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PREDELAVA VREMENSKIH PODATKOV ZA PROGRAM TCD

WEATHER DATA MODIFICATION FOR TCD PROGRAM

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Avtor:	**Mija Sušnik**
Mentor:	**doc.dr. Mitja Košir**
Somentor:	**izr. prof. Jørgen Erik Christensen**
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IZVLEČEK

Program TCD (angl. Thermal Calculator by Design) je kalkulator za notranje toplotno okolje, ki je bil razvit na oddelku za gradbeništvo na Danski tehnični univerzi (DTU). Solarni dobitki temeljijo na integriranih sončnih krivuljah za lokacijo na Danskem. Le-te so pridobljene iz literature, ki pa ne zajema pojasnila o tem, kako so bile pridobljene. Na ta način je uporaba programa TCD omejena, saj se lahko uporabi le za analize za lokacijo na Danskem.

Namen naloge je bil analizirati obstoječe sončne krivulje in poiskati metodo za določitev novih sončnih krivulj za namene razširitve uporabnosti programa TCD.

Obstoječe sončne krivulje so bile analizirane in z izvedbo številnih simulacij in izračunov je bilo ugotovljeno, kako se jih lahko pridobi. To je služilo kot temelj za razvoj metode za določanje sončnih krivulj iz široko dostopnih vremenskih datotek.

Vsak korak postopka je v nalogi natančno opisan, saj je namen bil izdelati pregled, ki se ga lahko uporabi kot vodič oziroma priročnik. S sledenjem opisanih korakov se lahko določi sončne krivulje za katerokoli izbrano lokacijo. To je bilo dokazano tako, da je metoda bila uporabljena za določanje sončnih krivulj za Slovenijo.

Na novo pridobljene krivulje in s tem tudi metoda sama so bile preverjene z vnosom novih sončnih krivulj v program TCD in primerjavo rezultatov s simulacijami, izvedenimi v bolj naprednem simulacijskem orodju BSim. Ugotovljeno je bilo, da metoda dobro deluje in se jo lahko uporabi za določanje sončnih krivulj za katerokoli lokacijo.

Razvita metoda zagotavlja dobre rezultate in prispeva k večji uporabnosti programa TCD tako, da širi možnosti njegove uporabe za analize za katerokoli izbrano lokacijo.

BIBILIOGRAPHIC-DOCUMENTALISTIC INFORMATION AND ABSTRACT

UDC:	**620.92:004.43(043.2)**
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ABSTRACT

The TCD (Thermal Calculator by Design) program is a thermal calculator, developed at the Department of Civil Engineering at Technical University of Denmark (DTU). Solar gain calculations are based on implemented sun curves for a location in Denmark. These sun curves come from a literature, which includes no explanation on how they were composed. This is limiting the use of the TCD, since it can only be used for a location in Denmark.

Therefore, the aim of the study was to investigate the existing sun curves and find a method to obtain new ones in order to expand the use of the TCD program.

The existing sun curves have been investigated, and by performing several simulations and calculations it has been explained, how sun curves can be obtained. This investigation was a foundation for developing a method to obtain sun curves from a broadly accessible weather file.

Each step of the procedure is thoroughly explained, since the aim of the study was to develop an overview or a guide that can be read as a manual. Following the steps, new sun curves can be obtained – not only for Denmark, but also for any chosen location. This was proved by using the method to obtain sun curves for a location in Slovenia.

The newly obtained sun curves and thus the method itself have been verified by implementing the new sun curves into the TCD program and comparing the results with simulations, performed in a more advanced simulation tool called BSim. It was concluded that method works well and can be used to obtain sun curves for any location.

Altogether, the developed method provides good results and it contributes to the use of the TCD by expanding its scope to any chosen location.

PREDGOVOR IN ZAHVALA

Zaključna naloga je nastajala tekom študijske izmenjave na Tehnični Univerzi na Danskem, kot projekt na oddelku za gradbeništvo pod mentorstvom izrednega profsorja Jørgen Erik Christensena.

Cilj projekta je bil nadgraditi obstoječi program TCD in zagotoviti podatke za nadaljnje raziskave in izboljšanje programa. Moje delo predstavlja manjši delež veliko večjega projekta, ki se je začel leta 2009. Biti del večje zgodbe mi je dalo dodatno spodbudo v časih, ko so bili izzivi večji od mene. V takšnih trenutkih je izredni profesor Jørgen Erik Christensen zagotovil potrebno mentorstvo in pomoč. Vedno si je vzel čas za razprave in poskrbel, da sem razumela celoto zastavljene naloge. Za to sem izredno hvaležna in se mu iskreno zahvaljujem za priložnost delati na projektu.

Zahvalila bi se tudi mentorju doc. dr. Mitji Koširju, ki je bil pripravljen sodelovati z izrednim profesorjem Jørgen Erik Christensenom, ter s strokovno pomočjo in nasveti omogočil, da se je projekt iz tujine razvil v magistrsko nalogo na Fakulteti za gradbeništvo in geodezijo.

Prav tako se želim zahvaliti tudi družini in prijateljem za vso ljubezen in potrebno podporo.

PREFACE AND ACKNOWLEDGEMET

This project is a final product of a special course at the Danish Technical University, the Department of Civil Engineering, under the supervision of Jørgen Erik Christensen, Associate Professor at the Department of Civil Engineering, DTU.

The aim of the project was to contribute and upgrade the existing program TCD and to provide data for further work on improving the program. Therefore, the present work is a piece of a larger project that began in 2009 and is yet to be continued. Being a part of a bigger story gave me extra encouragement in times when challenges were bigger than me. At such moments, Associated Professor Jørgen Erik Christensen provided the needed mentoring and help. He always took time for discussions and made sure I saw the bigger picture. I am very grateful for this and I would like to sincerely thank him for the opportunity to work on the project.

I would also like to thank mentor assist. prof. dr. Mitja Košir, who was willing to collaborate with associate professor Jørgen Erik Christensen, and with professional help and advices, made possible that the project from DTU expanded into a Master's thesis at the Faculty of Civil Engineering and Geodesy.

Finally yet importantly, I would like to thank my family and friends for all the love and needed support.

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OKRAJŠAVE

ASHRAE	Ameriško združenje inženirjev za ogrevanje, hlajenje in klimatske naprave
DRY	Oblikovno referenčno leto
DST	Poletni čas
GrossSun	Celotno sončno sevanje, prejeto skozi okna v coni
N, E, S, W	sever, vzhod, jug, zahod
NE, SE, SW, NW	severovzhod, jugovzhod, jugozahod, severozahod
Reference window	standardno okno z dvoslojno zasteklitvijo (4 mm stekla, 12 mm zraka in 4 mm stekla) z g-faktorjem 0,76
SMOT	Standardizirana poskusna metoda
XSun Distribution	solarna distribucija

ABBREVIATIONS

ASHRAE	American society of heating, refrigerating and air-conditioning engineers
DRY	Design Reference Year
DST	Daylight Saving Time
GrossSun	Total solar radiation through WinDoors in the zone
N, E, S, W	north, east, south, west
NE, SE, SW, NW	north-east, south-east, south-west, north-west
Reference window	Standard double-glazed window (4 mm float glass, 12 mm air and 4 mm float glass) with g-value 0.76
SMOT	Standard Method of Test
XSun Distribution	Solar distribution

1 INTRODUCTION

Energy performance simulations are a vital tool for designing and retrofitting energy-efficient buildings. These are usually carried out by detailed simulation programs, such as IDA ICE, BSim and others. They require high level of details and parameters in order to give reliable results. Consequently, a lot of time is spent on building a model. It is also necessary to use a proper weather information for the desired location of a building, such as annual weather files, which are available online.

In general, simulation software is used to analyse buildings and give an estimation of a building's behaviour. Different tools require different amount of details as an input. Complexity and accuracy usually go hand in hand and different results might thus appear for the same model when different tools are used. American society of heating, refrigerating and air-conditioning engineers (ASHRAE) has developed a standard method of test (SMOT) which can be used for "identifying and diagnosing predictive differences from whole building energy simulation software that may possibly be caused by algorithmic differences, modelling limitations, input differences, or coding errors" (ASHRAE, 2004). Standardized building has been analysed with different simulation tools and the comparison of results for annual heating in different programs is shown in Figure 1.1.

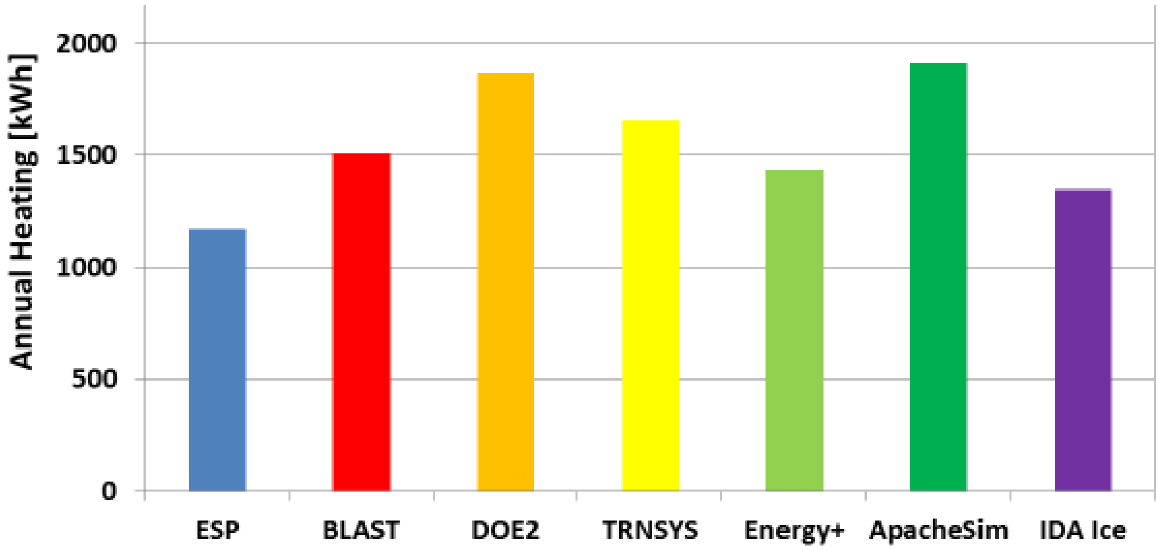


Figure 1.1 Comparison of results for annual heating in [kWh] with different simulation tools (Kazanci, 2017)

Slika 1.1 Primerjava rezultatov potrebne energije za ogrevanje v [kWh] v različnih simulacijskih orodjih (Kazanci, 2017)

It can be observed that different tools give different results, meaning that even though many inputs are put into the model, the result will always be just an estimation.

While building a model in one of the simulation tools, one might encounter some difficulties. For example, in an early design stage the information is not reliable enough to build a detailed model for simulation purposes. It is also at this stage that different designs are considered, which leads into building several versions of a model. (Hing, et al., 1999)

Altogether, it can be concluded that quick and reliable answers in an early design stage cannot be obtained by using detailed simulation programs. This problem has already been considered at the Department of Civil Engineering at the Technical University of Denmark and thus an Excel-based program has been developed in 2009. The TCD (Thermal Calculator by Design) is an indoor climate calculator that provides a daily mean temperature for a given date as an output. As an input, one needs to enter the data about building orientation, windows and solar shading, building envelope, infiltration, internal gains, ventilation and outside temperature for a chosen date. The small amount of data that is needed is the key for getting the results in a shorter time. Changing parameters allows you to analyse what affects they have on the daily mean temperature. This makes the program optimal for creating rough estimations in an early design stage before making a more precise model with one of the detailed simulation programs. By using the TCD, quick answers and preliminary estimation can be obtained.

2 PROBLEM DESCRIPTION

It has been proven that the TCD program is suitable for doing preliminary evaluations (Boesgaard, 2017); however, it can only be used for locations in Denmark. Integrated solar data is based on literature, which provides sun curves for a location in Denmark and it cannot be changed for whichever desired location. This indicates a necessary measure to improve the program in a way that it can be used for any chosen location.

The aim of this study is to investigate the existing sun curves from the literature and develop a manual for obtaining sun curves, independently from the literature. The values, which are now in use, can serve as a reference and guidance. Results of this study can therefore be used for modification and thus improvement of the TCD program by making it suitable for calculations for any location.

3 CALCULATIONS IN TCD

The TCD is a tool for obtaining quick answers regarding the daily mean temperature. Its purpose is to give practical information in an early design stage, when not so many parameters are known. It provides an estimate and it should not be considered as a precise tool or compared to advanced simulation programs. This chapter will provide a quick overview of the TCD program.

The TCD is a simple, Excel-based program. The user needs to fill the data into the cells, which are marked with yellow. Green represents cells where calculations are made. Orange cells provide a drop-down menu, where user can choose between different possibilities. Blue cells show results and pink cells contain explanatory text. Inputs that need to be entered into Excel sheets by the user are going to be presented in the sections further after. For easier orientation, section names correspond to the names of Excel tabs, which are written in Danish, but have an English translation in brackets.

3.1 Inddata (Input)

The *Inddata* sheet in Excel is where the user enters data, such as date (day and month) as seen from Figure 3.1. The values, required from the user, are entered into yellow areas.

Dato	
Måned	
Dato	

Figure 3.1 Date input in the TCD
Slika 3.1 Vnos datuma v TCD

Four different windows can be analysed by entering values about orientation, angle, glass area, g-value, solar radiation factor, shadow factor, shadings and maximum solar gain as seen from Figure 3.2. Solar shadings can be modelled in two ways. One is based on a time-dependant solar shading and the other one is based on the maximum solar gain that is allowed through the window.

Orientering 1		
Vinduets orientering		
Orientering		
Vinkel		[°]
Vinduets data		
Glas areal		[m^2]
g-værdi		[-]
Faktor for Solindfald		[-]
Faktor for skygger		[-]
Afskærmning		
Tidsafhængig solafskærmning		Fra kl.
		Til kl.
Solafskærmnings faktor		[-]
Maksimalt solenergibidrag		[W/m^2]

Figure 3.2 Window orientation, window data and shading input in the TCD
Slika 3.2 Orientiranost, podatki o oknu in senčilih v TCD

In transmission table, the user enters area and U-value for a building part, such as window area, roof, wall etc. With this inputs, the thermal conductance of a building is calculated. Transmission part of the program is seen in Figure 3.3.

Transmission			
Bygningsdel	A [m^2]	U [W/m^{2}K]	U*A [W/K]
			0
			0
	B_u=	ΣU*A [W/K]:	0

Figure 3.3 Transmission input in the TCD
Slika 3.3 Vnos podatkov o prenosu toplote v TCD

In the infiltration part, the user enters data about volume and air changes of the zone as seen from Figure 3.4.

Infiltration				
Type	V [m^3]	n [h^{-1}]	c [-]	Varmetab [W/K]
			0,34	0
			0,34	0
	B_i=	Σ varmetab [W/K]:		0

Figure 3.4 Infiltration input in the TCD
Slika 3.4 Vnos podatkov o infiltraciji v TCD

Internal heat loads include different sources, such as people, lightning, IT equipment, cooling beams and others. The user needs to enter the data for how long the source is present, how many of them there are or the area of the source, and the power the sources produce. Afterwards, the total internal gain is calculated as seen from Figure 3.5.

Intern Varmelast					
Kilde	h timer	Antal [Stk]	A [m^2]	P [W]	ΣP [Wh]
Personer					0
Arbejdsbelysning					0
Almindelig belysning					0
IT-udstyr					0
					0
					0
Kølebafler					0
			Σ Intern Varmelast [Wh]:		0

Figure 3.5 Intern gains input in the TCD
Slika 3.5 Vnos podatkov notranjih toplotnih dobitkih v TCD

Figure 3.6 shows how the data about ventilation is entered. User needs to provide information about ventilation, night cooling, cooling and/or others. The data about temperature, volume, air change and time is required.

Ventilation						
Type	t_l [°C]	V [m^3]	n [h^{-1}]	h timer	c [-]	Varmetab [Wh/K]
					0,34	0
					0,34	0
Ventilation					0,34	0
Natkøling					0,34	0
Køling					0,34	0
			B_l=	Σ varmetab [W/K]:		0

Figure 3.6 Ventilation input in the TCD
Slika 3.6 Vnos podatkov o prezračevanju v TCD

The last thing that needs to be entered in this sheet is the data about maximum and minimum outdoor temperature or the average temperature of the day, as seen from Figure 3.7.

Udetemperatur	
Type	T_u [°C]
t_{maks}	
t_{min}	
$\bar{t}_u$	
$\bar{t}_u$	0

Figure 3.7 Outdoor temperature input in the TCD
Slika 3.7 Vnos podatkov o zunanji temperaturi v TCD

3.2 Køling + Natkøling, Varmeakkumulering and Amplitude + EL forbrug (Cooling and night cooling, Thermal heat storage, and Amplitude and power consumption)

The description of the next three sheets is combined in this section. The sheet named *Køling + Natkøling* enables you to calculate the values for different kinds of cooling and ventilation. The sheet *Varmeakkumulering* calculates thermal heat storage of the construction, based on used materials. Next sheet, named *Amplitude + EL forbrug*, estimates the amplitude of the indoor temperature and the energy consumption of the ventilation or cooling system.

3.3 Døgnstationære temperature (Daily stationary temperature)

The daily mean temperature can be calculated by using three different approaches. The first one uses the outdoor temperature from weather data for the location that is already integrated in the program. The second one is based on the data for the outdoor temperature that is entered by the user and the third way is based on the handbook *Indeklimahåndbog* that provides data for Denmark.

In this sheet, the results from other sheets are summed up in order to calculate the daily stationary temperature. An example of a result is shown in Figure 3.8 where the first value is temperature when shading is not used, second one is a temperature with a time-dependant solar shading and the last one is a temperature when shading is on and maximum solar gain is set.

Døgnstationære temp. $\overline{\text{ti}}$ [°C]	
uden solafskærmning:	25.6
med tidsafhængig solafskærmning:	23.7
med solafskærmning "maksimalt solenergibidrag":	22.6

Figure 3.8 Daily stationary temperature results in the TCD
Slika 3.8 Rezultat povprečne dnevne ravnovesne temperature v TCD

3.3.1 Calculating daily stationary temperature

In this subsection, a more detailed procedure of calculating a daily stationary temperature is presented. First, the symbols are explained:

- U is the thermal transmittance coefficient, U-value in [W/m^2 K].
- A is the area in [m^2].
- n_{inf} is the air change per hour of the infiltration in [h^{-1}].
- V is the volume in [m^3].
- h_{inf} is the number of hours a day when infiltration is present (usually 24 hours) in [h].
- $\overline{T_o}$ is the temperature of night outside air in [°C].
- $\overline{T_{adj}}$ is the temperature in adjacent room in [°C].
- n_{vent} is the air change per hour of the ventilation in [h^{-1}].
- h_{vent} is the number of hours a day when ventilation is present in [h].
- $\overline{T_{vent}}$ is the ventilation air temperature in [°C].
- $\overline{T_{ncool}}$ is the temperature of the outside air during the night (used for cooling) in [°C].
- Q_{int} is the energy gain from internal source in [J, Wh].
- Q_s is the energy gain from solar radiation in [J, Wh].

Daily stationary temperature is calculated according to equation (1).

$$\overline{T_i} = \frac{(H_L + H_{inf}) \cdot \overline{T_o} + H_{L,adj} \cdot \overline{T_{adj}} + H_{vent} \cdot \overline{T_{vent}} + H_{ncool} \cdot \overline{T_{ncool}} + \overline{\phi_{int}} + \overline{\phi_s}}{H_L + H_{inf} + H_{L,adj} + H_{vent} + H_{ncool}} \tag{1}$$

Where:

- H_L is the thermal conductance in [W/K] between inside and outside, calculated as

$$H_o = \sum_{i=1}^{n} (U_1 \cdot A_1 + U_2 \cdot A_2 + \cdots + U_n \cdot A_n) \tag{2}$$

- H_{inf} is the capacity of the infiltration air in [W/K], calculated as

$$H_{inf} = 0.34 \cdot n_{inf} \cdot V \cdot \frac{h_{inf}}{24h} \tag{3}$$

- $H_{L,adj}$ is the thermal conductance in [W/K] between inside and adjacent room, calculated as

$$H_{L,adj} = \sum_{i=1}^{n} (U_{L,adj,1} \cdot A_{L,adj,1} + U_{L,adj,2} \cdot A_{L,adj,2} + \cdots + U_{L,adj,n} \cdot A_{L,adj,n}) \tag{4}$$

- H_{vent} is the ventilation air capacity in [W/K], calculated as

$$H_{vent} = 0.34 \cdot n_{vent} \cdot V \cdot \frac{h_{vent}}{24h} \tag{5}$$

- H_{ncool} is the cooling capacity of the night cooling (night cooling is done by using the cool night air and blowing it into the building at night to get free cooling) in [W/K], calculated as

$$H_{ncool} = 0.34 \cdot n_{ncool} \cdot V \cdot \frac{h_{ncool}}{24h} \tag{6}$$

- $\overline{\phi_{int}}$ is the average power from internal heat load [W], calculated as

$$\overline{\phi_{int}} = \frac{Q_{int}}{24h} \tag{7}$$

- $\overline{\phi_s}$ is the average power from solar radiation (load) in [W], calculated as

$$\overline{\phi_s} = \frac{Q_s}{24h} \tag{8}$$

4 SOLAR GAIN

In contrast to the internal gains, such as people, equipment, lightning and others, solar gain depends on the location. In terms of solar radiation, three concepts need to be distinguished:

- Direct solar radiation is radiation that comes directly from the sun, without being dispersed in the atmosphere.
- Diffuse solar radiation is radiation that is dispersed in the atmosphere and thus does not come directly from the sun, but from other parts of the sky.
- Reflected solar radiation is radiation that hits the surface or other objects and reflects back from there. (Christensen, 2014)

A simple representation of all three components of solar radiation can be seen in Figure 4.1.

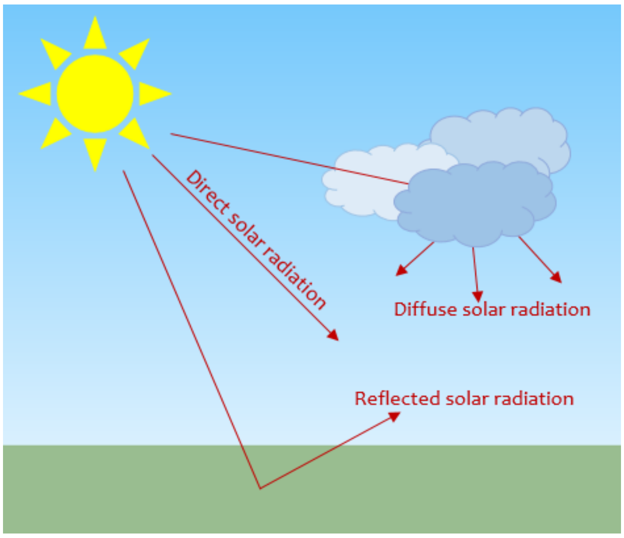


Figure 4.1 Direct, diffuse and reflected component of solar radiation
Slika 4.1 Direktna, difuzna in odbita komponenta sončnega sevanja

Solar radiation can be presented as sun curves. They represent the amount of solar radiation that comes through a reference window on a clear day. Those kind of curves are used in the TCD program.

The data about solar gain in the TCD derives from a literature (Danvak, 2006) and it is already integrated into the program. Therefore, there is no need to use a weather file as an input, contrary to more advanced simulation tools. Sun curves that can be found in this book correspond to hourly values of solar transmission through a vertical reference window on a clear day for eight different orientations – north, north-east, east, south-east, south, south-west, west and north-west.

A standard double glazed window is used as a reference window (further on referred to as a reference window). It consists of 4 mm float glass, 12 mm air and 4 mm float glass. When solar radiation hits the window, part of it is reflected (R), part absorbed (A) and part transmitted (T) as seen in Figure 4.2. This depends on glass type, window structure, angle of incidence and radiation spectral distribution. For the reference window, the transmission factor for solar energy (g-value) is 0.76 and its light transmission is 0.8. The properties of the reference window refer only to the glazing area and not to the combination of glazing and frame area. (Christensen, 2014)

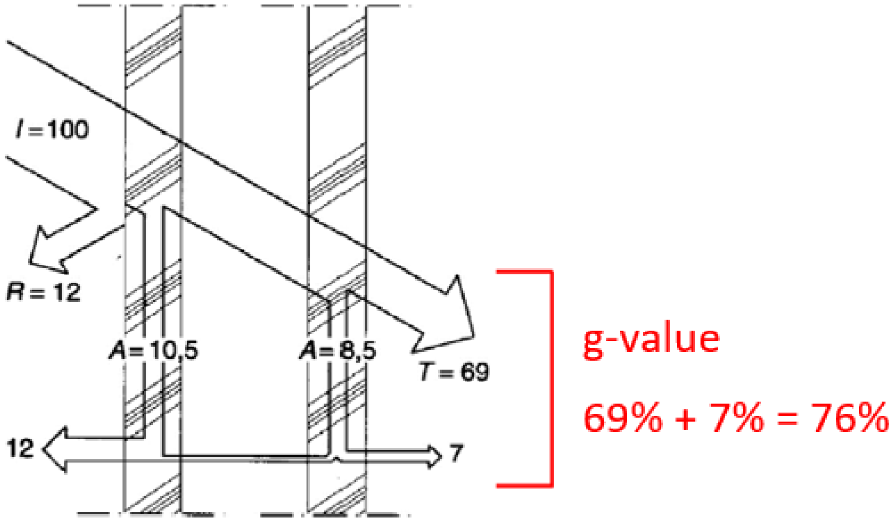


Figure 4.2 Reflection, absorption and transmission through reference window (4 mm float glass, 12 mm air and 4 mm float glass) and with g-value of 0.76 (Christensen, 2014)
Slika 4.2 Odboj, absorpcija in propustnost referenčnega okna (4 mm steklo, 12 mm zraka in 4 mm stekla) z g-faktorjem 0,76 (Christensen, 2014)

Sun curves, used in the TCD represent direct and diffuse solar radiation through a reference window on the 21st of each month for eight different orientations (N, E, S, W, NE, SE, SW, NW) as seen in Figure 4.3. Even though the data for solar gain applies only to the 21st of each month, any day can be chosen in the TCD program since linear interpolation is used in order to obtain values for other days.

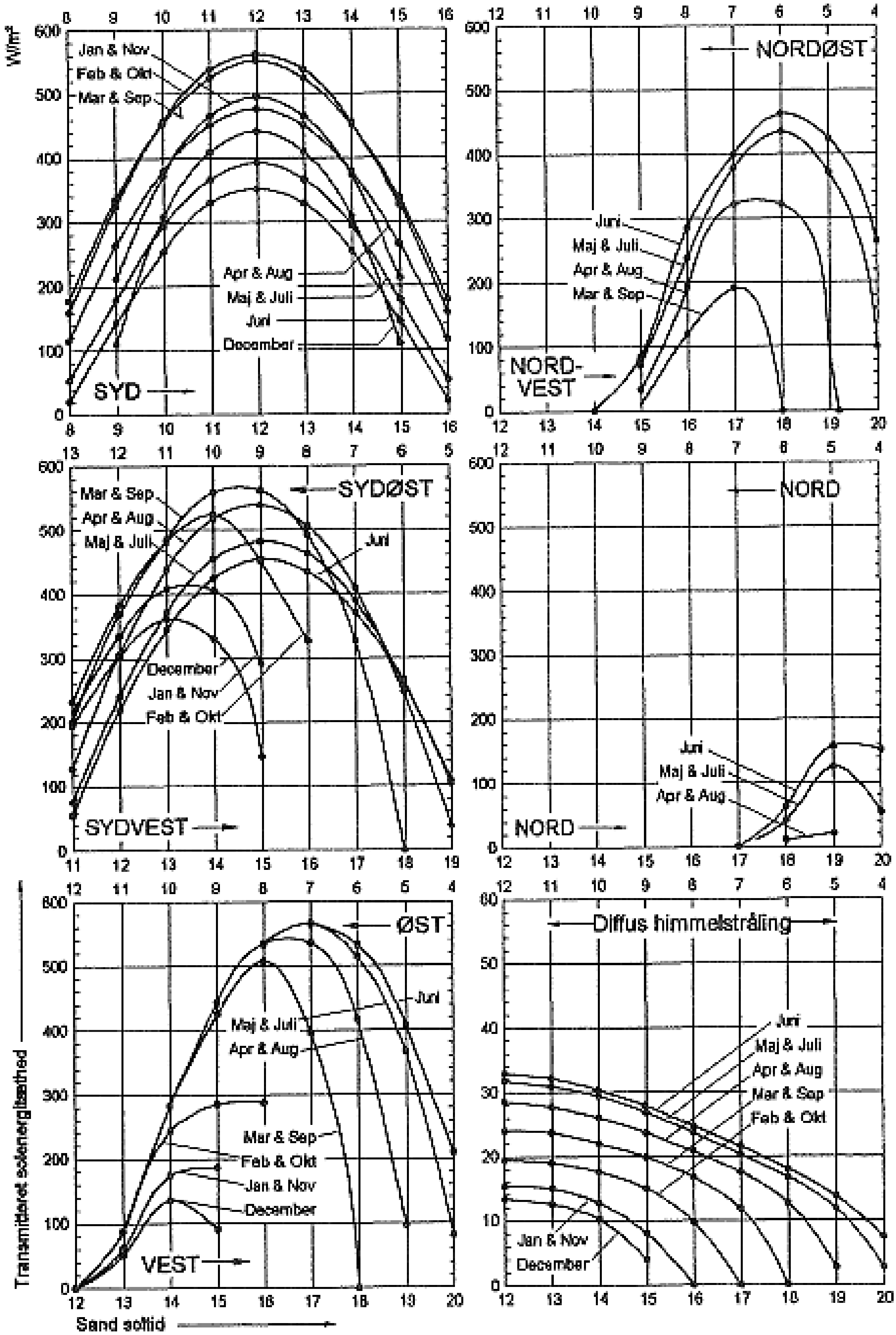


Figure 4.3 Danvak's sun curves on the 21st of the month for direct and diffuse solar irradiance in [W/m²] through a reference window for Denmark in true solar time (Danvak, 2006)

Slika 4.3 Danvakove sončne krivulje na 21. dan v mesecu za direktno in difuzno komponento solarnega sevanja v [W/m²] skozi referenčno okno za Dansko v solarnem času (Danvak, 2006)

5 SUN CURVES

The use of the TCD program is limited to a location in Denmark due to sun curves. Therefore, it is desired to upgrade the program in a way that it will be suitable for any location. That means that the integrated sun curves should be available for more locations and not just for Denmark. Since there is no guarantee that such literature with sun curves exists for any chosen location, it would be useful if the user could obtain the sun curves on their own. The goal of this project, as it was mentioned before, is to develop a method on how sun curves can be obtained from a weather file by the user, independently from the literature.

The idea about how to approach this problem is to try to obtain the sun curves from a weather file for a location in Denmark and compare them with the existing Danvak's sun curves. They can serve as a control and a guidance. If this is achieved and new sun curves match Danvak's curves, the method can be considered as successful and it can be used for other locations as well.

To obtain sun curves, another program has to be used. In this case, BSim (Danish building research institute, 2007) was chosen. It is an integrated PC tool for analysing buildings and installations. BSim needs weather data as an input. It was decided to use Danish weather data in order to compare the results with Danvak's sun curves. The same procedure can then be used with any weather data.

5.1 Weather data

The weather file that was used in this project was DRY2013. DRY stands for Design Reference Year. DRY2013 is the most recent and updated weather file and it is representative for the whole Denmark. Global irradiance in DRY weather file is measured to Local Standard Time, Central European Time. (Lund, 1995)

The weather file includes data for every hour from "0" to "8784", where last 24 hours are used in a case of a leap year. Parameters that can be found in a weather file are temperature, relative humidity, x and y component of wind, direct and diffuse solar radiation and sky cover. Besides that, the information about latitude, longitude, time zone and height above sea level is also included.

5.2 Building a model

A model, as seen in Figure 5.1, has been build in order to investigate how much solar radiation goes through a reference window. The purpose was to find all three components of solar radiation – direct, diffuse and reflected. Four zones with the same geometry were modeled in a way that each has a reference window with different orientation and a glazing area of 1 m^2. It is important not to confuse the window area with the glazing area, since window area includes the area of the frame as well. Besides having four zones with the same size windows and different orientations, the geometry at this point does not play a big role.

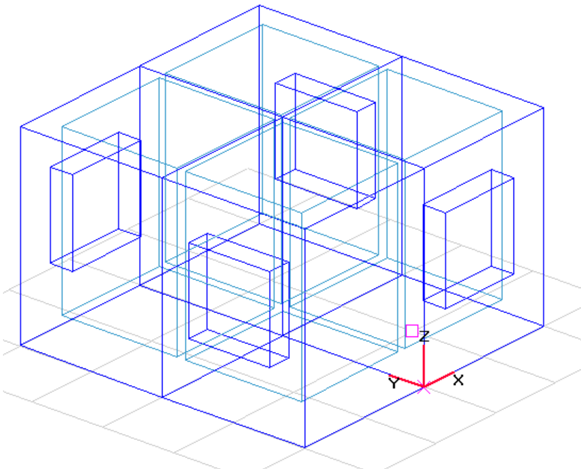


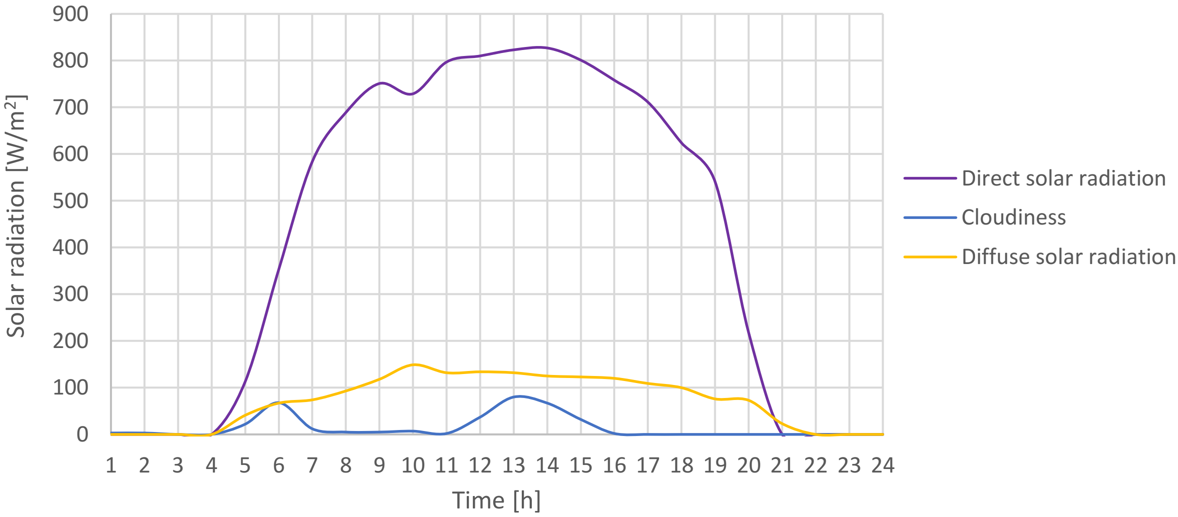
Figure 5.1 Model of four zones with different orientation of a reference windows in BSim
Slika 5.1 Model štirih con z različno orientacijo referenčnega okna v BSim

5.3 Chosing the right solar model

There are four different models for solar radiation in BSim:

- Petersen's solar model,
- Munier's solar model,
- Lund's solar model,
- Perez's solar model.

The aim was to use the one that assumes uniformly distributed diffuse component. Distribution like this makes it possible to easily obtain all three radiation components as it will be described further on. Different programs might provide different solar models. To find the right one, one can do a simple experiment by runing a simulation and analysing the results for a day with a clear sky. Such days can be found by examing the weather data. In previous research (Boesgaard, 2017), it was established that for the location in Denmark one of those days is 1 July. Solar distribution and cloudiness for 1 July is presented in Graph 5.1.



Graph 5.1 Solar distribution in [W/m^2] and cloudiness in [%] for 1 July in Denmark, obtained from the weather file
Grafikon 5.1 Distribucija sončnega sevanja v [W/m^2] in oblačnost v [%] za 1. julij na Danskem, pridobljeno iz vremenske datoteke

At the time of the day, when the sun has the highest altitude, a combination of direct and diffuse solar radiation should only go through the south-oriented window, while east-, west- and north-oriented window receives only diffuse radiation. That indicates that if the diffuse component is distributed evenly, the value in east, north and west orientation will be the same. This is only possible if the ground reflection is set to "0" in order to neglect the reflected component of solar radiation. Such kind of distribution is presented in Figure 5.2.

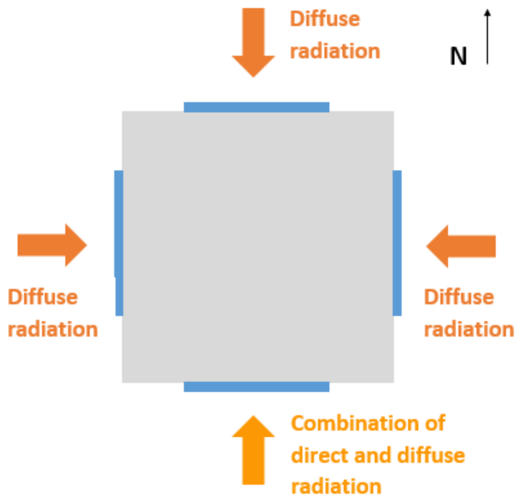


Figure 5.2 View of a zone from above with a window on each side, representing uniformly distributed diffuse solar radiation

Slika 5.2 Tloris obravnavanih con z okni na vsaki strani, predstavitev enakomerno porazdeljene difuzne komponente solarnega sevanja

One should pay attention to the definition of time that is used in a certain program. The speed of "true sun" varies along the ecliptic during the year. That means that one hour varies in durations throughout the year, according to solar time, which is the time that is kept with the reference to the sun's actual position in the sky. On the other hand, "mean sun" is a manmade invention and represents the sun with a uniform movement. Therefore, mean solar time is the time that is kept with the respect to the average length of a solar day, which is 24 hours (Cheprasov, 2002). One of the manmade adjustments in the mean solar time is also daylight saving time (DST) that is used in summer time. It is important to distinguish between true solar time and local standard time (clock time), and to know if the DST is used in the chosen location, since it makes a big difference in reading the simulation results.

Solar noon is defined as the moment in time, when the sun has the highest altitude, which, in solar time, occurs at noon. Since the DST is used in Denmark, in summertime solar noon will occur at 1 p.m. according to local standard time. This difference is important because the TCD uses solar time, while BSim operates in the standard time of the location, defined in the weather file.

With all this in mind, a simulation was run. The value one should look for is a total solar radiation through window in the zone, which is labelled as "GrossSun" in BSim. This gives values in kW. In order to obtain values in kW/m^2 one should divide results with the glazing area. In this case, this is not necessary since the glazing area is 1 m^2.

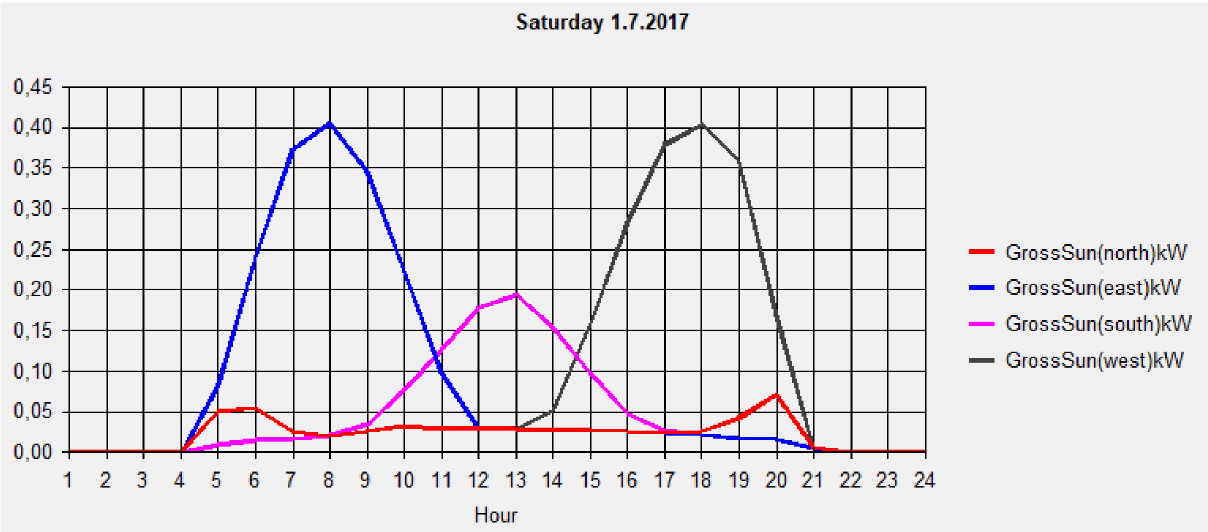
It was found out that the right solar model for this purpose was Munier's model, since it has the smallest difference between the values in east, north and west orientation, as seen from Table 5.1.

Table 5.1 Comparison of solar models – diffuse solar radiation in [W/m²] at 1 p.m. through the north (N), east (E) and west (W) oriented reference window

Preglednica 5.1 Primerjava solarnih modelov – difuzna komponenta v [W/m²] ob 1 pop. skozi severno (N), vzhodno (E) in zahodno (W) orientirano referenčno okno

	PETERSEN		MUNIER		LUND		PEREZ	
	1 Jul	**6 Aug**	**1 Jul**	**6 Aug**	**1 Jul**	**6 Aug**	**1 Jul**	**6 Aug**
N	31	37	29	23	40	29	31	29
E	37	41	29	23	41	33	31	29
W	38	42	28	21	42	37	35	31

The distribution of solar radiation can be seen in Graph 5.2, where y-axis represents the total solar radiation through a reference window in zone in kW. The amount of solar radiation in north, west and east zone at 1 p.m. is 29 W, 28 W and 29 W respectively, while the south-oriented window receives 194 W.



Graph 5.2 Total solar radiation through a reference window in all four orientations in [kW], obtained with BSim on 1 July

Grafikon 5.2 Skupno sončno sevanje skozi referenčno okno pri vseh štirih orientacijah v [kW], pridobljeno z BSim 1. julija

If one is still in doubt about which model to choose, the experiment can be re-done by installing bigger window. When a window with glazing area of 10 m² is installed, more digits can be obtained, providing a more accurate result. An example is presented in Figure 5.3.

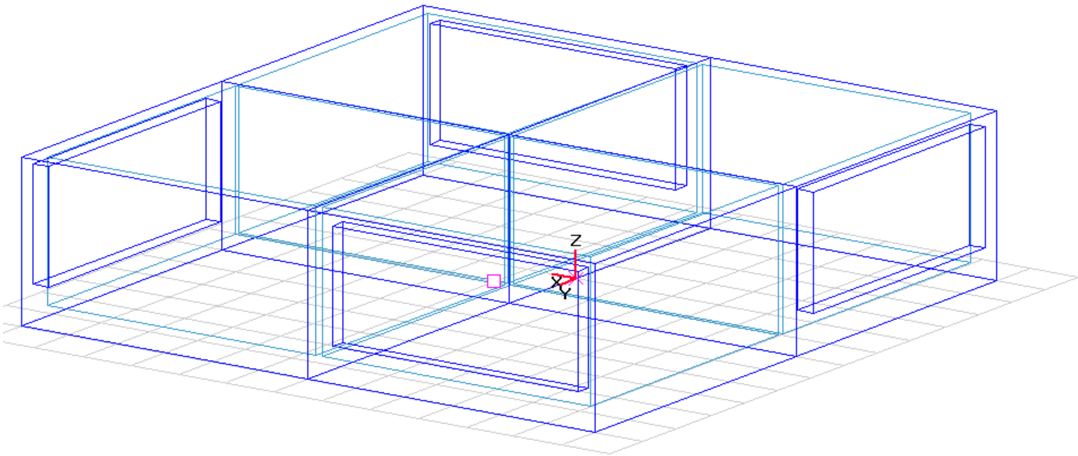


Figure 5.3 Model in BSim with bigger windows
Slika 5.3 Model v BSim z večjimi okni

The results are presented in the Table 5.2 where south orientation with a combination of direct and diffuse solar radiation is also included. The second part of the table presents minimum and maximum value of diffuse solar radiation (value in the north, east and west) and the difference between them. This way it is more obvious that Munier's model is the right solar model to use, since it has the smallest difference between values.

Table 5.2 Comparison of solar models, total solar radiation [W/m^2] at 1 p.m. through the north (N), east (E), south (S) and west (W) oriented reference window (model with bigger windows)
Preglednica 5.2 Primerjava solarnih modelov – difuzna komponenta v [W/m^2] ob 1 pop. skozi severno (N), vzhodno (E) in zahodno (W) orientirano referenčno okno (model z večjimi okni)

	PETERSEN		**MUNIER**		**LUND**		**PEREZ**	
	1 Jul	**6 Aug**	**1 Jul**	**6 Aug**	**1 Jul**	**6 Aug**	**1 Jul**	**6 Aug**
N	31.4	37.3	28.9	22.6	39.6	28.5	31.0	28.8
E	36.8	40.9	28.9	22.6	41.2	33.4	31.0	28.8
W	37.8	42.1	27.6	21.3	42.2	36.6	34.8	31.0
S	240.4	327.6	250.9	314.5	247.6	327.2	260.3	320.4
Min diffuse	31.4	37.3	27.6	21.3	39.6	28.5	31.0	28.8
Max diffuse	37.8	42.1	28.9	22.6	42.2	36.6	34.8	31.0
Difference	6.4	4.8	1.3	1.3	2.6	8.1	3.8	2.2

5.4 Obtaining values

A similar approach as choosing a solar model can also be used to define solar radiation and its components. When choosing a solar model, only solar noon is important. However, in order to define all three components of solar radiation, different hours of the day need to be examined.

Hours can be chosen by observing the results – in this case Graph 5.2. It can be seen that at 8 a.m. there is high radiation through the east-oriented window. It can be assumed that this is the case when the sun is shining directly through the east-oriented window, which provides a combination of direct and diffuse radiation, while at this time, north-, east- and south-oriented windows receive only diffuse radiation. Similar thing happens at 6 p.m., when the sun is setting and a combination of direct and diffuse solar radiation goes through the west-oriented window. Furthermore, it can also be observed that at around 11 a.m., a combination of direct and diffuse solar component goes through the east- and the south-oriented window, and at 3 p.m., a combination of direct and diffuse solar component goes through the west- and the south-oriented window. The same process can be used for other hours of the day.

One can use different tools or apps, available online, to help determine the exact location of the sun and thus assess which components of sun radiation are present at a certain orientation. In this case, the Sun Calculator (Agafonkin, 2009) was used. The location of the sun for Copenhagen at 6 a.m. can be seen in Figure 5.4 as the orange line. Here it can be assumed, that a combination of direct and diffuse radiation is present in the north- and the east-oriented window.

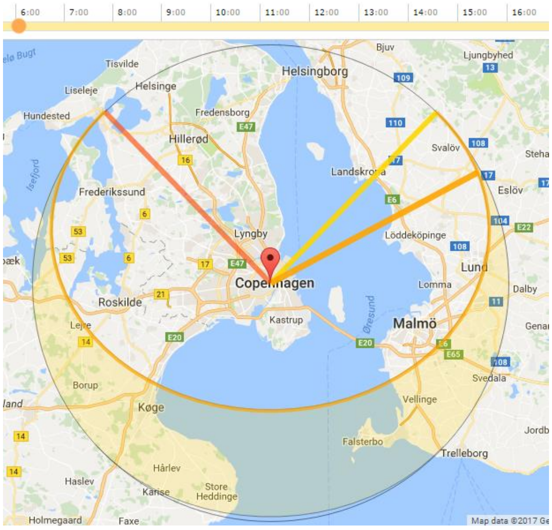


Figure 5.4 Location of the sun during sunrise (yellow), at 6 a.m. (orange), and during sunset (red), (Agafonkin, 2009)

Slika 5.4 Lokacija sonca v času sončnega vzhoda (rumena), ob 6 dop. (oranžna) in ob sončnem zahodu (rdeča), (Agafonkin, 2009)

After this is considered and the examined hours are chosen, one can determine the value of the direct and the diffuse component of solar radiation for different hours of the day. This is done by subtracting diffuse radiation from a combination of direct and diffuse radiation. An example can be observed in the Table 5.3. At 6 a.m., for example, in the north-oriented window, a combination of direct and diffuse component can be found. Since the diffuse component is uniformly distributed, the same would be present in all of the orientations. Therefore, it can be concluded that in the north orientation, the diffuse component is the same as in the south and the west orientation, which is 15 W. Now the direct component can be found by subtracting this value from the obtained value, which is a combination of both components.

Here it can be seen why it is important to use solar model with uniformly distributed diffuse radiation. The results for the location in Denmark on 1 July are presented in Table 5.3, where Time represents local standard time.

Table 5.3 Direct and diffuse component of solar radiation through a reference window on 1 July, obtained with BSim

Preglednica 5.3 Direktna in difuzna komponenta solarnega sevanja skozi referenčno okno 1. julija, pridobljeno z BSim

Time	Window orientation	Solar radiation component	Obtained values [W]	Direct [W]	Diffuse [W]
6 a.m.	N	Direct + diffuse	55	40	15
	E	Direct + diffuse	241	226	15
	S	Diffuse	15	-	15
	W	Diffuse	15	-	15
8 a.m.	N	Diffuse	20	-	20
	E	Direct + diffuse	405	385	20
	S	Diffuse	21	-	21
	W	Diffuse	20	-	20
11 a.m.	N	Diffuse	29	-	29
	E	Direct + diffuse	99	70	29
	S	Direct + diffuse	127	98	29
	W	Diffuse	29	-	29
1 p.m.	N	Diffuse	29	-	29
	E	Diffuse	29	-	29
	S	Direct + diffuse	194	165	29
	W	Diffuse	28	-	28
3 p.m.	N	Diffuse	27	-	27
	E	Diffuse	27	-	27
	S	Direct + diffuse	97	70	27
	W	Direct + diffuse	158	131	27
6 p.m.	N	Diffuse	26	-	26
	E	Diffuse	22	-	22
	S	Diffuse	22	-	22
	W	Direct + diffuse	404	381	23
8 p.m.	N	Direct + diffuse	71	55	16
	E	Diffuse	16	-	16
	S	Diffuse	16	-	16
	W	Direct + diffuse	168	152	16

Now that the direct and the diffuse components are known, one can also obtain the third component of solar radiation. This can be done by setting the reflection of solar radiation from the ground to a value, different from "0". In this case, a value of 0.2 has been chosen. The new values of total solar radiation from BSim now represent a combination of direct, diffuse and reflected component. Since the direct and the diffused components are already known, the reflected component can be calculated by subtracting the direct and the diffuse component from the obtained value. The results can be seen in Table 5.4.

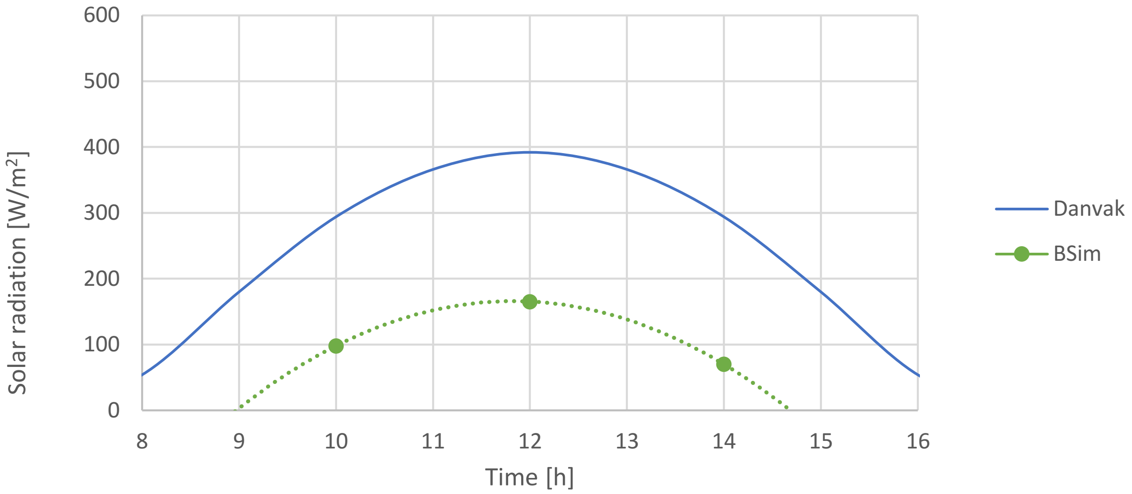
Table 5.4 Reflected component of solar radiation through a reference window on 1 July, obtained with BSim
Preglednica 5.4 Odbita komponenta solarnega sevanja skozi referenčno okno 1.julija, pridobljeno z BSim

Time	Window orientation	Obtained values [W]	Reflected [W]
6 a.m.	N	61	6
	E	249	8
	S	19	4
	W	19	4
8 a.m.	N	25	5
	E	428	23
	S	26	5
	W	26	6
11 a.m.	N	37	8
	E	119	20
	S	151	24
	W	37	8
1 p.m.	N	37	8
	E	37	8
	S	225	31
	W	36	8
3 p.m.	N	35	8
	E	35	8
	S	116	19
	W	183	25
6 p.m.	N	32	6
	E	28	6
	S	28	6
	W	424	20
8 p.m.	N	77	6
	E	20	4
	S	20	4
	W	174	6

The reflected component is smaller compared to the direct and the diffuse component and it depends on the settings for ground reflection.

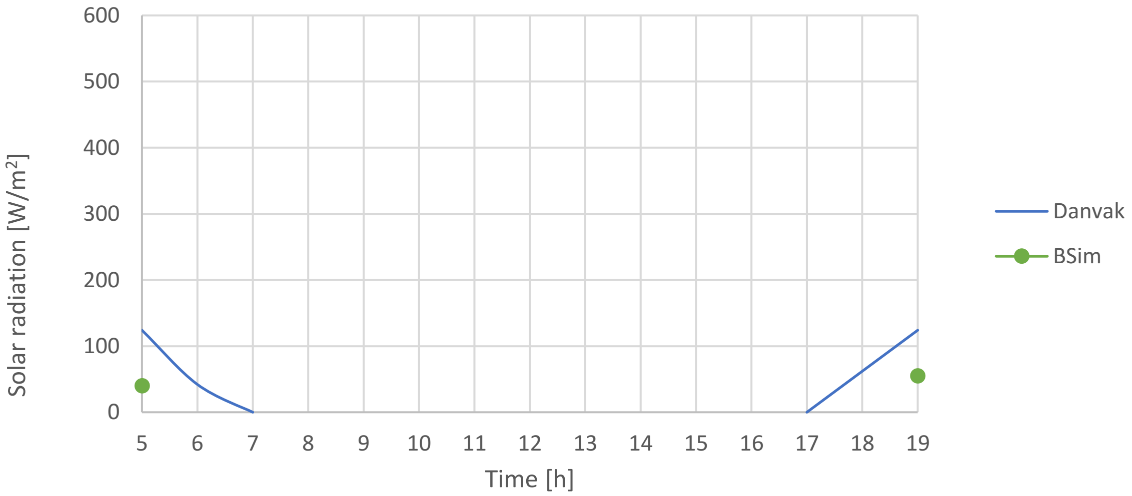
5.5 Comparison of BSim and Danvak's sun curves

From Figure 4.3, it can be assumed that Danvak's curves consider only the direct and the diffuse component since there is no graph for the reflected component. Therefore, the calculated values for the direct and the diffuse components from Table 5.3 correspond to Danvak's values. If they are organised by orientation, the obtained and Danvak's sun curves can be compared. The results can be seen in Graph 5.3, Graph 5.4, Graph 5.5, Graph 5.6, and Graph 5.7, where hours correspond to solar time. Danvak's curves represent values for the month of July, while the BSim values represent data for the design day of 1 July. As it can be seen from Table 5.3, the values from BSim were not gathered for every hour. Therefore, a dotted polynomic trend line was used to connect the values.



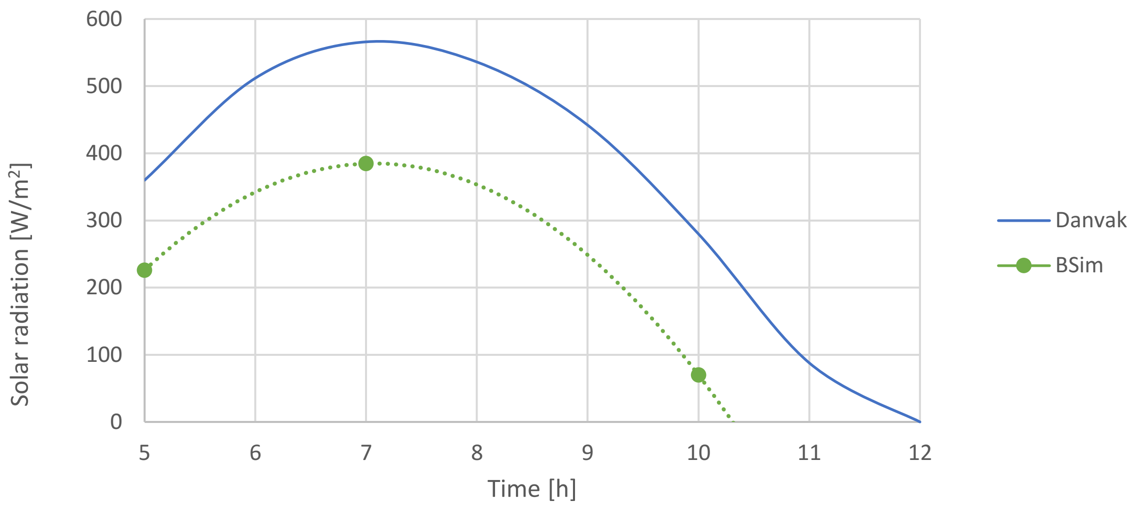
Graph 5.3 Comparison of Danvak's and BSim values for direct radiation in [W/m^2] in the south-orientated reference window

Grafikon 5.3 Primerjava Danvakovega direktnega sevanja in direktnega sevanja, pridobljenega z BSim v [W/m^2] skozi južno orientirano referenčno okno

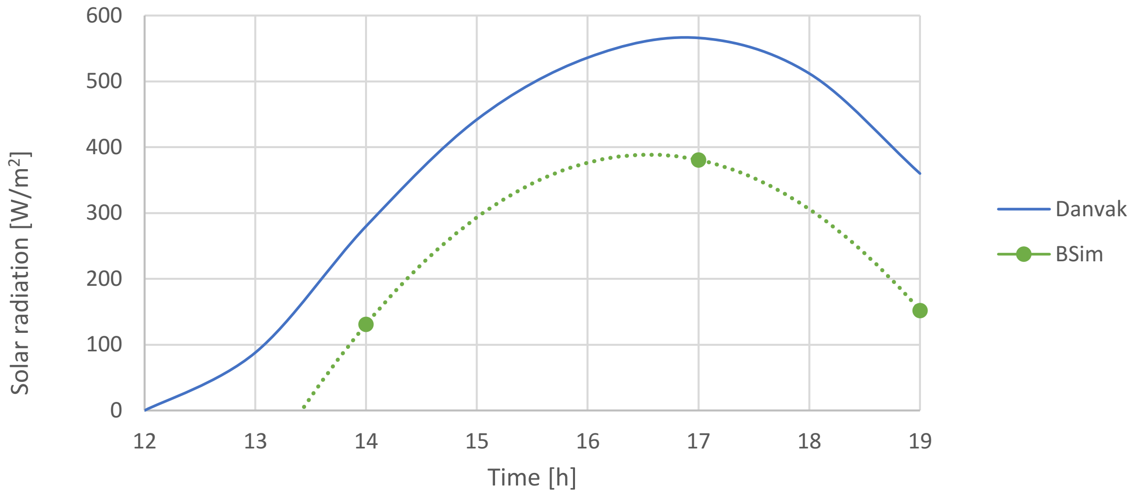


Graph 5.4 Comparison of Danvak and BSim values for direct radiation in [W/m^2] in the north-orientated reference window

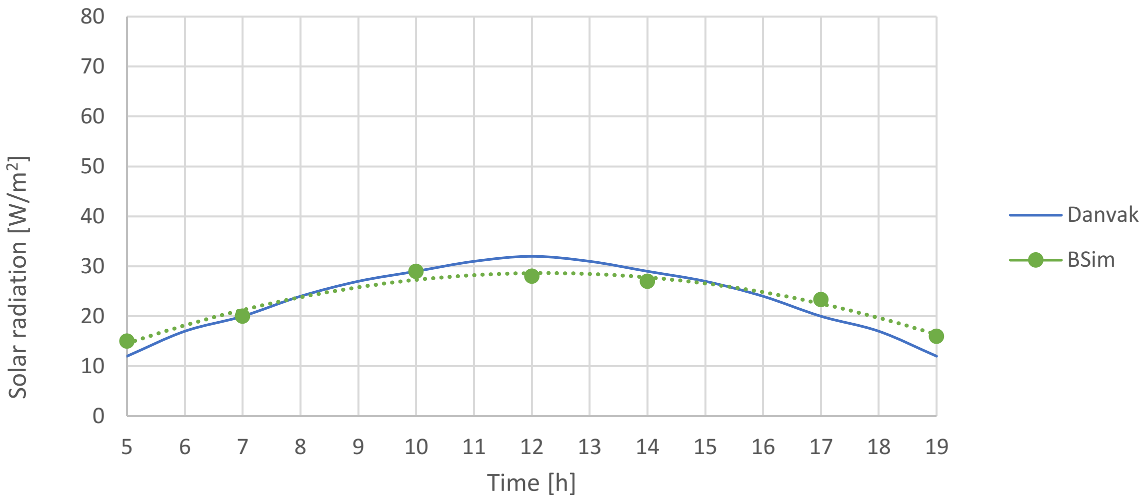
Grafikon 5.4 Primerjava Danvakovega direktnega sevanja in direktnega sevanja, pridobljenega z BSim v [W/m^2] skozi severno orientirano referenčno okno



Graph 5.5 Comparison of Danvak's and BSim values for direct radiation in [W/m^2] in the east-orientated reference window
Grafikon 5.5 Primerjava Danvakovega direktnega sevanja in direktnega sevanja, pridobljenega z BSim v [W/m^2] skozi vzhodno orientirano referenčno okno



Graph 5.6 Comparison of Danvak's and BSim values for direct radiation in [W/m^2] in the west-orientated reference window
Grafikon 5.6 Primerjava Danvakovega direktnega sevanja in direktnega sevanja, pridobljenega z BSim v [W/m^2] skozi zahodno orientirano referenčno okno



Graph 5.7 Comparison of Danvak's and BSim values for diffuse radiation in [W/m^2] through the reference window

Grafikon 5.7 Primerjava Danvakovega difuznega sevanja in difuznega sevanja, pridobljenega z BSim v [W/m^2] skozi referenčno okno

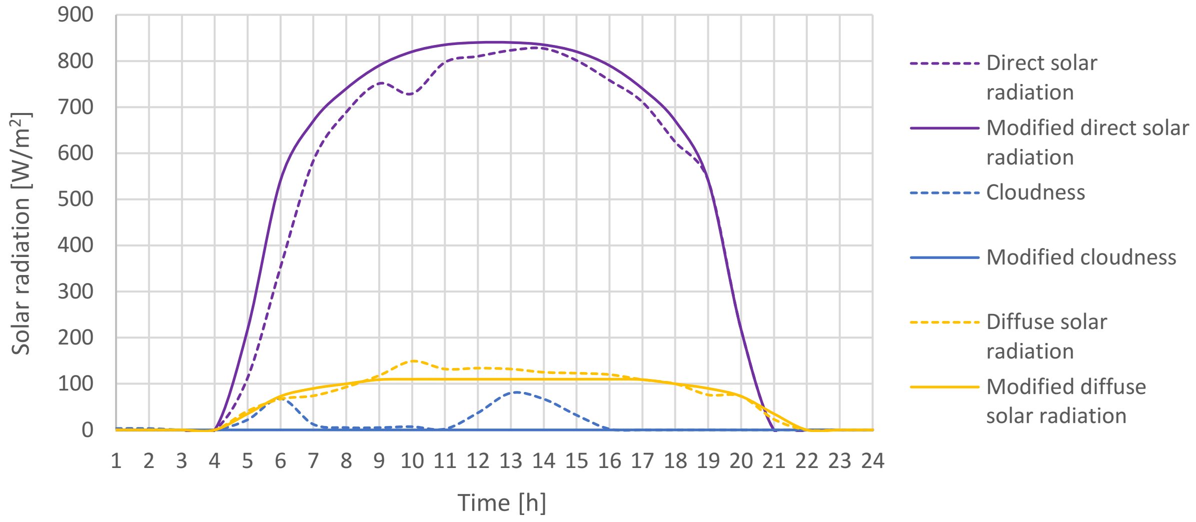
Big differences can be observed in the direct component of solar radiation in all of the orientations. In south orientation, the difference between values at noon is 58% and the difference is even higher in north orientation. Smaller deviation can be found in the east and the west orientation, where the difference is around 30%. On the other hand, the values for diffuse radiation in BSim match Danvak's numbers quite well.

5.6 Improving BSim model

It would be desired that values are similar to Danvak's, since the goal is to obtain curves that can be used in the same manner as Danvak's curves.

5.6.1 Weather data modification

One thing that needs to be considered is that Danvak assumes that the sky is clear with cloudiness set to 0% throughout the whole day. To have the same conditions in BSim, weather data needs to be modified. This can be done by changing the cloudiness to 0% on the chosen day. This influences the direct and the diffuse component of solar radiation, which then needs to be modified as well. When cloudiness is set to 0%, the diffuse component is uniformly distributed throughout the day and the direct component is increased in the time of the day where cloudiness was previously present. This modification was done for 1 July and it is presented in Graph 5.8.



Graph 5.8 Modified weather data for 1 July
Grafikon 5.8 Predelani vremenski podatki za 1. julij

Dotted lines represent the original data, while full lines represent the modification. Between 4 a.m. and 7 a.m., and noon and 3 p.m., original cloudiness goes up to 68% and 80% respectively, while modified cloudiness is set to 0% the whole time. In these periods, direct solar radiation is increased. The easiest way to increase direct solar radiation is to copy the original data for the direct solar radiation from the period when cloudiness was originally 0%. In this case, the data between 7 p.m. and 9 p.m. was mirrored to the period between 4 a.m. and 6 a.m. The rest was connected in a way that forms a smooth curve without bumps that appear due to cloudiness.

Modified values were used to make a new, modified weather file, which was then used in BSim. BSim requires .dry as a file format of a weather file. Since the modifications were made in Excel, another tool needed to be used in order to obtain the right file format. This was done with a free, open-source, cross-platform software tool called Elements, which is used for creating and editing custom weather files for building energy modelling (Big Ladder Software, 2016). This can provide a weather file in an .epw file format. Further transformation from .epw to .dry can be done directly in BSim.

5.6.2 Position of a window - Recess

Windows were modelled without paying any special attention to the position. In other words, the retraction of the glass in relation to the outside of the wall was not considered.

Reading BSim User's Guide, one can learn, that "if Recess = 0 is given, shading will be calculated as if the glazing was located parallel to the inner face of the construction. If the glass is to be placed parallel to the outer face of the construction, a small value (larger than 0.0001) must be given. NB: Recess only works if XSun solar distribution is turned on." (Danish building research institute, 2007)

The meaning of recess can be seen in Figure 5.5. Left case has a window, which is parallel to the inner face of the wall and so the rest of the construction wall provides shade to the window. The amount of solar radiation that comes through this window is therefore reduced. Window on the right side is aligned with the outer face of the wall, which means that no shading is provided by the rest of the construction and solar radiation can come through without reduction.

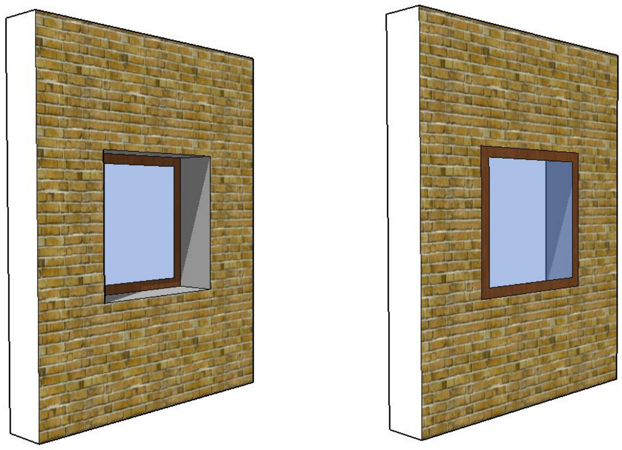


Figure 5.5 Window is parallel to the inner face (left), window is parallel to the outer face (right) of the wall
Slika 5.5 Okno je vzporedno z notranjo stranjo (levo), okno je vzporedno z zunanjo stranjo (desno) stene

Following the instructions in BSim User's Guide, window properties were changed. First, the recess was set to a small value of 0.0001 under Window Property as seen in Figure 5.6Figure 5.6 (left). To make this work, the XSun solar distribution needed to be turned on. This was done by checking the box in front of XSun Distribution in Options that can be found in the tab *tsbi5*. Figure 5.6 (right) shows how to do this.

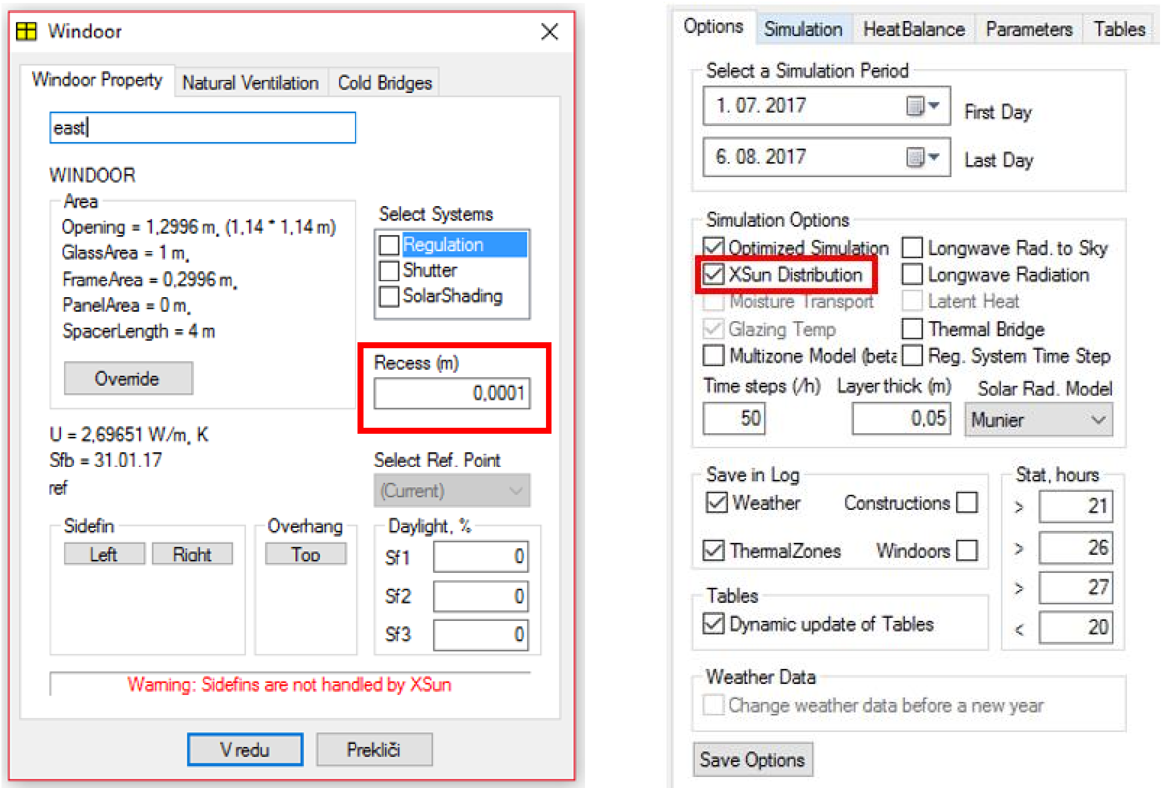
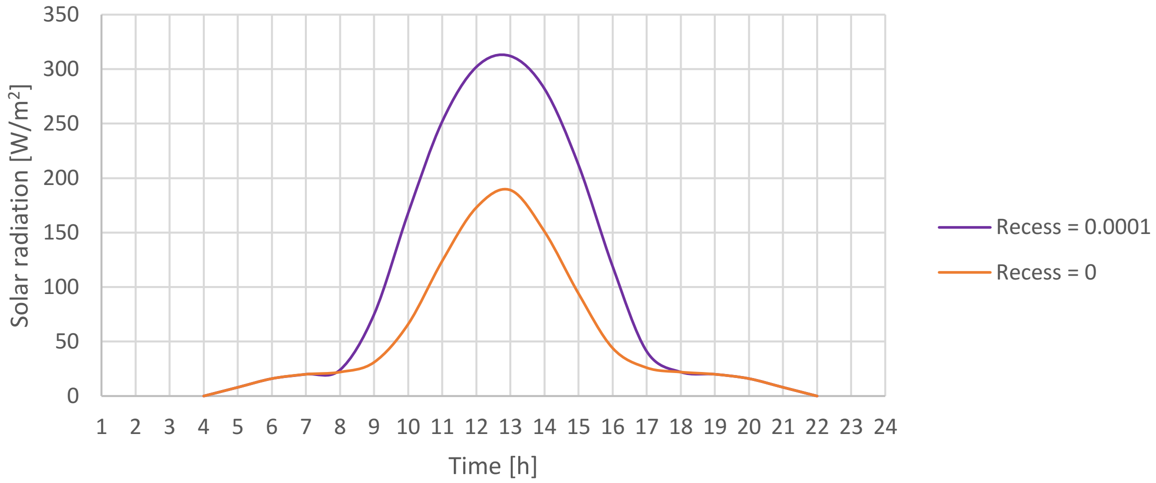


Figure 5.6 Changing recess of a window in Windoor settings (left) and turning XSun solar distribution on in Options (right)
Slika 5.6 Sprememba niše v nastavitvah za okna (levo) in vklop XSun solarne distribucije v nastavitvah

The importance of using the right window position can be seen in the following graph, where two curves represents two different settings – one where Recess is considered and one where it is not.

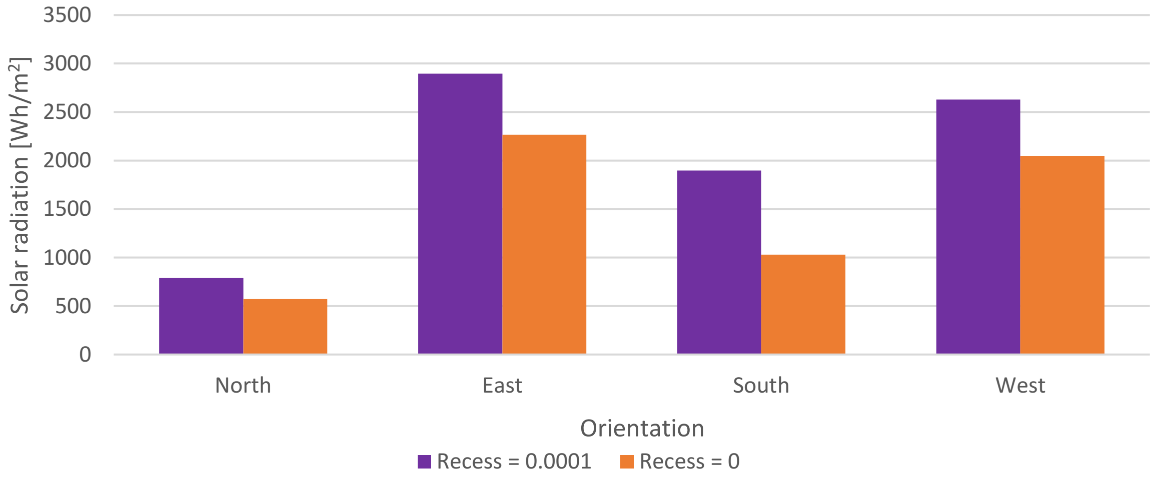
Graph 5.9 represents total solar radiation through the south-oriented reference window on 1 July with the modified weather data. Ground reflection is "0", which means that values represent a sum of the direct and the diffuse radiation. The purple curve represents a situation when a window is aligned to the outer wall and the orange curve represents a situation when a window is aligned to the inner wall.



Graph 5.9 Comparison of solar irradiance in [W/m^2] through the south-oriented reference window with and without recess

Grafikon 5.9 Primerjava solarnega sevanja v [W/m^2] skozi južno orientirano referenčno okno z in brez niše

The values are almost 50% lower when recess is set to "0", which corresponds to a window, parallel to the inner face. The biggest difference is found in the south-oriented window, which can be observed in Graph 5.10, where the daily sum of solar radiation in each orientation is presented for 1 July.



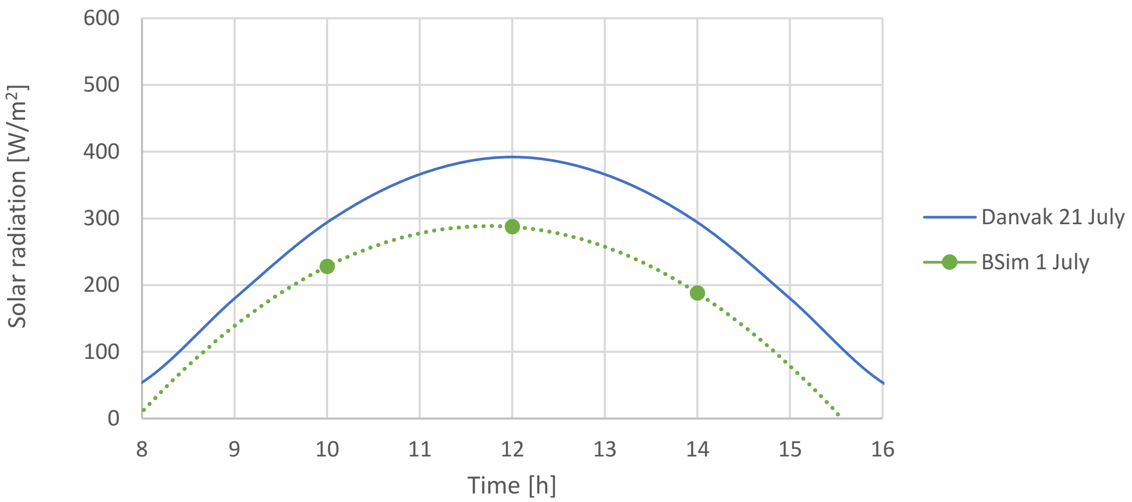
Graph 5.10 Comparison of the daily sum in [Wh/m^2] through a reference window with and without recess

Grafikon 5.10 Primerjava vsote urnih vrednosti solarnega sevanja za 1. julij v [Wh/m^2] skozi referenčno okno z in brez niše

It can be concluded that it is essential to choose the right position of windows. In south-orientated rooms, such mistake could cause a very big difference in results and therefore lead to the wrong dimensioning of the ventilation system.

5.7 Comparison of BSim and Danvak's sun curves with improved model

With the right position of windows by using Recess, turning the XSun on and with the modified weather data, one can obtain new results from BSim. The procedure is the same as described earlier. The results for direct radiation through the south-oriented window are presented in Graph 5.11



Graph 5.11 Comparison of direct solar radiation in [W/m^2] in the south-orientated reference window after window and weather data modification

Grafikon 5.11 Primerjava direktne komponente solarnega sevanja v [W/m^2] v južno orientiranem referenčnem oknu po prilagoditvi okna in predelavi vremenskih podatkov

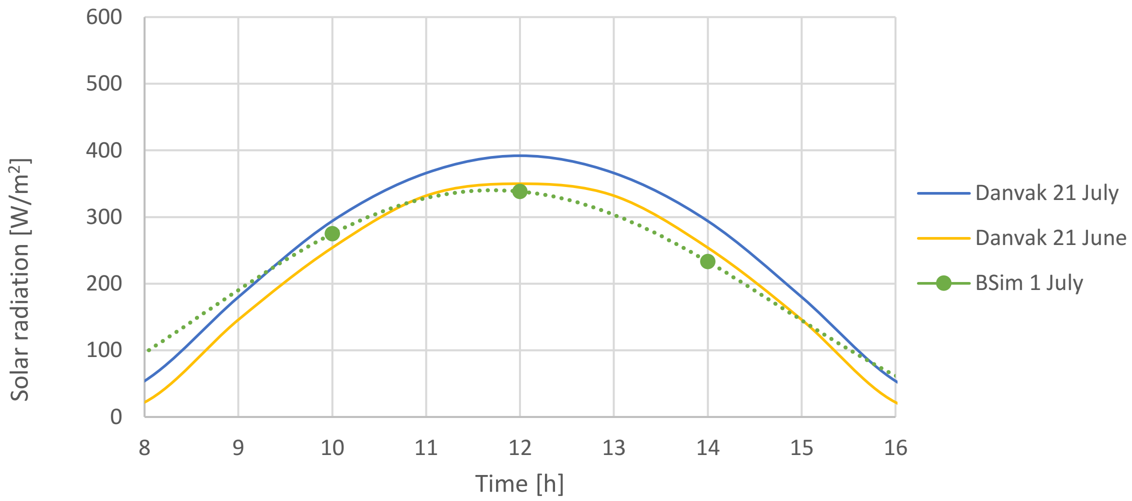
The values from BSim are now higher and thus closer to Danvak's values. In Graph 5.3, the value for the direct solar radiation at noon in BSim was 165 W/m^2, while now it is 287 W/m^2. This represents 73% of the Danvak value, which is 392 W/m^2.

5.8 Comparison of BSim and Danvak's sun curves with improved model and data consideration

Even though the model and the weather data are now modified, the values are still quite low. Another aspect one might consider is why Danvak's values do not include the reflected component, which is also very important and should not be neglected. Since this is not explained in the book, it is possible that the graph with the direct component includes the reflected component as well. Therefore, a new comparison was done, where the direct and reflected component are summed up as one value.

One should also keep in mind that Danvak's curves represent values for the 21st of each month. That means that since values from BSim represent solar radiation for the 1st of July, the compared values are 20 days apart. On the other hand, Danvak's curve for June is only 10 days apart. The obtained values from BSim should therefore be somewhere between Danvak's curves for June and July. It would be wrong to compare the obtained values only to the ones that are within the same months, without considering other available data.

Keeping both of the mentioned points in mind, a new comparison was done. Graph 5.12 represents the comparison between Danvak's curves for June and July, and the obtained BSim values, where the direct and the reflected component are summed up as one value. The ground reflection in this case is 20%.

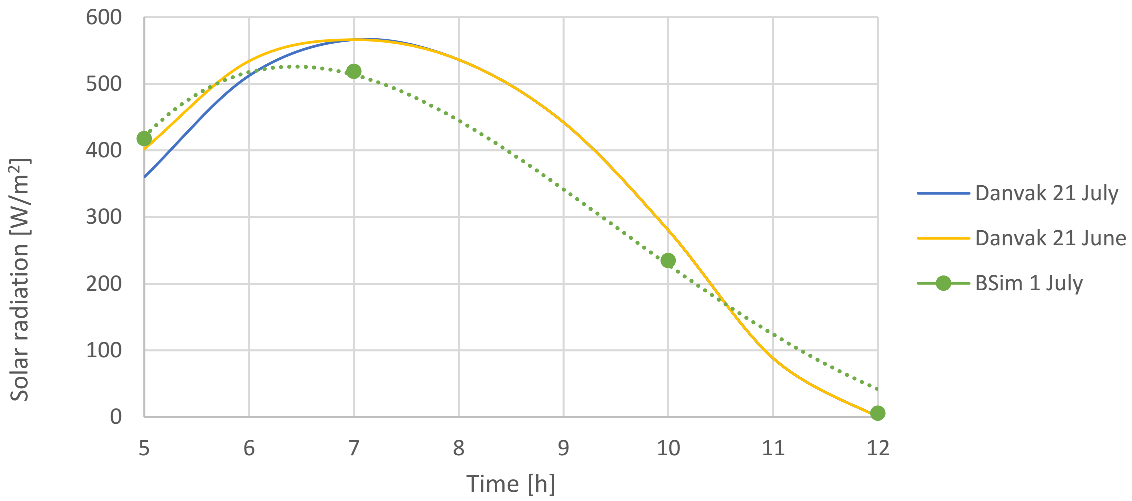


Graph 5.12 Comparison of direct and reflected (0.2) solar radiation in [W/m²] in the south-orientated reference window

Grafikon 5.12 Primerjava direktnega in odbitega (0,2) solarnega sevanja v [W/m²] v južno orientiranem referenčnem oknu

It can be seen that the values from BSim are now much closer to Danvak's curves. At noon, the value from BSim is 338 W/m^2, the value of Danvak's July curve is 392 W/m^2 and the one of Danvak's June curve is 350 W/m^2. The obtained values are closer to Danvak's values than before, but are not completely in between both of the Danvak's curves as expected.

It might seem that the obtained values are getting close to the desired ones, but if the east orientation is observed (Graph 5.13), one can see that there is still a big disparity between Danvak's sun curves and the sun curves, obtained with BSim.



Graph 5.13 Comparison of direct and reflected (0.2) solar radiation in [W/m²] in the east-orientated reference window

Grafikon 5.13 Primerjava direktnega in odbitega (0,2) solarnega sevanja v [W/m²] v vzhodno orientiranem referenčnem oknu

The discrepancy in the east could be explained by looking at Table 5.2, where solar radiation values are the smallest in the west and the east orientation when using Munier's solar model. Solar radiation values in Lund's solar model, for example, are almost 50% higher than those in Munier's solar model. One might consider also looking into other solar models or increasing the value of ground reflection in order to obtain higher values.

Therefore, another comparison was made, which is presented in Table 5.5. Lund's and Munier's solar models with different ground reflection were used for 1 July. The values, obtained with BSim, are shown as daily sums [Wh/m^2]. The modified weather data was used and recess was set to "0.0001". The last line in the table represents values, obtained from Danvak's sun curves. They were calculated by the TCD as a linear interpolation between 21 June and 21 July in order to obtain the values for 1 of July. The percentages, next to each obtained value from BSim, represent the discrepancy from values, obtained with the TCD.

Table 5.5 Daily sums [Wh/m^2] through a reference window and their discrepancies from the TCD values

Preglednica 5.5 Vsota urnih vrednosti solarnega sevanja [Wh/m^2] skozi referenčno okno in odstopanja od TCD vrednosti

Solar model	Ground reflection	North		East		South		West	
MUNIER	20%	952	94%	3187	95%	2334	100%	2916	87%
	25%	992	98%	3263	97%	2444	104%	2989	89%
	30%	1028	101%	3334	99%	2557	109%	3058	91%
LUND	20%	1008	99%	3205	95%	2515	107%	2977	88%
	25%	1049	103%	3279	97%	2623	112%	3051	91%
	30%	1093	108%	3353	99%	2735	117%	3122	93%
TCD (DANVAK)		1016		3371		2341		3371	

From Table 5.5, it can be seen that the majority of values from BSim do not completely correspond to Danvak's values, obtained with the TCD. Munier's solar model gives slightly better values with smaller discrepancies from the TCD values than Lund's model. In Munier's model with 20% ground reflection, the values from BSim in north, east and west are 5%–13% lower than the TCD values, while south orientation completely matches the TCD values. However, the values from a model with 25% ground reflection have a better match with the TCD values. In north, east and west, the values are 2%–11% lower than the TCD values, while the south orientation exceeds the TCD value for 4%. On the other hand, Lund's solar model gives values with higher discrepancies.

In this comparison, Lund's solar model was added in order to see, if using Munier's solar model was a correct choice. Seeing that Lund's solar model does not provide better match with the TCD values, it can be confirmed that using Munier's solar model is a correct choice.

The sum of solar radiation in the east and the west orientation should be the same. This can also be seen by looking into Danvak's sun curves in Figure 4.3, where the east and the west are presented in the same graph. However, looking into Table 5.5, the discrepancy of 8% between the east and the west can be found.

The definition of solar noon says that solar noon is defined as the time of the day when the sun's rays are directly perpendicular to a given line of longitude. It takes 24 hours for the

Earth to rotate for 360° which means that solar noon occurs one hour earlier every 15 degrees of longitude to the west. The longitude that is used in Denmark's weather file is 12.16°. By changing the location from longitude 12.16° to longitude 15°, more symmetrical results might appear. To test that, a new location was chosen, which can be seen from Figure 5.7.

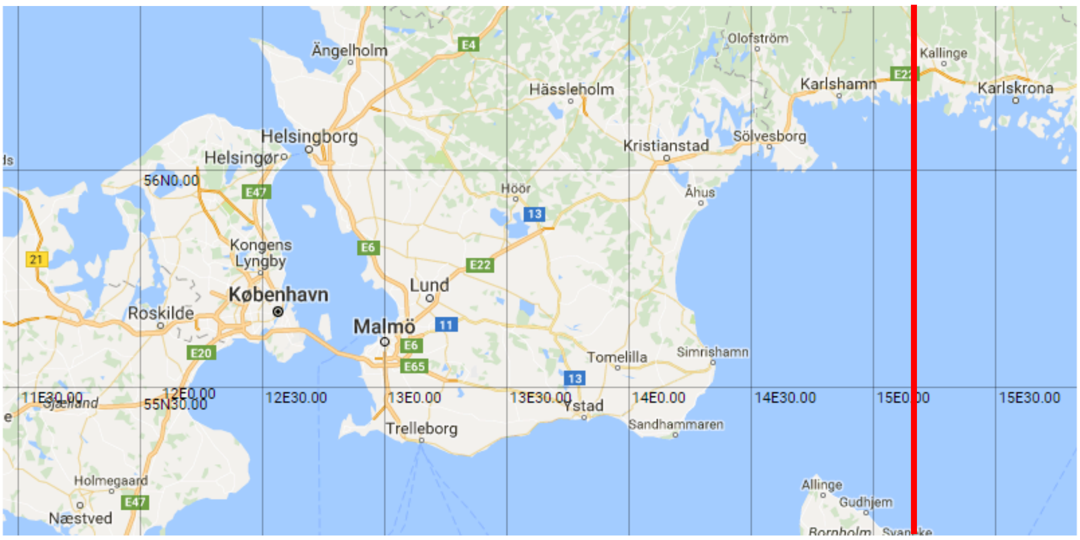


Figure 5.7 Longitude 15° (Bracknell District Caving Club, 2010)

Slika 5.7 Geografska dolžina 15° (Bracknell District Caving Club, 2010)

One must be aware that changing longitude does not mean changing the whole weather file data. All parameters are kept the same and are not affected by the change of longitude.

New simulations were done by using Munier's solar model with ground reflection of 25% and changed longitude to 15°. The distribution of solar radiation in the east and the west orientation can be seen from Figure 5.8 where solar radiation in each zone is presented.

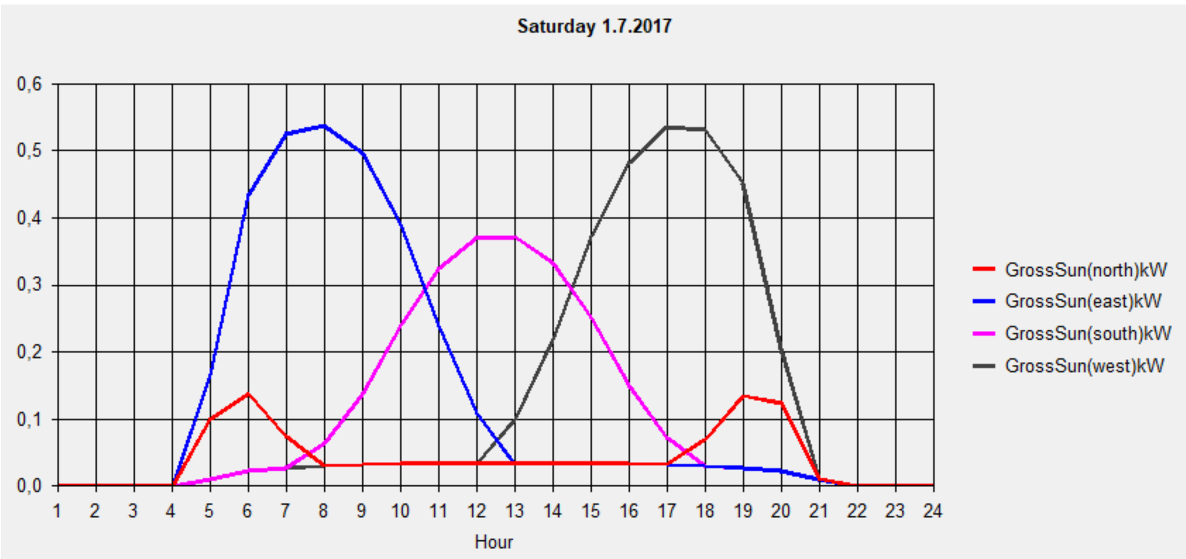


Figure 5.8 Total solar radiation through a reference window in all four orientations in [kW] obtained with BSim on 1 July, with longitude 15°

Slika 5.8 Skupno sončno sevanje skozi referenčno okno v vseh štirih orientacijah v [kW], pridobljeno z BSim na 1. julij, z geografsko dolžino 15°

It can be seen that in the case of 1 July, changing longitude gave better results in terms of the east and the west solar distribution. In the same way as in Table 5.5, in Table 5.6 the daily sums and their discrepancies from the TCD values are presented for the new model with the longitude 15°. In this case, only Munier's solar model is presented.

Table 5.6 Daily sums [Wh/m^2] through a reference window and their discrepancies from the TCD values for the model with longitude 15°

Preglednica 5.6 Vsota urnih vrednosti solarnega sevanja [Wh/m^2] skozi referenčno okno in odstopanja od TCD vrednosti za model z geografsko dolžino 15°

Solar model	Ground reflection	North		East		South		West	
MUNIER	20%	935	92%	3074	91%	2342	100%	3050	90%
	25%	975	96%	3151	93%	2458	105%	3129	93%
	30%	1007	99%	3223	96%	2570	110%	3201	95%
TCD (DANVAK)		1016		3371		2341		3371	

It can be seen that in this case, the east and the west orientation have more similar values than before. It can also be observed that Munier's solar model still offers better match with the TCD values at the ground reflection of 25%.

By comparing values from BSim and the TCD, it can be concluded that Danvak's sun curves, which are used in the TCD program, correspond to the sun curves, obtained with Munier's solar model with 25% ground reflection and the longitude of 15°.

5.9 Other literature

As mentioned before, the sun curves used in the TCD are based on the textbook (Danvak, 2006). In order to broaden the amount of data for the comparison, some other literature was investigated as well.

Different sun curve analysis were found in an earlier edition of Danvak's textbook from 1988 (Danvak, 1988) and in a book about heat and ventilation from 1971 (Becher, 1971). Both of them are presented further on.

5.9.1 Poul Becher

In Poul Becher's book (Becher, 1971), the sun curves for direct, diffuse and reflected solar radiation can be found. Direct radiation is presented for different angles of orientation (every 15 degrees) between east and south and west and south. There are no values for north, north-east or north-west orientation. It also provides direct solar radiation for a horizontal window. Diffuse radiation in horizontal window is double the value of a vertical window. The reflected component includes the values with 0.1 and 0.25 of ground reflection. Available data includes months from May to September. A unit of solar radiation, used in this literature, is kcal/m^{2}h. 1 kcal/m^{2}h corresponds to 1.16298 W/m^2. The graphs of sun curves can be seen in Figure 5.9.

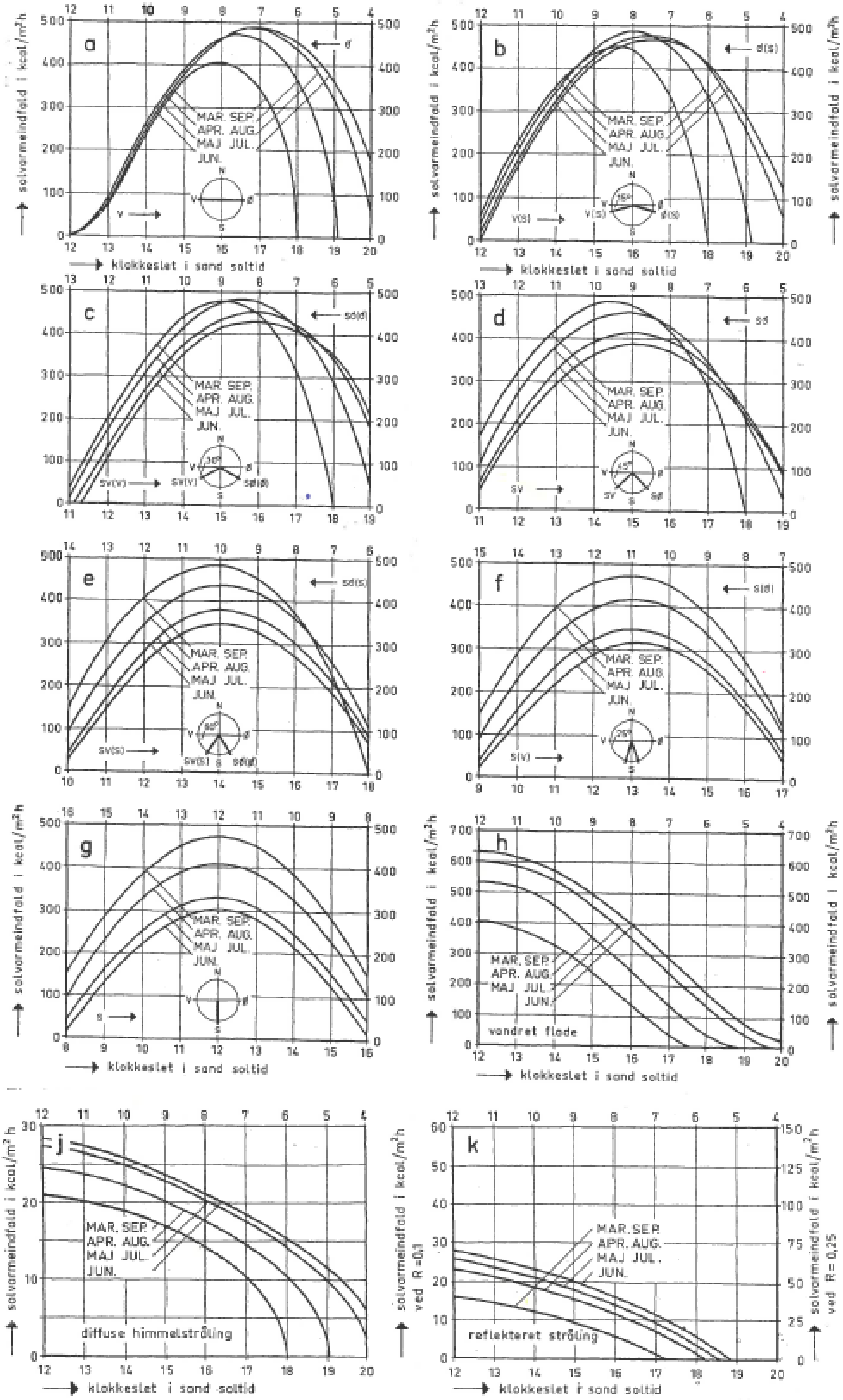


Figure 5.9 Becher's sun curves on the 21st of the month for direct, diffuse and reflected solar radiation in [kcal/m^{2}h] through a reference window for Denmark in true solar time (Becher, 1971)

Slika 5.9 Becherjeve sončne krivulje za 21. dan v mesecu za direktno, difuzno in odbito sončno sevanje v [kcal/m^{2}h] skozi referenčno okno za Dansko v solarnem času (Becher, 1971)

5.9.2 Danvak, 1st edition

Up to this point, whenever Danvak's book has been mentioned, it referred to Danvak's third edition of a book. However, the first edition is worth looking into as well.

The first edition of Danvak's textbook provides sun curves for total and direct solar radiation. It is not explained what exactly total radiation includes, but it can be assumed that it represents the sum of direct, diffuse and reflected radiation, since the difference between total and direct radiation in south orientation at noon is around 130 W/m^2. The value of ground reflection is unknown. Same as in Becher's case, Danvak's first edition includes months from May to September. All orientations with a difference of 45 degrees are presented, except the north. Units, used in this case, are W/m^2. Graphs can be seen in Figure 5.10.

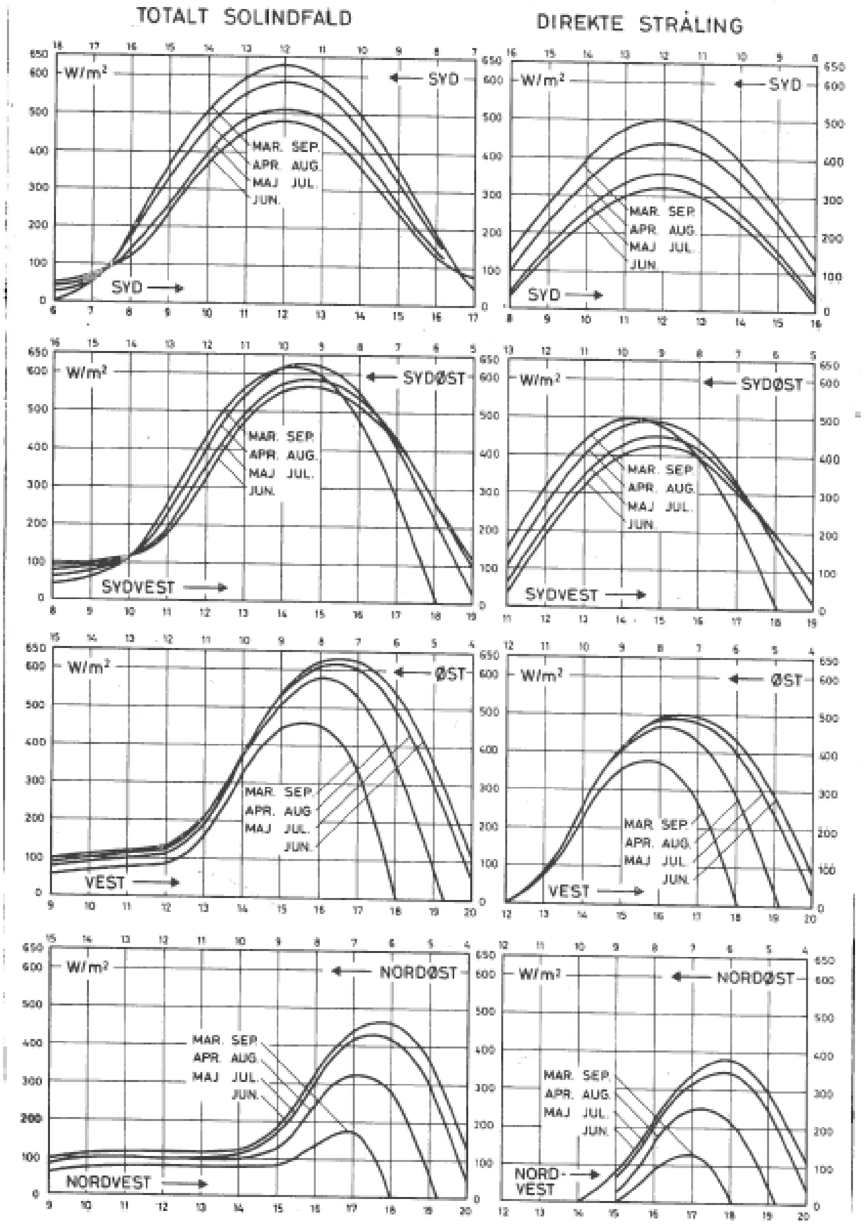


Figure 5.10 Danvak's sun curves on the 21st of the month for total and direct solar radiation in [W/m2] through a reference window for Denmark in true solar time (Danvak, 1988)

Slika 5.10 Danvakove sončne krivulje na 21. dan v mesecu za celotno in direktno sončno sevanje v [W/m^2] skozi referenčno okno za Dansko v solarnem času (Danvak, 1988)

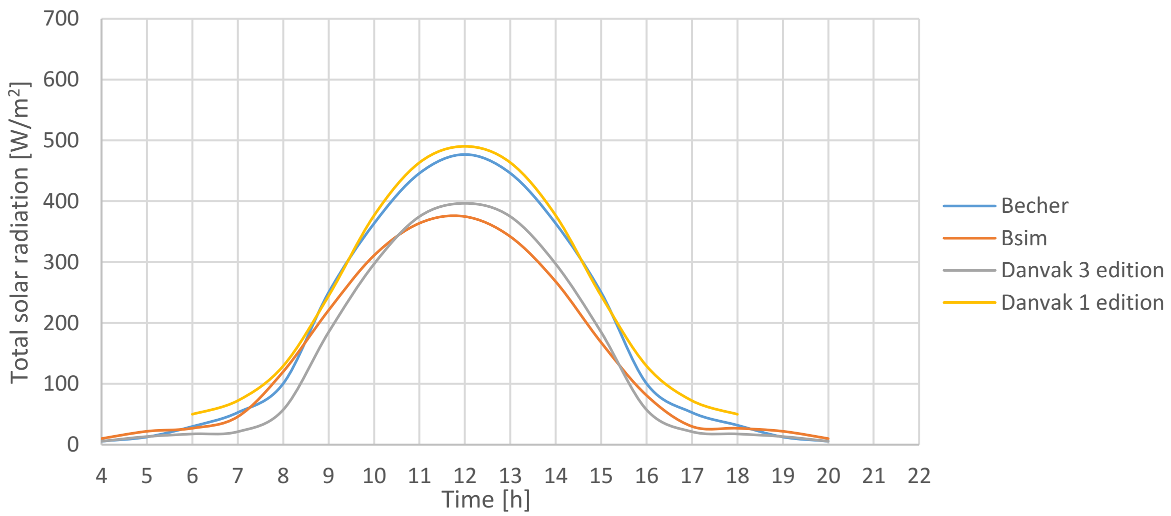
5.9.3 Comparison of literature

In order to compare all the different sun curves with the results from BSim, the TCD program had to be used. The reason for that is that BSim results show values for 1 July, while the sun curves from the literature are done for the 21st of the month. Since the interpolation between 21 June and 21 July had to be done, the values from the literature were imported into the TCD.

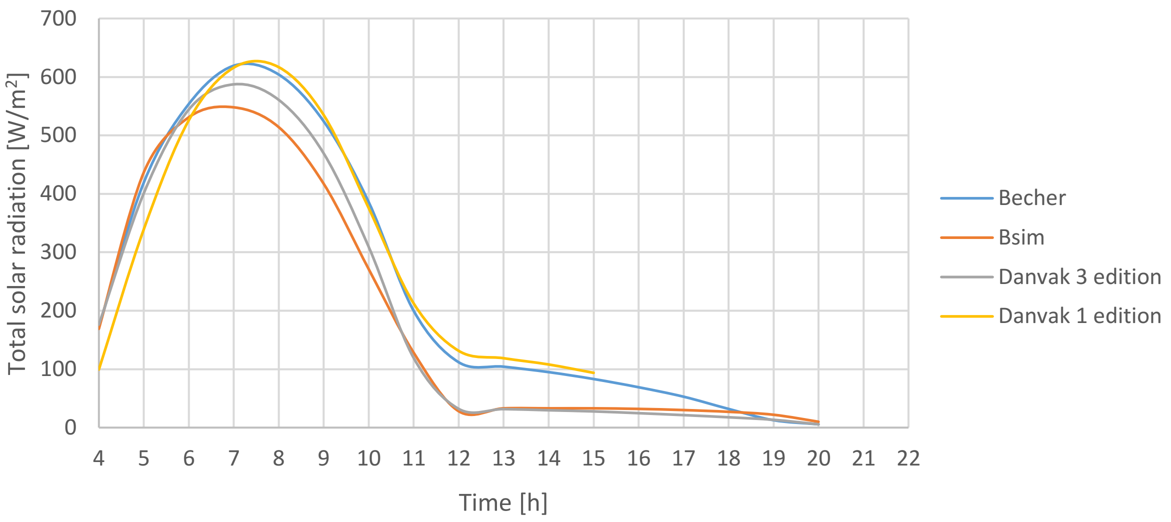
The graphs below show sun curves for 1 July. The values from Becher, first edition of Danvak, third edition of Danvak and BSim are compared. From Figure 4.3, Figure 5.9 and Figure 5.10 it can be seen that sun curves are presented in different ways – showing different components of solar radiation. Therefore, the easiest way was to compare total solar radiation. Looking into each literature separately, it means that compared values are:

- "total" values in Danvak's first edition,
- "total" values in Danvak's third edition,
- sum of "direct, diffuse and reflected component with 5% of ground reflection" in Becher,
- total solar radiation with 25% of ground reflection in BSim.

Since the east and the west orientation have the same, but mirrored values, only the east is shown in these graphs. Besides total solar radiation, the daily sums are presented as well.

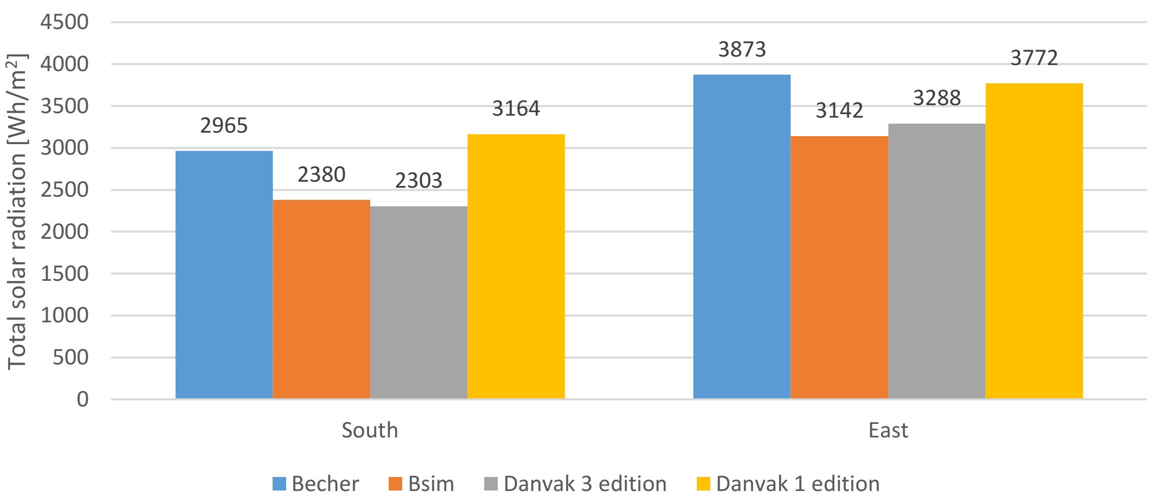


Graph 5.14 Comparison of total solar radiation (direct, diffuse and reflected component with 25% of ground reflection) in [W/m^2] in the south orientation on 1 July through a reference window
Grafikon 5.14 Primerjava celotnega solarnega sevanja (direktna, difuzna in odbita komponenta s 25% odbojnostjo tal) v [W/m^2] v južni orientaciji na 1. julij skozi referenčno okno



Graph 5.15 Comparison of total solar radiation (direct, diffuse and reflected component with 25% of ground reflection) in [W/m^2] in the east orientation on 1 July through a reference window
Grafikon 5.15 Primerjava celotnega solarnega sevanja (direktna, difuzna in odbita komponenta s 25% odbojnostjo tal) v [W/m^2] v vzhodni orientaciji na 1. julij skozi referenčno okno

Different literature does not provide data in the same time range. For example, in Graph 5.15 it can be seen that Danvak's first edition gives data from 4 a.m. to 3 p.m., while Becher and Danvak's third edition give data from 4 a.m. to 8 p.m. Therefore, certain limits were drawn in order to make a comparison more reasonable. In the south orientation, the daily sum is compared in the range from 6 a.m. to 6 p.m., while in the east orientation, the range is between 4 a.m. and 3 p.m. The results are presented in Graph 5.16.



Graph 5.16 Comparison of daily sum in [Wh/m^2] in the south- and the east-orientated reference window
Grafikon 5.16 Primerjava vsote urnih vrednosti solarnega sevanja v [Wh/m^2] v južnem in vzhodno orientiranem referenčnem oknu

From Graph 5.14 and Graph 5.15, it can be observed that Becher and the first edition of Danvak's book give the highest values of solar radiation in both orientations. Consequently, the daily sums in these cases are the highest. Becher gives values in the south and the east orientation that are higher for 25% and 23% respectively. Similar values can be found in

Danvak’s first edition, when in the south and the east orientation, the values are higher for 33% and 20% respectively. On the other hand, Danvak’s third edition gives values that are 3% lower in the south orientation and 5% higher in the east orientation. Danvak’s third edition is therefore the best match with the values from BSim. This confirms that the TCD uses the most accurate option that is available in the presented literature.

5.9.4 Norwegian sun curves

In the same manner as Becher and Danvak’s sun curves were made for Denmark, Norwegian sun curves were made in *Inneklimateknikk* book (Stensaas, 2000). The data, presented in this book is total solar radiation through a single glazed vertical window for all eight orientations and a horizontal window. Unlike for Denmark, the Norwegian sun curves correspond to the 15th of the month through the summer period (May, June, July, and August). The three tables that are presented in the book correspond to three different latitudes - 60° N, 64° N and 68° N.

Similar comparison could be done for a location in Norway by running the simulation in BSim with a Norwegian weather file. Because of the time limit, this was not done, but it could be considered as a further work for this project. For this reason, the three mentioned tables can be found in the appendix H.

5.10 Conclusion on the sun curves

The main idea of this chapter was to investigate what Danvak’s sun curves represent and how to obtain them from available weather data. To sum the chapter up, four important conclusions can be drawn.

The first one is that sun curves in Danvak’s book, described as a direct component, are in fact a combination of the direct and the reflected component.

The second is that the position of a window has a large impact on solar gain in a room. Recess settings should not be neglected while modelling windows in a room. It was shown that for example in the south orientation, this could cause almost 50 % of difference in a daily sum of total solar radiation.

The third conclusion is that from the reviewed literature, Danvak’s third edition offers the most accurate results, which deviate from the BSim results only for a few percent.

The fourth and also the main conclusion is that Danvak’s sun curves correspond to the sun curves, which are obtained with Munier’s solar model with 25% of ground reflection, modified weather data and changed longitude to 15°.

6 NEW WEATHER DATA

The comparison of 1 July in BSim and Danvak's sun curves in the previous chapter showed how BSim can be used in order to obtain a sun curve from a weather file. Now that the procedure is known, it can be used with other days as well. The goal is to find sun curves for each 21st of the month so they can be used in the TCD program.

In order to do so, other days from a weather file with similar solar radiation and cloudiness distribution to 1 July need to be found. Their data should then be modified and together they can form a new weather file, which can be used in BSim for new simulations. The obtained results would represent new sun curves, which can be compared with Danvak's values.

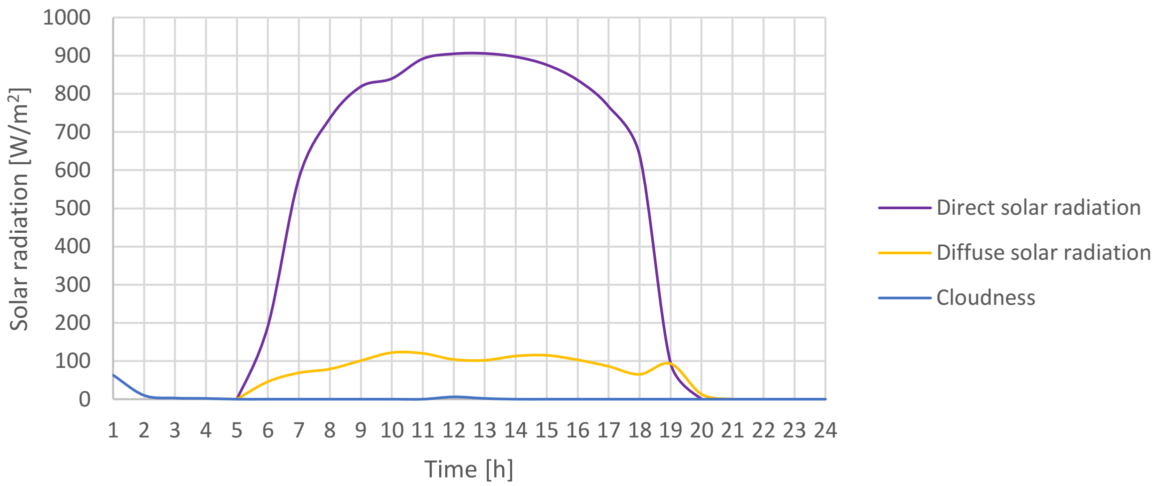
6.1 Choosing design days

The first step is to find other days from the weather file for Denmark. The critical period when overheating appears is in summer, thus, one should look for the design days for this purpose in a period between April and August. Looking through the weather file, one might notice that even higher values of solar radiation can be found in February or March, but in this time of the year, solar heat gain in the zone is desirable due to low outside temperatures.

Chosen design days need to have low cloud cover, so that only little changes are to be done in the process of modifying. It has been established that besides 1 July, the days with almost 0% cloudiness and thus uniformly distributed diffuse radiation are:

- 24 April
- 9 May
- 11 May
- 6 August
- 20 August
- 1 September

24 April, which is one of the chosen design days, is presented in Graph 6.1.



Graph 6.1 Solar distribution in [W/m^2] and cloudiness [%] for 24 April in Denmark, obtained from the weather file

Grafikon 6.1 Distribucija solarnega sevanja v [W/m^2] in oblačnost v [%] za 24. april na Danskem, pridobljeno iz vremenske datoteke

6.2 Mirroring days

Six new design days were established from the weather file, which together with the 1 July form seven design days. Since the period from April to August consists of more than 150 days, having more than just seven design days would be beneficial. Therefore, the idea is that days, which were found, can be mirrored over a certain point in order to form extra days. This means that when the design day is established from the weather file, its data can be used for another – mirrored – day as well. A mirrored day is located in the same distance from a certain point as the original day. The principle of the mirroring method is shown in Figure 6.1.

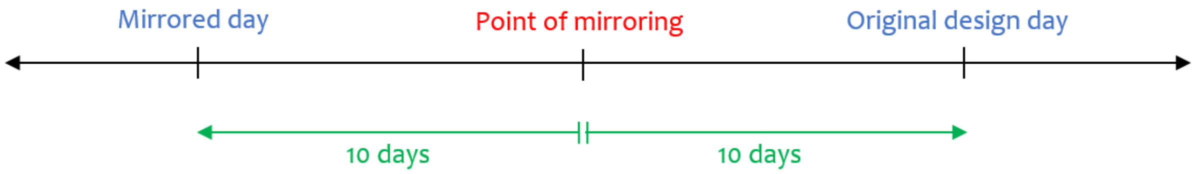


Figure 6.1 Graphical representation of the mirroring method
Slika 6.1 Grafična upodobitev metode zrcaljenja

This method can be used due to symmetric distribution of solar radiation throughout the year, which can be seen from Figure 6.2. Here, a day duration throughout the year is shown as a light blue colour. In order for this method to work, this certain point needs to be the day with the highest daily sum of solar radiation. From Figure 6.2, it can be seen that such day is somewhere between Jun and July.

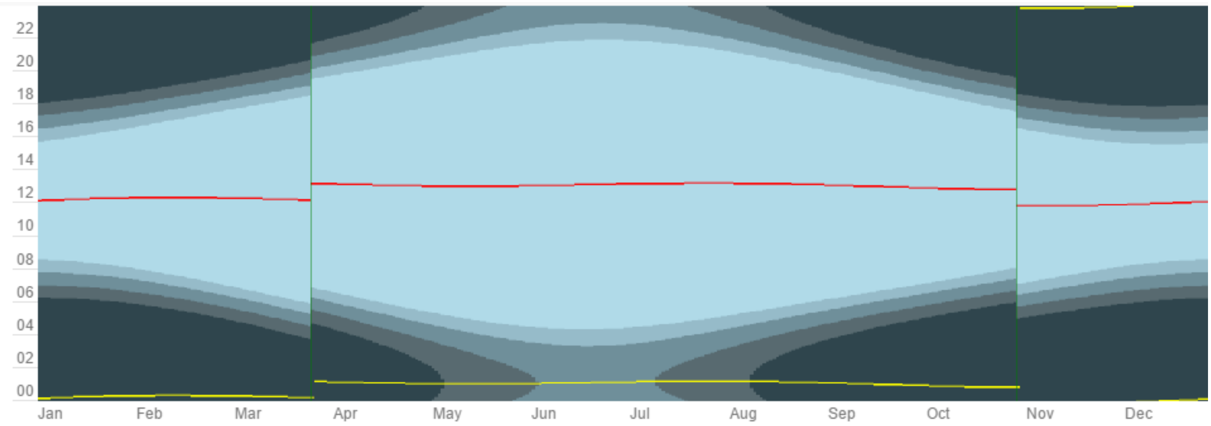


Figure 6.2 Yearly Sun Graph for Copenhagen (Thorsen, 1995)
Slika 6.2 Letni graf dolžine dneva za Kopenhagen (Thorsen, 1995)

6.2.1 Choosing the point of mirroring

The point of mirroring needs to be a day with the highest daily sum of solar radiation. Usually 21 June is considered as such. However, if one would like to be certain about which day to choose, day durations can be compared. This was done for 21 June and four other days around it. Day durations can be seen from Table 6.1. The sunrise and sunset on those days occur at almost the same time, small differences can only be found in the duration of a day. It was determined that the longest day and consequently having the highest daily sum is indeed 21 June.

Table 6.1 Day durations for Copenhagen
Preglednica 6.1 Dolžina dneva za Kopenhagen

Date	Sunrise	Sunset	Duration
19 June	4:25 a.m.	9:57 p.m.	17:32:02
20 June	4:25 a.m.	9:57 p.m.	17:32:12
21 June	4:25 a.m.	9:57 p.m.	17:32:13
22 June	4:25 a.m.	9:57 p.m.	17:32:07
23 June	4:25 a.m.	9:57 p.m.	17:31:53

6.2.2 Days of the new weather data

With the method of mirroring, new days were found by mirroring the existing design days over 21 June. Together with original design days, they form the new weather data. They are presented in Table 6.2.

Table 6.2 Days of the new weather data for Copenhagen
Preglednica 6.2 Dnevi nove vremenske datoteke za Kopenhagen

Original design day	Mirrored day
24 April	18 August
9 May	3 August
11 May	1 August
1 July	11 June
6 August	6 May
20 August	22 April
1 September	10 April

To confirmation that the mirroring method is accurate enough to be used, the duration of original and mirrored days was compared. The data is obtained from (Thorsen, 1995) and the results are presented in Table 6.3.

Table 6.3 Comparison of the day durations of original and mirrored days
Preglednica 6.3 Primerjava dolžine dneva originalnih in zrcaljenih dni

		Sunrise	Sunset	Duration	Difference
Original design day	1 Sep	6:14 a.m.	8:03 p.m.	13:48:26	
Mirrored day	10 Apr	6:17 a.m.	8:05 p.m.	13:48:24	00:00:02
Original design day	20 Aug	5:51 a.m.	8:33 p.m.	14:41:31	
Mirrored day	22 Apr	5:47 a.m.	8:29 p.m.	14:42:11	00:00:40
Original design day	6 Aug	5:24 a.m.	8:05 p.m.	15:40:19	
Mirrored day	6 May	5:16 a.m.	8:57 p.m.	15:41:37	00:01:18
Original design day	1 Jul	4:30 a.m.	9:56 p.m.	17:25:29	
Mirrored day	11 Jun	4:26 a.m.	9:52 p.m.	17:26:12	00:00:43
Original design day	11 May	5:06 a.m.	9:07 p.m.	16:01:20	
Mirrored day	1 Aug	5:15 a.m.	9:15 p.m.	15:59:54	00:01:26
Original design day	9 May	5:09 a.m.	9:03 p.m.	15:53:34	
Mirrored day	3 Aug	5:19 a.m.	9:11 p.m.	15:52:11	00:01:23
Original design day	24 Apr	5:43 a.m.	8:33 p.m.	14:50:57	
Mirrored day	18 Aug	5:47 a.m.	8:37 p.m.	14:50:11	00:00:46

It can be observed that the differences are very small, with the biggest being less than a minute and a half. All of the available data – original and modified days – is shown in Table 6.4. Days are presented in a form of a calendar, where the days, marked with grey, represent the days of a new weather file and the day, marked with red, represents a point of mirroring.

Table 6.4 Days of the new weather data shown as a calendar
Preglednica 6.4 Dnevi nove vremenske datoteke, predstavljeni v obliki koledarja

APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER
1	1	1	1	1	1
2	2	2	2	2	2
3	3	3	3	3	3
4	4	4	4	4	4
5	5	5	5	5	5
6	6	6	6	6	6
7	7	7	7	7	7
8	8	8	8	8	8
9	9	9	9	9	9
10	10	10	10	10	10
11	11	11	11	11	11
12	12	12	12	12	12
13	13	13	13	13	13
14	14	14	14	14	14
15	15	15	15	15	15
16	16	16	16	16	16
17	17	17	17	17	17
18	18	18	18	18	18
19	19	19	19	19	19
20	20	20	20	20	20
21	21	21	21	21	21
22	22	22	22	22	22
23	23	23	23	23	23
24	24	24	24	24	24
25	25	25	25	25	25
26	26	26	26	26	26
27	27	27	27	27	27
28	28	28	28	28	28
29	29	29	29	29	29
30	30	30	30	30	30
	31		31	31	

6.3 Modifying design days

Each of the chosen design days needs to be modified in order to be comparable with Danvak's sun curves that represent a clear sky. One must be aware that using clear sky as a reference will result in values that are higher than in real life.

Modifying cloudiness to 0% influences the direct and the diffuse component of solar radiation. The diffuse component is thus uniformly distributed and direct component has a smooth shape with no bumps, which occur when cloudiness is present. However, bad modifying of weather data might lead into major inaccuracy. To avoid it, one should set some boundaries or a certain guidance should be followed.

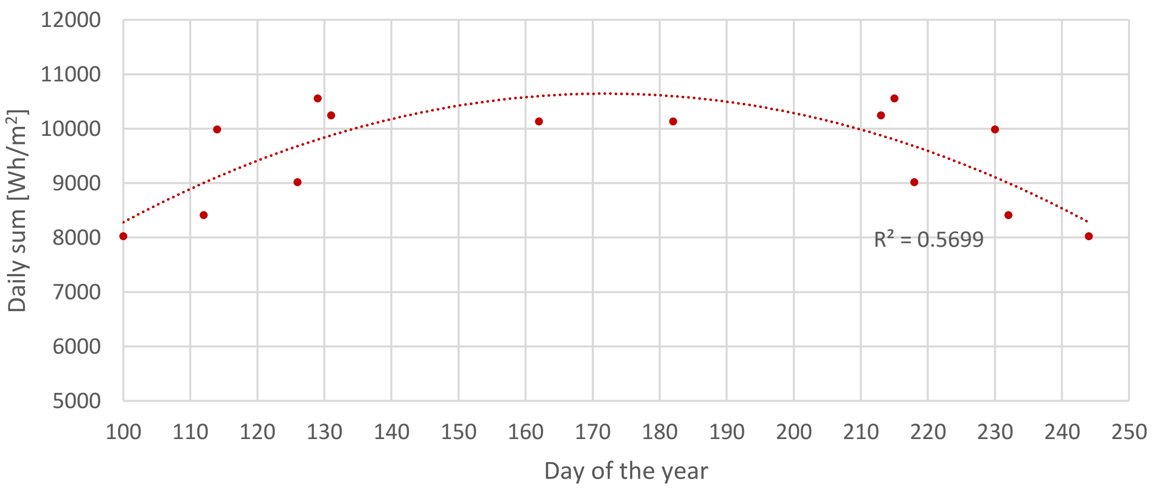
One approach to the modification of days can be comparing the daily sum of the direct component of solar radiation. It was shown before that the daily sum distribution is symmetrical throughout the year, with the highest point on 21 June as seen from Figure 6.2. Daily sums of design days (original and mirrored ones) should therefore form the same symmetrical shape.

In order to make it more clear, the chosen dates are presented as numbers, which correspond to the day of the year. For example, 1 January would be day number 1 and 31 December would be day number 365. Numbers that correspond to the design days in this case are shown in Table 6.5.

Table 6.5 Day of the year for Copenhagen
Preglednica 6.5 Dnevi v letu za Kopenhagen

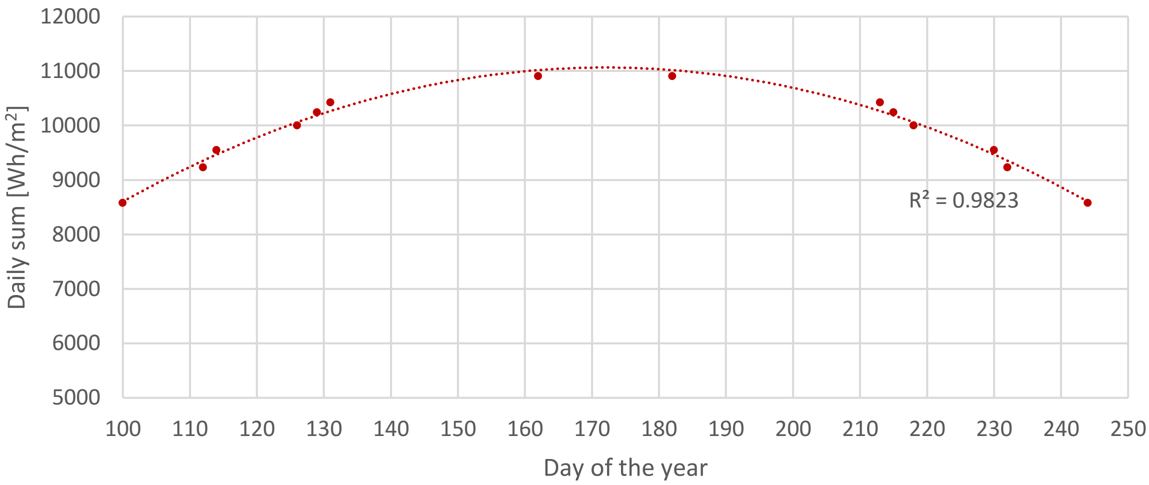
10 Apr	100	1 July	182
22 Apr	112	1 August	213
24 Apr	114	3 August	215
6 May	126	6 August	218
9 May	129	18 August	230
11 May	131	20 August	232
11 June	162	1 September	244

The daily sums of direct solar radiation of the non-modified data of the original and the mirrored days from the weather file have been calculated. Those values are presented in a graph, where x-axis shows days of the year that correspond to Table 6.5 and y-axis shows the daily sum. The trend line for this data was formed. It can be seen from Graph 6.2 that the trend line forms a symmetric shape, but data does not properly fit the trend line. R-square on the graph, which is a number between “0” and “1”, shows how well the data fits to the trend line. Closer it is to the number “1”, better fit the data has to the trend line.



Graph 6.2 Daily sum in [Wh/m^2] of the non-modified weather data
Grafikon 6.2 Vsota urnih vrednosti solarnega sevanja v [Wh/m^2] ne predelane vremenske datoteke

This data has to be modified in a way that it will fit to the trend line as much as possible. The modification should be done in the same way as it has been done before, but this time the trend line serves as a guidance of how much should data be modified. Even though in Graph 6.2 only direct solar radiation is presented, diffuse solar radiation and cloudiness should be modified as well. Since mirrored days share the same data as original days, only the original data is modified and then copied into mirrored days. The result of such modification is shown in Graph 6.3, where the R-square is almost 1.



Graph 6.3 Daily sum in [Wh/m^2] of the modified weather data
Grafikon 6.3 Vsota urnih vrednosti solarnega sevanja v [Wh/m^2] predelane vremenske datoteke

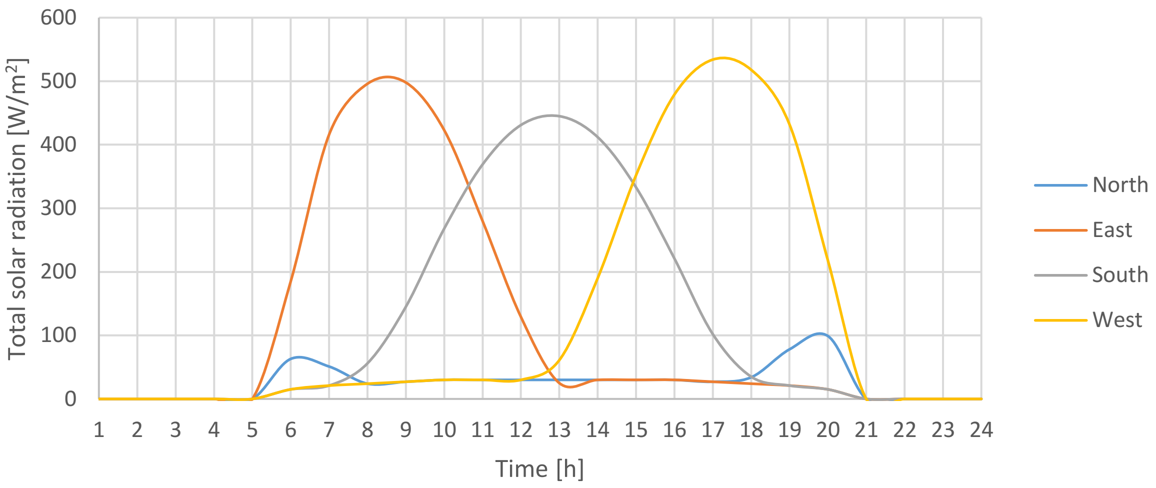
These seven modified days, which were mirrored over 21 June, now represent the data of the new weather file.

The purpose of making a new weather file is to use it in BSim. Running a simulation in a model as seen in Figure 5.1 will provide information of total solar radiation in a zone. Those results, with some further work, correspond to sun curves used in the TCD. Since in this case the sun curves for Denmark already exist, they can be used as a comparison in order to test the method and see how accurate it is.

6.4 Testing the new weather data

The test of the new weather data was done by performing a simulation in BSim. The model from Figure 5.1 had ground reflection of 25% and Munier's solar model. In order to have a broader set of results, besides the longitude 15°, the original longitude of 12.16° was tested as well.

The results of total solar radiation in each zone were obtained for all of the design days that have a modified weather data. One example is shown in Graph 6.4.



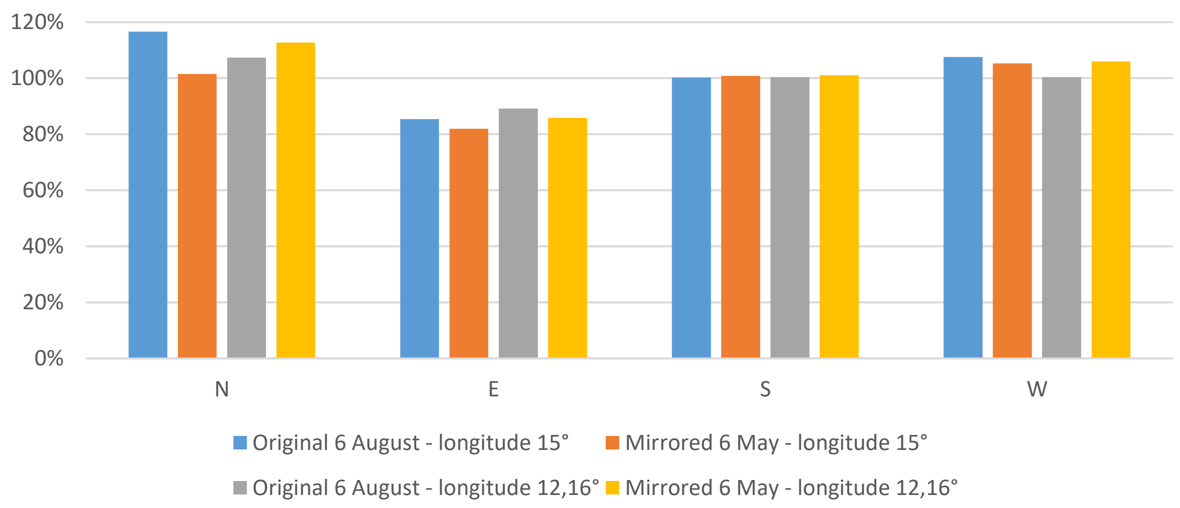
Graph 6.4 Total solar radiation through a reference window in all four orientations in [kW] obtained with BSim on 6 August

Grafikon 6.4 Skupno sončno sevanje skozi referenčno okno v vseh štirih orientacijah v [kW], pridobljeno z BSim za 6. avgust

The idea is that the obtained values are compared to Danvak's values. Since Danvak's sun curves represent only the 21st of each month, the TCD needed to be used. The needed linear interpolation between the 21st of each month was done there. The compared values were the daily sums of total solar radiation. The differences in percentage between BSim and the TCD values were calculated. Besides comparing BSim values to the TCD, it was also looked into accuracy of the method of mirroring days. Therefore, seven design days were investigated by comparing:

- Original day with longitude of 12.16°
- Mirrored day with longitude 12.16°
- Original day with longitude 15°
- Mirrored day with longitude 15°

The case of 6 August and its mirrored day, 6 May is presented in Graph 6.5. For each orientation, the difference between BSim and the TCD is shown in percentages. The TCD value is considered as 100%, which means that in the case where value exceeds 100%, BSim provided higher values than the TCD.



Graph 6.5 Difference of the daily sum through a reference window between BSim and TCD values for 6 August and 6 May

Grafikon 6.5 Razlike v vsoti urnih vrednosti solarnega sevanja skozi referenčno okno med BSim in TCD vrednostmi za 6. avgust in 6. maj

Graph 6.5 shows that all of the values are close to 100%, which means that the values from BSim are a good match with the values from the TCD. However, this graph shows only one case. All of the other values are shown in Table 6.6.

Table 6.6 Difference of the daily sum through a reference window between BSim and TCD values for all days

Preglednica 6.6 Razlike v vsoti urnih vrednosti solarnega sevanja skozi referenčno okno med BSim in TCD vrednostmi za vse dni

	N	E	S	W
Original 24 April - longitude 15°	95%	91%	107%	93%
Mirrored 18 August - longitude 15°	96%	93%	107%	91%
Original 24 April - longitude 12.16°	96%	96%	107%	88%
Mirrored 18 August - longitude 12.16°	98%	98%	106%	85%
Original 9 May - longitude 15°	90%	91%	105%	96%
Mirrored 3 August - longitude 15°	90%	95%	104%	93%
Original 9 May - longitude 12.16°	89%	95%	105%	92%
Mirrored 3 August - longitude 12.16°	91%	99%	104%	88%
Original 11 May - longitude 15°	92%	87%	106%	99%
Mirrored 1 August - longitude 15°	92%	90%	105%	96%
Original 11 May - longitude 12.16°	90%	91%	106%	95%
Mirrored 1 August - longitude 12.16°	93%	94%	105%	91%
Original 1 July - longitude 15°	96%	93%	105%	93%
Mirrored 11 June - longitude 15°	95%	89%	93%	93%
Original 1 July - longitude 12.16°	98%	97%	104%	89%
Mirrored 11 June - longitude 12.16°	97%	92%	93%	90%
Original 6 August - longitude 15°	117%	85%	100%	108%

it continuous…

continuation of Table 6.6

Mirrored 6 May - longitude 15°	102%	82%	101%	105%
Original 6 August - longitude 12.16°	107%	89%	100%	100%
Mirrored 6 May - longitude 12.16°	113%	86%	101%	106%
Original 20 August - longitude 15°	112%	92%	100%	94%
Mirrored 22 April - longitude 15°	111%	90%	101%	96%
Original 20 August - longitude 12.16°	114%	97%	100%	89%
Mirrored 22 April - longitude 12.16°	111%	95%	101%	91%
Original 1 September - longitude 15°	123%	82%	103%	110%
Mirrored 10 April - longitude 15°	122%	82%	103%	109%
Original 1 September - longitude 12.16°	115%	86%	103%	101%
Mirrored 10 April - longitude 12.16°	114%	87%	103%	100%

The results, presented in Table 6.6, are showing a good match between the values in BSim and the TCD as well. Out of 112 values, 66 of them are lower than the TCD and 46 of them give higher value than the TCD. The average value is 98%.

However, it can also be observed that longitude 15° does not necessarily provide better results. In fact, in some cases the original longitude gives a better match between the east and the west orientation.

The goal is to have the same value in the east and the west orientation. The easiest way would be that in each case, the value that is the closest match to the TCD value (either east or west) is used and copied to the other one. There would be no problem of doing so in this case, but one has to keep in mind, that this method is planned to be used for other locations as well, which do not already have an existing sun curves data for comparison. For different location, the percentages of discrepancy will not be available, thus another approach has to be used. To overcome this problem, a decision had to be made regarding which value should be used in both orientations.

Having results with two different longitudes gives more possibilities. The values in the east and the west orientation at both longitudes were investigated. It was decided, that the case where the difference between the east and the west value is larger has to be eliminated. The chosen longitude is therefore the one, which provides the smallest difference in the east and the west orientation.

Since mirrored days are taking data from the original days, this procedure should only be done for the original day. Values can then be copied to the mirrored days. The case of 24 April and its mirrored day, 18 August, is shown in Table 6.7. Looking only at the original days, the difference between the east and the west in smaller in the case with longitude of 15°. In this case, the chosen longitude is 15°.

Table 6.7 Choosing the longitude for 24 April
Preglednica 6.7 Izbira geografske dolžine za 24. april

	N	E	S	W
Original 24 April - longitude 15°	95%	91%	107%	93%
Mirrored 18 August - longitude 15°	96%	93%	107%	91%
Original 24 April - longitude 12.16°	96%	96%	107%	88%
Mirrored 18 August - longitude 12.16°	98%	98%	106%	85%

In the chosen longitude, the difference between the east and the west is small, but still not the same. Therefore, one of the values, either east or west, has to be chosen. Picking the higher value keeps one on the safe side. In the shown case, the value in the west is higher; thus it was chosen to be copied to the east orientation. The same data is then used also in the mirrored day as seen from Table 6.8.

Table 6.8 Copied values for 24 April and 18 August
Preglednica 6.8 Kopiranje vrednosti za 24. april in 18. avgust

	N	E	S	W
Original 24 April - longitude 15°	95%	93%	107%	93%
Mirrored 18 August - longitude 15°	96%	93%	107%	93%

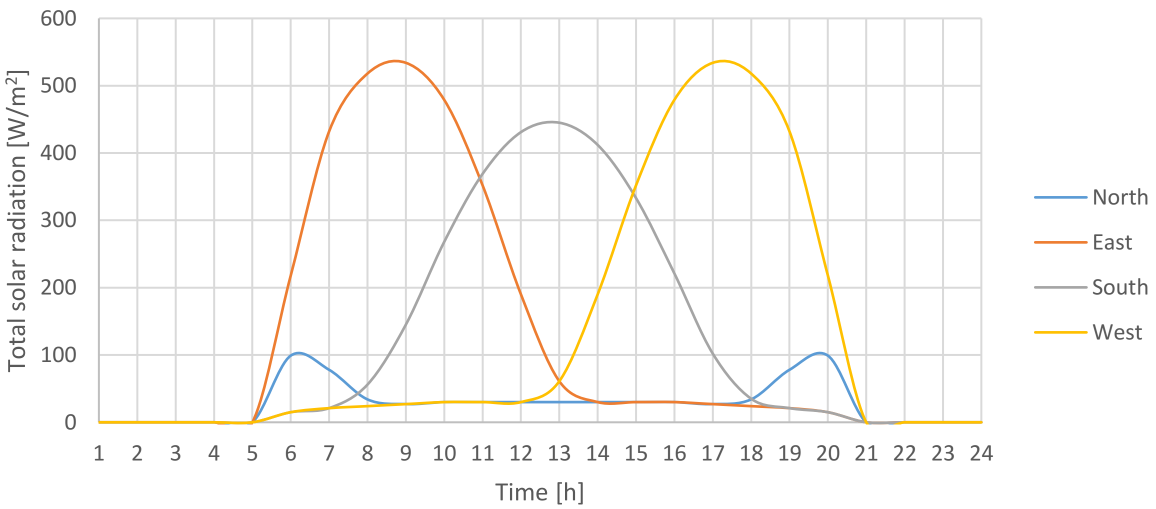
The same procedure has been used for all of the other design day. The chosen longitudes and copied values are shown in Table 6.9. Now there are 28 values out of 56, which are below 100% and 28 values, which are over 100%. The average value is now 99% with a standard deviation of 8%.

Table 6.9 Chosen longitudes and copied values
Preglednica 6.9 Izbrane geografske dolžine in kopirane vrednosti

	N	E	S	W
Original 24 April - longitude 15°	89%	93%	107%	93%
Mirrored 18 August - longitude 15°	89%	93%	107%	93%
Original 9 May - longitude 12.16°	93%	95%	105%	95%
Mirrored 3 August - longitude 12.16°	94%	95%	105%	95%
Original 11 May - longitude 12.16°	84%	95%	106%	95%
Mirrored 1 August - longitude 12.16°	85%	95%	105%	95%
Original 1 July - longitude 15°	96%	93%	105%	93%
Mirrored 11 June - longitude 15°	96%	93%	105%	93%
Original 6 August - longitude 12.16°	120%	100%	100%	100%
Mirrored 6 May - longitude 12.16°	118%	100%	101%	100%
Original 20 August - longitude 15°	105%	94%	100%	94%
Mirrored 22 April - longitude 15°	105%	94%	100%	94%
Original 1 September - longitude 12.16°	120%	101%	103%	101%
Mirrored 10 April - longitude 12.16°	120%	101%	103%	101%

Copying values from east to west or the other way around was in this case done only for the daily sum. However, in order to obtain the sun curve, values for each hour need to be known. The procedure of copying hourly values in east and west orientation follows the same idea that was used in the beginning when solar model had to be chosen. At solar noon, when the sun has the highest altitude, the east and the west receive the same amount of solar radiation (the north will not have the same value in this case due to the reflected component, which is present in this case). This moment in time is the mirroring point and corresponds to 1 p.m. in local standard time. More specifically, if the west has highest daily sum, than the value at 1 p.m. in the west is copied to the value at 1 p.m. in the east, the value at 2 p.m. in the west is copied to the value at 11 a.m. in the east, and the value at 11 a.m. in the west is copied to the value at 2 p.m. in the east, and so on.

In Danvak's sun curves from Figure 4.3, it can be seen that values in the north are the same in the morning and in the afternoon, while in Graph 6.4 the values vary. Making values the same can be achieved by the same procedure of mirroring, but in this case, it is mirrored from morning into afternoon or the other way around. For example, in case of 6 August, where values were copied from the west to the east, the north should be done in a way, that values from afternoon are symmetrically copied to morning over the mirroring point. The result of such mirroring can be seen from Graph 6.6.



Graph 6.6 Modification of total solar radiation through a reference window in all four orientations in [kW] obtained with BSim on 6 August
Grafikon 6.6 Predelava celotnega solarnega sevanja skozi referenčno okno v vseh štirih orientacijah v [kW], pridobljeno v BSim za 6. avgust

The values from BSim are organised by dates. For further work, one should organise values by orientation, meaning that all values from e.g. south are together, but still organised by date. This will make it easier for further comparison with Danvak's curves. An example of such organisation of values in [W/m^2] is shown in Table 6.10.

Table 6.10 Data organisation for the south orientation – hourly values of sun curves in [W/m^2] through a reference window for the south orientation in Denmark

Preglednica 6.10 Organizacija podatkov za južno orientacijo – vrednosti sončnih krivulj vsako uro v [W/m^2] skozi referenčno okno z južno orientacijo za Dansko

SOUTH	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
10.4.	0	0	0	0	0	0	20	73	207	348	458	515	524	489	404	274	132	39	15	0	0	0	0	0
22.4.	0	0	0	0	0	11	28	88	205	333	425	476	477	435	347	222	98	29	11	0	0	0	0	0
24.4.	0	0	0	0	0	14	29	93	228	359	455	506	504	453	355	219	90	26	15	4	0	0	0	0
6.5.	0	0	0	0	0	15	21	56	145	268	369	431	445	412	333	221	102	35	21	15	0	0	0	0
9.5.	0	0	0	0	5	15	21	67	169	294	392	447	453	409	320	200	88	35	21	11	0	0	0	0
11.5.	0	0	0	0	5	18	26	71	164	285	385	442	451	409	319	199	87	32	19	11	0	0	0	0
11.6.	0	0	0	0	10	22	27	63	137	239	324	370	372	332	252	150	71	30	27	22	10	0	0	0
1.7.	0	0	0	0	10	22	27	63	137	239	324	370	372	332	252	150	71	30	27	22	10	0	0	0
1.8.	0	0	0	0	5	18	26	71	164	285	385	442	451	409	319	199	87	32	19	11	0	0	0	0
3.8.	0	0	0	0	5	15	21	67	169	294	392	447	453	409	320	200	88	35	21	11	0	0	0	0
6.8.	0	0	0	0	0	15	21	56	145	268	369	431	445	412	333	221	102	35	21	15	0	0	0	0
18.8.	0	0	0	0	0	14	29	93	228	359	455	506	504	453	355	219	90	26	15	4	0	0	0	0
20.8.	0	0	0	0	0	11	28	88	205	333	425	476	477	435	347	222	98	29	11	0	0	0	0	0
1.9.	0	0	0	0	0	0	20	73	207	348	458	515	524	489	404	274	132	39	15	0	0	0	0	0

6.5 Linear interpolation

As it is known, the TCD uses sun curves that represent the 21st of each month. That means that if new sun curves are to be put into the TCD program, they should also represent the 21st of each month. Since none of the design days fit this criterion, linear interpolation had to be done. Equation (9) was used in order to obtain the total solar radiation on the 21st of the month.

$$S_{21} = \frac{(S_p - S_f) \cdot (D_{21} - D_p)}{(D_f - D_p)} + S_f \qquad (9)$$

Where S_f is total solar radiation on the following day,

S_p is total solar radiation on the previous day,

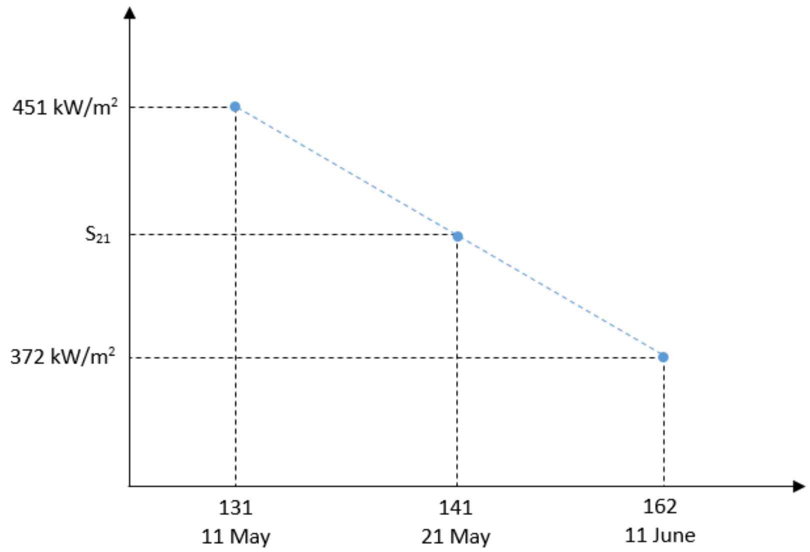
S_{21} is total solar radiation on the 21st of the month,

D_f is the day of the year of the following day,

D_p is the day of the year of the previous day,

D_{21} is the day of the year of the 21st of the month.

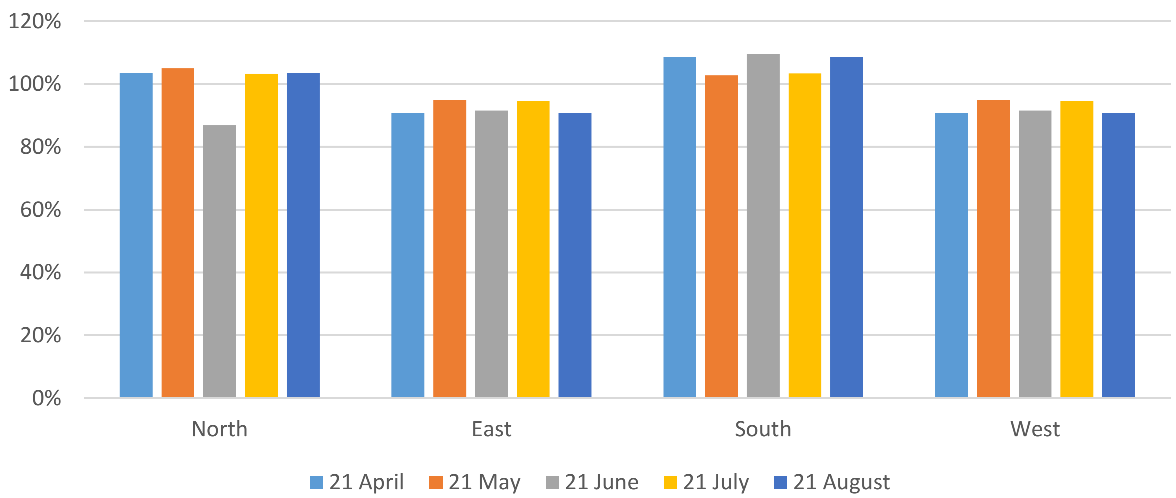
The interpolation for 21 May is done between 11 May and 11 June. Visual representation of this linear interpolation can be seen in Graph 6.7. By using equation (9) value for 1 p.m. has been calculated as seen from equation (10).



Graph 6.7 Linear interpolation of 21 May
Grafikon 6.7 Linearna interpolacija za 21. maj

$$S_{21} = \frac{(451\ kW/m^2\ - 372\ kW/m^2) \cdot (141 - 131)}{(162 - 131)} + 372\ kW/m^2 = 397\ kW/m^2 \qquad (10)$$

With this equation, all the other values for each 21st of the month have been calculated. Linear interpolation is not the most accurate way of calculating the missing data; however, it is the simplest way to do it. The accuracy can again be checked by comparing the obtained data with Danvak's sun curves. The comparison as a difference [%] between Danvak's and BSim's daily sum is shown in Graph 6.8. The TCD value is again considered as 100%, so if the value on the graph exceeds 100%, it means that the BSim value was higher than the TCD value.

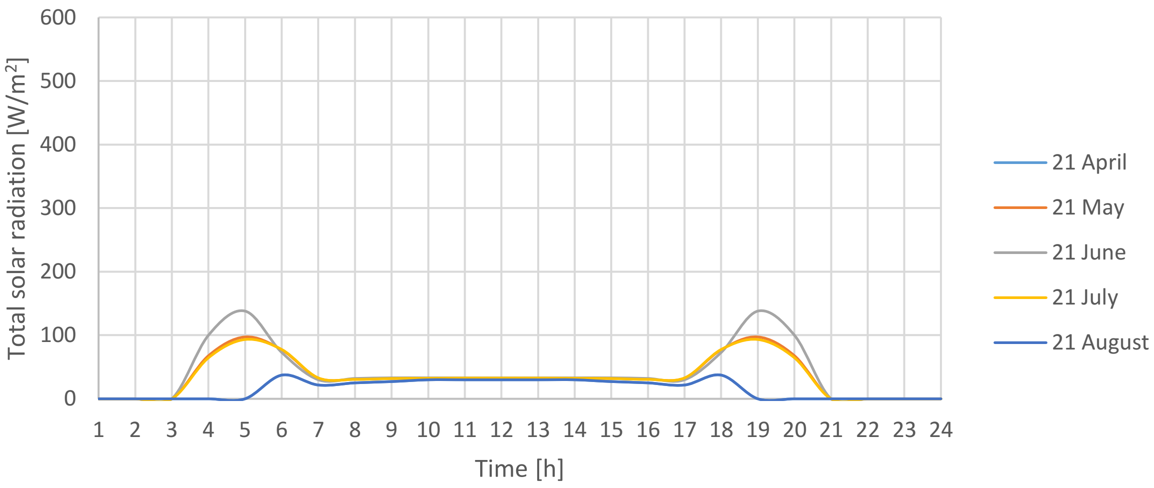


Graph 6.8 Difference in the daily sum between BSim and the TCD
Grafikon 6.8 Razlika med vsoto urnih vrednosti solarnega sevanja iz BSim in TCD

It can be observed, that the east and the west orientation provide results that are slightly below 100%, while all results in the south orientation exceed 100%. The north orientation is somewhere in between. Nevertheless, the average value is 98% with a standard deviation of 7%.

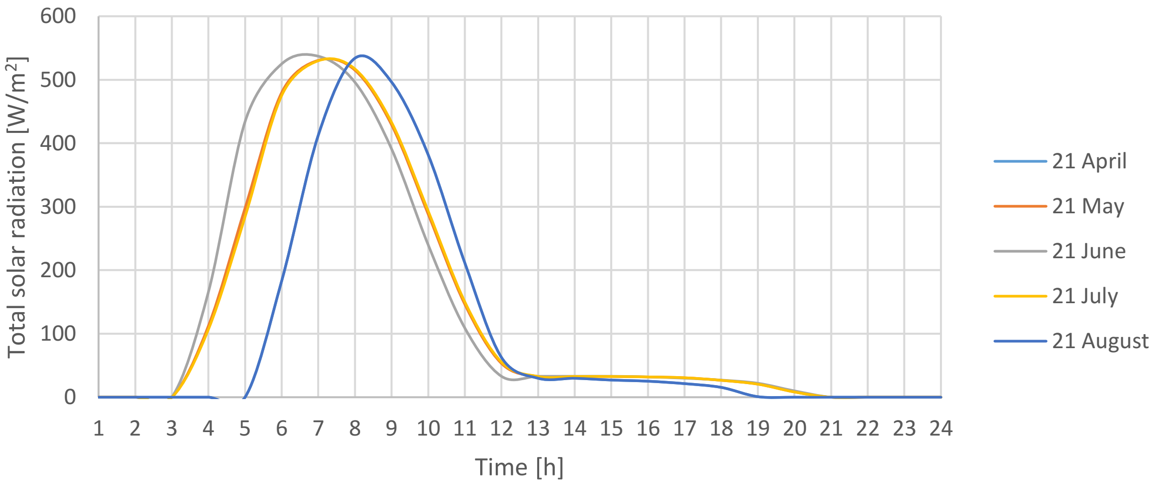
6.6 Sun curves, obtained from the new weather data

The final result of this method are the sun curves for the 21st of the month. In order for them to be compatible with the TCD programme, solar time needs to be used. The obtained curves are presented in Graph 6.9, Graph 6.10, Graph 6.11, and Graph 6.12.



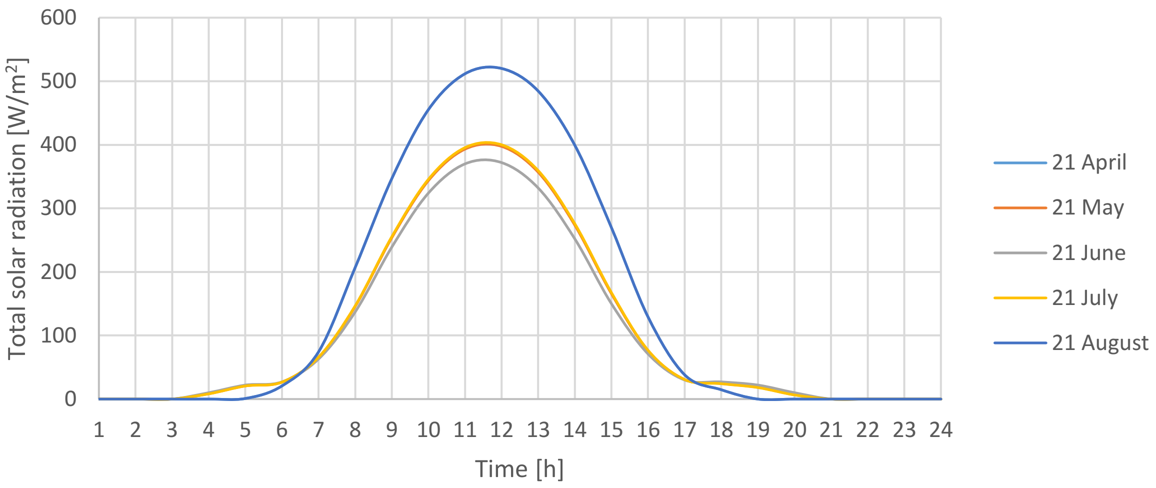
Graph 6.9 Obtained sun curves with BSim in [W/m²] for the north orientation through a reference window for the 21st of the month

Grafikon 6.9 Pridobljene sončne krivulje z BSim v [W/m²] skozi referenčno okno za severno orientacijo na 21. dan v mesecu

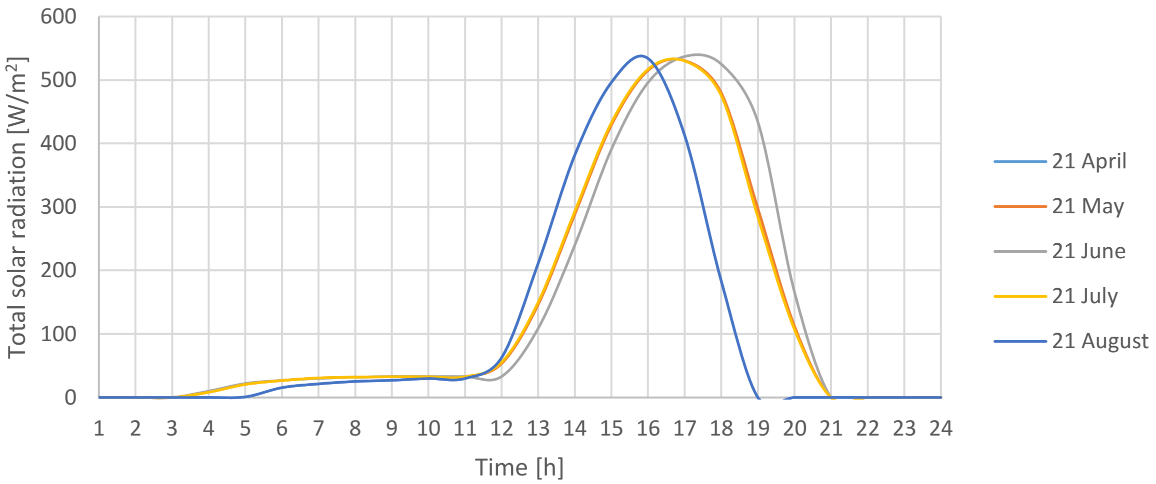


Graph 6.10 Obtained sun curves with BSim in [W/m²] for the east orientation through a reference window for the 21st of the month

Grafikon 6.10 Pridobljene sončne krivulje z BSim v [W/m²] skozi referenčno okno za vzhodno orientacijo na 21. dan v mesecu



Graph 6.11 Obtained sun curves with BSim in [W/m^2] for the south orientation through a reference window for the 21st of the month
Grafikon 6.11 Pridobljene sončne krivulje z BSim v [W/m^2] skozi referenčno okno za južno orientacijo na 21. dan v mesecu



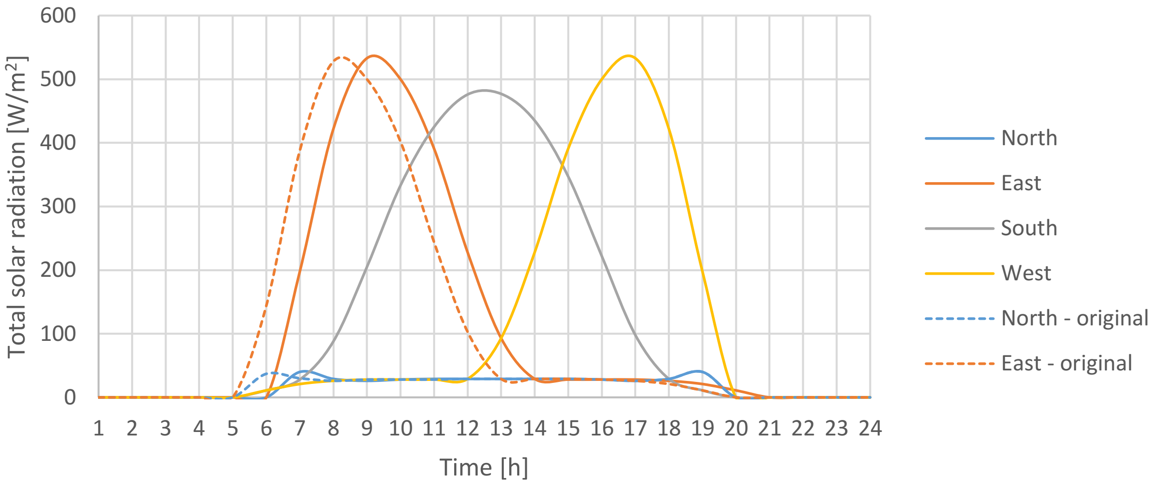
Graph 6.12 Obtained sun curves with BSim in [W/m^2] for the west orientation through a reference window for the 21st of the month
Grafikon 6.12 Pridobljene sončne krivulje z BSim v [W/m^2] skozi referenčno okno za zahodno orientacijo na 21. dan v mesecu

One might notice that in the south orientation, the values are not completely symmetrical as in Danvak's case, meaning that values at 11 a.m. and 1 p.m. are not the same. This probably happens as a consequence of using a weather file, which gives values that are more realistic and not simplified as in Danvak's case. The same shape of solar distribution in the south orientation can be found in Graph 5.2, which shows non-modified values. However, the sun curves, obtained from the weather file with BSim have in general high resemblance to Danvak's sun curves from Figure 4.3. The obtained values are more precisely shown in appendixes.

6.7 Evaluation of new sun curves

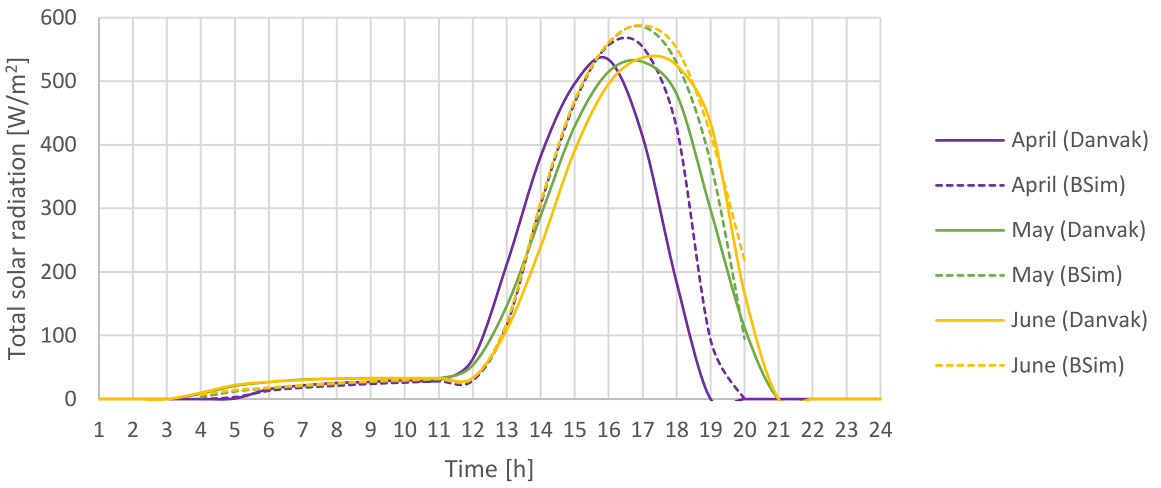
Looking into the obtained sun curves, one might notice a slightly different distribution of solar radiation, compared to Danvak's values from Figure 4.3. Further observation showed that in some cases, when values were mirrored from the east to the west or the other way around, larger discrepancies occurred. One of such cases is presented in Graph 6.13, which shows values for the design day of 20 August.

Full lines on the graph represent sun curves after the values were mirrored from the west to the east, since values in the west were higher than in the east. Dotted lines represent the original values without any modification. One-hour difference can be observed in the east curve in the morning hours.



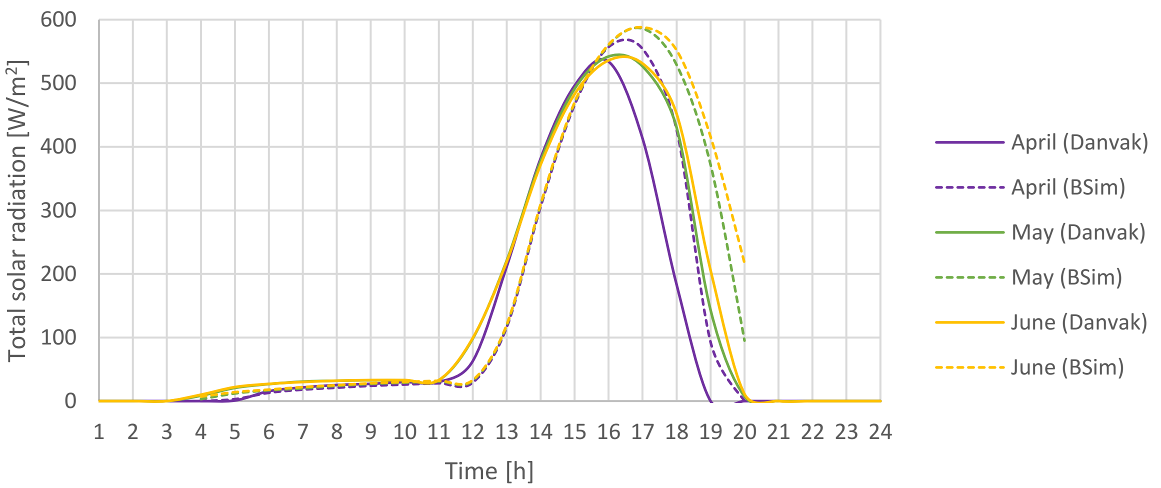
Graph 6.13 Comparison of original and mirrored values for 20 August
Grafikon 6.13 Primerjava originalnih in zrcaljenih vrednosti za 20. avgust

Mirroring values from one orientation to another gives the same values in both orientation, however, it lowers the accuracy of the results, which will show one-hour difference. Closer look into the west orientation is shown in Graph 6.14, where full line represents Danvak's values and the dotted lines represent values, obtained with BSim. Values represent total solar radiation through the reference window on the 21st of the month. BSim values were obtained by mirroring from one orientation to another, in order to obtain the same values in the east and the west. Since April shares the same values as August, and May shares the same values as July, only April, May and June are shown.



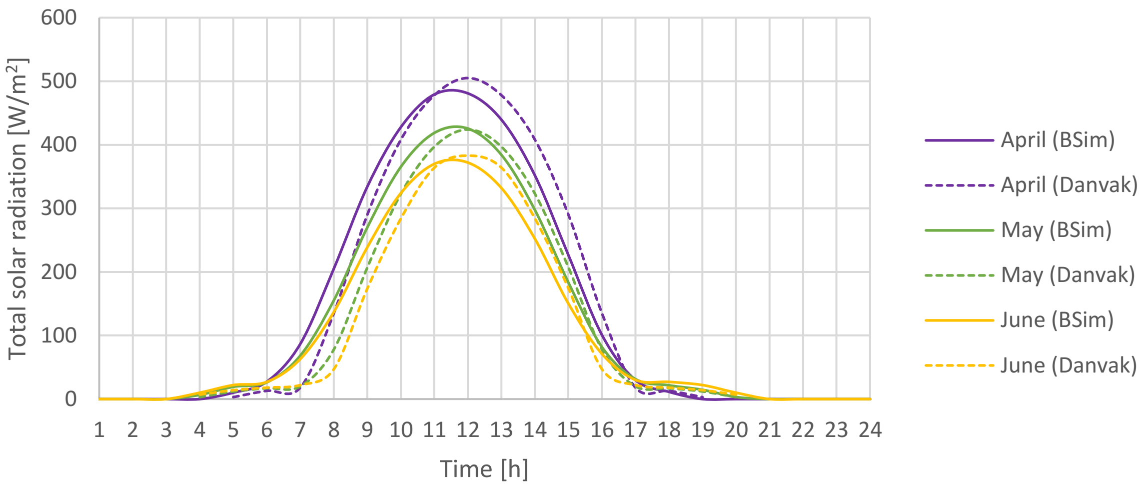
Graph 6.14 Sun curves, obtained with BSim for the west orientation when values are mirrored, and Danvak's sun curves for the west orientation through a reference window
Grafikon 6.14 Sončne krivulje, pridobljene z BSim za zahodno orientacijo in zrcaljenimi vrednostmi ter Danvakove sončne krivulje za zahodno orientacijo skozi referenčno okno

If values from one orientation to another are not copied, but the longitude with the smallest difference is still chosen, different sun curves can be obtained. Values in the east and the west side will therefore not be the same; however, the accuracy of sun curves will be higher. Sun curves, obtained with BSim and without mirroring values are shown in Graph 6.15. The distribution of sun curves from BSim in this case is closer to Danvak's sun curves.



Graph 6.15 Sun curves, obtained with BSim for the west orientation when values are not mirrored, and Danvak's sun curves for the west orientation through a reference window
Grafikon 6.15 Sončne krivulje, pridobljene z BSim za zahodno orientacijo in originalnimi vrednostmi ter Danvakove sončne krivulje za zahodno orientacijo skozi referenčno okno

By looking into other orientations, it was found out that peak values in east, west and north appear more or less at the same hours in BSim and Danvak values. On the other hand, peak values in the south orientation are just slightly different. In BSim, they all tend to appear earlier than in Danvak's sun curves.



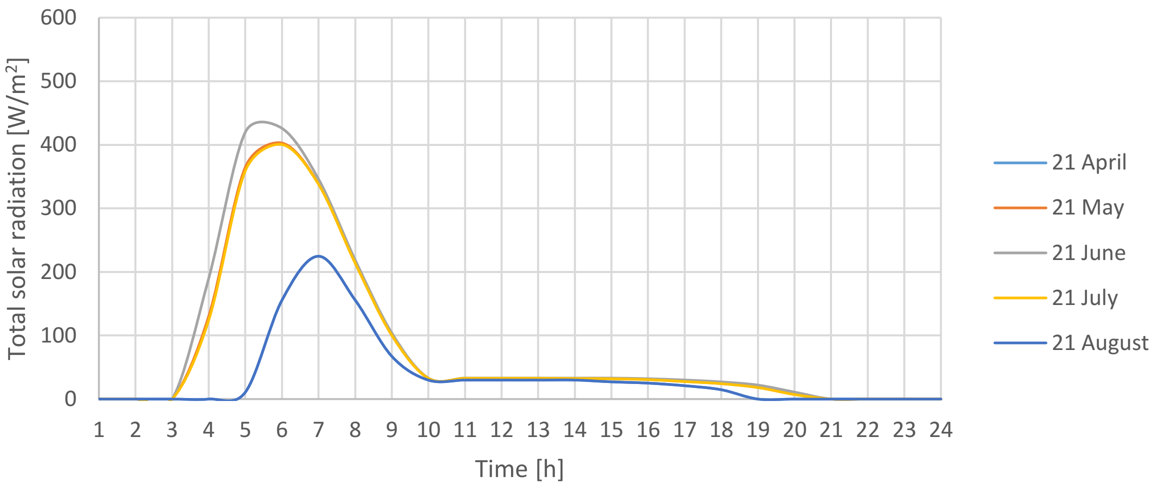
Graph 6.16 Sun curves, obtained with BSim for the south orientation when values are not mirrored and Danvak's sun curves for the south orientation through a reference window

Grafikon 6.16 Sončne krivulje, pridobljene z BSim za južno orientacijo in originalnimi vrednostmi ter Danvakove sončne krivulje za južno orientacijo skozi referenčno okno

From this observation, it was concluded that if values are not copied from one orientation to another, a better match with Danvak's curves can be found, regarding the shape of the curves.

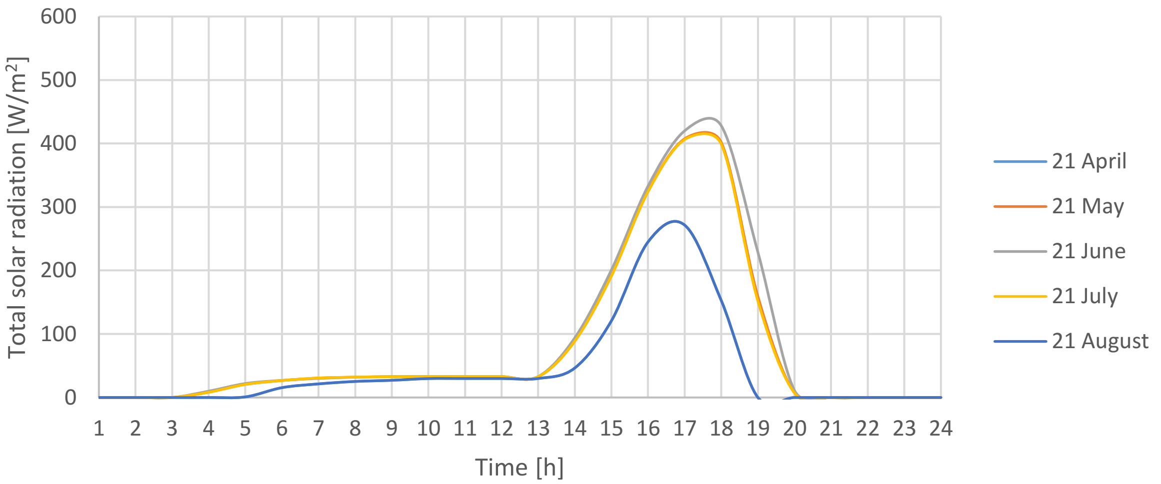
6.8 Other orientations

The same procedure as for obtaining values for north, east, south and west, can be also used to obtain sun curves for other four orientations – north-east, south-east, south-west and north-west. The same BSim model can be used; it just needs to be rotated for 45°. When values from BSim for the two longitudes are gathered in Excel, one can choose the one, which has the smallest difference in the daily sum. In this case, north-east to north-west and south-east to south-west should be compared. It was found out, that the longitudes that gave the smallest difference in the daily sum for north, east, south and west orientation, gave the smallest difference also in the case of other four orientations. Following the conclusion from the previous chapter, none of the values is mirrored over the solar noon. The next step was to organise them by orientation, add mirrored days to the original ones and do the interpolation the same way as before. After time modification, the final values were obtained. Besides rotating the model, sun curves were obtained by following the exact same steps as before. The results are presented in Graph 6.17, Graph 6.18, Graph 6.19 and Graph 6.20. The exact values can be found in the appendixes.



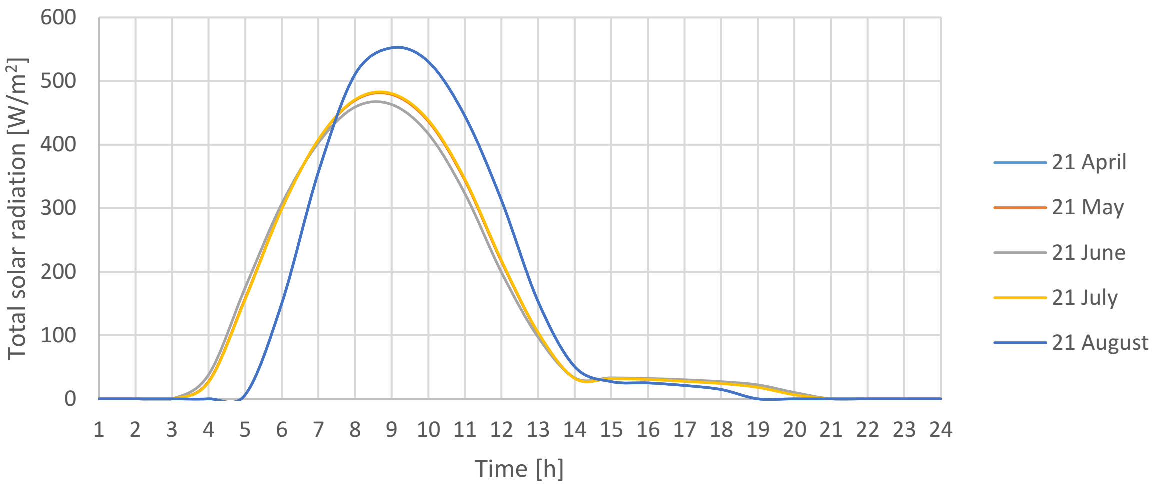
Graph 6.17 Obtained sun curves with BSim in [W/m^2] for the north-east orientation through a reference window for the 21st of the month

Grafikon 6.17 Pridobljene sončne krivulje z BSim v [W/m^2] skozi referenčno okno za severovzhodno orientacijo na 21. dan v mesecu

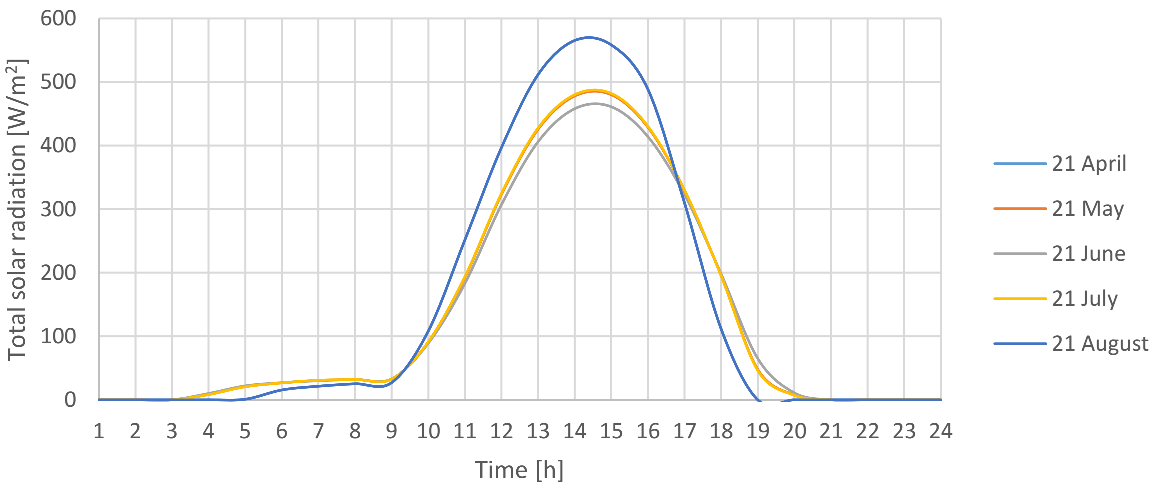


Graph 6.18 Obtained sun curves with BSim in [W/m^2] for the north-west orientation through a reference window for the 21st of the month

Grafikon 6.18 Pridobljene sončne krivulje z BSim v [W/m^2] skozi referenčno okno za severozahodno orientacijo na 21. dan v mesecu



Graph 6.19 Obtained sun curves with BSim in [W/m^2] for the south-east orientation through a reference window for the 21st of the month
Grafikon 6.19 Pridobljene sončne krivulje z BSim v [W/m^2] skozi referenčno okno za jugovzhodno orientacijo na 21. dan v mesecu



Graph 6.20 Obtained sun curves with BSim in [W/m^2] for the south-west orientation through a reference window for the 21st of the month
Grafikon 6.20 Pridobljene sončne krivulje z BSim v [W/m^2] skozi referenčno okno za jugozahodno orientacijo na 21. dan v mesecu

6.9 Sun curves for a horizontal window

Besides having all eight orientations, the TCD could in future be further improved by allowing to analyse a horizontal window as well. Values can be obtain by the same procedure. In this case, the BSim model needs to be modified a bit. Only one zone is necessary and it needs to have a roof window. Windows properties are the same as before – 1 m^2 of glazing area and the g-values of 0.76. An example of such model can be seen in Figure 6.3.

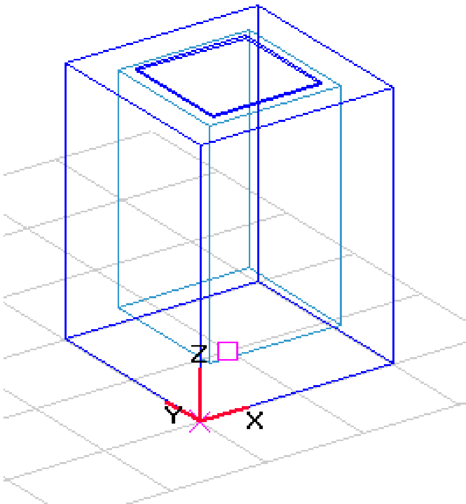
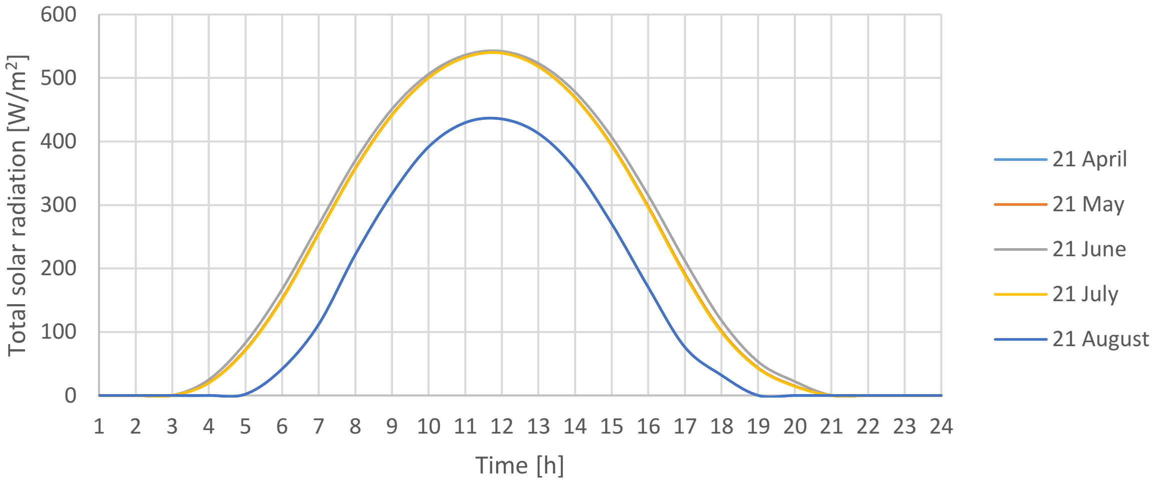


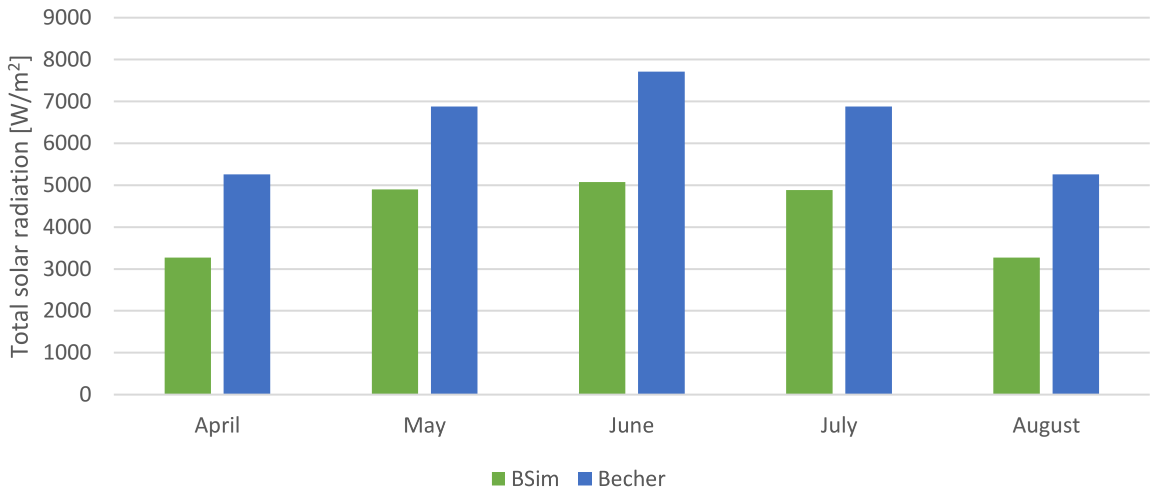
Figure 6.3 Model in BSim for a horizontal window
Slika 6.3 Model v BSim za horizontalno okno

The values, obtained with two different longitudes, gave almost the same results, thus it was decided that the original longitude is going to be used. The values were then organised, mirrored days were added, interpolation was done in order to obtain values for the 21st of the month and time was modified to fit the TCD program. Result can be seen from Graph 6.21.



Graph 6.21 Obtained sun curves with BSim in [W/m²] for a horizontal reference window for the 21st of the month
Grafikon 6.21 Pridobljene sončne krivulje z BSim v [W/m²] skozi horizontalno referenčno okno na 21. dan v mesecu

As previously mentioned, Becher's sun curves also include values for the horizontal window. When daily sums for a vertical window with the south and the west orientation were compared, a difference of about 20% was found. When the daily sum for the horizontal window was compared, an even bigger difference was observed. Graph 6.22 shows the comparison of the daily sum from the curves, obtained with BSim, and Becher's curves.



Graph 6.22 Comparison of daily sum in [Wh/m^2] through a reference window from BSim and Becher's sun curves

Grafikon 6.22 Primerjava vsote urnih vrednosti solarnega sevanja v [Wh/m^2] skozi referenčno okno v BSim in Becherjevih sončnih krivulj

Becher's values for April and August are higher than BSim values for 61%, for May and July for 40% and for June are higher for 52%. In the description of Becher's values, it is written that values for a horizontal window are obtained as a sum of the direct component and a double value of the diffuse component. Becher's diffuse radiation is higher than the one, obtained with BSim, thus a higher discrepancy was expected to be found.

6.10 Conclusion on the new weather data

After analysing what Danvak's sun curves represent, which was described in chapter "5 SUN CURVES", new sun curves were obtained. The procedure started by forming a new weather file. To do so, some decisions and simplifications had to be made that led to lower accuracy. However, one has to keep in mind that this data is going to be used in the TCD program, which is a simplified tool. Its purpose is to provide practical information in an early stage of design when accuracy does not need to be high. Nonetheless, it is believed, that the new sun curves will give better results when simulation results will be compared to results from a more advanced simulation tool, since the procedure for obtaining sun curves is based on the real weather data. This is also a reason why the values in the east and the west are not completely the same, and the values in the south orientation are not symmetrical as in Danvak's sun curves. Quick answers that will be obtained with the TCD program with new sun curves will probably show results that are more realistic. Afterwards, higher accuracy can be obtained later in the process by using simulation tools that require more input than the TCD. Before that, at an early stage of design, more practical and faster answers are required.

7 OBTAINING SUN CURVES FOR SLOVENIA

The method that was used to obtain sun curves for Denmark provided satisfying results. If there is an available weather file, one can obtain data for any desirable location by using the same procedure. Hereafter the method is going to be tested by using it to obtain data for a location in Slovenia. Each step of the procedure is going to be explained in details. This chapter will therefore serve as a manual for weather data modification for the TCD program.

Figure 7.1 Location of Slovenia
Slika 7.1 Lokacija Slovenije

The first step is to get a weather file, which is usually available online. The Slovenian weather file was downloaded from (EnergyPlus, 1996) as an .epw file format. For further analysis, the data should be imported into Excel. This can be done in several ways. For example, a simulation tool IDA ICE, which uses weather file in .epw file format, could be used to export weather data into Excel. Time, used in the weather file, are hours from "0" to "8760" with extra 24 hours for the case of a leap year. A better form of a time arrangement would be by organising the weather data by hour of the day (from 1 to 24), by day of the month (from the 1st to the 30th or the 31st) and by month (from January to December) as seen from Figure 7.2. This way it is easy to find a certain date in a weather file.

	A	B	C	D	E	F	G	H	I	J	K
1	Hour	Day	Month	Time	Dry-bulb temperature, Deg-C	Rel humidity of air, %	Wind speed, x-component, m_s	Wind speed, y-component, m_s	Direct normal rad, W_m2	Diffuse rad on hor surf, W_m2	Cloudness, %
2				0	0.9	94	0	0	0	0	100
3	1	1	1	1	0.9	94	0	0	0	0	100
4	2	1	1	2	0.9	95	1.48	-0.26	0	0	100
5	3	1	1	3	0.8	95	2.1	0	0	0	100
6	4	1	1	4	0.8	96	0.64	0.77	0	0	100
7	5	1	1	5	0.7	96	0.64	0.77	0	0	100
8	6	1	1	6	0.8	97	0.64	0.77	0	0	100
9	7	1	1	7	0.5	97	-0.87	0.5	0	0	100
10	8	1	1	8	0.6	97	-1.13	0.65	0	0	100
11	9	1	1	9	0.6	97	-1.47	0.85	0	9	100
12	10	1	1	10	0.7	97	1.73	-1	0	34	100
13	11	1	1	11	0.9	97	1.47	-0.85	0	58	100
14	12	1	1	12	1.1	97	1.13	-0.65	0	71	100

Figure 7.2 Organizing weather data
Slika 7.2 Organizacija vremenskih podatkov

After the weather data is organized, one can proceed by examining the solar radiation and cloudiness in order to find design days. There are several ways of doing that as well. The easiest one is again to use one of the simulation software and look at the results for the "*outdoor*". The aim is to find days in a period between April and August that has little or no cloudiness, uniformly distributed diffuse radiation and thus high and symmetric distribution of direct solar radiation. Since the goal is to have data on the 21st of the month in a period between April and August, a broader period might be used in order to have a sufficient amount of data for interpolation. For the location in Slovenia, the following days were chosen as design days:

- 26 April
- 17 May
- 31 May
- 30 June
- 21 July
- 27 July
- 14 August
- 30 September

The next step is mirroring the original days, as it was explained in section "6.2 Mirroring days". Since the location is different from before, it needs to be checked if the point of mirroring is the same. This is done in the same way as before. Table 7.1 shows day durations for the location in Ljubljana. The data was taken from (Thorsen, 1995).

Table 7.1 Day durations for Ljubljana
Preglednica 7.1 Dolžina dneva za Ljubljano

Date	Sunrise	Sunset	Duration
19 June	5:10 a.m.	8:56 p.m.	15:45:28
20 June	5:10 a.m.	8:56 p.m.	15:45:34
21 June	5:10 a.m.	8:56 p.m.	15:45:35
22 June	5:11 a.m.	8:56 p.m.	15:45:31
23 June	5:11 a.m.	8:56 p.m.	15:45:23

The point of mirroring is found to be the same as in Denmark, thus one can proceed with mirroring the original days over the 21st of June. This way, new days are formed and together they represent the new weather file.

Table 7.2 Days of the new weather data for Ljubljana
Preglednica 7.2 Dnevi nove vremenske datoteke za Ljubljano

Original design day	Mirrored day
26 April	16 August
17 May	26 July
31 May	12 July
30 June	12 June
21 July	22 May
27 July	16 May
14 August	28 April
30 September	12 March

Even though it has been shown that the mirroring method is accurate enough for this purpose, one might repeat the process of comparing the day duration of original and mirrored days in order to see the level of accuracy in the new location. The results are in Table 7.3.

Table 7.3 Comparison of day durations of original and mirrored days
Preglednica 7.3 Primerjava dolžine dneva originalnih in zrcaljenih dni

		Sunrise	Sunset	Duration	Difference
Original design day	26 Apr	5:56 a.m.	8:03 p.m.	14:06:49	
Mirrored day	16 Aug	6:02 a.m.	8:08 p.m.	14:06:15	00:00:34
Original design day	17 May	5:27 a.m.	8:29 p.m.	15:02:33	
Mirrored day	26 Jul	5:37 a.m.	8:38 p.m.	15:01:36	00:00:57
Original design day	31 May	5:15 a.m.	8:44 p.m.	15:29:24	
Mirrored day	12 Jul	5:23 a.m.	8:51 p.m.	15:28:36	00:00:48
Original design day	30 Jun	5:14 a.m.	8:56 p.m.	15:42:15	
Mirrored day	12 Jun	5:10 a.m.	8:53 p.m.	15:42:39	00:00:24
Original design day	21 Jul	5:31 a.m.	8:45 p.m.	15:12:25	
Mirrored day	22 May	5:22 a.m.	8:35 p.m.	15:13:21	00:00:56
Original design day	27 Jul	5:38 a.m.	8:37 p.m.	14:59:18	
Mirrored day	16 May	5:28 a.m.	8:28 p.m.	15:00:15	00:00:57
Original design day	14 Aug	6:00 a.m.	8:15 p.m.	14:12:02	
Mirrored day	28 Apr	5:53 a.m.	8:06 p.m.	14:12:40	00:00:38
Original design day	30 Sep	6:59 a.m.	6:43 p.m.	11:44:47	
Mirrored day	12 Mar	6:20 a.m.	6:03 p.m.	11:43:19	00:01:28

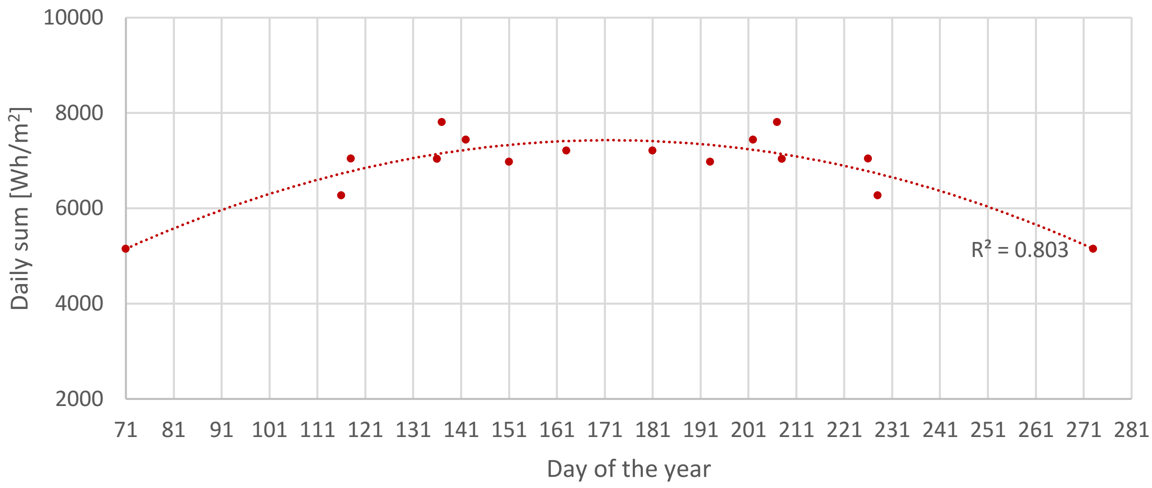
The difference between the original and mirrored days for Slovenia is smaller than for Denmark, which leads to a higher accuracy.

When the days of a new weather data are known, one can proceed by modifying the design days as explained in section "6.3 Modifying design days". In order to compare the daily sum of the direct component of solar radiation, the dates need to be written as numbers that correspond to the day of the year. Those numbers are shown in Table 7.4.

Table 7.4 Day of the year for Ljubljana
Preglednica 7.4 Dnevi v letu za Ljubljano

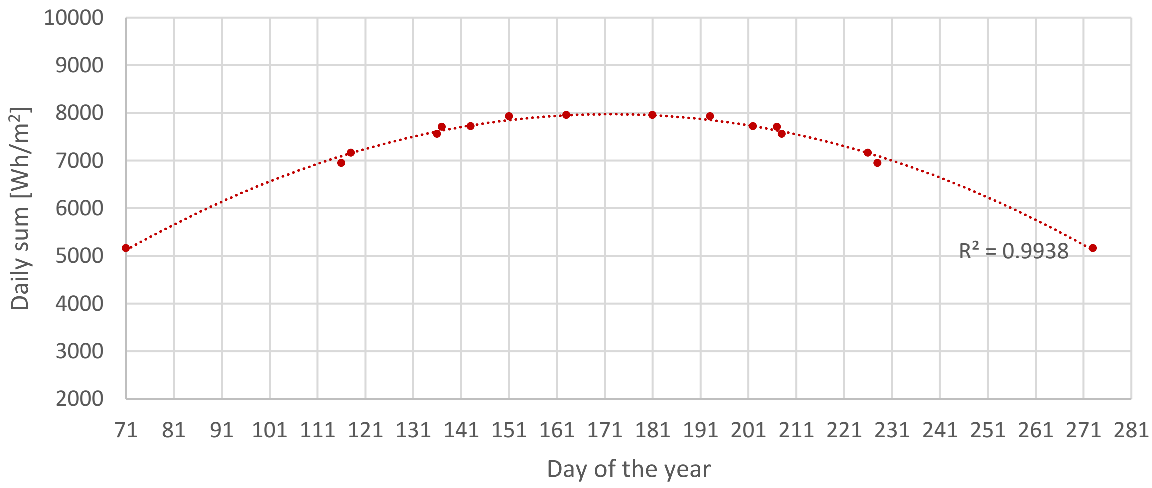
12 Mar	71	17 May	137	30 Jun	181	27 Jul	208
26 Apr	116	22 May	142	12 Jul	193	14 Aug	226
28 Apr	118	31 May	151	21 Jul	202	16 Aug	228
16 May	136	12 Jun	163	26 Jul	207	30 Sep	273

The graphs below show the daily sums of the direct component of the design days. The data is connected with a trend line that shows how scattered the data is. Graph 7.1 presents the non-modified data for Slovenia, before any modification is done. R-square is not close enough to number "1", but it is not very far either. This shows that the design days were chosen properly and they do not need a lot of modification.



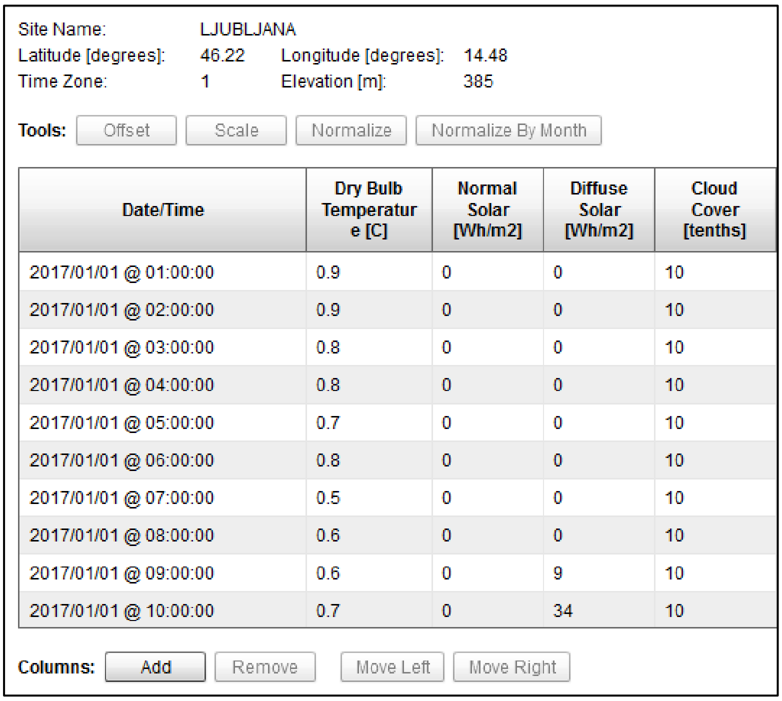
Graph 7.1 Daily sum in [Wh/m^2] of the original weather data for Slovenia
Grafikon 7.1 Vsota urnih vrednosti solarnega sevanja v [Wh/m^2] originalne vremenske datoteke za Slovenijo

The aim is to modify the data in a way that the R-square is as close to "1" as possible. Since mirrored days are using the data of the original day, only original days should be modified. The values are then copied to the mirrored days. It is important to remember that besides direct solar radiation, diffuse solar radiation and cloudiness should be modified as well. In Graph 7.2 the modified values are presented, where R-square is very close to "1".



Graph 7.2 Daily sum in [Wh/m^2] of the modified weather data for Slovenia
Grafikon 7.2 Vsota urnih vrednosti solarnega sevanja v [Wh/m^2] predelane vremenske datoteke za Slovenijo

Now the data for the new weather file is obtained. However, this data is now an Excel file, which is not compatible with simulation software. Therefore, the next step is to process this data in a way that it will be suitable for the chosen program. If BSim is going to be used, the weather data should be in a .dry file format. Again, there are many ways of how one can converse one file format into another. Hereafter, one of the possibilities is going to be presented. Software tool Elements (Big Ladder Software, 2016) as seen from Figure 7.3 can be used to change the values in the original weather data by simply copying and pasting the modified data into it. This can then be saved as an .epw file format. The conversion from .epw to .dry can later on be done in BSim.



Date/Time	Dry Bulb Temperature [C]	Normal Solar [Wh/m2]	Diffuse Solar [Wh/m2]	Cloud Cover [tenths]
2017/01/01 @ 01:00:00	0.9	0	0	10
2017/01/01 @ 02:00:00	0.9	0	0	10
2017/01/01 @ 03:00:00	0.8	0	0	10
2017/01/01 @ 04:00:00	0.8	0	0	10
2017/01/01 @ 05:00:00	0.7	0	0	10
2017/01/01 @ 06:00:00	0.8	0	0	10
2017/01/01 @ 07:00:00	0.5	0	0	10
2017/01/01 @ 08:00:00	0.6	0	0	10
2017/01/01 @ 09:00:00	0.6	0	9	10
2017/01/01 @ 10:00:00	0.7	0	34	10

Figure 7.3 Software Elements
Slika 7.3 Programska oprema Elements

The modified weather file is going to be used in a model from Figure 5.1. As described in chapter “5 SUN CURVES”, the model consists of four zones, where each has a reference window, oriented in a different direction. When setting window properties one must not forget to set Recess properly. The importance of these settings was described in subsection “5.6.2 Position of a window - Recess”. When the geometry of a model is ready, one can continue with the next step of a weather file conversion, which is from .epw to .dry. Once the tab *tsbi5* in BSim is open, one can click File – Weather Data – ASHRAE and the window from Figure 7.4 will appear. By clicking Select, one can select a weather file that was produced with software Elements and click Convert in order to convert it into a .dry file format.

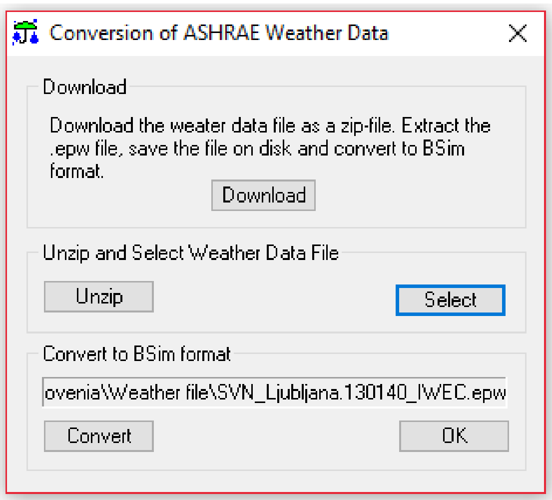
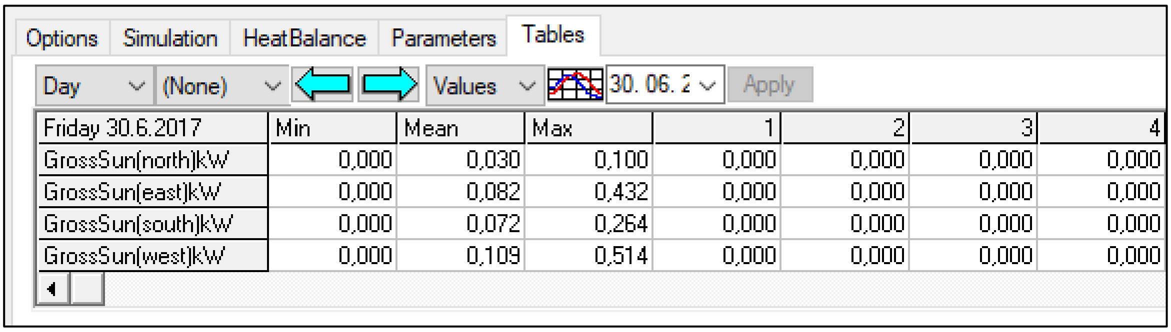


Figure 7.4 Conversion in BSim
Slika 7.4 Pretvorba v BSim

When the weather file is ready to use, one must remember to select 25% of ground reflection under *Site property*, turn on the XSun Distribution and select Munier's Solar model under *Simulation Options*. In order to optimise the simulation, one can manually select a simulation period. In this case, a period from 26 April to 30 September was chosen. Now everything is ready and the simulation can be run.

When the simulation is done, one can gather the results. This is done by clicking *Parameters* in the tab *tsbi5* where *GrossSun* for each zone needs to be selected. The results are then shown under *Tables* as seen from Figure 7.5. The hourly values of *GrossSun* for each zone are presented in a table. By clicking a graph icon, they can also be presented as a graph. Next to the graph icon, one can choose a day, which can also be done by clicking the arrows.



Friday 30.6.2017	Min	Mean	Max	1	2	3	4
GrossSun(north)kW	0,000	0,030	0,100	0,000	0,000	0,000	0,000
GrossSun(east)kW	0,000	0,082	0,432	0,000	0,000	0,000	0,000
GrossSun(south)kW	0,000	0,072	0,264	0,000	0,000	0,000	0,000
GrossSun(west)kW	0,000	0,109	0,514	0,000	0,000	0,000	0,000

Figure 7.5 Results in BSim
Slika 7.5 Rezultati v BSim

For further analysis, hourly values for all of the design days should be copied into Excel. These are now sun curves on the design days for the location in Slovenia.
In the case of Denmark, longitude 15° was used besides the original one, in order to obtain similar values in the east and the west zone. The longitude in the Slovenia's weather file is 14.48°. This is very close to longitude 15° at which the sun is exactly in the south, so the difference might not be that big. Therefore, to get better results, other longitudes should be used. It has been decided that ±2° from the original longitude are going to be used. The result is therefore a combination of four different longitudes: 12.5°, 14.48°, 15° and 16.5°.

The change of longitude can again be done with the software tool Elements (Big Ladder Software, 2016). However, this can only be done in an .epw file format. By clicking on *Header*, one can among other things change longitude value. After that, an .epw file needs to be again converted into a .dry file in order to be compatible with BSim. The procedure of simulating and gathering results can be repeated with the three new longitudes.

When the data from all four simulations is gathered in one place, one can start creating the final sun curves. Since there are four different solutions for each design day, corresponding to four different longitudes, the daily sums in the east and the west orientation need to be compared. The case that has the smallest difference between the daily sum in the east and the west orientation is going to be used for further analysis. Table 7.5 shows the difference between daily sum in the east and the west orientation for different longitudes on each design day. Grey areas mark longitudes with the smallest difference, which are also the longitudes that are going to be used.

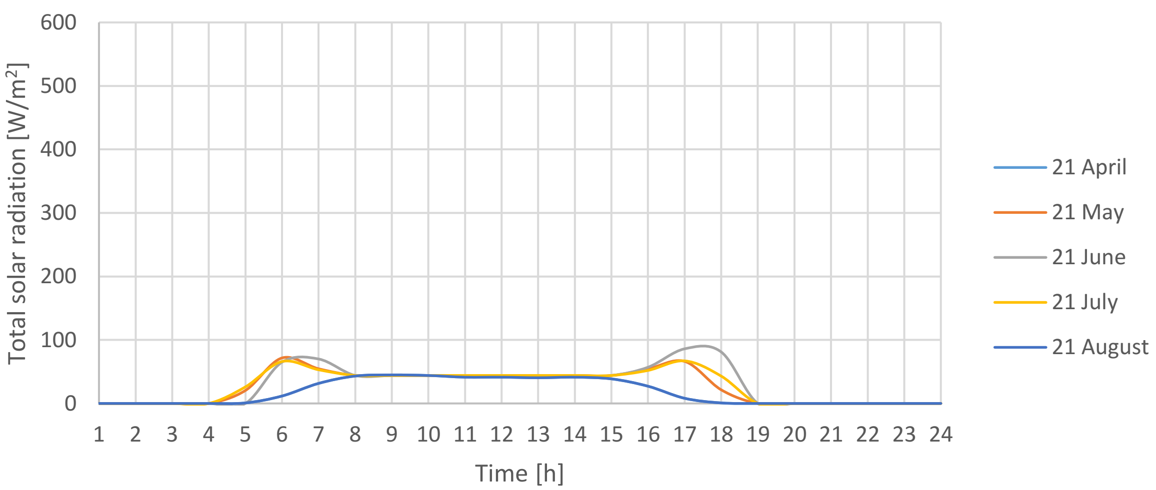
Table 7.5 The difference of daily sum [Wh/m²] between the east and the west orientation
Preglednica 7.5 Razlika vsote urnih vrednosti solarnega sevanja v [Wh/m²] med vzhodno in zahodno orientacijo

	Longitude			
	14.48°	**12.5°**	**15°**	**16.5°**
26 April	51	92	92	201
17 May	46	104	85	198
31 May	8	142	45	155
30 June	485	312	523	634
21 July	45	209	8	104
27 July	107	268	69	42
14 August	5	169	43	158
30 September	19	105	50	157

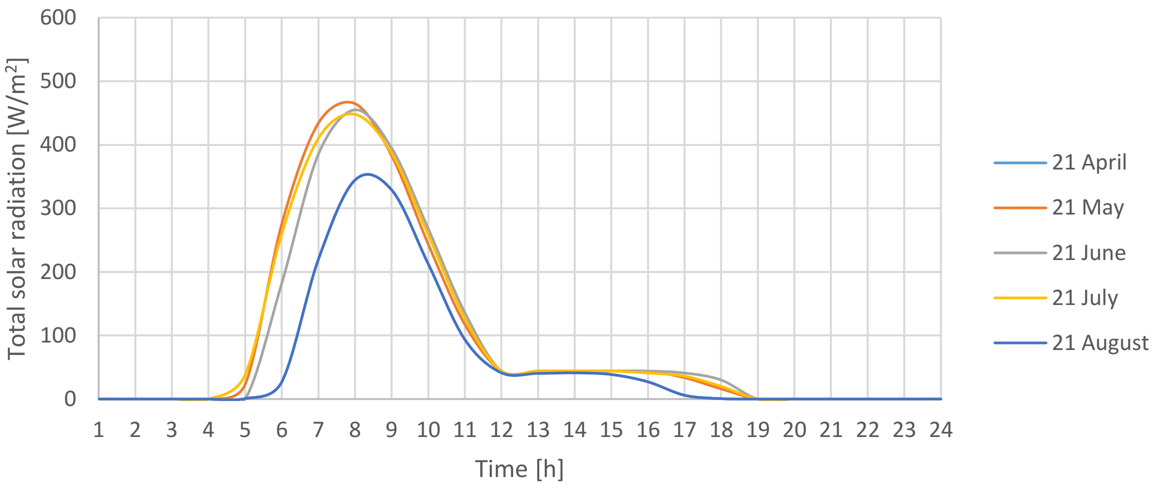
Now, for each original design day, values from one longitude were chosen and they represent the values with the smallest difference of the daily sum in the east and the west orientation. The data from those days apply to their mirrored days as well. At this point, all of the values for original and mirrored days should be organised by orientation in the same way as it was shown in Table 6.10 for the Denmark case.

After such organisation of values, one can proceed with linear interpolation in order to calculate the values for the 21st of the month. The procedure of interpolation was explained in section "6.5 Linear interpolation". By using equation (9) one can obtain values for the 21st of the month.

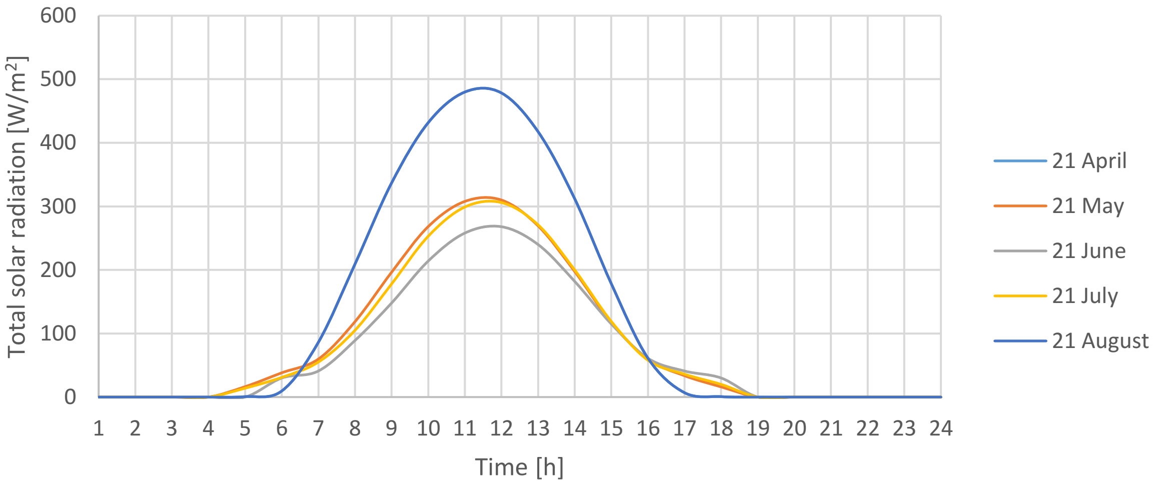
Sun curves need to be modified in a way that they fit into the TCD program, which means that time needs to be corrected. After this is done, the final sun curves for a chosen location are obtained. The results are shown in Graph 7.3, Graph 7.4, Graph 7.5 and Graph 7.6. The exact values can be found in appendixes.



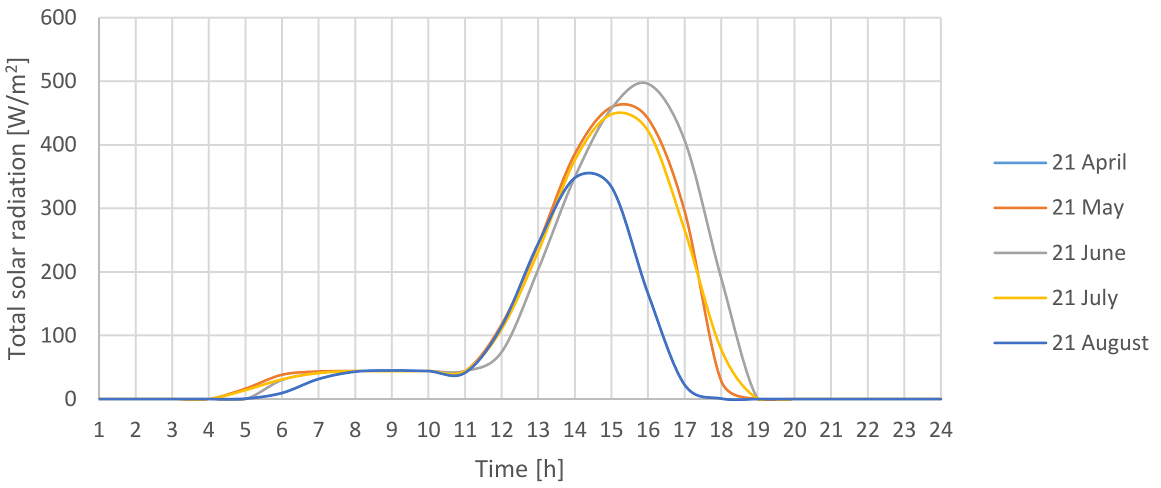
Graph 7.3 Obtained sun curves with BSim in [W/m²] for the north orientation through a reference window on the 21st of the month for the location in Slovenia
Grafikon 7.3 Pridobljene sončne krivulje z BSim v [W/m²] skozi referenčno okno za severno orientacijo na 21. dan v mesecu za Slovenijo



Graph 7.4 Obtained sun curves with BSim in [W/m^2] for the east orientation through a reference window on the 21st of the month for the location in Slovenia
Grafikon 7.4 Pridobljene sončne krivulje z BSim v [W/m^2] skozi referenčno okno za vzhodno orientacijo na 21. dan v mesecu za Slovenijo

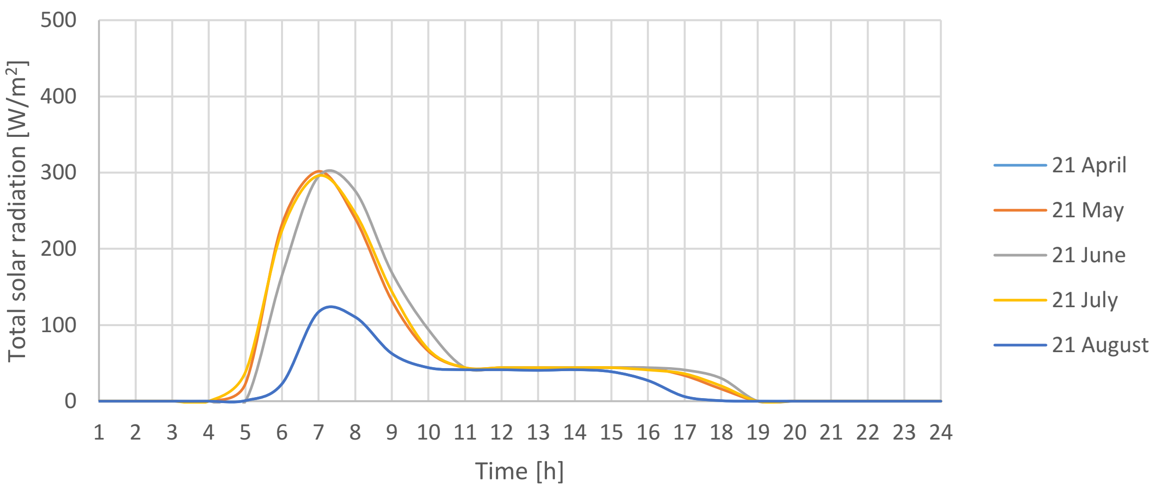


Graph 7.5 Obtained sun curves with BSim in [W/m^2] for the south orientation through a reference window on the 21st of the month for the location in Slovenia
Grafikon 7.5 Pridobljene sončne krivulje z BSim v [W/m^2] skozi referenčno okno za južno orientacijo na 21. dan v mesecu za Slovenijo

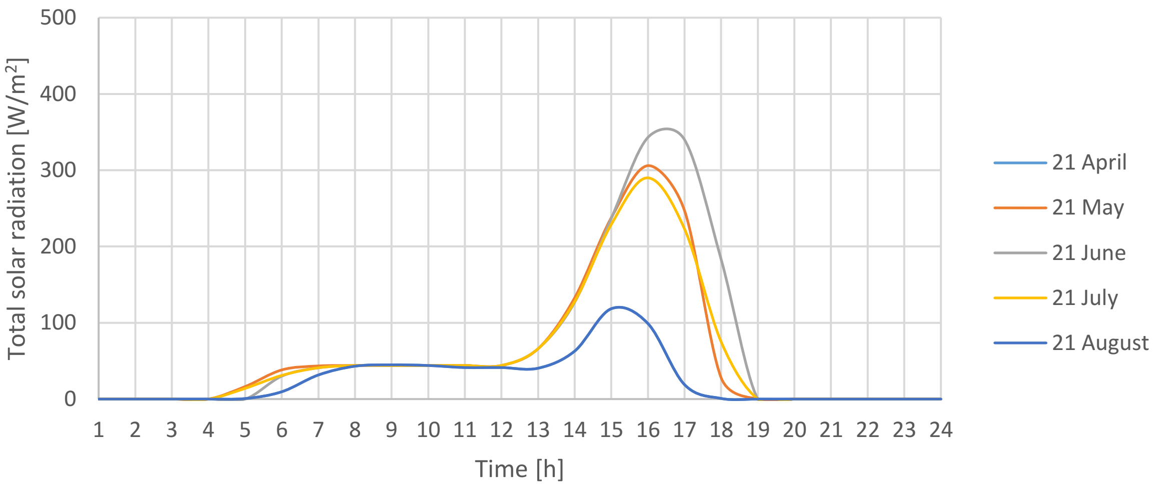


Graph 7.6 Obtained sun curves with BSim in [W/m^2] for the west orientation through a reference window on the 21st of the month for the location in Slovenia
Grafikon 7.6 Pridobljene sončne krivulje z BSim v [W/m^2] skozi referenčno okno za zahodno orientacijo na 21. dan v mesecu za Slovenijo

Following the same procedure as earlier, other four orientations can be analysed as well. BSim model needs to be rotated for 45° and after the simulations are done, the values for *GrossSun* can be copied into Excel. The comparison of the daily sum for different longitudes should be done in a way as explained in section "6.8 Other orientations". The obtained results are shown in Graph 7.7, Graph 7.8, Graph 7.9 and Graph 7.10. The exact values can be found in appendixes.

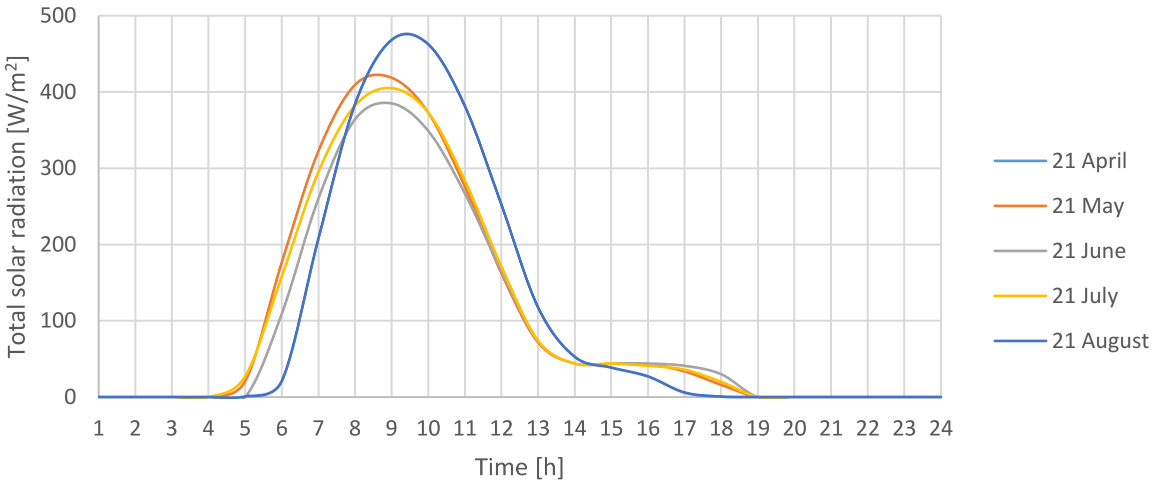


Graph 7.7 Obtained sun curves with BSim in [W/m^2] for the north-east orientation through a reference window on the 21st of the month for the location in Slovenia
Grafikon 7.7 Pridobljene sončne krivulje z BSim v [W/m^2] skozi referenčno okno za severovzhodno orientacijo na 21. dan v mesecu za Slovenijo



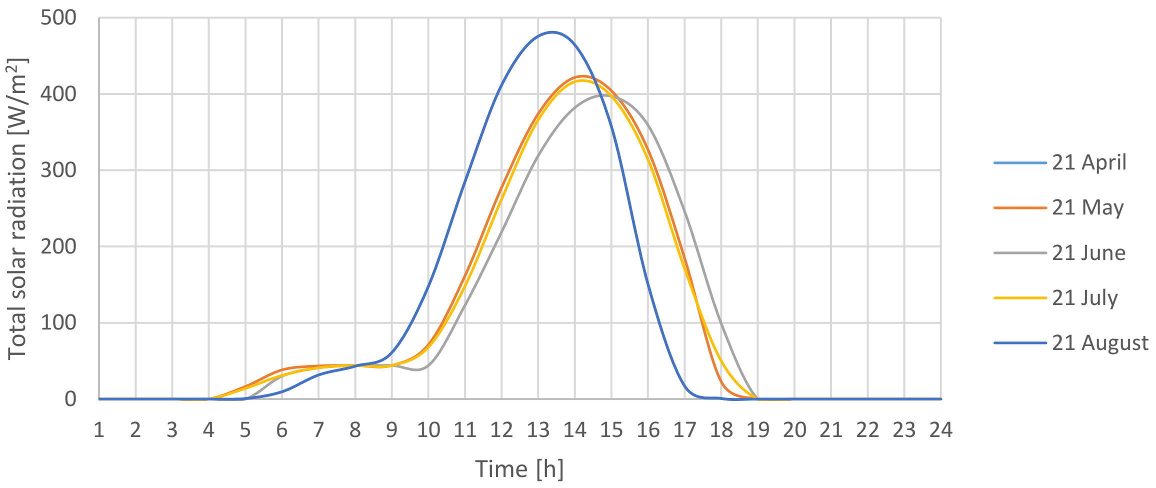
Graph 7.8 Obtained sun curves with BSim in [W/m²] for the north-west orientation through a reference window on the 21st of the month for the location in Slovenia

Grafikon 7.8 Pridobljene sončne krivulje z BSim v [W/m²] skozi referenčno okno za severozahodno orientacijo na 21. dan v mesecu za Slovenijo



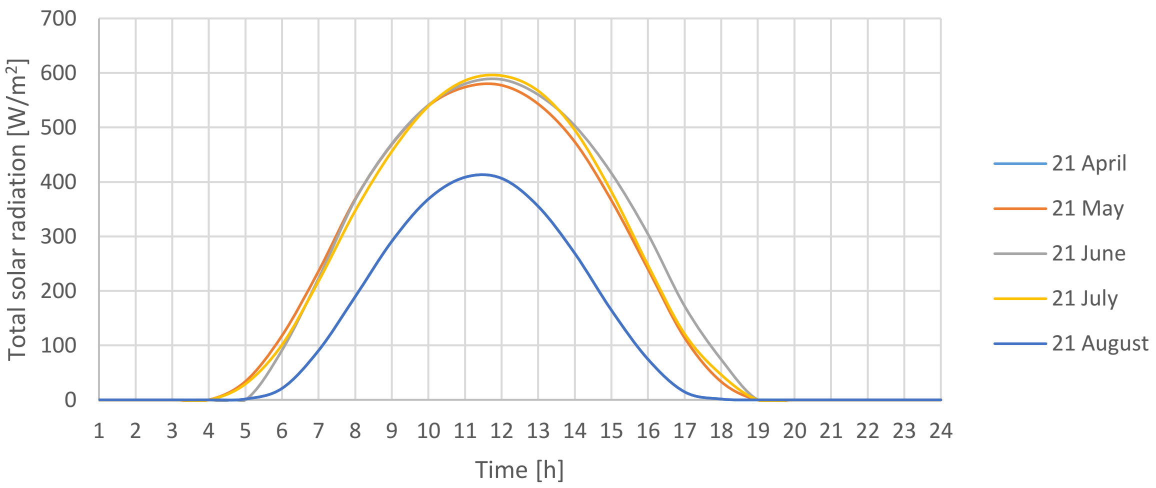
Graph 7.9 Obtained sun curves with BSim in [W/m²] for the south-east orientation through a reference window on the 21st of the month for the location in Slovenia

Grafikon 7.9 Pridobljene sončne krivulje z BSim v [W/m²] skozi referenčno okno za jugovzhodno orientacijo na 21. dan v mesecu za Slovenijo



Graph 7.10 Obtained sun curves with BSim in [W/m^2] for the south-west orientation through a reference window on the 21st of the month for the location in Slovenia
Grafikon 7.10 Pridobljene sončne krivulje z BSim v [W/m^2] skozi referenčno okno za jugozahodno orientacijo na 21. dan v mesecu za Slovenijo

In order to obtain the values for a horizontal window, a different BSim model needs to be used as explained in section "6.9 Sun curves for a horizontal window". The same procedure is used and the result is presented in Graph 7.11. The values can be found in appendixes.



Graph 7.11 Obtained sun curves with BSim in [W/m^2] for a horizontal reference window on the 21st of the month for the location in Slovenia
Grafikon 7.11 Pridobljene sončne krivulje z BSim v [W/m^2] skozi horizontalno referenčno okno na 21. dan v mesecu za Slovenijo

8 STEP-BY-STEP PROCEDURE

Previous chapters contain detailed information on each step of the procedure for obtaining the sun curves. The following table serves as a short sum up of the procedure and it can be used as a guide or an overview.

Table 8.1 Step-by-step procedure
Preglednica 8.1 Postopek po korakih

1st step:	Obtaining a weather file, importing the data into Excel.
2nd step:	Organizing weather data by hour, day and month.
3rd step:	Searching for design days
4th step:	Choosing the point of mirroring, mirroring days, comparing day duration.
5th step:	Comparing the daily sum of direct solar radiation and modifying the data to fit the trend line.
6th step:	Making a weather file in an .epw file format.
7th step:	Building a model in BSim.
8th step:	Converting the weather file from .epw to .dry.
9th step:	Select ground reflection, turn on XSun Distribution, select solar model.
10th step:	Run the simulation.
11th step:	Select GrossSun for each zone and copy the results into Excel.
12th step:	Obtain new weather files with different longitudes.
13th step:	Compare the daily sum in the east and the west orientation, choose the one with the smallest difference.
14th step:	Organising values by orientation.
15th step:	Linear interpolation.
16th step:	Time modification.
17th step:	Sun curves for the chosen location.
18th step:	Rotate the BSim model for 45° in order to obtain values for north-east, south-east, south-west and north-west.
19th step:	Repeat the 10th to the 16th step (in the 13th step, north-east and north-west as well as south-east and south-west need to be compared).
20th step:	Modify the BSim model (one zone with a roof window) in order to obtain the values for a horizontal window.
21st step:	Run the simulation with the original longitude.
22nd step:	Repeat the 11th step, move to the 14th step, and continue to the 17th step.

9 TESTING THE NEW SUN CURVES

Now that all the sun curves are obtained, they need to be tested with a more advanced tool. Investigation of new curves' accuracy was done by comparing the results from the TCD with the results from simulations in BSim. Such comparison has already been done in the previous project (Boesgaard, 2017), but with already existing sun curves. However, new sun curves were obtained during this project and are to be tested in the same manner.

The TCD with new sun curves was used to design ventilation with night cooling for a meeting room. It was modelled in a way to maintain 23°C as a daily mean temperature in the TCD. Air change that was used in the TCD in [h^{-1}] was transformed into [m^3/s] in order to be used in BSim. The results from both programs were then compared.

9.1 Choosing design days

In the TCD, only the date is important when choosing a design day, since the program does not distinguish between weekdays, weekends or holidays. Days differ from each other only by outdoor temperature and solar radiation. Therefore, 21 June and 15 August were chosen as design days in the TCD for both locations. 21 of June can be considered as a critical day in the east and the west orientation due to the longest span of solar radiation. 15 August has been chosen because it is the end of the summer period and as such, it can be considered as a critical day for the south orientation.

In BSim, more parameters need to be considered when choosing the design day. Since simulations in BSim are done with the original weather file, days with almost no cloud cover and high solar radiation need to be chosen in order to be comparable with the TCD results. The procedure of choosing such days has already been done when the new weather file was composed. Besides that, it is also important to choose the right day of the week. The design day needs to be one of the last three days of the weekday, because ventilation systems are not running during the weekends and Monday and Tuesday are therefore affected by the room temperature of the weekend.

In order to fulfil all the criteria, 11 June, 1 July and 6 August 2015 were chosen for the location in Denmark. Those days are Thursday, Wednesday and Thursday respectively. For the location in Slovenia, 30 June, 27 July and 16 August 2017 were chosen. Those days are Friday, Thursday and Wednesday respectively.

All of the chosen days are shown in Table 9.1.

Table 9.1 Design days
Preglednica 9.1 Tipični načrtovalski dnevi

Design days in TCD	Design days in BSim DK	Design days in BSim SLO
21 June	11 June 2015	30 June 2017
15 August	1 July 2015	27 July 2017
	6 August 2015	16 August 2017

9.2 Model of a meeting room

The main interest of this comparison is to compare daily mean temperature between BSim and different versions of the TCD – with existing and new sun curves. Therefore, only a short sum up of model parameters is presented in this report. Further explanations and parameter details can be found in another report (Boesgaard, 2017), which used the same model for analysis.

Simulations were done for a meeting room, which is located in the first floor of a three-storey building. This means that there is only one wall, which is facing the outside. Room dimensions are 4.8 m x 4.8 m x 2.7 m. The model can be seen in Figure 9.1.

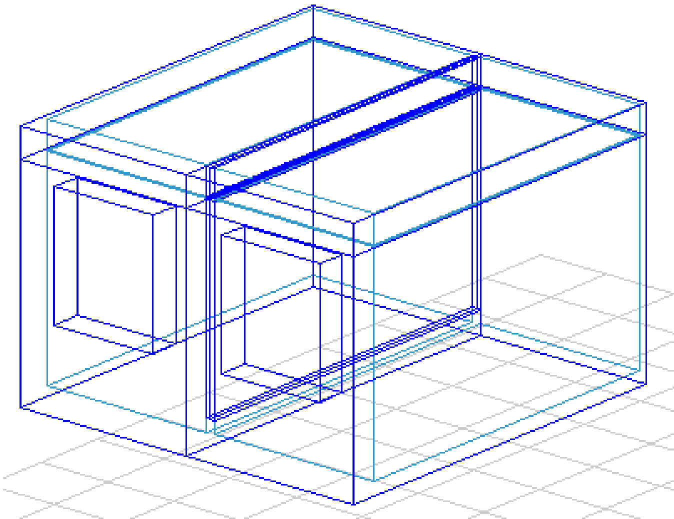


Figure 9.1 Model of a meeting room in BSim
Slika 9.1 Model sejne sobe v BSim

Hereafter, the structure of walls and floor is presented:

- Outer wall: 70 mm concrete, 190 mm insulation, 150 mm concrete
- Inner wall: 13 mm gyps. wall-board, 12 mm wood pine lath, 70 mm min. wool, 12 mm wood pine lath, 13 mm gyps. wall-board
- Floor structure: 20 mm parquet, 320 mm concrete (BETONHULDÆK), 400 mm cavity, 20 mm mineral wool

The outer wall has a U-value of 0.2 W/m^{2}K.

The meeting room has two windows. The size of the windows corresponds to 22% of the floor area. The dimensions of the window are 1.49 m x 1.7 m with the glazing area of 2.106 m^2 and the frame area of 0.427 m^2. Glazing properties are:

- Light transmittance (LT): 0.78
- Solar transmittance (g-value): 0.6
- Thermal transmittance (U-value): 1.2 W/m^{2}K

Thermal transmittance (U-value) of a frame is 1.8 W/m^{2}K and of a whole window is 1.4 W/m^{2}K. Windows have solar shading with shading coefficient (a value between 0 and 1) of 0.2, where a low figure is an expression of an effective shading. Shading schedule is different for different orientations. Besides controlled shading, the meeting room has a VAV (Variable Air Volume) ventilation system and mechanical night cooling, explained in Table 9.2.

Internal gains of the room include occupants, lightning and equipment (PC and TV), scheduled to be present every weekday from 8 a.m. to 5 p.m.

9.3 Simulations for Denmark

As it has already been mentioned, simulations were done by using the same model as it has been used in the previous project, made by (Boesgaard, 2017) (later referred as the "previous project"). Those results were used as a reference and compared with the results, obtained with the new sun curves for Denmark.

Hereafter, parameters for simulation are explained:

Design days	In the previous project, 1 July and 6 August were used as design days in BSim and 21 June and 15 August were used as design days in the TCD. For a better comparison, the same days were chosen in this project as well and one extra day was added, as seen from Table 9.1.
BSim	Previous project used Petersen's solar model, ground reflection of 20% and recess was set to 0.001. In order to maintain the same procedure as it has been used before in this project, new settings were set in BSim. The solar model was changed into Munier's solar model, ground reflection was set to 25% and recess was put to 0.0001.
TCD	The previous project used the original version of the TCD, meaning that solar radiation was calculated based on sun curves from Danvak's 3rd edition. The goal of this test was to compare those results with newly obtained sun curves with a modified version of the TCD.
Orientation	The previous project compared only the south and the west orientation, because Danvak's sun curves have the same value for the east and the west orientation. The west orientation was chosen since it is considered as the worst orientation regarding the overheating potential. In the west, the sun will enter the zone in the afternoon, after the room has already been occupied and exposed to internal heat gains for the whole day. In this project, the east orientation is tested as well.

For better transparency, symbols were used to mark the results:

*****	Petersen's solar model, ground reflection is 20%, recess is 0.001
******	Munier's solar model, ground reflection is 25%, recess is 0.0001
+	Original (Danvak's) sun curves
++	Modified (newly obtained) sun curves

The procedure for obtaining results followed these steps:

- The results from BSim from the previous project were not changed or modified in any way. They are marked with (*).
- The same model in BSim was modified by changing the solar model, ground reflection and recess. None of the other settings was changed. Results are marked with (**).
- Results from the TCD from the previous project were not changed or modified in any way. They are marked with (+).
- The same model in the TCD was modified by changing the original sun curves with the new sun curves. None of the other settings was changed. Results are marked with (++).

In Table 9.2 the settings for different orientations are shown.

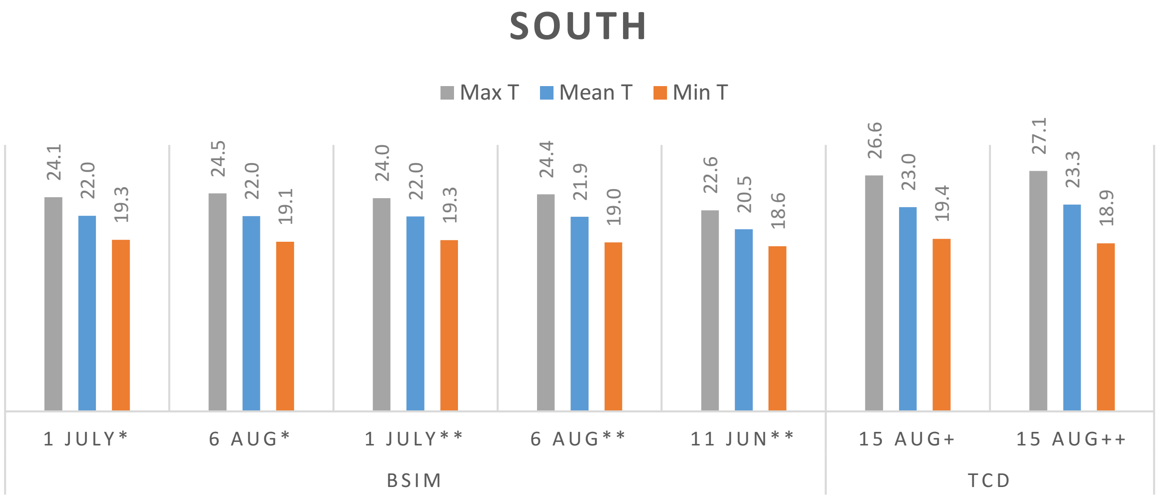
Table 9.2 Settings for different orientations for Denmark
Preglednica 9.2 Nastavitve za različne orientacije za Dansko

	South	West	East
Glazing area	4.2 m^2	4.2 m^2	4.2 m^2
g-value	0.6	0.6	0.6
TCD date	15 August	21 June	21 June
Ventilation			
– Air change TCD	6 h^{-1}	5.55 h^{-1}	5.6 h^{-1}
– Air change BSim	0.104 m^3/s	0.096 m^3/s	0.097 m^3/s
– Night cooling:			
• Inlet air temperature	15.8°C	15.8°C	15.8°C
• Duration	8 h (10 p.m. – 6 a.m.)	8 h (10 p.m. – 6 a.m.)	8 h (10 p.m. – 6 a.m.)
– Cooling			
• Inlet air temperature	16.5°C	16.5°C	16.5°C
• Duration	11 h (8 a.m. – 7 p.m.)	11 h (8 a.m. – 7 p.m.)	11 h (8 a.m. – 7 p.m.)
Shading schedule	10 a.m. – 2 p.m.	2 p.m. – 8 p.m.	5 a.m. – 1 p.m.
Outdoor temperature, entered in TCD	Min T = 14°C, Mean T = 20°C, Max T = 26°C		

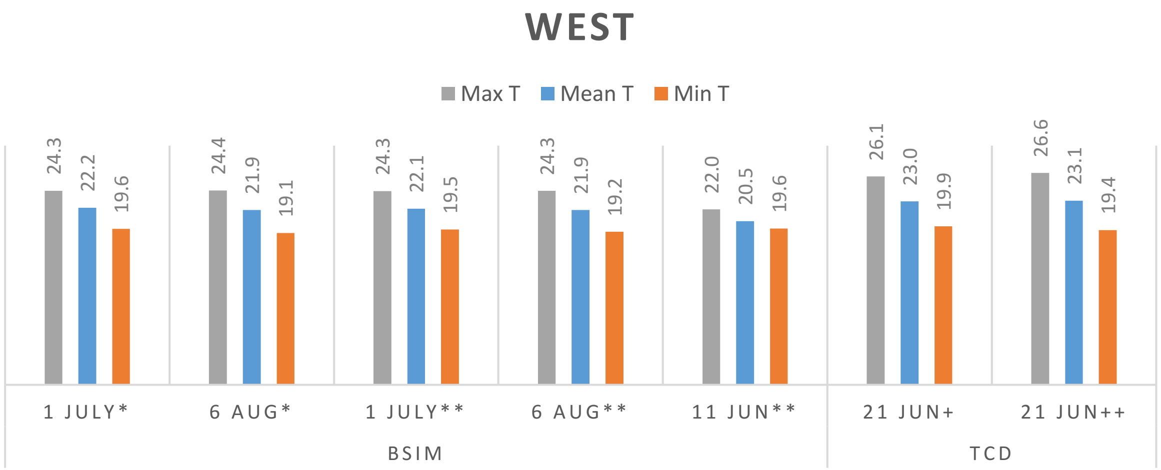
9.4 Results for Denmark

Graph 9.1, Graph 9.2 and Graph 9.3 show results for maximum, mean and minimum temperature for different orientations. All values are in [°C].

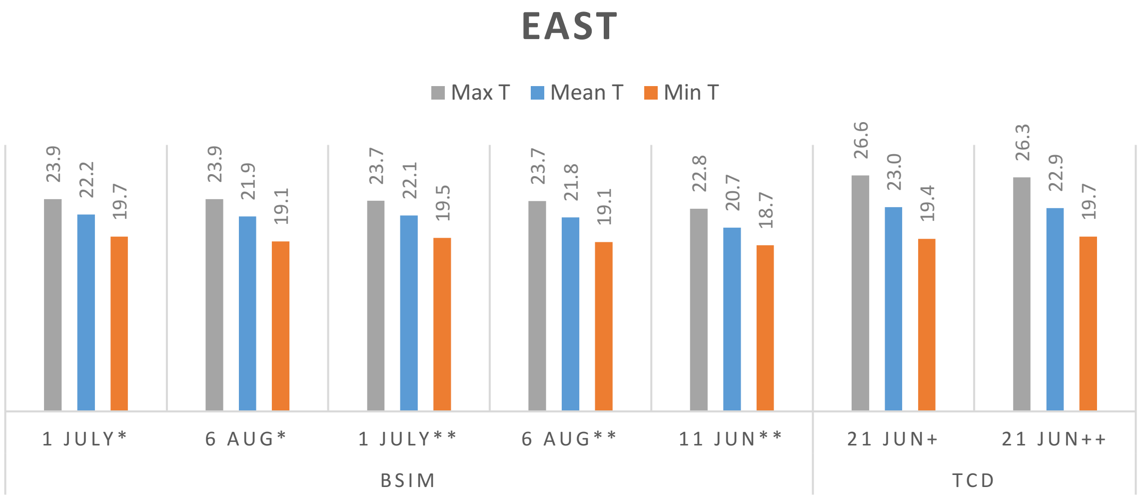
For each day, all three temperatures are shown. The first two days in the graph, marked with (*) show the results from the previous project. Next three days in the graph, marked with (**) show the results from this project, where solar model, ground reflection and recess were changed. All of those days represent the results from BSim. The last two days in the graphs represent results from the TCD. The one, marked with (+) is with the original sun curves and the one with (++) is with the modified sun curves, obtained in this project.



Graph 9.1 Comparison of max, mean and min temperature, found in BSim and the TCD on design days with different settings (* represents the previous project, ** represents this project, + represents original sun curves, ++ represents modified sun curves) for the south orientation in Denmark
Grafikon 9.1 Primerjava maks, povprečne in min temperature, pridobljene v BSim in TCD na tipične načrtovalske dni z različnimi nastavitvami (predstavlja predhodni projekt, ** predstavlja pričujoči projekt, + predstavlja originalne sončne krivulje, ++ predstavlja predelane sončne krivulje) za južno orientacijo na Danskem*



Graph 9.2 Comparison of max, mean and min temperature, found in BSim and the TCD on design days with different settings (* represents the previous project, ** represents this project, + represents original sun curves, ++ represents modified sun curves) for the west orientation in Denmark
Grafikon 9.2 Primerjava maks, povprečne in min temperature, pridobljene v BSim in TCD na tipične načrtovalske dni z različnimi nastavitvami (predstavlja predhodni projekt, ** predstavlja pričujoči projekt, + predstavlja originalne sončne krivulje, ++ predstavlja predelane sončne krivulje) za zahodno orientacijo na Danskem*



Graph 9.3 Comparison of max, mean and min temperature, found in BSim and the TCD on design days with different settings (* represents the previous project, ** represents this project, + represents original sun curves, ++ represents modified sun curves) for the east orientation in Denmark
Grafikon 9.3 Primerjava maks, povprečne in min temperature, pridobljene v BSim in TCD na tipične načrtovalske dni z različnimi nastavitvami (predstavlja predhodni projekt, ** predstavlja pričujoči projekt, + predstavlja originalne sončne krivulje, ++ predstavlja predelane sončne krivulje) za vzhodno orientacijo na Danskem*

Several conclusions can be drawn from the obtained graphs. First thing one can notice is that the amplitude between min and max temperatures from the TCD is larger than in BSim.

Secondly, the difference in the results, obtained with different settings in BSim, is found to be very small. When comparing the values of 1 July and 6 August with (*) and (**), which correspond to different solar model, ground reflection and recces, the largest difference is found on both days in the east orientation for max T, where 0.2°C difference can be found.

The difference between the TCD values, marked with (+) and (++) is slightly bigger. 0.5°C difference is found in min and max values in the south and the west orientation, while the biggest difference in mean T is 0.3°C in the south orientation.

However, the most important comparison is the comparison between values, obtained with BSim and the TCD. The absolute difference between the values, obtained with BSim and the TCD, is shown in the following tables. Table 9.3 represents the difference between the values from BSim from the previous project and the values from the TCD with the original sun curves. In short, this is a comparison between (*) and (+). The values have quite a good match, with the biggest difference of 2.7°C.

Table 9.3 Difference in [°C] between the values from BSim from the previous project (*) and the values from the TCD with the original sun curves (+)
Preglednica 9.3 Razlike v [°C] med vrednostmi iz BSim predhodnega projekta (*) in vrednostmi iz TCD z originalnimi krivuljami (+)

	South		**West**		**East**	
	1 July	**6 Aug**	**1 July**	**6 Aug**	**1 July**	**6 Aug**
Mean ΔT	1.0	1.0	0.8	1.1	0.8	1.1
Min T	0.1	0.3	0.3	0.8	0.2	0.3
Max T	2.4	2.0	1.8	1.8	2.7	2.7

Table 9.4 represents the difference between the values from BSim from this project, where different solar model, ground reflection and recess is used and the values from the TCD with the new sun curves. In this case, one extra day is added in June. It can be observed that values have a rather good match, except on 11 June. The biggest difference there is 4.6°C. The reason for this is that 11 June is one of the mirrored days. This means that in reality this day does not necessarily have low cloud cover and high solar radiation as a design day should have for the comparison with the TCD. By looking into the weather file in order to check that, one can see that 11 June does not have the required solar distribution and has low temperatures. The mean outdoor temperature on this day is 11.5°C, which is really low. This explains why values from BSim are lower than the ones, obtained with the TCD, where a clear day is assumed. If 11 June is not taken into account, the biggest difference between the TCD and the BSim values is 3.1°C.

This example shows the mistake one can make if the TCD is used without any consideration. In reality, days with low cloud cover are rare, which means that the TCD will have a good match on only few days of the year. Rest of the days can have a difference of almost 5°C, as seen in this case. However, the purpose of the TCD programme is to give an estimation and not an exact result.

Table 9.4 Difference in [°C] between the values from BSim from this project (**) and the values from the TCD with the modified sun curves (++)
Preglednica 9.4 Razlike v [°C] med vrednostmi iz BSim pričujočega projekta (**) in vrednostmi iz TCD s predelanimi krivuljami (++)

	South			**West**			**East**		
	11 June	**1 July**	**6 Aug**	**11 June**	**1 July**	**6 Aug**	**11 June**	**1 July**	**6 Aug**
Mean ΔT	2.8	1.4	1.4	2.6	1.0	1.2	2.2	0.8	1.1
Min T	0.3	0.4	0.1	0.2	0.1	0.2	1.0	0.1	0.6
Max T	4.4	3.1	2.6	4.6	2.3	2.3	3.5	2.6	2.7

In general, the results from BSim have quite a good match with the results from the TCD with the newly obtained sun curves, especially if mean temperatures are compared. However, in this case the window was only 22% of the floor area. In order to see if this method is suitable also for bigger windows, which are usually the critical ones, additional analysis were done. Windows in the model were replaced with bigger ones, with 27% and 51% of the floor area. With the inner floor area of 23.04 m^2, window properties for different sizes are as shown in Table 9.5.

Table 9.5 Window properties
Preglednica 9.5 Lastnosti okna

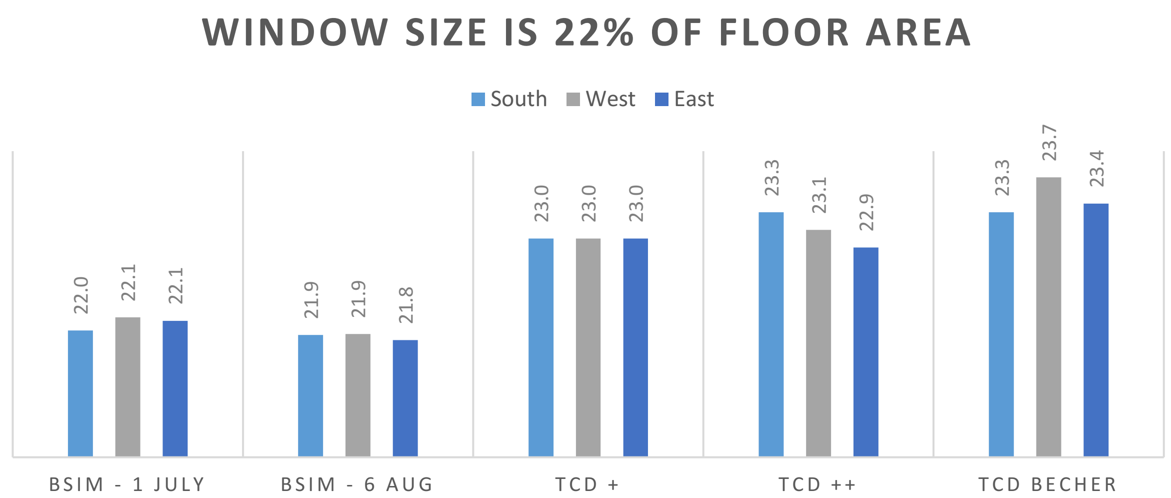
	22% of floor area	**27% of floor area**	**51% of floor area**
Windows area [m^2]	5.0	6.2	11.8
One window area [m^2]	2.5	3.1	5.9
One glazing area [m^2]	2.1	2.6	5.2
Glazing area of both windows [m^2]	4.2	5.2	10.4

A this point, it should be mentioned that if these results are compared to the results from the previous project (Boesgaard, 2017), there will not be a complete match. In the previous project, the largest window has slightly different size properties and it therefore cannot be directly compared with the results from this project. However, the simulations from the previous project were redone with a window size from Table 9.5 and the results are gathered in appendixes.

The comparison includes the results from BSim where Munier's solar model was used with 25% of ground reflection and the values from three different types of the TCD. First one, marked with (+) is the original one, with the sun curves from Danvak. The one with (++) has sun curves, that were obtained in this project. To enhance the comparison, another TCD was used, namely with Becher's sun curves. These sun curves are more than 40 years old and were once in use. The following graphs therefore present how sun curves have improved with years by showing how new sun curves (+ and ++) have a better match with the values from BSim than Becher's sun curves.

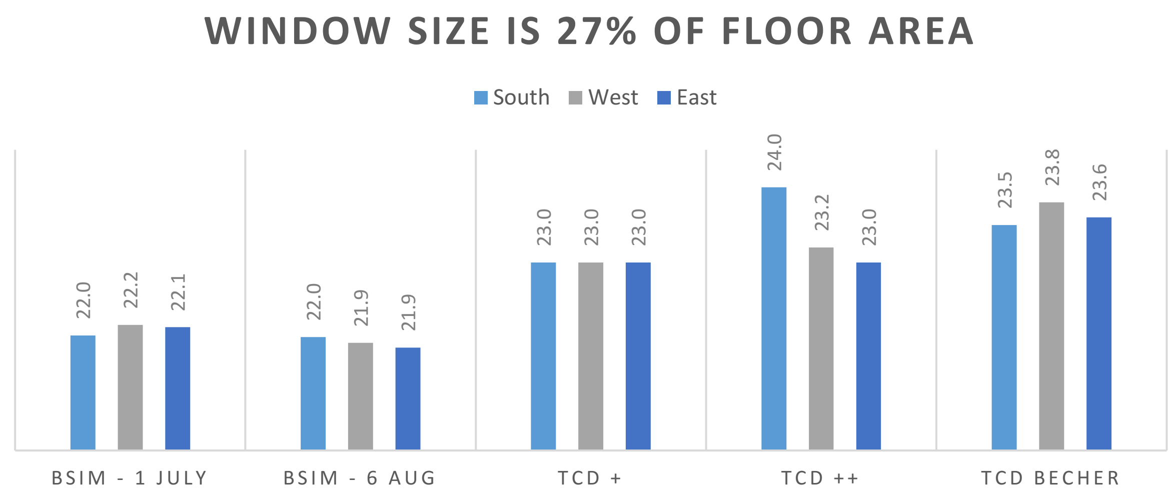
It is important to keep in mind that in these simulations, ventilation and shadings are used, which are reducing the impact of solar gain in the room. Hence, the difference between different sun curves is not as obvious as it was in the previous comparison such as in Graph 5.14.

In Graph 9.4, Graph 9.5 and Graph 9.6, three different sizes of window are shown. The columns represent mean temperatures for three different orientations. All values are in [°C].



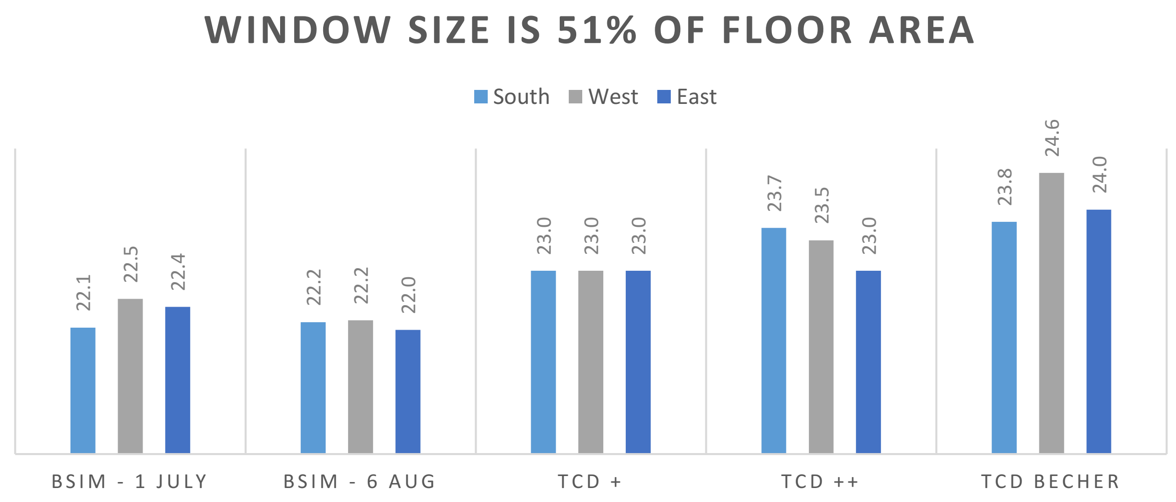
Graph 9.4 Comparison of mean temperatures [°C] for a window with 22% of floor area. The values are from BSim, TCD with Danvak's sun curves, TCD with new sun curves, and TCD with Becher's sun curves.

Grafikon 9.4 Primerjava povprečnih temperatur [°C] za okno z 22% tlorisne površine. Vrednosti so iz BSim, TCD z Danvakovimi krivuljami, TCD z novimi krivuljami in TCD z Becherjevimi krivuljami



Graph 9.5 Comparison of mean temperatures [°C] for a window with 27% of floor area. The values are from BSim, TCD with Danvak's sun curves, TCD with new sun curves and TCD with Becher's sun curves.

Grafikon 9.5 Primerjava povprečnih temperatur [°C] za okno s 27% tlorisne površine. Vrednosti so iz BSim, TCD z Danvakovimi krivuljami, TCD z novimi krivuljami in TCD z Becherjevimi krivuljami



Graph 9.6 Comparison of mean temperatures [°C] for a window with 51% of floor area. The values are from BSim, TCD with Danvak's sun curves, TCD with new sun curves and TCD with Becher's sun curves.

Grafikon 9.6 Primerjava povprečnih temperatur [°C] za okno z 51% tlorisne površine. Vrednosti so iz BSim, TCD z Danvakovimi krivuljami, TCD z novimi krivuljami in TCD z Becherjevimi krivuljami

It can be seen that the largest difference can be found in the south orientations. In the case with a window size of 27% of floor area, the biggest discrepancy from the original TCD results can be observed, with a difference of 1°C. On the other hand, the differences in the west orientations are increasing with the increasing window size, while the east orientation has a perfect match with the original TCD results in window size of 27% and 51% of floor area. In all cases, the south has the highest mean temperatures and the east has the lowest mean temperatures.

Therefore, it can be concluded, that the method works better with east- and west-oriented windows, however, the results are still satisfying when south-oriented windows are installed.

9.5 Simulations for Slovenia

For the case of Slovenia, no previous results were available for comparison. Therefore, this comparison was done by comparing the results from the TCD with sun curves, obtained in this project, and the results from BSim with the Slovenian weather file and only one type of settings.

Design days	As mentioned before, design days for the location in Slovenia in BSim are 30 June, 27 July and 16 August 2017, and 21 June and 15 August in TCD.
BSim	Settings in BSim for the location in Slovenia correspond to the settings, used through the whole project. The solar model is Munier's, ground reflection is set to 25% and recess is put to 0.0001.
TCD	For the location in Slovenia, there are only sun curves that were obtained in this project.
Orientation	Simulations were done for the orientation of south, west and east.

The procedure for obtaining the results followed these steps:

- The same model in BSim was used as in (**) case for Denmark, whereas the weather file was changed into the Slovenian one.
- The same model in the TCD was used and modified by changing the original sun curves with the new sun curves for Slovenia. None of the other settings was changed.

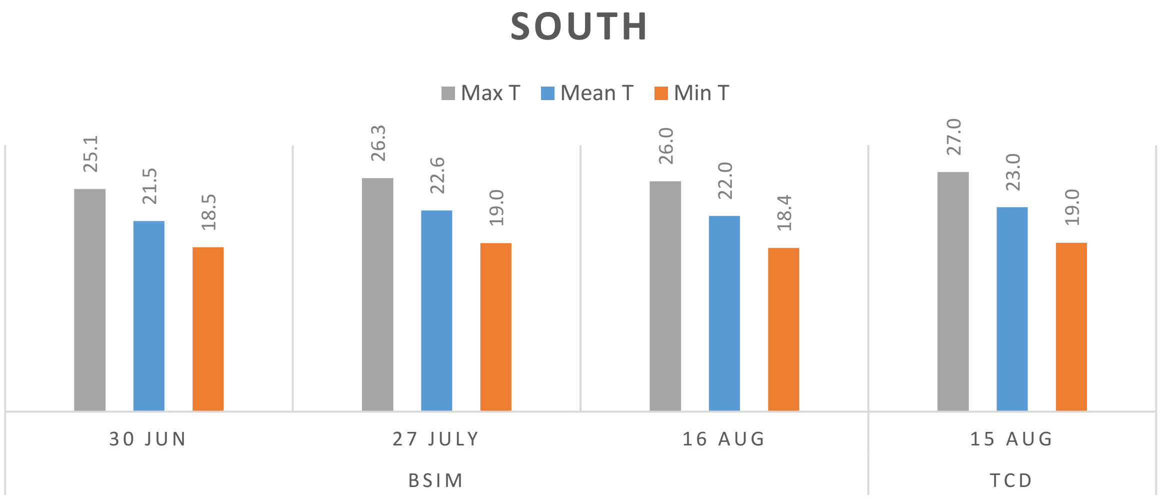
In Table 9.6, the settings for different orientations are shown. The only difference in settings, compared to Denmark case, was the air change. This was modified in a way to maintain the 23°C as a mean daily temperature.

Table 9.6 Settings for different orientations for Slovenia
Preglednica 9.6 Nastavitve za različne orientacije za Slovenijo

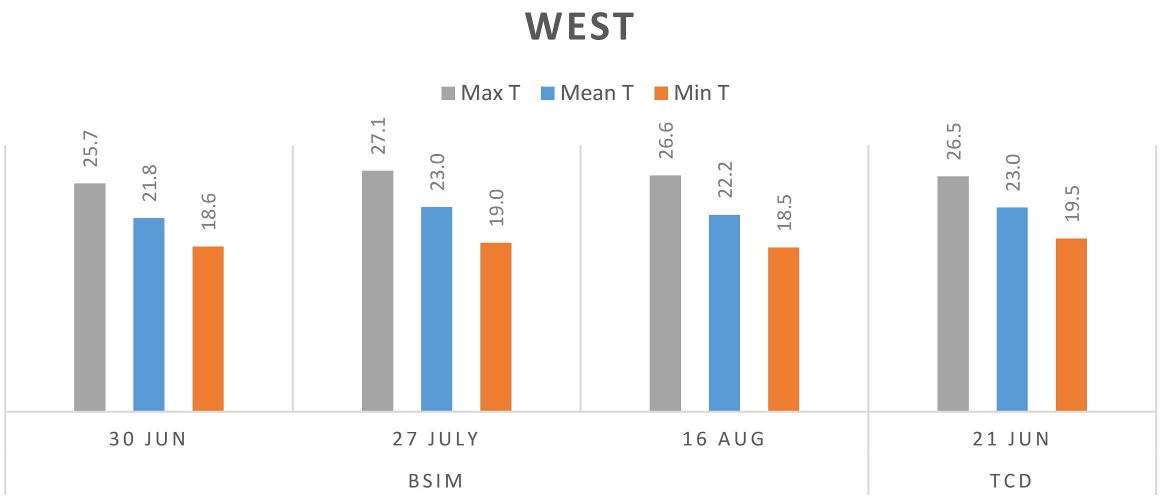
	South	West	East
Glazing area	4.2 m^2	4.2 m^2	4.2 m^2
g-value	0.6	0.6	0.6
TCD date	15 August	21 June	21 June
Ventilation			
– Air change TCD	5.9 h^{-1}	5.5 h^{-1}	5.1 h^{-1}
– Air change BSim	0.102 m^3/s	0.095 m^3/s	0.088 m^3/s
– Night cooling:			
• Inlet air temperature	15.8°C	15.8°C	15.8°C
• Duration	8 h (10 p.m. – 6 a.m.)	8 h (10 p.m. – 6 a.m.)	8 h (10 p.m. – 6 a.m.)
– Cooling			
• Inlet air temperature	16.5°C	16.5°C	16.5°C
• Duration	11 h (8 a.m. – 7 p.m.)	11 h (8 a.m. – 7 p.m.)	11 h (8 a.m. – 7 p.m.)
Shading schedule	10a.m. – 2 p.m.	2 p.m. – 8 p.m.	5 a.m. – 1 p.m.
Outdoor temperature, entered in TCD	Min T = 20°C, Mean T = 25°C, Max T = 30°C		

9.6 Results for Slovenia

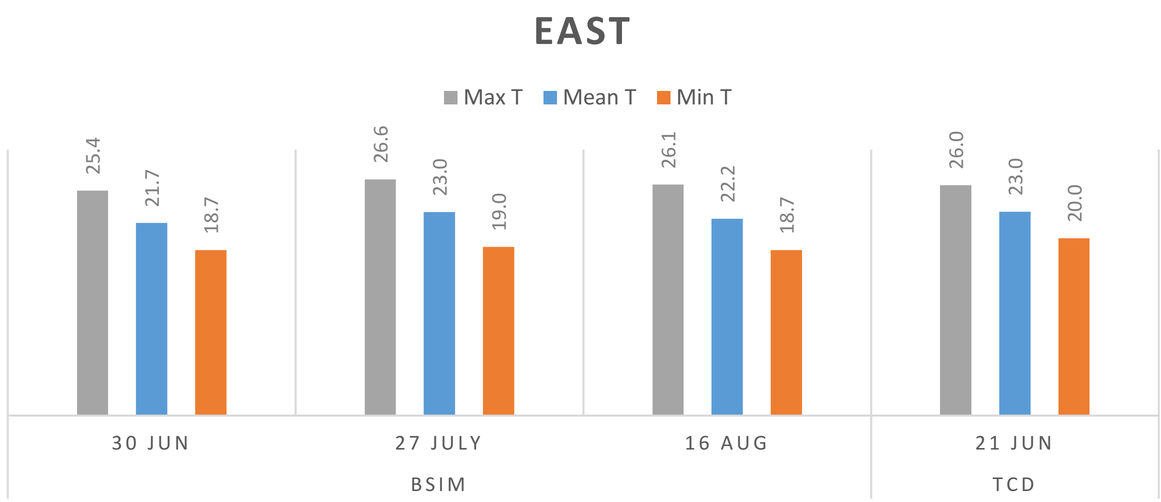
Graph 9.7, Graph 9.8 and Graph 9.9 show the results for maximum, mean and minimum temperature for different orientations, obtained with BSim and the TCD. BSim is using the weather file for Slovenia and the TCD has sun curves, obtained in this project for the location in Slovenia. All values are in [°C].



Graph 9.7 Comparison of max, mean and min temperature, found in BSim and the TCD on design days for the south orientation in Slovenia
Grafikon 9.7 Primerjava maks, povprečne in min temperature, pridobljene v BSim in TCD na tipične načrtovalske dni za južno orientacijo v Sloveniji



Graph 9.8 Comparison of max, mean and min temperature, found in BSim and the TCD on design days for the west orientation in Slovenia
Grafikon 9.8 Primerjava maks, povprečne in min temperature, pridobljene v BSim in TCD na tipične načrtovalske dni za zahodno orientacijo v Sloveniji



Graph 9.9 Comparison of max, mean and min temperature, found in BSim and the TCD on design days for the east orientation in Slovenia

Grafikon 9.9 Primerjava maks, povprečne in min temperature, pridobljene v BSim in TCD na tipične načrtovalske dni za vzhodno orientacijo v Sloveniji

From the obtained graphs it can be concluded that values, obtained with the TCD, have a good match with the values, obtained with BSim. Compared to results for Denmark, the amplitude between min and max temperature are very similar in the BSim and the TCD case for Slovenia.

In general, mean temperatures from BSim are lower or the same as mean temperature, obtained with the TCD. The best match can be found for 27 July, where the differences between the TCD and BSim are very small. This can be explained by looking into outdoor temperatures for all of the days: for June, July and August, the mean outdoor temperature is 22.3°C, 24.8°C and 21.5°C respectively. The mean outdoor temperature in the TCD is set to 25°C, which is the same as real outdoor temperature in July. It can be concluded that if a different mean outdoor temperature is chosen in the TCD for other days, a better match can be found in there as well.

Table 9.7 represents the absolute difference between the values, obtain with BSim and the TCD. The biggest difference is found in June in the south orientation, when BSim value is 1.9°C lower than the TCD value.

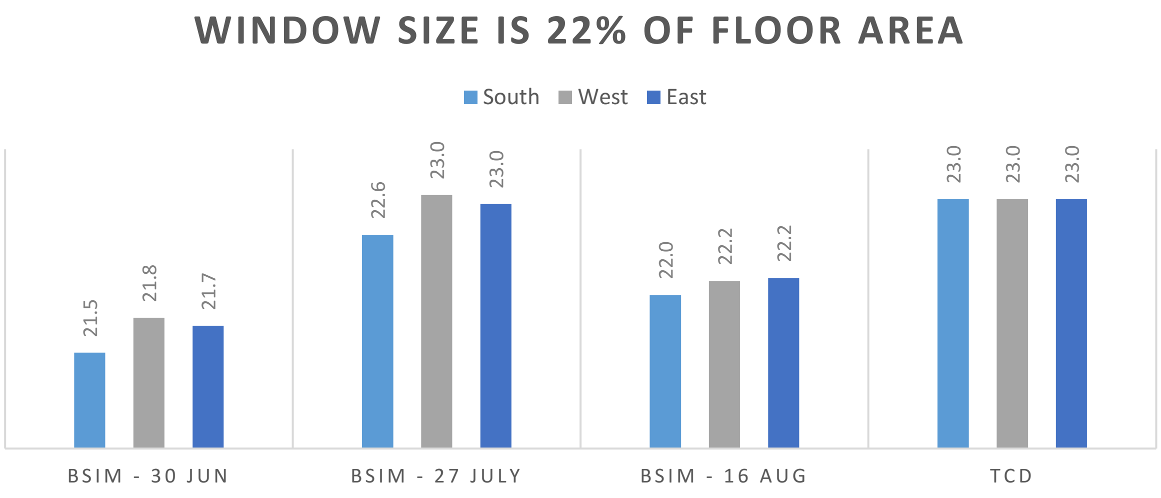
Table 9.7 Difference in [°C] between the values from BSim and the values from TCD

Preglednica 9.7 Razlike v [°C] med vrednostmi iz BSim in vrednostmi iz TCD

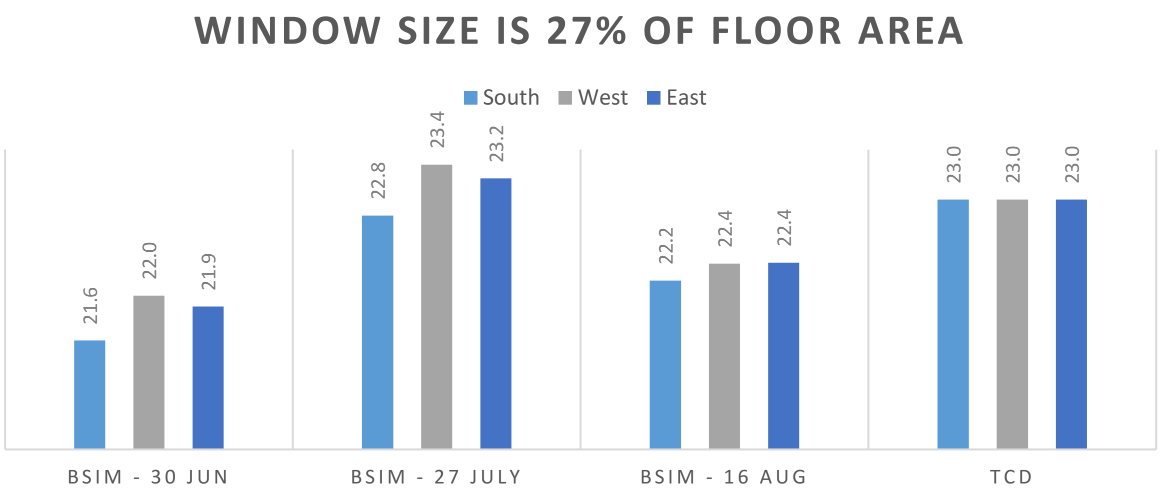
	South			West			East		
	30 Jun	**27 Jul**	**16 Aug**	**30 Jun**	**27 Jul**	**16 Aug**	**30 Jun**	**27 Jul**	**16 Aug**
Mean T	1.5	0.4	1.0	1.2	0.0	0.8	1.3	0.1	0.8
Min T	0.5	0.0	0.6	0.9	0.5	1.0	1.3	1.0	1.3
Max T	1.9	0.7	1.0	0.8	0.6	0.1	0.6	0.6	0.1

The same comparison as in the case of Denmark was done for Slovenia, when bigger windows were analysed. In Graph 9.10, Graph 9.11 and Graph 9.12, the mean temperatures in [°C] are shown for three different orientations. The compared values are from BSim with the Slovenian weather file and from the TCD with the sun curves, obtained in this project.

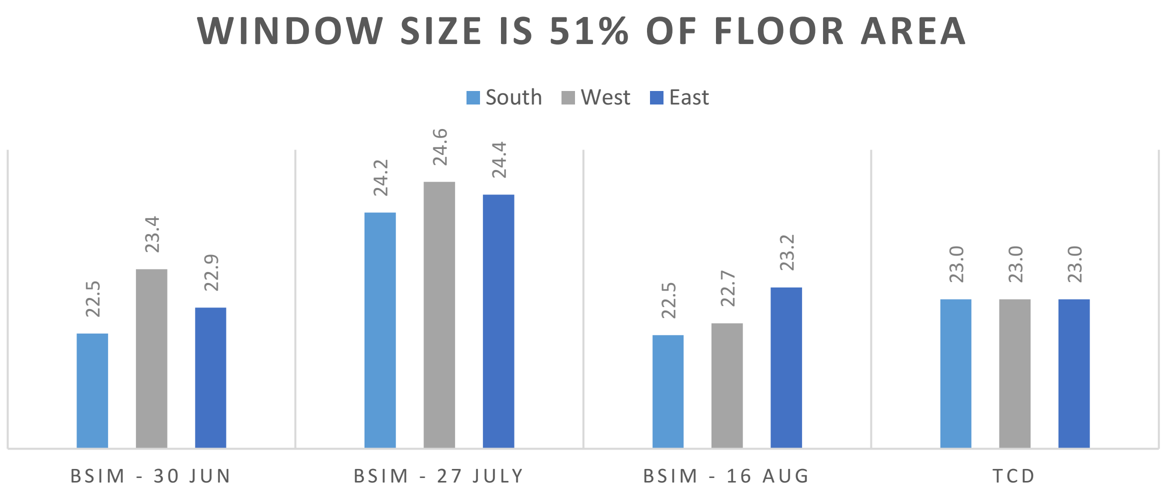
When looking into graphs, it is important to keep in mind that the three chosen days differ from each other in the outdoor temperature. In July, the outdoor temperatures are the highest. Shown values are in [°C].



Graph 9.10 Comparison of mean temperatures [°C] for a window with 22% of floor area. The values are from BSim and the TCD for the location in Slovenia.
Grafikon 9.10 Primerjava povprečnih temperature [°C] za okno z 22% tlorisne površine. Vrednosti so iz BSim in TCD za lokacijo v Sloveniji



Graph 9.11 Comparison of mean temperatures [°C] for a window with 27% of floor area. The values are from BSim and the TCD for the location in Slovenia.
Grafikon 9.11 Primerjava povprečnih temperature [°C] za okno s 27% tlorisne površine. Vrednosti so iz BSim in TCD za lokacijo v Sloveniji



Graph 9.12 Comparison of mean temperatures [°C] for a window with 22% of floor area. The values are from BSim and the TCD for the location in Slovenia.
Grafikon 9.12 Primerjava povprečnih temperature [°C] za okno z 51% tlorisne površine. Vrednosti so iz BSim in TCD za lokacijo v Sloveniji

From obtained results, it can be seen that in the case of Slovenia, the TCD values are not always higher than BSim values as it is in the case of Denmark. In the smallest and in the middle-sized window, the best match can be observed for the day in July, while June and August have lower mean temperatures than the ones, obtained with the TCD. The opposite can be observed in the case with the biggest window, where the values in July exceed the values from the TCD, while the values for June and August show quite a good match.

9.7 Conclusion on testing the new sun curves

This chapter served as a confirmation that sun curves, obtained in this project, can serve in the same manner as the ones, found in the literature.

It was expected, however, that the new sun curves for Denmark would give higher accuracy and a better match with BSim values than the original ones. Mostly because they were obtained from a weather file. The discrepancies that were found in the process of obtaining sun curves, when comparing Danvak's sun curves and the ones, obtained with BSim, were at that point interpreted as a possibility that the new sun curves will show results that are more accurate. It turned out that this was not the case. The results, obtained with the new sun curves are, however, closer to Danvak's sun curves than to Becher's sun curves. It was shown earlier that Becher provided sun curves with higher values and, therefore, the simulation results with those sun curves give high values as well.

In the case of Slovenia, it was observed, that the TCD gives results with good match, when outdoor temperature is chosen correctly. However, in the case with the biggest windows, a correct outdoor temperature does not provide a good match, since values from BSim exceeded the TCD values.

Nevertheless, the procedure for obtaining sun curves was developed and in this chapter, it was confirmed that it gives satisfying results.

10 CONCLUSION

The TCD is a simplified tool for an early stage design, which means, that many things are based on assumptions and simplifications. It should not be considered as a tool for final and exact answers, but as a practical tool that provides quick answers.

This study focused on solar gains, which are as sun curves implemented in the TCD program. The existing sun curves for Denmark were taken from literature, which has no explanation on how these curves were obtained.

The first task was to investigate Danish sun curves and find a procedure to obtain them from a broadly accessible weather file. It was shown that total solar radiation, described in Danvak's book, is composed from direct, diffused and reflected component with ground reflection of 25%. A solar model, which appeared to be the most suitable, was Munier's solar model. At this point it was also mentioned that incorrect modelling, such as wrong window positioning, can influence results to a large extent. For further confirmation, sun curves from other literature were compared as well. It turned out that the ones, which are now in use and are the base for this study, give the most accurate results.

The investigation of the sun curves from Danvak's literature served as a foundation for developing a method on how to form a new weather file that can be used for obtaining new sun curves. Each step, from choosing design days, testing the mirroring method, linear interpolation etc. is thoroughly explained. At the evaluation of new sun curves it was concluded, that values should not be modified in a way that east and west share the same value. Therefore, small discrepancies can be found in those two orientations. One further step was done at this point, by obtaining values for the horizontal window as well.

The next thing was to use the developed method to obtain sun curves for a new location, since this was one of the purposes of the study. Following the same procedure, sun curves for a location in Slovenia were composed. In addition, the procedure for obtaining the sun curves was summed up in a step-by-step form, which can serve as a guidance for future work.

Lastly, multiple tests were carried out to confirm that the developed method could be used to form sun curves for any chosen location. It was concluded that when the obtained sun curves are used in the TCD, the results have a good match with the results from a more advanced simulation tool. Therefore, the method works well and it can be used to expand the scope of the TCD program.

The newly obtained sun curves for Denmark are in values similar to Danvak's. However, the main contrast between them is that Danvak's procedure remains unknown while this study provides a detailed explanation on how to obtain sun curves for any chosen location.

11 POVZETEK V SLOVENSKEM JEZIKU

Uvod

Simulacije energijske učinkovitosti igrajo pomembno vlogo pri načrtovanju novih ali že obstoječih energijsko učinkovitih objektov. Večinoma se za izvedbo simulacij uporabljajo kompleksni programi, kot so IDA ICE, BSim in drugi. Pri tem je za zanesljive rezultate potrebno poznati veliko podrobnosti in parametrov stavbe, kar posledično pomeni, da izdelava modela zahteva veliko časa. Pomembno je tudi, da se uporabijo primerni podnebni podatki za izbrano lokacijo stavbe, kot na primer letna vremenska datoteka, ki je dostopna na spletu (EnergyPlus, 1996).

V splošnem se s programsko opremo za simulacijo energijske učinkovitosti stavb analizira njihov toplotni odziv. Različna orodja pri vnosu podatkov zahtevajo različne stopnje podrobnosti, pri čemer višja stopnja prinaša natančnejše rezultate. Zaradi tega se lahko zgodi, da pri analizi izbranega modela z uporabo različnih orodji, dobimo različne rezultate. Ameriško združenje inženirjev za ogrevanje, hlajenje in klimatske naprave (angl. *America society of heating, refrigerating and air-conditioning engineers*, kratica ASHRAE) je razvilo standardizirani test, ki prepozna in odkrije predvidljive razlike v rezultatih simulacijskih programskih orodij, ki so lahko posledica različnih algoritmov, omejitev pri modeliranju, razlike pri vnosu podatkov ali napake v programiranju. To nam pove, da so rezultati simulacijskih programov vedno zgolj približki in ne natančne vrednosti.

Pri izdelavi modela v simulacijskem programu se lahko pojavijo določene ovire. V začetni fazi načrtovanja, na primer, podatki še niso dovolj zanesljivi za izdelavo natančnega modela. V tej fazi se tudi načrti lahko še bistveno spreminjajo, kar pripelje do potrebe po izdelavi več različnih variant modela.

Iz povedanega lahko zaključimo, da v začetni fazi načrtovanja hitrih in zanesljivih odgovorov s pomočjo simulacijskih orodij ni mogoče dobiti. S tem problemom so se soočili že na Oddelku za gradbeništvo na Danski tehnični univerzi, kjer so leta 2009 začeli z razvojem računalniškega programa, ki temelji na Excel programski opremi. Program TCD (angl. *Thermal Calculator by Design*) je kalkulator za analizo notranjega okolja, ki kot rezultat poda povprečno dnevno ravnovesno temperaturo v coni za katerikoli dan v letu. Za ta izračun je v program potrebno vnesti podatke o orientiranosti objekta, lastnosti oken in senčil, ovoju stavbe, infiltraciji, notranjih dobitkih, prezračevanju in povprečni zunanji temperaturi za izbrani dan. Prednost takšnega kalkulatorja je majhno število potrebnih vhodnih podatkov in posledično hiter izračun. S spreminjanjem parametrov se lahko spremlja vpliv, ki ga le-ti imajo na povprečno dnevno ravnovesno notranjo temperaturo. Program je uporaben za podajanje hitrih ocen v zgodnji fazi načrtovanja, predno se za natančnejše odgovore izdela model v enem izmed bolj sofisticiranih simulacijskih programov. Program TCD je torej namenjen pridobivanju hitrih odgovorov in predhodnih ocen.

Opis problema

Dokazano je bilo, da je program TCD primeren za pridobivanje predhodnih ocen, vendar je uporaben le za lokacijo na Danskem. Integrirani podatki o solarnih dobitkih so namreč pridobljeni iz literature, ki vsebuje sončne krivulje za lokacije na Danskem in jih posledično ni mogoče uporabiti za katerokoli drugo državo. To narekuje, da je za splošno uporabo programa potrebno tega izboljšati tako, da ga bo moč uporabiti tudi za izračune na katerikoli drugi lokaciji.

Cilj pričujoče naloge je preučiti obstoječe sončne krivulje iz literature in razviti priročnik za pridobivanje le-teh, neodvisno od literature. Vrednosti, ki so trenutno v uporabi, bodo služile kot referenca in vodilo. Namen te študije je poiskati način za modifikacijo in posledično izboljšavo programa TCD tako, da bo uporaben za izračun predhodnih ocen za katerokoli izbrano lokacijo.

Računanje v TCD

Program TCD je orodje za pridobivanje hitrih ocen povprečne dnevne temperature v obravnavanem prostoru. Njegov namen je pridobivanje praktičnih informacij v zgodnji fazi načrtovanja, ko večina parametrov še ni poznanih. Pomembno se je zavedati, da program poda zgolj oceno in se ga ne sme uporabljati kot natančno načrtovalsko orodje ali ga primerjati z naprednimi simulacijskimi programi.

Uporabnik v za to pripravljeni Excel razpredelnici vpiše vrednosti v polja, obarvana z rumeno. Zelena polja predstavljajo delne izračune, oranžna pa vsebujejo seznam možnosti, ki jih ima uporabnik na voljo. Modra polja prikazujejo končne rezultate, v roza poljih pa se nahajajo dodatna pojasnila glede uporabe programa. Za izračun je potrebno vnesti podatke o datumu, zasteklitvi, prenosu toplote, infiltraciji, notranjih toplotnih dobitkih, prezračevanju in zunanji povprečni temperaturi. Na podlagi tega program izračuna povprečno dnevno temperaturo cone.

Solarni dobitki

V sklopu sončnega sevanja je pomembno razlikovati med tremi pojmi: direktno sončno sevanje, difuzno sončno sevanje in odbito sončno sevanje. Solarni dobitki so za razliko od drugih toplotnih dobitkov odvisni od lokacije. Ena izmed oblik zapisa količine sončnega sevanja, ki vsako uro prodre skozi vertikalno referenčno okno na jasen dan, so sončne krivulje. Takšna oblika zapisa je uporabljena v programu TCD. Podatki so pridobljeni iz literature (Danvak, 2006) in so vključeni v program. To pomeni, da običajne vremenske datoteke niso potrebne za delovanje programa TCD. V omenjeni literaturi se kot referenčno okno uporablja okno s faktorjem prepustnosti sončnega sevanja (g-faktor) 0,76 in prepustnostjo za vidni del sončnega sevanja (LT) 0,80.

Sončne krivulje

Uporaba programa TCD je zaradi sončnih krivulj omejena na eno lokacijo. Ker ni zagotovila, da za vsako lokacijo obstaja literatura, ki bi vsebovala sončne krivulje, bi bilo smotrno poiskati način, kako lahko, neodvisno od literature, uporabnik sam pridobi sončne krivulje.

Ideja, kako pristopiti k temu problemu, je, da se sončne krivulje poskusi določiti s pomočjo vremenske datoteke za Dansko in primerja z že obstoječimi krivuljami iz literature. Če se novo pridobljene krivulje ujemajo s krivuljami iz literature, pomeni, da je metoda primerna in se jo lahko uporabi za določanje krivulj katerekoli druge lokacije. Za izvedbo tega je potrebno uporabiti enega izmed simulacijskih programov. V tem primeru je bil izbran program BSim, uporabljena vremenska datoteka pa DRY2013.

V programu BSim je bil izdelan model za analizo količine sončnega sevanja, ki prodre skozi referenčno okno. Model je sestavljen iz štirih enakih con, pri čemer ima vsaka različno orientirano okno, z zasteklitvijo v velikosti 1 m^2.

Program BSim ponuja štiri različne solarne modele, med katerimi je potrebno izbrati tistega, ki predvideva enakomerno porazdeljeno difuzno komponento sončnega sevanja.

Najprimernejši solarni model je bil poiskan s pomočjo poskusa, in sicer tako, da so bile vrednosti solarnega sevanja na jasen dan (1. julij) primerjane v trenutku, ko je sonce najvišje na nebu. Če je refleksivnost okolice enaka nič, potem bo skozi južno orientirano okno prodirala kombinacija direktne in difuzne komponente, medtem ko bodo cone, orientirane vhodno, zahodno in severno prejemale le difuzno komponento. Iskani solarni model je tisti, ki poda v teh conah enako vrednost. Za najprimernejšega se je izkazal Munierjev solarni model.

Določanje vrednosti direktne in difuzne komponente lahko poteka na podoben način kot izbira solarnega modela, le da se v tem primeru analizirajo različne ure dneva. V dopoldanskem času bo kombinacija direktne in difuzne komponente prisotna v severno in vzhodno orientirani coni, medtem ko bo v poznem popoldanskem času ta kombinacija prisotna v zahodni in severni coni. Za določitev natančne lege sonca ob določeni uri se lahko uporabijo različna orodja ali aplikacije. Ko je določeno katere komponente sončnega sevanje so ob določeni uri prisotne v coni z določeno orientacijo, se vrednosti lahko izračuna s preprostim računom. Od vrednosti, ki predstavlja kombinacijo direktne in difuzne komponente se odšteje vrednost, ki je prisotna v conah, v katere prodira le difuzna komponenta sončnega sevanja. Rezultat je vrednost direktne komponente. Ko sta direktna in difuzna komponenta poznani, lahko v nastavitvah spremenimo vrednost odboja tal in na podoben način pridobimo še vrednost odbite komponente.

Dobljene vrednosti za direktno in difuzno komponento lahko primerjamo z vrednostmi iz Danvakove literature, kjer pa odbita komponenta ni omenjena. Izkaže se, da so med primerjanimi vrednostmi velike razlike.

Zaželeno bi bilo, da so vrednosti čimbolj podobne, saj je cilj poiskati postopek, kako določiti krivulje, ki bodo enake Danvakovim in se lahko uporabijo na enak način. Ena izmed možnosti je prilagoditev modela v programu BSim. Danvakove vrednosti predstavljajo sončno sevanje na sončen dan brez oblačnosti. Da bi dosegli takšne pogoje v modelu BSim, je potrebno prilagoditi vremensko datoteko. A z znižanjem oblačnosti na 0 % se spremeni tudi direktna in difuzna komponenta. Prilagoditev vrednosti je bila izvedena v programu Elements, ki omogoča urejanje .epw datotek. Na dobljene rezultate poleg vremenskih pogojev vpliva tudi način, kako so v modelu definirana okna. Izkazalo se je, da je v nastavitvah privzeto okno, ki je vzporedno notranji strani stene. Na ta način zunanje stene senčijo del zasteklitve, kar ima za posledico nižje vrednosti prejetega sončnega sevanja v prostoru. BSim model je bil spremenjen tako, da je okno vzporedno z zunanjo površino stene.

Z upoštevanjem sprememb v vremenski datoteki in prilagoditvijo BSim modela so bile določene nove vrednosti. Izvedla se je ponovna primerjava, pri čemer se je pokazalo, da je ujemanje boljše kot prej.

Za izvedbo naslednjega koraka je bilo potrebno razmisliti o podatkih, ki so na voljo, saj so bile izračunane vrednosti še vedno nižje od ciljnih. Potrebno se je bilo vprašati, zakaj v literaturi ni omenjena odbita komponenta, ki je ravno tako pomembna kot direktna in difuzna. Obstajala je možnost, da graf direktne komponente vključuje tudi vrednosti odbite komponente. Naslednji razmislek, ki ga je bilo potrebno narediti, se nanaša na datum primerjanih podatkov. Danvakove krivulje so izdelane za 21. dan v mesecu, medtem ko se izračunane vrednosti nanašajo na 1. julij. Primerjavi je bilo torej smotrno dodati 21. junij, saj je le-ta bliže 1. juliju, kot pa 21. julij. Ponovna primerjava je bila narejena z upoštevanjem obeh razmislekov.

Na novo pridobljene vrednosti so bile veliko bliže Danvakovim, a skladnost še vedno ni bila zadovoljiva. Odstopanja so bila še toliko bolj očitna v primeru vzhodne orientacije. Eden izmed razlog za večje odstopanje na vzhodni strani bi lahko bila izbira solarnega modela. Munierjev solarni model namreč podaja najnižje vrednosti solarnega sevanja na vzhodni orientaciji, medtem ko na primer Lundov solarni model poda skoraj 50 % višje vrednosti. Zaradi tega je ponovna primerjava poleg Munierjevega, vključevala tudi Lundov solarni model. Poleg tega so bile uporabljene še različne vrednosti odbojnosti tal. Primerjava je pokazala, da se Danvakovim vrednostim najbolj približa primer, ko je uporabljen Munierjev solarni model in izbrana 25 % odbojnost tal. S tem je bilo ponovno potrjeno, da je Munierjev solarni model pravilna izbira.

Sončni poldan je čas v dnevu, ko so sončni žarki pravokotni na izbran poldnevnik. Po tej definiciji bi morale biti vrednosti solarnega sevanja na vzhodu in zahodu enake, česar pa v pridobljenih rezultatih ne vidimo. Ker se Zemlja v 24 urah zavrti za 360°, se sončni poldan vsakih 15° proti zahodu zgodi eno uro prej. Lokacija v vremenski datoteki za Dansko vsebuje poldnevnik 12,16°. Če podatke prilagodimo in za poldnevnik izberemo 15°, lahko pričakujemo bolj simetrične rezultate za vzhodno in zahodno orientacijo. Ostali podatki se pri tem ne spremenijo. Rezultati so pokazali, da je z uporabo novega poldnevnika ujemanje med vrednostmi veliko boljše. Ker so pridobljeni rezultati zelo blizu Danvakovim krivuljam in ker literatura ne navaja, kako so te krivulje bile pridobljene, lahko zaključimo, da je eden izmed možnih načinov, kako določiti krivulje ta, da se uporabi Munierjev solarni model, z odbojnostjo tal 25 % in na lokaciji s poldnevnikom 15°.

Za razširitev obsega podatkov primerjave je bila poiskana in pregledana še dodatna literatura, ki vsebuje sončne krivulje. Poleg obstoječe Danvakove knjige iz leta 2006, je bila v obravnavo dodana še predhodna izdaja te knjige iz leta 1988 in knjiga o toploti in prezračevanju avtorja Becherja iz leta 1971. V vseh treh knjigah so vrednosti predstavljene na različne načine. Za lažjo primerjavo vpogled ni bil narejen v posamezne komponente, temveč v celotno vrednost solarnega sevanja, ki predstavlja vsoto vseh komponent. Izkazalo se je, da Danvak iz leta 1988 in Becher podajata precej višje vrednosti od tistih v Danvaku iz leta 2006 ter vrednosti, pridobljenih s programom BSim. To nam dokazuje, da so v programu TCD uporabljeni podatki, ki so izmed pregledane literature najbolj natančni.

S temi primerjavami so bile raziskane sončne krivulje, ki so predstavljene v Danvakovi knjigi in uporabljene v programu TCD. Prikazano je bilo, kako lahko sončne krivulje določimo iz vremenske datoteke. Iz do sedaj povedanega lahko izluščimo štiri glavne zaključke:

- direktna komponenta, predstavljena v knjigi, predstavlja kombinacijo direktne in odbite komponente,
- pozicija okna igra bistveno vlogo pri določitvi solarnih dobitkov v prostoru,
- najbolj natančne sončne krivulje so tiste, ki jih najdemo v Danvakovi knjigi iz leta 2006,
- uporabljen je Munierjev solarni model z odbojnostjo tal 25 %, prilagojeno vremensko datoteko in spremenjeno geografsko dolžino na 15°.

Nova vremenska datoteka

Primerjave predstavljene v prejšnjem poglavju so pokazale, kako se lahko program BSim uporabi za določanje sončnih krivulj. Cilj je poiskati sončne krivulje za vsak 21. dan v mesecu z namenom, da se bodo lahko le-te uporabile v programu TCD.

Prvi korak k temu je predstavljalo iskanje dni v danski vremenski datoteki s podobno razporeditvijo oblačnosti in sončnega sevanja kot 1. julij. Iskani dnevi se morajo nahajati v obdobju pregrevanja, tj. med aprilom in avgustom. Poleg 1. julija je bilo najdenih še 6 drugih t.i. tipičnih načrtovalskih dni. Ker pa zgolj 7 dni za obdobje 5-ih mesecev ne zagotavlja visoke natančnosti, je bila uporabljena metoda zrcaljenja. Podatki izbranega tipičnega načrtovalskega dne so bili zrcaljeni preko določene točke, z namenom da se tvori nov – zrcaljeni – tipični načrtovalski dan. Takšna metoda je mogoča zaradi narave sončnega sevanja, ki je skozi leto simetrično. Med junijem in julijem se nahaja dan, ki ima največji dnevni seštevek sončnega sevanja. Ta dan je točka zrcaljenja tipičnih načrtovalskih dni.

Z analizo časa sončnih vzhodov in zahodov in posledično dolžine dneva se je izkazalo, da je dan z največjim dnevnim seštevkom prejetega sončnega sevanja 21. junij. Z metodo zrcaljenja je tako bilo pridobljenih 7 novih dni. Da bi potrdili ustreznost metode zrcaljenja, je bila izvedena primerjava dolžine dneva med originalnimi in zrcaljenimi dnevi. Odstopanja so bila zelo majhna, kar je potrdilo ustreznost metode.

Naslednji korak je bila predelava vremenskih podatkov tipičnih načrtovalskih dni, da bi ustrezali pogojem, ki jih navaja Danvak, to je jasen dan brez oblačnosti. Pri tem je bilo potrebno paziti, da prilagajanje vremenske datoteke ni bilo pretirano, saj to lahko vodi do netočnosti in posledično nezanesljivosti metode. Temu v izogib je bilo potrebno postaviti določene smernice oziroma meje. Eden izmed načinov je bila primerjava dnevnega seštevka prejetega sončnega sevanja, saj je le-to, kot je bilo že prej omenjeno, skozi leto simetrično. Vrednosti so bile predstavljene na grafu, kjer je x-os predstavlja dan v letu, y-os pa dnevni seštevek direktnega prejetega sončnega sevanja. Na podlagi vrednosti je bila izrisana trendna linija, ki je služila kot vodilo pri prilagajanju vremenskih podatkov. Rezultati so zadovoljivi šele, ko so njihove vrednosti čim bliže trendni liniji. Novi, prilagojeni vremenski podatki skupaj tvorijo novo vremensko datoteko, ki se lahko uporabi v programu BSim. Iskani rezultati simulacije so količina sončnega sevanja v prostoru. To so tudi vrednosti, ki jih predstavljajo Danvakove krivulje in ki se uporabljajo v programu TCD. Ker je trenutna analiza potekala za lokacijo na Danskem in ker se Danvakove krivulje nanašajo na isto lokacijo, bo primerjava obeh pokazala ustreznost metode.

Danvakove krivulje se nanašajo na 21. dan v mesecu, zato je za primerjavo bilo potrebno uporabiti program TCD, ki omogoča linearno interpolacijo ter tako poda rezultate za katerikoli izbrani dan. Med seboj primerjane vrednosti so dnevni seštevki celotnega sončnega sevanja. Danvakove vrednosti, pridobljene s programom TCD so bile primerjane s štirimi različnimi vrednostmi, in sicer, originalnimi in zrcaljenimi tipičnimi načrtovalskimi dnevi s poldnevnikom 12,16° ter originalnimi in zrcaljenimi tipičnimi načrtovalskimi dnevi s poldnevnikom 15°. Razlika med primerjanimi vrednostmi je bila prikazana v odstotkih. Ujemanje je bilo v splošnem precej dobro, vendar pa je bilo razvidno tudi, da izbira poldnevnika 15° ni podala vedno boljšega ujemanja kot originalni poldnevnik. Cilj je bil, da bi pri vzhodni in zahodni orientaciji pridobili enake vrednosti, kar se lahko doseže s kopiranjem vrednosti z ene orientacije na drugo. Kateri poldnevnik bo za to izbran je bilo v tem primeru jasno, saj so bile na voljo Danvakove že obstoječe vrednosti, ki so služile za primerjavo. Izbran je bil tisti, pri katerem so bili rezultati najbližji ciljnim (Danvakovim) vrednostim. Takšen pristop za primer druge lokacije žal ni mogoč, saj referenca, ki bi jo uporabili za primerjavo, ne obstaja. Zaradi tega se je bilo potrebno odločiti za nekakšen sistem, ki se mu bo sledilo v vseh nadaljnjih primerih in ki bo določal, katera vrednost se uporabi pri vzhodni in zahodni orientaciji. Zrcaljeni dnevi prevzemajo podatke originalnih dni, zato se ta sistem izbire nanaša le na originalne dni. S podrobnejšim pregledom rezultatov pri vzhodni in zahodni orientaciji je bilo odločeno, da se izmed rezultatov obeh poldnevnikov izbere tistega, pri katerem je razlika v vrednostih na vzhodu in zahodu najmanjša. Ker pa ti dve vrednosti še vedno nista bili identični, je bilo potrebno narediti korak dlje. Potrebno je bilo izbrati vrednost ene orientacije, ter jo kopirati na drugo. Na varni strani smo, če izberemo tisto orientacijo, ki poda višje vrednosti. Končne vrednosti originalnih dni so se nato uporabile še pri zrcaljenih dneh. Na ta način so bile določene vrednosti dnevnega seštevka sončnega sevanja za vse tipične načrtovalske dni, pri čemer so vrednosti na vzhodu in zahodu enake. Da pa bi lahko izrisali sončne krivulje, je bilo potrebno poznati vrednosti za vsako uro in ne le dnevnega seštevka. Te so bile pridobljene s podobnim načinom kopiranja, le da so bile vrednosti iz, na primer, vzhoda zrcaljene na zahod. Ravnina oziroma ura zrcaljenja je tisti del dneva, ko je sonce najvišje na nebu. Podoben postopek kopiranja vrednosti se lahko uporabi tudi v primeru severne orientacije. Iz Danvakovih krivulj je namreč razvidno, da so pri severni orientaciji jutranje vrednosti simetrično enake večernim. Vse na novo pridobljene vrednosti so bile za nadaljnjo primerjavo razvrščene po orientaciji.

V programu TCD so trenutno uporabljene Danvakove krivulje, ki se nanašajo na 21. dan v mesecu. Ker pa noben od tipičnih načrtovalskih dni ne ustreza temu kriteriju, je bilo za namene primerjave med razpoložljivimi dnevi potrebno narediti linearno interpolacijo. Ta metoda ni najbolj natančna, je pa najpreprostejša. Interpolirane vrednosti za 21. dan v mesecu so bile primerjane z Danvakovimi krivuljami in so pokazale dobro ujemanje. Končni rezultat te metode so torej sončne krivulje na 21. dan v mesecu. Da bi bile popolnoma kompatibilne s programom TCD, je bilo potrebno prilagoditi še čas, in sicer iz lokalnega v solarni.

Natančnejši pregled rezultatov je pokazal, da pridobljene krivulje na nekaterih mestih precej odstopajo od Danvakovih. Izkazalo se je, da kopiranje vrednosti iz zahoda na vzhod ali obratno sicer poda iste vrednosti v obeh orientacijah, vendar se ob tem zmanjša natančnost in ustvari do eno-urni zamik. Če vrednosti na teh dveh orientacijah (ter na severni orientaciji) ne kopiramo, a vseeno izberemo poldnevnik z manjšo razliko med vzhodom in zahodom, dobimo boljše ujemanje. Iz tega je bilo zaključeno, da kopiranje vrednosti iz ene orientacije na drugo ni več del metode.

Na enak način, kot so bile pridobljene sončne krivulje za sever, jug, vzhod in zahod, so se pridobile še krivulje za ostale štiri orientacije: severovzhod, jugovzhod, jugozahod, severozahod. V ta namen se je uporabil enak model v programu BSim, le da se ga je zavrtelo za 45°. Nadaljnji postopek je ostal enak. V programu BSim se je izvedla simulacija z dvema različnima poldnevnikoma in primerjale vrednosti dnevnega seštevka na vzhodu in zahodu. Izbran je bil tisti poldnevnik, pri katerem je razlika najmanjša. V tem primeru, so se med seboj primerjali orientaciji severovzhod in severozahod ter jugovzhod in jugozahod. Z upoštevanjem predhodnih dognanj se nobene izmed vrednosti niso kopirale preko sončnega poldneva. Za tem so bile vrednosti urejene po orientaciji, originalnim dnem so bili dodani zrcaljeni, izvedena je bila linearna interpolacija in prilagodil se je čas.

Zamisel je bila, da bi poleg vseh osmih orientacij, v prihodnosti program TCD omogočal tudi analizo horizontalnega okna. Vrednosti se bile pridobljene na enak način kot prej, le da je bilo potrebno model v programu BSim prilagoditi. Potrebna je le ena cona, ki ima strešno okno. Lastnosti zasteklitve ostajajo enake. V tem primeru so bile vrednosti pri dveh različnih poldnevnikih skoraj enake, zato se je v tem primeru uporabil originalni poldnevnik. Nadaljevanje je bilo enako kot doslej: vrednosti so bile organizirane, zrcaljeni dnevi dodani, linearna interpolacija izračunana in čas prilagojen tako, da ustreza programu TCD. V

Becherjevi verziji sončnih krivulj so poleg vertikalnih oken dodane tudi vrednosti za horizontalna okna, zato je bila izvedena primerjava z njimi. Odstopanja so bila v tem primeru še večja kot pri primerjavi vrednosti vertikalnih oken.

Če povzamemo, se je postopek celotne analize začel s pregledom Danvakovih sončnih krivulj, z namenom ugotoviti, kako se jih lahko pridobi s programom BSim. Ko je bilo to razjasnjeno, so neodvisno od Danvakovih krivulj nastale nove krivulje. Formirala se je nova vremenska datoteka, pri izdelavi katere je bilo potrebno sprejeti nekaj odločitev in poenostavitev. Posledica tega je manjša natančnost, a potrebno se je zavedati, da bodo ti podatki uporabljeni v programu TCD, ki je preprosto orodje za računanje. Njegov namen je pridobivanje praktičnih informacij v zgodnji fazi načrtovanja, ko visoka natančnost še ni potrebna. Lahko pa se pričakuje, da bodo rezultati, pridobljeni z novimi krivuljami natančnejši od obstoječih, saj nove sončne krivulje bazirajo na vremenski datoteki, ki se sicer uporablja pri simulacijah z naprednejšimi orodji. Vsekakor pa je za rezultate visoke natančnosti potrebno uporabiti natančnejša simulacijska orodja, ki zahtevajo več podatkov.

Sončne krivulje za Slovenijo

Metoda za določitev sončnih krivulj je za lokacijo na Danskem podala zadovoljive rezultate. Z enakim postopkom se sončne krivulje lahko določi za katero koli drugo lokacijo, če je le na voljo ustrezna vremenska datoteka. V nadaljevanju je bila metoda testirana tako, da smo z njo določili sončne krivulje za Slovenijo. Vsak korak je bil podrobno opisan in posledično lahko služi kot priročnik za predelavo vremenskih podatkov za program TCD.

Najprej je bilo potrebno pridobiti vremensko datoteko, ki je običajno dostopna na spletu v .epw obliki. Za analizo je bilo potrebno podatke uvoziti v program Excel. Čas v vremenski datoteki je zapisan v obliki ur od »0« do »8760« z dodatnimi 24-mi urami za primer prestopnega leta. Za boljšo organizacijo je bilo smiselno čas urediti po urah v dnevu, dnevih v mesecu in mesecih v letu. Naslednji korak je bil pregled sončnega sevanja in oblačnosti, z namenom, da se poišče primerne tipične načrtovalske dni. Najenostavnejši način za to je uporaba katerega izmed simulacijskih orodij, ki omogoča pregled iskanih količin za vsak posamezen dan. Ko so tipični načrtovalski dnevi poiskani, sledi proces zrcaljenja. Smotrno je bilo preveriti, ali je točka zrcaljenja enaka kot v primeru Danske ali ne, saj gre za drugo lokacijo. Izkazalo se je, da tudi za Slovenijo velja, da ima 21. junij največji dnevni seštevek sončnega sevanja. Originalni in zrcaljeni dnevi skupaj tvorijo novo vremensko datoteko. Primerjana je bila tudi dolžina dneva originalnih in zrcalnih dni in pokazalo se je zelo dobro ujemanje. Postopek se je nadaljeval s predelavo tipičnih načrtovalskih dni. Pri tem je ponovno pomagal graf, ki prikazuje dnevni seštevek direktne komponente sončnega sevanja in trendno linijo, ki te točke povezuje. Pri predelavi podatkov originalnih dni se poleg direktne komponente ne sme pozabiti še na difuzno komponento ter oblačnost. Končne vrednosti so se iz originalnih, prenesle na zrcaljene dni. Na ta način je bila izdelana nova vremenska datoteka. Vrednosti so v tem trenutku bile zapisane v programu Excel, ki pa ni kompatibilen s simulacijskimi orodji. Za simulacije v programu BSim je potrebna .dry oblika datoteke. Do nje pridemo s pomočjo programa Elements, ki omogoča urejanje .epw datotek. V njem odpremo originalno .epw datoteko ter spremenimo podatke predelanih tipičnih načrtovalskih dni. Pretvorbo nove .epw datoteke v .dry datoteko lahko izvedemo kar v programu BSim. Simulacija je potekala na enak način kot v primeru lokacije na Danskem: uporabil se je enak model s štirimi conami, pri čemer ima vsaka okno, orientirano v drugo smer. Pomembno je bilo, da je okno pravilno definirano, da je nastavljena 25 % odbojnost tal ter da je izbran Munierjev solarni model. Ko je simulacija izvedena, se poiščejo rezultati sončnega sevanja ter kopirajo v program Excel. Te vrednosti so postale sončne krivulje za tipične načrtovalske dni za lokacijo v Sloveniji.

Slovenija leži na poldnevniku 14,48°, kar je zelo blizu poldnevnika 15°. Za večji spekter vrednosti je bilo odločeno, da se bo poleg originalnega poldnevnika uporabil še poldnevnik, ki je za ±2° oddaljen od originalnega. Rezultati so bili torej kombinacija štirih različnih poldnevnikov: 12,5°, 14,48°, 15° in 16,5°. Spreminjanje poldnevnika za potrebe simulacije se lahko izvede v programu Elements, vendar le v datoteki oblike .epw. Ko je poldnevnik spremenjen, je datoteko ponovno treba spremeniti v obliko .dry za simulacijo v programu BSim. Potem ko so rezultati vseh štirih poldnevnikov zbrani na kupu, se lahko začne primerjava razlik med vzhodom in zahodom. Izbran je bil tisti poldnevnik, pri katerem je bila razlika v dnevnem seštevku najmanjša. Ko so originalni dnevi imeli določen poldnevnik, se je njihove vrednosti preneslo še v njihove zrcaljene dni. Podatki so bili v tej točki organizirani glede na orientacijo za namene linearne interpolacije. Z enakim postopkom kot pri lokaciji Danske, so se izračunale vrednosti za 21. dan v mesecu. Zadnji korak je bila korekcija časa za kompatibilnost s programom TCD.

Sončne krivulje za ostale štiri orientacije so bile pridobljene na popolnoma enak način, le da je bilo pred tem potrebno model zavrteti za 45°. Nič drugače ni bilo pri pridobivanju podatkov za horizontalno okno. Postopek je bil enak, le model drugačen – tokrat je bila potrebna le ena cona s strešnim oknom.

Opis postopka po korakih

Po podrobnem opisu postopka v prejšnjih poglavij je v nadaljevanju narejen seznam s kratkim opisom vseh korakov. Pričujoča tabela lahko služi kot priročnik oziroma kot pregled postopka.

1. korak:	pridobivanje vremenske datoteke, izvoz podatkov v Excel
2. korak:	urejanje vremenske datoteke po urah, dnevih in mesecih
3. korak:	iskanje tipičnih načrtovalskih dni
4. korak:	iskanje točke zrcaljenja, zrcaljenje, primerjava dolžine dneva
5. korak:	primerjava dnevnega seštevka direktne komponente sončnega sevanja in predelava podatkov tako, da se ujemajo s trendno linijo
6. korak:	izdelava vremenske datoteke v formatu .epw
7. korak:	izdelava modela v programu BSim
8. korak:	pretvorba vremenske datoteke iz .epw v .dry format
9. korak:	izbira odbojnosti tal, pravilno oblikovanje oken, izbira solarnega modela
10. korak:	izvedba simulacije
11. korak:	izvoz podatkov sončnega sevanja v coni v program Excel
12. korak:	izdelava nove vremenske datoteke z različnimi poldnevniki
13. korak:	primerjava dnevnega seštevka vzhodne in zahodne orientacije in izbor tiste, pri kateri je razlika najmanjša
14. korak:	ureditev vrednosti glede na orientacijo
15. korak:	linearna interpolacija
16. korak:	prilagoditev časa
17. korak:	izdelava sončnih krivulj za izbrano lokacijo

se nadaljuje…

nadaljevanje preglednice

18. korak:	zasuk modela v programu BSim za 45° za določanje vrednosti pri orientaciji severovzhod, jugovzhod, jugozahod in severozahod
19. korak:	ponovitev postopka od 10. do 16. koraka (pri 13. koraku sta primerjani količini severovzhod in severozahod ter jugovzhod in jugozahod)
20. korak:	prilagoditev modela v programu BSim za potrebe določanja vrednosti horizontalne zasteklitve (ena cona s strešnim oknom)
21. korak:	izvedba simulacije z originalnim poldnevnikom
22. korak:	ponovitev 11. koraka, skok na 14. korak in nadaljevanja na 17. koraku

Testiranje novih sončnih krivulj

Zdaj, ko so bile pridobljene vse sončne krivulje, jih je bilo potrebno testirati z bolj naprednim simulacijskim orodjem. Primerjava rezultatov iz programa BSim in iz programa TCD z uporabo Danvakovih krivulj je že bila narejena v predhodnih projektih. Ti rezultati so bili primerjani z rezultati iz programa TCD z novimi, v tem projektu pridobljenimi krivuljami.

Obravnavana je bila sejna soba, za katero je za načrtovanje prezračevanja z nočnim hlajenjem bil uporabljen program TCD. Cilj je bil, da je v prostoru vzdrževana povprečna dnevna temperatura 23°C.

Izbira dni, na katere se je izvedla simulacija, je bila v programu TCD zelo preprosta, saj le-ta ne loči med dnevi v tednu in vikendi ter počitnicami. Dnevi se med seboj razlikujejo le po zunanji temperaturi ter količini solarnega sevanja. Izbrana sta bila 21. junij ter 15. avgust, ker lahko oba smatramo kot kritična. 21. junij je kritičen za vzhodno in zahodno orientacijo, saj solarno sevanje na ta dan traja najdlje. 15. avgust pa zato, ker se nahaja na koncu poletnega obdobja in je kritičen predvsem za južno orientacijo.

Izbira dni v programu BSim, za razliko od programa TCD, vključuje več parametrov. Ker se za to simulacijo uporablja originalna vremenska datoteka, morajo izbrani dnevi imeti čim manj oblačnosti, da bodo primerljivi s programom TCD. Proces izbire takšnih dni je tekom tega projekta že bil izveden. Za testiranje so izmed vseh dni najprimernejši tisti, ki se nahajajo v drugi polovici delovnega tedna. Prezračevanje v prostoru čez vikend namreč ne deluje, kar pomeni da na ponedeljek in torek vpliva temperatura sobe čez vikend. Na dneve 11. junij, 1. julij in 6. avgust so izpolnjeni vsi od naštetih pogojev za lokacijo na Danskem, na dneve 30. junij, 27. julij in 16. avgust pa so izpolnjeni vsi pogoji za lokacijo v Sloveniji.

Obravnavana sejna soba za namene testiranja novih sončnih krivulj se nahaja v prvem nadstropju tri-nadstropne stavbe. Le ena stena meji na zunanjost. Ta ima dve okni, ki skupaj predstavljata 22 % tlorisne površine. Okna so opremljena s senčili, ki imajo za vsako orientacijo določen drugačen urnik. Poleg tega je prostor prezračevan s sistemom spremenljivega zračnega volumna (angl. *variable air volume*, kratica VAV) in nočnim hlajenjem. Kot notranji dobitki se smatrajo uporabniki, razsvetljava ter oprema (računalnik in TV). Glavni namen tega testa je bil primerjava povprečne dnevne temperature, dobljene v programu BSim, ter v obeh verzijah programa TCD – enega z obstoječimi ter drugega z novimi krivuljami.

Simulacija za lokacijo na Danskem je osnovana na rezultatih predhodnega projekta. Tam je bila izbira dni v programu TCD in BSim je enaka, le da je v pričujočem projektu dodan še en dan več. V predhodnem projektu je bil v programu BSim uporabljen Petersenov solarni model, 20 % odbojnost tal in drugače oblikovana okna. Za potrebe primerjave so te nastavitve bile prilagojene trenutnemu projektu.

Rezultati programa TCD so bili v predhodnem projektu pridobljeni z uporabo Danvakovih krivulj. Cilj testa je bil te rezultate primerjati z vrednostmi, ki jih bo podal program TCD z novimi sončnimi krivuljami. Predhodni projekt je obravnaval le južno ter zahodno orientacijo, saj so Danvakove vrednosti enake za vzhodno in zahodno orientacijo. Zahod je bil izbran zato, ker je bolj kritičen glede nastopa pregrevanja – sonce v ta prostor namreč posije šele popoldne, po tem ko je le-ta bil cel dan zaseden in izpostavljen toplotnim dobitkom. V pričujočem projektu je v primerjavo dodana tudi vzhodna orientacija.

Med seboj so primerjane štiri vrednosti, ki vsebujejo naslednje lastnosti:

- Petersenov solarni model, odbojnost tal 20 %, okna oblikovana po predhodnem projektu. Te vrednosti predstavljajo rezultate predhodnega projekta, brez da bi bili ti kakorkoli spremenjeni.
- Munierjev solarni model, odbojnost tal 25 %, okna oblikovana po pričujočem projektu. Te vrednosti predstavljajo rezultate predhodnega projekta s prilagojenimi lastnostmi.
- Originalne Danvakove sončne krivulje. Te vrednosti predstavljajo rezultate predhodnega projekta, brez da bi bili ti kakorkoli spremenjeni.
- Predelane (na novo pridobljene) sončne krivulje. Te vrednosti predstavljajo rezultate predhodnega projekta z novimi krivuljami.

Rezultati primerjave so zapisani v obliki maksimalne, minimalne ter povprečne dnevne temperature v prostoru, pridobljene za na zgoraj naštete štiri načine za tri omenjene orientacije. Iz rezultatov lahko razberemo več stvari. Prvo kar opazimo je, da je amplituda med maksimalno in minimalno temperaturo večja pri rezultatih iz programa TCD. Opazimo lahko tudi, da je razlika med rezultati iz programa BSim pri različnih nastavitvah zelo majhna. Malo večje, a še vedno majhno, je odstopanje med rezultati iz programa TCD z različnimi krivuljami. Najpomembnejša pa je primerjava rezultatov iz programa BSim ter TCD. Pod drobnogled so vzete vrednosti, pridobljene v BSim iz pričujočega projekta (Munierjev solarni model, 25 % odbojnost tal) ter vrednosti iz programa TCD z novimi sončnimi krivuljami. Ujemanje obeh vrednosti je precej dobro, z izjemo 11. junija, kjer je razlika precej velika. Vzrok za to je, da je to eden izmed zrcaljenih dni, kar pomeni, da v originalni vremenski datoteki nima nujno ničelne oblačnosti in visokih vrednosti solarnega sevanja. Te lastnosti je ta dan pridobil z zrcaljenjem vrednosti za namen določitve nove vremenske datoteke. Vpogled v originalno vremensko datoteko je ta sum potrdil, saj je 11. junij dan s precej nizkimi temperaturami.

Takšno odstopanje je lahko za zgled, saj nam pokaže kakšno napako lahko naredimo, če program TCD uporabljamo, brez da bi rezultate kritično presodili. V realnosti je precej malo dni, ki bi imeli skoraj nično oblačnost, kar pomeni, da se bodo rezultati programa TCD z realnostjo ujemali le v nekaj primerih. Zaradi tega je vedno potrebno imeti v mislih, da je program TCD namenjen grobim ocenam in ne podajanju točnih rezultatov.

V splošnem so rezultati iz programa BSim in TCD izkazovali precej dobro ujemanje. A v tem primeru so okna predstavljala le 22 % tlorisne površine. Da bi preverili, ali je ta metoda uporabna tudi za primere z večjimi okni, ki so navadno bolj kritična, je bila narejena še analiza oken s površino, enakovredno 27 % in 51 % tlorisne površine.

Primerjava z različno velikimi okni je obogatena še z rezultati programa TCD z Becherjevimi krivuljami. Le-te so stare več kot 40 let in so bile nekoč v rabi. Rezultati tako prikazujejo tudi to, kako so se sončne krivulje s časom spremenile in izboljšale. A ker je sejna soba, ki je predmet analize, opremljena s prezračevanjem in nočnim hlajenjem, je razlika med rezultati manj izrazita, kot je bila v predhodni primerjavi krivulj iz različnih literatur. Iz rezultatov lahko povzamemo, da so odstopanja največja pri južni orientaciji. Najboljše ujemanje najdemo pri vzhodni orientaciji, medtem ko se razlike na zahodu večajo z večanjem površine okna. Iz tega lahko zaključimo, da metoda poda boljše rezultate za vzhodno in zahodno orientacijo, a nam nudi precej dobro ujemanje tudi za južno orientacijo.

Testiranje sončnih krivulj je bilo izvedeno tudi za lokacijo v Sloveniji. V tem primeru ni bilo na voljo nobenih predhodnih projektov in rezultatov. Primerjava je bila tako izvedena le med rezultati iz programa TCD s krivuljami, pridobljenimi v tem projektu in rezultati iz programa BSim, v katerem je bila uporabljana slovenska vremenska datoteka. V programu BSim so bili uporabljeni že prej omenjeni datumi za analizo, v programu TCD pa sta bila izbrana enaka dneva kot za lokacijo na Danskem. Simulacija v programu BSim je potekala pod enakimi pogoji kot v celotnem projektu do sedaj in v programu TCD so bile uporabljene slovenske sončne krivulje. Obravnavane so bile vzhodna, južna in zahodna orientacija.

Rezultati so pokazali, da je ujemanje rezultatov iz programov TCD in BSim dobro. Razlike med minimalno in maksimalno temperaturo imajo manjši razpon kot v primeru Danske. Rezultati iz programa BSim v splošnem podajajo malce nižje notranje povprečne temperature kot rezultati programa TCD. Natančnejši vpogled je pokazal, da je to posledica ocene zunanje povprečne temperature, ki jo mora uporabnik sam vnesti v program TCD. Dejanske zunanje temperature v vremenski datoteki so nižje od zunanje temperature, ki je bila vnesena v program TCD.

Nadaljnja analiza je vključevala okna različnih velikosti, tako kot je to bilo prej izvedeno za lokacijo na Danskem. Pri tem je bilo potrebno imeti v mislih prejšnjo opazko, da so zunanje temperature v vremenski datoteki nižje od tiste, ki je bila predvidena v programu TCD. Rezultati so pokazali, da v primeru lokacije v Sloveniji TCD vrednosti niso vedno višje kot BSim vrednosti, kakor je to bilo moč opaziti pri rezultatih iz lokacije na Danskem. Pri majhnem in srednje velikem oknu se vrednosti najbolje ujemajo v mesecu juliju, medtem ko je pri največjem oknu situacija obrnjena, saj julijske vrednosti iz programa BSim presegajo TCD vrednosti.

Testiranje metode je pokazalo, da lahko krivulje, pridobljene v tem projektu, služijo na enak način kot krivulje, ko so pridobljene v literaturi. Pričakovano je sicer bilo, da bodo na novo pridobljene krivulje za Dansko podale višjo natančnost pri primerjavi z rezultati iz programa BSim, saj so bile pridobljene iz vremenske datoteke. Razlike, ki so se tekom procesa pokazale med Danvakovimi in novimi krivuljami so v tistem trenutki bile interpretirane kot razlika, ki bo podala boljše rezultate, a se je izkazalo, da temu ni tako. V primeru Slovenije je TCD podal dobre in ujemajoče rezultate, a le če je bila zunanja temperatura primerno izbrana. Odstopanja so bila prisotna le v primeru velikih oken, kjer so rezultati iz BSim podali višje temperature kot TCD. Vsekakor pa lahko povzamemo, da je bila razvita metoda za določanje sončnih krivulj, ki poda zadovoljive rezultate, kar je bilo dokazano s testiranjem.

Zaključek

Program TCD je poenostavljeno orodje za uporabo v zgodnji fazi projektiranja, kar pomeni, da veliko stvari temelji na predpostavkah in poenostavitvah. Ni mišljeno, da se rezultati tega programa smatrajo kot natančni in končni, temveč kot orodje za praktične in hitre odgovore.

Pričujoča naloga se osredotoča na solarne dobitke, ki so v obliki sončnih krivulj implementirani v program TCD. Obstoječe sončne krivulje za Dansko so bile vzete iz literature, ki pa ne vsebuje pojasnila, kako so bile pridobljene.

Prva naloga je bila raziskati danske sončne krivulje in poiskati način, kako jih določiti na podlagi široko dostopnih vremenskih datotek. Pokazano je bilo, da je skupno sončno sevanje, opisano v Danvakovi knjigi, vsota direktne, difuzne in odbojne komponente, pri čemer je odbojnost tal 25 %. Solarni model, ki se je izkazal za najbolj primernega, je Munierjev solarni model. Na tem mestu se je opozorilo tudi na odstopanja, do katerih lahko pride, če okna niso pravilno oblikovana. Raziskane so bile tudi krivulje iz drugih literatur, ki pa so pokazale, da so trenutno v rabi tiste, ki se najbolje skladajo z rezultati naprednejših simulacijskih orodij.

Raziskava Danvakovih krivulj je služila kot osnova za razvijanje metode za pridobivanje nove vremenske datoteke, s katero se določi nove sončne krivulje. Vsi koraki, od izbire oblikovnih dni, testiranja metode zrcaljenja, linearne interpolacije in ostali, so podrobno opisani. Ob pregledu rezultatov je bilo odločeno, da je bolje, če podatki niso spremenjeni na način, da je na vzhodu in zahodu enaka vrednost. V primerjavi z Danvakovimi vrednostmi, je tu bil storjen korak dlje – izračunane so bile tudi vrednosti za primer horizontalnega okna.

Metoda za določanje sončnih krivulj je bila v naslednjem koraku uporabljena za pridobivanje vrednosti za drugo lokacijo, kar je bil tudi namen celotnega projekta. Z enakim postopkom so bile pridobljene sončne krivulje za lokacijo v Sloveniji. Dodan je bil tudi opis postopka po korakih, ki v prihodnosti lahko služi kot priročnik.

Nazadnje je bilo izvedenih še več testov, ki so potrdili, da se omenjena metoda lahko uporabi za pridobivanje sončnih krivulj za katerokoli lokacijo. Povzetek rezultatov kaže na dobro ujemanje rezultatov iz bolj naprednih simulacijskih orodij, ko se v programu TCD uporabijo nove sončne krivulje. Posledično se lahko smatra, da metoda poda dobre rezultate in se jo lahko uporabi za razširitev obsega uporabnosti programa TCD.

Na novo nastale sončne krivulje za Dansko so zelo podobne Danvakovim. Glavna razlika med njimi je, da postopek Danvakovih krivulj ostaja neznan, medtem ko pričujoča naloga vsebuje podrobno razlago o tem, kako samostojno določiti sončne krivulje za izbrano lokacijo.

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PRILOGE

A SUBMITTED FILES

Excel files, submitted with the report, are shown in the following table. For a better orientation, the corresponding graphs and tables that can be found in the report are stated next to each file's name.

	FILE NAME	CORRESPONDING GRAPH/TABLE
SUN CURVES	01 Solar gain-Denmark-recess=0 (not modified)	Table 5.3, Table 5.4, Graph 5.3, Graph 5.4, Graph 5.5, Graph 5.6, Graph 5.7
	02 New weather data-Denmark	Graph 5.1, Graph 5.8, Graph 6.1, Table 6.4, Graph 6.2, Graph 6.3
	03 Comparison of recess	Graph 5.9, Graph 5.10
	04 Solar gain-Denmark-recess=0.0001 (modified)	Graph 5.11, Graph 5.12, Graph 5.13, Table 5.5
	05 Solar gain-Denmark-recess=0.0001 (modified) longitude 15	Table 5.6
	06 Comparison for 1 July	Graph 5.14, Graph 5.15, Graph 5.16
NEW WEATHER DATA	07 Duration of days	Table 6.1, Table 6.3, Table 7.1, Table 7.3
	08 Sun curves N, E, S, W – with copying	Graph 6.4, Graph 6.5, Table 6.6, Table 6.7, Table 6.8, Table 6.9, Graph 6.6, Table 6.10, Graph 6.8, Graph 6.9, Graph 6.10, Graph 6.11, Graph 6.12
	09 Sun curves N, E, S, W – without copying	Graph 6.13, Graph 6.14, Graph 6.15, Graph 6.16
	10 Sun curves NE, SE, SW, NW – without copying	Graph 6.17, Graph 6.18, Graph 6.19, Graph 6.20
	11 Sun curves HORIZONTAL – without copying	Graph 6.21, Graph 6.22
OBTAINING SUN CURVES FOR SLOVENIA	12 Weather file, new weather data-Slovenia	Graph 7.1, Graph 7.2
	13 Sun curves N, E, S, W	Graph 7.3, Graph 7.4, Graph 7.5, Graph 7.6
	14 Sun curves NE, SE, SW, NW	Graph 7.7, Graph 7.8, Graph 7.9, Graph 7.10
	15 Sun curves HORIZONTAL	Graph 7.11
RESULTS	16 Simulation results	Graph 9.1, Graph 9.2, Graph 9.3, Graph 9.4, Graph 9.5, Graph 9.6, Graph 9.7, Graph 9.8, Graph 9.9, Graph 9.10, Graph 9.11, Graph 9.12, Table 9.3, Table 9.4, Table 9.7

Besides Excel file, BSim and TCD files were submitted as well. All of the handed in files are stated in the following table. In the case of BSim, for each different window size, there are three subfolders for each orientation.

BSim	**TCD**

– Denmark
  o N, E, S, E sun curves
  o NE, SE, SW, NW sun curves
  o HORIZONTAL sun curves
  o Weather file
– Slovenia
  o N, E, S, E sun curves
  o NE, SE, SW, NW sun curves
  o HORIZONTAL sun curves
  o Weather file
– Simulations
  o Denmark
    ▪ Munier's solar model
      • Window 22%
      • Window 27%
      • Window 51%
    ▪ Petersen solar model
      • Window 22%
      • Window 27%
      • Window 51%
  o Slovenia
      • Window 22%
      • Window 27%
      • Window 51%
	– Denmark
	  o Modified sun curves
	    ▪ Window 22%
	    ▪ Window 27%
	    ▪ Window 51%
	  o Original sun curves
	    ▪ Window 22%
	    ▪ Window 27%
	    ▪ Window 51%
	  o TCD Becher
	– Slovenia
	  o Window 22%
	  o Window 27%
	  o Window 51%

B DANVAK'S SUN CURVES

The following tables show hourly values of Danvak's sun curves. These values are used in the existing TCD program. They represent solar transmission through a reference window with the g-value of 0.76. They correspond to the 21st of the month on a clear day. Values are in [W/m^2] and hours are in true solar time.

NORTH	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
January					0	8	13	15	16	15	13	8					
February				0	10	15	18	19	20	19	18	15	10	0			
March			0	12	17	20	22	24	24	24	22	20	17	12	0		
April		25	23	18	21	24	26	28	29	28	26	24	21	18	23	25	
May	57	136	59	20	24	27	29	31	32	31	29	27	24	20	59	136	57
June	159	170	80	22	25	28	30	32	33	32	30	28	25	22	80	170	159
July	57	136	59	20	24	27	29	31	32	31	29	27	24	20	59	136	57
August		25	23	18	21	24	26	28	29	28	26	24	21	18	23	25	
September			0	12	17	20	22	24	24	24	22	20	17	12	0		
October				0	10	15	18	19	20	19	18	15	10	0			
November					0	8	13	15	16	15	13	8	0				
December						4	10	13	14	13	10	4					

NORTHEAST	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
January					0	8	13	15	16	15	13	8	0				
February				0	10	15	18	19	20	19	18	15	10	0			
March			0	202	139	32	22	24	24	24	22	20	17	12	0		
April		103	325	332	213	60	26	28	29	28	26	24	21	18	13	3	
May	103	382	451	400	264	101	29	31	32	31	29	27	24	20	17	12	3
June	271	438	482	422	321	122	30	32	33	32	30	28	25	22	18	14	7
July	103	382	451	400	264	101	29	31	32	31	29	27	24	20	17	12	3
August		103	325	332	213	60	26	28	29	28	26	24	21	18	13	3	
September			0	202	139	32	22	24	24	24	22	20	17	12	0		
October				0	10	15	18	19	20	19	18	15	10	0			
November					0	8	13	15	16	15	13	8	0				
December						4	10	13	14	13	10	4					

EAST	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
January					0	196	185	77	16	15	13	8	0				
February				0	308	309	262	107	20	19	18	15	10	0			
March			0	406	525	442	302	112	24	24	22	20	17	12	0		
April		93	427	554	557	466	306	116	29	28	26	24	21	18	13	3	
May	95	372	529	586	560	469	309	119	32	31	29	27	24	20	17	12	3
June	217	416	552	588	561	470	310	120	33	32	30	28	25	22	18	14	7
July	95	372	529	586	560	469	309	119	32	31	29	27	24	20	17	12	3
August		93	427	554	557	466	306	116	29	28	26	24	21	18	13	3	
September			0	406	525	442	302	112	24	24	22	20	17	12	0		
October				0	308	309	262	107	20	19	18	15	10	0			
November					0	196	185	77	16	15	13	8	0				
December						94	146	65	14	13	10	4					

SOUTHEAST	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
January					0	300	419	423	352	231	13	8	0				
February				0	338	463	542	501	414	251	18	15	10	0			
March			0	336	509	580	580	508	394	226	22	20	17	12	0		
April		39	257	426	527	562	544	466	335	156	26	24	21	18	13	3	
May	3	118	279	408	486	509	485	403	276	107	29	27	24	20	17	12	3
June	7	120	280	392	459	482	456	378	255	88	30	28	25	22	18	14	7
July	3	118	279	408	486	509	485	403	276	107	29	27	24	20	17	12	3
August		39	257	426	527	562	544	466	335	156	26	24	21	18	13	3	
September			0	336	509	580	580	508	394	226	22	20	17	12	0		
October				0	338	463	542	501	414	251	18	15	10	0			
November					0	300	419	423	352	231	13	8	0				
December						150	340	375	316	209	10	4					

SOUTH	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
January					0	220	385	481	510	481	385	220	0				
February				0	170	339	474	557	582	557	474	339	170	0			
March			0	12	195	356	476	548	576	548	476	356	195	12	0		
April		3	13	18	135	290	408	478	505	478	408	290	135	18	13	3	
May	3	12	17	20	78	207	323	397	424	397	323	207	78	20	17	12	3
June	7	14	18	22	47	174	284	364	383	364	284	174	47	22	18	14	7
July	3	12	17	20	78	207	323	397	424	397	323	207	78	20	17	12	3
August		3	13	18	135	290	408	478	505	478	408	290	135	18	13	3	
September			0	12	195	356	476	548	576	548	476	356	195	12	0		
October				0	170	339	474	557	582	557	474	339	170	0			
November					0	220	385	481	510	481	385	220	0				
December						114	320	421	456	421	320	114					

SOUTHWEST	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
January					0	8	13	231	352	423	419	300	0				
February				0	10	15	18	251	414	501	542	463	338	0			
March			0	12	17	20	22	226	394	508	580	580	509	336	0		
April		3	13	18	21	24	26	156	335	466	544	562	527	426	257	39	
May	3	12	17	20	24	27	29	107	276	403	485	509	486	408	279	118	3
June	7	14	18	22	25	28	30	88	255	378	456	482	459	392	280	120	7
July	3	12	17	20	24	27	29	107	276	403	485	509	486	408	279	118	3
August		3	13	18	21	24	26	156	335	466	544	562	527	426	257	39	
September			0	12	17	20	22	226	394	508	580	580	509	336	0		
October				0	10	15	18	251	414	501	542	463	338	0			
November					0	8	13	231	352	423	419	300	0				
December						4	10	209	316	375	340	150					

WEST	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
January					0	8	13	15	16	77	185	196	0				
February				0	10	15	18	19	20	107	262	309	308	0			
March			0	12	17	20	22	24	24	112	302	442	525	406	0		
April		3	13	18	21	24	26	28	29	116	306	466	557	554	427	93	
May	3	12	17	20	24	27	29	31	32	119	309	469	560	586	529	372	95
June	7	14	18	22	25	28	30	32	33	120	310	470	561	588	552	416	217
July	3	12	17	20	24	27	29	31	32	119	309	469	560	586	529	372	95
August		3	13	18	21	24	26	28	29	116	306	466	557	554	427	93	
September			0	12	17	20	22	24	24	112	302	442	525	406	0		
October				0	10	15	18	19	20	107	262	309	308	0			
November					0	8	13	15	16	77	185	196	0				
December						4	10	13	14	65	146	94					

NORTHWEST	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
January					0	8	13	15	16	15	13	8	0				
February				0	10	15	18	19	20	19	18	15	10	0			
March			0	12	17	20	22	24	24	24	22	32	139	202	0		
April		3	13	18	21	24	26	28	29	28	26	60	213	332	325	103	
May	3	12	17	20	24	27	29	31	32	31	29	101	264	400	451	382	103
June	7	14	18	22	25	28	30	32	33	32	30	122	321	422	482	438	271
July	3	12	17	20	24	27	29	31	32	31	29	101	264	400	451	382	103
August		3	13	18	21	24	26	28	29	28	26	60	213	332	325	103	
September			0	12	17	20	22	24	24	24	22	32	139	202	0		
October				0	10	15	18	19	20	19	18	15	10	0			
November					0	8	13	15	16	15	13	8	0				
December						4	10	13	14	13	10	4					

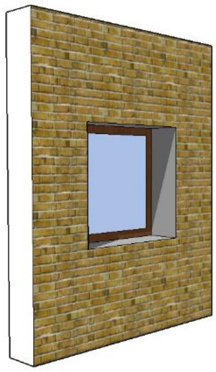
C COMPARISON OF BSIM AND DANVAK'S SUN CURVES

In order to explain what Danvak's sun curves represent, several test were done in BSim. The obtained results were compared to Danvak's sun curves. The steps of the comparison were explained in sections "5.5 Comparison of BSim and Danvak's sun curves", "5.7 Comparison of BSim and Danvak's sun curves with improved model" and "5.8 Comparison of BSim and Danvak's sun curves with improved model and data consideration". The exact values are presented in the following tables.

C.1 Not modified weather file, recess and ground reflection are "0"

The following tables show the comparison between the sun curves from Danvak and BSim. Both values represent solar transmission through a reference window. This was the first step of the comparison, so the weather data in this case is not modified, recess is set to "0", and ground reflection is 0%.

The meaning and the importance of recess has been explained in the subsection "5.6.2 Position of a window - Recess". To sum up shortly: when recess is set to "0", it means that a window is parallel to the inner face, so the rest of the construction wall provides shade to the window. The amount of solar radiation that comes through this window is therefore reduced. The example is shown in the figure on the right side.



Values in tables show the direct and the diffuse component of solar radiation (reflected component is "0") in [W/m^2] through a reference window. Time is divided in the time representation from BSim, which includes DST, and the time representation from the TCD, which corresponds to true solar time.

File: 01 Solar gain-Denmark-recess=0 (not modified)

SOUTH - July							
Time BSim	Time TCD	BSim			Danvak		
		direct	diffuse	sum	direct	diffuse	sum
6	5		15	15		12	12
	6					17	17
8	7		21	21	0	20	20
	8				54	24	78
	9				180	27	207
11	10	98	29	127	294	29	323
	11				366	31	397
13	12	165	29	194	392	32	424
	13				366	31	397
15	14	70	27	97	294	29	323
	15				180	27	207
	16				54	24	78
18	17		22	22	0	20	20
	18					17	17
20	19		16	16		12	12

NORTH - July							
Time BSim	Time TCD	BSim			Danvak		
		direct	diffuse	sum	direct	diffuse	sum
6	5	40	15	55	124	12	136
	6				42	17	59
8	7		20	20	0	20	20
	8					24	24
	9					27	27
11	10		29	29		29	29
	11					31	31
13	12		29	29		32	32
	13					31	31
15	14		27	27		29	29
	15					27	27
	16					24	24
18	17		26	26	0	20	20
	18				62	17	79
20	19	55	16	71	124	12	136

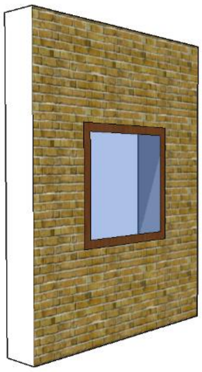
EAST - July							
Time BSim	Time TCD	BSim			Danvak		
		direct	diffuse	sum	direct	diffuse	sum
6	5	226	15	241	360	12	372
	6				512	17	529
8	7	385	20	405	566	20	586
	8				536	24	560
	9				442	27	469
11	10	70	29	99	280	29	309
	11				88	31	119
13	12		29	29	0	32	32
	13					31	31
15	14		27	27		29	29
	15					27	27
	16					24	24
18	17		22	22		20	20
	18					17	17
20	19		16	16		12	12

WEST - Jjuly							
Time BSim	Time TCD	BSim			Danvak		
		direct	diffuse	sum	direct	diffuse	sum
6	5		15	15		12	12
	6					17	17
8	7		20	20		20	20
	8					24	24
	9					27	27
11	10		29	29		29	29
	11					31	31
13	12		28	28	0	32	32
	13				88	31	119
15	14	131	27	158	280	29	309
	15				442	27	469
	16				536	24	560
18	17	381	23	404	566	20	586
	18				512	17	529
20	19	152	16	168	360	12	372

C.2 Modified weather file, recess is 0.0001 and ground reflection is 20%

The following tables show the comparison between the sun curves from Danvak and BSim. Both values represent solar transmission through a reference window. This was the second step of the comparison, so the weather data in this case is modified, recess is set to "0.0001", and ground reflection is 20%.

The meaning and importance of recess has been explained in the subsection "5.6.2 Position of a window - Recess". To sum up shortly: when recess is set to "0.0001", it means that the window is aligned to the outer face of the construction so all of the solar radiation can come through. The example is shown in the figure on the right side.



The values show direct, diffuse and reflected component of solar radiation in [W/m^2] through a reference window. Time is divided in the time representation from BSim, which includes DST, and the time representation from the TCD, which corresponds to true solar time.

File: 04 Solar gain-Denmark-recess=0.0001 (modified)

SOUTH									
Time BSim	Time TCD	BSim 1.7.				Danvak 21.7.		Danvak 21.6.	
		direct	diffuse	reflected 0.2	direct + reflected	direct	diffuse	direct	diffuse
6	5		16	4	4		12	0	12
	6						17	0	17
8	7		24	18	18	0	20	0	20
	8					54	24	22	24
	9					180	27	146	27
11	10	228	24	47	275	294	29	254	29
	11					366	31	332	31
13	12	287	25	51	338	392	32	350	32
	13					366	31	332	31
15	14	188	24	45	233	294	29	254	29
	15					180	27	146	27
	16					54	24	22	24
18	17		22	6	6	0	20	0	20
	18						17	0	17
20	19		16	4	4		12	0	12

NORTH									
Time BSim	Time TCD	BSim 1.7.				Danvak 21.7.		Danvak 21.6.	
		direct	diffuse	reflected 0.2	direct + reflected	direct	diffuse	direct	diffuse
6	5	128	16	12	140	124	12	156	12
	6					42	17	62	17
8	7		21	16	16	0	20	0	20
	8						24		24
	9						27		27
11	10		24	7	7		29		29
	11						31		31
13	12		24	7	7		32		32
	13						31		31
15	14		24	7	7		29		29
	15						27		27
	16						24		24
18	17		31	24	24	0	20	0	20
	18					62	17	62	17
20	19	86	16	7	93	124	12	156	12

EAST									
Time BSim	Time TCD	BSim 1.7.				Danvak 21.7.		Danvak 21.6.	
		direct	diffuse	reflected 0.2	direct + reflected	direct	diffuse	direct	diffuse
6	5	406	16	12	418	360	12	402	12
	6					512	17	534	17
8	7	491	22	28	519	566	20	566	20
	8					536	24	536	24
	9					442	27	442	27
11	10	188	24	47	235	280	29	280	29
	11					88	31	88	31
13	12		20	6	6	0	32	0	32
	13						31		31
15	14		24	7	7		29		29
	15						27		27
	16						24		24
18	17		22	6	6		20		20
	18						17		17
20	19		16	4	4		12		12

WEST									
Time BSim	Time TCD	BSim 1.7.				Danvak 21.7.		Danvak 21.6.	
		direct	diffuse	reflected 0.2	direct + reflected	direct	diffuse	direct	diffuse
6	5		16	4	4		12	0	12
	6						17	0	17
8	7		22	6	6		20	0	20
	8						24	0	24
	9						27	0	27
11	10		24	7	7		29	0	29
	11						31	0	31
13	12		30	29	29	0	32	0	32
	13					88	31	88	31
15	14	263	24	45	308	280	29	280	29
	15					442	27	442	27
	16					536	24	536	24
18	17	469	25	23	492	566	20	566	20
	18					512	17	534	17
20	19	177	16	7	184	360	12	402	12

D BSIM SUN CURVES FOR DENMARK

When obtaining sun curves with BSim, two different approaches were analysed. The aim of the first one was to obtain the same values in the east and the west orientation. Such modification resulted in lower accuracy. Therefore, another procedure was tested, where values were not copied or modified. It turned out that this gave better results thus this procedure was chosen for obtaining sun curves with BSim. The results of both approaches are presented further on.

D.1 Copying the values

The following tables show the values of sun curves for Denmark, obtained with BSim. The values represent solar transmission through a reference window. In this case, values from the east are copied to the west orientation, or the other way around. The values in the north are mirrored over the solar noon. Weather file that was used was modified, recess was set to 0.0001, and ground reflection was set to 25%.

The values show total solar radiation (the sum of direct, diffuse and reflected component) in [W/m^2] through a reference window. The time, shown in the table, is true solar time.

These values do not represent the final values, since it has been decided to use the method without copying the values in east, west and north orientation. The chosen procedure with final values is shown in the next section.

File: 08 Sun curves N, E, S, W – with copying

NORTH	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
April	0	0	37	22	25	27	30	30	30	30	30	27	25	22	37	0	0
May	68	97	77	33	31	32	32	33	33	33	32	32	31	33	77	97	68
June	100	138	73	30	32	33	33	33	33	33	33	33	32	30	73	138	100
July	65	93	78	33	31	32	32	33	33	33	32	32	31	33	78	93	65
August	0	0	37	22	25	27	30	30	30	30	30	27	25	22	37	0	0

EAST	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
April	0	0	183	413	534	496	382	212	63	30	30	27	25	21	16	1	0
May	112	298	480	531	515	429	288	146	53	33	33	33	32	31	27	21	8
June	166	434	525	537	496	391	240	109	33	33	33	33	32	30	27	22	10
July	107	284	475	530	517	433	293	150	55	33	33	33	32	31	27	21	8
August	0	0	183	413	534	496	382	212	63	30	30	27	25	21	16	1	0

SOUTH	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
April	0	1	21	74	207	347	455	512	520	485	399	270	129	38	15	0	0
May	8	21	27	66	146	254	344	393	397	357	274	166	76	31	24	18	7
June	10	22	27	63	137	239	324	370	372	332	252	150	71	30	27	22	10
July	8	21	27	66	147	255	346	396	400	359	276	167	77	31	24	18	6
August	0	1	21	74	207	347	455	512	520	485	399	270	129	38	15	0	0

WEST	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
April	0	1	16	21	25	27	30	30	63	212	382	496	534	413	183	0	0
May	8	21	27	31	32	33	33	33	53	146	288	429	515	531	480	298	112
June	10	22	27	30	32	33	33	33	33	109	240	391	496	537	525	434	166
July	8	21	27	31	32	33	33	33	55	150	293	433	517	530	475	284	107
August	0	1	16	21	25	27	30	30	63	212	382	496	534	413	183	0	0

D.2 Without copying the values

The following tables show the values of sun curves for Denmark, obtained with BSim. The values represent solar transmission through a reference window. In this case, the values from east, west and north orientation are not modified. Weather file that was used was modified, recess was set to 0.0001, and ground reflection was set to 25%.

The values show total solar radiation (the sum of direct, diffuse and reflected component) in [W/m^2] through a reference window. Values were first obtained for north, east, south and west orientation. Afterwards, the model was rotated and the values for north-east, south-east, south-west and north-west were obtained. The time, shown in the table, is true solar time.

These values represent the final values, since the chosen procedure is the one without copying the values in east, west and north orientation.

File: 09 Sun curves N, E, S, W – without copying
File: 10 Sun curves NE, SE, SW, NW – without copying

NORTH	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
April	0	3	21	21	25	27	30	30	30	30	30	27	25	22	37	0	0
May	69	119	67	31	32	33	33	33	33	33	32	32	31	59	119	88	7
June	100	138	73	30	32	33	33	33	33	33	33	33	32	69	135	124	11
July	66	117	67	31	32	33	33	33	33	33	32	32	31	58	118	84	7
August	0	3	21	21	25	27	30	30	30	30	30	27	25	22	37	0	0

NORTHEAST	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
April	0	11	156	225	156	67	30	30	30	30	30	27	25	21	15	0	0
May	130	365	403	339	214	101	33	33	33	33	32	32	31	28	24	18	7
June	190	420	426	346	219	104	33	33	33	33	33	33	32	30	27	22	11
July	124	359	400	338	214	100	33	33	33	33	32	32	31	28	24	18	7
August	0	11	156	225	156	67	30	30	30	30	30	27	25	21	15	0	0

EAST	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
April	0	12	214	417	490	418	271	115	30	30	30	27	25	21	15	0	0
May	114	380	501	534	500	399	248	112	33	33	32	32	31	28	24	18	7
June	166	434	525	537	496	391	240	109	33	33	33	33	32	30	27	22	10
July	109	374	499	534	500	400	249	112	33	33	32	32	31	28	24	18	6
August	0	12	214	417	490	418	271	115	30	30	30	27	25	21	15	0	0

SOUTHEAST	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
April	0	6	151	357	511	552	531	445	312	153	51	27	25	21	15	0	0
May	27	158	300	408	470	479	437	344	216	104	32	32	31	28	24	18	7
June	38	175	307	403	459	463	417	323	199	97	33	33	32	30	27	22	10
July	26	157	299	408	471	480	439	346	218	104	32	32	31	28	24	18	6
August	0	6	151	357	511	552	531	445	312	153	51	27	25	21	15	0	0

SOUTH	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
April	0	1	21	74	207	347	455	512	520	485	399	270	129	38	15	0	0
May	8	21	27	66	146	254	344	393	397	357	274	166	76	31	24	18	7
June	10	22	27	63	137	239	324	370	372	332	252	150	71	30	27	22	10
July	8	21	27	66	147	255	346	396	400	359	276	167	77	31	24	18	6
August	0	1	21	74	207	347	455	512	520	485	399	270	129	38	15	0	0

SOUTHWEST	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
April	0	1	16	21	25	27	108	252	397	512	565	558	489	310	112	0	0
May	8	21	27	31	32	33	91	193	323	426	478	480	429	329	195	48	7
June	10	22	27	30	32	33	89	183	307	406	458	461	414	323	198	65	11
July	8	21	27	31	32	33	91	194	325	428	480	482	430	330	195	46	7
August	0	1	16	21	25	27	108	252	397	512	565	558	489	310	112	0	0

WEST	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
April	0	1	16	21	25	27	30	30	63	212	382	496	534	413	183	0	0
May	8	21	27	31	32	33	33	33	98	221	378	491	542	526	430	143	7
June	10	22	27	30	32	33	33	33	99	219	372	483	536	531	452	206	11
July	8	21	27	31	32	33	33	33	98	221	378	492	543	526	428	137	7
August	0	1	16	21	25	27	30	30	63	212	382	496	534	413	183	0	0

NORTHWEST	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
April	0	1	16	21	25	27	30	30	30	30	47	121	245	272	153	0	0
May	8	21	27	31	32	33	33	33	33	33	89	192	325	407	402	159	7
June	10	22	27	30	32	33	33	33	33	33	94	201	333	420	428	229	11
July	8	21	27	31	32	33	33	33	33	33	89	191	324	406	399	152	7
August	0	1	16	21	25	27	30	30	30	30	47	121	245	272	153	0	0

D.3 Sun curves for a horizontal window

The following table shows the values of sun curves for a horizontal window for Denmark, obtained with BSim. The values represent solar transmission through a horizontal reference window. In this case, the chosen procedure is used (values are not copied or modified). The weather file that was used was modified, recess was set to 0.0001, and ground reflection was set to 25%.

The values show total solar radiation (the sum of direct, diffuse and reflected component) in [W/m^2] through a horizontal reference window. The time, shown in the table, is true solar time.

These values represent the final values for a horizontal window, since the chosen procedure is used.

File: 11 Sun curves HORIZONTAL – without copying

HORIZONT.	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
April	0	2	42	112	222	318	392	430	435	413	357	271	170	76	32	0	0
May	20	72	152	256	358	442	501	533	539	518	469	394	297	191	101	43	15
June	25	83	167	269	370	451	506	536	542	523	478	407	315	212	118	53	22
July	20	71	151	254	357	441	500	532	539	518	468	393	295	189	100	42	14
August	0	2	42	112	222	318	392	430	435	413	357	271	170	76	32	0	0

E BSIM SUN CURVES FOR SLOVENIA

When analysing sun curves for Denmark, it was decided, that the procedure without copying and modifying values was going to be used. Therefore, in the case of Slovenia, only this procedure was used.

The following tables show the values of sun curves for Slovenia, obtained with BSim. The values represent solar transmission through a reference window. In this case, the values from east, west and north orientation are not modified. The weather file that was used was modified, recess was set to 0.0001, and ground reflection was set to 25%.

The values show total solar radiation (the sum of direct, diffuse and reflected component) in [W/m^2] through a reference window. Values were first obtained for north, east, south and west orientation. Afterwards, the model was rotated and values for north-east, south-east, south-west and north-west were obtained. The time, shown in the table, is true solar time.

These values represent the final values, since the chosen procedure is the one without copying the values in east, west and north orientation.

File: 13 Sun curves N, E, S, W
File: 14 Sun curves NE, SE, SW, NW

NORTH	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
April	0	1	12	32	43	45	44	41	41	40	41	39	27	8	1	0	0
May	0	20	72	55	44	44	44	44	44	44	44	44	54	66	21	0	0
June	0	0	65	70	44	44	44	44	44	44	44	44	57	86	81	0	0
July	0	26	66	53	44	44	44	44	44	44	44	44	52	67	43	0	0
August	0	1	12	32	43	45	44	41	41	40	41	39	27	8	1	0	0

NORTHEAST	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
April	0	1	23	117	110	63	44	41	41	40	41	39	27	6	1	0	0
May	0	23	232	302	240	132	66	44	44	44	44	44	43	34	16	0	0
June	0	0	165	295	276	169	94	44	44	44	44	44	44	41	30	0	0
July	0	38	224	296	247	144	68	44	44	44	44	44	41	36	20	0	0
August	0	1	23	117	110	63	44	41	41	40	41	39	27	6	1	0	0

EAST	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
April	0	1	27	220	344	329	213	94	41	40	41	39	27	6	1	0	0
May	0	23	275	434	465	383	244	117	44	44	44	44	43	34	16	0	0
June	0	0	182	385	455	395	268	136	44	44	44	44	44	41	30	0	0
July	0	38	260	410	448	387	259	127	44	44	44	44	41	36	20	0	0
August	0	1	27	220	344	329	213	94	41	40	41	39	27	6	1	0	0

SOUTHEAST	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
April	0	1	21	207	384	468	463	382	252	118	53	39	27	6	1	0	0
May	0	21	176	322	409	419	373	276	162	72	44	44	43	34	16	0	0
June	0	0	109	260	364	385	349	267	165	73	44	44	44	41	30	0	0
July	0	27	158	295	382	405	373	284	171	74	44	44	41	36	20	0	0
August	0	1	21	207	384	468	463	382	252	118	53	39	27	6	1	0	0

SOUTH	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
April	0	1	10	86	209	337	432	480	478	418	312	178	61	7	1	0	0
May	0	16	38	60	119	196	268	308	310	269	198	117	60	34	16	0	0
June	0	0	30	41	89	148	214	258	268	240	182	115	61	41	30	0	0
July	0	14	31	55	105	178	253	299	306	271	200	119	58	36	20	0	0
August	0	1	10	86	209	337	432	480	478	418	312	178	61	7	1	0	0

SOUTHWEST	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
April	0	1	10	32	43	61	148	285	412	476	464	357	150	17	1	0	0
May	0	16	38	43	44	44	71	162	277	374	422	404	327	185	23	0	0
June	0	0	30	41	44	44	44	123	219	319	382	397	359	246	99	0	0
July	0	14	31	41	44	44	68	148	262	366	416	397	314	171	50	0	0
August	0	1	10	32	43	61	148	285	412	476	464	357	150	17	1	0	0

WEST	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
April	0	1	10	32	43	45	44	41	114	245	348	334	166	22	1	0	0
May	0	16	38	43	44	44	44	44	117	244	386	459	441	296	28	0	0
June	0	0	30	41	44	44	44	44	74	204	349	457	496	407	190	0	0
July	0	14	31	41	44	44	44	44	110	232	376	448	422	266	78	0	0
August	0	1	10	32	43	45	44	41	114	245	348	334	166	22	1	0	0

NORTHWEST	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
April	0	1	10	32	43	45	44	41	41	40	63	118	99	19	1	0	0
May	0	16	38	43	44	44	44	44	44	66	133	238	306	247	28	0	0
June	0	0	30	41	44	44	44	44	44	66	127	237	343	340	183	0	0
July	0	14	31	41	44	44	44	44	44	66	128	229	290	223	75	0	0
August	0	1	10	32	43	45	44	41	41	40	63	118	99	19	1	0	0

E.1 Sun curves for a horizontal window

The following tables show the values of sun curves for a horizontal window for Slovenia, obtained with BSim. The values represent solar transmission through a horizontal reference window. In this case, the chosen procedure is used (values are not copied or modified). The weather file that was used was modified, recess was set to 0.0001, and ground reflection was set to 25%.

The values show total solar radiation (the sum of direct, diffuse and reflected component) in [W/m^2] through a horizontal reference window. The time, shown in the table, is true solar time.

These values represent the final values for a horizontal window, since the chosen procedure is used.

File: 15 Sun curves HORIZONTAL

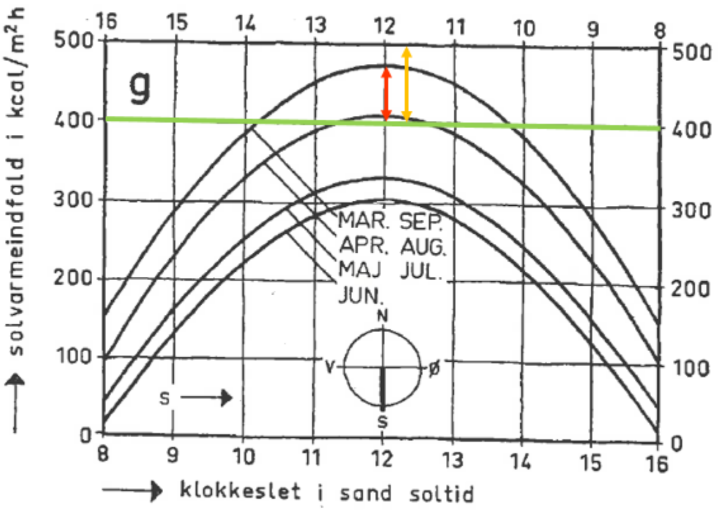
HORIZONT.	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
April	0	1	21	91	189	291	369	409	407	355	269	165	74	15	1	0	0
May	0	34	118	236	369	469	540	574	577	543	473	366	240	114	33	0	0
June	0	0	91	223	367	470	541	580	588	560	503	416	304	172	74	0	0
July	0	29	101	218	347	456	539	586	595	567	495	382	247	121	46	0	0
August	0	1	21	91	189	291	369	409	407	355	269	165	74	15	1	0	0

F OTHER LITERATURE

F.1 Obtaining the values

The values from other literature were obtained by manually measuring the distances with a ruler. To be more accurate, the graphs were first scanned in order to obtain a digital form. Values were measured by using a PDF viewer that has a measuring tool. Having graphs in a digital form allows you to enlarge the image which results in having values that are more accurate with less effort.

The procedure for obtaining the values follows the idea of cross-multiplication. An example is shown in the following figure, which shows direct solar radiation through a reference window. First, the distance, marked with orange, is measured. This distance represents 100 kcal/m^{2}h. Then, the distance, marked with red, is measured. This distance represents the intersection of the curve. Knowing that the green line represents 400 kcal/m^{2}h, the value can be calculated.



For example, if one wants to know the value for March or September at noon, the marked distances should be measured:

- Orange: 11.39 mm
- Red: 8.31 mm

That means that:

100 kcal/m^{2}h………….11.39 mm
x kcal/m^{2}h…………….8.31 mm

Unknown value "x" can be calculated with a cross-multiplication, as shown:

$$x = \frac{8.31\ mm \cdot 100\ kcal/m^2h}{11.39\ mm} = 72.9\ kcal/m^2h$$

By adding 400 kcal/m^{2}h to this value, the direct component can be obtained. In order to get total solar radiation, the diffuse and reflected component need to be added as well. They can be obtained by following the same procedure.

- Direct component: 473 kcal/m^{2}h
- Diffuse component: 20.9 kcal/m^{2}h
- Reflected (25% ground reflection) component: 39.8 kcal/m^{2}h

Total solar radiation is therefore 533.7 kcal/m^{2}h. By multiplying it with 1.16298, one can obtain the value in [W/m^2], which is 621 W/m^2.

All the other values have been calculated in the same way. They are shown in the tables in the following sections.

F.2 Poul Becher

Becher's sun curves represent total solar radiation in [W/m^2] as a sum of direct, diffuse and reflected component with 25% of ground reflection. For the purposes of comparison, only south, west and east orientation were needed. Becher also includes values for a horizontal window. Following the instructions in the book, the values for a horizontal window were formed as a sum of the direct component and 2-times diffuse component. The unit is again [W/m^2]. In all of the cases, a reference window is used and hours are shown in true solar time.

SOUTH	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Mar, Sep			0	16	218	380	508	590	621	590	508	380	218	16	0		
Apr, Aug		0	16	38	169	337	463	543	571	543	463	337	169	38	16	0	
May, Jul	3	11	20	48	119	270	382	464	493	464	382	270	119	48	27	11	3
June	7	13	35	55	91	240	354	437	469	437	354	240	91	55	35	13	7

WEST	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Mar, Sep			0	16	33	46	57	65	71	156	331	472	504	415	0		
Apr, Aug		0	16	38	54	68	79	89	95	196	390	521	591	570	445	106	
May, Jul	3	11	27	48	64	78	90	99	107	195	381	519	599	612	536	386	79
June	7	13	35	55	71	86	97	107	114	202	388	526	606	623	563	437	220

EAST	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Mar, Sep			0	415	504	472	331	156	71	65	57	46	33	16	0		
Apr, Aug		106	445	570	591	521	390	196	95	89	79	68	54	38	16	0	
May, Jul	79	386	536	612	599	519	381	195	107	99	90	78	64	48	27	11	3
June	220	437	563	623	606	526	388	202	114	107	97	86	71	55	35	13	7

HORIZONTAL	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Mar, Sep									514								
Apr, Aug		0	72	197	326	458	582	658	676	658	582	458	326	197	72	0	
May, Jul	6	74	192	322	455	586	684	741	762	741	684	586	455	322	192	74	6
June	44	122	259	380	514	636	723	779	799	779	723	636	514	380	259	122	44

F.3 Danvak's 1st edition

Danvak's 1st edition represent total solar radiation in [W/m^2]. It is not specified in the book, what these values include. However, it can be assumed that total solar radiation represents a sum of direct, diffuse and reflected component with 25% of ground reflection. For the purposes of comparison only south, west and east orientation were needed. The values represent solar transmission through a reference window in true solar time.

SOUTH	6	7	8	9	10	11	12	13	14	15	16	17	18
Mar, Sep	0	53	188	362	505	594	628	594	505	362	188	53	0
Apr, Aug	29	61	173	329	462	552	583	552	462	329	173	61	29
May, Jul	44	67	142	260	394	487	511	487	394	260	142	67	44
June	53	75	123	237	368	452	480	452	368	237	123	75	53

WEST	9	10	11	12	13	14	15	16	17	18	19	20
Mar, Sep	57	69	78	87	164	326	445	453	334	7		
Apr, Aug	76	91	101	114	194	369	509	580	528	349	82	
May, Jul	87	102	112	126	209	372	530	608	602	496	301	62
June	97	111	122	134	214	377	537	621	623	541	359	118

EAST	4	5	6	7	8	9	10	11	12	13	14	15
Mar, Sep			7	334	453	445	326	164	87	78	69	57
Apr, Aug		82	349	528	580	509	369	194	114	101	91	76
May, Jul	62	301	496	602	608	530	372	209	126	112	102	87
June	118	359	541	623	621	537	377	214	134	122	111	97

G SIMULATION RESULTS

The results from simulations where different solar models, ground reflection, and recess were tested in BSim and compared with the results from the TCD are shown in the following tables. For Denmark and Slovenia, three different window sizes were tested (equivalent to 22%, 27% and 51% of floor area) and three different orientations. For each simulation, minimum, mean and maximum temperature was compared. For BSim and the TCD, the air change is written as well, marked with "AC". Following subsections show results for Denmark and Slovenia. The temperatures are in [°C].

The simulations correspond to window areas, shown in the following table.

	22% of floor area	**27% of floor area**	**51% of floor area**
Windows area [m^2]	5.0	6.2	11.8
One window area [m^2]	2.5	3.1	5.9
One glazing area [m^2]	2.1	2.6	5.2
Glazing area of both windows [m^2]	4.2	5.2	10.4

G.1 Simulation results for Denmark

The explanation of symbols in the table for the location in Denmark:

*	Petersen's solar model, ground reflection is 20%, recess is 0.001
**	Munier's solar model, ground reflection is 25%, recess is 0.0001
+	Original (Danvak's) sun curves
++	Modified sun curves
TCD Becher	Becher's sun curves
AC	Air change

			BSim						TCD			
			1 Jul *	6 Aug *	1 Jul **	6 Aug **	11 Jun **	AC [m3/s]	TCD +	TCD ++	TCD Becher	AC [1/h]
22%	South	Min T	19.3	19.1	19.3	19.0	18.6		19.4	18.9	19.2	
		Mean T	22.0	22.0	22.0	21.9	20.5	0.104	23.0	23.3	23.3	6
		Max T	24.1	24.5	24.0	24.4	22.6		26.6	27.1	26.8	
	West	Min T	19.6	19.1	19.5	19.2	19.6		19.9	19.4	19.8	
		Mean T	22.2	21.9	22.1	21.9	20.5	0.096	23.0	23.1	23.7	5.55
		Max T	24.3	24.4	24.3	24.3	22.0		26.1	26.6	26.2	
	East	Min T	19.7	19.1	19.5	19.1	18.7		19.4	19.7	19.7	
		Mean T	22.2	21.9	22.1	21.8	20.7	0.097	23.0	22.9	23.4	5.6
		Max T	23.9	23.9	23.7	23.7	22.8		26.6	26.3	26.3	
27%	South	Min T	19.3	19.0	19.2	19.0	18.6		19.0	17.7	18.9	
		Mean T	22.1	22.1	22.0	22.0	20.5	0.109	23.0	24.0	23.5	6.3
		Max T	24.4	24.9	24.3	24.8	22.9		27.0	28.4	27.1	
	West	Min T	19.5	19.1	19.4	19.1	18.5		19.8	19.2	19.6	
		Mean T	22.3	22.1	22.2	21.9	20.9	0.1	23.0	23.2	23.8	5.8
		Max T	24.6	24.6	24.6	24.6	23.4		26.2	26.8	26.5	
	East	Min T	19.7	19.1	19.5	19.0	18.7		19.2	19.5	19.5	
		Mean T	22.3	22.0	22.1	21.9	20.8	0.1	23.0	23.0	23.6	5.8
		Max T	24.1	24.0	23.9	23.8	23.1		26.8	26.5	26.6	
51%	South	Min T	18.8	18.2	18.6	18.0	18.1		18.1	16.7	17.1	
		Mean T	22.3	22.4	22.1	22.2	20.6	0.14	23.0	23.7	23.8	8.1
		Max T	25.4	26.3	25.3	26.2	23.6		28.0	29.3	28.9	
	West	Min T	19.2	18.5	19.0	18.4	18.2		19.3	17.9	18.4	
		Mean T	22.9	22.5	22.5	22.2	21.6	0.121	23.0	23.5	24.6	7
		Max T	25.8	25.9	25.7	25.7	25.2		26.7	28.1	27.6	
	East	Min T	19.3	18.2	19.0	18.2	18.0		18.3	18.5	18.2	
		Mean T	22.6	22.2	22.4	22.0	21.2	0.123	23.0	23.0	24.0	7.1
		Max T	25.1	25.0	24.9	24.8	24.3		27.7	27.5	27.8	

G.2 Simulation results for Slovenia

In the case of Slovenia, only one kind of BSim and TCD results is used. In BSim, Munier's solar model was used with 25% of ground reflection. The sun curves in the TCD are the ones, obtained in this project.

			BSim				TCD	
			30 Jun	27 July	16 Aug	AC [m3/s]	TCD	AC [1/h]
22%	South	Min T	18.5	19.0	18.4	0.102	19.0	5.9
		Mean T	21.5	22.6	22.0		23.0	
		Max T	25.1	26.3	26.0		27.0	
	West	Min T	18.6	19.0	18.5	0.095	19.5	5.5
		Mean T	21.8	23.0	22.2		23.0	
		Max T	25.7	27.1	26.6		26.5	
	East	Min T	18.7	19.0	18.7	0.088	20.0	5.1
		Mean T	21.7	23.0	22.2		23.0	
		Max T	25.4	26.6	26.1		26.0	
27%	South	Min T	18.4	18.9	18.4	0.109	18.7	6.3
		Mean T	21.6	22.8	22.2		23.0	
		Max T	25.5	27.2	26.7		27.3	
	West	Min T	18.6	19.1	18.5	0.1	19.3	5.8
		Mean T	22.0	23.4	22.4		23.0	
		Max T	26.5	28.3	27.8		26.7	
	East	Min T	18.6	19.0	18.5	0.092	19.9	5.3
		Mean T	21.9	23.2	22.4		23.0	
		Max T	25.7	27.6	26.8		26.1	
51%	South	Min T	18.7	20.4	18.5	0.14	17.0	8.1
		Mean T	22.5	24.2	22.5		23.0	
		Max T	25.7	27.7	26.4		29.0	
	West	Min T	18.5	20.8	18.8	0.123	18.1	7.1
		Mean T	23.4	24.6	22.7		23.0	
		Max T	27.0	28.2	26.7		27.9	
	East	Min T	18.0	18.5	17.9	0.107	19.4	6.2
		Mean T	22.9	24.4	23.2		23.0	
		Max T	28.9	32.3	31.7		26.6	

H NORWEGIAN SUN CURVES

Norwegian sun curves from *Inneklimateknikk* book (Stensaas, 2000) represent total solar radiation through a single glazed vertical window for all eight orientations and a horizontal window. They correspond to the 15th of the month through the summer period (May, June, July, and August). The three following tables show three different latitudes - 60° N, 64° N and 68° N.

Månad	Klokkeslett	Solinnstråling i W/m² gjennom enkelt vindaugsglas mot:								
	↓ →	N	NØ	Ø	SØ	S	SV	V	NV	HOR
	4 og 20	1	2	1	0	0	0	0	0	0
	5 » 19	135	366	371	149	22	22	22	22	51
	6 » 18	87	508	621	367	44	42	42	47	148
	7 » 17	61	471	718	546	73	57	57	57	272
15. mai	8 » 16	69	333	706	658	212	69	69	69	395
	9 » 15	80	154	610	708	390	82	80	80	498
	10 » 14	87	92	447	689	532	105	87	87	576
	11 » 13	92	92	232	605	619	266	97	92	625
	12	93	93	100	461	649	461	100	93	641
	4 » 20	121	206	169	26	11	11	11	11	21
	5 » 19	198	487	479	177	32	32	32	32	93
	6 » 18	116	555	656	368	50	48	48	48	202
	7 » 17	68	498	724	525	70	62	62	62	327
15. juni	8 » 16	74	357	700	630	181	74	74	74	446
	9 » 15	84	175	602	673	348	85	84	84	545
	10 » 14	91	97	440	652	487	102	91	91	620
	11 » 13	95	95	230	569	573	238	95	95	667
	12	97	97	104	426	602	426	104	97	684
	4 » 20	65	112	93	15	6	6	6	6	11
	5 » 19	173	439	437	166	28	28	28	28	75
	6 » 18	104	532	636	363	97	45	45	45	180
	7 » 17	65	484	715	526	70	60	60	60	305
15. juli	8 » 16	72	346	697	634	190	72	72	72	425
	9 » 15	82	166	601	680	360	84	82	82	525
	10 » 14	89	95	440	660	499	102	89	89	601
	11 » 13	93	93	229	578	585	245	93	93	649
	12	95	95	102	435	614	435	102	95	665
	4 » 20									
	5 » 19	44	134	140	60	7	7	7	7	14
	6 » 18	56	408	518	321	34	32	32	32	92
	7 » 17	52	419	670	525	77	49	49	49	206
15. august	8 » 16	63	297	683	659	235	63	63	63	329
	9 » 15	73	129	598	718	418	76	73	73	436
	10 » 14	81	85	441	705	559	110	81	81	516
	11 » 13	86	86	227	624	648	287	86	86	566
	12	87	87	94	483	679	483	94	87	582
60° N	↑ →	N	NV	V	SV	S	SØ	Ø	NØ	HOR

Månad	Klokkeslett ↓ →	Solinnstråling i W/m² gjennom enkelt vindaugsglas mot:								
		N	NØ	Ø	SØ	S	SV	V	NV	HOR
15. mai	4 og 20	63	112	94	17	6	6	6	6	10
	5 » 19	153	424	434	178	27	27	27	27	68
	6 » 18	81	509	634	383	46	43	43	43	157
	7 » 17	60	454	714	554	81	56	56	56	267
	8 » 16	67	306	697	670	238	67	67	67	374
	9 » 15	76	131	601	722	421	79	76	76	466
	10 » 14	83	87	439	706	563	114	83	83	534
	11 » 13	87	87	225	625	652	292	87	87	577
	12	88	88	96	486	682	486	96	88	591
15. juni	4 » 20	203	347	285	47	19	19	19	20	43
	5 » 19	207	525	523	200	36	36	36	36	115
	6 » 18	106	553	667	386	52	50	50	50	214
	7 » 17	67	479	722	541	76	62	62	62	324
	8 » 16	72	328	694	647	209	72	72	72	428
	9 » 15	81	149	594	692	385	83	81	81	516
	10 » 14	87	92	433	674	525	107	87	87	582
	11 » 13	91	91	224	594	611	266	91	91	623
	12	92	92	100	455	640	455	92	92	637
15. juli	4 » 20	153	265	220	37	14	14	14	15	30
	5 » 19	185	484	486	191	32	32	32	32	95
	6 » 18	95	531	648	381	49	47	47	47	191
	7 » 17	64	466	712	540	76	59	59	59	301
	8 » 16	70	318	689	649	217	70	70	70	406
	9 » 15	79	141	592	697	395	81	79	79	495
	10 » 14	85	90	432	680	534	108	85	85	562
	11 » 13	89	89	223	601	621	273	89	89	603
	12	90	90	98	463	651	463	98	90	618
15. august	5 » 19	70	216	227	99	12	12	12	12	25
	6 » 18	53	414	532	335	35	33	33	33	98
	7 » 17	51	403	662	530	85	48	48	48	198
	8 » 16	60	272	670	663	255	60	60	60	305
	9 » 15	69	110	585	725	440	73	69	69	399
	10 » 14	76	80	430	715	583	119	76	76	470
	11 » 13	81	81	220	638	673	309	81	81	514
	12 » 12	82	82	89	501	704	501	89	82	529
64°	↑ →	N	NV	V	SV	S	SØ	Ø	NØ	HOR

Månad	Klokkeslett	Solinnstråling i W/m² gjennom enkelt vindaugsglas mot:								
	↓ →	N	NØ	Ø	SØ	S	SV	V	NV	HOR
15. mai	4 og 20	150	270	228	43	14	14	14	15	29
	5 » 19	165	470	485	205	31	31	31	31	85
	6 » 18	74	508	644	399	47	44	44	44	165
	7 » 17	59	436	709	564	91	56	56	56	259
	8 » 16	65	280	686	679	262	65	65	65	351
	9 » 15	73	111	589	732	447	76	73	73	429
	10 » 14	79	82	429	718	589	124	79	79	489
	11 » 13	82	82	218	640	679	314	82	82	525
	12 » 12	83	83	90	505	710	505	90	83	538
15. juni	4 » 20	261	451	374	65	27	27	27	28	69
	5 » 19	211	554	559	223	40	40	40	40	137
	6 » 18	95	549	677	405	54	51	51	51	224
	7 » 17	65	460	719	556	85	61	61	61	319
	8 » 16	70	300	686	661	237	70	70	70	408
	9 » 15	78	126	585	708	418	81	78	78	483
	10 » 14	83	87	424	692	557	117	83	83	540
	11 » 13	87	87	218	614	644	292	87	87	575
	12 » 12	88	88	95	479	673	479	95	88	588
15. juli	4 » 20	221	387	323	58	22	22	22	23	53
	5 » 19	192	518	527	215	36	36	36	36	116
	6 » 18	86	528	658	398	51	48	48	48	201
	7 » 17	62	447	708	553	86	59	59	59	295
	8 » 16	68	290	680	661	243	68	68	68	385
	9 » 15	75	120	582	711	425	79	75	75	461
	10 » 14	81	85	423	696	564	118	81	81	519
	11 » 13	84	84	217	619	651	297	84	84	555
	12 » 12	86	86	93	485	681	485	93	86	567
15. august	4 » 20	4	8	7	1	0	0	0	0	1
	5 » 19	92	288	304	135	17	17	17	17	37
	6 » 18	51	417	543	349	37	34	34	34	103
	7 » 17	49	385	652	533	94	47	47	47	189
	8 » 16	57	248	654	664	272	57	57	57	279
	9 » 15	66	94	570	727	457	69	66	66	359
	10 » 14	72	74	418	720	600	129	72	72	421
	11 » 13	75	75	211	646	691	326	75	75	459
	12 » 12	77	77	83	513	723	513	83	77	472
68°	↑ →	N	NV	V	SV	S	SØ	Ø	NØ	HOR