# INFLUENCE OF SOLAR RADIATION DATA PROCESSING ON BUILDING SIMULATION RESULTS

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## ABSTRACT

A new set of climatic data for different kinds of calculations has been compiled for various Swiss localities. This includes the generation of new design reference year data sets with hourly values for e.g. building simulations. The procedure conforms to a set of new European standards describing the algorithms. One key element in this is the processing of solar radiation information, especially for the separation into direct and diffuse components. The most advanced methodology was used. Simulation examples for testing the data showed surprisingly high differences in the energy consumption results compared to the old data sets. Differences as high as +34% in cooling energy resulted for a realistic case. Analysis showed the main reason being the radiation data and especially the direct/diffuse split. This puts into perspective some controversies concerning model details.

## KEYWORDS

Heating; cooling; lighting; weather data; energy consumption.

## INTRODUCTION

A new set of climatic data for different kinds of calculations has been compiled for various Swiss localities (SIA 2007). This includes the generation of new design reference year data sets with hourly values for e.g. building simulations. The procedure conforms to a set of European standards describing the algorithms (EN ISO 2003). One key element in this is the processing of solar radiation information. Typically, programs need as an input direct normal and diffuse horizontal radiation data. Although the Swiss Federal Office of Meteorology and Climatology increasingly measures these separate components, the usual case is still that the only measured information is the global horizontal radiation. Consequently, the data must be processed to obtain the separate direct and diffuse parts. The respective algorithms have been developed and improved in time.

## RADIATION DATA PROCESSING

Until 1980 the direct (or beam) normal radiation $I_{b,n}$ was traditionally derived from simultaneous measurements of the global horizontal radiation $I_{G,H}$ and the diffuse horizontal radiation $I_{D,H}$. This was because pyranometry was easier that pyrrheliometry. From the existing data sets relations of the type in equation (1) could be derived which enabled the estimation of $I_{D,H}$ from $I_{G,H}$ in the absence of measurements:

$$I_{D,H} / I_{G,H} = f(I_{G,H} / I_{G,H,TOA}, P1, P2, \ldots) \quad (1)$$

where

$I_{G,H,TOA}$ is the global horizontal radiation at the top of the atmosphere

$P1, P2$ are possible additional parameters.

Among the best functions of this type are those of (Erbs et al. 1982), (Skartveit and Olseth 1987) and (Reindl et al. 1990). While the function from (Erbs et. al. 1982) gets by with $I_{G,H} / I_{G,H,TOA}$ alone, (Skartveit and Olseth 1987) use the solar altitude as an additional parameter. In addition to this, (Reindl et al. 1990) use the relative humidity and the air temperature as additional selection criteria.

The general problem with all models of type (1) is their ambiguity with partly cloudy skies, because a range of different cloud distribution patterns can lead to the same $I_{D,H}$ values.

With the dissemination of the “Normal Incidence Pyrheliometer (NIP)” by Eppley, the normal beam radiation $I_{b,n}$ could also be measured routinely and, accordingly, models of the type in equation (2) could be developed for the direct calculation of $I_{b,n}$ from the global horizontal radiation $I_{G,H}$.

$$I_{b,n} / I_{G,H} = f(I_{G,H} / I_{G,H,TOA}, P1, P2, \ldots) \quad (2)$$

Here the ambiguity is less because as soon as $I_{b,n}$ is not zero, the scatter originates from the diffuse part $I_{D,H}$ (Maxwell 1987). Finally, this could be further reduced by introduction of a parameter which includes the hourly variability of $I_{G,H}$.

For the calculation of the new data sets the so called "dynamic" model of (Perez et al. 1991) and (Perez et.al. 1992) is used. In this model the normal beam radiation is derived from the atmospheric transmissivity $I_{G,H} / I_{G,H,TOA}$, the solar altitude, the time variability of $I_{G,H}$ (difference with respect to the hours before and after) and the dew-point temperature.

The diffuse component then follows from

$$I_{D,H} = I_{G,H} - I_{b,n} \cdot \cos(\vartheta_z) \qquad (3)$$

Consistency between the components is assured by the condition $I_{b,n} \cdot \cos(\vartheta_z) < I_{G,H}$.

### Model Comparison

The choice of the above model to calculate the radiation components is in contradiction to (EN ISO 2003) which recommends using the function of (Erbs et.al. 1982).

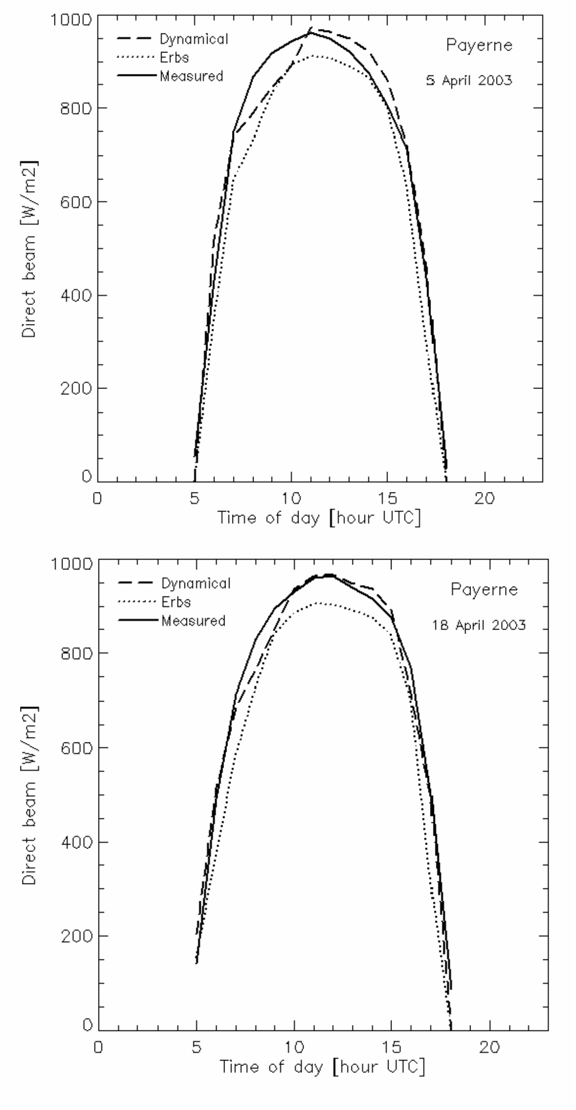

*Figure 1. Comparison of normal beam radiation from different models and measured data.*

This function had also been used for the existing data sets used in Switzerland until the new data were generated. Figure 1 shows a comparison between the two models and measured data of the normal beam radiation for two sunny days.

It can be seen that during most of the time the Perez model has a considerable smaller deviation from the measured data than the Erbs model. Especially during the morning and evening hours the measured and Perez values are considerably higher than the "old" Erbs values.

Within the simulation programs the direct and diffuse components are used to calculate radiation on tilted surfaces. Therefore the above finding will have an effect on these, as shown below.

## TEST SIMULATIONS

### General

In order to get an impression of the effect of differences between the newly generated weather data compared with previously existing data, simulations were carried out with both the old and new data for the same station, using the program IDA-ICE.

An existing input for an air conditioned building was used, which had been created for a different project with a different purpose, but which was considered to be a typical case to demonstrate the influence of differences in the weather data.

### Weather Data Comparison

Some of the differences in the results shown below originate from general differences in the weather data, since the period of measured data used for the generation of the "design reference years" was different (1982 to 1991 for the old, 1984 to 2003 for the new data), and also the procedure for the generation was similar, but not equal. Therefore the cumulative frequency distribution of the dry bulb temperature and the global horizontal radiation is shown in figures 2 and 3. It can be seen that

- The dry-bulb temperature in the new data set is higher than in the old one by 0.5 to 1°C during a large portion of the time. Or expressed in frequency, the same temperature value is exceeded during about 100 to 200 more hours for a large portion of the temperatures. This was expected and can be considered as being the effect of global warming.
- The global horizontal radiation is slightly higher in the new data set, which is consistent with the "brightening" observed since 1990 over land in Europe.

Similar differences would be expected for the relative humidity.

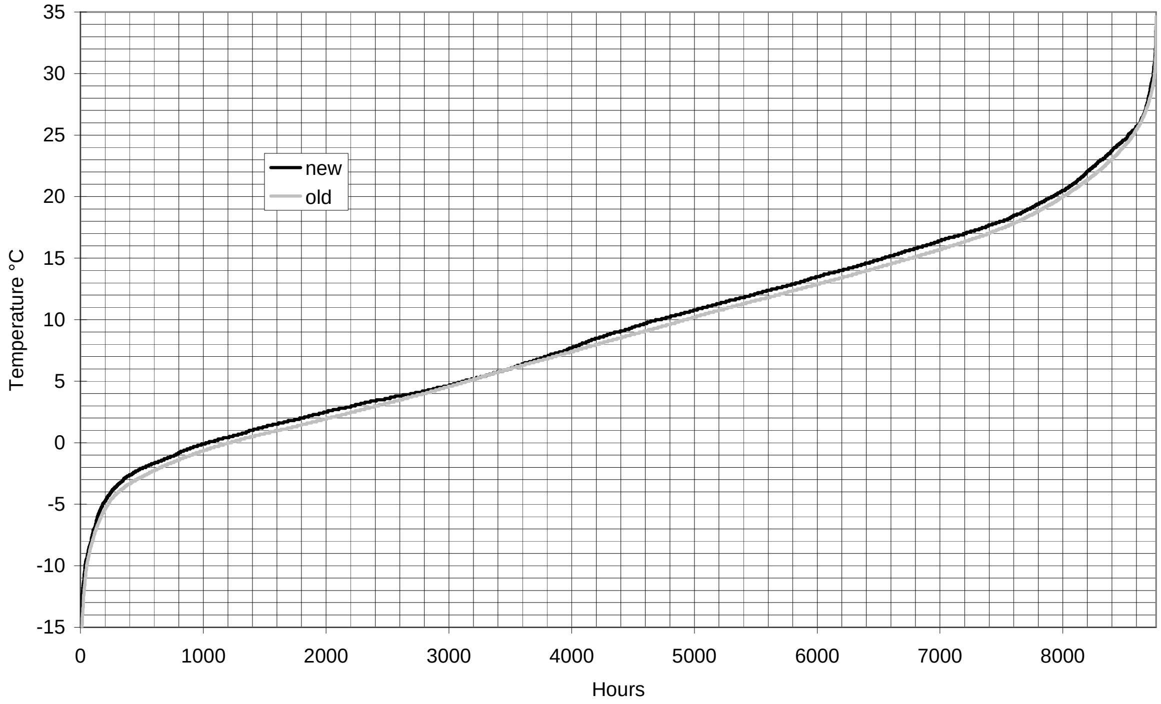

*Figure 2. Cumulative frequency distribution of the dry-bulb temperature in the old and new data set*

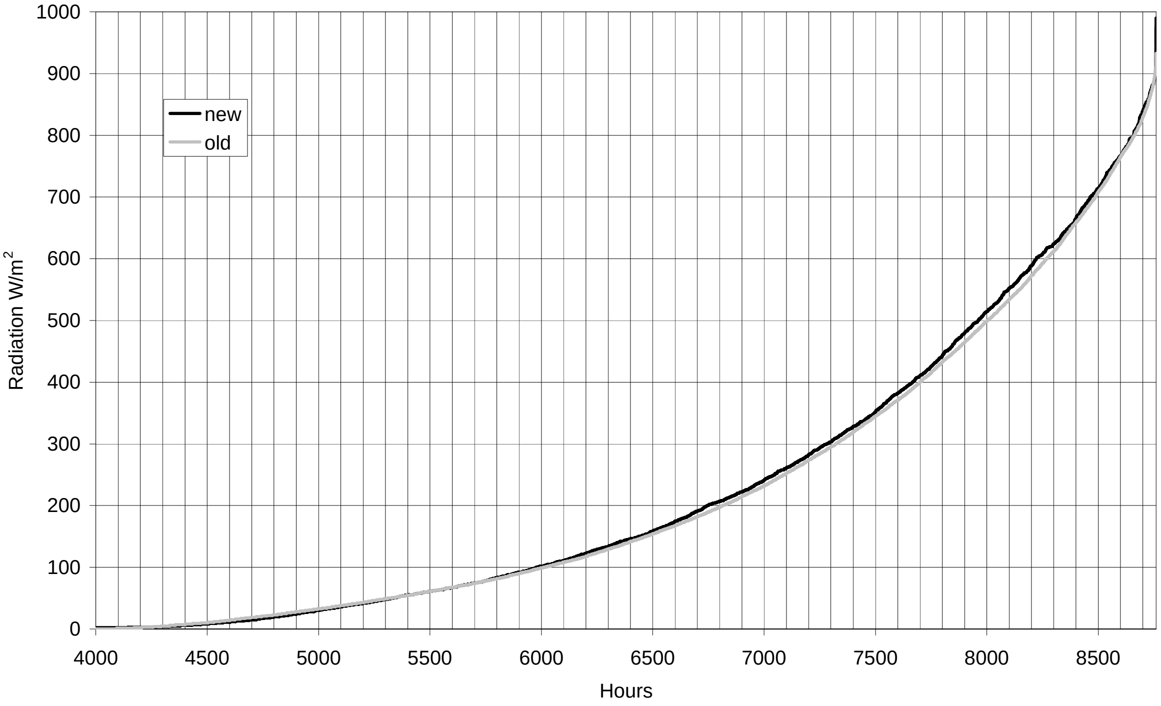

*Figure 3. Cumulative frequency distribution of the global horizontal radiation in the old and new data set*

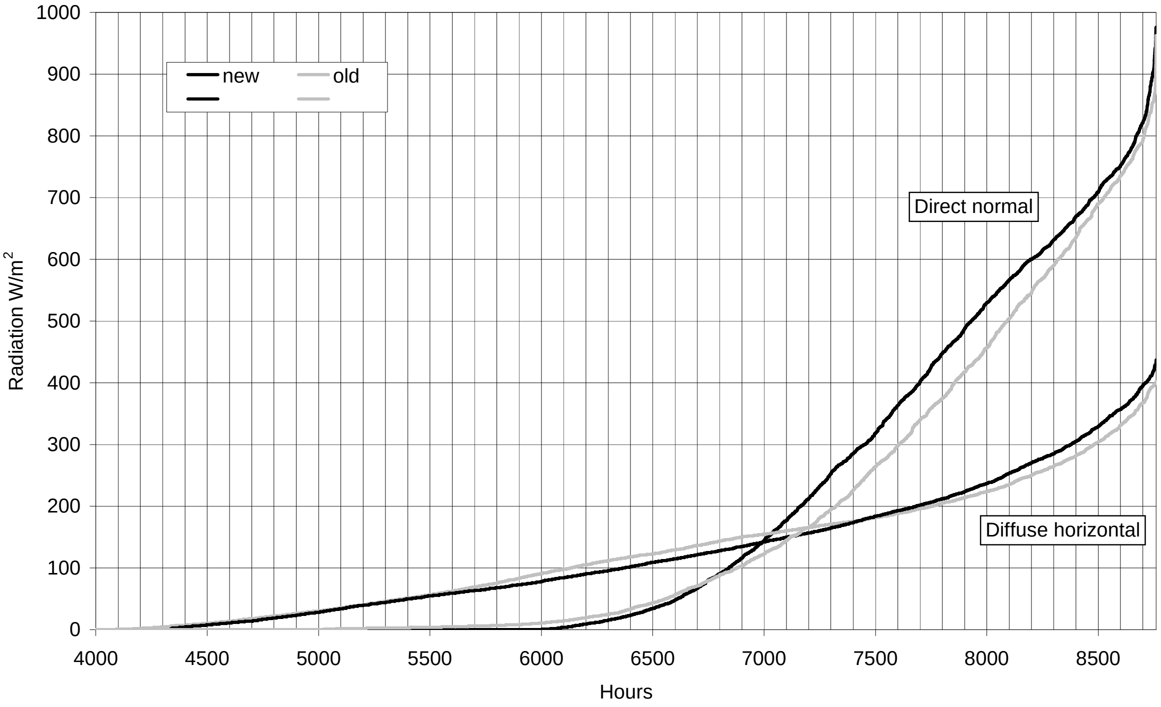

*Figure 4. Cumulative frequency distribution of the beam normal and diffuse horizontal radiation in the old and new data set*

A bigger difference, however, can be seen when looking at the direct and diffuse portions of the radiation, as shown in figure 4. Normal beam values between 200 and 600 W/m$^2$ appear about 150 h more frequently in the new data. The diffuse horizontal values tend to be higher for high values (cloudy days) and lower for low values (which correspond with high beam values, clear days). The origin of this is not the measured data as in the previous two cases, but the model applied, as described above.

## Building Example

The case-study building used for the comparison had initially been used for a control study on a VAV ventilation system. It was kept unchanged and has the following characteristics:

- It is a part of one floor of an office building with 5 Zones, two of them external with two facades each, on the NE and SE corner (see also floor plan in figure 5).
- Highly glazed facades with double glazed windows and exterior blinds, controlled according to solar radiation (threshold).
- Lighting in external zones controlled by schedule and daylight illumination.
- VAV air conditioning
- Radiator heating

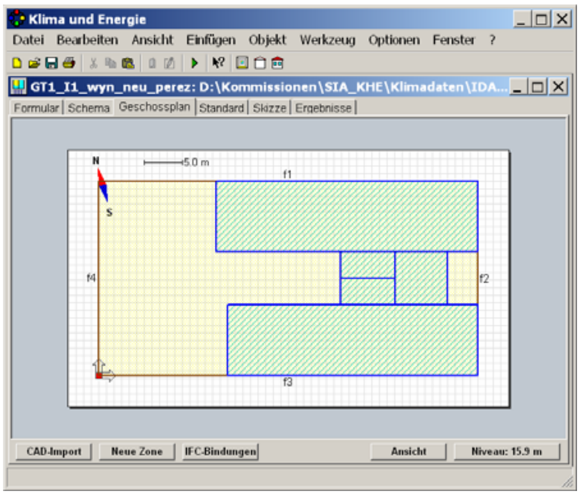

*Figure 5. Floor plan of case study building*

## Results

Simulations were carried out for a full annual cycle, using both the old and the new data sets for the same station (Wynau, a place in the Swiss midland region, which can be considered as typical for the densely populated and industrialized area of the country).

*Table 1. Annual energy demands*

| | HEATING | | COOLING | | LIGHTING | |
|---|---|---|---|---|---|---|
| **DATA** | **kWh** | **%** | **kWh** | **%** | **kWh** | **%** |
| old | 14’520 | 100 | 5’307 | 100 | 3’886 | 100 |
| new | 13’464 | 93 | 7’125 | 134 | 3’860 | 99 |

Table 1 shows the respective annual heating, cooling and lighting energy demands of the building for the two data sets.

The lower heating energy demand with the new data is understandable and expected in the appearing range with the higher outdoor temperatures.

There is, however, an increase in the cooling demand which is much higher than might be expected from the differences in the weather data. A small part is due to the outdoor temperature and the global horizontal radiation, but this does not explain the large overall difference. It must be supposed that the change in the radiation calculation models shown above and in figure 4 accounts for the major portion of the difference.

The effect in lighting energy is small because, even with different radiation on the windows, the effects of blind control and illumination control are in opposite direction and cancel each other out.

## Analysis

In order to see more details of the influence of the radiation model, the radiation components and the global radiations on a vertical window have been analyzed. The window has an orientation of 105°east from north. A calendar day was found (Aug. 14) where coincidently both data sets had very similar conditions.

The global horizontal radiation is almost identical in figures 6 and 7. Even the temperature (not shown) is almost the same. Therefore the differences in the radiation components and consequently in the global vertical radiation in the window plane are a clear result of the differences in the model.

As in most cases, the calculation of the radiation on vertical surfaces is done within the simulation program. IDA-ICE has several models for this to choose from. The results shown here were generated by using the anisotropic model according to (Perez et.al. 1987) in both cases.

In figures 6 and 7 it can be noticed that the direct normal radiation has steeper rates of change during morning and evening hours and a flatter peak in the new data set, which is a result from the Perez split model. Correspondingly, the diffuse horizontal radiation shows a clearer peak.

The effect on the vertical global radiation is in the range of 100 W/m$^2$ for several hours.

In figures 8 and 9, the effect on the solar and lighting heat gains in the zone behind the window (it has also a north facing window) is shown. The curves show also the effect of the controlled blinds applied between hours 5431/5432 and 5436/5437. Nevertheless, the new data set leads to a considerably higher peak of the solar load in the morning.

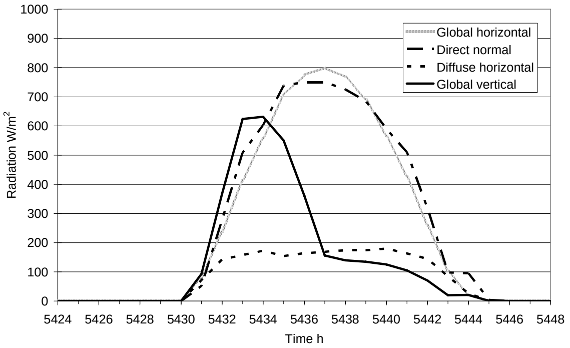

*Figure 6. Radiation components and vertical global radiation in window pane for a clear day, old data*

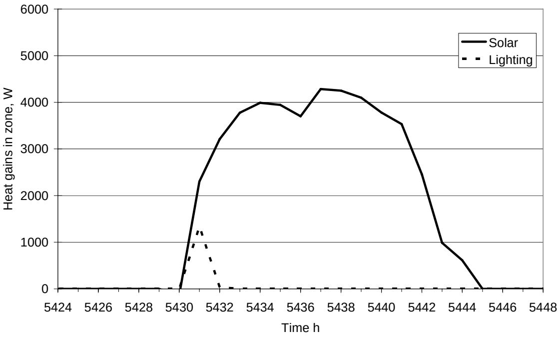

*Figure 8. Solar and lighting heat gains in the zone for a clear day, old data set*

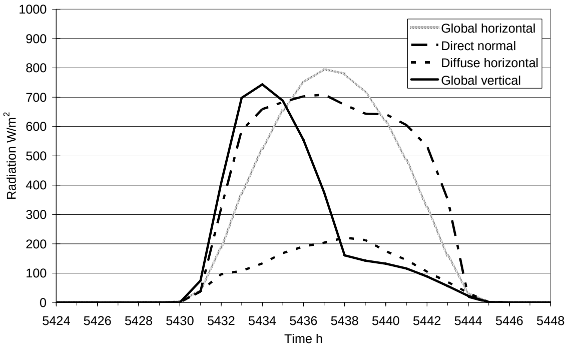

*Figure 7. Radiation components and vertical global radiation in window pane for a clear day, new data*

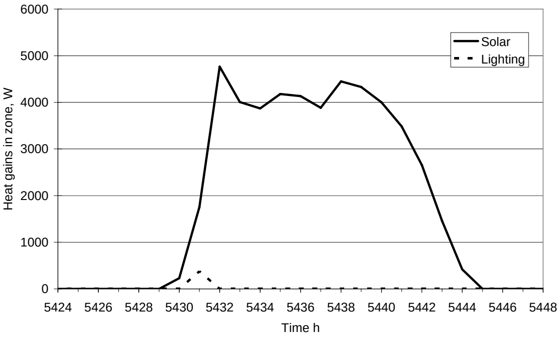

*Figure 9. Solar and lighting heat gains in the zone for a clear day, new data set*

## CONCLUSIONS

It has been shown that improvements in modeling for the radiation data processing can have a considerable effect on building simulation results. An influence coming from a domain outside the models of the simulation programs themselves turns out to be of significant magnitude, maybe larger than some complex modeling details for minor accuracy improvements.

## NOMENCLATURE

| | |
|---|---|
| $I_{b,n}$ | Direct (beam) normal radiation, W/m$^2$ |
| $I_{G,H}$ | Global horizontal radiation, W/m$^2$ |
| $I_{G,H,TOA}$ | Global horizontal radiation outside the atmosphere (“top of atmosphere”), W/m$^2$ |
| $I_{D,H}$ | Diffuse horizontal radiation, W/m$^2$ |
| $\vartheta_z$ | Solar altitude, angle between the horizontal plane and the direction of the beam radiation |

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