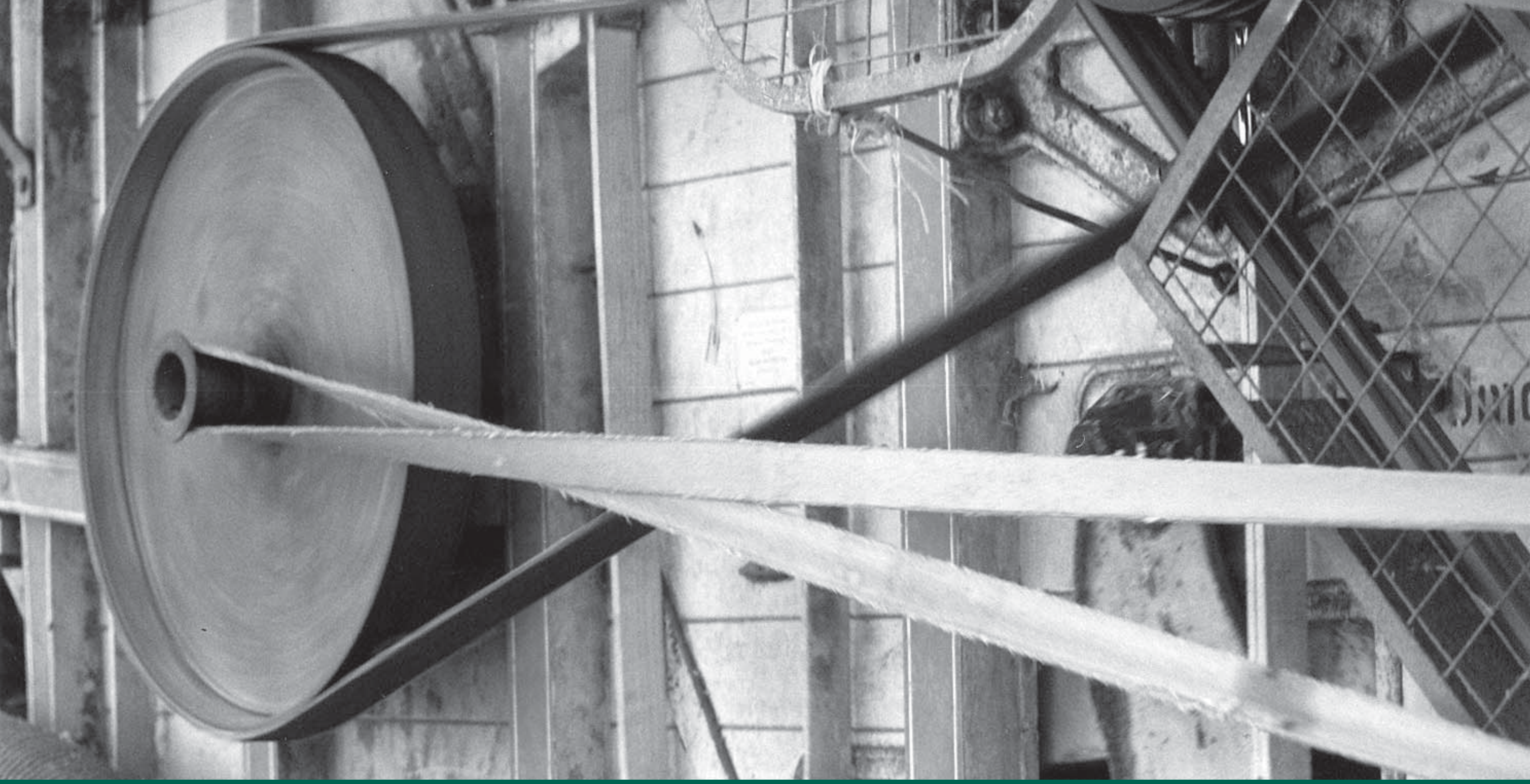

# reference

## Climate Change Weather File Generators

**Technical reference manual for the CCWeatherGen and CCWorldWeatherGen tools**

Version 1.2

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**November 2012**

# Introduction

This technical reference manual lists the calculation routines underlying the CCWeatherGen and CCWorldWeatherGen tools for generating hourly climate change adapted weather data for the UK and worldwide locations respectively. The calculations base on well established methods. References to the sources of the equations are given at the back of this document.

The equations used for the calculation routines of the CCWorldWeatherGen tool largely follow those used for the CCWeatherGen tool. Therefore, in this document, only where the equations differ, they have been specified for the CCWorldWeatherGen tool. For all other equations regarding this tool please consult the CCWeatherGen section of this reference manual.

For further details on how to operate the weather file generation tools and where to obtain the required baseline data please refer to the respective manuals. The tools can be downloaded from www.energy.soton.ac.uk/climatechange/climate.html

# Contents

# Abbreviations

| | |
|---|---|
| CIBSE | Chartered Institution of Building Services Engineers |
| DSY | Design Summer Year |
| EPW | EnergyPlus/ESP-r Weather |
| HadCM3 | Hadley Centre Coupled Model 3 |
| TMY2 | Typical Meteorological Year 2 |
| TRY | Test Reference Year |
| UKCIP02 | UK Climate Impacts Programme 2002 climate change scenarios |

# Nomenclature

| | | |
|---|---|---|
| $\alpha$ | = | $\ln p_w$ |
| $\alpha dbt_m$ | = | Scaling factor for monthly dry bulb temperature variance change. |
| $\alpha\gamma_m$ | = | Scaling factor for monthly specific humidity change. |
| $\alpha I_m$ | = | Scaling factor for monthly downward surface shortwave flux change. |
| $\alpha rr_m$ | = | Scaling factor for monthly precipitation change. |
| $\alpha ws_m$ | = | Scaling factor for monthly wind speed change. |
| $cc$ | = | Future cloud cover (deca). |
| $cc_0$ | = | Present day CIBSE TRY / DSY cloud cover (octa). |
| $d$ | = | Day of the year. |
| $d'$ | = | Day angle (degrees). |
| $d_{shift}$ | = | Median day of the month containing the minimum surface temperature (values: 15, 46, 74, 95, 135, 166, 196, 227, 258, 288, 319, 349). |
| $D_s$ | = | Thermal diffusivity of the ground / soil (m²/day) |
| $dbt$ | = | Future dry bulb temperature (°C). |
| $dbt_0$ | = | Present day CIBSE TRY / DSY dry bulb temperature (°C). |
| $dbt_a$ | = | Future annual mean dry bulb temperature (°C). |
| $dbt_{amp}$ | = | Amplitude of the warmest and coldest future average monthly dry bulb temperatures (°C). |
| $\langle dbt_0 \rangle_m$ | = | Mean dry bulb temperature of the CIBSE TRY / DSY data for the given month m (°C). |
| $\langle dbt_{0\max} \rangle_m$ | = | Average daily maximum dry bulb temperature of the CIBSE TRY / DSY data for the given month m (°C). |
| $\langle dbt_{0\min} \rangle_m$ | = | Average daily minimum dry bulb temperature of the CIBSE TRY / DSY data for the given month m (°C). |
| $depth$ | = | Depth below surface (m). |
| $dpt$ | = | Future dew point temperature (°C). |
| $\delta$ | = | Declination (degrees). |
| $\Delta$ | = | Atmospheric brightness (dimensionless). |
| $\Delta DSWF_m$ | = | UKCIP02 predicted absolute change of the mean downward surface shortwave flux for the given month m (W/m²). |
| $\Delta MSLP_m$ | = | UKCIP02 predicted absolute change of the mean sea level pressure for the given month m (Pa), [converted to (Pa) from (mbar)]. |
| $\Delta RHUM_m$ | = | UKCIP02 predicted absolute change of the mean relative humidity for the given month m (%). |

| | | |
|---|---|---|
| $\Delta TCLW_m$ | = | UKCIP02 predicted absolute change of the mean total cloud in long wave radiation for the given month m (% points). |
| $\Delta TEMP_m$ | = | UKCIP02 predicted absolute change of the mean dry bulb temperature for the given month m (°C). |
| $\Delta TMAX_m$ | = | UKCIP02 predicted absolute change of the average daily maximum dry bulb temperature for the given month m (°C). |
| $\Delta TMIN_m$ | = | UKCIP02 predicted absolute change of the average daily minimum dry bulb temperature for the given month m (°C). |
| $EOT$ | = | Equation of time (h). |
| $\varepsilon_{at}$ | = | Actual atmospheric emissivity (dimensionless). |
| $\varepsilon_c$ | = | Clear sky atmospheric emissivity (dimensionless). |
| $\varepsilon_d$ | = | Correction factor for the varying solar distance to the Earth (dimensionless). |
| $\varepsilon_{sc}$ | = | Atmospheric clearness (dimensionless) |
| $\phi$ | = | Latitude of the weather site (degrees). |
| $\Phi$ | = | Future relative humidity (%). |
| $\Phi_0$ | = | Present day relative humidity (%). |
| $gt_d$ | = | Future mean ground temperature for the given day d of the year (°C). |
| $\gamma$ | = | Future specific humidity (kg/kg). |
| $\gamma_0$ | = | Present day specific humidity (kg/kg). |
| $\gamma_s$ | = | Solar altitude angle (degrees). |
| $h_m$ | = | Number of hours in the given month m (h). |
| $i_{difhor}$ | = | Diffuse horizontal illuminance (lux). |
| $i_{dnor}$ | = | Direct normal illuminance (lux). |
| $i_{glhor}$ | = | Global horizontal illuminance (lux). |
| $I_0$ | = | Solar constant: 1367 (W/m²). |
| $I_{difhor}$ | = | Future diffuse horizontal radiation (Wh/m²). |
| $I_{difhor0}$ | = | Present day CIBSE TRY / DSY diffuse horizontal radiation (Wh/m²). |
| $I_{dnor}$ | = | Future direct normal radiation (Wh/m²). |
| $I_{dwlw}$ | = | Downwelling long-wave radiation (W/m²). |
| $I_{exhor}$ | = | Extraterrestrial horizontal radiation (W/m²). |
| $I_{exnor}$ | = | Extraterrestrial direct normal radiation (W/m²). |
| $I_{glhor}$ | = | Future global horizontal radiation (Wh/m²). |

| | | |
|---|---|---|
| $I_{glhor0}$ | = | Present day CIBSE TRY / DSY global horizontal radiation (Wh/m²) |
| $\left\langle I_{glhor0} \right\rangle_m$ | = | Mean global horizontal radiation of the baseline data for the given month m (W/m²). |
| $\sum_{x \in m} I_{glhor0}$ | = | Total global horizontal radiation of the baseline data for the given month m (kWh/m²). |
| $KT_d$ | = | Daily clearness index (dimensionless). |
| $KT_h$ | = | Hourly clearness index (dimensionless). |
| $L_{vz}$ | = | Zenith luminance (Cd/m²). |
| $LST$ | = | Local standard time (h), [midpoint of a given weather file hour node]. |
| $\lambda$ | = | Longitude of the weather site (degrees), [positive values denote east]. |
| $\lambda_R$ | = | Longitude of the time zone in which the weather site is situated (degrees), [positive values denote east]. |
| $m$ | = | Relative optical air mass (dimensionless), values for m obtained from Table 2 of the paper by Kasten and Young [11] in relation to the given solar altitude angle. |
| $occ$ | = | Future opaque sky cover (deca). |
| $occ_0$ | = | Present day EPW opaque sky cover (deca). |
| $p_{at}$ | = | Future atmospheric pressure calculated according to equation (15) (kPa). |
| $p_{at0}$ | = | Present day CIBSE TRY / DSY atmospheric pressure (kPa) |
| $p_w$ | = | Future partial pressure of water vapour (kPa). |
| $p_{w0}$ | = | Present day partial pressure of water vapour (kPa). |
| $p'_{ws}$ | = | Saturation pressure of water vapour in the absence of air at a given temperature numerically equal to the wet bulb temperature of the air being considered (kPa). Values are taken from a table provided in the ASHRAE handbook [6]. |
| $PREC_m$ | = | HadCM3 predicted relative change of the precipitation rate for the given month m (%). |
| $PWC$ | = | Precipitable water content (cm). |
| $rr$ | = | Future precipitable water (mm). |
| $rr_0$ | = | Present day precipitable water (mm). |
| $SOT$ | = | Solar time (h). |
| $SPHU_m$ | = | UKCIP02 predicted relative change of the specific humidity for the given month m (%). |
| $\sigma$ | = | Stefan-Boltzmann constant: 5.67 x $10^{-8}$ (W $K^{-4}$ $m^{-2}$). |
| $\theta_s$ | = | Solar zenith angle (degrees). |
| $W$ | = | Future humidity ratio (kg/kg). |

| | | |
|---|---|---|
| $W_0$ | = | Present day humidity ratio (kg/kg). |
| $wbt_0$ | = | Present day CIBSE TRY / DSY wet bulb temperature (°C). |
| $WIND_m$ | = | UKCIP02 predicted relative change of the wind speed for the given month m (%). |
| $ws$ | = | Future wind speed (m/s). |
| $ws_0$ | = | Present day CIBSE TRY / DSY wind speed (knots). |
| $\omega$ | = | Hour angle (degrees). |
| $\psi$ | = | Clearness index persistence (dimensionless). |

# 1. CCWeatherGen Calculation Methods

**Detailed equations used for transforming existing CIBSE 'Test Reference Year' (TRY) and 'Design Summer Year' (DSY) weather data with UKCIP02 climate change predictions into future time series.**

A range of different sources have been used for transforming hourly 'present day' CIBSE TRY / DSY weather data into climate change adapted weather data, addressing the majority of parameters given in a standard TMY2 / EPW file. The basic methodology for this weather data 'morphing' process bases on the work of Belcher et al [1]. The list below provides all equations applied for generating climate change TMY2 / EPW files from the UKCIP02 climate change scenario data. Structurally it follows the EPW file data convention [2]. The CCWeatherGen tool can be downloaded from www.energy.soton.ac.uk/ccweathergen

### EPW header node: Ground Temperature

The EPW file header usually contains information on the monthly mean ground temperature at one or more levels of depth. The mean ground temperature for a given day of the year is derived from the predicted annual mean dry bulb temperature and the amplitude of the warmest and coldest average monthly dry bulb temperatures following the method developed by Kusuda and Achenbach [3]. The calculations presented here are based on routines developed by Lawrie [4] for the EnergyPlus Weather Converter. They require prior calculation of the future hourly dry bulb temperatures using equations (2) and (3). The future mean ground temperature for a given day of the year can then be calculated by:

**(1)** $$gt_d = dbt_a - dbt_{amp} \cdot \cos\left[2 \cdot \left(\frac{\pi}{365}\right) \cdot d - \left(d_{shift} \cdot 0.017214 + 0.341787\right) - \arctan(z)\right] \cdot \sqrt{y}$$

(source: [3, 4])

***Where:***

$$z = \frac{1 - \exp(-x) \cdot [\cos(x) + \sin(x)]}{1 - \exp(-x) \cdot [\cos(x) - \sin(x)]}$$

***And:***

$$y = \frac{\exp(-x)^2 - 2 \cdot \exp(-x) \cdot \cos(x) + 1}{2 \cdot x^2}$$

***With:***

$$x = \sqrt{\frac{\pi}{D_s \cdot 365}} \cdot depth$$

***Where:***

| | | |
|---|---|---|
| $gt_d$ | = | Future mean ground temperature for the given day d of the year (°C). |
| $dbt_a$ | = | Future annual mean dry bulb temperature (°C). |
| $dbt_{amp}$ | = | Amplitude of the warmest and coldest future average monthly dry bulb temperatures (°C). |
| $depth$ | = | Depth below surface (m). |
| $D_s$ | = | Thermal diffusivity of the ground / soil (m²/day) |
| $d$ | = | Day of the year. |
| $d_{shift}$ | = | Median day of the month containing the minimum surface temperature (values: 15, 46, 74, 95, 135, 166, 196, 227, 258, 288, 319, 349). |

Depths of 0.5, 2 and 4 m below surface have been chosen for the future weather files. As no site specific information is available for the thermal diffusivity of the ground, the default value of 0.055741824 m²/day given by Lawrie [4] has been selected for the calculations. After performing equation (1) for each day of the year, the monthly mean ground temperatures can be easily calculated.

**EPW node N6: Dry bulb temperature (°C)**

The UKCIP02 data provides mean, average daily maximum and minimum temperature change predictions, thus giving information on monthly changes of the mean temperature as well as changes in the diurnal temperature range in that month. In order to account for this the CIBSE TRY / DSY data is shifted by the UKCIP02 mean temperature value and stretched by the predicted change in the diurnal range following Belcher et al [1]. The scaling factor for the stretch function is calculated as follows:

**(2)** $$\alpha dbt_m = \frac{\Delta TMAX_m - \Delta TMIN_m}{\langle dbt_{0\max} \rangle_m - \langle dbt_{0\min} \rangle_m}$$ (source: [1])

***Where:***

| | | |
|---|---|---|
| $\alpha dbt_m$ | = | Scaling factor for monthly dry bulb temperature variance change. |
| $\Delta TMAX_m$ | = | UKCIP02 predicted absolute change of the average daily maximum dry bulb temperature for the given month m (°C). |
| $\Delta TMIN_m$ | = | UKCIP02 predicted absolute change of the average daily minimum dry bulb temperature for the given month m (°C). |
| $\langle dbt_{0\max} \rangle_m$ | = | Average daily maximum dry bulb temperature of the CIBSE TRY / DSY data for the given month m (°C). |
| $\langle dbt_{0\min} \rangle_m$ | = | Average daily minimum dry bulb temperature of the CIBSE TRY / DSY data for the given month m (°C). |

The future dry bulb temperature for a given hour is then calculated in a combined stretch and shift function:

**(3)** $dbt = dbt_0 + \Delta TEMP_m + \alpha dbt_m \cdot \left(dbt_0 - \langle dbt_0 \rangle_m\right)$ (source: [1])

***Where:***

| | | |
|---|---|---|
| $dbt$ | = | Future dry bulb temperature (°C). |
| $dbt_0$ | = | Present day CIBSE TRY / DSY dry bulb temperature (°C). |
| $\Delta TEMP_m$ | = | UKCIP02 predicted absolute change of the mean dry bulb temperature for the given month m (°C). |
| $\langle dbt_0 \rangle_m$ | = | Mean dry bulb temperature of the CIBSE TRY / DSY data for the given month m (°C). |

**EPW node N7: Dew point temperature (°C)**

Neither the CIBSE TRY / DSY data nor the UKCIP02 data contains information on dew point temperature. To determine the future dew point temperature it is at first required to calculate the 'present day' specific humidity from the CIBSE TRY / DSY data using psychrometric formulae given in Jones [5] and the ASHRAE handbook [6]. This is undertaken in a three step approach. In a first step the 'present day' partial pressure of water vapour is determined from the available data for atmospheric pressure, dry bulb and wet bulb temperature:

**(4)** $p_{w0} = p'_{ws} - p_{at0} \cdot A \cdot \left(dbt_0 - wbt_0\right)$ (source: [5])

***Where:***

| | | |
|---|---|---|
| $p_{w0}$ | = | Present day partial pressure of water vapour (kPa). |
| $p_{ws}^{'}$ | = | Saturation pressure of water vapour in the absence of air at a given temperature numerically equal to the wet bulb temperature of the air being considered (kPa). Values are taken from Table 3 provided in Chapter 6 of the ASHRAE handbook [6]. |
| $p_{at0}$ | = | Present day CIBSE TRY / DSY atmospheric pressure (kPa) |
| $A$ | = | Constant: If $wbt_0 \geq 0$ then $A = 6.66 \cdot 10^{-4}\ °C^{-1}$. If $wbt_0 < 0$ then $A = 5.94 \cdot 10^{-4}\ °C^{-1}$. |
| $wbt_0$ | = | Present day CIBSE TRY / DSY wet bulb temperature (°C). |

The calculated 'preset day' partial pressure of water vapour is then used to determine the humidity ratio:

**(5)** $W_0 = 0.62198 \cdot \dfrac{p_{W0}}{p_{at0} - p_{W0}}$ (source: [6])

***Where:***

| | | |
|---|---|---|
| $W_0$ | = | Present day humidity ratio (kg/kg). |

This can then be used to calculate the 'present day' specific humidity:

**(6)** $\gamma_0 = \dfrac{W_0}{(1 + W_0)}$ (source: [6])

***Where:***

| | | |
|---|---|---|
| $\gamma_0$ | = | Present day specific humidity (kg/kg). |

In order to obtain the future specific humidity the value for the 'present day' specific humidity is stretched according to Belcher et al [1] by using the relative change for specific humidity given in the UKCIP02 data. The scaling factor for the stretch function is calculated as follows:

**(7)** $\alpha\gamma_m = 1 + SPHU_m / 100$ (source: [1])

***Where:***

$\alpha\gamma_m$ = Scaling factor for monthly specific humidity change.

$SPHU_m$ = UKCIP02 predicted relative change of the specific humidity for the given month m (%).

The future specific humidity for a given hour is then calculated in a stretch function:

**(8)** $\gamma = \alpha\gamma_m \cdot \gamma_0$ (source: [1])

***Where:***

$\gamma$ = Future specific humidity (kg/kg).

The future dew point temperature can then be calculated from the morphed specific humidity by converting equations (6) and (5). Equation (6) then becomes:

**(9)** $W = \dfrac{\gamma}{(1-\gamma)}$

***Where:***

$W$ = Future humidity ratio (kg/kg).

Equation (5) then becomes:

**(10)** $p_W = \dfrac{W \cdot p_{at}}{(0.62198 + W)}$

***Where:***

$p_W$ = Future partial pressure of water vapour (kPa).

$p_{at}$ = Future atmospheric pressure calculated according to equation (15) (kPa).

Finally the dew point temperature can be calculated according to equations given by ASHRAE [6]. For dew points between 0 and 93 °C the following equation is used:

**(11)** $dpt = C_{14} + C_{15} \cdot \alpha + C_{16} \cdot \alpha^2 + C_{17} \cdot \alpha^3 + C_{18} \cdot (p_w)^{0.1984}$ (source: [6])

***Where:***

| | | |
|---|---|---|
| $dpt$ | = | Future dew point temperature (°C). |
| $\alpha$ | = | $\ln p_w$ |
| $C_{14}$ | = | Constant: 6.54 |
| $C_{15}$ | = | Constant: 14.526 |
| $C_{16}$ | = | Constant: 0.7389 |
| $C_{17}$ | = | Constant: 0.09486 |
| $C_{18}$ | = | Constant: 0.4569 |

For dew points below 0 °C the following equation is used:

**(12)** $dpt = 6.09 + 12.608 \cdot \alpha + 0.4959 \cdot \alpha^2$ (source: [6])

As dew point temperature is yet to be calculated, equations (11) and (12) are selected on grounds of the value calculated for the future partial pressure of water vapour in equation (10), i.e. for a partial pressure of water vapour above 0.61115 kPa equation (11) is selected and for a partial pressure of water vapour below 0.61115 kPa equation (12).

## EPW node N8: Relative humidity (%)

The 'present day' CIBSE TRY / DSY data does not contain relative humidity information. Therefore, the 'present day' relative humidity has to be determined prior to performing any morphing calculations. Following the ASHRAE handbook [6] it can be derived from the present day partial pressure of water vapour calculated in equation (4) and the saturation pressure of water vapour in the absence of air at the 'present day' dry bulb temperature by applying the following equation:

**(13)** $\Phi_0 = \left. \frac{p_{w0}}{p'_{ws}} \right|_{dbt_0, p_{at0}}$ (source: [6])

***Where:***

| | | |
|---|---|---|
| $\Phi_0$ | = | Present day relative humidity (%). |
| $\Big\|_{dbt_0, p_{at0}}$ | = | At a given CIBSE TRY / DSY dry bulb temperature and atmospheric pressure. |

Belcher et al [1] do not provide a method for morphing ‘present day’ relative humidity into future relative humidity. However, as the UKCIP02 data gives the predicted change for relative humidity as absolute values in percentage points, a shift function is used:

**(14)** $\Phi = \Phi_0 + \Delta RHUM_m$

***Where:***

| | | |
|---|---|---|
| $\Phi$ | = | Future relative humidity (%). |
| $\Delta RHUM_m$ | = | UKCIP02 predicted absolute change of the mean relative humidity for the given month m (%). |

**EPW node N9: Atmospheric pressure (Pa)**

The UKCIP02 data gives predictions for the absolute change in the mean sea level pressure in Millibar (mbar), which, converted to Pascal (Pa), is used in a shift function according to Belcher et al [1] to determine the future atmospheric pressure:

**(15)** $p_{at} = p_{at0} + \Delta MSLP_m$ (source: [1])

***Where:***

| | | |
|---|---|---|
| $\Delta MSLP_m$ | = | UKCIP02 predicted absolute change of the mean sea level pressure for the given month m (Pa), [converted to (Pa) from (mbar)]. |

**EPW node N10: Extraterrestrial horizontal radiation (Wh/m²)**

The extraterrestrial horizontal radiation for a given location and time of the day is calculated based on solar geometry equations given in CIBSE Guide J [7]. It requires prior calculation of the solar altitude angle and the extraterrestrial direct normal radiation using equation (24). As the time nodes given in TMY2 / EPW files are in ‘local standard time’ and not in ‘solar time’, the solar altitude angle calculation needs to consider differences between the two time systems for a given location in order to receive the true solar altitude angle at the given ‘local standard time’. This conversion also needs to take into account the perturbations in the Earth’s rotation as the distance between the Earth and the Sun is not constant which affects the speed of the Earth’s rotation around its polar axis. Mathematically this is accounted for by the equation of time which, in a first step, requires calculation of the day angle to express the given day of the year in an angular form:

$$d' = d \cdot \frac{360}{365.25} \quad \textbf{(16)}$$ (source: [7])

***Where:***

$d'$ = Day angle (degrees).

In order to account for leap years 365.25 days per year are used instead of 365. The day angle is then used in the equation of time as follows:

$$EOT = -0.128 \cdot \sin(d' - 2.8) - 0.165 \cdot \sin(2 \cdot d' + 19.7) \quad \textbf{(17)}$$ (source: [7])

***Where:***

$EOT$ = Equation of time (h).

The 'solar time' can then be calculated using the following equation:

$$SOT = LST + (\lambda - \lambda_R)/15 + EOT \quad \textbf{(18)}$$ (source: [7])

***Where:***

$SOT$ = Solar time (h).
$LST$ = Local standard time (h), [midpoint of a given weather file hour node].
$\lambda$ = Longitude of the weather site (degrees), [positive values denote east].
$\lambda_R$ = Longitude of the time zone in which the weather site is situated (degrees), [positive values denote east].

For a given CIBSE TRY / DSY weather file the midpoint of the current hour node is selected as 'local standard time' for calculating the solar altitude angle. The 'local solar time' is then used to determine the hour angle which is the angle the Earth's rotation has passed through since solar noon:

$$\omega = \frac{360}{24} \cdot (SOT - 12) \quad \textbf{(19)}$$ (source: [7])

***Where:***

$\omega$ = Hour angle (degrees).

In a last step before being able to determine the solar altitude angle it is necessary to calculate the Earth's declination which is the angle between the Sun's direction and the equatorial plane:

**(20)** $\delta = \sin^{-1} \cdot \left\{0.3978 \cdot \sin\left[d' - 1.4 + 0.0355 \cdot \sin\left(d' - 0.0489\right)\right]\right\}$ (source: [7])

***Where:***

$\delta$ = Declination (degrees).

The solar altitude angle is then given by:

**(21)** $\sin\gamma_s = \sin\phi \cdot \sin\delta + \cos\phi \cdot \cos\delta \cdot \cos\omega$ (source: [7])

***Where:***

$\gamma_s$ = Solar altitude angle (degrees).

$\phi$ = Latitude of the weather site (degrees).

Finally, the extraterrestrial horizontal radiation can be calculated from the solar altitude angle and the extraterrestrial direct normal radiation determined in equation (24) by using the sine rule:

**(22)** $I_{exhor} = \sin\gamma_s \cdot I_{exnor}$

***Where:***

$I_{exhor}$ = Extraterrestrial horizontal radiation (W/m²).

$I_{exnor}$ = Extraterrestrial direct normal radiation (W/m²).

The extraterrestrial horizontal radiation is then given in Wh/m² for each hourly time step in the climate change adapted weather file for all hours with incident solar radiation.

## EPW node N11: Extraterrestrial direct normal radiation (Wh/m²)

The extraterrestrial direct normal radiation is related to the solar constant, i.e. the extraterrestrial irradiance normal to the beam at mean solar distance [7]. In order to allow for the fact that the orbit of the Earth is elliptical with a varying distance to the Sun, a correction factor is introduced for the extraterrestrial direct normal radiation following CIBSE Guide J

[7]. This correction factor requires the day angle determined in equation (16) and is calculated as follows:

**(23)** $\varepsilon_d = 1 + 0.03344 \cdot \cos(d' - 2.8)$ (source: [7])

***Where:***

$\varepsilon_d$ = Correction factor for the varying solar distance to the Earth (dimensionless).

The extraterrestrial direct normal radiation can then be calculated as follows:

**(24)** $I_{exnor} = I_0 \cdot \varepsilon_d$ (source: [7])

***Where:***

$I_0$ = Solar constant: 1367 (W/m²).

The extraterrestrial direct normal radiation is then given in Wh/m² for each hourly time step in the climate change adapted weather file for all hours with incident solar radiation.

## EPW node N12: Horizontal infrared radiation from the sky (Wh/m²)

The horizontal infrared radiation from the sky (downwelling long-wave radiation) can be calculated from the values for the future dry bulb temperature, partial pressure of water vapour and cloud cover as determined by equations (3), (10) and (43) following the methodology given by Crawford and Duchon [8]. For these calculations the dry bulb temperature needs to be transformed from °C to Kelvin. In a first step it is necessary to determine the clear sky atmospheric emissivity:

**(25)** $\varepsilon_c = 1.24 \cdot \left( \frac{p_w}{dbt} \right)^{1/7}$ (source: [8])

***Where:***

$\varepsilon_c$ = Clear sky atmospheric emissivity (dimensionless).

The value for clear sky atmospheric emissivity is then used with the fraction of the future cloud cover calculated in equation (43) to calculate the actual atmospheric emissivity:

$$\textbf{(26)}\ \varepsilon_{at} = \frac{cc}{10} + (1 - \frac{cc}{10}) \cdot \varepsilon_c$$ (source: [8])

***Where:***

| | | |
|---|---|---|
| $\varepsilon_{at}$ | = | Actual atmospheric emissivity (dimensionless). |
| $cc$ | = | Future cloud cover (deca). |

The actual atmospheric emissivity is then used to determine the downwelling long-wave radiation:

$$\textbf{(27)}\ I_{dwlw} = \varepsilon_{at} \cdot \sigma \cdot dbt^4$$ (source: [8])

***Where:***

| | | |
|---|---|---|
| $I_{dwlw}$ | = | Downwelling long-wave radiation (W/m²). |
| $\sigma$ | = | Stefan-Boltzmann constant: 5.67 x $10^{-8}$ (W $K^{-4}$ $m^{-2}$). |

The horizontal infrared radiation from the sky (downwelling long-wave radiation) is then given in Wh/m² for each hourly time step in the climate change adapted weather file.

**EPW node N13: Global horizontal radiation (Wh/m²)**

The future global horizontal radiation is calculated from the UKCIP02 predictions for the change in absolute monthly mean downward surface shortwave flux and the 'present day' CIBSE TRY / DSY data for global horizontal radiation according to the method described by Belcher et al [1]. As a shift function would not be appropriate for this calculation, since the sun would then radiate at night, a scaling factor is determined from the UKCIP02 absolute change and the monthly mean from the observed baseline climate. Because no long term global horizontal radiation data is available for the 14 CIBSE weather stations, the closest weather stations in the Meteonorm [9] dataset are selected for the baseline climate. This data is given in Table 1.1 for the 14 CIBSE weather stations as shown below. As the data is provided in monthly totals it is necessary to transform it into monthly mean values by using the following equation:

$$\textbf{(28)}\ \langle I_{glhor0} \rangle_m = \frac{\sum_{x \in m} I_{glhor0} \cdot 1000}{h_m}$$

***Where:***

| | | |
|---|---|---|
| $\left\langle I_{glhor0} \right\rangle_m$ | = | Mean global horizontal radiation of the baseline data for the given month m (W/m²). |
| $\sum_{x \in m} I_{glhor0}$ | = | Total global horizontal radiation of the baseline data for the given month m (kWh/m²). |
| $h_m$ | = | Number of hours in the given month m (h). |

The required scaling factor can then be calculated as follows:

**(29)** $$\alpha I_m = 1 + \left( \frac{\Delta DSWF_m}{\left\langle I_{glhor0} \right\rangle_m} \right)$$ (source: [1])

***Where:***

| | | |
|---|---|---|
| $\alpha I_m$ | = | Scaling factor for monthly downward surface shortwave flux change. |
| $\Delta DSWF_m$ | = | UKCIP02 predicted absolute change of the mean downward surface shortwave flux for the given month m (W/m²). |

The future global horizontal radiation for a given hour is then calculated in a stretch function:

**(30)** $$I_{glhor} = \alpha I_m \cdot I_{glhor0}$$ (source: [1])

***Where:***

| | | |
|---|---|---|
| $I_{glhor}$ | = | Future global horizontal radiation (Wh/m²). |
| $I_{glhor0}$ | = | Present day CIBSE TRY / DSY global horizontal radiation (Wh/m²) |

**Table 1.1** Meteonorm [9] long term average monthly totals for global horizontal radiation in (kWh/m²) as selected for the 14 CIBSE weather stations (see equation (28)).

| **CIBSE Station** | **Belfast** | **Birmingham** | **Cardiff** | **Edinburgh** | **Glasgow** | **Leeds** | **London** |
|---|---|---|---|---|---|---|---|
| **Meteonorm Station** | Belfast-Aldergrove | Sutton Bonington | Cardiff Wales | Dundee/ Mylnefi | Dunstaffnage | Cawood | Kew |
| **Data period** | 1981-2000 | 1981-1990 | 1981-1990 | 1981-1990 | 1981-2000 | 1981-1990 | 1981-1990 |
| **Jan** | 16 | 19 | 22 | 16 | 12 | 18 | 21 |
| **Feb** | 31 | 32 | 35 | 31 | 26 | 28 | 34 |
| **Mar** | 64 | 58 | 72 | 62 | 60 | 63 | 70 |
| **Apr** | 106 | 102 | 103 | 103 | 104 | 94 | 103 |
| **May** | 143 | 131 | 146 | 144 | 138 | 138 | 140 |
| **Jun** | 144 | 130 | 150 | 140 | 146 | 146 | 147 |
| **Jul** | 135 | 132 | 144 | 144 | 132 | 144 | 143 |
| **Aug** | 114 | 118 | 124 | 115 | 106 | 115 | 124 |
| **Sep** | 77 | 78 | 89 | 78 | 71 | 76 | 87 |
| **Oct** | 45 | 44 | 54 | 42 | 39 | 46 | 53 |
| **Nov** | 21 | 24 | 27 | 20 | 17 | 24 | 26 |
| **Dec** | 12 | 13 | 17 | 10 | 9 | 15 | 16 |

| **CIBSE Station** | **Manchester** | **Newcastle** | **Norwich** | **Nottingham** | **Plymouth** | **Southampton** | **Swindon** |
|---|---|---|---|---|---|---|---|
| **Meteonorm Station** | Aughton | Cawood | Hemsby | Sutton Bonington | Cardiff Wales | Efford | Efford |
| **Data period** | 1984-1996 | 1981-1990 | 1984-2000 | 1981-1990 | 1981-1990 | 1981-1990 | 1981-1990 |
| **Jan** | 18 | 18 | 21 | 19 | 22 | 25 | 25 |
| **Feb** | 34 | 28 | 38 | 32 | 35 | 46 | 46 |
| **Mar** | 67 | 63 | 74 | 58 | 72 | 77 | 77 |
| **Apr** | 108 | 94 | 115 | 102 | 103 | 127 | 127 |
| **May** | 150 | 138 | 157 | 131 | 146 | 158 | 158 |
| **Jun** | 150 | 146 | 156 | 130 | 150 | 159 | 159 |
| **Jul** | 147 | 144 | 156 | 132 | 144 | 162 | 162 |
| **Aug** | 121 | 115 | 136 | 118 | 124 | 140 | 140 |
| **Sep** | 82 | 76 | 86 | 78 | 89 | 95 | 95 |
| **Oct** | 47 | 46 | 54 | 44 | 54 | 59 | 59 |
| **Nov** | 22 | 24 | 26 | 24 | 27 | 32 | 32 |
| **Dec** | 13 | 15 | 16 | 13 | 17 | 20 | 20 |

### EPW node N14: Direct normal radiation (Wh/m²)

The direct normal radiation can be calculated from the solar altitude angle, the global horizontal radiation and the diffuse horizontal radiation determined in equations (21), (30) and (32) by using the sine rule:

**(31)** $$I_{dnor} = \frac{\left(I_{glhor} - I_{difhor}\right)}{\sin \gamma_s}$$

***Where:***

$I_{dnor}$ = Future direct normal radiation (Wh/m²).

$I_{difhor}$ = Future diffuse horizontal radiation (Wh/m²).

### EPW node N15: Diffuse horizontal radiation (Wh/m²)

The UKCIP02 data does not provide any information on future changes in diffuse horizontal radiation. Therefore, the method proposed by Belcher et al [1] is used where changes in diffuse horizontal radiation are assumed to be proportional to changes in global horizontal radiation. This permits applying the scaling factor calculated in equation (29) to stretch the ‘present day’ CIBSE TRY / DSY value for diffuse horizontal radiation as given below:

**(32)** $$I_{difhor} = \alpha I_m \cdot I_{difhor0}$$ (source: [1])

***Where:***

$I_{difhor0}$ = Present day CIBSE TRY / DSY diffuse horizontal radiation (Wh/m²).

### EPW node N16: Global horizontal illuminance (lux)

Global horizontal illuminance is calculated from the future global horizontal radiation determined in equation (30) based on equations derived from empirical data by Perez et al [10]. However, before being able to calculate the global horizontal illuminance, the solar zenith angle, atmospheric precipitable water and atmospheric brightness need to be determined. The solar zenith angle is determined from the solar altitude angle calculated in equation (21):

**(33)** $\theta_s = 90 - \gamma_s$

***Where:***

| | | |
|---|---|---|
| $\theta_s$ | = | Solar zenith angle (degrees). |

The atmospheric precipitable water is calculated as follows:

**(34)** $PWC = \exp(0.07 \cdot dpt - 0.075)$ (source: [10])

***Where:***

| | | |
|---|---|---|
| $PWC$ | = | Precipitable water content (cm). |

The atmospheric or sky's brightness is given by:

**(35)** $\Delta = I_{difhor} \cdot m / I_{exnor}$ (source: [10])

***Where:***

| | | |
|---|---|---|
| $\Delta$ | = | Atmospheric brightness (dimensionless). |
| $m$ | = | Relative optical air mass (dimensionless), values for m obtained from Table 2 of the paper by Kasten and Young [11] in relation to the given solar altitude angle. |

Furthermore, the atmospheric clearness, also termed sky clearness needs to be calculated. The results of this calculation are sorted into 8 discrete sky clearness categories. The data range of each of these 8 categories is given in Table 1 in the paper by Perez et al [10]. The equation for calculating the atmospheric clearness is as follows:

**(36)** $\varepsilon_{sc} = \left[ \dfrac{(I_{difhor} + I_{dnor})}{I_{difhor} + 1.041 \cdot \theta_s^3} \right] \Big/ (1 + 1.041 \cdot \theta_s^3)$ (source: [10])

***Where:***

| | | |
|---|---|---|
| $\varepsilon_{sc}$ | = | Atmospheric clearness (dimensionless) |
| $\theta_s$ | = | Solar zenith angle (radians). |

It has to be noted that the solar zenith angle needs to be in radians for equation (36) and all following equations related to lighting parameters. The discrete sky clearness categories determined with the help of equation (36) are required for selecting the appropriate coefficients needed for the calculation of the global horizontal illuminance. These coefficients are given in Table 4 of the paper by Perez et al [10]. The global horizontal illuminance can then be determined by:

**(37)** $i_{glhor} = I_{glhor} \cdot \left( a_i + b_i \cdot PWC + c_i \cdot \cos\theta_s + d_i \cdot \ln\Delta \right)$ (source: [10])

***Where:***

| | | |
|---|---|---|
| $i_{glhor}$ | = | Global horizontal illuminance (lux). |
| $a_i$ | = | Coefficient given in Table 4 of the paper by Perez et al [10]. |
| $b_i$ | = | Coefficient given in Table 4 of the paper by Perez et al [10]. |
| $c_i$ | = | Coefficient given in Table 4 of the paper by Perez et al [10]. |
| $d_i$ | = | Coefficient given in Table 4 of the paper by Perez et al [10]. |

**EPW node N17: Direct normal illuminance (lux)**

Direct normal illuminance is calculated from the future direct normal radiation determined in equation (31) based on equations derived from empirical data by Perez et al [10]. The values for the solar zenith angle, atmospheric precipitable water content and atmospheric brightness, i.e. the sky condition parameters calculated in equations (33), (34) and (35) are required for this purpose. Furthermore the appropriate coefficients given in Table 4 of the paper by Perez et al [10] need to be selected for the calculation. These coefficients which are dependent on the sky clearness category determined with equation (36) are specific to the direct normal illuminance calculation and not related to the coefficients of equation (37). Direct normal illuminance is calculated as follows:

**(38)** $i_{dnor} = \max\left\{0, I_{dnor} \cdot \left[ a_i + b_i \cdot PWC + c_i \cdot \exp\left(5.73 \cdot \theta_s - 5\right) + d_i \cdot \Delta \right]\right\}$ (source: [10])

***Where:***

| | | |
|---|---|---|
| $i_{dnor}$ | = | Direct normal illuminance (lux). |

## EPW node N18: Diffuse horizontal illuminance (lux)

Diffuse horizontal illuminance is calculated from the future diffuse horizontal radiation determined in equation (32) according to equations derived from empirical data by Perez et al [10]. The values for the sky condition parameters calculated in equations (33), (34) and (35) are required as well as the appropriate coefficients given in Table 4 of the paper by Perez et al [10]. Again, these coefficients which are dependent on the sky clearness category determined with equation (36) are specific to the diffuse horizontal illuminance calculation and not related to the coefficients of equations (37) or (38). Diffuse horizontal illuminance is calculated as follows:

**(39)** $i_{difhor} = I_{difhor} \cdot \left(a_i + b_i \cdot PWC + c_i \cdot \cos\theta_s + d_i \cdot Ln\Delta\right)$ (source: [10])

***Where:***

$i_{difhor}$ = Diffuse horizontal illuminance (lux).

## EPW node N19: Zenith luminance (Cd/m²)

The zenith luminance is calculated from the future diffuse horizontal radiation determined in equation (32) and the sky condition parameters calculated in equations (33) and (35) using a method developed by Perez et al [10]. Again, a set of coefficients specific to this equation is required. These are given in Table 4 of the paper by Perez et al and are related to the sky clearness categories calculated in equation (36).

**(40)** $L_{vz} = I_{difhor} \cdot \left[a_i + c_i \cdot \cos\theta_s + c_i^{'} \cdot \exp\left(-3 \cdot \theta_s\right) + d_i \cdot \Delta\right]$ (source: [10])

***Where:***

$L_{vz}$ = Zenith luminance (Cd/m²).

$c_i^{'}$ = Coefficient given in Table 4 of the paper by Perez et al [10].

## EPW node N20: Wind direction (degrees)

The UKCIP02 climate predictions do not contain any information on possible changes in terms of frequency or distribution of the future wind direction for a given location. Therefore, in accordance with Belcher et al [1], the wind direction of the 'present day'

CIBSE TRY / DSY data is assumed to remain unchanged and transferred to the climate change adapted weather file.

### EPW node N21: Wind speed (m/s)

The UKCIP02 data provides wind speed as a relative change to the baseline climate. Therefore, as proposed by Belcher et al [1] a stretch function is used to generate future wind speed data. The scaling factor for this stretch is calculated as follows:

**(41)** $\alpha ws_m = 1 + WIND_m / 100$ (source: [1])

***Where:***

| | | |
|---|---|---|
| $\alpha ws_m$ | = | Scaling factor for monthly wind speed change. |
| $WIND_m$ | = | UKCIP02 predicted relative change of the wind speed for the given month m (%). |

The future wind speed for a given hour is then calculated in a stretch function. Furthermore, the result of this stretch is transformed from knots to m/s by multiplying it with 0.514444 as the ‘present day’ CIBSE TRY / DSY data is given in knots and the TMY2 / EPW file convention requires m/s.

**(42)** $ws = (\alpha ws_m \cdot ws_0) \cdot 0.514444$ (source: [1])

***Where:***

| | | |
|---|---|---|
| $ws$ | = | Future wind speed (m/s). |
| $ws_0$ | = | Present day CIBSE TRY / DSY wind speed (knots). |

### EPW node N22: Total sky cover (deca)

Total sky cover denotes tenths of the sky dome covered (deca) and is given as integer values from 0 to 10. The UKCIP02 data gives the predicted future change of total sky cover as absolute values in percentage points. Therefore, a shift function is used for generating future time series as suggested by Belcher et al [1]. However, in order to suit the TMY2 / EPW file convention the UKCIP02 data needs to be converted into tenths of sky covered. Furthermore, the ‘present day’ CIBSE TRY / DSY data is give as eighth of the sky covered (octa), i.e.

requires multiplication with 1.25 to obtain tenths of sky covered. The equation for generating the future cloud cover is as follows:

**(43)** $$cc = \max\left\{0, \min\left[10, \left(cc_0 \cdot 1.25\right) + \frac{\Delta TCLW_m}{10}\right]\right\}$$

***Where:***

| | | |
|---|---|---|
| $cc_0$ | = | Present day CIBSE TRY / DSY cloud cover (octa). |
| $\Delta TCLW_m$ | = | UKCIP02 predicted absolute change of the mean total cloud in long wave radiation for the given month m (% points). |

The result of equation (43) is then rounded to the nearest integer. In case the value is lower than 0 or exceeds 10 it is set to equal to 0 or 10 respectively.

**EPW node N23: Opaque sky cover (deca)**

Opaque sky cover denotes the amount of sky dome covered by clouds that do not permit observing the sky at higher levels and is again given in tenths of the sky dome covered (deca). Therefore, the value for opaque sky cover is either smaller or equal to total sky cover. As the CIBSE TRY / DSY data does not provide any information on opaque sky cover the approach has been taken to assume opaque sky cover as being half the value of total sky cover. This approach is crude, yet appears to have been used for a number of TMY2 / EPW files.

**EPW nodes N24 to N31**

All EPW nodes from N24 to N31 have been classified as missing data, the reasons being as follows:

- The nodes N24 'Visibility' and N25 'Ceiling height' are not relevant to building performance simulation and have therefore not been considered. In addition, no appropriate calculation routines could be identified for deriving these parameters from known data.
- The nodes N26 'Present weather observation' and N27 'Present weather code' denote physical observation particularities such as snow, fog or type of rain. As the climate change adapted TMY2 / EPW weather data is calculated data, such information cannot be provided. Therefore, the fields must be classified as missing data.

- As the ‘present day’ CIBSE TRY / DSY data does not give any information on rainfall, node N28 ‘Precipitable water’ has to be classified as missing data. In addition, rainfall information will not be relevant for most building performance simulation applications.
- The node N29 ‘Aerosol optical depth’ relates to the transparency of the atmosphere in view of aerosols present in the air. Whilst there are a range of different calculation approaches for determining aerosol optical depth [12, 13], these are complex, often require information not readily available in the CIBSE TMY2 / EPW data or relate to specific sky conditions. Therefore, in accordance with the commercial weather file generation package Meteonorm [9], it was decided to classify node N29 as missing data.
- As no precipitation information is available in the ‘present day’ CIBSE DSY / TRY data, the nodes N30 ‘Snow depth´ and N31 ‘Days since last snowfall’ cannot be specified and are classified as missing data. In addition, this information will not be relevant for most building performance simulation applications.

# 2 CCWorldWeatherGen Calculation Methods

**Equations for climate change adaptation of present day weather data for worldwide locations with HadCM3 predictions where these differ from Section 1**

The procedures for transforming hourly ‘present day’ EPW weather data into climate change adapted weather data with the HadCM3 climate change predictions largely follow the methods described in Section 1 for the UKCIP02 data. The list below provides the equations for parameters where alternative methods to the ones given in Section 1 were used for ‘morphing’ EPW weather files with HadCM3 data. The CCWorldWeatherGen tool can be downloaded from www.energy.soton.ac.uk/ccworldweathergen

### EPW node N7: Dew point temperature (°C)

Unlike CIBSE TRY / DSY files which contain information on the wet bulb temperature, EPW files contain relative humidity and dew point temperature data. Therefore, equations (4) to (10) of Section 1 are not needed. The required future partial pressure of water vapour can be derived directly from the calculated future relative humidity and the saturation pressure of water vapour at the future dry bulb temperature using a transposed version of equation (13) of Section 1:

**(1)** $$p_w = \Phi \cdot p_{ws}^{'} \Big|_{dbt, p_{at}}$$ (source: [6])

***Where:***

| | | |
|---|---|---|
| $p_w$ | = | Future partial pressure of water vapour (kPa). |
| $\Phi$ | = | Future relative humidity (%). |
| $p_{ws}^{'}$ | = | Saturation pressure of water vapour in the absence of air at a given temperature numerically equal to the dry bulb temperature of the air being considered (kPa). Values are taken from Table 3 provided in Chapter 6 of the ASHRAE handbook [6]. |
| $\Big\|_{dbt, p_{at}}$ | = | At a given dry bulb temperature and atmospheric pressure. |

Once the future partial pressure of water vapour has been calculated using equation (1) above, equations (11) and (12) of Section 1 can be used to determine the future dew point temperature.

## EPW node N8: Relative humidity (%)

As EPW files contain relative humidity information, equation (14) of Section 1 can be used directly with the HadCM3 predicted absolute change of the mean relative humidity for the given month. Equation (13) of Section 1 is not required.

## EPW node N10: Extraterrestrial horizontal radiation (Wh/m²)

Instead of selecting the midpoint of the current hour node for calculating the extraterrestrial horizontal radiation as discussed in Section 1, the extraterrestrial horizontal radiation is calculated for each minute of the hour and the mean radiation derived from this.

## EPW node N13: Global horizontal radiation (Wh/m²)

Using tabulated long term average monthly totals for global horizontal radiation as given in Table 1.1 in Section 1 for the CIBSE TRY / DSY weather stations is not practical for worldwide locations. Therefore the monthly totals of the underlying EPW file for the data 'morphing' are used instead in equation (28) of Section 1.

## EPW node N15: Diffuse horizontal radiation (Wh/m²)

Rather than assuming changes in diffuse horizontal radiation being proportional to changes in global horizontal radiation as discussed in section 1, for the CCWorldWeatherGen tool the model developed by Boland, Ridley and Lauret [14] is used for calculating the future diffuse horizontal radiation. In a first step this method requires calculation of the hourly clearness index which is derived from the future global horizontal radiation and extraterrestrial horizontal radiation as follows:

**(2)** $$KT_h = \frac{I_{glhor}}{I_{exhor}}$$ (source: [14])

***Where:***

$KT_h$ = Hourly clearness index (dimensionless).

$I_{glhor}$ = Future global horizontal radiation (Wh/m²).

$I_{exhor}$ = Extraterrestrial horizontal radiation (Wh/m²).

In addition to the hourly clearness index, the daily clearness index is required which is determined by using the hourly values of the respective day:

**(3)** $$KT_d = \frac{\sum_{h=1}^{24} \cdot I_{glhor}}{\sum_{h=1}^{24} \cdot I_{exhor}}$$ (source: [14])

***Where:***

$KT_d$ = Daily clearness index (dimensionless).

Persistence to address the lag and lead of the clearness index is accounted for as follows:

**(4)** $$\psi = \begin{cases} \frac{KT_{h-1} + KT_{h+1}}{2} sunrise < h < sunset \\ KT_{h+1} \qquad h = sunrise \\ KT_{h-1} \qquad h = sunset \end{cases}$$ (source: [14])

***Where:***

$\psi$ = Clearness index persistence (dimensionless).

Using the solar time and the solar altitude angle as calculated in equations (18) and (21) in section 1 above, the diffuse horizontal radiation can then be calculated as follows:

**(5)** $$I_{difhor} = I_{glhor} \cdot \frac{1}{1 + \exp(-5.38 + 6.63 KT_h + 0.006 SOT - 0.007 \gamma_s + 1.75 KT_d + 1.31 \psi)}$$ (source: [14])

***Where:***

$I_{difhor}$ = Future diffuse horizontal radiation (Wh/m²).

$SOT$ = Solar time (h).

$\gamma_s$ = Solar altitude angle (degrees).

**EPW node N23: Opaque sky cover (deca)**

Opaque sky cover denotes the amount of sky dome covered by clouds that do not permit observing the sky at higher levels and is given in tenths of the sky dome covered (deca). Whilst the CIBSE TRY / DSY data does not give any information on opaque sky cover, it is provided in EPW files. Therefore, the crude approach to assume opaque sky cover as being half the value of total sky cover which was previously used for ‘morphing’ CIBSE TRY /

DSY data was not followed. Instead, it was assumed that the relation between total sky cover and opaque sky cover remains the same under a changed climate. Therefore, the equation for generating future opaque sky cover is as follows:

**(6)** $occ = \dfrac{cc \cdot occ_0}{cc_0}$

***Where:***

| | | |
|---|---|---|
| $occ$ | = | Future opaque sky cover (deca). |
| $cc$ | = | Future cloud cover (deca). |
| $occ_0$ | = | Present day EPW opaque sky cover (deca). |
| $cc_0$ | = | Present day EPW cloud cover (deca). |

**EPW node N28: Precipitable water (mm)**

Unlike CIBSE TRY / DSY files which do not contain any rainfall information, this information is given in some EPW files, depending on the data source. The HadCM3 data provides precipitation as a relative change to the baseline climate. Therefore, as proposed by Belcher et al [1] a stretch function is used to generate future precipitation data. The scaling factor for this stretch is calculated as follows:

**(7)** $\alpha rr_m = 1 + PREC_m / 100$ (source: [1])

***Where:***

| | | |
|---|---|---|
| $\alpha rr_m$ | = | Scaling factor for monthly precipitation change. |
| $PREC_m$ | = | HadCM3 predicted relative change of the precipitation rate for the given month m (%). |

The future precipitation for a given hour is then calculated in a stretch function:

**(8)** $rr = (\alpha rr_m \cdot rr_0)$ (source: [1])

***Where:***

| | | |
|---|---|---|
| $rr$ | = | Future precipitable water (mm). |
| $rr_0$ | = | Present day EPW precipitable water (mm). |

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