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Creating custom BSim weather files using a decomposition of global solar radiation to direct and diffuse solar radiation

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DEPARTMENT OF THE BUILT ENVIRONMENT
AALBORG UNIVERSITY

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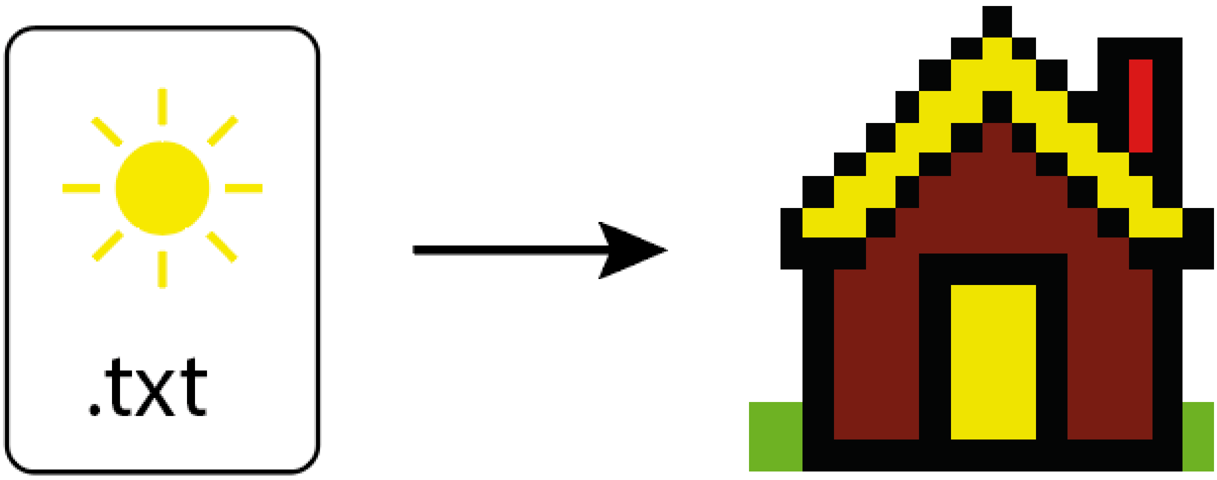
Martin Veit
Martin Frandsen



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Aalborg University
Department of the Built Environment
Division of Sustainability, Energy & Indoor Environment

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Creating custom BSim weather files using a decomposition of global solar radiation to direct and diffuse solar radiation

by

Martin Veit
Martin Frandsen

June 2023

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Table of Contents

1 Foreword

Weather data is an essential part of performing building performance simulations, as conditions such as outdoor temperature, solar irradiance, humidity etc. has a direct impact on the building under investigation. The Danish building regulations requires a specific weather data file to be used in the simulation for compliance of the indoor environment quality. However, in other cases, it can be useful to compare measurements of the indoor environmental data of a building with simulation results. To obtain accurate results, it is adviced to use the actual weather data for the building location, as it will otherwise yield erroneous results. One of the largest difficulties with creating a custom weather file, is using a solar irradiance model to decompose the global solar radiation to diffuse and direct radiation, which is used in the building performance simulation software *BSim*.

This lecture note will go through the theoretical background and the practical implementation in Excel, to make the use of weather data more approachable for students and faculty at Aalborg University, Department of the Built Environment (https://www.en.build.aau.dk/). An Exceel spreadsheet is uploaded as an appendix to this lecture note, with the implementation of the shown theoretical background from this lecture note.

2 Introduction and motivations

The following guide is used to determine the direct and diffuse solar radiation, such that custom weather files can be created and inserted into BSim. The steps of calculating the direct and diffuse solar radiation, and the implementation into BSim is shown. A detailed procedure to recreate the steps is given in section 2 while the practical approach with a custom-made Excel sheet and BSim is shown in section 3 and 4, respectively. Finally, appendix A explains the procedure for calculating the sun altitude, which is needed to perform the decomposition of global radiation. The calculation of the sun altitude is implemented in the Excel sheet, but for clarity it is explained in the appendix.

3 Theoretical basis

This section is based on [1] unless otherwise specified.

For each hour each year, the direct and diffuse solar radiation is calculated. Therefore, it is advised to use Excel (either the specific Excel spreadsheet made for this lecture note or a custom one made by the user of this guide).

3.1 Assumptions

For each hour, the following data has to be determined.

Table 1. *Variables needed to perform calculation procedure. *Check to see if all the hourly data is there, otherwise, the missing hours can be substituted for the corresponding hours in another year.*

Variable	Symbol	Where to find
Minimum temperature in the morning (Before 8 am)	t_{min}	DMI, using API or manual download*.
Global solar radiation	G_h	DMI
Day number	DN	Determine manually
Sun altitude	h_s	Is calculated hourly based on the latitude and longitude, see appendix A.

3.2 Calculation procedure

For the given day, the distance factor, *DA,* between the sun and earth, is calculated. This is given by equation **(1)**.

$$DA = 1 + 0.0334 \cdot \cos\left(\frac{\pi \cdot DN}{182.5}\right) \qquad (1)$$

After this, the cosmic radiation, I_e, on the horizontal plane is calculated using equation **(2)**.

$$I_e = 1353 \cdot DA \cdot \sin\left(h_s \cdot \frac{\pi}{180}\right) \qquad (2)$$

The absolute humidity, $RMIN$, is calculated using equation **(3)**.

$$RMIN = 0.165 + 0.004 \cdot t_{min} \qquad (3)$$

Important: For values of $RMIN$ lower than 0.14, the equation should be ignored, and 0.14 should be used.

The ratio between the global and cosmic radiation, K_t, is calculated using equation **(4)**.

$$K_t = \frac{G_h}{I_e} \quad (4)$$

Based on the value of the ratio, the relation to the absolute humidity, $RELD$, is calculated using different equations, see below. [2]

$$RELD = \begin{cases} 1 - 0.249\,K_t & \textit{if} \quad 0 \le K_t < 0.35 \\ 0.913 - \dfrac{(0.913 - RMIN)\cdot(K_t - 0.36)}{0.4} & \textit{if} \quad 0.35 \le K_t \le 0.75 \\ RMIN & \textit{if} \quad 0.75 \le K_t \end{cases} \quad (5)$$

Finally, the direct, I_0, and diffuse solar radiation, D_h, is calculated for the given hour, using equation **(6)** and **(7)**, respectively.

$$I_0 = G_h \cdot \frac{1-RELD}{\sin\left(h_s \cdot \frac{\pi}{180}\right)} \quad (6)$$

$$D_h = G_h - I_0 \cdot \sin\left(h_s \cdot \frac{\pi}{180}\right) \quad (7)$$

To avoid having unrealistic large values for direct radiation, the computed values are checked. This is shown in the following section.

3.3 Control of computed values of direct radiation

This method is based on [1], and uses the relative density of air, based upon an empirical approximation dependent on the sun altitude, an 'apparent solar constant' and a maximum reasonable direct normal radiation.

Firstly, the relative density of air, m_{air}, is approximated, using equation **(8)**.

$$m_{air} = \frac{1.02}{\sin\,(h_s + 0.02)} \quad (8)$$

Next, the extinction coefficient, EXT, for the day is calculated using equation **(9)**.

$$EXT = 0.007\,T_{min} + 0.12 \quad (9)$$

IMPORTANT: *If the temperature, T_{min}, is less than 10 °C, then the extinction coefficient should be equal to 0.05.*

The maximum reasonable direct normal radiation, I_{max}, can then be calculated using equation **(10)**.

$$I_{max} = C_{sun} \cdot DA \cdot EXP(-EXT \cdot m_{air}) \quad (10)$$

Where C_{sun} is the apparent solar constant, with a value of $419\,\frac{\mathrm{J}}{\mathrm{cm}^2}$, which can be rewritten to $1164\,\frac{\mathrm{W}}{\mathrm{m}^2}$. The computed direct radiation, I_0, from equation **(6)** is then compared to the maximum value.

If $I_O > I_{max} + 56\,\frac{\mathrm{W}}{\mathrm{m}^2}$, then I_0 is reduced to I_{max} and diffuse radiation is recalculated using equation **(7)**.

Using this calculation and control procedure, it is possible to calculate the direct and diffuse solar radiation for each hour, using the global solar radiation. This is implemented in Excel, as shown in the following section.

4 Implementation in Excel

In the following, the implementation is shown in Excel. This will feature a custom-made Excel spreadsheet, which includes the equations presented in section 3. The different columns will be explained, along with which equations and information are used.

The Excel sheet 'Calculations' includes the calculation for each hour of a year, however, only a single day is shown in Figure 1. Only colored columns require user input. In the sheet 'Main window', a description of the sheet is given, along with a step by stop on how to use the sheet.

Important: *User input is needed in sheet 'Main window', as the latitude, longitude and time zone need to be inserted.*

Calculation of direct and diffuse radiation

	A	B	C	D	E	F	G	H	I	J	K
2	Day number	Hour	Distance factor	Air temperature (from DMI)	Min. temperature until 8.00 am	Fraction year in radians	Equation of time	Declination	Solar hour angle	Sun altitude	Cosmic radiation
3	DN	h	DA	T_{air}	T_{min}	V	EoT	D	H	h_s	I_o
4	[-]	[h]	[-]	[°C]	[°C]	[rad]	[-]	[°]	[°]	[°]	[W/m²]
5	1	0	1,03	5,8	0	-0,01	-2,68	-23,01	-183,07	-57,33	-1177
6	1	1	1,03	5,9	0	-0,01	-2,70	-23,01	-168,07	-56,24	-1162
7	1	2	1,03	5,7	0	-0,01	-2,72	-23,01	-153,08	-51,83	-1099
8	1	3	1,03	5,3	0	-0,01	-2,74	-23,01	-138,08	-45,19	-992
9	1	4	1,03	5	0	-0,01	-2,75	-23,01	-123,09	-37,33	-848
10	1	5	1,03	4,7	0	-0,01	-2,77	-23,01	-108,09	-28,95	-677
11	1	6	1,03	4,5	4,5	0,00	-2,79	-23,01	-93,10	-20,53	-490
12	1	7	1,03	4,4	0	0,00	-2,81	-23,01	-78,10	-12,44	-301
13	1	8	1,03	4,4	0	0,00	-2,83	-23,01	-63,11	-5,01	-122
14	1	9	1,03	4,2	0	0,00	-2,85	-23,01	-48,11	1,41	34
15	1	10	1,03	4,1	0	0,00	-2,87	-23,01	-33,12	6,49	158
16	1	11	1,03	4,2	0	0,00	-2,89	-23,01	-18,12	9,88	240
17	1	12	1,03	4,5	0	0,00	-2,90	-23,01	-3,13	11,34	275
18	1	13	1,03	4,4	0	0,00	-2,92	-23,01	11,87	10,74	261
19	1	14	1,03	4,3	0	0,00	-2,94	-23,01	26,86	8,13	198
20	1	15	1,03	4,5	0	0,00	-2,96	-23,01	41,86	3,71	91
21	1	16	1,03	4,9	0	0,00	-2,98	-23,01	56,86	-2,19	-53
22	1	17	1,03	5,5	0	0,00	-3,00	-23,01	71,85	-9,24	-225
23	1	18	1,03	6,2	0	0,00	-3,02	-23,01	86,85	-17,09	-411
24	1	19	1,03	6,7	0	0,01	-3,03	-23,01	101,84	-25,42	-600
25	1	20	1,03	7,8	0	0,01	-3,05	-23,01	116,84	-33,87	-779
26	1	21	1,03	8,2	0	0,01	-3,07	-23,01	131,83	-42,02	-936
27	1	22	1,03	8,4	0	0,01	-3,09	-23,01	146,83	-49,27	-1060
28	1	23	1,03	8,5	0	0,01	-3,11	-23,01	161,82	-54,75	-1142

	L	M	N	O	P	Q	R	S	T	U	V
1							Control of calculated radiation			Final values	
2	Global radiation (from DMI)				Direct radiation	Diffuse radiation	Relativ air density	Extermination-Coefficient	Maximum 'reasonable' direct normal radiation	Direct radiation	Diffuse radiation
3	G_h	RMIN	KT	RELD	I_b	D_h	m	EXT	I_{max}	I_b	D_h
4	[W/m²]	[-]	[-]	[-]	[W/m²]	[W/m²]	[-]	[-]	[W/m²]	[W/m²]	[W/m²]
5	0	0,17	0,00	1,00	0,00	0,00	-1,24	0,12	1396,06	0,00	0,00
6	0	0,17	0,00	1,00	0,00	0,00	-1,26	0,12	1398,74	0,00	0,00
7	0	0,17	0,00	1,00	0,00	0,00	-1,33	0,12	1411,23	0,00	0,00
8	0	0,17	0,00	1,00	0,00	0,00	-1,48	0,12	1436,53	0,00	0,00
9	0	0,17	0,00	1,00	0,00	0,00	-1,74	0,12	1482,05	0,00	0,00
10	0	0,17	0,00	1,00	0,00	0,00	-2,20	0,12	1565,93	0,00	0,00
11	0	0,18	0,00	1,00	0,00	0,00	-3,08	0,15	1919,49	0,00	0,00
12	0	0,17	0,00	1,00	0,00	0,00	-5,22	0,12	2250,81	0,00	0,00
13	1	0,17	0,00	1,00	0,00	1,00	-15,15	0,12	7406,37	0,00	1,00
14	11	0,17	0,32	0,92	35,47	10,13	22,85	0,12	77,55	35,47	10,13
15	28	0,17	0,18	0,96	10,94	26,76	7,67	0,12	479,18	10,94	26,76
16	36	0,17	0,15	0,96	7,83	34,66	5,32	0,12	635,15	7,83	34,66
17	43	0,17	0,16	0,96	8,51	41,33	4,71	0,12	683,75	8,51	41,33
18	37	0,17	0,14	0,96	7,02	35,69	4,94	0,12	664,66	7,02	35,69
19	17	0,17	0,09	0,98	2,58	16,64	6,32	0,12	563,30	2,58	16,64
20	5	0,17	0,06	0,99	1,06	4,93	12,04	0,12	283,74	1,06	4,93
21	0	0,17	0,00	1,00	0,00	0,00	-55,94	0,12	990006,87	0,00	0,00
22	0	0,17	0,00	1,00	0,00	0,00	-7,26	0,12	2873,26	0,00	0,00
23	0	0,17	0,00	1,00	0,00	0,00	-3,72	0,12	1880,48	0,00	0,00
24	0	0,17	0,00	1,00	0,00	0,00	-2,49	0,12	1622,21	0,00	0,00
25	0	0,17	0,00	1,00	0,00	0,00	-1,90	0,12	1510,61	0,00	0,00
26	0	0,17	0,00	1,00	0,00	0,00	-1,57	0,12	1452,38	0,00	0,00
27	0	0,17	0,00	1,00	0,00	0,00	-1,38	0,12	1419,93	0,00	0,00
28	0	0,17	0,00	1,00	0,00	0,00	-1,28	0,12	1402,65	0,00	0,00

Figure 1. *Snippet of Excel sheet to calculate direct and diffuse radiation. Columns with calculations are colored grey,columns where user input is needed is colored orange, the calculated radiation is colored yellow and the final values are colored green.*

Column A: Includes Day Number, *DN*, which is an integer value from 1-365, such that each day is 24 hours long. After 24 hours (it starts at 0 and ends at 23, see **column B**), the integer will be incremented by 1.

Column B: This includes the hour number, *h*, on the day, such that each day has 24 hours. This starts at 0 and ends at 23, after which it will start over.

Column C: The distance factor between the sun and the earth, *DA*, is included in this column. The calculation is based on equation **(1)**.

Column D: Hourly air temperature measurement from a weather station, see Table 1.

Column E: The minimum temperature in the morning, which is based on the weather data used. Take the minimum temperature that has occurred between 0 to 7 am. The 7th hour of each day (integer value 6, as it starts at 0) should have this value, with the remaining values set to 0.

Column F – I: Calculations performed to determine the sun altitude.

Column J: The sun altitude is calculated here, which is changing for each hour. It can be calculated using latitude and longitude coordinates. The calculation procedure is performed based on the method shown in appendix A.

Column K: The cosmic radiation, I_e, is calculated using equation **(2)**.

Column L: The global radiation, G_h, is inserted for each hour. As shown in Table 1, this can be found from DMI.

Column M: The absolute humidity, $RMIN$, is calculated using equation **(3)**.

Column N: The ratio between the global radiation and cosmic radiation, K_t, is calculated using equation **(4)**.

Column O: The relation to the absolute humidity, $RELD$, is calculated using equation **(5)**, based on which inequality it fulfills.

Column P: The direct radiation, I_0, is calculated using equation **(6)**.

Column Q: The diffuse radiation, D_h, is calculated using equation **(7)**.

Column R-T: Calculations for control of high values using equation **(8)**, **(9)** and **(10)**.

Column U: Final value of direct radiation.

Column V: Final value of diffuse radiation.

For each hour in the year, each of the calculations are done. Therefore, data from the minimum temperature in the morning for each day, and global radiation, should be collected for each hour in the day.

5 Import of custom weather file in BSim

To import a custom weather file into BSim, it must have a certain format. A total of 16 parameters can be inserted, which are listed below. Not all of them are necessary to make a file, the minimum amount of information needed is shown below the table. The actual parameter name, as shown in BSim, is shown in Table 2 along with a description of the parameter and the unit.

Table 2. *Overview of parameters needed in the BSim weather file.*

Parameter name	Description	Unit
Ambient Temp.	Outdoor temperature	[°C] or [°F]
Dew Point Temp.	Dew point temperature	[°C] or [°F]
Rel. Humidity	Outdoor relative humidity	[%]
Humidity Ratio	Absolute humidity	[kg/kg]

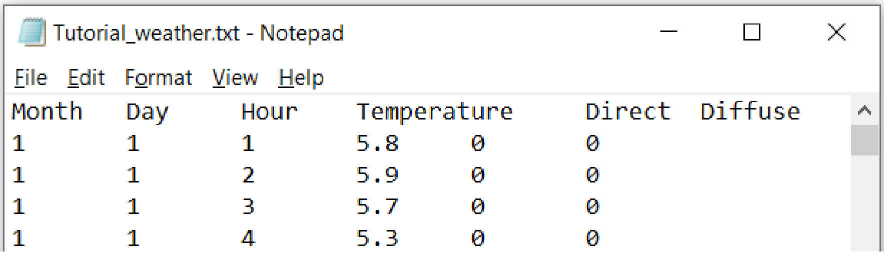
Enthalpy	Enthalpy of outdoor air	[kJ/kg]
Normal Radiation	Normal radiation	[W/m^2]
Diffuse Radiation	Diffuse radiation	[W/m^2]
Global Radiation	Global radiation	[W/m^2]
Direct Radiation on Horizontal	Direct radiation *One of four combinations of solar radiation **must** be given, see below table.*	[W/m^2]
Cloud cover	Cloud cover given in okta (0-8 scale)	[-]
Wind Speed	Wind speed	[m/s]
Wind Direction	Wind direction (north = 0°, east = 90°, etc.)	[°]
AtmPressure	Atmospheric pressure	[Pa]
Month	Month, from 1 to 12	[-]
Day	Day, from 1 to 31	[-]
Hour	Hour, from 1-24	[-]

Not all parameters are needed to create a weather file. The minimum amount of information needed to create a weather file, is given below:

- Month (1 to 12)
- Day (1 to 28/29/30/31) ***OR*** day number (1 to 365-366)
- Hour in the day (1 to 24)
- Outdoor temperature
- One of the four following combination of sun data (***Important:*** *The bold option is the one implemented in Excel*):
    1. Normal radiation + diffuse radiation on the horizontal plane
    2. Normal radiation + global radiation on the horizontal plane
    3. Global radiation on the horizontal plane + diffuse radiation on the horizontal plane
    4. **Diffuse radiation + direct radiation on the plane**

Besides the minimum amount of information needed, it is advised to include a parameter for the humidity of the air (dew point temperature, releative humidity, absolute humidity or enthalpy), as the humidity is otherwise not included, and no sky cover can be calculated. Furthermore, wind direction and velocity, along with atmospheric pressure, is needed for simulations including natural ventilation.

The parameters are to be saved in a **.txt** file, such that each parameter has its own hourly data for a full year, in separate columns (tab separated), as shown in Figure 2.



Tutorial_weather.txt - Notepad

Month	Day	Hour	Temperature	Direct	Diffuse
1	1	1	5.8	0	0
1	1	2	5.9	0	0
1	1	3	5.7	0	0
1	1	4	5.3	0	0

Figure 2. *Example of .txt file that can be used for BSim weather file generation.*

Important: *If parameter names for each parameter in the file is given, the first line should be skipped, see 'Skip lines' in Figure 4.*

The file with the parameters for BSim can be made in Excel and then saved to **.txt** format. After this, go to BSim and then 'tsbi5' (the simulation core). Go to 'file' in the ribbon, then 'Weather Data' and finally 'Convert'. This is shown in Figure 3.

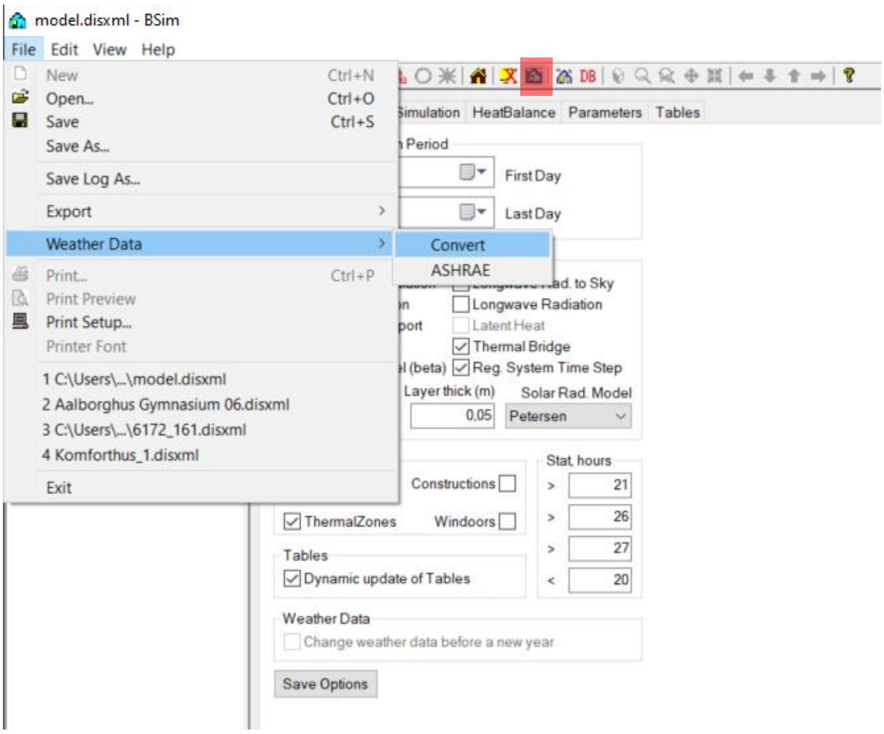


Figure 3. *Illustration of where to find the button to convert weather data from a .txt file.*

After clicking the 'Convert' button, a window named 'Conversion of Weather Data for tsbi5' will show up, Figure 4.

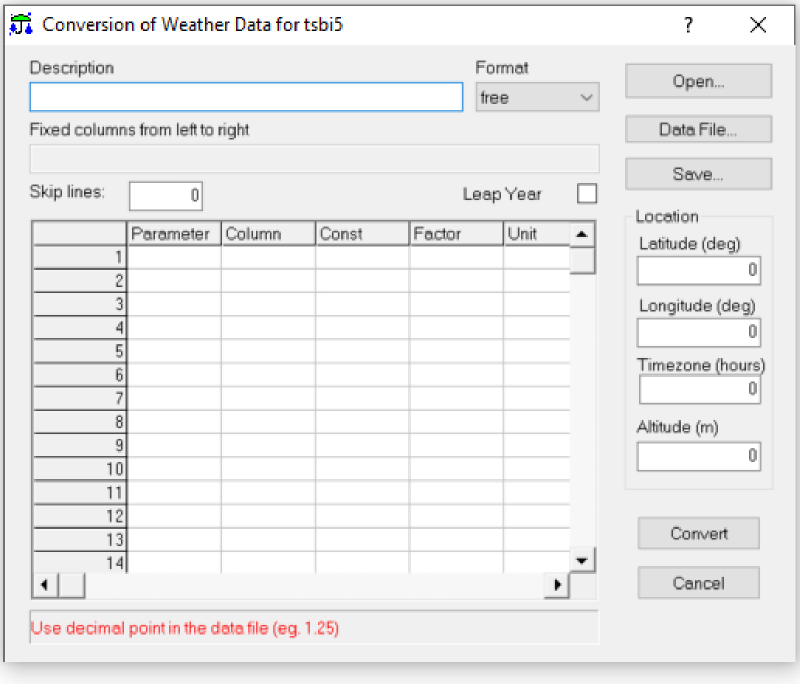


Figure 4. *Conversion window, where the .txt file with weather data can be chosen.*

To import the **.txt** file, click on 'Open' and choose the file *(change file format that is seen to 'All Files (*.*)' from 'Weather Data File (*.wdf)' next to the file name)*. After this, each parameter in the **.txt** file has to be attributed to one of the parameters shown in Table 2. Click on line 1 in the parameter list to add the first parameter. The window shown in Figure 5 will show up. By clicking on the 'Parameter' drop-down menu, the specific parameter can be chosen.

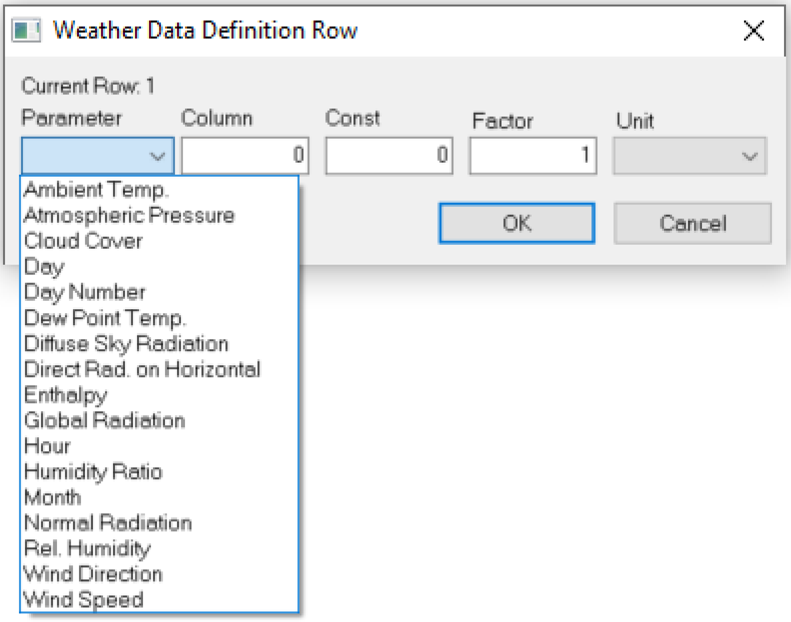


Figure 5. *Window where each parameter is assigned to a column in the weather .txt file.*

Choose the first parameter in the **.txt** file and choose the column corresponding to that specific parameter. The factor and constant can be left unchanged, as these will change the parameter as shown in equation **(11)**.

$$Parameter = factor \cdot (value - constant) \tag{11}$$

Click 'OK' and repeat the process for each parameter in the **.txt** file.

Important: *Write a description in the 'Description' box,* Figure 4, *as it will otherwise not be able to create a weather file.* When finished, it should look like as shown in Figure 6.

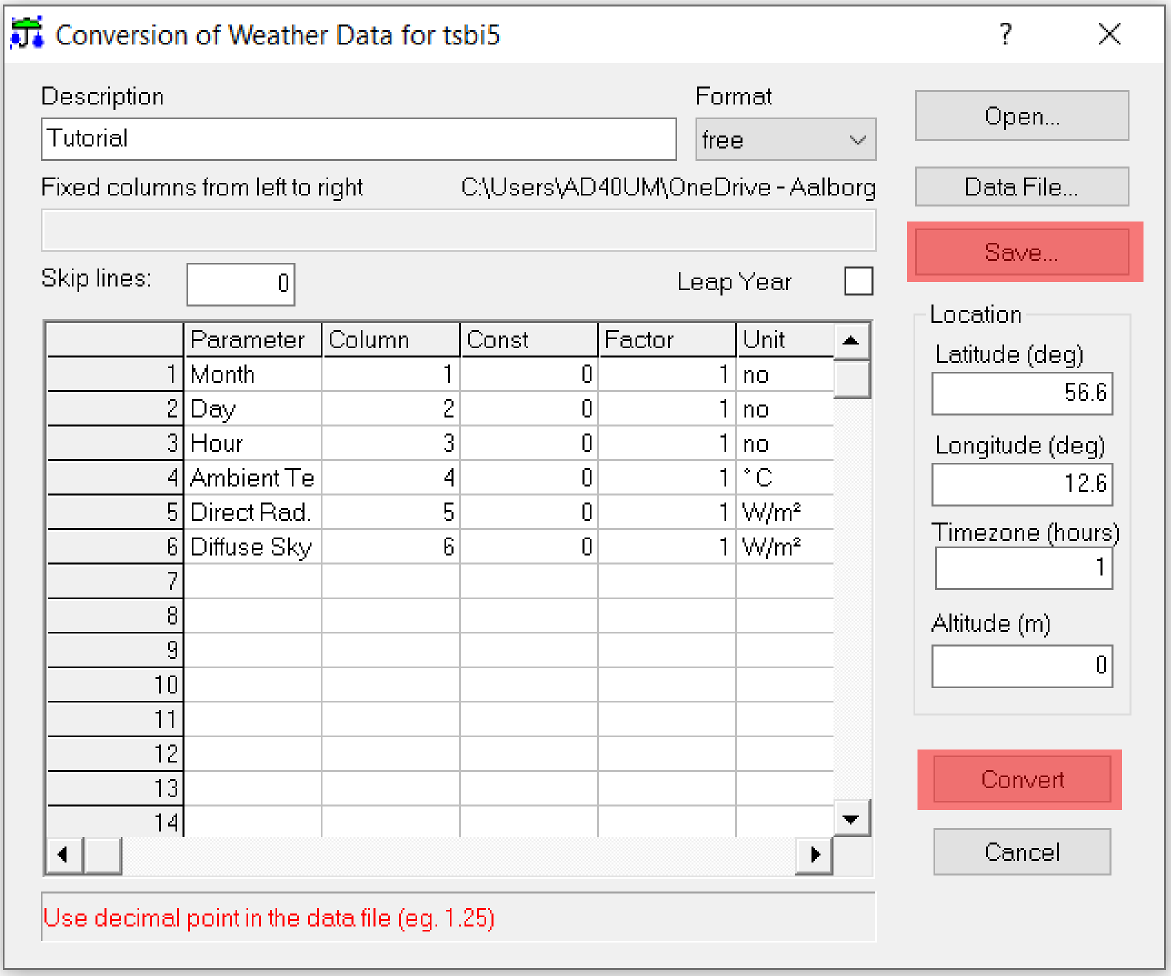


Figure 6. *Overview of the parameters included in the waether file, based on a .txt file.*

After this is done, click on 'Save', give the Weather Data File (**.wdf**) a name and save it. Finally, click 'Convert', in the lower left corner shown in Figure 6. Based on this, a **.dry** file will be made, and the screen shown in Figure 7 will show up, with data for each month, along with a warning that some data is not included. These warnings can be ignored, but it is important to note the limitations of the simulation if they are not included.

Figure 7. *Window to show that a .dry file has been successfuly created, with a summary of the weather data.*

The **.dry** file can now be loaded into the BSim model, the same way the DRY weather file is included normally.

References

[1] Lund, H. 1985. Short Reference years and Test Reference Years for EEC Countries. Technical University of Denmark.

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[3] Cooper, P. I. 1968. The absorption of radiation in solar stills. Solar Energy.

[4] National Oceanic and Atmospheric Administration. Global Monitoring Division. https://gml.noaa.gov/grad/solcalc/solareqns.PDF

Appendix A: Determination of altitude angle

This appendix is based on [3] and [4]. In this appendix, the calculation procedure to determine the altitude angle is shown. The calculation is based on longitudinal and latitudinal coordinates, along with the time zone. To calculate the altitude angle, equation **(A.1)** is used.

$$h_s = \arcsin[\cos(L) \cdot \cos(D) \cdot \cos(H) + \sin(L) \cdot \sin(D)] \tag{A.1}$$

h_s	Altitude height	$[°]$
L	Latitudinal coordinate	$[-]$
D	Declination	$[°]$
H	Hour angle	$[°]$

To determine the altitude angle, which is the goal of this calculation, the solar hour angle first has to be calculated. The solar hour angle is a measure of the angular distance between the sun at the local solar time and the sun at solar noon. The sun rises from the east and reaches its highest position at solar noon, after which it descends to the west. The solar hour angle is zero degrees at solar noon. The altitude angle can be calculated using equation **(A.2)**.

$$H = 15 \cdot \left(LST + \frac{offset}{60} - 12\right) \tag{A.2}$$

H	Solar hour angle	$[°]$
LST	Local Solar Time (the hour in 24-hour format)	$[-]$
$offset$	Offset	$[-]$

As LST is the Local Solar Time (the time in a 24-hour format), only the offset has to be calculated. The offset consists of two corrections: The Equation of Time, which is an empirical equation that corrects for the eccentricity of the earth's orbit and its axial tilt, and the longitudinal variation. This is shown in equation **(A.3)**.

$$offset = EoT + LongV \tag{A.3}$$

The Equation of Time is calculated using equation **(A.4)**.

$$\begin{aligned} EoT = 229.18 \cdot [0.000075 + 0.001868\cos(\gamma) \\ -0.032077\sin(\gamma) \\ -0.014615\cos(2\,\gamma) \\ -0.040849\sin(2\,\gamma) \end{aligned} \tag{A.4}$$

Where the fraction year in radians is calculated using equation **(A.5)**.

$$\gamma = \frac{2\,\pi}{365}\left(DN - 1 + \frac{hour-12}{24}\right) \tag{A.5}$$

γ	Fraction year	$[rad]$
DN	Day number	$[-]$
$hour$	Hourly value	$[-]$

The day number is simply the day number of the year, such that the first day of the year is 1, the second is 2 etc.

Lastly, the longitudinal variation, $LongV$, can be calculated using equation **(A.6)**.

$$LongV = 4 \cdot (longitude - 15 \cdot \Delta TZ) \tag{A.6}$$

$Longitude$	Longitudinal coordinate	$[-]$
ΔTZ	The time zone for the point of interest	$[-]$

The longitude is the longitudinal coordinate for a specific point on the globe, while the time zone is simply the time zone (expressed as Greenwich Mean Time, GMT) where the point of interest (the building or weather station) is located. Denmark is GMT+1.

The offset can then be calculated, such that the altitude height can be calculated. The final variable to determine is the declination, which is the tilt of the globe. This varies seasonally and can be calculated using equation **(A.7)**.

$$D = 23.45 \cdot \sin\left(\frac{360}{365} \cdot 284 + DN\right) \tag{A.7}$$

D	Declination	$[-]$
DN	Local Solar Time (the hour in 24-hour format)	$[-]$

Finally, the declination and the solar hour angle is calculated, which means that the altitude angle can be determined using equation (A.1), as only the latitudinal coordinate is missing. This is determined for the point of interest (meaning the location of the building or weather station where the remaining data is from).

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