method where the shading use is expressed when predicting the building performance. Furthermore, literature often refers to studies where complex fenestration systems are optimized for specific cases. However, there is a lack of a component-based, or room-independent tool to be used in the early-design phase in common practice which fills the gap and assesses the use of shading together with the building performance. In this perspective, an innovative tool was created to provide hints on how to predict the performance of fenestration systems in real life, and help designers when choosing the glazing and shading control. As input, location information as well as hourly radiation data, and the basic window geometry are asked. Three different shading control strategies are used, namely a solar gains threshold, incident solar radiation, and a prediction on the user's behaviour. Following, the tool assesses the solar gains and view to the outside per control strategy, and gives as an output the hourly shading use distribution and the View Quantity Index. Some important limitations that can be defined are: the simplification in the calculation of the secondary solar transmittance that is used for the solar heat gains; and the complexity of predicting the user's behaviour, which is combined with the direct sun beam as glare factor. The study showed how this tool assesses the performance of different glazing products combined with shading control systems and strategies, to help designing a functioning façade that fills the gap between shading systems and solar control.

Acknowledgements

We would like to give a big thanks to our main supervisors Niko Gentile and Harris Poirazis, who have not only given us solid supervision during this project, but also gave us the opportunity to extend our knowledge and dig for detailed information. Secondly, we would like to thank Henrik Davidsson, who, as a co-supervisor, has provided us with all the standards and codes that were needed in this project, as well as giving us proper supervision, especially for the calculation purposes. Also, our gratitude goes to Medina Deliahmedova, who has provided us with adequate supervision and help us build the data-matrix with the WIS software. And lastly, we would like to say thanks to our friends Evangelos Papaefthymiou for helping us with writing some scripts in Visual Basic, Bart Jan Stoutjesdijk for checking the English grammar of this report, and Vitaliya Mokhava and Christopher Nilsson for the valuable discussion sessions we had with our projects in mind.

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Glossary

q – Heat energy flow [W]
U – Overall coefficient of heat transfer, U-factor [$\text{W} / (\text{m}^2 \cdot \text{K})$]
 t_{in} – Interior air temperature [$^\circ\text{C}$]
 t_{out} – Exterior air temperature [$^\circ\text{C}$]
 A_{pf} – Total projected area of fenestration [m^2]
 E_t – Incident total irradiance [W / m^2]
Q – Heat energy flow per floor area [$\text{W} / \text{m}^2_{\text{floor area}}$]
 A_{floor} – Total floor area [m^2]
 T_{vis} – Light transmittance [non-dimensional]
 R_{vis} – Light reflectance [non-dimensional]
 R_{sol} – Solar reflectance [non-dimensional]
 G_b – Beam radiation [W / m^2]
 $G_{b,n}$ – Beam radiation on the normal of the surface [W / m^2]
 θ – Surface orientation from the south [$^\circ$]
 G_d – Diffuse radiation [W / m^2]
 $G_{d,h}$ – Diffuse radiation on a horizontal surface [W / m^2]
 β – Tilt angle of the surface (always 90°)
 G_g – Ground reflected radiation [W / m^2]
 ρ – Ground reflectance [non-dimensional]
 G_h – Radiation on horizontal surface [W / m^2]
 G_t – Total radiation [W / m^2]

Abbreviations

VBA – Visual Basic for Applications
SHGC – Solar Heat Gain Coefficient
HVAC – Heating, Ventilation and Air Conditioning
VQI -View Quantity Index
VCI -View Clarity Index
OF – Openness Factor
WIS – advanced Window Information System (software)
DGU – Double Glazed Unit
TGU – Triple Glazed Unit
DTM – Dynamic Thermal Modelling

1 Introduction

A recent review on solar control systems listed as much as ten key-criteria to evaluate the systems which are commonly investigated in literature, spacing from solar gains to outdoor effects in the urban context (Kuhn, 2017). Among those, solar gains and daylighting criteria are often investigated, as they are essential determinants of thermal and visual comfort. However, a large part of current researches either looks separately at these aspects, or investigates them in high detail for a limited number of specific case studies, typically with an optimisation approach. This then leaves a gap for the assessment of shading use at an early design stage, whilst investigating the building performance on a component-based level.

For example, a study from 2012 assessed shading prediction combined with the energy performance of office spaces. The authors researched user behaviour for venetian blinds, in combination with daylight levels. This study was, however, performed only for a specific case, and the energy efficiency aspect was calculated for the use of electrical lighting. This then left solar heat gains for energy measures out of the study perspective. (Silva, Leal, & Andersen, 2012)

Jelle (2013) made an extensive research about glazing properties in respect to solar radiation. The study provided measurement data of different double-, triple-, and electrochromic glazing units. Therefore, it showed an in-depth knowledge on selection of a glazing unit based on solar gains and daylight, leaving however a gap on the assessment of shading use.

On the subject of daylight levels after shading is applied, Athienitis and Tzempelikos (2002) studied an automated shading control system to maximise the daylight and to reduce the glare probability. Yet, only one specific office case was investigated. In addition, the authors studied the energy consumption of lighting, without including energy savings for the heating and cooling demand. Lastly, the study did not include different shading control strategies, which made clear that further investigation could be made.

Also, a detailed study on roller blinds and how they influence the energy demand and indoor environment (Chan, Tzempelikos, & Konstantzos, 2015) opened possibilities for a more extensive study. The authors assessed shading properties, such as Openness Factor (OF) and light transmittance to reduce glare. External environment parameters were used to investigate on a more diverse and detailed scale. This concluded in a study with a less room-dependent input, giving as a result upper and lower limits of shading properties to select in a certain environment. Nonetheless, there was no shading predictability study, nor were different schedules for the shading considered, leaving open the possibility for further studies.

On the software side, Dynamic Thermal Modelling tools, such as DesignBuilder, use an outdated way of assessing the use of shading devices in their models. The main focus lies on an “on-off” strategy which only accounts for shading either fully open or fully closed. Different strategies within this focus form thresholds for when the shading should be used or not. Secondly, regarding the strategy used for energy measures, incident solar radiation on the glass surface is used, which leaves a gap for what amount of solar heat gains actually enter through the window. In addition, occupant’s behaviour prediction and inclination of the slats of venetian blinds are not considered in these kinds of models (DesignBuilder, 2017).

In short, all the above-mentioned studies lack in a combined assessment of visual comfort, solar transmitted energy through windows, and shading use and can be used during the early design stage. Moreover, they lack a method which is not based on a specific case or, in other words, which is component-based. This suggests that a new method is needed to provide the missing information and fill the existing gap. For this reason, a component-based tool which combines the three variables under various control strategies at the early design stage, is proposed in this study.

1.1 Objectives

For this study, the main objective is to describe the methodology behind the newly developed tool. The basis lies within the question: how is shading used with different fenestration units in order to a) provide a fair visual transmittance, b) reduce the hours of shading use, and c) minimise the risk of overheating? The answer to this question is spread out in the methodology to break down the parts of the questions. Beta-tested results and the tool in total are also presented and discussed.

Note that this study is not the tool users' guide.

1.2 Boundaries

The tool was not developed to give an optimum solution, or to 'optimise' any form of shading use. It provides an indication and suggestions on how a specific shading unit behaves in several shading control strategies. This leads to somewhat generic results, which explains the other main limitation: the tool's results are to be used as an early design indicator. In other words, designers, for example architects, can get an indication of how their preferred shading or glazing unit behaves. The given results can lead to design decisions, but for complete and more detailed assessments, Dynamic Thermal Modelling tools need to be used.

1.3 Division of work

In this study the work between the authors has been divided equally. No clear distinction can be made in this study between which of the authors worked on what particular part, since both authors have been involved in the complete making of this study and report.

2 Methodology

In the following chapter, the methodology of this work is presented. The tool development process, as well as the input and output data, are described in detail.

2.1 Tool development process

In accordance with Kuhn (2017), solar control systems can only be understood by using a two multidimensional spaces framework: the ‘design space’ and the ‘evaluation space’. The design space includes the design parameters set by the designer, e.g. technology or type of control. The evaluation space provides criteria to evaluate the performance of such a system.

Following this framework, a first draft of the tool was sketched. Given some design input, such as location and orientation of the façade, the tool offered a set of ‘design space’ solutions which were satisfying the pre-defined ‘evaluation space’ criteria.

It was also important to find which output were necessary for the tool and what was the proper way to connect them with the input. The flowchart shown in Figure 1 describes the working process of the tool.

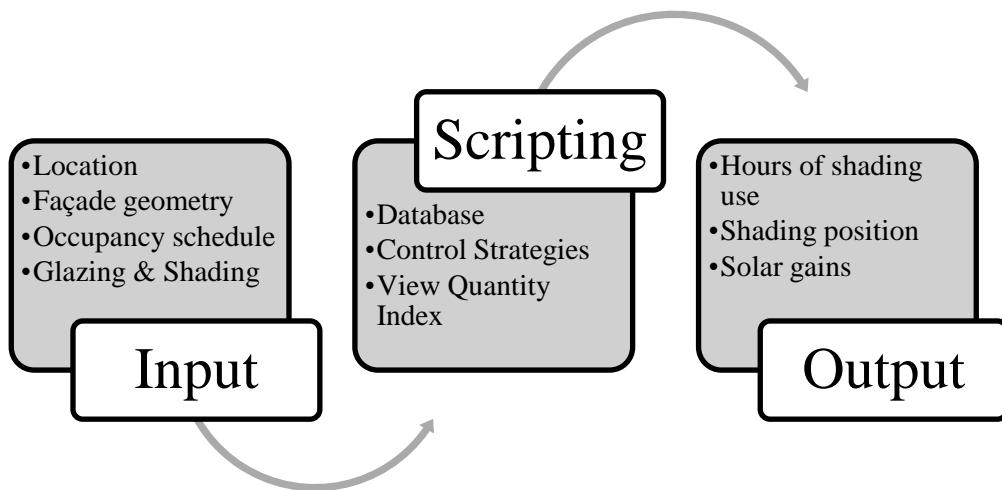


Figure 1: The working process of the tool

2.1.1 Scripting

The tool engine was programmed in Visual Basic (VBA). This is a functional programming language used to make macros in Excel. VBA allowed for external text files to be loaded in, a range of input data could be selected, and it holds the main engine for all calculations in the tool. The complete VBA scripts are given in the Appendices.

2.1.2 Input

The Input data that is needed to be filled in is summarised in the following points. The input is shown together with a brief explanation of the expected output. The output is explained in more detail in Chapter 2.1.5.

Input:

- Location;
- Orientation of the façade;
- Façade geometry;
- Floor area behind the window;
- Occupancy hours;
- Maximum allowed solar heat gains, per floor area;
- Weather data file;
- Glazing unit;
- Shading unit.

Output:

- Hours of shading used;
- View Quantity Index*;
- Hourly solar heat gains over a year;
- Shading position during the most critical week**.

* The View Quantity Index is explained in Chapter 2.1.4

** ‘Most critical week’ is referred to the week of the year with the highest solar gains

2.1.3 Control strategies

Shading use varies with type of shading device and glazing, as well as with the adopted control strategy. For this study three strategies were studied and the user of the tool can decide between one or more of them. These strategies were chosen to get different perspectives on how shading is used. The main division lies within how often the shading is used, being: too often in the incident solar radiation strategy, not often enough in a manual prediction, and a compromising strategy as a solar heat gains control strategy. The three control strategies are presented in the following sub-chapters.

2.1.3.1 Solar Heat Gains control strategy

There is often the need to control the solar heat gains and set their maximum threshold for better indoor climate. Thus, this control strategy is created to provide help in terms of applying the shading device properly with respect to this need.

Assessing the solar heat gains through a fenestration system appeared to be a complex task, however, essential for this control strategy. The process of this strategy can be described as following:

The user sets the maximum hourly allowed solar gains in $\text{W}/\text{m}^2_{\text{floor area}}$ as a threshold. This threshold could be useful, for example, for the HVAC system to be designed. The control strategy assesses the solar heat gains for each of the occupied hours of the year and then suggests the slat angle of the shading device, so the hourly solar gains do not exceed this

threshold, in case venetian blinds are chosen as the shading device. The strategy prioritises to select the angle with the most ‘open’ slats, between the available 0°, 30°, 60° and 90° angles of the slats, that the solar heat gains still do not exceed the respective threshold. If, for example, both a 60° and a 90° slat angle are allowed during a specific hour, the strategy picks 60° as the suggested angle of the slats, since this allows more daylight in the room and better view-out. If a fabric is chosen as a shading device, this strategy only suggests a binary ‘on/off’ for the shading position. The scripting for finding the shading position in this control strategy is shown in Appendix D.1.

In this way, a diary file is created that gives the hourly shading position throughout the year, aiming to control the solar heat gains and considering the view-out at the same time.

To calculate the hourly solar heat gains, Equation (1), obtained from the 2001 ASHRAE Handbook of fundamentals (ASHRAE, 2001), was used:

$$q = U \times A_{pf} \times (t_{out} - t_{in}) + (SHGC_t \times A_{pf} \times E_t) \quad (1)$$

Where:

q	= heat energy flow [W];
U	= overall coefficient of heat transfer, U-factor [$\text{W} / (\text{m}^2 \cdot \text{K})$];
t_{in}	= interior air temperature [$^\circ\text{C}$];
t_{out}	= exterior air temperature [$^\circ\text{C}$];
A_{pf}	= total projected area of fenestration [m^2];
$SHGC_t$	= overall solar heat gain coefficient [non-dimensional];
E_t	= incident total irradiance [W / m^2].

In this tool, for simplification reasons, t_{in} was selected to be steady-state throughout the year at 25 °C. This temperature was selected because it is used in WIS software - which is used for the database creation (Chapter 2.2) and described later in this report -, as a reference indoor temperature set with the EN-ISO 15099 summer conditions. Also, the overall heat gain coefficient at 0° incidence, $SHGC_t$, was not used. Instead, the angular dependent transmitted energy, which was obtained from WIS calculations, was applied in the equation. How the tool calculates and uses the angular transmitted energy is provided in Appendix C.1.

2.1.3.2 Incident Solar Radiation control strategy

This strategy is often used to assess a shading device in Dynamic Thermal Modelling tools. It accounts for the solar irradiation on the façade. Above a variable threshold, the shading devices goes down.

In this control strategy, the threshold can be one of the following: a) either a value that the users set by themselves in W/m^2 window area; or b) if this value is not set, the threshold automatically gets the value from the maximum hourly allowed solar gains. This was done by taking that input value and divide it by the solar heat gain coefficient of the glazing, set as Equation (2). Option b) was decided to be used as an attempt to take the glazing unit into account within this control strategy.

$$E = \left(\frac{Q \times A_{floor}}{A_{pf}} \right) / SHGC \quad (2)$$

Where:

- E = the incident solar radiation threshold [W / m²];
- Q = the heat energy flow per floor area [W / m²_{floor area}];
- A_{pf} = total projected area of fenestration [m²];
- A_{floor} = total floor area [m²];
- SHGC = g-value of the glazing [non-dimensional].

This control strategy may include simple calculations; however, it is considered to be important for comparative validation purposes with Dynamic Thermal Modelling tools, in terms of frequency of shading use. In Appendix A.2. the incident solar radiation scripting is given.

2.1.3.3 User predictability control strategy

Predicting the use of shading when manually operated is a complex task, mainly because every occupant has different preferences and different ways of acting. To give a proper prediction, literature about occupant behaviour was studied.

A typical day starts with the shading device up, until the direct solar component will interfere with the occupant's task. Short periods of direct sun will not cause the occupant to put the shading down, while longer periods, of more than one hour, will affect the occupant's behaviour. The shading is pulled down until the direct solar component is blocked. However, afterwards, the shading is not altered manually if some reason obstructs the sun, such as surroundings or clouds (Reinhart & Voss, 2003).

Moreover, people mostly put up the shading device early in the morning or at the end of the day. Which means that the shading device is open at the starting point of the occupied hours. Also, venetian blinds are either totally raised or totally lowered and users only adjust the tilt angle of the slats. The colour of the slats does not relate to the use of the shading. (Estia, 2015) Another given conclusion is that occupants use the shading devices to reduce glare on sunny days or increase daylight availability on overcast days. (Foster & Oreszczyn, 1999) Most of the mentioned studies in this paragraph show similar results and conclusions, which then also include the studies of Sutter, Dumortier & Fontoynont (2006), and Galasiu & Veitch (2006).

For the tool, this control strategy then takes into consideration these studies and aims to predict the manual shading use of the occupant placed in three different positions; one metre, two metres, and three metres from the window. The height of the point of view is at 1.2 metres, as this is considered to be the working position, as shown in Figure 2. The control strategy predicts the behaviour of two kinds of users, being responsive and non-responsive.

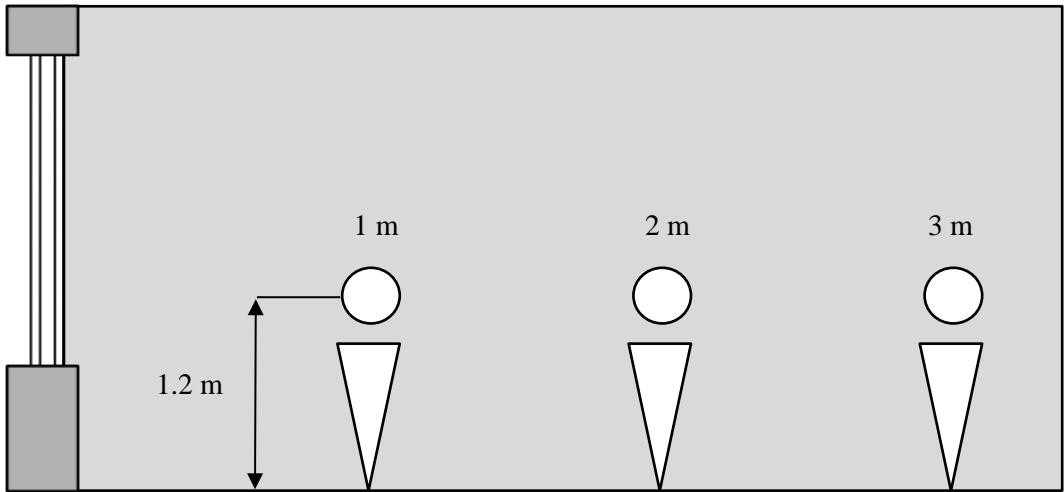


Figure 2: Three occupant positions that are used for the user predictability control strategy.

The responsive users apply the shading device and adjust the angle of the slats, if venetian blinds are selected, to block the direct sun beam, which could cause glare. They check every hour and can pull the shading up again to allow more daylight inside, if they do not experience the direct beam anymore. The reason these users are called responsive is that they care more about daylight and they are eager to pull the shading up to gather more of it.

The non-responsive users apply the shading device the same way as the responsive ones, with the difference that even though they check every hour as well, when they put the shading device down for first time of the day, they do not adjust or put it up during the rest of the day. They pull it up again at the first occupied hour of the next day. These users are called non-responsive because they do not mind pulling the shading device up to allow the daylight inside.

The responsive and non-responsive user are quite similarly defined in Lightswitch-2002, although named differently; ‘blind static and blind dynamic user’ (Reinhart C. F., 2004).

Calculating the hours of direct sun beam is a geometry calculation that takes into consideration the position of the user at all three mentioned distances from the window, the geometry of the façade, and the position of the sun calculated from the weather file that is selected. How the weather file is loaded in the tool is shown in Appendix A.1.

To make this calculation more realistic, two more factors are accounted for. Firstly, the shading device is not used in case the cloudiness factor, obtained from the weather file, is equal to, or higher than four. (Meteorology Glossary, 2017) This setpoint is based on the division between a mostly clear sky and a mostly overcast sky. In this way, it is considered when the sky is mostly clear, or cloudy, and the shading device is used accordingly. Secondly, the shading device is not used if the angular dependent transmitted energy of the glazing is lower than 0.22. The angular dependent transmitted energy is a unit obtained from the WIS software, which is similar to the g-value of the glazing unit with a changing angle of incidence. The shown value is the average tipping point where the light reflectance of the glazing, R_{vis} , is higher than the light transmittance, T_{vis} . This value was calculated using the WIS software

and it helps to account for the glazing properties in terms of frequency of shading use. For example, the user would not perceive the direct sun beam the same way sitting behind a clear-, or a solar control glazing unit. The scripting for finding the shading position for the user predictability control strategy is given in Appendices D.2. and D.3.

2.1.4 View Quantity Index

The View Quantity Index (VQI) is a unitless value between zero and one and it is an interpretation of the designers of this tool to quantify the view out. The VQI was conceived from inputs of other similar metrics, namely the openness factor. (Chan, Tzempelikos, & Konstantzos, 2015), the View Clarity Index (Konstanzos, et al., 2015), and the Daylight & View method (Hellinga & Hordijk, 2014). This index was created to make a comparison of the view-out between all the different combinations of glazing and shading units possible.

To implement the view index in the tool, two different methods were followed, depending on the shading type, being venetian blinds or fabrics. The two methods lead to results that were comparable to each other.

2.1.4.1 Venetian blinds

To calculate the View Quantity Index for a combination of a glazing unit with venetian blinds as shading, an innovative method needed to be created. This method includes two-dimensional sketches that are created using the software AutoCAD 2017. A one-meter height window was drawn and a view point was placed at 1.3 meters from the middle point of the window (Konstantzos & Tzempelikos, 2017). Then the blinds were designed and placed both internally and externally with all the available slat angles of 0° , 30° , 60° and 90° . For each of the sketches, the purpose was to calculate the length per width of the glazing that could be seen by the view point without being interrupted by the slats. This length was then compared to the length of the window that was visible without any blinds. In this way, data with all the different ratios was created. To account for the glazing unit, each of the ratios was multiplied with the light transmittance, T_{vis} , of the respective glazing in the fenestration system, giving the VQI.

Figure 3 shows two of the eight sketches designed for the VQI to be calculated, as an example and visualisation of the explained concept. In the first one, the slats are set at 30° and in the second at 60° , both with internally placed blinds. As expected, in the first occasion the area seen is much bigger compared to the second one, resulted in a higher VQI.

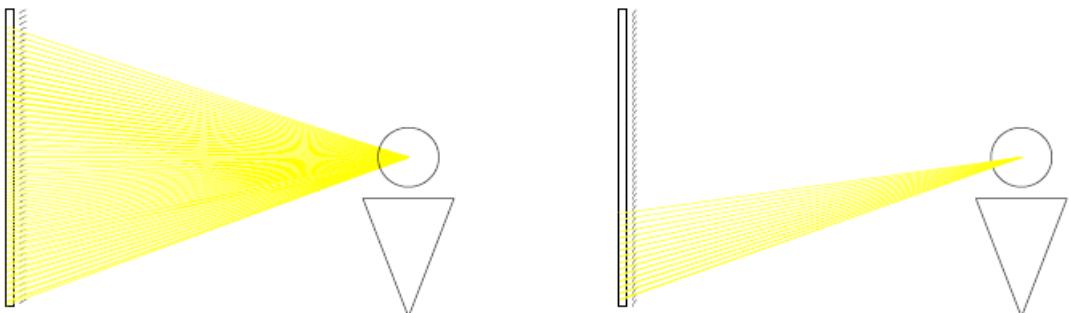


Figure 3: Sketches for the calculation of the View Quantity Index. The angle of the slats is set on the left-hand side sketch at: 30° and on the right-hand side at 60°

2.1.4.2 Fabrics

A different method was used when a fabric was selected as a shading unit. According to Konstanzos et al. (2015), an empirical model was created to evaluate the clarity of view through fabrics. It accounts for openness factor, light transmittance of the fabric, the colour of the fabric, and the contrast towards the outside. The model is called View Clarity Index (VCI) and the formula to calculate it is presented in Equation (3):

$$VCI = 1.43 \times OF^{0.48} + 0.64 \times \left(\frac{OF}{T_{vis}}\right)^{1.1} - 0.22 \quad (3)$$

Where:

- VCI = the View Clarity Index given between 0 and 1 [non-dimensional];
- OF = the openness factor of the fabric [non-dimensional];
- T_{vis} = the total light transmission of the fabric [non-dimensional].

The View Quantity Index was then calculated by multiplying the VCI of each fabric with the light transmittance of the respective glazing in the fenestration system. This way, the properties of the glass are also accounted for.

2.1.5 Output

After the calculations are done, the tool plots three outputs per control strategy. First, there is a table that shows the frequency of the shading use. For venetian blinds the frequency is divided over the available slat angles.

Secondly, the table includes the VQI per shading position. There is then a graph in which the weighted VQI is presented per control strategy. By weighted VQI, the tool intends a value which gives the VQI compared to the best possible case VQI-wise. In practice, the best case in the tool consists of a clear glass with a low-e coating, with a T_{vis} of 0.81. Without shading being used, this leads to having a VQI of 0.81. The correspondent weighted VQI is then one. A minimum weighted VQI of 0.6 is expected to give a proper view quantity. This setpoint was obtained by comparing the results of the VQI in the database of glazing-, and shading units. It is a subjective value based on the median VQI.

Finally, the tool shows one graph per strategy of the hourly solar gains over the year. For the solar gains control strategy, an extra graph is given for the most critical week, i.e. the week with the most solar gains. This last graph also shows the shading position on hourly basis. How the most critical week is found in the tool is shown in Appendix E.1.

An extra option for the end-user of the tool is to get a diary file of the shading use. This diary file can be exported for each control strategy and gives the hourly use of shading in an ‘on-off’ schedule. Additionally, it gives the hourly slat position when venetian blinds are selected. The scripting for creating the diary files is given in Appendix E.2.

2.2 Database creation

The data needed for the tool was, most importantly, different types of glazing and shading units. Five representative glass types were chosen to be used in both double-, and triple glazed

units. The shading systems were divided in three types of venetian blinds and six types of fabrics. The venetian blinds were equally calculated for internal and external systems. The fabrics were positioned internally or externally based on the manufacturers' data.

Note that the fabrics were chosen based on if it is an internal or external fabric, and on the openness factor of each fabric, the venetian blinds were chosen as general references. The properties of these glazing and shading devices, as declared by the manufacturers, are shown in Tables 1, 2, and 3. R_{sol} and T_{vis} refer to the solar reflectance and light transmittance respectively. The mentioned products, and products with similar or equal properties are expected to act in the same way.

Table 1: Chosen glazing units and their properties

Glazing unit	g-value / (-)	U-value / (W/(m ² ·K))	T _{vis} / (-)
DGU Guardian Climaguard 80/63	0.63	1.1	0.80
DGU Guardian Sunguard 70/37	0.37	1.0	0.70
DGU Guardian Sunguard SNX 62/27	0.27	1.0	0.62
DGU Ipasol Shine 40/22	0.22	1.1	0.40
DGU Guardian Sunguard Silver 19/17	0.17	1.1	0.19
TGU Guardian Climaguard 80/63	0.57	0.6	0.73
TGU Guardian Sunguard 70/37	0.36	0.6	0.63
TGU Guardian Sunguard SNX 62/27	0.27	0.6	0.56
TGU Ipasol Shine 40/22	0.21	0.6	0.36
TGU Guardian Sunguard Silver 19/17	0.15	0.6	0.17

Note: Double glazed units are mentioned with the abbreviation 'DGU', while triple glazed units are abbreviated to 'TGU'.

The 'Guardian Climaguard' refers to a glazing unit with a low emittance coating and the 'Guardian Sunguard' refers to one with a solar control glass. The 'Ipasol Shine' was chosen as reference from a different manufacturer and represents a similar solar control glazing unit as the 'Guardian Sunguard'. In each glazing unit, the low-e coating was placed at the outside surface of the inner pane, while the solar control coating was placed on the inside surface of the outer pane. Also, argon was used as the filling between the panes. The fraction that is mentioned after each glazing unit refers to the proportion of the respective visual transmittance with the solar transmitted energy, g-value.

Table 2: Chosen fabrics and their properties

Fabric	Openness Factor / (%)	Placement	R _{sol} / (-)	T _{vis} / (-)
Ohm	10	Internal	0.56	0.18
Duroscreen	5	Internal	0.83	0.05
Skyscreen	3	Internal	0.87	0.04
Nuovi	5	Internal	0.68	0.10
Soltis	14	External	0.42	0.20
Sunworker	5	External	0.35	0.06

Table 3: Chosen venetian blinds and their properties

Blinds	Placement	R_{sol} / (-)	T_{vis} / (-)
White	Internal / external	0.37	0.28
Black	Internal / external	0.03	0.12
Silver	Internal / external	0.42	0.20

Appendix B.1. and B.2. show how the glazing and shading units are loaded in the tool.

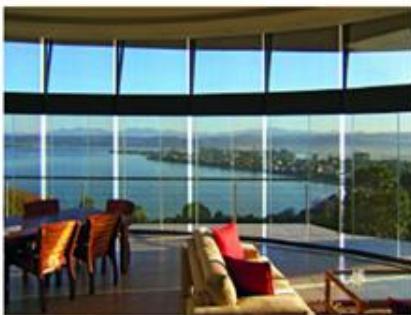
As a visualisation of the fabric properties, Figure 4 is given.



OHM



Duroscren 3%



Soltis



Sunworker

Figure 4: Some of the chosen fabrics in use: top-left internal OHM, top-right internal Duroscren, bottom-left external Soltis, bottom-right external Sunworker (Source: Harris Poirazis, Inform Design)

All the chosen venetian blinds have the same geometry as visualised in Figure 5.

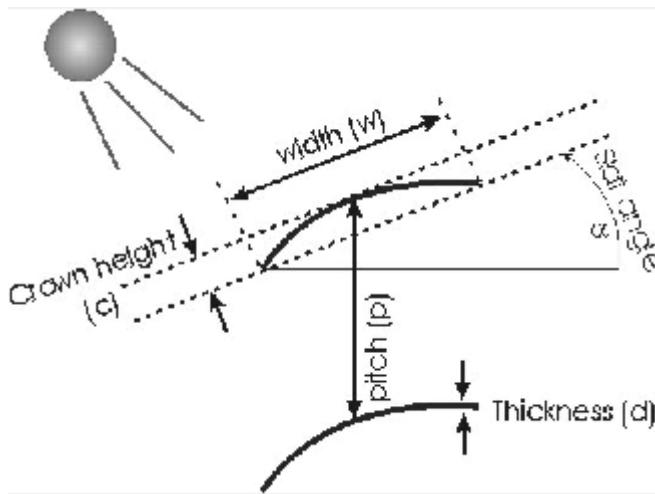


Figure 5: Geometry of the chosen venetian blinds; thickness of 0.22 mm, width of 25 mm, crown height of 2 mm and slat pitch of 20 mm (Source: WIS)

In order to collect useful output, this data was imported to WIS. This is a software tool that helps to determine the thermal and solar characteristics of window systems, such as glazing and shading devices. It contains databases with various component properties and it calculates the thermal and optical interactions of components in a window. After the WIS calculations were completed, all the useful information was copied in an excel files to make up the database of the tool. (TNO, 2017)

2.3 Preliminary calculations

Some calculations had a purpose not necessarily connected to one particular control strategy. These calculations were needed for one or more control strategies, or were used as general calculations which the tool needs to properly execute.

Firstly, the sun angles on each hours of the year needed to be calculated, towards the surface. Therefore, the surface orientation, longitude and latitude, were needed. Those values were then used to calculate if the solar radiation was coming in directly on the surface, and at what angle. This angle of incidence was important for the angular dependent solar transmitted energy of the fenestration system.

Secondly, the weather data was used to calculate the incident solar radiation on a vertical surface with Equations (4), (5), (6), and (7). (Duffie & Beckman, 2013)

$$G_b = G_{b,n} \times \cos(\theta) \quad (4)$$

$$G_d = G_{d,h} \times \frac{(1+\cos(\beta))}{2} \quad (5)$$

$$G_g = \rho \times G_h \times \frac{(1-\cos(\beta))}{2} \quad (6)$$

$$G_t = G_b + G_d + G_g \quad (7)$$

Where:

G_b	= Beam radiation [W / m ²];
$G_{b,n}$	= Beam radiation on the normal of the surface [W / m ²];
θ	= Surface orientation from the south [°];
G_d	= Diffuse radiation [W / m ²];
$G_{d,h}$	= Diffuse radiation on a horizontal surface [W / m ²];
β	= Tilt angle of the surface (always 90°);
G_g	= Ground reflected radiation [W / m ²];
ρ	= Ground reflectance [non-dimensional];
G_h	= Radiation on horizontal surface [W / m ²];
G_t	= Total radiation [W / m ²];

2.4 Beta-test

To be able to present the results of the tool, several beta-test calculations were run. These beta-test calculations did not differ in input settings other than the glazing- and shading units, in order to give comparable results that only show the difference for the selected glazing-, and/or shading unit. Table 4 refers to the input settings that were exactly the same for all the beta-test calculations.

Table 4: Input settings set for beta-test calculations

Input variable	Input value
Longitude	55°
Latitude	-13°
Standard meridian	-15°
Surface orientation	0°
Window head height	3.5 m
Total window height	3 m
Window width	2.5 m
Total floor area	12 m ²
Occupation hours	7-16
Max. allowed hourly solar gains	30 W/m ² floor area
Max. allowed hourly incident solar radiation	-* W/m ² window area

*The maximum allowed hourly incident solar radiation was calculated with the solar gains setpoint divided by the g-value of the window. Therefore, the input was the same, being empty, but it was calculated as variable.

The glazing- and shading units chosen for the beta-test calculations are as shown in Table 5.

Table 5: Combinations of glazing and shading units chosen for beta-test calculations

Glazing unit	Shading unit
Climaguard 80/63 TGU	Internal and external white venetian blinds
	Nuovi, internal fabric
	Soltis, external fabric
Sunguard 62/27 DGU*	Internal* and external white venetian blinds
	Nuovi, internal fabric
	Soltis, external fabric
Sunguard Silver 19/17 DGU	Internal and external white venetian blinds
	Nuovi, internal fabric
	Soltis, external fabric

*The results of the Sunguard 62/27, with internal white venetian blinds, are shown in Chapter 3.1

3 Results

In this chapter, the results are shown for the beta-test calculations, as explained in Chapter 2.4. Most of the results are directly obtained from the tool, whilst the comparison between the samples is how the designers interpreted these results.

3.1 Beta-test results

The following sub-chapters give the results from one of the beta-tests in the way they are presented as outputs in the tool. The beta-test that is shown is the combination of a DGU Sunguard 62/27 with internal white venetian blinds.

3.1.1 Shading use

The exact outputs as calculated and presented in the tool for the chosen beta-test are shown in Table 6. It shows the shading use for all the occupied hours for each of the control strategies. The number of hours of shading use is calculated for all the available slat angles. In case a fabric was chosen instead of the venetian blinds, the table would look slightly different, as in only one column would be used to show the number of hours that the fabric is used. Note that the ‘Failed’ hours correspond only to the ‘Solar gains Control strategy’ and they refer to the number of hours that the solar gains exceeded the maximum allowed set-point set by the user. The shown results are open for the subjective interpretation of the end-user.

Table 6: Hours of shading use for the combination of Sunguard 62/27 with internal white venetian blinds

		Solar gains Control strategy					
		<i>No shading</i>	<i>Blinds 0°</i>	<i>Blinds 30°</i>	<i>Blinds 60°</i>	<i>Blinds 90°</i>	<i>Failed</i>
		2185	313	123	228	436	195
					User predictability Control strategy		
Responsive user	<i>No shading</i>	<i>Blinds 0°</i>	<i>Blinds 30°</i>	<i>Blinds 60°</i>	<i>Blinds 90°</i>	<i>Position</i>	
	2859	0	119	172	135	1m	
	2978	0	0	172	135	2m	
	3063	0	0	87	135	3m	
Non-responsive user	2680	0	161	208	236	1m	
	2841	0	0	208	236	2m	
	2909	0	0	140	236	3m	
Incident solar radiation Control strategy							
	<i>No shading</i>	<i>Blinds 0°</i>	<i>Blinds 30°</i>	<i>Blinds 60°</i>	<i>Blinds 90°</i>		
	1910	0	450	620	305		
View Quantity Index							
	<i>No shading</i>	<i>Blinds 0°</i>	<i>Blinds 30°</i>	<i>Blinds 60°</i>	<i>Blinds 90°</i>		
	0.63	0.46	0.13	0.002	0.00		

3.1.2 Solar heat gains

The Table 7 shows how the solar gains changed after applying the shading, using the ‘Solar gains Control Strategy’. The solar gains were reduced by approximately 50 % after this strategy was applied.

Table 7: Total annual solar gains before and after applying the respective control strategy

Shading use	Total solar gains [kWh / m ² year]
With shading	45.1
Without shading	85.8

The Figure 6 shows the annual solar gains calculated using the previously mentioned control strategy, for the chosen beta-test. The solar gains in the figure are shown for each hour of the year. During some hours, the solar gains exceed the threshold set. These hours correspond to the ‘Failed’ hours.

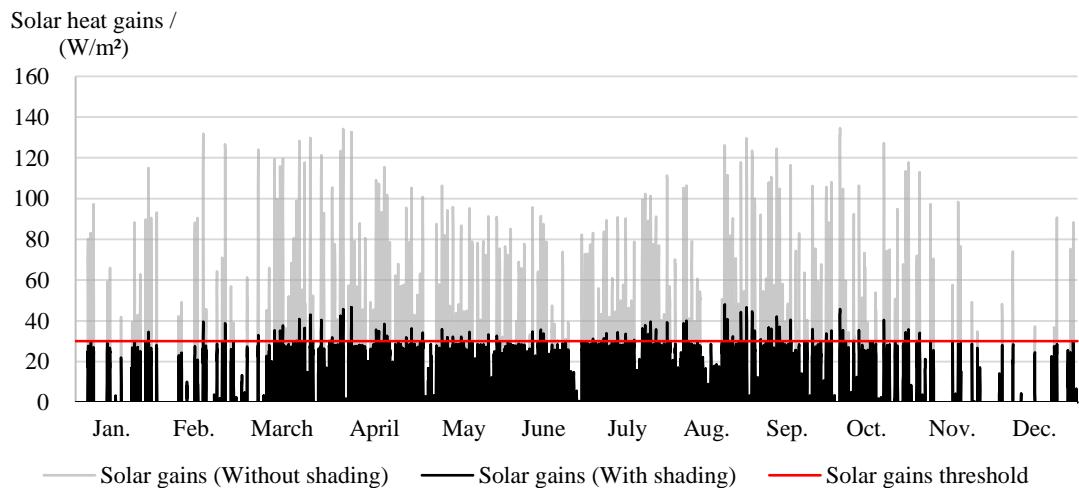


Figure 6: Graphical presentation of the total annual solar gains

A more detailed representation of the solar gains for the most critical week of the year is given in Figure 7. It shows the position of the shading during the week with the highest solar gains. In this beta-test, the respective week is the 35th week of the year. In case a fabric was chosen instead of the venetian blinds, the secondary axis of this figure would look slightly different. This difference lies in a fifth value above the 90°, which is named “Fabric down”.

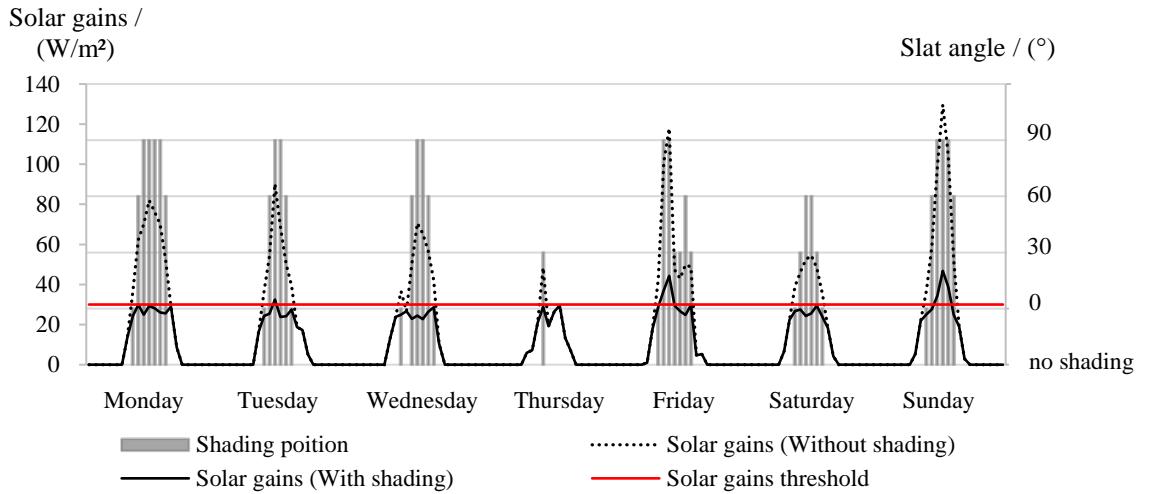


Figure 7: Graphical presentation of the solar gains during the most critical week of the year

3.1.3 View Quantity Index

The VQI is represented in Figure 8 for each of the control strategies. As explained in Chapter 2.1.4 the scale is from zero to one, and represents how much of the outdoor can be seen, combining the chosen shading and glazing system. In the figure, it is shown that a responsive user applies their shading device considering the view out, while on the other hand a non-responsive user cares less. The other two strategies, being the Solar Heat Gains control strategy and the Incident Solar Radiation control strategy, show a lower VQI, which in this beta-test lead to unsatisfactory results.

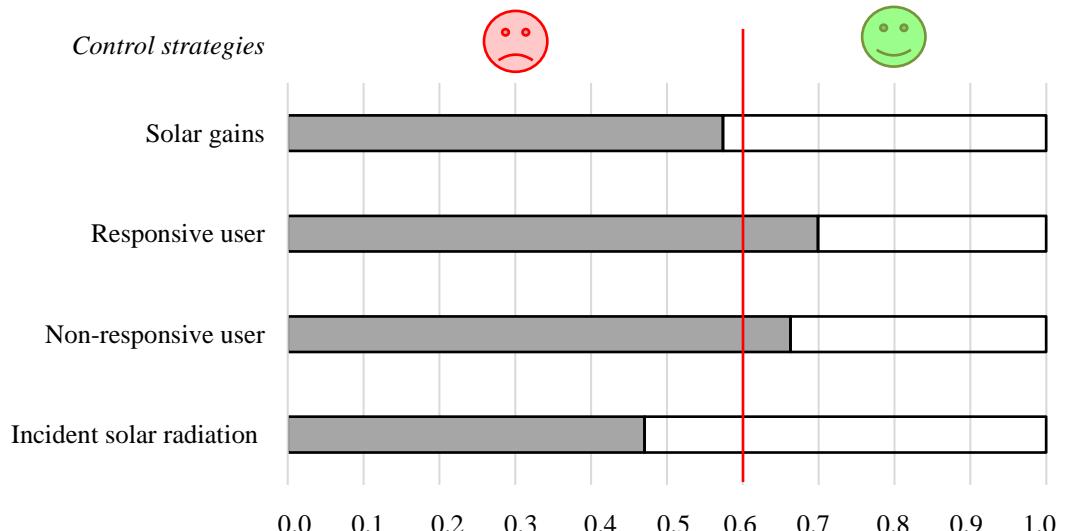


Figure 8: View Quantity Index for the combination of Sunguard 62/27 with internal white venetian blinds

3.1.4 Designers' interpretation of beta-tests

To get an overview of the tool, the three glazing units that were combined with the three shading units, as explained in Chapter 2.4, are presented in this sub-chapter. All combinations are compared with each other, per control strategy, based on the VQI results and the total yearly solar gains. The result of this comparison is shown in Figure 9. It can be seen that, for example, the Sunguard 62/27 with external fabric is relatively the best solution between the tested alternatives, as it provides satisfying results in both the examined factors. The clear Climaguard 80/63 performed poorly on solar gains, i.e. had the most solar gains of these combinations, and the Sunguard Silver 19/17 performed the worst on the VQI.

Note that this figure is an interpretation of the designers, meaning that it is one possible way to analyse and compare different combinations of glazing and shading units. However, such output is not yet implemented in the tool. The shown smiley faces are based on a ranking of how the fenestration systems compare with each other. The top 1/3 get a happy green face, the middle 1/3 get a neutral yellow face, and the lowest 1/3 get a sad red face.

	Solar gains VQI	Control Strategies			
Glazing unit	Shading unit	Solar gains	Responsive user	Non-responsive user	Incident solar radiation
Climaguard 80/63 TGU	Internal white blinds	(Sad)	(Neutral)	(Sad)	(Neutral)
	External white blinds	(Neutral)	(Sad)	(Neutral)	(Neutral)
	Nuovi, internal fabric	(Sad)	(Neutral)	(Neutral)	(Sad)
	Soltis, external fabric	(Neutral)	(Happy)	(Neutral)	(Neutral)
Sunguard 62/27 DGU	Internal white blinds	(Neutral)	(Sad)	(Neutral)	(Neutral)
	External white blinds	(Happy)	(Neutral)	(Neutral)	(Neutral)
	Nuovi, internal fabric	(Happy)	(Sad)	(Neutral)	(Neutral)
	Soltis, external fabric	(Happy)	(Sad)	(Neutral)	(Neutral)
Sunguard Silver 19/17 DGU	Internal white blinds	(Happy)	(Sad)	(Sad)	(Sad)
	External white blinds	(Happy)	(Sad)	(Sad)	(Sad)
	Nuovi, internal fabric	(Happy)	(Sad)	(Sad)	(Sad)
	Soltis, external fabric	(Happy)	(Sad)	(Sad)	(Sad)

Figure 9: Interpretation of the outputs for all the chosen beta-tests

4 Discussion & limitations

In the previous chapter results from several specific cases were shown. These results will only partly be discussed, since the actual result of this study was developing the tool itself. Therefore, the main part of this discussion and limitations chapter will be dedicated to the methodology and the tool, rather than the previously presented results.

4.1 Discussion of methodology

Even though the methodology was described in detail, there are still some factors that need to be discussed further in order to give a clear idea and a better understanding to the reader. Most of these factors are described in this chapter.

First, the threshold of 0.22 set for the solar transmitted energy in the user predictability control strategy, as described in Chapter 2.1.3.3, was arbitrary. It was the average tipping point where the visual reflectance, R_{vis} , was higher than the visual transmittance, T_{vis} . This threshold needed to be defined in order to ensure that the glazing properties were taken into consideration in the calculations for the user behaviour prediction. For example, high reflective glazing units allow less solar transmitted energy, meaning that the shading device needs to be used less. Without setting this threshold it would not be possible to account for this factor. The threshold was calculated by taking the average of the g-values at the tipping point between R_{vis} and T_{vis} , for each of the investigated glazing units. The values ranged between 0.18 and 0.23, and the average value of 0.22 was deemed to be a close enough margin.

Some special effort should be put on discussing the View Quantity Index. This index is an interpretation of the designers of this tool, meaning that it has not been tested or validated. It is, as its name mentions, a rough try to quantify the view out. It is only based on glazing properties and shading geometry, thus as a general summary it could be said that it is the multiplication of the light transmittance of the glazing with the openness factor of the shading. It has nothing to do with the view out as qualifying the surroundings or the landscape out of the window. It only offers a fair comparison to what can be seen when choosing between the glazing units and shading positions available in the tool.

Moreover, it should be noted that the VQI was calculated with a standard window height of one metre and a fixed view point of 1.3 metres from the window. In order to validate that the height of the window does not affect the VQI, the same calculations were run for a two metres window. The results showed that even though the height was 100 % increased, the VQI varied only 1 %, meaning that the first factor was deemed insignificant for the calculation method. Regarding the distance of the view point from the window, 1.3 meters was selected as the placement of the workstation in order to capture the ‘worst case’ scenario for daylight glare, while also providing adequate view out. For a different distance from the window the absolute value of the VQI would change, however at any distance the comparison between the VQIs of the available combinations would remain the same. This means that if at a certain distance from the window, the VQI of a glazing and shading system is higher than another one, it will be higher at any other distance.

Additionally, the authors defined 0.6 as the minimum weighted VQI that is expected to give a proper view quantity. This value was not arbitrary but came from calculations. The weighted VQIs for all the available combinations of glazing and shading units in the database of the tool were calculated. Then the average value of these indexes was found to be 0.6 and it was defined as the line between satisfying and non-satisfying results for the VQI.

Also, a small note could be made on how the data for the fabrics was imported in WIS. Since the material data needed to be created, some assumptions were made for the reflectance of the fabric. Both inside and outside reflectance was set the same as the reflectance obtained from manufacturer information. In reality, however, the reflectance on the inside is usually lower. This simplification did not influence the calculations, since only the outside reflectance was used for them.

4.1 Discussion of results

Most of the results seemed to be logical, however, some of them need to be discussed further. Following, these results are discussed in depth to offer a clear understanding.

Solar gains control puts the shading as open as possible, which gives reasonable view out whilst not exceeding the solar gains threshold. Contradictory, the incident solar radiation control gives lower values for solar heat gains, which in essence would be good, although, the VQI is lower, and the solar gains in the winter are reduced to almost zero. This means that the incident solar radiation strategy ‘over-uses’ the shading device.

On the other hand, the user predictability strategies, both responsive and non-responsive, showed the highest VQI. However, the shading was only used to ‘maximise’ the view out, whilst not allowing the direct sun beam to enter. This led to more solar heat gains than ‘allowed’.

Further interpretation of the results is subjective. The total solar heat gains need to be assessed further by the user of the tool. The tool cannot predict what the HVAC-engineer would allow for solar heat gains on a yearly basis, for example. This means, that the ‘failed’ hours are only viable to show in the solar gains control strategy, since the other strategies have a more subjective definition of ‘fail’.

4.2 Limitations

Given its nature of a quick evaluation tool for the early design stage, the tool has some limitations. They are mainly linked to some simplifications in the calculation methods and assumptions, even though they were based on literature studies and research.

To assess the user predictability, it was assumed that the direct sun beam, entering through the window, has a high probability to cause glare. Therefore, the occupant would close the blinds in order to block the direct sun beam. This is, however, a very simplified way of looking at a complex problem, like glare. The glare that an occupant experiences is dependent on many factors that were not possible to calculate without considering room-geometry and surroundings. This means that it cannot be said that glare was accounted for in the tool, but the occupant predictability of the shading use had its basis in glare probability.

Furthermore, the control strategies were limited by themselves. The strategies were assessed based on one setpoint or threshold. Thus, the solar gains control strategy was limited to only assess the shading use for solar gains and does not account for the direct sun beam i.e. glare possibility. The other way around, the occupant prediction control and the incident solar radiation control do not take the solar gains as a threshold into account.

The occupant behaviour control strategy is based only on literature review. This manual control strategy is scripted to represent the occupant behaviour in an automated shading control system, with two ‘types’ of occupants. This equals to divide a complex problem into ‘black and white’. Since occupant behaviour is impossible to predict with good accuracy in a simplified tool like this, it was assumed that such division gave a fair comparison for a manual solar control system.

The chosen shading devices were limited by several factors. The fabric products were randomly chosen from different suppliers, meaning the choice was merely based on difference in openness factor, reflectance, and if the fabric was for internal or external purposes. Besides this, the fabrics were calculated with an ‘on/off’ schedule, and no intermediate state was used in the calculations. The venetian blinds on the other hand had different limitations. Three ‘default’ blinds, white, black, and silver, were chosen as representative materials and colours. However, they were not chosen from suppliers, and therefore the presented material properties of the blinds in the tool should be used as reference. Also, the blinds only had four standard positions that were used in the calculations, being: 0°, 30°, 60°, and 90° slat angles. More slat angles could be considered for a more detailed study of when and how the blinds are used. Lastly for the blinds, the inter-reflectance and the directivity of the reflectance were not taken into consideration. This was thought of, but deemed too detailed for the use of the tool.

Finally, surroundings were not taken into account. Therefore, reflection from other buildings did not account for possible reflected direct sun beam in the tool. However, the option to load in a detailed calculation for incident radiation on the surface is available. In this way, the amount of detail put into the calculation is up to the end user of the tool.

4.3 Further studies

The developed tool gave a slight insight in several problems which occur whilst assessing the use of shading devices. As discussed, there were some limitations that had to be implemented in the tool, in order for it to work quickly and still give proper results. This then leads to three things for further study: a) the tool can be validated more thoroughly with Dynamic Thermal Modelling tools; b) more detailed studies can be done for the assessment of several calculations such as glare control or occupant behaviour predictability; and c) the database of the tool could be extended with more and different types of glazing and shading units.

For further development of the tool, a different approach could be studied. For example, the tool currently gives design suggestions for a selected fenestration system. However, a different approach could be to give a fenestration system as a result, rather than input. This would transform the tool from a performance assessment tool, to a design support making tool.

5 Conclusions

This study showed the development process of a new tool that assesses the use of shading in an early design stage. It addressed the problem that currently used Dynamic Thermal Modelling tools deal with, being that the shading use is assessed separately from either daylight or energy aspects, and that there is not a component-based assessment available.

The developed tool uses three shading control strategies to assess ten different glazing types, combined with six different venetian blinds, and six types of fabric. As a result, the tool gives the number of hours that the chosen shading is used for each strategy, as well as the solar heat gains.

An important new development in the tool was the implementation of the view out, expressed as the View Quantity Index. This index combines the properties of glazing and shading with the hours that the shading is used and gives a unit-less value between zero and one, for the comparison of the quantified view out.

The outputs given by the tool could further be subjectively interpreted by the user. An example of beta-tested results with the designers' interpretation was given, comparing three glazing units combined with three shading units. The comparison was made to evaluate the performance of the fenestration systems on solar gains and the View Quantity Index.

The tool could be questioned on its limitations, which were necessary to have to keep the study viable. Most of the limitations were created with assumptions and simplifications, based on literature studies. Further studies could be useful to improve the tool or to make it more accurate.

6 Summary

It is common knowledge that shading systems and solar control glasses are used to avoid glare and overheating at expenses of daylight. Nowadays there are many simulation software tools that assess shading systems as well as a big amount of literature studies that investigate them.

Most of the current Dynamic Thermal Modelling tools assess shading, however they do not account for the use of the shading when combined with various glazing units. Moreover, these tools usually demand a large amount of input variables and detailed geometry of the model. This makes it more difficult to get a quick assessment of the shading use together with the building performance during the early design phase of a project. Furthermore, literature studies regarding shading use showed a lack of a method that can combine both visual comfort, solar transmitted energy through windows, and shading use. It also showed that most of the studies were performed under fixed testing conditions and thus, their results are case specific and not always representative.

All these factors suggest that a new method is needed to provide the missing information and bridge the existing gap. For this reason, an excel-based tool was created to predict the performance of fenestration systems in real life. The tool uses a limited amount of input data that must be filled in by the end-user in a simple way. Moreover, it is a room independent tool, meaning that no geometry of the model needs to be created. It only considers the geometry of the window and the façade as it is a component-based tool. These factors make the tool easy to use by common practitioners, especially in the early design phase. The tool provides hints on what kind of glazing unit should be chosen and how to use a shading device properly in combination with the respective glazing.

As input, location information, occupancy schedules, as well as basic window geometry are asked. The user is asked to input a weather file and optionally insert a file with hourly radiation data that is obtained by preliminary simulations with a different software. Then the user is asked to choose between glazing and shading units that are available from the database of the tool. Regarding the glazing database, the user can choose between ten glazing units; a clear glazing with a low-emittance coating, three different solar control glazing units and a high reflective one. All these units are available both for double-glazed and triple-glazed units. The database for shading devices includes twelve units; venetian blinds and fabrics that can be placed either internally or externally. White, black, and silver venetian blinds are available for selection, while regarding fabrics the user can choose between an openness factor of 3 %, 5 %, and 10 % internally, or between 5 % and 14 % externally.

Three different shading control strategies are used, namely a solar gains threshold, incident solar radiation, and a prediction on the user's behaviour. The first one, Solar Heat Gains control strategy, uses a threshold for heat gains and adjusts the shading device in accordance with this. It tries to keep the shade as open as possible but keep the solar heat gains low at the same time. By doing that, it allows more daylight in the room and a better connection to the outside. The second control strategy, Incident Solar Radiation, uses a threshold for the radiation that hits the window externally. When the threshold is exceeded the control strategy applies the shading device depending on the sun position at that time. The final control strategy, User Predictability, is an attempt to predict the behaviour of the occupant regarding the manual use of shading. According to this control strategy, the user tries to adjust the

shading device in order to block the direct sun beam that may cause glare. Three different positions at one metre, two metres, and three metres from the window were studied. The control strategy predicts the behaviour of two kinds of users, being responsive and non-responsive with the difference lying on how much they care about daylight and how eager they are to pull the shading up to get a better connection to the outside.

An index was created by the authors as an attempt to assess the view. The View Quantity Index, as it is named, is a unitless value between zero and one and it is an interpretation of the designers of this tool to quantify the view out. It takes into account the glazing properties, such as the light transmittance, and it combines them with the position of the shading during a specific hour. It then calculates for all the occupied hours of the year to give the final result which can be translated as satisfying or not, regarding the quantity of the view.

As output, the tool first presents a table that summarises the shading use during all the occupied hours of the year for each of the control strategies. This table shows how many of these hours the shading is used at different positions. The VQI is weighted using the values of table and is then presented in a graph for all the control strategies. Moreover, the annual solar heat gains are calculated and shown in graphs. For the Solar Heat Gains control strategy, there is an additional graph that shows how the shading is used during the week of the year with the highest solar heat gains. Finally, the users of the tool have the option to obtain a diary file with the hourly shading positions that could be used further in their projects. To demonstrate the output of the tool in this report, a beta test was run for a combination of a double glazed solar control unit with internal white venetian blinds. The results were not explained analytically, since the purpose was to give the reader a clearer idea of how the tool works and not to analyse specific calculations.

Some important limitations that can be defined are: the simplification in the calculation of the secondary solar transmittance that is used for the solar heat gains; and the complexity of predicting the user's behaviour, which is combined with the direct sun beam as glare factor. The study showed how this tool assesses the performance of different glazing products combined with shading control systems and strategies, to help designing a functioning façade that fills the gap between shading systems and solar control.

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APPENDIX A

A.1. VBA code for loading a weather file

```
wbname = ThisWorkbook.Name
```

```
MsgBox ("Load a weather file with .epw extension")
```

```
vFileName = Application.GetOpenFilename(" epw File(*.epw), *.epw")
```

```
Workbooks.OpenText filename:=vFileName, _
Origin:=xlMSDOS, StartRow:=1, DataType:=xlDelimited, _
TextQualifier:=xlDoubleQuote, _
ConsecutiveDelimiter:=False, Tab:=False, _
Semicolon:=False, Comma:=True, Space:=False, _
Other:=False, TrailingMinusNumbers:=True, _
Local:=True
```

```
epwFile = Left(ActiveWorkbook.Name, (InStrRev(ActiveWorkbook.Name, ".", -1, vbTextCompare) - 1))
```

```
epwFileName = "Weather data"
```

```
Sheets(epwFile).Select
Cells.Select
Selection.Copy
Windows(wbname).Activate
Sheets(3).Visible = True
Sheets(3).Select
Cells.Select
Sheets(3).Paste
```

A.2. VBA code for loading incident solar radiation data

wbname = ThisWorkbook.Name

```
Sheets(5).Select  
Range("AA1", Range("AA1").End(xlDown)).Select  
Selection.ClearContents  
Sheets(5).Visible = False
```

```
MsgBox ("Load hourly radiation on the surface, as 1 column of 8760 values, in a text file")  
vFileName = Application.GetOpenFilename("Radiation text file (*.txt),*.txt")
```

```
Workbooks.OpenText filename:=vFileName, _  
Origin:=xlMSDOS, StartRow:=1, DataType:=xlDelimited, _  
TextQualifier:=xlDoubleQuote, _  
ConsecutiveDelimiter:=False, Tab:=False, _  
Semicolon:=False, Comma:=False, Space:=False, _  
Other:=False, TrailingMinusNumbers:=True, _  
Local:=True
```

```
RadFile = Left(ActiveWorkbook.Name, (InStrRev(ActiveWorkbook.Name, ".", -1, vbTextCompare) - 1))  
RadFileName = "Radiation data"
```

```
Sheets(1).Select  
Range("A1", Range("A1").End(xlDown)).Select  
Selection.Copy  
Windows(wbname).Activate  
Sheets(5).Visible = True  
Sheets(5).Select  
Range("AA1").Select  
ActiveSheet.Paste  
Application.DisplayAlerts = False  
Workbooks(RadFile).Close False
```

```
If IsEmpty(Sheets(5).Range("AA8760")) Then  
    MsgBox ("Your radiation file has too few hours. Please load a different file.")  
    Sheets(5).Range("AA1", Range("AA1").End(xlDown)).Select  
    Selection.ClearContents
```

End If

```
If Not IsEmpty(Sheets(5).Range("AA8760")) Then  
    MsgBox ("Your radiation file has too many hours. Please load a different file.")  
    Sheets(5).Range("AA1", Range("AA1").End(xlDown)).Select  
    Selection.ClearContents
```

End If

APPENDIX B

B.1. VBA code for choosing a glazing unit

index = DGUorTGU.ListIndex

GlazingUnit.Clear

Select Case index

Case Is = 0

With GlazingUnit

.AddItem "Guardian Climaguard low-e 80/63 D"
.AddItem "Guardian Sunguard 70/37 D"
.AddItem "Guardian Sunguard SNX 62/27 D"
.AddItem "Ipasol Shine 40/22 D"
.AddItem "Guardian Silver S20 19/17 D"

End With

Case Is = 1

With GlazingUnit

.AddItem "Guardian Climaguard low-e 80/63 T"
.AddItem "Guardian Sunguard 70/37 T"
.AddItem "Guardian Sunguard SNX 62/27 T"
.AddItem "Ipasol Shine 40/22 T"
.AddItem "Guardian Silver S20 19/17 T"

End With

End Select

B.2. VBA code for choosing a shading unit

```
index = InorOut.ListIndex
```

```
ShadingUnit.Clear
```

```
Select Case index
```

```
Case Is = 0
```

```
    With ShadingUnit
```

```
        .AddItem "White venetian blinds i"  
        .AddItem "Black venetian blinds i"  
        .AddItem "Silver venetian blinds i"  
        .AddItem "Fabric OHM (OF=10%)"  
        .AddItem "Fabric Sky screen (OF=3%)"  
        .AddItem "Fabric Nuovi (OF=5%)"  
        .AddItem "Fabric Duroscreen (OF=5%)"
```

```
    End With
```

```
Case Is = 1
```

```
    With ShadingUnit
```

```
        .AddItem "White venetian blinds e"  
        .AddItem "Black venetian blinds e"  
        .AddItem "Silver venetian blinds e"  
        .AddItem "Fabric Soltis (OF=14%)"  
        .AddItem "Fabric Sky screen (OF=5%)"
```

```
    End With
```

```
End Select
```

APPENDIX C

C.1. VBA code for finding the solar transmitted energy for different angles of incidence

For i = 1 To 8760

If Worksheets(5).Cells(i, 2).Value = "-" Then

 Worksheets(5).Cells(i, 7).Value = "-"

 Worksheets(5).Cells(i, 8).Value = "-"

 Worksheets(5).Cells(i, 9).Value = "-"

 Worksheets(5).Cells(i, 10).Value = "-"

 Worksheets(5).Cells(i, 11).Value = "-"

 Worksheets(5).Cells(i, 12).Value = "-"

Else

 If Worksheets(5).Cells(i, 2).Value = 0 Then

 Worksheets(5).Cells(i, 7).Value = Worksheets(5).Cells(2, 8).Value

 ElseIf Worksheets(5).Cells(i, 2).Value = 10 Then

 Worksheets(5).Cells(i, 7).Value = Worksheets(5).Cells(2, 9).Value

 ElseIf Worksheets(5).Cells(i, 2).Value = 20 Then

 Worksheets(5).Cells(i, 7).Value = Worksheets(5).Cells(2, 10).Value

 ElseIf Worksheets(5).Cells(i, 2).Value = 30 Then

 Worksheets(5).Cells(i, 7).Value = Worksheets(5).Cells(2, 11).Value

 ElseIf Worksheets(5).Cells(i, 2).Value = 40 Then

 Worksheets(5).Cells(i, 7).Value = Worksheets(5).Cells(2, 12).Value

 ElseIf Worksheets(5).Cells(i, 2).Value = 50 Then

 Worksheets(5).Cells(i, 7).Value = Worksheets(5).Cells(2, 13).Value

 ElseIf Worksheets(5).Cells(i, 2).Value = 60 Then

 Worksheets(5).Cells(i, 7).Value = Worksheets(5).Cells(2, 14).Value

 ElseIf Worksheets(5).Cells(i, 2).Value = 70 Then

 Worksheets(5).Cells(i, 7).Value = Worksheets(5).Cells(2, 15).Value

 ElseIf Worksheets(5).Cells(i, 2).Value = 80 Then

 Worksheets(5).Cells(i, 7).Value = Worksheets(5).Cells(2, 16).Value

 ElseIf Worksheets(5).Cells(i, 2).Value = 90 Then

 Worksheets(5).Cells(i, 7).Value = Worksheets(5).Cells(2, 17).Value

Else

 Worksheets(5).Cells(i, 7).Value = "-"

End If

If Worksheets(5).Cells(11, 6).Value = "Blinds" Then

 Worksheets(5).Cells(i, 12).Value = "-"

 If Worksheets(5).Cells(i, 2).Value = 0 Then

 Worksheets(5).Cells(i, 8).Value = Worksheets(5).Cells(3, 8).Value

 Worksheets(5).Cells(i, 9).Value = Worksheets(5).Cells(4, 8).Value

 Worksheets(5).Cells(i, 10).Value = Worksheets(5).Cells(5, 8).Value

 Worksheets(5).Cells(i, 11).Value = Worksheets(5).Cells(6, 8).Value

 ElseIf Worksheets(5).Cells(i, 2).Value = 10 Then

 Worksheets(5).Cells(i, 8).Value = Worksheets(5).Cells(3, 9).Value

 Worksheets(5).Cells(i, 9).Value = Worksheets(5).Cells(4, 9).Value

 Worksheets(5).Cells(i, 10).Value = Worksheets(5).Cells(5, 9).Value

 Worksheets(5).Cells(i, 11).Value = Worksheets(5).Cells(6, 9).Value

Else

```
    Worksheets(5).Cells(i, 8).Value = "-"
    Worksheets(5).Cells(i, 9).Value = "-"
    Worksheets(5).Cells(i, 10).Value = "-"
    Worksheets(5).Cells(i, 11).Value = "-"

    If Worksheets(5).Cells(i, 2).Value = 0 Then
        Worksheets(5).Cells(i, 12).Value = Worksheets(5).Cells(3, 8).Value
    ElseIf Worksheets(5).Cells(i, 2).Value = 10 Then
        Worksheets(5).Cells(i, 12).Value = Worksheets(5).Cells(3, 9).Value
    ElseIf Worksheets(5).Cells(i, 2).Value = 20 Then
        Worksheets(5).Cells(i, 12).Value = Worksheets(5).Cells(3, 10).Value
    ElseIf Worksheets(5).Cells(i, 2).Value = 30 Then
        Worksheets(5).Cells(i, 12).Value = Worksheets(5).Cells(3, 11).Value
    ElseIf Worksheets(5).Cells(i, 2).Value = 40 Then
        Worksheets(5).Cells(i, 12).Value = Worksheets(5).Cells(3, 12).Value
    ElseIf Worksheets(5).Cells(i, 2).Value = 50 Then
        Worksheets(5).Cells(i, 12).Value = Worksheets(5).Cells(3, 13).Value
    ElseIf Worksheets(5).Cells(i, 2).Value = 60 Then
        Worksheets(5).Cells(i, 12).Value = Worksheets(5).Cells(3, 14).Value
    ElseIf Worksheets(5).Cells(i, 2).Value = 70 Then
        Worksheets(5).Cells(i, 12).Value = Worksheets(5).Cells(3, 15).Value
    ElseIf Worksheets(5).Cells(i, 2).Value = 80 Then
        Worksheets(5).Cells(i, 12).Value = Worksheets(5).Cells(3, 16).Value
    ElseIf Worksheets(5).Cells(i, 2).Value = 90 Then
        Worksheets(5).Cells(i, 12).Value = Worksheets(5).Cells(3, 17).Value
    Else
        Worksheets(5).Cells(i, 12).Value = "-"

    End If
End If
Next i
```

APPENDIX D

D.1. VBA code for finding the shading position for Solar gains Control Strategy

For i = 1 To 8760

If Worksheets(5).Cells(i, 13).Value = "-" Then

 Worksheets(5).Cells(i, 20).Value = 0

Else

 If Worksheets(5).Cells(11, 6).Value = "Blinds" Then

 If Worksheets(5).Cells(i, 13).Value <= Worksheets(5).Cells(11, 19).Value Then

 Worksheets(5).Cells(i, 20).Value = 0

 ElseIf Worksheets(5).Cells(i, 14).Value <= Worksheets(5).Cells(11, 19).Value Then

 Worksheets(5).Cells(i, 20).Value = 1

 ElseIf Worksheets(5).Cells(i, 15).Value <= Worksheets(5).Cells(11, 19).Value Then

 Worksheets(5).Cells(i, 20).Value = 2

 ElseIf Worksheets(5).Cells(i, 16).Value <= Worksheets(5).Cells(11, 19).Value Then

 Worksheets(5).Cells(i, 20).Value = 3

 ElseIf Worksheets(5).Cells(i, 17).Value <= Worksheets(5).Cells(11, 19).Value Then

 Worksheets(5).Cells(i, 20).Value = 4

 Else

 Worksheets(5).Cells(i, 20).Value = "Fail"

 End If

Else

 If Worksheets(5).Cells(i, 13).Value <= Worksheets(5).Cells(11, 19).Value Then

 Worksheets(5).Cells(i, 20).Value = 0

 ElseIf Worksheets(5).Cells(i, 18).Value <= Worksheets(5).Cells(11, 19).Value Then

 Worksheets(5).Cells(i, 20).Value = 5

 Else

 Worksheets(5).Cells(i, 20).Value = "Fail"

 End If

End If

Next i

D.2. VBA code for finding the shading position for Responsive user Control Strategy

For i = 1 To 8760

If (Worksheets(5).Cells(i, 33).Value = "-" Or Worksheets(5).Cells(i, 7).Value <= 0.22 Or Worksheets(3).Cells(i - 2, 23).Value >= 4) Then

 Worksheets(5).Cells(i, 34).Value = 0

 Worksheets(5).Cells(i, 35).Value = 0

 Worksheets(5).Cells(i, 36).Value = 0

Else

 If Worksheets(5).Cells(i, 33).Value >= Worksheets(5).Cells(11, 30).Value Then

 Worksheets(5).Cells(i, 34).Value = 0

 Else

 If Worksheets(5).Cells(11, 6).Value = "Blinds" Then

 If Worksheets(5).Cells(i, 33).Value <= 90 And Worksheets(5).Cells(i, 33).Value > 67.5 Then

 Worksheets(5).Cells(i, 34).Value = 1

 ElseIf Worksheets(5).Cells(i, 33).Value <= 67.5 And Worksheets(5).Cells(i, 33).Value > 45 Then

 Worksheets(5).Cells(i, 34).Value = 2

 ElseIf Worksheets(5).Cells(i, 33).Value <= 45 And Worksheets(5).Cells(i, 33).Value > 22.5 Then

 Worksheets(5).Cells(i, 34).Value = 3

 Else

 Worksheets(5).Cells(i, 34).Value = 4

 End If

 Else

 Worksheets(5).Cells(i, 34).Value = 5

 End If

 End If

Next i

D.3. VBA code for finding the shading position for Non-responsive user Control Strategy

```
For hour = 1 To 8760
    Worksheets(5).Cells(hour, 37).Value = 0
    If Worksheets(5).Cells(hour, 23).Value >= Worksheets(1).Cells(15, 3).Value And
        Worksheets(5).Cells(hour, 23).Value < Worksheets(1).Cells(16, 3).Value Then
            If (Worksheets(5).Cells(hour, 33).Value < Worksheets(5).Cells(11, 30).Value And
                Worksheets(5).Cells(hour, 7).Value > 0.22 And Worksheets(3).Cells(hour - 2, 23).Value <
                4) Then
                If Worksheets(5).Cells(11, 6).Value = "Blinds" Then
                    If Worksheets(5).Cells(hour, 33).Value <= 90 And Worksheets(5).Cells(hour,
                        33).Value > 67.5 Then
                        Worksheets(5).Cells(hour, 37).Value = 1
                    ElseIf Worksheets(5).Cells(hour, 33).Value <= 67.5 And
                        Worksheets(5).Cells(hour, 33).Value > 45 Then
                        Worksheets(5).Cells(hour, 37).Value = 2
                    ElseIf Worksheets(5).Cells(hour, 33).Value <= 45 And Worksheets(5).Cells(hour,
                        33).Value > 22.5 Then
                        Worksheets(5).Cells(hour, 37).Value = 3
                    Else
                        Worksheets(5).Cells(hour, 37).Value = 4
                    End If
                Else
                    Worksheets(5).Cells(hour, 37).Value = 5
                End If
                temp = hour
                hour = 24 - Worksheets(5).Cells(hour, 23).Value + Worksheets(1).Cells(15,
                    3).Value + hour - 1
                For j = temp To hour
                    Worksheets(5).Cells(j, 37).Value = Worksheets(5).Cells(temp, 37).Value
                Next j
            End If
        End If
    Next hour
```

Appendix E

E.1. VBA code for finding the week with the highest solar heat gains

```
Worksheets(5).Activate
```

```
amax = WorksheetFunction.Max(Range("A$1", "A$8760"))
```

```
With Worksheets(5).Range("A$1:A$8760")
```

```
Set emax = .Find(amax, LookIn:=xlValues, lookat:=xlWhole)
```

```
If Not emax Is Nothing Then
```

```
    Set rALL1 = emax
```

```
    firstAddress1 = emax.Address
```

```
    Do
```

```
        Set rALL1 = Union(rALL1, emax)
```

```
        Worksheets(5).Range(emax.Address).Activate
```

```
        ActiveCell.EntireRow.Select
```

```
        Set maxday1 = Cells(Application.ActiveCell.Row, 24)
```

```
        Set maxday7 = Selection.Offset(167, 0)
```

```
        Set maxweek = Range(maxday1, maxday7)
```

```
        maxweek.Select
```

```
        Selection.Copy
```

```
        Worksheets(8).Activate
```

```
        ActiveSheet.Range("A3").Select
```

```
        Selection.PasteSpecial xlPasteValues
```

```
    Loop While Not emax Is Nothing And emax.Address <> firstAddress1
```

```
End If
```

```
End With
```

E.2. VBA code for exporting a diary file for each of the Control Strategies

ExportStrategies = Strategies.Value
ExportStrategies2 = Strategies2.Value

```
Select Case ExportStrategies
    Case Is = "Solar gains control strategy"
        Worksheets(5).Range("T1:T8760").Copy
        Worksheets(10).Activate
        Worksheets(10).Range("D2").Select
        Selection.PasteSpecial xlPasteValues
        If Worksheets(5).Range("F11").Value = "Fabric" Then
            Worksheets(10).Range("A1:B8760").Select
            Selection.Copy
            Workbooks.Add
            Range("A1").Select
            Selection.PasteSpecial xlPasteValues
            ActiveWorkbook.Close
        Else
            Worksheets(10).Activate
            Worksheets(10).Range("A1:C8760").Select
            Selection.Copy
            Workbooks.Add
            Range("A1").Select
            Selection.PasteSpecial xlPasteValues
            ActiveWorkbook.Close
        End If
    Case Is = "Incident solar radiation control strategy"
        Worksheets(5).Range("AP1:AP8760").Copy
        Worksheets(10).Activate
        Worksheets(10).Range("D2").Select
        Selection.PasteSpecial xlPasteValues
        If Worksheets(5).Range("F11").Value = "Fabric" Then
            Worksheets(10).Range("A1:B8760").Select
            Selection.Copy
            Workbooks.Add
            Range("A1").Select
            Selection.PasteSpecial xlPasteValues
            ActiveWorkbook.Close
        Else
            Worksheets(10).Activate
            Worksheets(10).Range("A1:C8760").Select
            Selection.Copy
            Workbooks.Add
            Range("A1").Select
            Selection.PasteSpecial xlPasteValues
            ActiveWorkbook.Close
        End If
```

```
End Select
Select Case ExportStrategies2
Case Is = "Responsive user at 1m"
    Worksheets(5).Range("AH1:AH8760").Copy
    Worksheets(10).Activate
    Worksheets(10).Range("D2").Select
    Selection.PasteSpecial xlPasteValues
    If Worksheets(5).Range("F11").Value = "Fabric" Then
        Worksheets(10).Range("A1:B8760").Select
        Selection.Copy
        Workbooks.Add
        Range("A1").Select
        Selection.PasteSpecial xlPasteValues
        ActiveWorkbook.Close
    Else
        Worksheets(10).Activate
        Worksheets(10).Range("A1:C8760").Select
        Selection.Copy
        Workbooks.Add
        Range("A1").Select
        Selection.PasteSpecial xlPasteValues
        ActiveWorkbook.Close
    End If
Case Is = "Responsive user at 2m"
    Worksheets(5).Range("AI1:AI8760").Copy
    Worksheets(10).Activate
    Worksheets(10).Range("D2").Select
    Selection.PasteSpecial xlPasteValues
    If Worksheets(5).Range("F11").Value = "Fabric" Then
        Worksheets(10).Range("A1:B8760").Select
        Selection.Copy
        Workbooks.Add
        Range("A1").Select
        Selection.PasteSpecial xlPasteValues
        ActiveWorkbook.Close
    Else
        Worksheets(10).Activate
        Worksheets(10).Range("A1:C8760").Select
        Selection.Copy
        Workbooks.Add
        Range("A1").Select
        Selection.PasteSpecial xlPasteValues
        ActiveWorkbook.Close
    End If
```

```

Case Is = "Responsive user at 3m"
    Worksheets(5).Range("AJ1:AJ8760").Copy
    Worksheets(10).Activate
    Worksheets(10).Range("D2").Select
    Selection.PasteSpecial xlPasteValues
If Worksheets(5).Range("F11").Value = "Fabric" Then
    Worksheets(10).Range("A1:B8760").Select
    Selection.Copy
    Workbooks.Add
    Range("A1").Select
    Selection.PasteSpecial xlPasteValues
    ActiveWorkbook.Close
Else
    Worksheets(10).Activate
    Worksheets(10).Range("A1:C8760").Select
    Selection.Copy
    Workbooks.Add
    Range("A1").Select
    Selection.PasteSpecial xlPasteValues
    ActiveWorkbook.Close
End If

Case Is = "Non-responsive user at 1m"
    Worksheets(5).Range("AK1:AK8760").Copy
    Worksheets(10).Activate
    Worksheets(10).Range("D2").Select
    Selection.PasteSpecial xlPasteValues
If Worksheets(5).Range("F11").Value = "Fabric" Then
    Worksheets(10).Range("A1:B8760").Select
    Selection.Copy
    Workbooks.Add
    Range("A1").Select
    Selection.PasteSpecial xlPasteValues
    ActiveWorkbook.Close
Else
    Worksheets(10).Activate
    Worksheets(10).Range("A1:C8760").Select
    Selection.Copy
    Workbooks.Add
    Range("A1").Select
    Selection.PasteSpecial xlPasteValues
    ActiveWorkbook.Close
End If

```

```
Case Is = "Non-responsive user at 2m"
    Worksheets(5).Range("AL1:AL8760").Copy
    Worksheets(10).Activate
    Worksheets(10).Range("D2").Select
    Selection.PasteSpecial xlPasteValues
    If Worksheets(5).Range("F11").Value = "Fabric" Then
        Worksheets(10).Range("A1:B8760").Select
        Selection.Copy
        Workbooks.Add
        Range("A1").Select
        Selection.PasteSpecial xlPasteValues
        ActiveWorkbook.Close
    Else
        Worksheets(10).Activate
        Worksheets(10).Range("A1:C8760").Select
        Selection.Copy
        Workbooks.Add
        Range("A1").Select
        Selection.PasteSpecial xlPasteValues
        ActiveWorkbook.Close
    End If
Case Is = "Non-responsive user at 3m"
    Worksheets(5).Range("AM1:AM8760").Copy
    Worksheets(10).Activate
    Worksheets(10).Range("D2").Select
    Selection.PasteSpecial xlPasteValues
    If Worksheets(5).Range("F11").Value = "Fabric" Then
        Worksheets(10).Range("A1:B8760").Select
        Selection.Copy
        Workbooks.Add
        Range("A1").Select
        Selection.PasteSpecial xlPasteValues
        ActiveWorkbook.Close
    Else
        Worksheets(10).Activate
        Worksheets(10).Range("A1:C8760").Select
        Selection.Copy
        Workbooks.Add
        Range("A1").Select
        Selection.PasteSpecial xlPasteValues
        ActiveWorkbook.Close
    End If
End Select
```



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