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# Solar Atlas for Latvia
## – A Reference Year

Sagsrapport
BYG • DTU SR-02-06
2002
ISSN 1601-9504

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## – A Reference Year

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May 2002

# I. Preface

The report describes how a test reference year for Latvia was designed. The test reference year is suitable in connection with designing solar heating systems in Latvia.

# II. Summary

A reference year contains a number of weather parameters, making it possible to carry out HVAC technical calculations in connection with design of HVAC systems. In connection with projecting of solar heating systems, the reference year can for instance be used for the determination of:

- expected performance of the system,
- necessary supplement from supplementary heating source,
- the course of temperature in the system,
- expected solar fraction of the solar heating system,
- statistics for periods with solar fractions or temperatures in the storage tank above a given level.

The data sets can also be used in connection with the estimation of energy consumption for heating of buildings.

In the reference year, in contradistinction to an average year, natural courses of outside temperature, global radiation on horizontal, and diffuse radiation on horizontal are described on annual basis. This makes it possible to use the reference year for detailed calculations by means of electronic data processing programs that require weather data on an hourly basis.

In this report a reference year for Latvia has been worked out from data from ”The European Solar Radiation Atlas” (ESRA). ESRA contains 10 years' monthly mean values of for instance minimum and maximum outside temperatures and global radiation.

With the program METEONORM, a reference year based on hour values has been generated from the ESRA data.

Even though the data sets of the reference year are based on observations from the neighbourhood of Riga, they are probably generally usable for calculations over the whole of Latvia. At a few positions, as e.g. areas near the coast (about 200 m from the coast), at the centre of Riga, and in the forest areas situated high in the middle of Latvia, deviations in the weather occur. It is considered, however, that for Latvia in general there are no deviations owing to the position that are larger than deviations between the single years and the reference year.

At appendix 5 of the report, hour values for outside temperature, global radiation, and diffuse radiation are reproduced graphically. Corresponding data can be obtained in electronic form.

# III. Resume på dansk

Et referenceår indeholder en række vejrparametre, der gør det muligt at gennemføre VVS-tekniske beregninger i forbindelse med projektering af VVS-anlæg. I forbindelse med projektering af solvarmeanlæg, kan referenceåret bl.a. benyttes til bestemmelse af:

- forventede ydelser fra anlægget,
- nødvendigt tilskud fra supplerende varmekilde,
- temperaturforløb i anlægget,
- forventet dækningsgrad fra solvarmeanlægget,
- statistik for perioder med dækningsgrader eller temperaturer i lagertanken over et givet niveau.

I forbindelse med vurderinger af energiforbrug til opvarmning af bygninger vil data-sættene også kunne anvendes.

I referenceåret er der, til forskel fra et gennemsnitsår, beskrevet naturlige forløb af udetemperatur, globalstråling på vandret og diffus stråling på vandret på timebasis. Dette muliggør at referenceåret kan anvendes til detaljerede beregninger ved hjælp af EDB programmer, der kræver vejrdata på timebasis.

I denne rapport er et referenceår for Letland udarbejdet ud fra data fra "The European Solar Radiation Atlas" (ESRA). ESRA indeholder 10 års månedsmiddelværdier for bl.a. minimum og maksimum udetemperatur og globalstråling.

Med programmet METEONORM er der, ud fra ESRA dataene, genereret et referenceår baseret på timeværdier.

Selv om referenceårets datasæt bygger på observationer fra Rigas omegn, kan de med rimelig sikkerhed anses for generelt anvendelige ved beregninger over hele Letland. I enkelte beliggenheder som fx kystnære områder (ca. 200 m fra kysten), i Riga centrum samt i de højtliggende skovområder midt i Letland, er der afvigelser i vejrliget. Det skønnes dog, at der generelt for Letland ikke forekomme afvigelser på grund af beliggenhed, der er større end afvigelser mellem de enkelte år indbyrdes og referenceåret.

I rapportens bilag 5 er timeværdier for Udetemperatur, globalstråling og diffus stråling gengivet grafisk. Tilsvarende data er kan rekvireres i elektronisk form.

# IV. Table of contents

# 1 The position of Latvia

Latvia is one of the Baltic countries. Latvia lies at the coast of the Baltic Sea between the degrees of latitude 55° 40` and 58° 05` N and the degrees of longitude 20° 58`and 28° 15` E. The area of Latvia is 63,700 km$^2$. Latvia has a northern border with Estonia and the Gulf of Riga, an eastern border with Russia, a southern border with White Russia and Lithuania, and a western border with the Baltic Sea (see Figure 1-1). There are a large number of small lakes, peat bogs and rivers in Latvia and about 47% of the area is covered with forest. Latvia consists mainly of low areas, and the most elevated place is about 200 m above sea level. Latvia’s climate is dominated by air from the Atlantic. The western part of the country has a relatively mild winter and a rather cool summer, whereas the winter in the eastern part of the country is somewhat colder and the summer is somewhat warmer. Latvia has a high level of humidity of the atmosphere and the sky is often clouded.

Aizkraukle lies ca. 90 km from Riga (see Figure 1-1). In 1995 the number of inhabitants was 10,085.


**Figure 1-1: Map of Latvia.**

# 2 General

To be able to design a solar heating system in Latvia it is necessary to take meteorological data for Latvia as a starting point and compile a reference year. Generally the preparation of a reference year is based on weather data for a minimum period of 10 years. By taking this data set as one's starting point, a reference year is formed by means of a selection method.

A reference year is to reflect the annual variation of the principal weather parameters (for 365 days) and as a rule be composed of time values belonging together, indicated at an hourly basis. A reference year is used as input data in computer simulations within indoor climate and also heating and cooling loads of buildings.

A test reference year for Denmark takes the following measured values as its starting point: outside temperature, dew point temperature, maximum and minimum outside temperature, wind speed, precipitation, and diffuse and global radiation on a horizontal surface.

With regard to the project, primarily the data for the solar radiation in Latvia should be procured, as this provides a basis for the use of solar energy. Furthermore, the thermal performance of the solar heating system depends on a number of other climatic parameters, such as outside temperature, relative moisture of the atmosphere, and wind speed. All these values can be expressed as average month, day or hour values.

To begin with, it was the idea to get the necessary information from the Meteorological Office in Latvia. To prepare a reference year for Latvia, it is necessary to have data for the solar radiation (global, diffuse, and direct), average outside temperature, relative moisture of the atmosphere, and wind speed for each hour within a minimum period of 10 years.

It turned out to be difficult to get the necessary data for a 10-year-period and a solar atlas for Latvia, as the Meteorological Office in Latvia was not able to provide the material at the appointed time. Furthermore, the price of data was rather high, exceeding the financial limits. It was therefore decided to investigate other options.

# 3 The choice of method

## 3.1 ESRA

The first time round, the contents of ”The European Solar Radiation Atlas” [1] – prepared and published in Paris in 2000 – were investigated. A database for a 10-year-period for a large number of stations has been stored on a CD-ROM. For Latvia there are monthly average values for 10 years for minimum and maximum outside temperatures, global radiation, precipitation and sunshine time.

In principle, the program has algorithms for converting monthly values into hourly values, but that part of the program does not work.
Below, average monthly values, fetched from ESRA, will be used for a 10-year-period for Riga, St. Petersburg, and Copenhagen (see appendix 2).

## 3.2 The Internet

Attempts were made to find the necessary data on the Internet. In fact there is much information on the Web-pages **http://wrdc-mgo.nrel.gov/** and **http://www.wordclimate.com/**, but in the first place they lack data for the solar radiation for Latvia, and in the second place there are only monthly values.

## 3.3 TRY for Copenhagen and St. Petersburg

The third proposal was to use a test reference year from those available. Cities, lying close to Riga and having a test reference year based on hourly values, are Copenhagen, Helsinki, Stockholm, and St. Petersburg. Copenhagen and St. Petersburg were chosen. Copenhagen was included for the sake of comparison. The reason why Helsinki and Stockholm were left out is that the two cities are situated very close to each other and quite openly by the sea, whereas Riga lies on the coast by the Riga Bay, being only partly open to the sea, just like St. Petersburg. It is a fact that the presence of the water influences the ratios between direct and diffuse radiation considerably, and ultimately this is very important for the thermal performance of solar heating systems.

A map of the Baltic region is shown in appendix 1.

A thorough investigation has shown that considerable errors will occur if calculations are carried out for Riga with a reference year for either Copenhagen or St. Petersburg. A comparison of average measurement values for a 10-year-period of temperature and global radiation for Riga/St. Petersburg and Riga/Copenhagen appears from the following paragraph.

### *3.3.1 Riga and St. Petersburg*

Riga is situated 3 m above sea level on the coast of the Baltic Sea at the latitude 56.97 N and the longitude 24.07 E, whereas St. Petersburg lies 4 m above sea level on the coast of the Gulf of Finland at the latitude 59.97 N and the longitude 30.3 E. In ESRA the average monthly maximum and minimum outdoor ambient temperature and global radiation on a horizontal surface are found for the 10-year-period for Riga and St. Petersburg. The table with data for the two cities is shown in appendix 2.

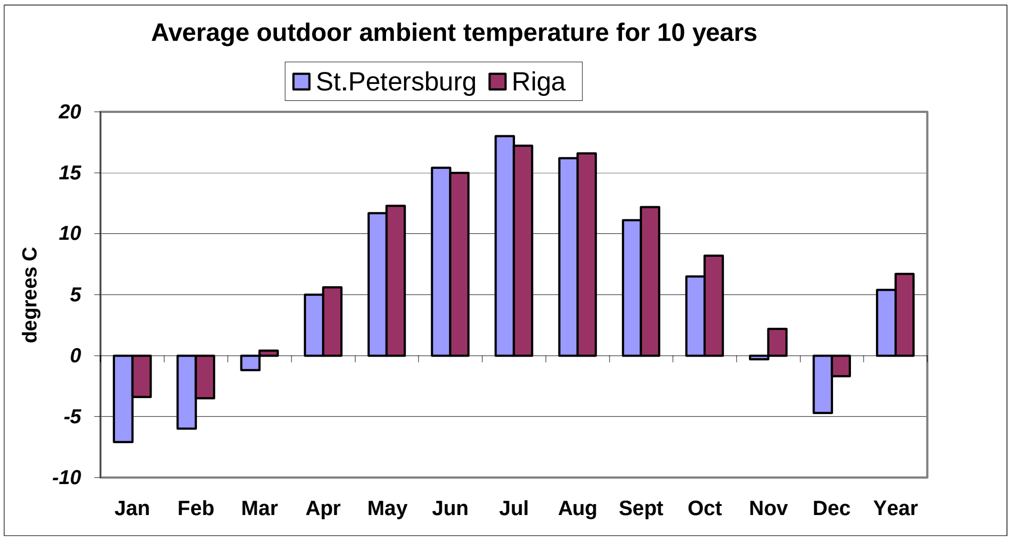



**Figure 3-1: Average outdoor ambient temperatures for Riga and St. Petersburg, based on 10 years' measurements.**

When comparing the outdoor ambient temperatures for the two cities, it appears that it is colder in St. Petersburg than in Riga, especially in winter, see Figure 3-1.

As appears from Figure 3-2, the global radiation on a horizontal surface for Riga is higher than for St. Petersburg, and the difference is about 8% on an annual basis.

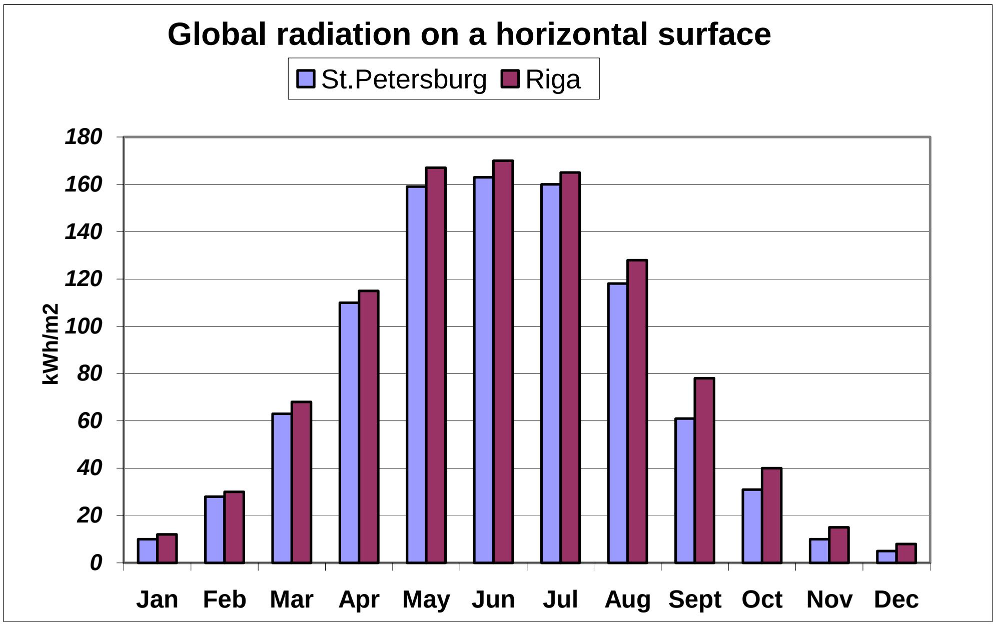



**Figure 3-2: Global radiation on a horizontal surface for Riga and St. Petersburg, based on 10 years' measurements.**

### *3.3.2 Riga and Copenhagen*

A corresponding comparison can be made for Riga and Copenhagen. Copenhagen (measuring station at Tåstrup) lies 28 m above sea level at the latitude 55.67 N and the longitude 12.3 E. The climate of Denmark is generally milder than the climate in Latvia. Measured data for Copenhagen (measuring station at Tåstrup) are also obtained from ESRA. The table with data for Copenhagen is shown in appendix 2.

From Figure 3-3 it appears that it is warmer in Copenhagen than in Riga, whereas Figure 3-4 shows that on an annual basis, global radiation on a horizontal surface is by and large the same. Global radiation on a horizontal surface is somewhat greater in March, May, and June for Riga and the same for both cities in July, whereas in the other months Copenhagen gets more sun. In spite of the fact that on an annual basis the global radiation data for Riga and Copenhagen are almost identical, it would be inappropriate to ignore the fact that to some extent the solar radiation depends on the ambient temperature.

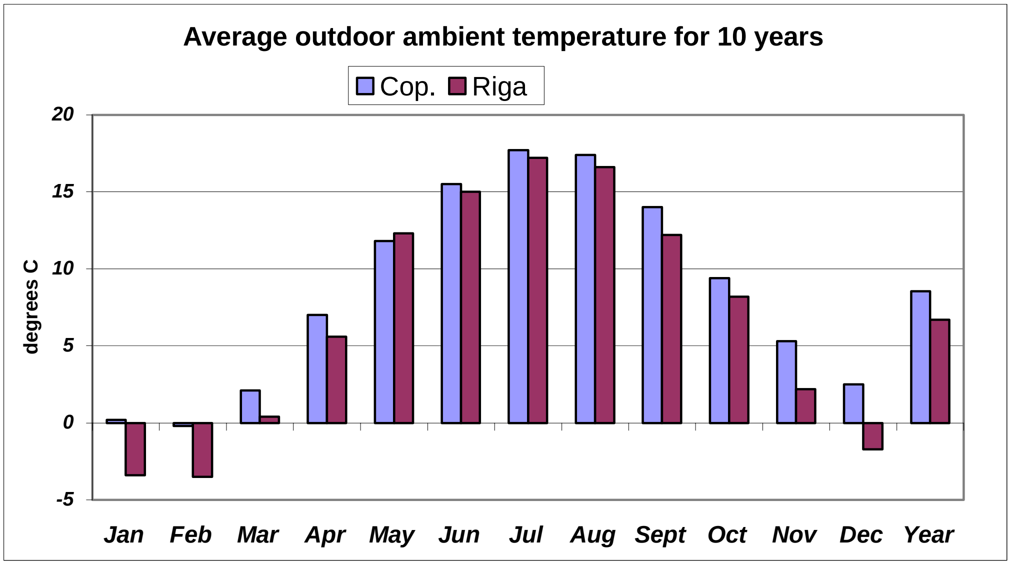



**Figure 3-3: Average outdoor ambient temperature for Riga and Copenhagen, based on 10 years' measurements.**

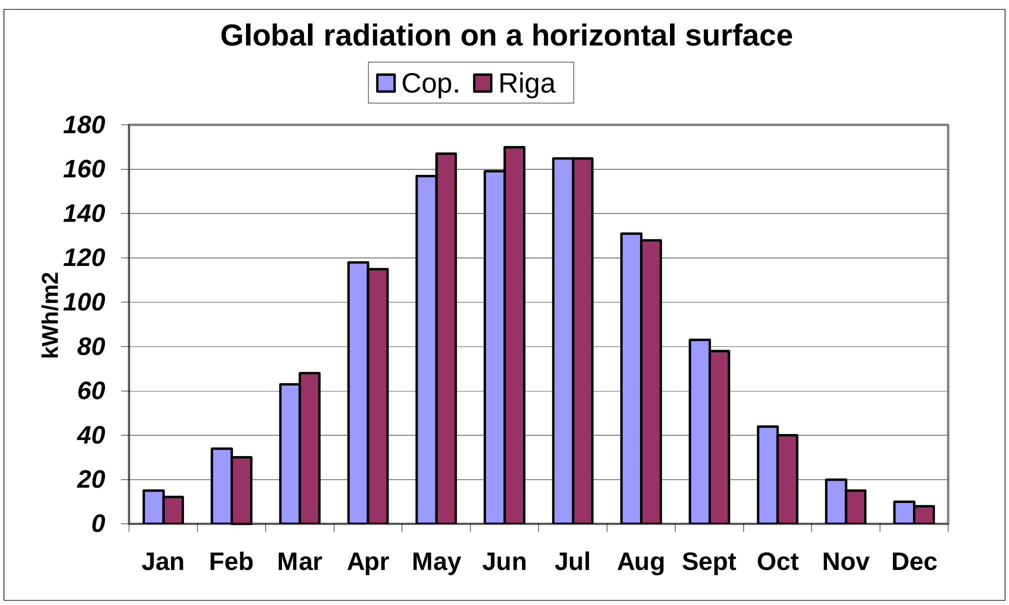



**Figure 3-4: Global radiation on a horizontal surface for Riga and Copenhagen, based on 10 years' measurements.**

## 3.4 Meteonorm

In addition to the possibilities mentioned above, there is a quite simple program "Meteonorm", from which one can get necessary information. Meteonorm is based on 10 years' measured data.

Below, data for Riga generated by Meteonorm are compared with average 10-year-values for Riga, which are available in ESRA: Outdoor ambient temperature and global radiation on a horizontal surface. In addition to that, the distribution of outdoor ambient temperature and global radiation for Copenhagen and St. Petersburg is shown, based on a 10-year-period (see Figure 3-5 - Figure 3-8). The graphs show that Meteonorm's data for Riga are in good agreement with the average data for a 10-year-period, month by month as well as on an annual basis.

A brief description of "Meteonorm", based on a manual for the program [2], appears below.

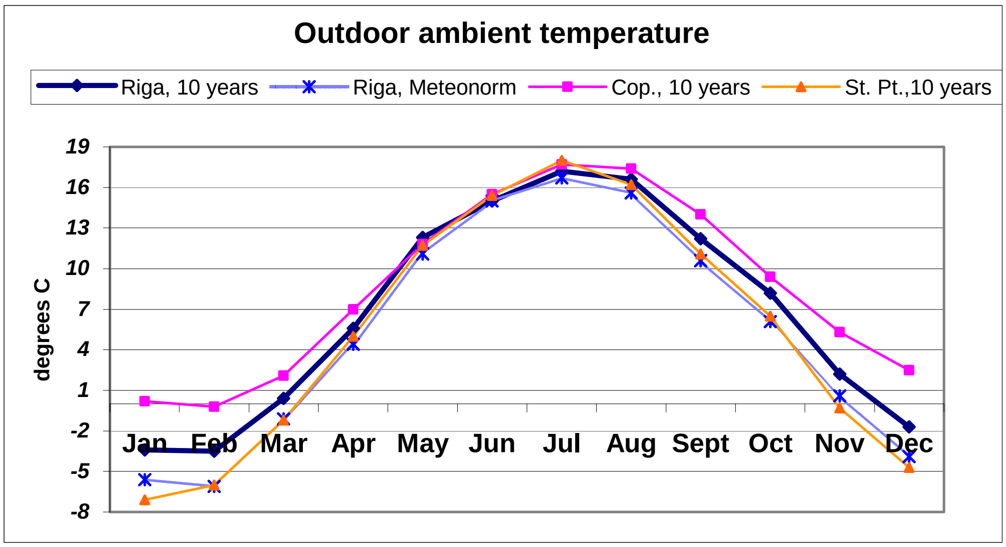



**Figure 3-5: Distribution of outdoor ambient temperature month by month, based on data for Riga from ESRA (10-year-period) and Meteonorm.**

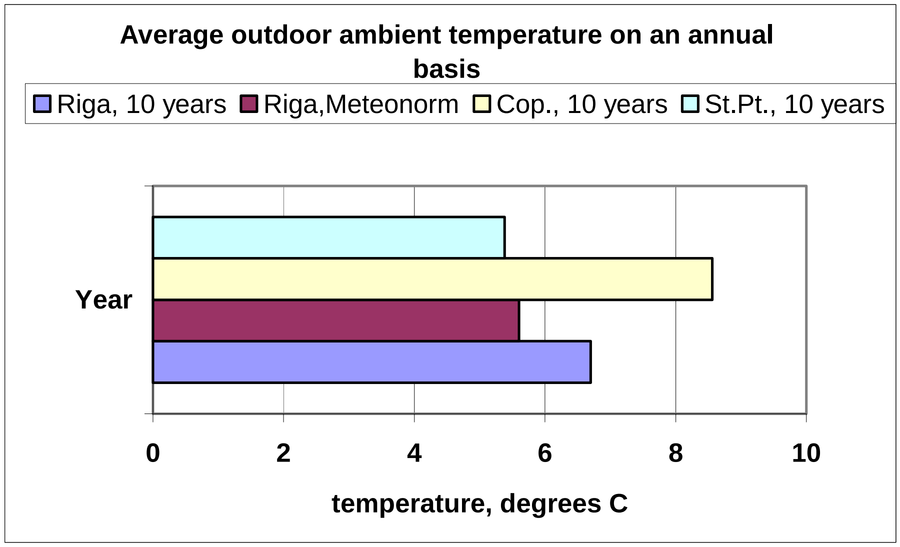



**Figure 3-6: Average annual outdoor ambient temperature, based on data for Riga from ESRA (10-year-period) and Meteonorm.**

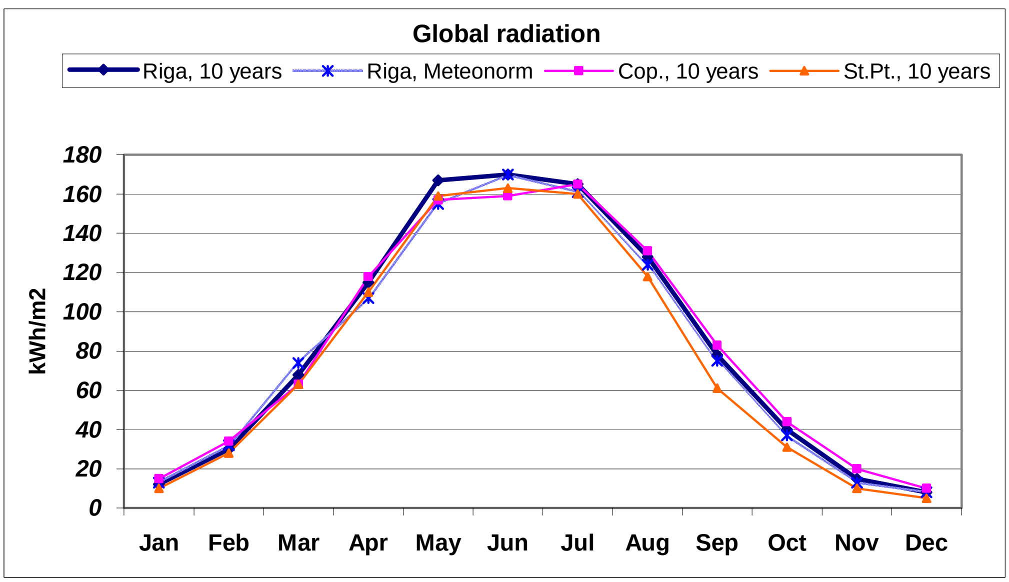



**Figure 3-7: Distribution of global radiation month by month, based on data for Riga from ESRA (10-year-period) and Meteonorm.**

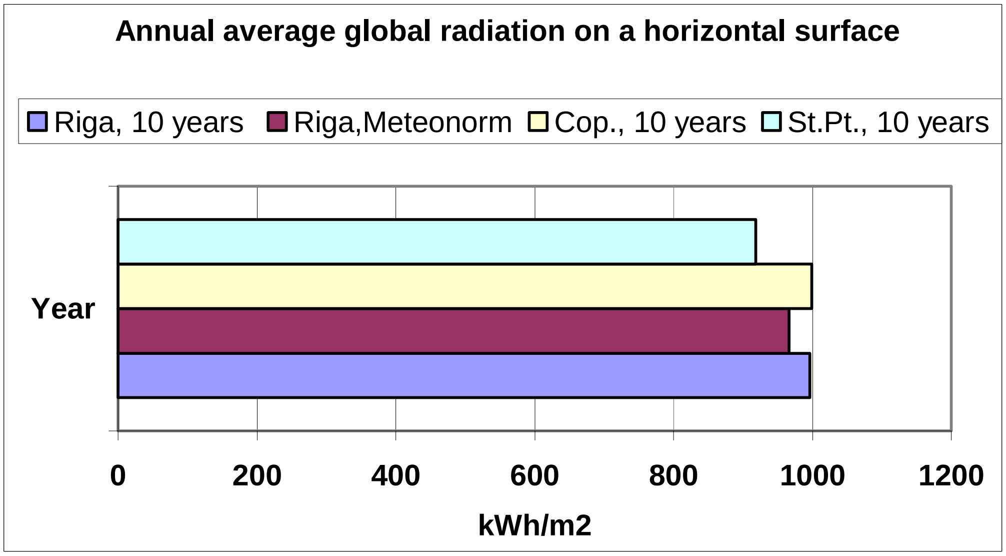



**Figure 3-8: Annual global radiation on a horizontal surface, based on data for Riga from ESRA (10-year-period) and Meteonorm.**

### *3.4.1 Contents*

The program contains measured data for a large number of stations over the world. Further it is possible to obtain data for any point on the surface of the earth by means of interpolation. In addition the program is provided with 4 calculation models, as described in Table 3-1. The table shows in which order the calculation models are connected with each other to generate hourly values for the radiation on an arbitrary tilted plate for a place with no measured data.

It is important to notice that an hourly-value generator in Meteonorm pictures temperature and radiation profiles belonging together. The model presupposes that during 24 hours the amplitude of the outdoor ambient temperature is proportional to the amplitude of the global radiation during the same 24 hours.

| | |
|---|---|
| Interpolation with average monthly values for $G_h$, $T_a$ model | Distance-dependent interpolation of horizontal global radiation and ambient temperature based on weather data. Altitude above sea level, topography, region etc. are taken into consideration. |
| Hourly values generator $G_h$, $T_a$ | Stochastic value generator of time-dependent data for the global radiation and ambient temperature by means of quasi natural distribution and average monthly values assumed to be equivalent to average 10-year monthly values. |
| Determination of the solar radiation $G_h \rightarrow D_h$, $B_h$ | With global radiation as point of reference, diffuse and direct radiations are determined. |
| Radiation on a tilted plate with cloud effect, hourly values for $G_k$ model | Calculation of the global radiation on an arbitrarily oriented surface, where reduction on account of the cloud is taken into consideration. |

**Table 3-1: . The order of 4 calculation models.**

### *3.4.2 Quality of results*

The producer has tested the program, and information on the aberrations is stated in a handbook [2].

Aberrations were discovered between the monthly and hourly values of the results, which depend on the used model. Errors in the interpolation of monthly values can account for maximum 11% for global radiation and 2.2 K for temperature.

The month model tends to overestimate the global radiation on a tilted surface. Disagreement with measured data can be maximum ± 3% per month and –2% on an annual basis.

The time model tends to underestimate global radiation on a tilted surface. Disagreement with measured data can be maximum ± 3% per summer month and +10% per winter month, but this will result in maximum +2% deviation on an annual basis.

The users must be aware that database for a place with lack of measured data and calculation models are just an approximation to reality, but the variation of the measured values from year to year can be greater than the inaccuracy of the model.

To investigate how exact Meteonorm is, data, which have been generated by means of Meteonorm, are compared with a test reference year (TRY) based on measurements and with average values for a 10-year-period for St. Petersburg and Copenhagen, respectively.

For Copenhagen data exist for a design reference year, too. A design reference year (DRY) differs from TRY by containing far more weather parameters. Furthermore, selected parameters in DRY have been adjusted to extreme values and mean values for the whole selection period.

Data generated by means of Meteonorm, TRY for St. Petersburg and Copenhagen, and DRY for Copenhagen appear from appendix 3.

*- Outdoor ambient temperature*.

A comparison of the average outdoor ambient temperature from different sources for Copenhagen shows that the values from Meteonorm are very close to the values of TRY and DRY, see Figure 3-9. The greatest difference between the values of TRY and Meteonorm is 1 K in January and May, whereas the difference compared with DRY's values is still smaller.

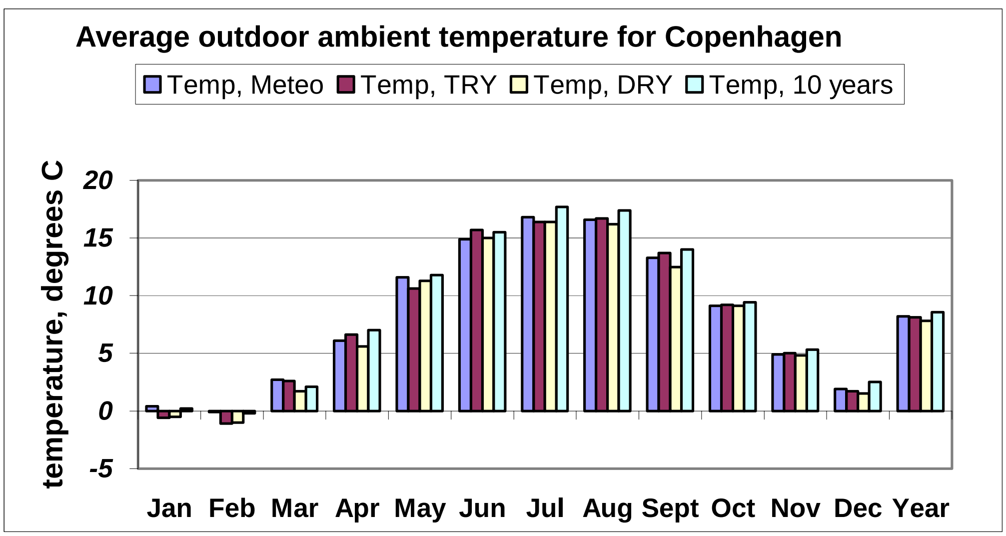



**Figure 3-9: Comparison of average outdoor ambient temperature from different sources for Copenhagen.**

As regards St. Petersburg, the aberrations between TRY's and Meteonorm's values for outdoor ambient temperatures are quite large. The worst aberration is in January, when the difference is 4.5 K. That can be explained from the fact that Meteonorm generates average monthly values, whereas data for TRY are chosen through a selection procedure by various criteria. Figure 3-10 confirms this fact, as there is almost no difference between average temperatures based on 10 years' measurements and values from Meteonorm, see appendices 2 and 3.

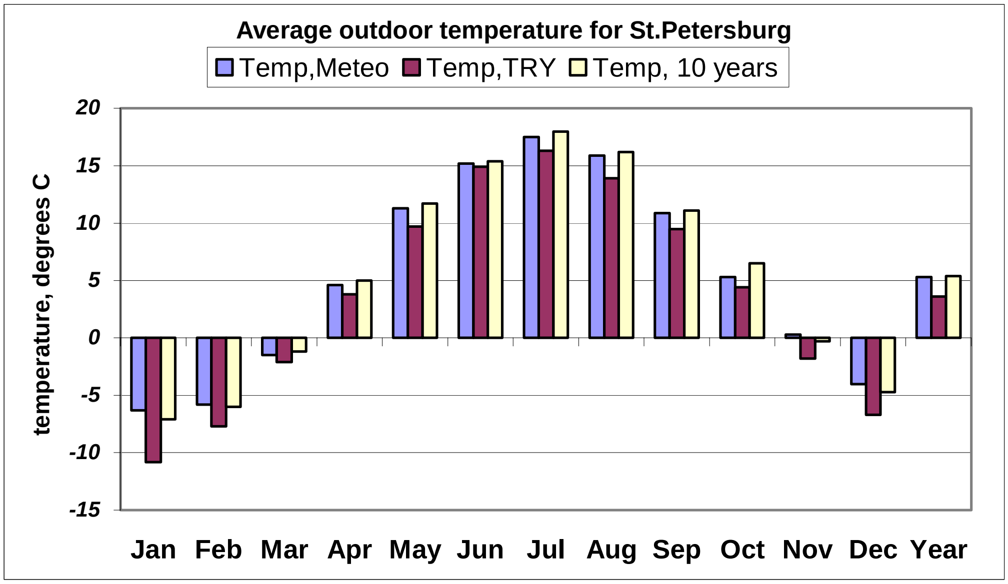



**Figure 3-10: Comparison of average outdoor ambient temperatures from different sources for St. Petersburg.**

*- Global radiation on a horizontal surface.*

Figure 3-11 shows that values of the global radiation for Copenhagen, found by means of Meteonorm, are in agreement with DRY and TRY for Copenhagen, except for June, where Meteonorm underestimates the global radiation by 16.7% compared with TRY and 6.0% compared with DRY. In spite of quite a great difference between these values in June, the aberration on an annual basis for the global radiation is just +3.6% compared with TRY and +1.9% compared with DRY, see Figure 3-12.

Again it should be noticed that Meteonorm states average monthly values for 10 years, and these values are almost equal to 10 years' average values for the global radiation from ESRA. The same applies to St. Petersburg.

For St. Petersburg, see Figure 3-13 and Figure 3-14, the difference between data from difference sources is very small, and Meteonorm overestimates the global radiation on a horizontal surface with only 1.6% on an annual basis.

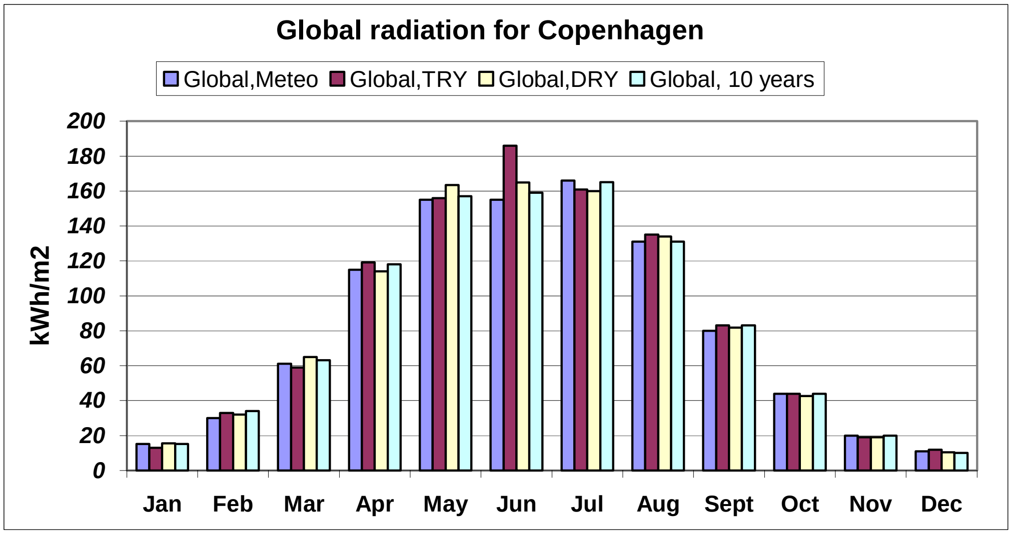



**Figure 3-11: Comparison of global radiation on a horizontal surface from different sources for Copenhagen.**

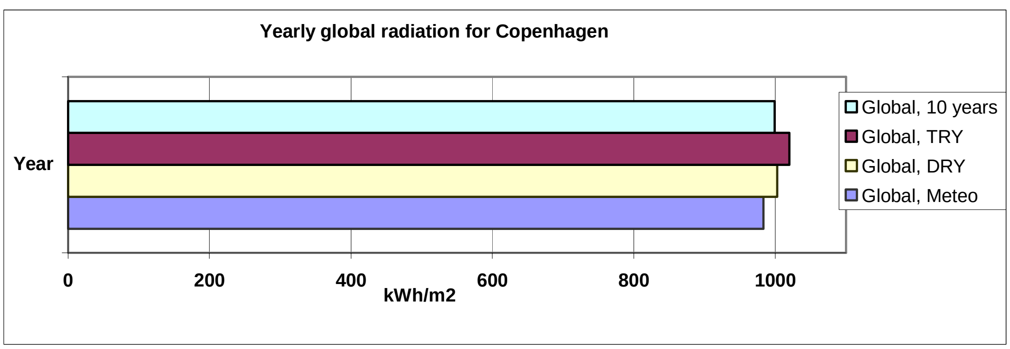



**Figure 3-12: Global radiation on a horizontal surface from different sources for Copenhagen on an annual basis.**

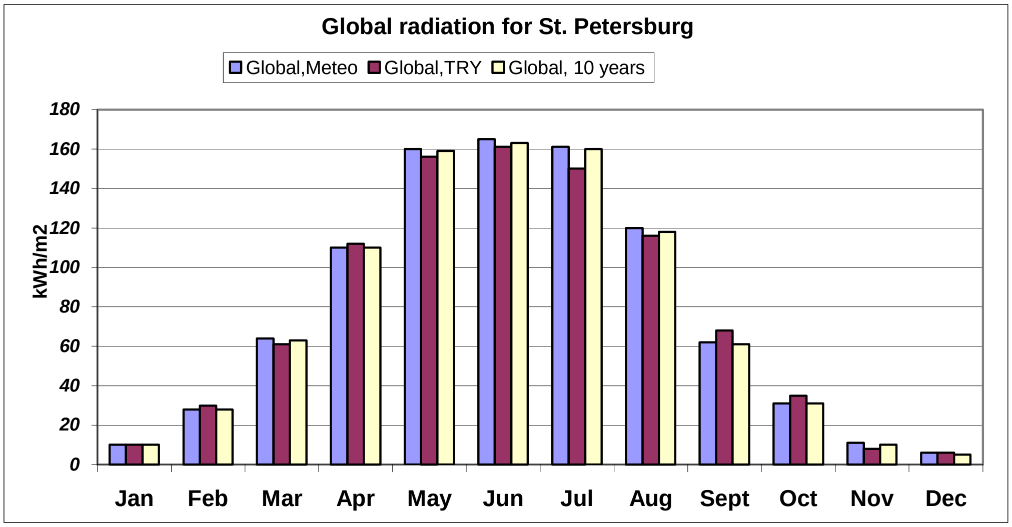



**Figure 3-13: Comparison of global radiation on a horizontal surface from different sources for St. Petersburg.**

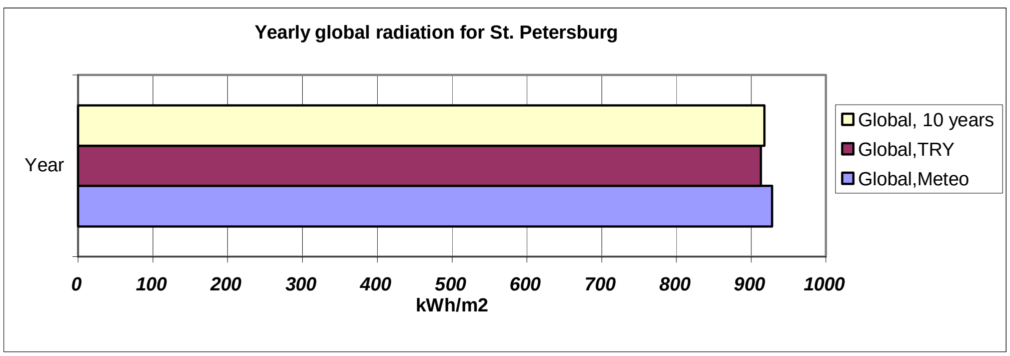



**Figure 3-14: Global radiation on a horizontal surface from different sources for St. Petersburg on an annual basis.**

*- Diffuse radiation on a horizontal surface.*

In Meteonorm, the so-called Perez and Molineaux models are used to calculate diffuse and direct radiation from the global radiation.

ESRA does not contain 10 years' measured data for diffuse radiation, so this is not usable for comparison.

By comparing diffuse radiation for Copenhagen from different sources it appears, see Figure 3-15 and Figure 3-16, that Meteonorm tend to overestimate the radiation by 15.5% on an annual basis compared with TRY and 12.0% compared with DRY.

As regards St. Petersburg, Figure 3-17 and Figure 3-18, Meteonorm underestimates the diffuse radiation on a horizontal surface by 2.7% on an annual basis compared with TRY.

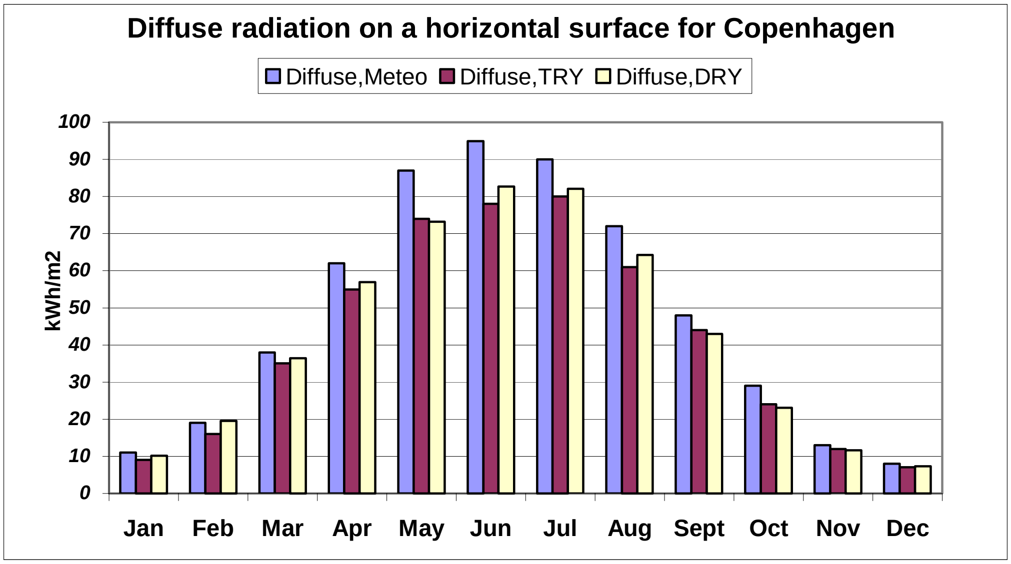



**Figure 3-15: Comparison of diffuse radiation on a horizontal surface from different sources for Copenhagen.**

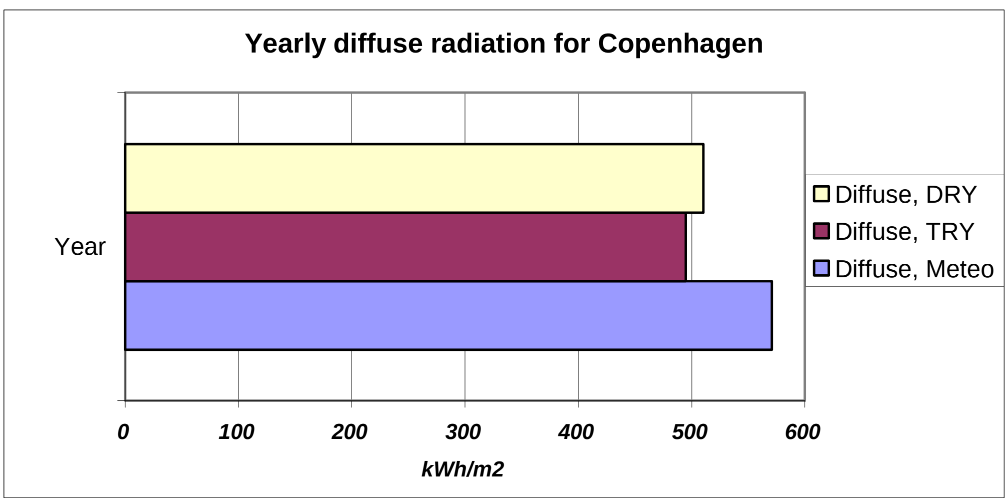



**Figure 3-16: Diffuse radiation on a horizontal surface from different sources for Copenhagen on an annual basis.**

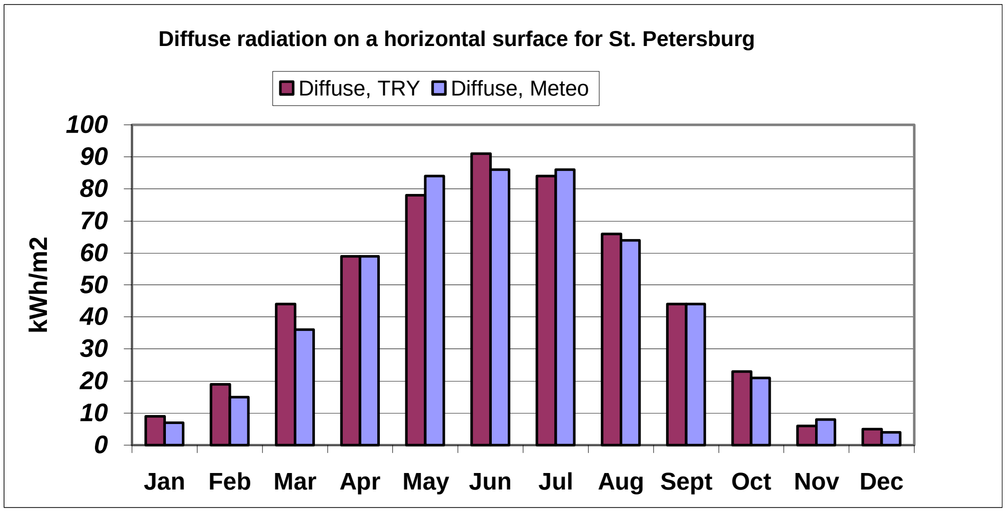



**Figure 3-17: Comparison of diffuse radiation on a horizontal surface from different sources for St. Petersburg.**

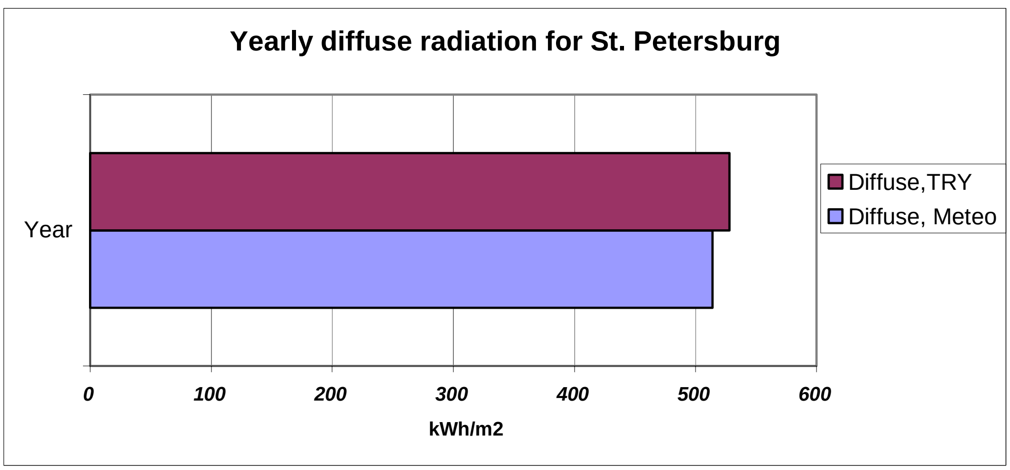



**Figure 3-18:Diffuse radiation on a horizontal surface from different sources for St. Petersburg on an annual basis.**

All in all Meteonorm was recognized as the best of the three options available to make a reference year for Latvia (Riga), i.e. TRY for either St. Petersburg or Copenhagen and Meteonorm.

A reference year for Latvia, which is produced by Meteonorm and consists of hourly values for temperature, global radiation, and diffuse radiation, appears from appendix 3 in the form of graphs month by month.

# 4 Comparison of solar radiation on a surface with different tilts and orientations for Riga and Copenhagen.

It is of interest to compare the solar radiation in Riga with the solar radiation in Copenhagen. Data are available for solar radiation on a surface with different tilts and orientations from TRY for Copenhagen, and solar radiation on a randomly tilted plate for Riga is calculated by means of Excel spreadsheets, where hourly values from Meteonorm are taken as a starting point.

Results of the calculations for Riga and data of the solar radiation for Copenhagen appear from appendix 4.

Figure 4-1 - Figure 4-8 show that the solar radiation is generally greater in Copenhagen than in Riga, and this difference is greatest for a 75-90° tilted surface facing south with +9.8%. Only for north-east facing 75-90° tilted surface and north-facing 45-90° tilted surface the solar radiation in Riga is greater than the solar radiation in Copenhagen, and this difference is greatest for a north-facing 90° tilted surface. It appears that solar radiation on a north-facing vertical surface in Riga is +14% greater than in Copenhagen.

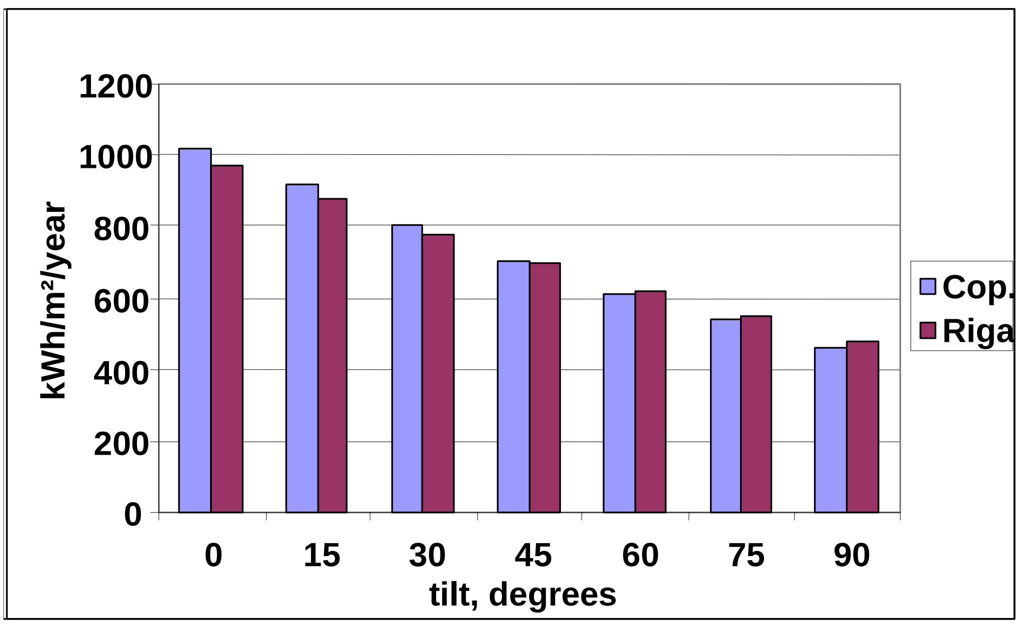



**Figure 4-1: Annual solar radiation on a north-west facing surface.**

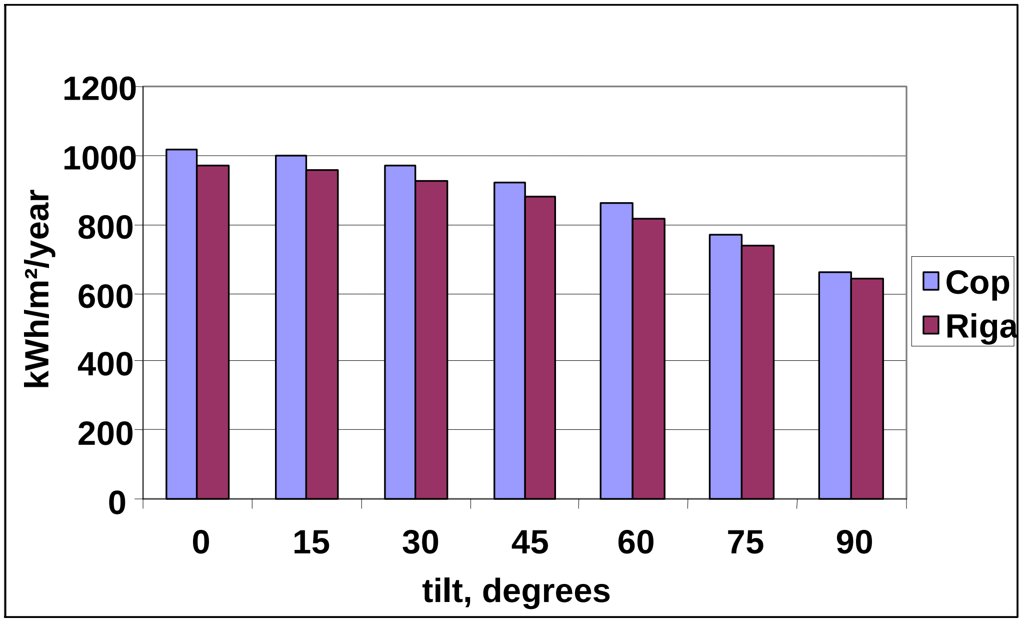



**Figure 4-2: Annual solar radiation on a west-facing surface.**

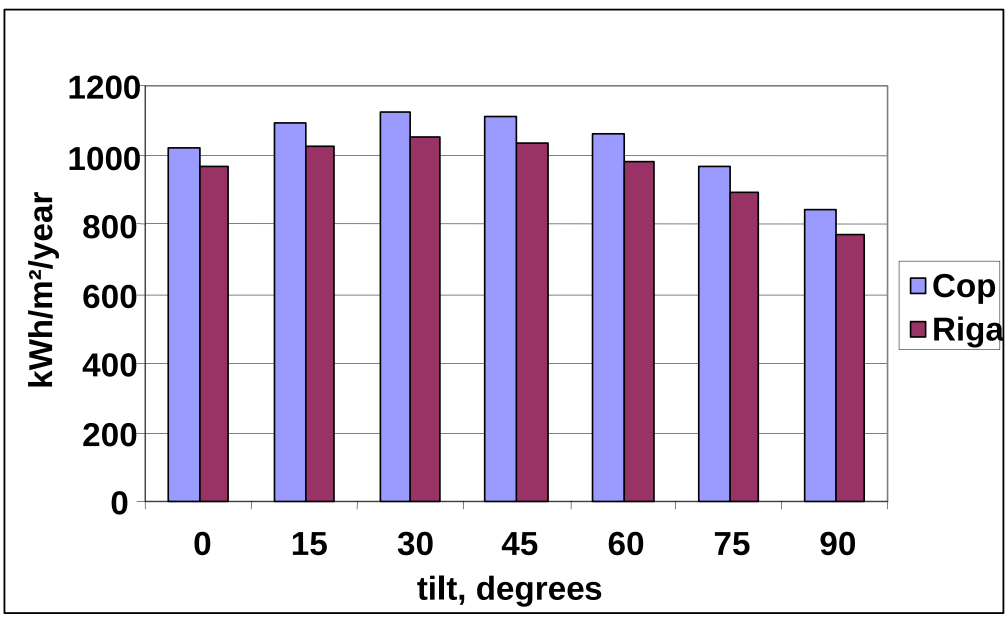



**Figure 4-3: Annual solar radiation on a south-west facing surface.**

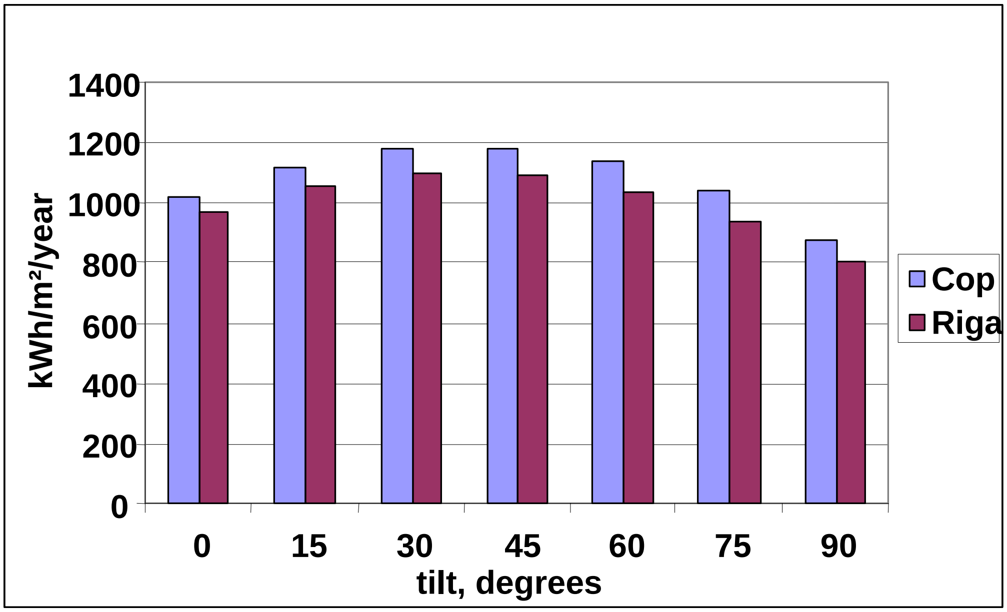



**Figure 4-4: Annual solar radiation on a south-facing surface.**

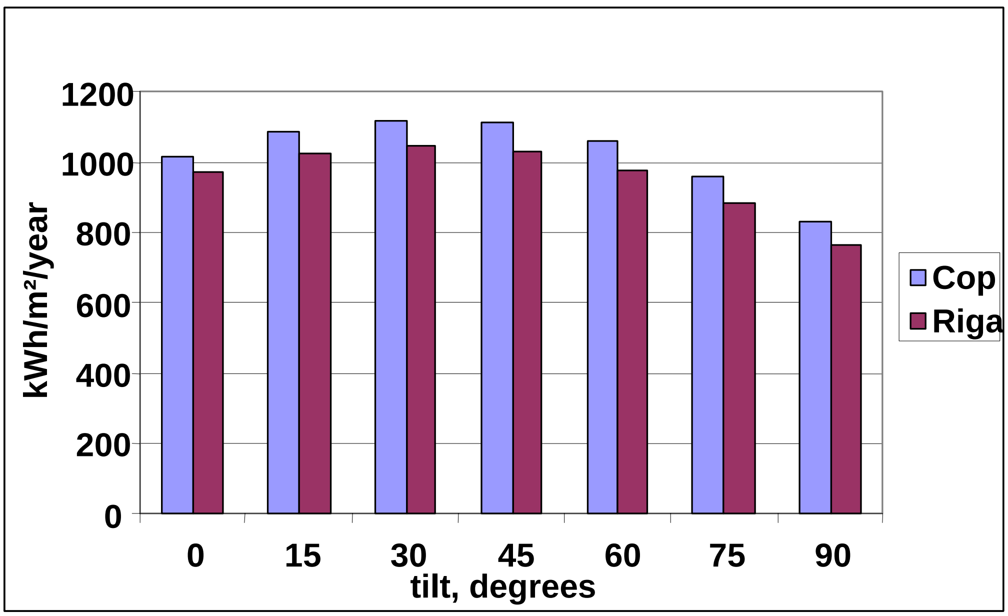



**Figure 4-5: Annual solar radiation on a south-east facing surface.**

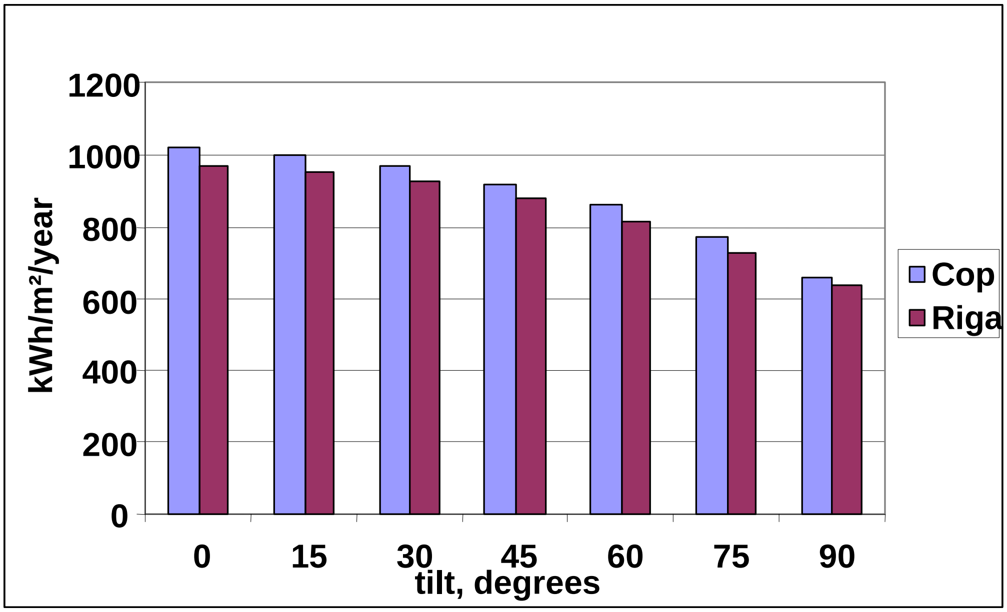



**Figure 4-6: Annual solar radiation on an east-facing surface.**

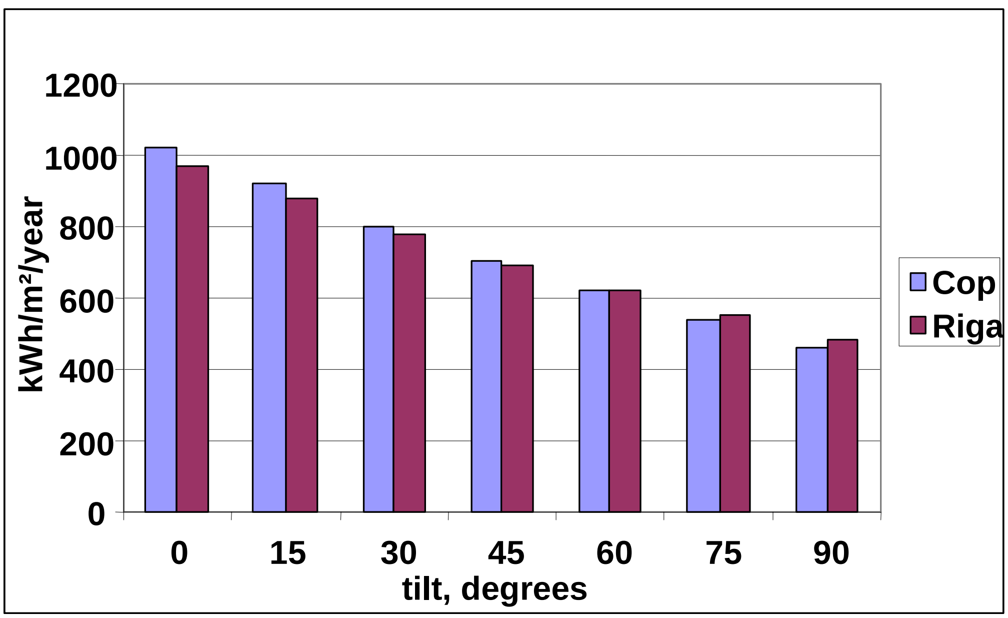



**Figure 4-7: Annual solar radiation on a north-east facing surface.**

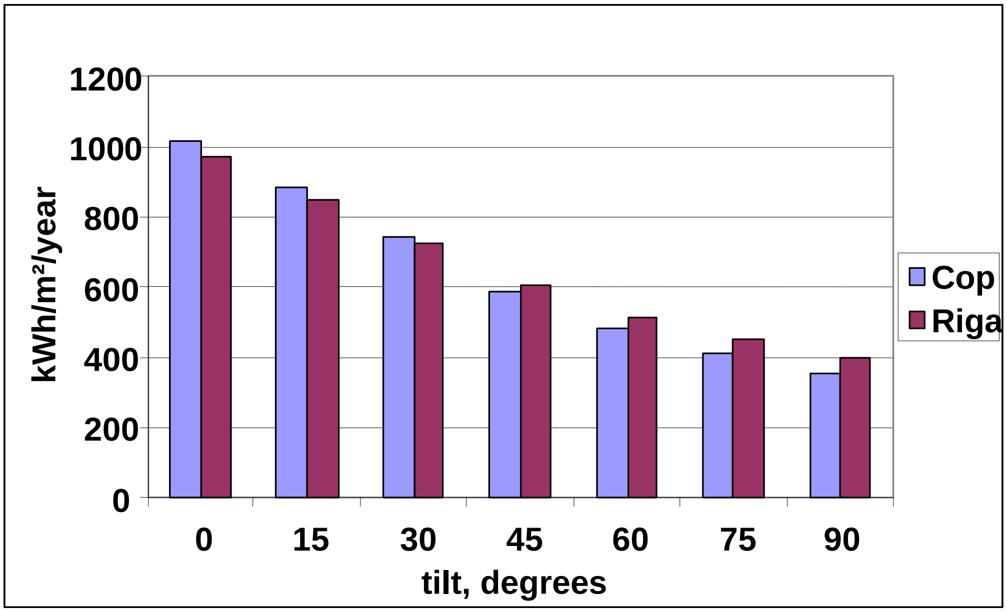



**Figure 4-8: Annual solar radiation on a north-facing surface.**

# 5 References


1. ”The European Solar Radiation Atlas (ESRA) Vol.2: Database, models and exploitation software”, E`cole des Mines de Paris, 2000 (+CD-ROM)
2. ”Solar Engineering Handbook METEONORM”, Meteotest Switzerland, 1997 (+ CD-ROM)

# 6 Symbol list

$G_h$ global radiation on a horizontal surface, [kWh/($m^2$·month) or W/$m^2$]

$T_a$ outdoor ambient temperature, °C

$D_h$ diffuse radiation on a horizontal surface, [kWh/($m^2$·month) or W/$m^2$]

$B_h$ direct radiation on a horizontal surface, [kWh/($m^2$·month) or W/$m^2$]

# Appendix 1: Map of Europe.

## Appendix 2: Average monthly values for 10 years from "European Solar Radiation Atlas".

### St. Petersburg

| Month | Temperature | Global radiation |
| --- | --- | --- |
| | $^0C$ | $kWh/m^2$ |
| Jan | -7.1 | 10 |
| Feb | -6 | 28 |
| Mar | -1.2 | 63 |
| Apr | 5 | 110 |
| May | 11.7 | 159 |
| Jun | 15.4 | 163 |
| Jul | 18 | 160 |
| Aug | 16.2 | 118 |
| Sept | 11.1 | 61 |
| Oct | 6.5 | 31 |
| Nov | -0.3 | 10 |
| Dec | -4.7 | 5 |
| Year | 5.4 | 918 |

### Copenhagen

| Month | Temperature | Global radiation |
| --- | --- | --- |
| | $^0C$ | $kWh/m^2$ |
| Jan | 0 | 15 |
| Feb | -0.2 | 34 |
| Mar | 2.1 | 63 |
| Apr | 7 | 118 |
| May | 11.8 | 157 |
| Jun | 15.5 | 159 |
| Jul | 17.7 | 165 |
| Aug | 17.4 | 131 |
| Sept | 14 | 83 |
| Oct | 9.4 | 44 |
| Nov | 5.3 | 20 |
| Dec | 2.5 | 10 |
| Year | 8.6 | 999 |

## Riga

| Month | Temperature | Global radiation |
|---|---|---|
| | $^0C$ | $kWh/m^2$ |
| Jan | -3.4 | 12 |
| Feb | -3.5 | 30 |
| Mar | 0.4 | 68 |
| Apr | 5.6 | 115 |
| May | 12.3 | 167 |
| Jun | 15 | 170 |
| Jul | 17.2 | 165 |
| Aug | 16.6 | 128 |
| Sept | 12.2 | 78 |
| Oct | 8.2 | 40 |
| Nov | 2.2 | 15 |
| Dec | -1.7 | 8 |
| Year | 6.7 | 996 |

# Appendix 3: Average monthly values from TRY, DRY and Meteonorm.

## St. Petersburg, TRY

| Month | Temperature | Global radiation | Diffuse radiation |
|---|---|---|---|
| | $^0C$ | $kWh/m^2$ | $kWh/m^2$ |
| Jan | -10.8 | 10 | 9 |
| Feb | -7.7 | 30 | 19 |
| Mar | -2.1 | 61 | 44 |
| Apr | 3.8 | 112 | 59 |
| May | 9.7 | 156 | 78 |
| Jun | 14.9 | 161 | 91 |
| Jul | 16.3 | 150 | 84 |
| Aug | 13.9 | 116 | 66 |
| Sept | 9.5 | 68 | 44 |
| Oct | 4.4 | 35 | 23 |
| Nov | -1.8 | 8 | 6 |
| Dec | -6.7 | 6 | 5 |
| Year | 3.6 | 913 | 528 |

## Copenhagen, TRY

| Month | Temperature | Global radiation | Diffuse radiation |
|---|---|---|---|
| | $^0C$ | $kWh/m^2$ | $kWh/m^2$ |
| Jan | -0.6 | 13 | 9 |
| Feb | -1.1 | 33 | 16 |
| Mar | 2.6 | 59 | 35 |
| Apr | 6.6 | 119 | 55 |
| May | 10.6 | 156 | 74 |
| Jun | 15.7 | 186 | 78 |
| Jul | 16.4 | 161 | 80 |
| Aug | 16.7 | 135 | 61 |
| Sept | 13.7 | 83 | 44 |
| Oct | 9.2 | 44 | 24 |
| Nov | 5 | 19 | 12 |
| Dec | 1.7 | 12 | 7 |
| Year | 8.1 | 1020 | 495 |

## Copenhagen,DRY

| Month | Temperature | Global radiation | Diffuse radiation (horizontal) |
|---|---|---|---|
| | $^0$C | kWh/m$^2$ | kWh/m$^2$ |
| Jan | -0.5 | 16 | 10.1 |
| Feb | -1 | 32 | 19.5 |
| Mar | 1.7 | 65 | 36.5 |
| Apr | 5.6 | 114 | 57.0 |
| May | 11.3 | 163 | 73.2 |
| Jun | 15 | 165 | 82.7 |
| Jul | 16.4 | 160 | 82.1 |
| Aug | 16.2 | 134 | 64.3 |
| Sept | 12.5 | 82 | 43.0 |
| Oct | 9.1 | 43 | 23.1 |
| Nov | 4.8 | 19 | 11.6 |
| Dec | 1.5 | 10 | 7.3 |
| Year | 7.8 | 1002 | 510.4 |

## Data from METEONORM for St. Petersburg, Copenhagen and Riga.

## St. Petersburg

| Month | Temperature | Global radiation | Diffuse radiation (horizontal) |
|---|---|---|---|
| | $^0$C | kWh/m$^2$ | kWh/m$^2$ |
| Jan | -6.3 | 10 | 7 |
| Feb | -5.8 | 28 | 15 |
| Mar | -1.5 | 64 | 36 |
| Apr | 4.6 | 110 | 59 |
| May | 11.3 | 160 | 84 |
| Jun | 15.2 | 165 | 86 |
| Jul | 17.5 | 161 | 86 |
| Aug | 15.9 | 120 | 64 |
| Sept | 10.9 | 62 | 44 |
| Oct | 5.3 | 31 | 21 |
| Nov | 0.3 | 11 | 8 |
| Dec | -4 | 6 | 4 |
| Year | 5.3 | 928 | 514 |

## Copenhagen

| Month | Temperature | Global radiation | Diffuse radiation (horizontal) |
|---|---|---|---|
| | $^0C$ | $kWh/m^2$ | $kWh/m^2$ |
| Jan | 0.4 | 15 | 11 |
| Feb | -0.1 | 30 | 19 |
| Mar | 2.7 | 61 | 38 |
| Apr | 6.1 | 115 | 62 |
| May | 11.6 | 155 | 87 |
| Jun | 14.9 | 155 | 95 |
| Jul | 16.8 | 166 | 90 |
| Aug | 16.6 | 131 | 72 |
| Sept | 13.3 | 80 | 48 |
| Oct | 9.1 | 44 | 29 |
| Nov | 4.9 | 20 | 13 |
| Dec | 1.9 | 11 | 8 |
| Year | 8.2 | 983 | 572 |

## Riga

| Month | Temperature | Global radiation | Diffuse radiation (horizontal) |
|---|---|---|---|
| | $^0C$ | $kWh/m^2$ | $kWh/m^2$ |
| January | -5.6 | 13 | 10 |
| February | -6.1 | 32 | 17 |
| March | -1.1 | 74 | 40 |
| April | 4.4 | 107 | 55 |
| May | 11.1 | 155 | 82 |
| June | 15 | 170 | 89 |
| July | 16.7 | 161 | 87 |
| August | 15.6 | 124 | 76 |
| September | 10.6 | 75 | 48 |
| October | 6.1 | 37 | 25 |
| November | 0.6 | 13 | 10 |
| December | -3.9 | 8 | 6 |
| Year | 5.3 | 966 | 545 |

# Appendix 4: Annual solar radiation for Copenhagen and Riga.

**Data from TRY and Meteonorm.**
**Unit: [kWh/m²/year]**

## Copenhagen, data from TRY

| tilt / orient. | north west | west | south west | south | south east | east | north east | north |
|---|---|---|---|---|---|---|---|---|
| $0^0$ | 1020 | 1020 | 1020 | 1020 | 1020 | 1020 | 1020 | 1020 |
| $15^0$ | 920 | 1000 | 1090 | 1120 | 1090 | 1000 | 920 | 880 |
| $30^0$ | 800 | 970 | 1120 | 1180 | 1120 | 970 | 800 | 740 |
| $45^0$ | 700 | 920 | 1110 | 1180 | 1110 | 920 | 700 | 590 |
| $60^0$ | 610 | 860 | 1060 | 1140 | 1060 | 860 | 620 | 480 |
| $75^0$ | 540 | 770 | 970 | 1040 | 960 | 770 | 540 | 410 |
| $90^0$ | 460 | 660 | 840 | 880 | 830 | 660 | 460 | 350 |

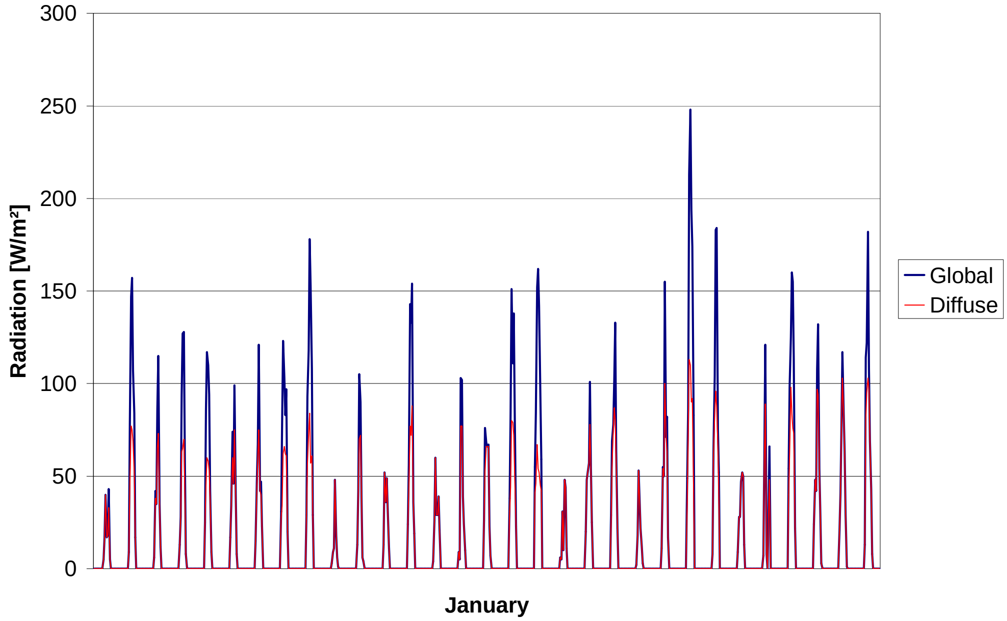
## Copenhagen, data from Meteonorm

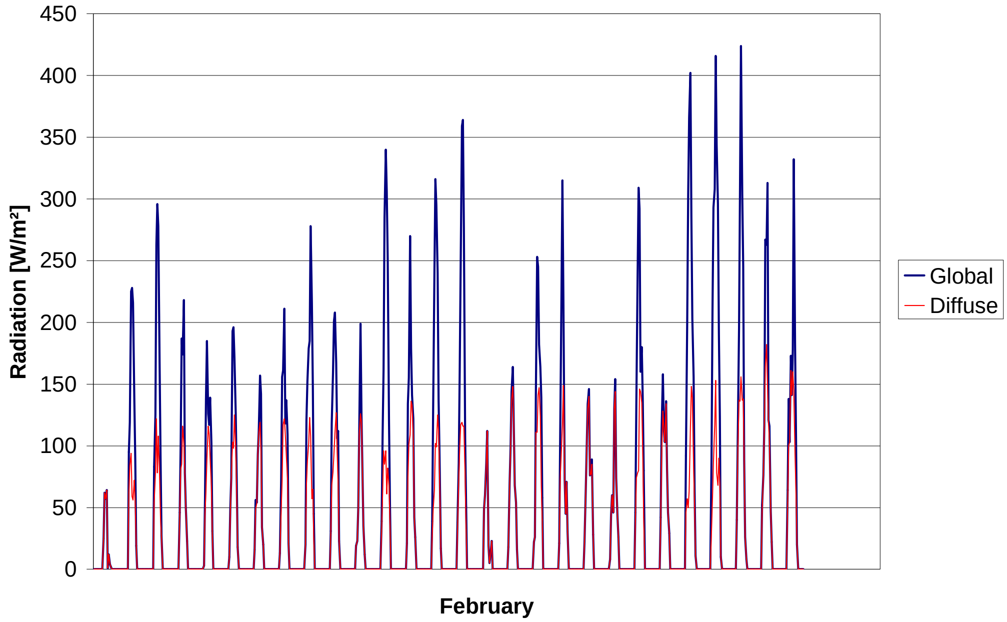
| tilt / orient. | north west | west | south west | south | south east | east | north east | north |
|---|---|---|---|---|---|---|---|---|
| $0^0$ | 980 | 980 | 980 | 980 | 980 | 980 | 980 | 980 |
| $15^0$ | 873 | 969 | 1062 | 1101 | 1066 | 974 | 877 | 836 |
| $30^0$ | 757 | 938 | 1102 | 1168 | 1109 | 948 | 764 | 689 |
| $45^0$ | 660 | 894 | 1099 | 1179 | 1108 | 908 | 669 | 550 |
| $60^0$ | 588 | 833 | 1049 | 1135 | 1062 | 849 | 596 | 452 |
| $75^0$ | 527 | 755 | 959 | 1035 | 973 | 771 | 534 | 407 |
| $90^0$ | 468 | 663 | 833 | 891 | 845 | 676 | 473 | 369 |

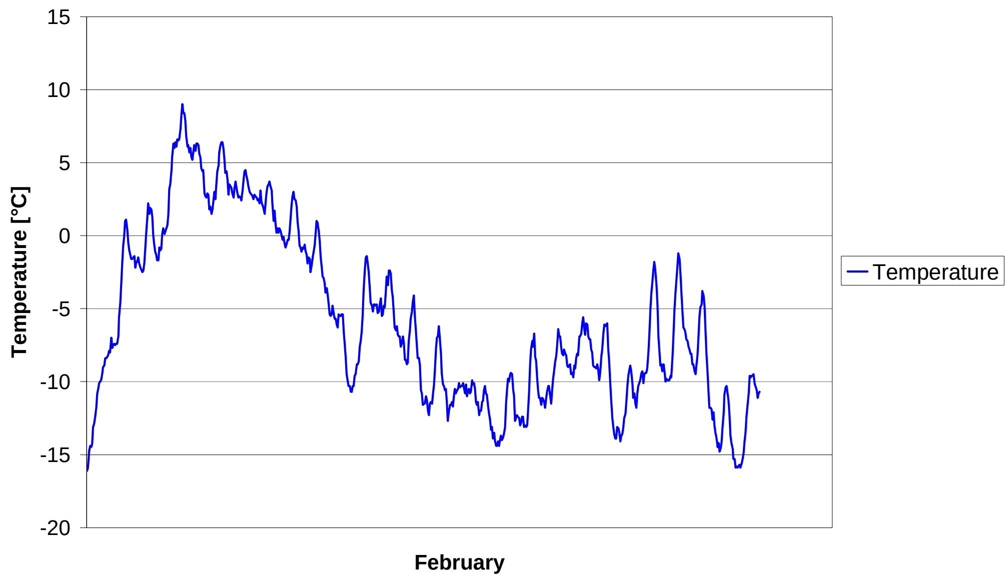
## Riga, data from Meteonorm

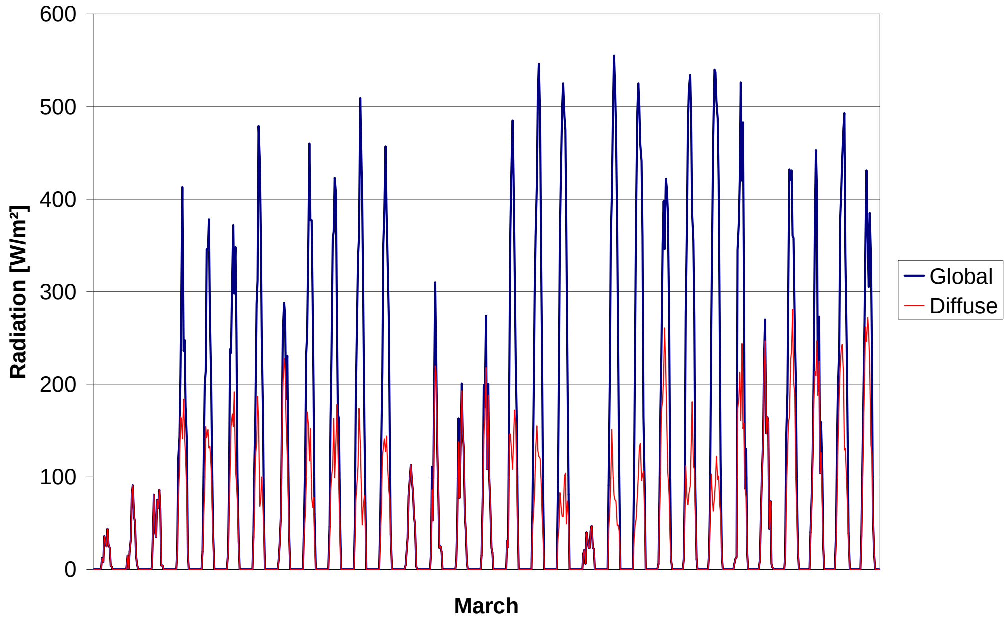
| tilt / orient. | north west | west | south west | south | south east | east | north east | north |
|---|---|---|---|---|---|---|---|---|
| 0 | 969 | 969 | 969 | 969 | 969 | 969 | 969 | 969 |
| 15 | 880 | 955 | 1027 | 1054 | 1025 | 954 | 878 | 848 |
| 30 | 781 | 925 | 1050 | 1095 | 1048 | 923 | 779 | 721 |
| 45 | 694 | 880 | 1034 | 1089 | 1031 | 877 | 692 | 604 |
| 60 | 622 | 817 | 980 | 1034 | 977 | 814 | 619 | 511 |
| 75 | 552 | 736 | 887 | 938 | 885 | 732 | 550 | 453 |
| 90 | 482 | 640 | 768 | 803 | 764 | 636 | 479 | 399 |

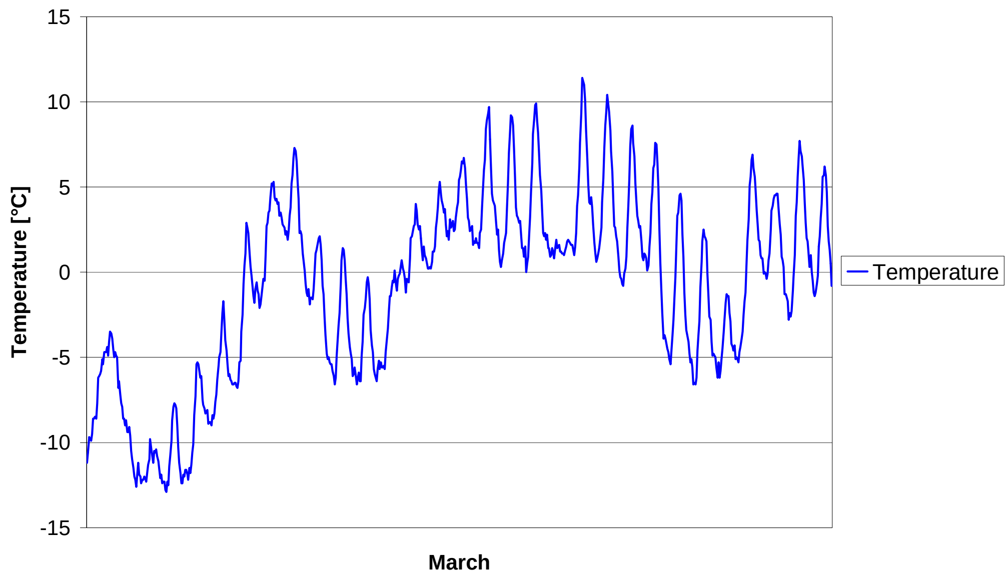
## Appendix 5. A reference year for Latvia.

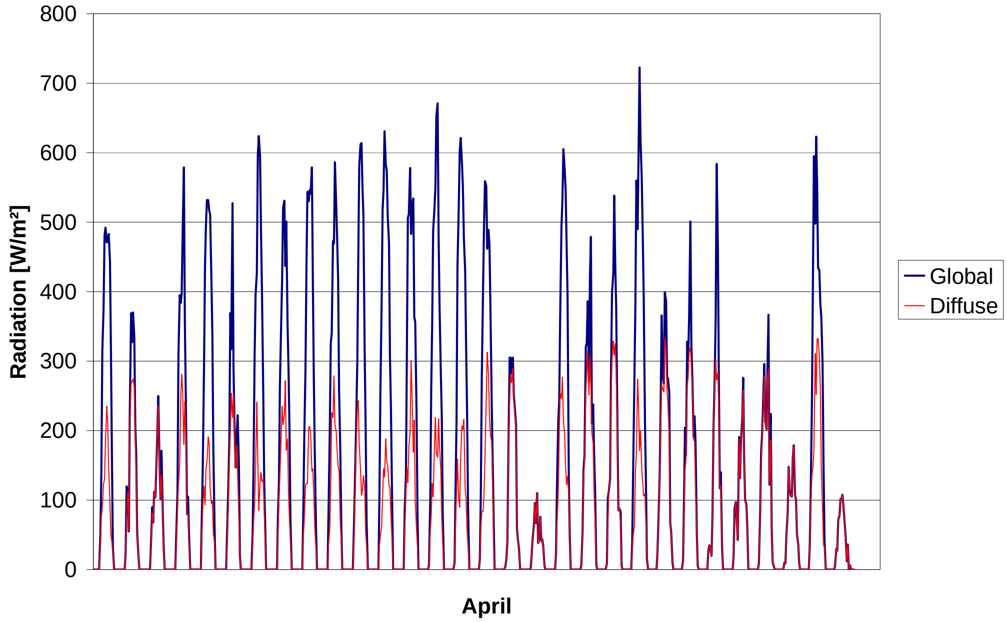


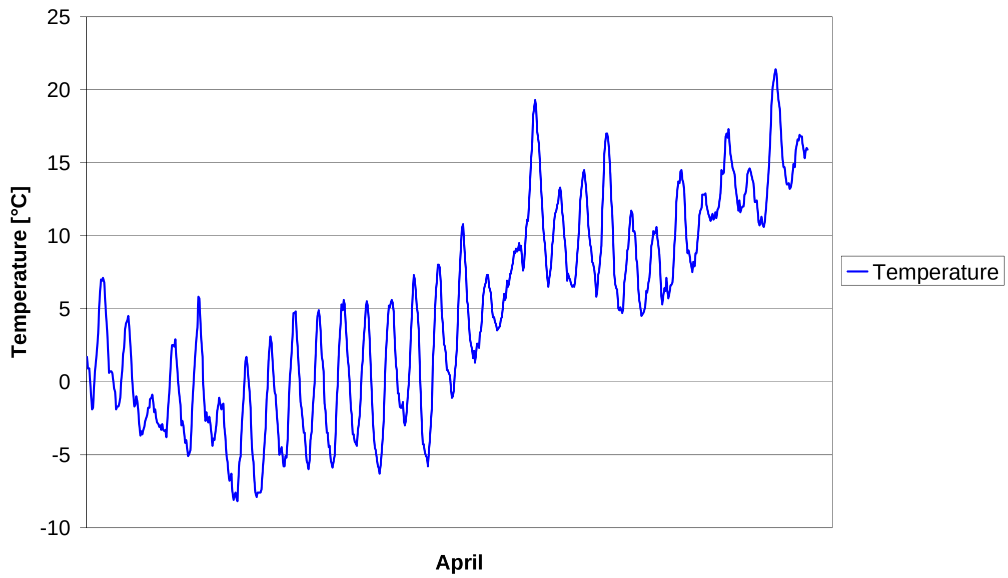


450
400
350
300
250
200
150
100
50
0
Radiation [W/m²]
February
Global
Diffuse

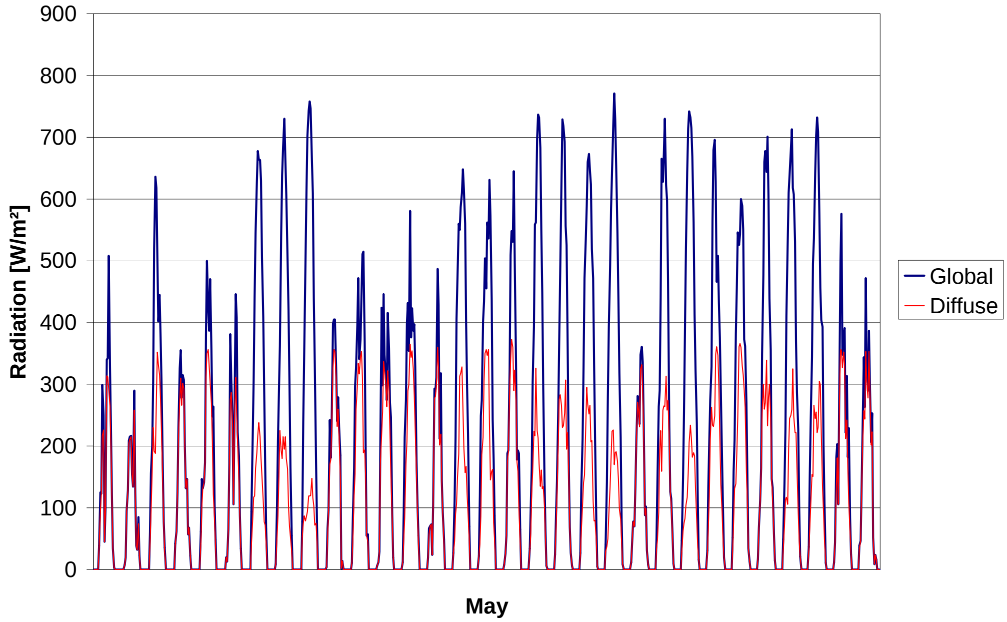

15
10
5
0
-5
-10
-15
-20
Temperature [°C]
February
Temperature

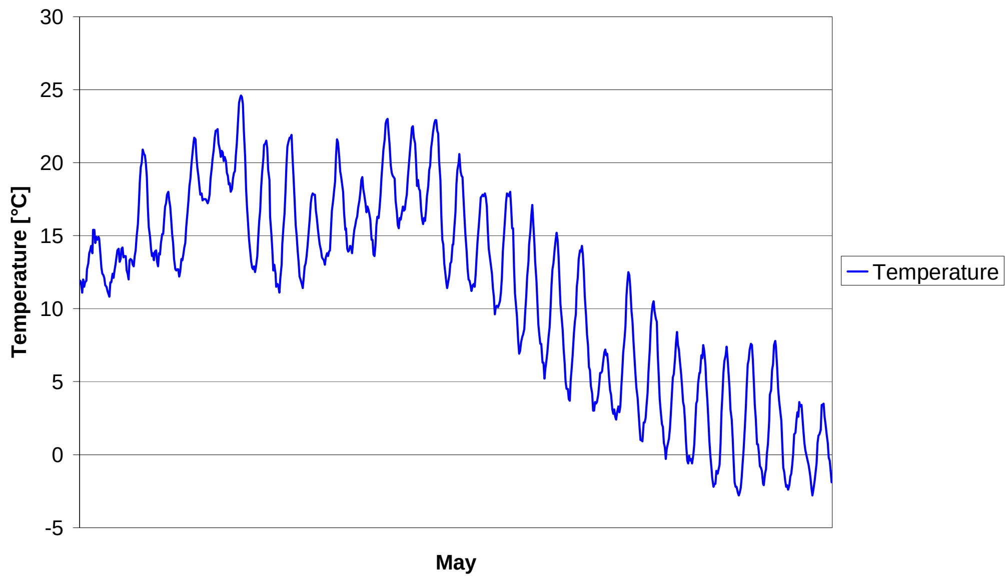

600
500
400
300
200
100
0
Radiation [W/m²]
March
Global
Diffuse

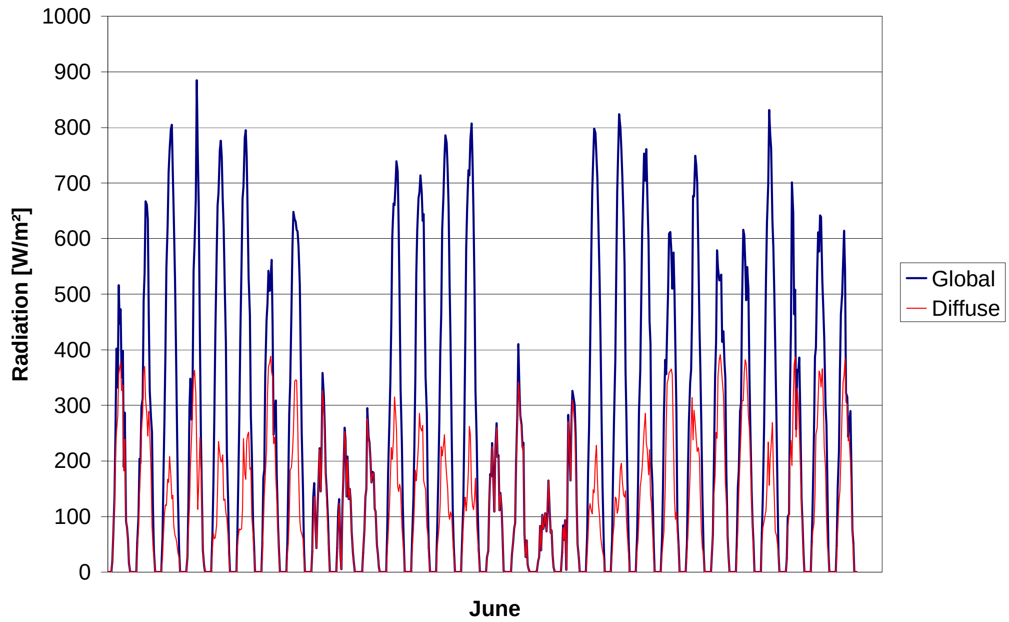

15
10
5
0
-5
-10
-15
Temperature [°C]
March
Temperature

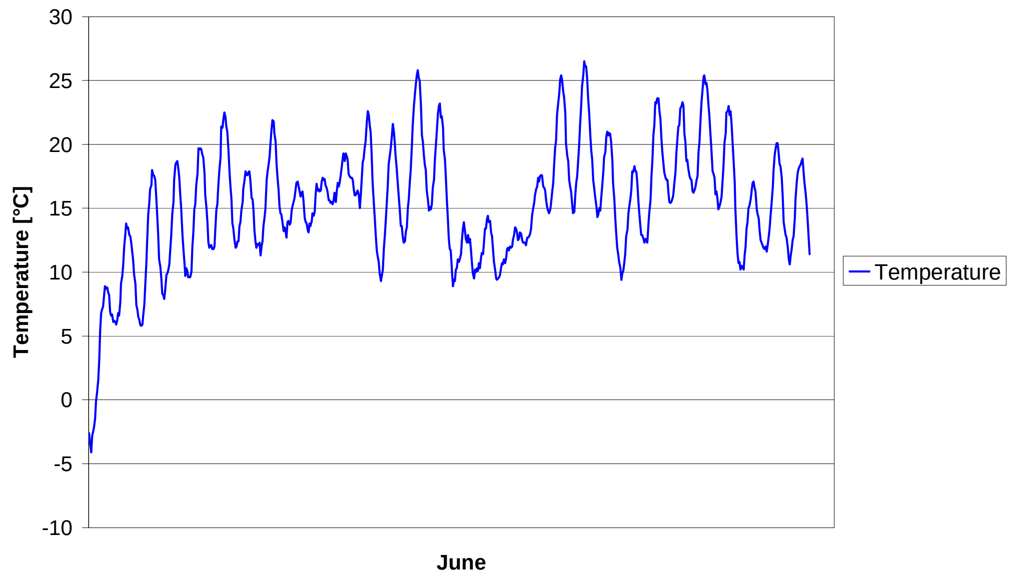

800
700
600
500
400
300
200
100
0
Radiation [W/m²]
April
Global
Diffuse

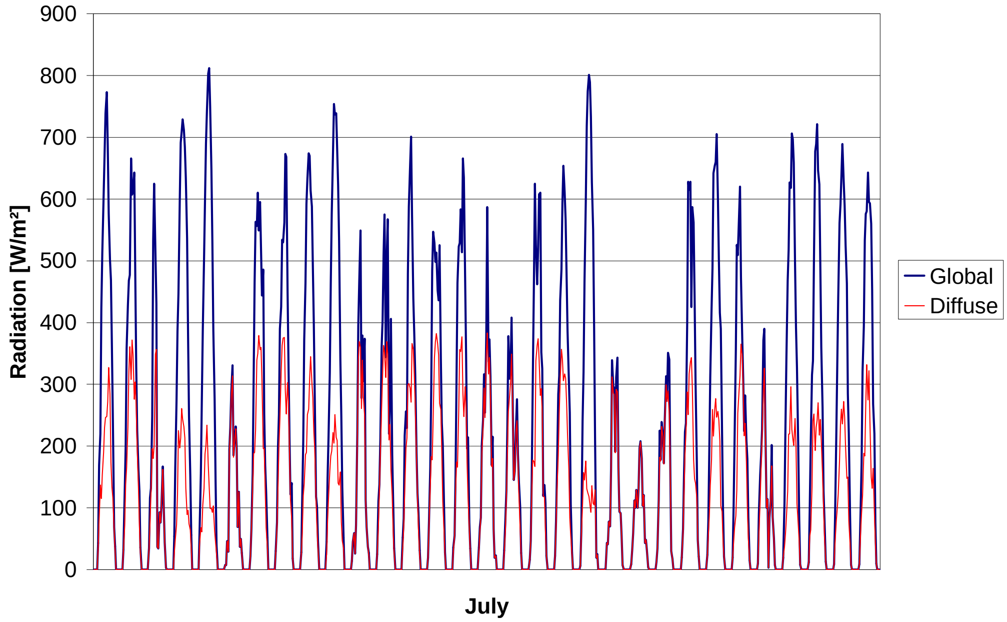

25
20
15
10
5
0
-5
-10
Temperature [°C]
April
Temperature

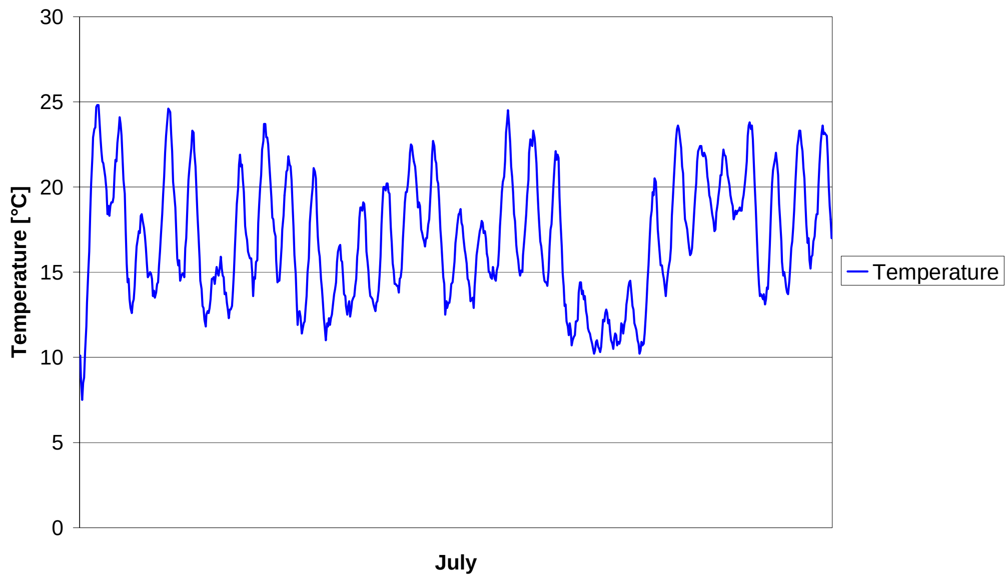

900
800
700
600
500
400
300
200
100
0
Radiation [W/m²]
May
Global
Diffuse

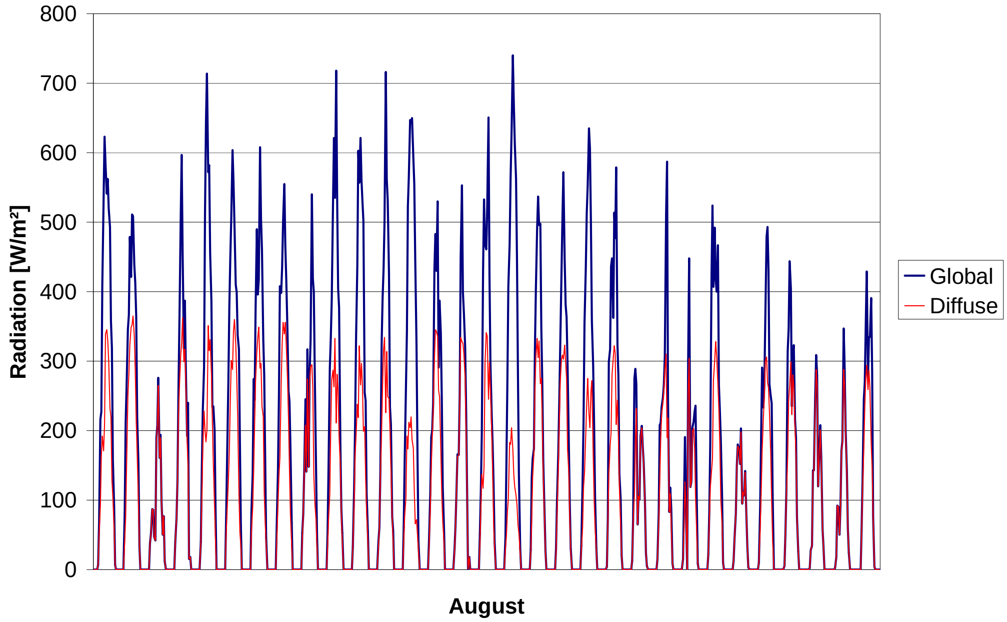

30
25
20
15
10
5
0
-5
Temperature [°C]
May
Temperature

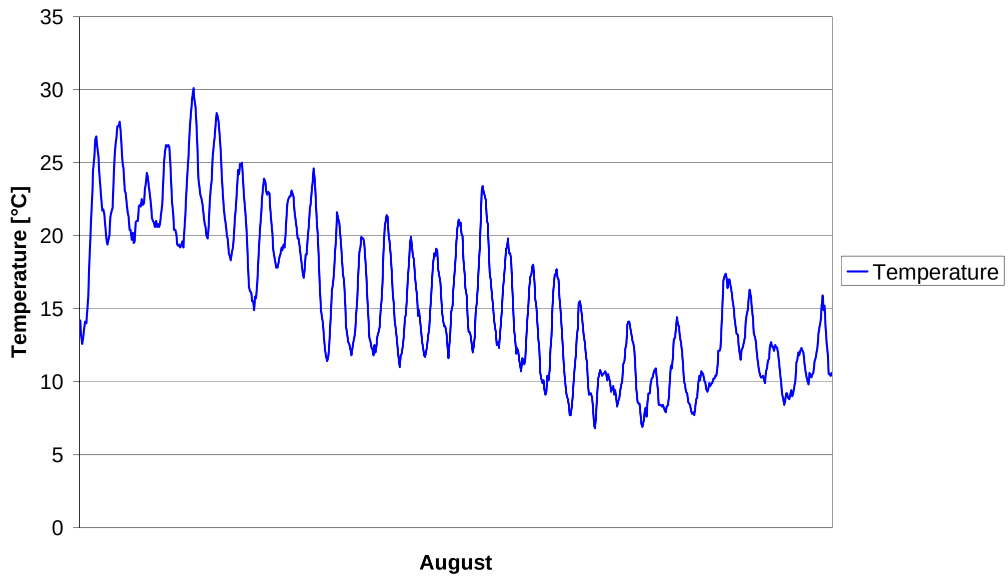

1000
900
800
700
600
500
400
300
200
100
0
Radiation [W/m²]
June
Global
Diffuse

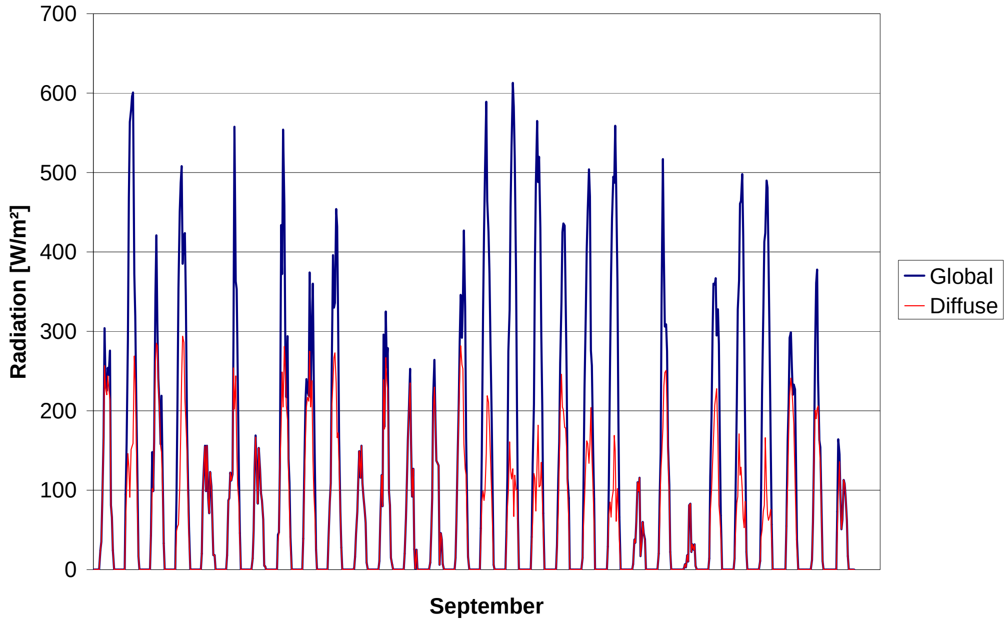

30
25
20
15
10
5
0
-5
-10
Temperature [°C]
June
Temperature

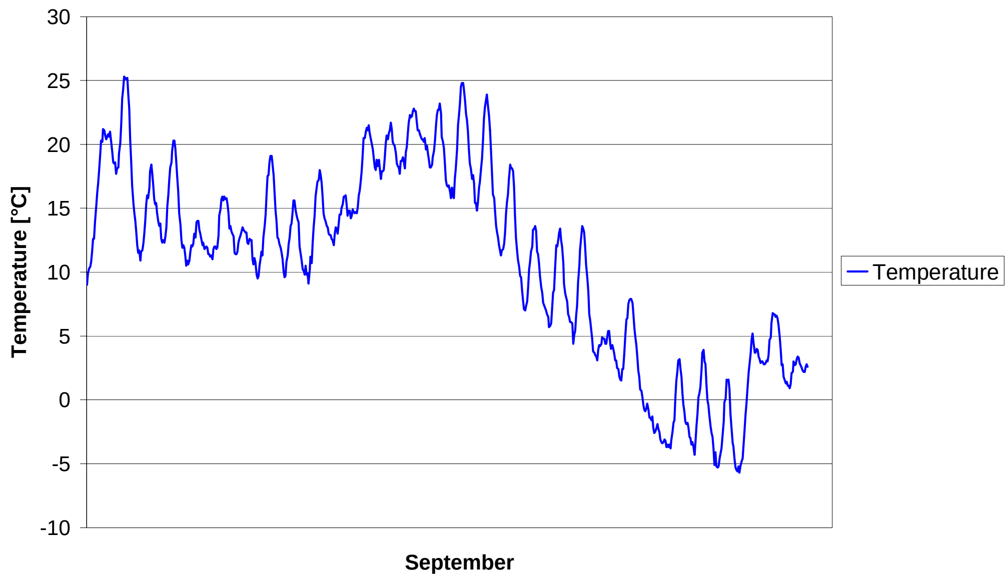

900
800
700
600
500
400
300
200
100
0
Radiation [W/m²]
July
Global
Diffuse

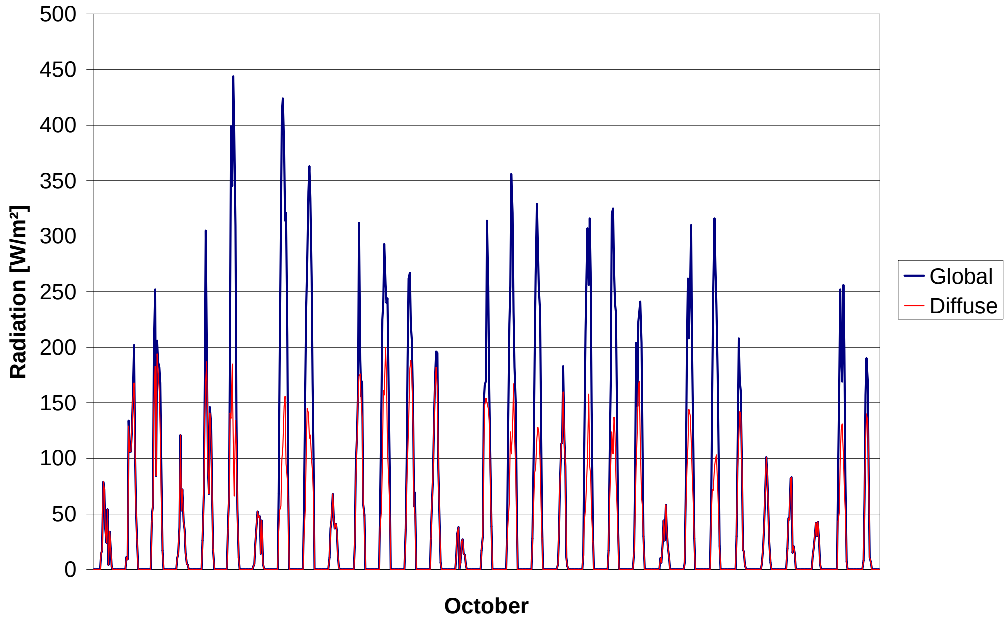

30
25
20
15
10
5
0
Temperature [°C]
July
Temperature

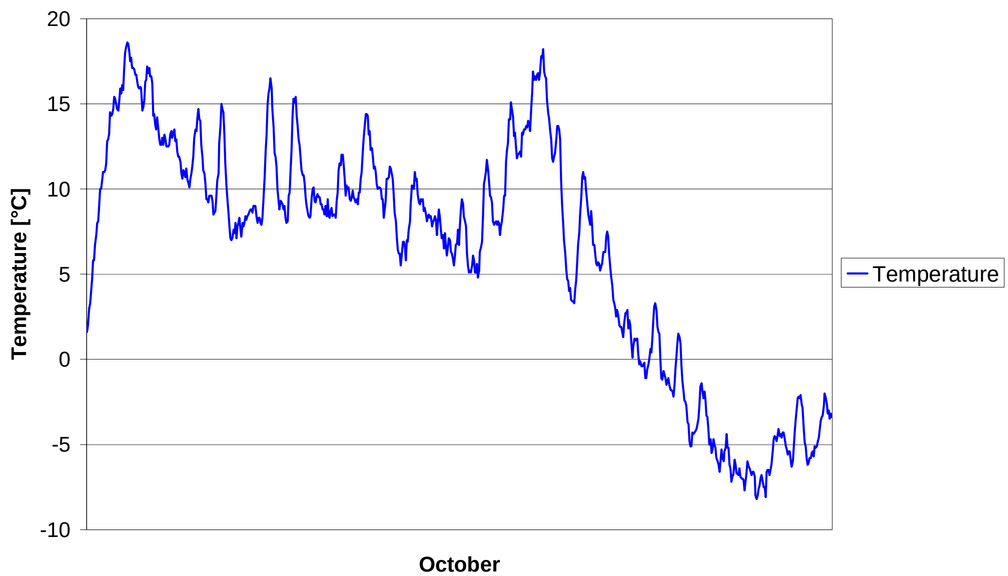

800
700
600
500
400
300
200
100
0
Radiation [W/m²]
August
Global
Diffuse

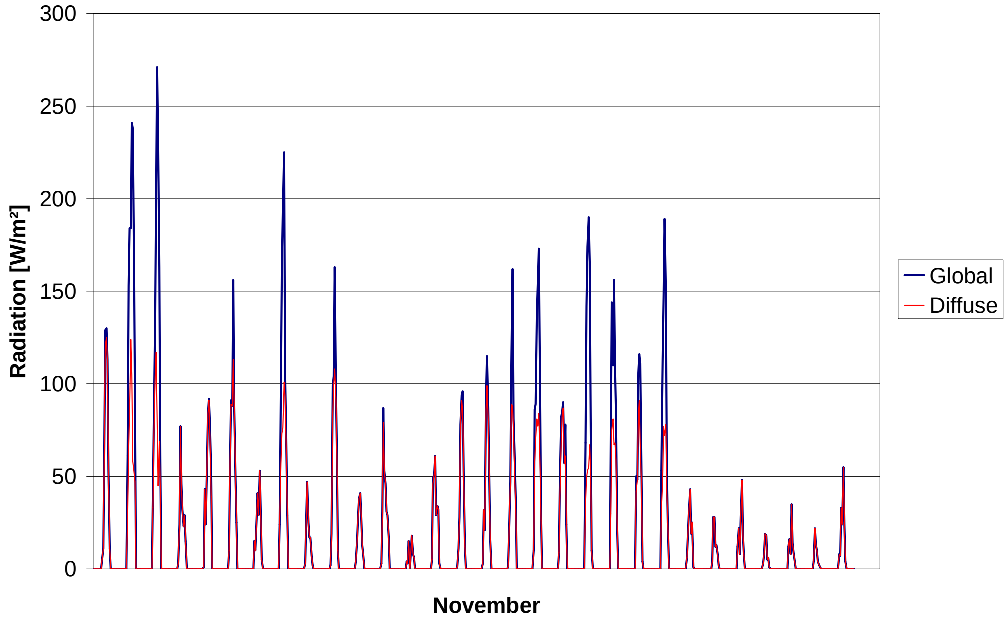

35
30
25
20
15
10
5
0
Temperature [°C]
August
Temperature


700
600
500
400
300
200
100
0
Radiation [W/m²]
September
Global
Diffuse

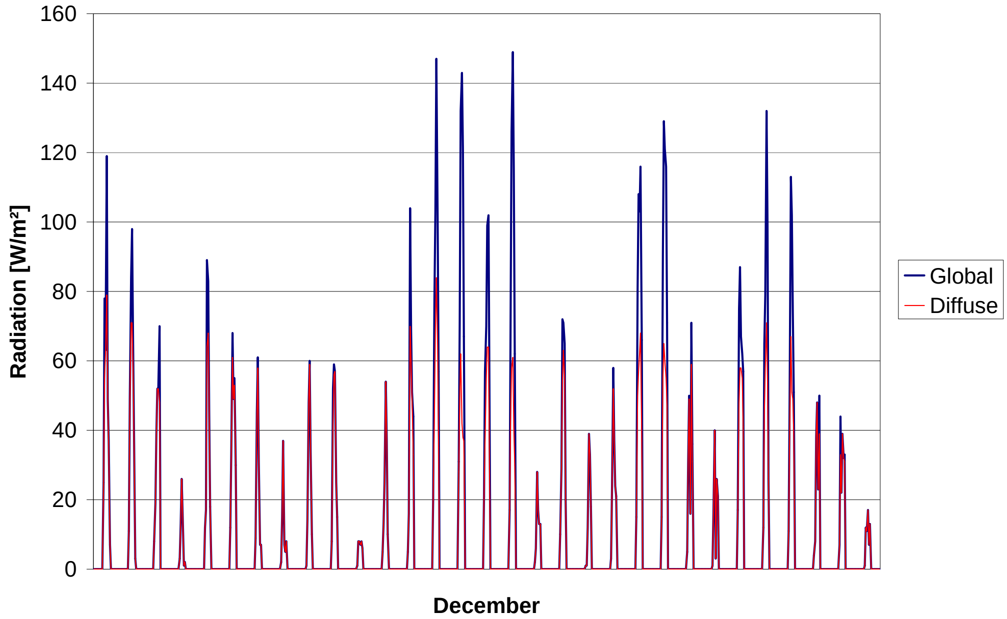

30
25
20
15
10
5
0
-5
-10
Temperature [°C]
September
Temperature


500
450
400
350
300
250
200
150
100
50
0
Radiation [W/m²]
October
Global
Diffuse

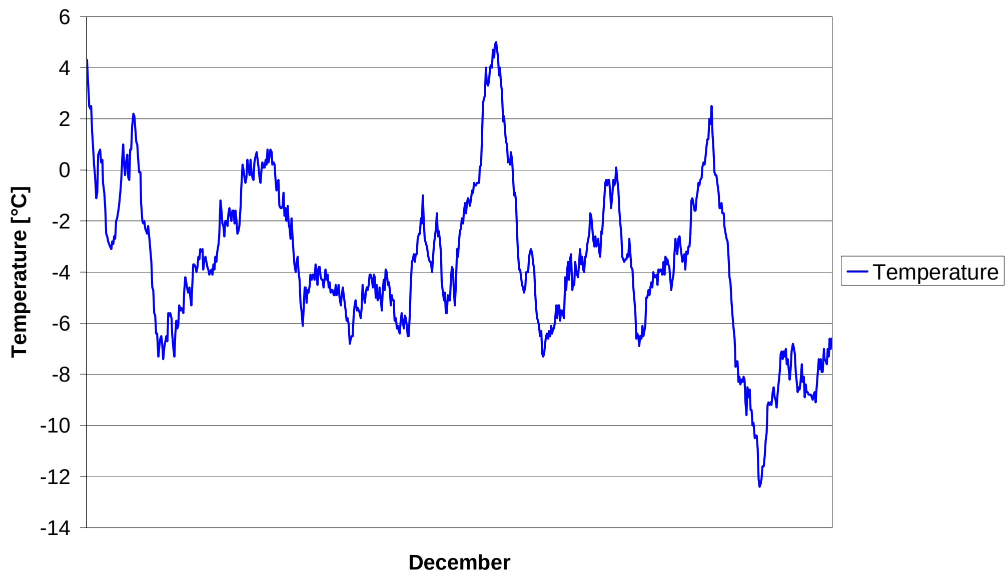

20
15
10
5
0
-5
-10
Temperature [°C]
October
Temperature


300
250
200
150
100
50
0
Radiation [W/m²]
November
Global
Diffuse


15
10
5
0
-5
-10
-15
Temperature [°C]
November
Temperature



160
140
120
100
80
60
40
20
0
Radiation [W/m²]
December
Global
Diffuse

6
4
2
0
-2
-4
-6
-8
-10
-12
-14
Temperature [°C]
December
Temperature

# Appendix 6: Description of the electronic reference year file.

**File name:** Latvia Reference Year.xls
**File format:** Microsoft Excel 2000
**File date:** 22-05-2002
**File size:** 718 KB

The reference year file consists of 8762 lines in four columns, as shown in the table below. In the first line a description of each column is given. The second line shows the unit for each column, and the next 8760 lines include hourly values for the global radiation (horizontal, W/m²), diffuse radiation (horizontal, W/m²) and the ambient temperature (°C).

From Excel, the file can easily be exported as an ASCII file and be used as data for simulation programs for solar systems.

| Hour | Global Radiation | Diffuse Radiation | Temperature |
|---|---|---|---|
| [-] | [W/m²] | [W/m²] | [°C] |
| 1 | 0 | 0 | -5.3 |
| 2 | 0 | 0 | -6.3 |
| 3 | 0 | 0 | -7 |
| 4 | 0 | 0 | -7.8 |
| 5 | 0 | 0 | -8.1 |
| . | . | . | . |
| . | . | . | . |
| . | . | . | . |
| 4904 | 223 | 187 | 12.3 |
| 4905 | 237 | 221 | 13.3 |
| 4906 | 402 | 288 | 14.5 |
| 4907 | 628 | 251 | 15.4 |
| 4908 | 615 | 317 | 17.1 |
| . | . | . | . |
| . | . | . | . |
| . | . | . | . |
| 8757 | 0 | 0 | -7.3 |
| 8758 | 0 | 0 | -6.6 |
| 8759 | 0 | 0 | -7 |
| 8760 | 0 | 0 | -6.6 |

**Format of the reference file.**