

# **The Design Reference Year Users Manual**

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**A Report of Task 9: Solar Radiation and Pyranometer Studies**

**February 1995**

<p><b>Thermal Insulation Laboratory Report No. 274 Technical University of Denmark</b></p>
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## THE INTERNATIONAL ENERGY AGENCY SOLAR HEATING AND COOLING PROGRAMME

### International Energy Agency

The International Energy Agency, headquartered in Paris, was formed in November 1974 as an autonomous body within the framework of the Organization for Economic Cooperation and Development to establish cooperation in the area of energy policy. Twenty-one countries are presently members, with the Commission of the European Communities participating under a special arrangement.

Collaboration in the research, development and demonstration of new energy technologies to help reduce dependence on oil and to increase long-term energy security has been an important part of the Agency's programme. The IEA R&D activities are headed by the Committee on Research and Development (CRD) which is supported by a small Secretariat staff. In addition, four Working Parties (in Conservation, Fossil Fuels, Renewable Energy and Fusion) are charged with monitoring the various collaborative energy Agreements, identifying new areas for cooperation and advising the CRD on policy matters.

### Solar Heating and Cooling Programme

On of the first collaborative R&D agreements was the IEA Solar Heating and Cooling Programme which was initiated in 1977 to conduct joint projects in active and passive solar technologies, primarily for building applications. The twenty members of the Programme are:

Australia	France	Spain
Austria	Germany	Sweden
Belgium	Italy	Switzerland
Canada	Japan	Turkey
Denmark	Netherlands	United Kingdom
European Community	New Zealand	United States
Finland	Norway	

A total of twenty projects or "Tasks" have been undertaken since the beginning of the Programme. The overall programme is managed by an Executive Committee composed of one representative from each of the member countries, while the leadership and management of the individual Tasks is the responsibility of Operating Agents. These Tasks and their respective Operating Agents are:

- \*Task 1: Investigation of the Performance of Solar Heating and Cooling Systems - Denmark
- \*Task 2: Coordination of Research and Development on Solar Heating and Cooling - Japan
- \*Task 3: Performance Testing of Solar Collectors - United Kingdom
- \*Task 4: Development of an Insolation Handbook and Instrument Package - United States
- \*Task 5: Use of Existing Meteorological Information for Solar Energy Application - Sweden
- \*Task 6: Solar Heating, Cooling, and Hot Water Systems Using Evacuated Collectors - United States
- \*Task 7: Central Solar Heating Plants with Seasonal Storage - Sweden
- \*Task 8: Passive and Hybrid Solar Low Energy Buildings - United States
- \*Task 9: Solar Radiation and Pyranometry Studies - Germany
- \*Task 10: Material Research and Testing - Japan
- \*Task 11: Passive and Hybrid Solar Commercial Buildings - Switzerland
- Task 12: Building Energy Analysis and Design Tools for Solar Applications - United States
- Task 13: Advanced Solar Low Energy Buildings - Norway
- Task 14: Advanced Active Solar Systems - Canada
- Task 16: Photovoltaics in Buildings - Germany
- Task 17: Measuring and Modelling Spectral Radiation - Germany
- Task 18: Advanced Glazing Materials - United Kingdom
- Task 19: Solar Air Heating - Switzerland
- Task 20: Solar Retrofit Systems for Buildings - Sweden
- Task 21: Daylighting Systems - Denmark (in planning stage)

\*Completed Task

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This report documents work performed within the IEA Solar Heating and Cooling Programme  
Task 9: Solar Radiation and Pyranometry  
Subtask E: Representative Design Years.

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# The Design Reference Year Users Manual

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## Legal disclaimer

The Design Reference Years described in this manual are the property of the producers in each country.

Some of the Design Reference Years described in this manual are tentative, and for research or experimental use only.

## Contents

0.	Summary	4
1.	Introduction	5
1.1	Requirements	5
1.2	Production process	6
1.3	Selection of sites for Design Reference Years	8
1.4	Selection method	8
1.5	Adjustment method	9
1.6	Corrected data	10
2.	Availability of Design Reference Years	11
2.1	Restrictions for use	11
3.	Parameters in Design Reference Years	12
4.	The Danish Design Reference Year	16
4.1	Tables, monthly values of important parameters	17
	References	19

Appendix A. List of participants in the IEA SHCP subtask 9 E work.

Appendix B. Design Reference Years in Europe, and sources. (as of January 1995)

## Design Reference Years, Users Manual

### 0. Summary

This manual gives a survey of data available in "Design Reference Years" (DRY) for some locations in Europe.

A DRY is, like earlier Test Reference Years, a collection of climate data for a given location and for one year, arranged as 8760 sets of hourly, simultaneous weather parameters. DRY's are used as input data for computer simulations of the all-year performance of solar energy systems, and of indoor thermal climate and heating and cooling loads of buildings. Today simulation programs are available using many climate parameters not present in the existing TRY's. The new Design Reference Years will therefore contain such data.

DRY's contain, as hourly data: Dry bulb and dew point temperature, global, diffuse and direct normal (beam) irradiance, wind speed and direction, cloud information, and some new parameters measured in routine meteorological systems. The general rule has been to include what is available for the location. Among new data especially to be mentioned are:

- Illuminance, global, diffuse and beam.
- 5-min values of direct irradiance, for use with active solar systems.
- Weather forecast data, for simulations of "intelligent" building energy management systems.
- Longwave sky radiation.

Some parameters are considered mandatory, and generated if missing. Other parameters are recommended for the new DRY's, although not at the moment available for all locations.

Design Reference Years are, like the earlier TRY's, compiled from 12 months of measured climate data for a location, in true sequences within each month. After the selection of 12 months an adjustment procedure has given each month true mean values and variances for the most important parameters, corresponding to the multi-year period from which the DRY-months have been selected, or corresponding to meteorological normals.

DRY's have been produced for Oslo, Bergen, Andoya, Stockholm, Copenhagen, and 22 sites in Switzerland. Some DRY's may be labelled "Tentative, for experimental use only".

A detailed description of methods and computer programs available for the production of DRY's can be found in "Design Reference Years, Producer's Manual". (To be published)

The "Design Reference Years" and this "Design Reference Year Users Manual" are the outcome of a working group. This manual is produced also as a possible paradigm for similar national manuals in the national languages.

The work has been organized under the IEA Solar Heating and Cooling Programme task 9: Radiation Data and Pyranometry, Subtask E: Representative Design Years. Participants in subtask E have been Norway, Sweden, Switzerland, Italy and Denmark. (App. A). In Denmark the work has been funded by the Ministry of Energy, under the Energy Research Programme.



## **1. Introduction**

Design Reference Years are used as climatic data for computer calculations - simulations - mainly of solar energy systems, and of building energy consumption, energy conservation, indoor climate and comfort.

DRY's can be seen as a new generation of such data collections already known as Test Reference Years in Europe or Typical Meteorological Year (TMY) or Weather Years for Energy Calculations (WYEC) in USA. The advantages of DRY's compared to existing TRY's are:

- more correct monthly mean values and standard deviations for many parameters
- some new parameters not available in the existing TRY's
- new types of parameters, eg 5 minute values for direct irradiance, or forecast information to be used with simulation of " intelligent" energy management systems.

A DRY consists of hourly values for a period of one year of a number of weather parameters, considered important for the purposes mentioned above. Because of the large amount of data, comprising 8760 hourly sets of many weather parameters, DRY's are used only in connection with computerized calculation methods. They are therefore provided on a data medium eg a diskette. A DRY is valid for a limited geographical area only, and for most countries several DRY's are needed to cover the entire area.

DRY's can be used either:

- a) for a single project to calculate eg energy gain, consumption, loads, or mean values or frequencies of temperatures or efficiencies, or illuminance. The evaluation of the results must then be based upon experiences gained from earlier calculation or upon standards or building codes, or
- b) for comparison of two or more alternative project, eg by cost-benefit analyses.

The ability of a DRY to render reliable results for the two sorts of calculations depends on how accurately it reproduces the local climate. Calculations of type a) will place the highest demands of accuracy on the data, and DRY's will most likely be better than existing TRY's.

### **1.1 Requirements**

The basic requirements for a DRY (as for a TRY) are that it corresponds to an average year, both regarding monthly or seasonal mean values, and occurrence and persistence of warm, cold, sunny or overcast periods. It can be written as three requirements:

- I true frequencies, ie as near as possible true mean values over a longer period, eg a month, and a natural distribution of higher and lower values for single days;
- II true sequences, ie the weather situations must have a duration and follow each other like often-recorded courses for the location;
- III true correlation between different parameters, ie temperature, solar irradiance, cloud cover, wind etc.

Initially the working group intended to construct DRY's in a fully synthetic way, using known (we assumed) methods and available statistical values - means, variances and auto- and crosscorrelations between different parameters - derived from measurements over many years.

Our search did not reveal any method, which could handle correlations between many parameters, and for many different weather situations. Although the requirement of I) could be fulfilled by the generation of a synthetic year, from available mean values, standard deviations etc., so far II) and III) could not be satisfied in this way, because many of the relations between individual parameters cannot yet be described mathematically.

The use of real, measured data in the DRY is therefore still the only feasible way to obtain the desired qualities of a DRY. Afterwards the DRY is then improved through an adjustment process.

The justification for the three main quality demands mentioned above (I-III) is derived from the nature of the most common uses of DRY. Both solar energy systems and building energy systems contain a storage or "memory", which justifies the demand for true frequencies and true sequences (I-II). Furthermore, they both contain non-linearities, which in many cases prohibit the use of superposition principles in the calculations, and which therefore cause the demand for true frequencies and true correlations (I and III).

As a main purpose of DRY's is to assess the influence of solar irradiance in solar energy systems or in building climatology, it is necessary to give detailed solar irradiance data. Global radiation on a horizontal surface alone is not sufficient. Although direct normal irradiance and diffuse sky irradiance on a horizontal surface are not generally available as measured data, these values must be available in a DRY. Otherwise most users are left into difficulties. Several adequate procedures exist for splitting the global irradiance into direct-normal and diffuse components utilizing global irradiance data alone, or combined with other weather parameters eg cloud cover or sunshine duration.

A list of data requirements for various applications can be seen in table 1. It has been compiled by mr. Toni Püntener (former at EMPA, Switzerland), based on questionnaires answered by many different users.

## **1.2 Production process**

The production of DRY's shows three steps:

- A selection process, where the "best" periods, normally months, are selected from available machine-readable climatic data for the location. Preferably 10 years of data, or more, should be at hand. [1].
- An adjustment process, where the selected "best" months are given the desired long-term average values and standard deviations, [2] and
- processes where needed, missing parameters are derived from existing data.

The selection process precedes the adjustment process, the generation of other data, however, is to some degree interwoven in the selection or the adjustment.

Before the selection process can start two important initial steps must be taken:

- Selection of sites for which DRY should be created, and
- a careful check of the daily values of the parameters used for the selection process.



After the selection process hourly values used for the adjustment procedure must be checked especially regarding extreme values.

**Table 1. Data demands for Design Reference Year for various applications.**

Application Parameter	ACT	PAS	INC	BEN	BEC	ILL	PV	STS	POL	new DRY ?
(Year), month, day, hour	h	h	h	h	h	h	h	d	h	h
Dry bulb temperature (dbt)	h	h	h	h	h		h	d	3	h
Daily max and min dbt		12	12							12
Ground temp.		d	d	d	d			d		
Vertical temp. profile, or inver- sions									3	?
Global irradiance	h	h	h	h	h	h	h	h		h
Direct normal irradiance	m	h	h	h	h	h	h	h		m,h
Diffuse irradiance	h	h	h	h	h	h	h	h		h
Longwave rad. or sky temp.	h	h	h	h	h					h
Spectral distribution or color temp.							?		?	h
Illuminance						h	h		3	h
Turbidity		h	h							
Total cloud amount		h	h	h	h					h
Cloud type, 3 or 4 layers		3	3	3	(3)	3				
Cloud amount, lowest layer		(3)	3	(3)		3				h
Equivalent opaque cloud amount										
Dewpoint or wet bulb temp. or relative humidity		h	h	h	h					h
Entalpi					h					
Wind speed and direction	h	h	h	h	h				h	h
Pressure			(h)		(h)					3
Surface conditions, snow		(d)	(d)	(d)	(d)					d
Weather type		3	3	3				3		3
Precipitation								d		
Visibility								3		
Forecasts, per 12 or 24 hour					d					d or 12

Applications:

Time intervals:

ACTive Solar, PASsive solar system

h

hourly

INDoor (thermal) CLimate,

3

synoptic data are sufficient

Building Energy calc. NO cooling

12

12 - hour values

Building Energy calc. with Cooling

d

daily values

ILLuminance, PHoto Voltaics

m

interval < 1 h eg 5 min, or hourly  
variance

Seasonal Thermal Storages, POLlution

( )

less important data

### 1.3 Selection of sites for Design Reference Years

A number of criteria must be considered for selection of sites for DRY. Desirable are:

A site with high activity economical and regarding construction. Town, or airport near town.

Meteorological data available with an acceptable quality and for 10 years or more. The most recent period available should be used. Preferably hourly data, however, tri-hourly (synoptic) data can be used.

Sufficient data available, including global irradiance, and diffuse irradiance, or sunshine duration or cloud cover and types to enable a generation of global, diffuse and direct normal irradiance. Use of stations with at least measured hourly global irradiance is strongly recommended. Generation of hourly irradiance data from sunshine duration alone, or cloud data alone, is possible, but should be avoided for this purpose.

Sites shall be selected considering the orography (mountains, distance to oceans), population centers, distance to other DRY locations, and national climatological descriptions, and also, and that is normally the most important question, where measured climate data of good quality are available for many years.

After the successful production of a DRY, two limitations should be remembered:

- The DRY should not be considered a climatological description of a specific town or a region. A DRY is merely a tool for calculations (simulations) with computer programmes.
- Within each region for which a DRY is valid there might be difference in climate, but generally the deviations from the locations for which DRY has been generated should be small compared with the deviations from year to year. Very particular orographic conditions (eg mountains) for a given location, make the DRY for that region less representative, or usable for a limited area only.

### 1.4 Selection method

Several adequate selection methods have been developed for the generation of TRY's (in Europe) or TMY's (in USA).

The method described here is the "Danish" method used for some of the EEC TRY's and described in [1]. It contains two parts: A climatological evaluation, "Criterion A", in which 10-20 parameters are treated, and a mathematical selection ("Criteria B and C") where three parameters are treated statistically.

In the climatological evaluation mean values and standard deviations for the month are checked to be within plus or minus one standard deviation from the multi-year mean for the month. Otherwise the month is flagged. The parameters evaluated during the selection of months for the Danish Design Reference Year are monthly values of:

- Mean temperature
- Average of daily maximum and of daily minimum temperature
- Frequencies of wind velocities and wind directions
- Pressure
- Sunshine hours

- Precipitation
  - Relative humidity
- and, with less weight in the evaluation:
- Absolute monthly maximum and minimum temperature
  - Days with precipitation
  - Number of clear days, overcast days and days with fog
  - For the winter months:
    - Number of frost days, ice days and days with snow
    - Days with snow cover
  - For the summer months:
    - Number of days with maximum temperature  $> 25^{\circ}\text{C}$
    - Days with thunder

Each month is given a qualification character Qualified, Acceptable, Poor, but usable if no better exists, or Impossible, according to the number of flags and parameter.

The other part is a mathematical selection ("Criteria B and C)" based on means and variances for three important daily values: Dry bulb temperature, daily max. temperature and global irradiance. This selection gives three months with the best priorities, and of these the month with the best qualification is chosen.

For locations at high latitudes, eg Copenhagen, global irradiance is substituted by sunshine hours during four winter month.

For other locations with a cooling need daily max. temperature could be substituted by enthalpy or dewpoint temperature.

Other methods for selection of months or shorter or longer intervals exist, and can also deliver absolutely useable results. [13, app. G. in 1].

A paper by C.R. Ratto and R. Festa describes a modification of the "Danish" method using Kolmogorov - Smirnov statistics for the mathematical selection. [11].

### **1.5 Adjustment method**

The hourly values of the most important weather parameters to be presented in the DRY are adjusted so that the distributions, month by month, in the DRY are in accordance with the respective distributions in the source weather data set. For each parameter all hourly values for a month in the source weather data set are arranged in ascending order by value. For a 15-years source data set, this gives 11520 hourly values for a 30 days month. Similarly, the 720 hourly values in the DRY-month are sorted in ascending order. Each DRY-hour value is then substituted by the median value for the corresponding fractile from the multi-year data set. Finally, the new DRY hour values are turned back into their original, chronological order.

This adjustment is performed on dry bulb temperature (dbt), wind velocity and normal irradiance. Daily max. and min. dbt are adjusted like the highest and lowest hourly value for the day.

Dewpoint temperature (dpt) is adjusted for each hour like the dbt, keeping the relative humidity (nearly) unchanged.

For Copenhagen the global irradiance is adjusted. Then the hourly values of direct normal irradiance are calculated from the global and the diffuse irradiance. For most other DRYs the adjustment is made on the direct normal irradiance, and then a new value of global irradiance is calculated from diffuse and direct.

Finally "jumps" by change from month to month, from different years, are smoothed over 6 night hours, for dbt, dpt and wind speed and long-wave sky radiation. For the Danish DRY 10 hours were needed for the January-February jump.

### 1.6 Corrected data

A large number of correction has been made in the input data, most of them after a careful visual inspection of the entire weather situation. This chapter describes the corrections made of the Danish data, and reflects experiences gained here.

The input data for a TRY selection are daily values, for Copenhagen 15 years.

For identification of "suspicious" days tests are made on temperatures, and on irradiances versus sunshine duration. Five tests are made on temperatures:

- 1 Missing values, or values given with -999.
- 2 Difference between daily mean temperature and daily max. hourly temperature exceeding a given limit.  
For Copenhagen the limit is, for 12 months: 4, 4.5, 5, 6, 7, 7, 7, 7, 6, 5, 4.5, 4.
- 3 Difference between daily mean temperature and daily max. instantaneous temperature exceeding a given limit.  
For Copenhagen same limits as by item 2.
- 4 Daily max instantaneous temperature lower than daily max. hourly temperature.
- 5 Difference between daily mean temperatures for two consecutive days equals or exceeds a given limit, for Copenhagen 4°C.

One test is made on global irradiance versus sunshine duration:

Daily sum of global irradiance  $G_s$  is checked against an empirical expression, derived from Danish data, for day  $n$  (1-365) and actual sunshine duration  $SS$  in h, giving the "probable maximum daily sum of global irradiance":

$$G_{smax} = 1470 (1 + 0,135 SS + 0,15 \sqrt{SS}) - 1080(1 + 0,09SS + 0,18 \sqrt{SS}) * \cos((n + 15) * 2\pi/365) \text{ Wh/m}^2 \text{ day}$$

For days where  $G_s \geq 1.2 * G_{smax}$  then global irradiance and sunshine duration are checked, if possible also the hourly values for the day.

All corrections are made manually, after a visual inspection of the total weather situation, and where possible after a comparison with nearby stations.

February 29 in leap years is removed.

After the correction of daily data, the selection of months for the TRY is made, the hourly data are assembled and hourly direct normal radiation is computed.



Only radiation is always available as hourly data, temperatures and other data are for some years hourly data, for other years synoptic data only, at hour 1, 4, 7 --22, LST.

The hourly data are then checked, for hour  $h$  against hour  $h-1$ :

Dry bulb temp.  $T_h$ :  $|T_h - T_{h-1}| < 4^\circ\text{C}$

or for months with synoptic values only

$|T_h - T_{h-3}| < 8^\circ\text{C}$

Dew point temp.  $T_d$ :  $T_h - 20 < T_d \leq T_h$

Global radiation  $G$  is compared with a "probable clear sky" global radiation  $G_{\text{max}}$  and corrected if  $G - G_{\text{max}} > 50 + 0,2 G_{\text{max}}$   $\text{W/m}^2$ .

Inconsistencies between global and diffuse radiation and sunshine duration are checked. Normally the global radiation value is considered most reliable. The sunshine duration delivered in the input data is used only for quality control. The sunshine duration values in the Danish DRY are derived from computed 5-minutes values of direct normal radiation.

The diffuse irradiance is corrected for shading band, however, monthly mean of the difference ( $G - D$ ) for day hours with sunshine duration = 0 indicates errors in the shading band correction or/and the calibration factor for the pyranometers for global and diffuse radiation. For each of the 180 months used, the diffuse radiation has been adjusted with a factor (for Danish data in the range 0,95 - 1,07), which brings a low (but not zero) number of hours with  $D > G$ .

For some months also fractions of the month has been corrected separately, and some single days and hours have been corrected manually.

## **2. Availability of Design Reference Years**

For a number of locations Design Reference Years have been produced, and are available for commercial, technical and research purposes. DRY's are ready for locations in Denmark Norway, Sweden and Switzerland. Regarding locations and sources, see app. B.

Production and distribution (sale) of DRY's should be left to a single or few, competent organisations or institutions in each country, and DRY's should be produced for a limited number of locations in each country only.

Area of validity for a TRY was earlier estimated to appr. 400 x 400 km, in uniform landscapes, and considerably less in mountainous areas [2]. That could also be used for DRY's.

### **2.1 Restrictions for use**

It is the intention that the Design Reference Year, DRY, documented in this manual and in the Design Reference Year Producers Manual, should be the common basis of outdoor climate data for many HVAC and energy simulations.

To ensure that calculations based on the DRY really will be comparable, the following restrictions for using the weather data of a DRY have been defined:

1. The Design Reference Year should not be copied or handed over to other institutions or companies. Distribution of DRY should be handled by the parent institutions or appointed distributors only. Errors in a DRY must be reported to the parent institution.

2. Nothing should be modified in or added to the data of the Design Reference Year, DRY. It is permissible to make extracts from DRY, ie to omit all data of a certain sort, eg the wind velocity or the weather symbols.
3. When selecting data from the DRY for calculations, where only certain values are used, it has to be documented when referring to "Design Reference Year" for the location, how these data have been selected or extracted.
4. The designation "Design Reference Year" or "DRY" should be used for data or indicated in connection with calculations or results only if the above-mentioned conditions are observed.
5. Design Reference Years, labelled "tentative" should be used for research or experimental use only. Results obtained with "tentative" DRY's should be indicated as such.

### 3. Parameters in the Design Reference Years

(The information here refers to the Danish DRY, for Copenhagen. It must be corrected for other locations).

All data are given per hour unless otherwise specified. All data are mean values for the preceding hour, unless otherwise specified. All data are measured at Værløse Air Base, unless otherwise specified. Global and diffuse irradiance, and sunshine duration used for the selection process, are measured at Taastrup, 12 km South of Værløse.

The record format follows the recommendation originally set up for Test Reference Years [12]. (Table 2 and 3).

Station name or number. The name, abbreviated if necessary, or the WMO station number.

Time indicator for irradiance measurements. Global irradiance is measured for the preceding hour, to True Solar Time (TST) or Local Standard Time (LST), indicator T or L. Data measured to True Solar Time are not recalculated to Local Standard Time.

For the Danish DRY the indicator is L, (Local Standard Time ~ Central European Time, CET). Please observe the difference to the Danish TRY's (from 1973 and 1980) where irradiance values were given from 30 minutes before to 30 minutes after the full hour (indicators I or F, which are still used for some stations).

Dry bulb temperature. Measured 2 m above ground, shaded from radiation. 0.1°C. Adjusted.

Dew point temperature. 0.1°C. Measured. Adjusted in such a way as to keep the relative humidity unchanged.

Maximum and minimum dbt. Given at h 7 and h 19 for the preceding 12 hours. 0.1°C. Instantaneous values, read from max or min thermometers, or read from automated equipment. Adjusted, following the highest and lowest hourly dbt.

Wind direction and wind speed. Measured 10 m above ground, mean value for 10 minutes. Direction is given as deka-degrees from north. 09 is east, 18 south, 27 west, 36 north, 00 is calm and 99 is unsteady, low speed. Wind speed, 0.1 m/s. Wind speed is adjusted.

Barometric pressure Station pressure, not reduced to sea surface. Corrected for temperature. 0.1 hPa. Not adjusted.

Sunshine time. Given for day hours. Derived from computed 5 min values of direct normal irradiance, threshold value 120 W/m<sup>2</sup>. Minutes.

Global irradiance, on a horizontal surface, W/m<sup>2</sup>. Measured at Tåstrup. Adjusted.

Diffuse irradiance on a horizontal surface. Measured. W/m<sup>2</sup>. Not adjusted.

Direct normal irradiance (beam irradiance). W/m<sup>2</sup>. Derived from diffuse and adjusted global irradiance and solar altitude. Given as hourly value and, if > 5 W/m<sup>2</sup>, in a separate, following record, as computed 5-minutes values. (For Copenhagen not adjusted. For most other DRY's the adjustment is made on direct normal irradiance, and not on global irradiance).

(Year), month, day. For the Danish DRY year is given as "12". The format allows its use also for real, measured, unprocessed data, with the year given with last two digits.

Hour, local standard time. If the irradiance data are measured to True Solar Time it is indicated in the "Time Indicator". Summer-time or Daylight Saving Time is not used, always Winter time.

Continuation, 0 or 1. 1 indicates a following record for the same hour, with 5-min. values of direct (beam) irradiances.

About some of the new parameters:

### Illuminance

Illuminance is given in the same way as irradiance, as global illuminance on horizontal, diffuse illuminance on horizontal, and direct normal illuminance.

As illuminance is not normally available as measured data for the sites where the other parameters in the DRY are collected, the values are derived from the irradiance values, solar zenith angle and cloud cover, precipitable water or turbidity, according to the method proposed by Perez et al. [8].

### Cloud cover

Cloud observations are processed to two parameters only: Total cloud cover, as N in the Synop-weather data, and an "equivalent opaque cloud amount" in which high, partly transparent clouds are reduced by a factor 0,5 or by individual factors for the most common transparent cloud types for the location. [9].

Cloud amounts are normally observed and recorded either in oktas or tenths. To obtain a common format independent of the original recordings, a scale 0-80 is used, also giving room for fractions of tenths or oktas in the computed values "Equivalent opaque cloud amount".

If cloud observations are not available for the location a computed value should be derived from the global irradiance, at least for solar zenith angles < 80 degree, or from hourly sunshine.

Pos		Freq	Format	Col.
1.	Station name or number	h	A5	1-5
2.	Time indicator for rad. measurements	h	I1	6
3.	Dry bulb temperature, 0.1°C	h	I4	7-10
4.	Dew point temperature, 0.1°C or %	h	I4	11-14
5.	Global irradiance W/m <sup>2</sup>	h	I4	15-18
6.	Diffuse irradiance W/m <sup>2</sup>	h	I4	19-22
7.	Direct normal irradiance, beam W/m <sup>2</sup>	h	I4	23-26
8.	Downward longwave irradiance W/m <sup>2</sup>	h	I4	27-30
9.	Illuminance, global, lux	h	I5	31-35
10.	Illuminance, diffuse, lux	h	I5	36-40
11.	Illuminance, direct normal, lux	h	I5	41-45
12.	Total cloud amount 0-80, observed	h	I2	46-47
13.	Equivalent opaque cloud amount 0-80	3 h or h	I2	48-49
14.	Sunshine duration, minutes	h	I3	50-52
15.	Wind direction, deka-deg	h	I2	53-54
16.	Wind speed 0.1 m/s	h	I3	55-57
17.	Indicator for special data (= 0)	h	I2	58-59
18.	Maximum temperature 0.1°C	7 & 19	I4	60-63
19.	Minimum temperature 0.1°C	7 & 19	I4	64-67
20.	Pressure hPa	3h	I4	68-71
21.	Precipitation 0.1 mm	1,7,13,19	I4	72-75
22.	Weather W/W	3h	I2	76-77
23-24.	Weather since last observation W1 and W2	3h	2I2	78-81
25-27.	Empty		3X	82-84
28.	Relative humidity	h	I3	85-87
29.	Solar altitude 0.1°, visible	h	I4	88-91
30-32.	(Year), month, day. (For DRY, year = 12)	h	3I2	92-97
33.	Hour, local standard time, 01-24	h	I2	98-99
34.	Continuation, 0 or 1	h	I1	100

Table 2. Design Reference Year Format, Recommended

1. record, all hours, 100 characters

Special data, pos 17-29, tentative, example for Copenhagen. This group of data must be tailored to utilize locally available data as well as possible.

Precipitation at h 1 and h 13 is integrated over 6 hours, at h 7 and h 19 over 12 hours. Daily sum = h 7 + h 19.



Pos.		Format	Col.
1.	Direct normal irradiance, computed highest clear sky intensity for the hour, W/m <sup>2</sup>	I5,1X	1-6
2-13.	Computed 5 min. intensity, % of pos. 1	12I3	7-42
14-16.	Month, day, hour	1X,3I2	43-49
17.	Continuation (here always 0)	I1	50

Table 3. 2. record, for day hours with direct normal irradiance  $> 5 \text{ W/m}^2$  only. 50 characters

This cloud cover will be strongly related to the cloud near to the position of the sun. That is permissible because the accuracy demands are normally low for the cloud data used in various application programmes, eg for distribution of diffuse irradiance from the sky.

If cloud cover is to be used for generation of longwave irradiance from the sky, especially during the night hours, the accuracy demands are higher stressed, and real observations are desirable.

### Longwave downward irradiance

Longwave downward irradiance is important during night hours. During daytime it is normally masked by the shortwave irradiance. It is most often not available as a measured value. It is therefore computed from dry bulb temp., humidity, cloud amount, types and altitudes of various cloud layers. [4]. If cloud data are not available for night hours the cloud data must be extrapolated from the last evening hours or the first morning hours, or interpolated between them.

### Short time variations

Hourly values of climatic data are normally sufficient for today's common applications, except for active solar systems. For active solar systems with lightweight absorbers and suitable control-systems, increased average efficiency is computed in simulations, as well as measured in reality, if short time-interval values of irradiance are available.

Analyses by Olseth and Skarveit [5] have shown that especially for direct irradiance there is a clear bimodality in cloudy weather - the sun is either visible or covered - and this bimodality is practically the same for instantaneous values, through 30 sec average, 2-min. or 5-min. averages. Averages over more than 5 min. reduce the bimodality. Although this 5-min. limit might possibly be site-dependant we have chosen 5-min. values of direct irradiance as a sufficient short time interval.

Short time interval values are not normally available as measured data. They are computed using a model by Olseth and Skartveit [6], using the variation in hourly global irradiance.

Only direct normal irradiance is given as 5-min. values. The diffuse irradiance can be considered constant, or interpolated between hourly values.

### Forecasts

Forecasts can be used for the simulation of "intelligent" energy managements systems, preferably with short time horizons, 1-3 days.

Such forecasts should contain dry bulb temperature, windspeed and cloud amount. In regions, where air condition is frequently used, also a humidity parameter should be included in the forecast. The forecast data should be given as numerical values, and as they are delivered today from the National Meteorological Services.

Because the form of presentation of forecasts has changed much in recent years, and the time horizon for the routine prognoses has grown to five days, it might well happen that 10-year old forecasts do not fulfil the present requirements, or cover less than five days. Then an experienced meteorologist should be asked to create "forecasts" for the older months in DRY, based on the available parameters and corresponding to todays forms.

Forecasts will later be included in the Danish DRY.

### 4. The Danish Design Reference Year

This chapter gives a brief climatological description of the sites, and tables 4A and 4B compares means and extremes from the DRY with values from the source data ("1975-89") and with meteorological normals for Denmark, generally for 1961-90.

The data for the Danish Design Reference Year are taken from 16 years, 1975-1990, for Værløse, a military air base, 17 km NW of Copenhagen. Hourly values are from Synop records. Irradiance data are from the agricultural research station Højbakkegaard at Tåstrup 12 km S of Værløse. 12 months in 1987-1990 have been discarded due to larger lacunes for one or more parameters, giving 15 years for the selection ("1975-89").

#### Short description of climate for the Danish Design Reference Year sites

Copenhagen, Denmark.

Denmark is, apart from Greenland, part of the northern temperate zone. Airmasses of maritime origin are most common, however, in appr. 2000 h yearly we receive dry, continental airmasses. Both situations are possible in all months, with easterly winds most often, relatively, in the first half of the year. Further, because the temperature is generally rising in the first half of the year, humidity and precipitation is generally low during the spring.

The dominant wind direction is for all stations and all months W or SW, although all months, and especially February through May and October - November show a large number of E or SE winds. The wind is most seldom from north.

Sunshine hours show small variations over the area of Denmark. This variation is smaller than the variation from year to year.

Generally Denmark, apart from the Faroe Islands and Greenland, can be considered as a single zone, with only one DRY needed.

#### 4.1 Tables, monthly values of important parameters.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Yearly Sum or Mean
Global irradi. Wh/m <sup>2</sup> per day	501 502	1142 1148	2096 2095	3801 3805	5271 5277	5495 5502	5162 5221	4323 4319	2723 2720	1375 1372	631 628	333 333	M 2746 M 2752
Diffuse irradi. Wh/m <sup>2</sup> per day	327 343	697 699	1176 1211	1899 1899	2362 2362	2756 2754	2648 2653	2075 2101	1432 1451	746 782	387 399	235 235	M 1398 M 1419
Sunshine hours >120 W/m <sup>2</sup>	66	79	134	200	271	263	248	245	180	120	71	45	S 1922
Sunshine hours (DRY)	59	70	118	176	236	223	215	212	155	104	56	37	S 1661
>200 W/m <sup>2</sup> Risø	48	74	110	179	253	235	237	224	146	101	63	36	S 1704
Copenh. harbour	43	67	103	178	257	241	242	229	147	96	59	33	S 1696
All stations	39	69	114	179	246	233	236	220	145	97	58	36	S 1670
Cloudcover, pct	67 74 79	69 70 73	56 68 69	65 59 63	56 52 60	62 55 59	56 55 62	52 52 59	58 58 63	58 66 70	66 68 74	79 74 77	M 62 M 63 M 69
Equiv.Cloudc. pct DRY	65	65	49	58	47	55	52	46	50	53	61	78	M 57
Wind velocity m/s	5.0 4.5	4.4 4.5	4.8 4.2	4.5 4.2	4.1 3.9	3.8 3.8	3.9 3.7	3.5 3.6	4.4 3.7	4.5 4.0	4.5 4.1	4.9 4.2	M 4.4 M 4.0

Table 4 A. Monthly irradiance and wind from the Design Reference Year, the source period 1975-89, and the meteorological normal 1961-90.

Due to later corrections of global irradiance the monthly DRY-values are not exactly equal to the 1975-89 values, despite the adjustment process.

Sunshine hours in the DRY are computed from 5-min. values, threshold value 120 W/m direct normal irradiance. For comparison sunshine hours are also shown with 200 W/m threshold for the DRY, and for Risø (14 km W of Taastrup), for Copenhagen Harbour, Customs House (19 km E of Taastrup), and for all Danish sunshine recording stations 1961-90.

Wind velocity is compared with all inland stations 1931-60.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly Mean or Peak
Dry bulb temp. °C	-0.5	-1.0	1.7	5.6	11.3	15.0	16.4	16.2	12.5	9.1	4.8	1.5	M 7.8
DRY 1961-90	0.0	0.0	2.1	5.7	10.8	14.3	15.6	15.7	12.7	9.1	4.7	1.6	M 7.7
Mean daily max. dbt °C	2.5	1.8	5.5	9.0	16.2	19.3	20.7	20.4	16.3	12.5	6.7	3.2	M 11.2
1975-89	1.3	1.0	4.2	9.2	15.3	18.8	20.1	20.2	15.8	11.6	6.8	3.2	M 10.6
1961-90	2.0	2.2	4.9	9.6	15.0	18.7	19.8	20.0	16.4	12.1	7.0	3.7	M 10.7
Abs. max. dbt °C	10.3	9.2	14.0	18.9	25.3	29.7	29.2	32.1	26.2	21.2	12.5	10.6	P 32.1
1975-89	10.6	10.3	16.6	19.8	27.0	30.9	31.1	32.8	27.8	22.1	13.2	11.9	P 32.8
1961-90	8.3	9.1	14.0	20.0	25.7	29.4	29.5	29.3	24.5	20.0	13.8	10.4	P 31.3
Mean daily min. dbt °C	-3.5	-4.5	-2.1	2.1	6.0	10.7	12.1	12.3	9.3	6.2	3.1	-0.9	M 4.3
1975-89	-2.5	-3.1	-0.5	2.3	7.1	10.7	12.5	12.3	9.5	6.9	2.9	-0.5	M 4.7
1961-90	-2.9	-2.8	-0.8	2.1	6.5	9.9	11.5	11.3	9.1	6.1	2.3	-0.7	M 4.3
Abs. min. dbt °C	-21.1	-18.0	-20.1	-4.9	-0.2	4.5	6.7	5.4	0.8	-3.4	-8.9	-15.0	P -21.1
1975-89	-21.8	-19.0	-23.5	-6.2	-2.3	2.6	5.9	4.0	-0.7	-4.6	-10.7	-15.0	P -23.8
1961-90	-16.3	-15.8	-12.3	-7.1	-3.6	0.0	2.9	1.5	-1.2	-3.7	-9.2	-14.7	P -20.6
Daily dbt var. °C	6.0	6.3	7.6	6.9	9.8	8.7	8.8	8.3	7.0	6.2	3.6	4.1	M 6.9
max-min. °C	3.8	4.1	4.7	6.9	8.3	8.1	7.6	7.9	6.3	4.7	3.9	3.8	M 5.8
1961-90	4.9	5.0	5.7	7.5	8.5	8.8	8.3	8.7	7.3	6.0	4.7	3.0	M 6.4
Dew point temp. °C	-1.9	-3.0	-1.0	1.9	6.2	10.8	12.5	11.6	10.2	5.9	3.5	-0.9	M 4.7
1975-89	-2.2	-3.1	-1.0	1.0	5.5	9.8	11.4	11.4	8.9	6.6	2.8	-0.1	M 4.3
Relative humidity pct.	89	85	81	80	73	78	80	76	87	81	91	83	M 82
1975-89	87	85	82	74	70	74	75	75	80	85	87	88	M 80
1961-90	91	90	87	80	75	77	79	79	83	87	89	90	M 83

Table 4 B. Temperatures and humidity in Design Reference Year, in the source period 1975-89, and for the Met. Normal 1961-90.

Maximum and minimum temperatures are hourly values. Min. temp. is taken from 19h through 19h. Max. temp. is taken from 1h through 19h for DRY and 1975-89, and for 1h through 24h for 1961-90.

All abs. max and min. temp. are hourly values taken from 1h through 24h.

All values for 1961-90 are Normals, ie means for all stations.



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Several other scientists, in task 9 or outside, have also delivered valuable information, datafiles or algorithms.

Design Reference Years in Europe  
State as on Januar 1995.

The Design Reference Year (for Switzerland, Sweden, Norway and Denmark) are produced according to methods agreed to in IEA Solar Heating and Cooling Programme, Subtask 9 E, Solar Radiation and Pyranometry Studies.

<u>Switzerland</u>		Longitude	Latitude	Altitude m.a.s.l.
Altdorf	ALT	8° 38' E	46° 52' N	449
Basel-Binningen	BAS	7° 35' E	47° 33' N	316
Bern-Liebefeld	BER	7° 25' E	46° 56' N	565
Chur-Ems	CHU	9° 32' E	46° 52' N	555
Davos	DAV	9° 51' E	46° 49' N	1590
Geneve-Cointrin	GVE	6° 8' E	46° 15' N	420
Glarus	GLA	9° 4' E	47° 2' N	515
Interlaken	INT	7° 52' E	46° 40' N	580
La Chaux-de-Fonds	CDF	6° 48' E	47° 5' N	1018
Locarno-Magadino	MAG	8° 53' E	46° 10' N	197
Luzern	LUZ	8° 18' E	47° 2' N	456
Samedan-St.Moritz	SAM	9° 53' E	46° 32' N	1705
Sion	SIO	7° 20' E	46° 13' N	482
St.Gallen	STA	9° 24' E	47° 26' N	779
Zürich SMA	SMA	8° 34' E	47° 23' N	556
Zürich-Kloten	KLO	8° 32' E	47° 29' N	436
Payerne	PAY	6° 57' E	46° 49' N	490
Pully	PUY	6° 40' E	46° 31' N	461
Wynau	WYN	7° 47' E	47° 15' N	422
Guettingen	GUT	9° 17' E	47° 36' N	440
Lugano	LUG	8° 58' E	46° 0' N	273
Montana-Vermala	MVE	7° 29' E	46° 19' N	1508

Sweden

Stockholm (tentative)	18° 4' E	59° 21' N	30
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Norway

Oslo	10° 44' E	59° 56' N	94
Bergen	5° 19' E	60° 24' N	45
Andøya	16° 18' E	69° 9' N	10

Denmark

Copenhagen	COP	12° 19' E	55° 40' N	19
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## Where to get DRY files (diskettes)

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Nova Energie GmbH  
 Schachenallee 29, 5000 Aarau

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062 834 0300

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