<u>Weather Generator Read-me file</u>

The files on this page have been created using the outputs of the UKCP09 weather generator, which uses the 2009 climate change scenario predictions and a gridded set of baseline data from the period 1961 to 1990. These files enable users to run weather through a buildings simulation model to predict behaviour in the future under a range of climate change scenarios as well as the control period. The weather files are presented in the .epw weather format, which is compatible with many building performance simulation programs. The methodology for the creation of these files has been peer-reviewed and will be published in Building Services Engineering Research and Technology as **"On the creation of future probabilistic design weather years from UKCP09"** currently available as doi:10.1177/0143624410379934. A pre-print version is available from the publications page of the PROMETHEUS website along with web links to the published version.

A brief description of the idea of probabilistic climate projections follows, taken from the UKCP09 Briefing Report (available from http://ukclimateprojections.defra.gov.uk/)

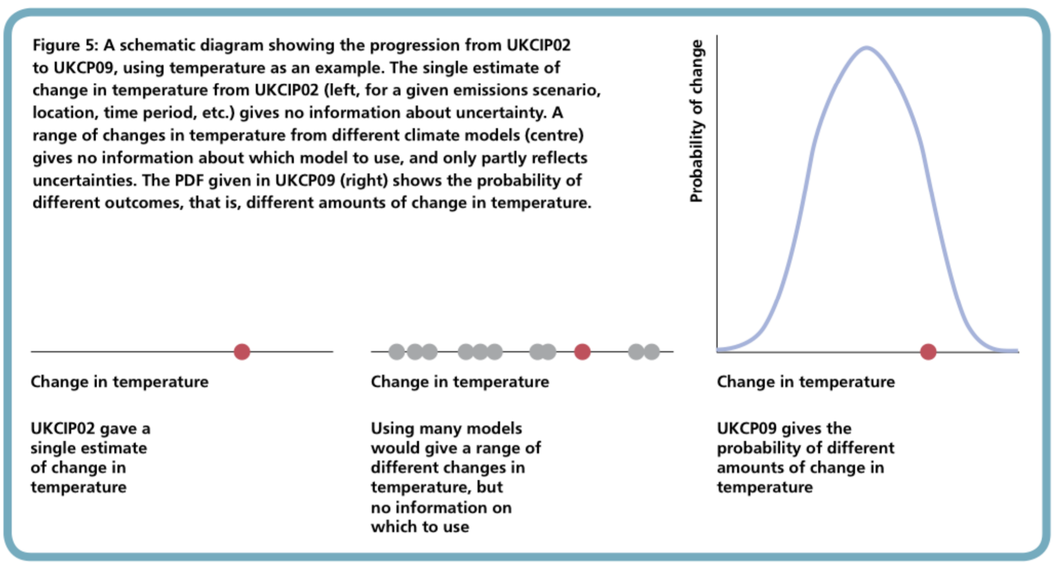

Figure 1 Illustration of how many climate models can give information about the probability of different amounts of climate change.

Using many runs of climate models, a probability density function (PDF) can be created, giving information about the range and relative likelihood of a certain amount of climate change. An example of the PDFs of change in summer-mean daily maximum temperature in the 2080's for the three climate change scenarios is shown below. The PDF shows the range of possible values and the relative likelihood of different amounts of climate change.

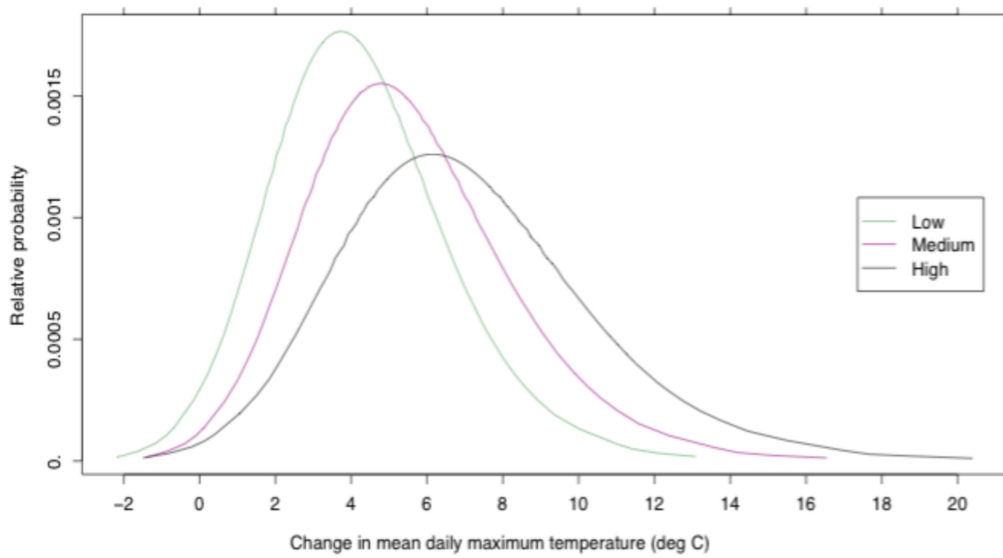

Figure 2 PDFs of change in summer-mean daily maximum temperature in South East England for the Low (green), Medium (purple) and High (black) emissions scenarios, for the 2080s. (Taken from the UKCP09 Briefing Report)

The probabilities used in UKCP09 are cumulative distribution function (CDF) probabilities. CDF probabilities are in the range 0-100% and in this case give the likelihood of climate change being less than a given value, for example the 90th percentile of change in temperature implies that there is a 90% chance of the actual climate change being less than that value. More details can be found in figure 3 (taken from the UKCP09 Briefing Report).

Box 3: How are probabilistic projections presented and how should they be interpreted?

What are PDFs and CDFs?

The provision of probabilistic projections is the major improvement which the UKCP09 brings to users. However, to utilise these appropriately, it is essential that users have a good understanding of what they mean and how they are communicated.

Probabilistic projections assign a probability to different possible climate change outcomes, recognising that (a) we cannot give a single answer and (b) giving a range of possible climate change outcomes is better, and can help with making robust adaptation decisions, but would be of limited use if we could not say which outcomes are more or less likely than others.

Within any given range of plausible climate changes, we cannot talk about the absolute probability of climate changing by some exact value — for example a temperature rise of exactly 6.0°C. Instead we talk about the probability of climate change being less than or greater than a certain value, using the Cumulative Distribution Function (CDF). This is defined as the probability* of a climate change being less than a given amount. The climate change at the 50% probability level is that which is as likely as not to be exceeded; it is properly known as the median, but in UKCP09 we refer to it by the more user-friendly name of *central estimate*. In Figure 8(a), the CDF (a hypothetical example at a certain location, by a certain future time period, for a given month of the year, under a particular emissions scenario) shows that there is a 10% probability of temperature change being less than about 2.3°C and a 90% probability of temperature change being less than about 3.6°C. In line with IPCC, we adopt the terminology *very likely* to refer to 90% probability and *very unlikely* to refer to the 10% probability. Thus, in Figure 8(a), we say that it is very unlikely that the temperature rise will be less than 2.3°C and very likely that it will be less than 3.6°C.

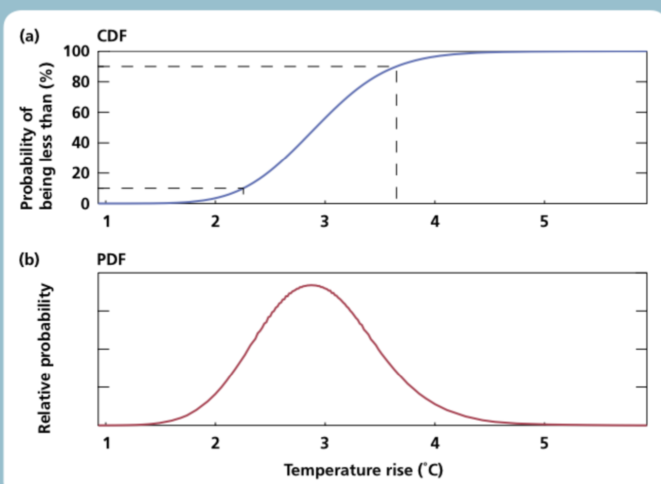

Figure 8: (a) Cumulative distribution function of temperature change for a hypothetical choice of emission scenario, location, time period and month. (b) Corresponding probability density function for this hypothetical case.

* Probabilities in CDFs are conventionally taken to range between 0 and 1, although we refer to them here as percentages, between 0 and 100%

Figure 3 Illustration of how CDFs can be formed from PDFs of climate change.

The output of the weather generator on an hourly time scale consists of 100 different realisations of a possible future climate with each realisation consisting of a thirty-year time series. For each realisation the weather generator samples from the UKCP09 probability density function and then stochastically progresses for the thirty-year period. Thus, each sample represents a single value of future climate change chosen at random with natural variability added to it. Each set of thirty-years is processed using the Finkelstein-Schafer statistical method to generate a test reference year consisting of the most average months from the period based on dry bulb temperature, wind speed and sunshine fraction. Simultaneously, the design summer year is calculated by taking the 90th percentile year ordered by the mean dry bulb temperature from April to September inclusive. This method gives 100 sets of weather files (TRYs and DSYs) each of which have a different climate signal. By doing this process the natural variability has been ordered. For both the sets of 100 design summer years and 100 test reference years each month is ordered according to the mean monthly temperature (the average of the mean daily temperatures over that month), ranked from lowest to highest and then the required percentile (e.g. 50th, 90th etc) are selected. The process is repeated for each month with data selected at the required percentile to produce either a probabilistic test reference year or probabilistic near extreme weather year as required. The method uses pointwise statistics to order the underlying climate signal as shown by figure 4. For example, for the 90th percentile weather year, the mean monthly temperature in each month is unlikely to be greater than that given by the file. Likewise for the 10th percentile each month the mean monthly temperature is unlikely to be less than that given by the file.

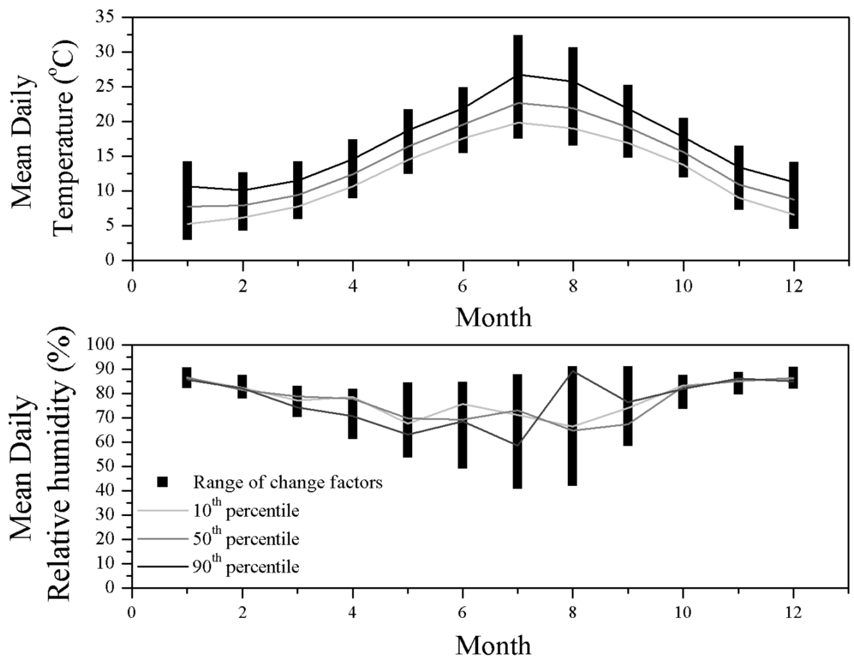

Figure 4 Graphs showing the extent of change factors for the mean monthly temperature and relative humidity. The lines demonstrate the selection procedure and have been ordered in terms of the mean temperature. Although the 90th percentile of mean temperature change is always much greater than the 10th percentile, the corresponding selection of relative humidity does not follow the same trend.

The weather generator provides data for the hourly precipitation, temperature, vapour pressure, relative humidity, sunshine fraction, diffuse radiation and direct radiation. The wind speed is inferred from potential evapotranspiration (which is output on a daily time series) and compared to observations to create an hourly time series. The wind direction and air pressure is inferred from the observed relationships with the season and observed daily wind speed. All other required variables are calculated from standard formulas.

Files Provided

Currently 14 locations have been processed which are Belfast, Birmingham, Cardiff, Edinburgh, Glasgow, Leeds, London, Manchester, Newcastle, Norwich, Nottingham, Plymouth, Southampton and Swindon (This is the same set as currently distributed by CIBSE) for three future time periods – the 2030s, the 2050s and 2080s and 5 CDF probability levels – 10 %, 33 %, 50 %, 66 %, and 90 %. Also provided are TRY and DSY files representing the base period from 1961 to 1990 (also known as the 1970s).

Furthermore a climate change amplification coefficient of a given building can be calculated from using just two files. These files have been chosen as the base line test reference year (as calculated from the weather generator to avoid copyright issues) and a morphed version using UKCP02 change factors for the 2080s under the high emissions scenario. This also has the advantage of being able to look at a given week or month of each file and examine the difference in weather due to climate change only (using weather generator files has both a different climate and different weather making this direct comparison harder). To calculate the climate change amplification coefficient the mean internal temperature is plotted against the mean external temperature or the maximum internal temperature against the maximum external temperature. The gradient of the line which joins the points is the climate change amplification coefficient. A building with a low climate change amplification coefficient is better suited to a warming climate. For further details of the climate change amplification coefficient use and calculation procedure see: Building and Environment, **45**, 89, 2010.

Format of the weather Files

The file name refers to the future time period, the UKCP09 5km grid box, which was selected (this corresponds to the meteorological weather station location of the CIBSE weather file), the emissions scenario (a1b = medium, a1fi = high) and percentile of the arranged underlying climate information. The first line of the header contains information about the location as shown by figure 5. The number, in this case, 1300540 refers to the UKCP09 5km grid reference, while 003917 represents the station id for the nearest meteorological weather station (WMO number), average observations from which, are used to inform the pressure, wind speed and wind direction. All other data follows the standard format.

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LOCATION,1300540,-,UK,WG data,003917,54.659,-6.226,0, 63
DESIGN CONDITIONS,0
TYPICAL/EXTREME PERIODS,0
GROUND TEMPERATURES,1,1.0,,,,8.7,7.9,7.8,8.2,9.2,10.5,11.7,12.5,12.7,12.2,11.2,10.3
HOLIDAYS/DAYLIGHT SAVINGS,No,0,0,0
COMMENTS 1,created by using weather generator output
COMMENTS 2,wind speed wind direction and pressure based on observations at station id 03917
DATA PERIODS,1,1,Data,Sunday,1/1,12/31
2080,1,1,1,60,*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?,1,-
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2080,1,1,2,60,*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?,3.7,3.1,95,101800,0,0,339,0,0,0,0,0,0,0,0,0,1,1,9999,99999,9,999999999,0,99
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2080,1,1,8,60,*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?*?,3.2,3.1,99,101800,0,0,332,0,0,0,0,0,0,0,0,0,8,4,9999,99999,9,999999999,0,99
9,999,99
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Figure 5 an example of the weather file format.

The files are comma separated variable and can be viewed in Excel or similar, from left to right the different variables are:

Year, month, day, hour, minute, uncertainty flags (*?*? (none present)), dry bulb temperature (°C), dew point temperature (°C), relative humidity (%), atmospheric pressure (Pa), extraterrestrial horizontal radiation (Wh/m^2), extraterrestrial direct normal radiation (Wh/m^2), horizontal infrared radiation from sky (Wh/m^2), global horizontal radiation (Wh/m^2), direct normal radiation (Wh/m^2), diffuse horizontal radiation (Wh/m^2), global horizontal illuminance (lux), direct normal illuminance (lux) diffuse horizontal illuminance (lux), zenith luminance (Cd/m^2), wind direction (degrees east of north), wind speed (m/s), total sky cover, opaque sky cover, visibility (km), ceiling height (m), present weather observation, present weather codes, precipitable water (mm), aerosol optical depth (1/1000th's), snow depth (cm), days since last snow fall.

Not all fields are required or filled in which case the field is populated with 9's to indicate to the program no data is present. All data required for building thermal simulation is present.

Use of the Weather Files

The .zip file downloaded from the website for a particular location and timescale i.e. Belfast 2080's contains 20 files; 10 TRY and 10 DSY files. These 10 TRYs and DSYs comprise of five different CDF percentiles for both the medium (a1b) and high (a1fi) emissions scenario. The low (b1) emissions scenario has not been included, as this seems increasingly unlikely considering current carbon emissions.

With UKCIP02 a single estimate of future climate was provided a hence a single result is produced when UKCIP02 future weather files are used for building simulation. The UKCP09 probabilistic climate projections encompass a range that lays either side of the UKCIP02 predicted value; this is shown in figure 6. In order to make use of the probabilistic nature of the climate projections it makes sense to perform multiple simulations using the files representing the different CDF percentiles. To fully explore the range of values for encompassed by the UKCP09 probabilistic projections five different percentiles are provided 10%, 33%, 50%, 66% and 90%, as mentioned above these percentiles are defined according to mean air temperature. These are defined as unlikely to be less than (10%), unlikely to be greater than (90%), 50% is the central estimate or median, everything between 33% and 66% is generally considered to be equally likely. Simulations performed using these different percentiles allows practitioners to make risk based decisions. This idea of risk-based analysis of using future weather years is a large step forward beyond what was possible using the non-probabilistic UKCIP02 climate projections. Using the Belfast 2080's example again running all five of the high emissions scenario could give an indication of the minimum provision of cooling required by a building, the potential heat related health risks to occupants and an indication of the likelihood and scope of overheating within the building. Perhaps most usefully this could enable the cost-benefit analysis of different architectural / structural design alternatives to minimise the risk of building failure as a result of climatic change.

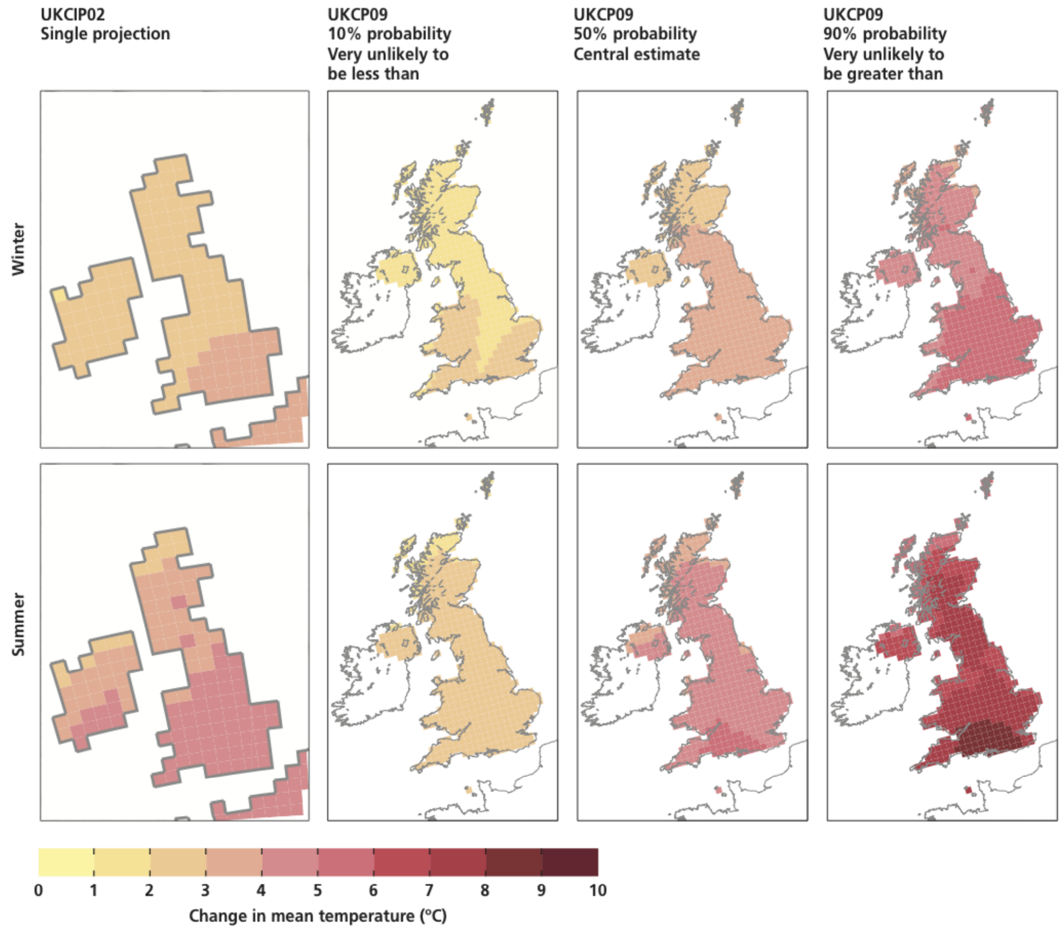

Figure 6 Comparison of changes in seasonal mean temperature, summer and winter, by the 2080s under High emissions scenarios, from the UKCIP02 report (far left panels) and as projected in UKCP09 (10, 50 and 90% probability level). (Taken from UKCP09 Climate Change Projections report).

In addition to the weather generator, UKCP09 contains estimates of future climate change that can be used to morph observations of current weather using the method of Belcher *et al* (BSER&T **26**, 49, 2005). These morphing 'change factors' can be used to modify 1961-1990 base line data (from the BADC) or CIBSE TRY and DSY files to produce future weather years. The future files produced contain the same weather patterns as the base line data and these morphed files will carry copyright associated with the BADC or CIBSE data. For this reason these files cannot be distributed via this website. However, comparison of the two types of future file created from the weather generator and from morphing produce similar results (pending publication).

Troubleshooting and Limitations

The weather files are created using the UKCP09 weather generator and hence each file contains different weather patterns. This means that for the lower percentile files such as the 10% and to a certain extent the 33% the climate signal is small and the variation between weather files due to different weather patterns is more apparent. This can lead to some unexpected results when using these files such as reduced hours of overheating in 2080 compared to 2050. This is not an error in the weather files but instead an aspect of the probabilistic climate information and the variation in the weather patterns.

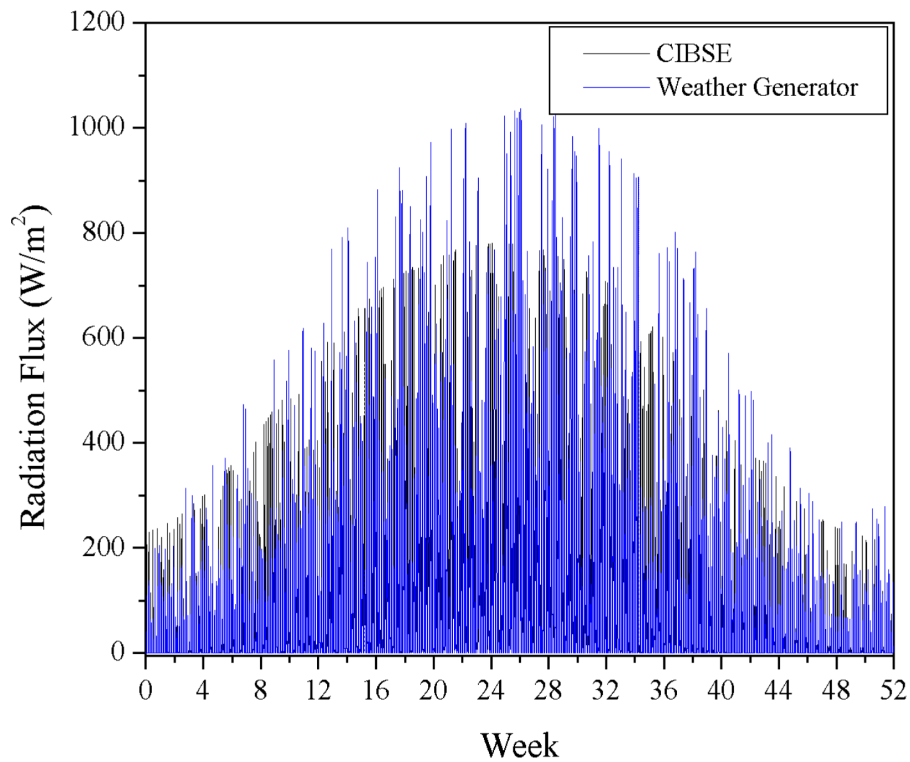

Figure 7 Comparison between the radiation flux in the CIBSE and weather generator files.

The solar model used in the weather generator to create values for solar radiation differs from that used to create solar radiation values for the CIBSE TRY and DSY files. For this reason it is not advisable to compare weather generator files with CIBSE files, instead future files should be compared with the base line 1961-1990 period data output by the weather generator and also available from the PROMETHEUS website. The variation between the different solar models is shown in figure 7.

The weather generator generates daily values, which are then disaggregated into the hourly values these are used to create the weather files. As a result there is a discontinuity between hourly values at midnight. This is shown for air temperature in figure 8, the discontinuity can be positive or negative and varies in magnitude. However, the effect of this discontinuity on the results of a thermal simulation is negligible as also shown in figure 8 is the internal air temperature of a typical primary school classroom. This however means that care should be taken when using the weather files with any control system that monitors the change in temperature with respect to time *dT*/*dt*.

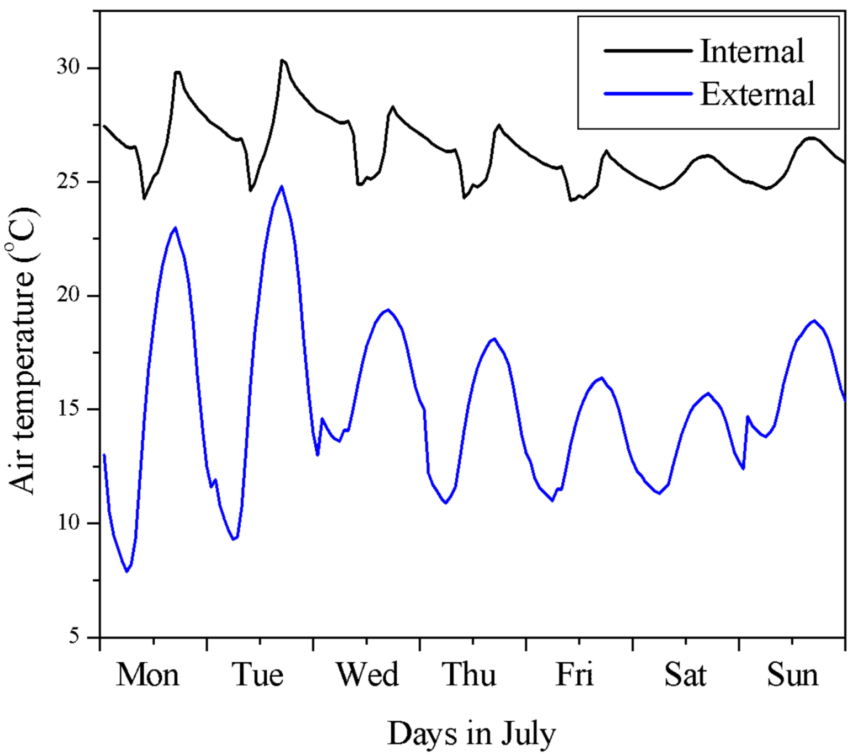

Figure 8 plot of internal and external air temperatures for a typical school classroom showing the fluctuation in weather variables at midnight each day and the effect on simulation data.