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# Overheating risk of UK dwellings under a changing climate

Chunde Liu[a],*, David Coley[a]

[a]*University of Bath, Bath, BA2 7AY, United Kingdom*

**Abstract**

Building practitioners assess the overheating risk of buildings via dynamic thermal comfort simulation with hotter than average reference weather years. In the UK, the near-extreme hot summer years called Design Summer Years (DSY) offered by the Chartered Institute of Building Services Engineers (CIBSE) are provided for fourteen locations for the purpose of estimating overheating risk of naturally ventilated buildings. The current DSY is selected based on the third warmest mean summer dry bulb temperature (DryT) during April to September. However, it has been proved that the simple method used for creating DSY leads to obvious problems into the thermal comfort simulations. In this research, a new design summer year termed as a Hot Summer Year (HSY) is created based on weather data generated from the UK Climate Projections weather generator and the Physiological Equivalent Temperature (PET). The effects of using the DSY and the HSY on indoor thermal comfort are analyzed based on a static overheating risk criterion recommended by CIBSE. With the aim of predicting future overheating risk, future HSYs are created for 2050s and 2080s under the high emission scenario for fourteen locations. These are created to investigate overheating risk of dwellings across the UK.


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*Keywords:* climate change, Hot Summer Year, overheating risk

## 1. Introduction

The global surface temperature has been on the rise since past decades. Intergovernmental Panel on Climate Change (IPCC) projected that the likely range of the global average surface warming under A1FI emission scenario is 2.4°C to 6.4°C (best estimation is 4°C) at the end of 21st century and the temperature will increase much greater over the high-latitude of the Northern Hemisphere[1]. The issue of the overheating risk has raised public concern. According to the Earth Policy Institute report [2], the European Heat Wave in 2003 caused more than 52,000 heat-related deaths including 900 deaths in London and 14,800 deaths in Paris. CIBSE provides DSYs (available for fourteen UK sites) for overheating risk assessment. In order to estimate the overheating risk of naturally ventilated buildings, a suitable

* Corresponding author. Tel.: +44-757-725-7812
*E-mail address:* cl717@bath.ac.uk


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weather file is required for thermal comfort simulation. The DSYs have been selected from typically 22 years of measured complete weather data based on the third warmest mean dry bulb temperature (DryT) during April to September. However, there are several limitations in this simple selection method [3]. For example, there are insufficient number of years with a complete weather data for selecting DSYs in several UK sites. Recently, new DSYs have been created based on the weather data generated by UKCP09 weather generator [13] rather than measured weather data. As each running of UKCP09 weather generator can produce one hundred sets of 30-year period weather data, one hundred DSYs can be created. These one hundred DSYs are ranked based on single weather variable e.g. the mean summer dry bulb temperature or solar radiation or relative humidity and then a new DSY is obtained with required percentile [4] [5] [6]. Furthermore, future DSY can be created since the UKCP09 weather generator can produce future weather data. The thermal comfort is affected by the combination of various thermally relevant climate parameters rather than single one. In this study, therefore, these one hundred DSYs were ranked based on Physiological Equivalent Temperature (PET) which considers multi-weather variables e.g. air temperature, wind speed, solar radiation and relative humidity. PET is defined as the equivalent air temperature in a standardized indoor environment and for a standardized human [7]. The new DSY is termed as Hot Summer Year (HSY). EnergyPlus which has been validated and widely used in building simulation is used for overheating risk predictions. In addition, naturally ventilated semi-detached house, one of the most common UK dwellings is selected for thermal modelling. Overheating risk in the first floor main bedroom is assessed based on the static overheating criterion recommended by CIBSE Guide A [8]. Though there are some arguments against this criterion, it is normally used as a primary one for overheating risk assessment of the UK dwellings. The current and future overheating risk of naturally ventilated buildings in fourteen UK locations are calculated using HSY.

## 2. Creation of Hot Summer Years (HSY)

### *2.1. The weather generator*

As mentioned above, DSYs were created base on around 20 years (typically 1983-2004) of observed weather data. For HSY, calculated weather data from UKCP09 weather generator are used instead of observed ones. UKCP09 weather generator which was developed by Centre for Earth Systems Engineering Research at University of Newcastle is based on the stochastic rainfall model. It takes precipitation sequence as a primary variable whereas other variables can be calculated from it by maintaining the inter-variable relationships with rainfall. The control year (1961-1990) weather data agrees well with the observations since the observed weather data was used to calibrate the UKCP09 weather generator. UKCP09 climate change projections have been incorporated into the outputs of UKCP09 weather generator. Thus, it can produce not only control year but also future year (time periods from 2020s to 2080s) daily/hourly weather data under three different emission scenarios presented in the IPCC Special Report on Emissions Scenarios (SRES). Three levels are low, medium and high corresponding to SRES B1, SRES A1B and SRES A1FI respectively. For each time period, UKCP09 weather generator produces one hundred sets of 30-year sample weather data. In addition, it can produce weather data at a spatial resolution of 5 km, which makes it possible to create HSY with same resolution to do location-dependent overheating risk assessment. In this research, UKCP09 weather generator runs three times for each of fourteen UK locations for control year as well as two future time periods i.e. 2050s and 2080s under high emission scenario which is the worst emission scenarios since the actual average global temperature could be much higher than the previous projection under SRES A1FI with the current climate change mitigation efforts [8].

### *2.2. Physiological Equivalent Temperature (PET)*

PET is equivalent to the air temperature at which the heat of a standardized person is balanced in a typical indoor environment. The thermo-physiological heat balance model ‘Munich Energy Balance Model for Individuals (MEMI)’ is the basis for the PET calculation. PET is assumed to be suitable for applying to both outdoor and indoor thermal comfort analysis [7]. It is a thermal index which includes the integral effects of thermally relevant weather variables such as air temperature, relative humidity, wind speed and global solar radiation. The new German guidelines for urban and regional planners recommends to use PET as one of the thermal indices due to its advantages over other biometeorological indices such as wind chill, apparent temperature and heat stress index. HSY was created based on the weather data from UKCP09 weather generator combined with PET. The freely available RanMan software provided by Matzarakis from University of Freiburg in Germany is used to calculate PET. The methodology for creating HSY is as follows.

One hundred sets of 30-year period of weather data are offered by UKCP09 weather generator for a given location. Control year weather data are produced for comparing HSY with the DSY, while future year weather data are produced to create future HSY for the purpose of predicting overheating risk of UK dwellings under a changing climate. Second, since the UKCP09 weather generator only produces nine daily weather variables and seven hourly weather variables which are much fewer than required for standard building simulation weather files, the missing weather variables were calculated according to the equations in CIBSE Guide J [10]. In particular, the method presented by Eames *et al* [11] was used for calculating wind speed and wind direction. In fact, most of the missing weather variables e.g. ground temperature, dew point temperature and solar radiation, can be calculated using correlative weather variables generated by UKCP09 weather generator. Third, three thousands of complete weather years were constructed from UKCP09 weather generator outputs and calculated missing weather variables. One hundred of DSYs were generated from three thousands of complete weather years by the same method used in the DSY; then they were converted into the standard format of building simulation weather files i.e. EPW file. Fourth, hourly PET was calculated via running RayMan software with RayMan input files generated from one hundred DSYs; then mean summer PET of each DSY was calculated. One hundred DSYs were ranked based on the ascending order of mean summer PET. Last, HSY was obtained by selecting the DSY with the highest mean summer PET.

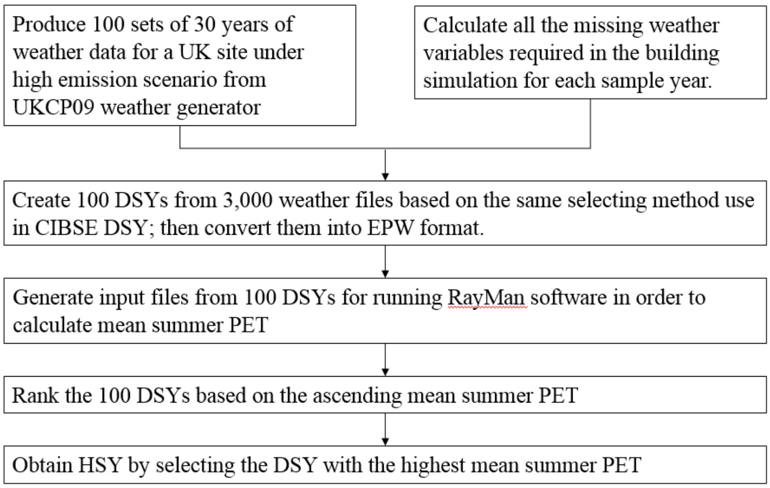



Figure 1 Diagram of creating HSY based on the UKCP09 weather generator and RayMan software

## 3. Mean summer outdoor temperature

Mean summer DryT is calculated from DSY and control year HSY for fourteen UK locations. Then, the difference between DSY and control year HSY is analyzed in terms of mean summer DryT. Furthermore, current values are compared with the future ones which incorporate the information of UKCP09 climate change projections.

As can be seen in Figure 2, most of the locations show mean summer DryT in DSY is slightly higher than the one in HSY except for Newcastle, Nottingham, Plymouth, Southampton and Swindon. In fact, the absolute difference is no more than 1°C except for Leeds (1.3°C). For both DSY and HSY, Heathrow shows the highest mean summer DryT whereas Belfast shows the lowest value. For DSY, the difference of mean summer DryT between Heathrow and Belfast is around 4°C, for HSY it is around 3.5°C. According to the comparison, HSY is consistent with the one from DSY in terms of the mean summer DryT. Furthermore, mean summer DryT for both DSY and HSY shows below the 19°C, which is unlikely to cause high mean indoor temperature during summer.

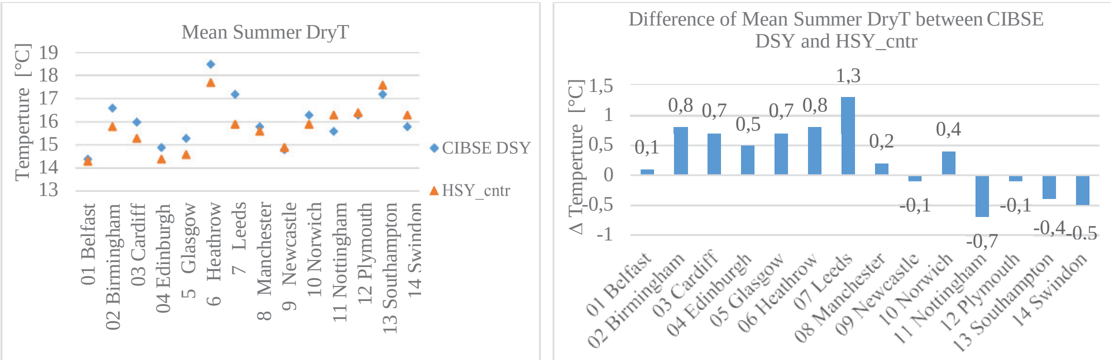
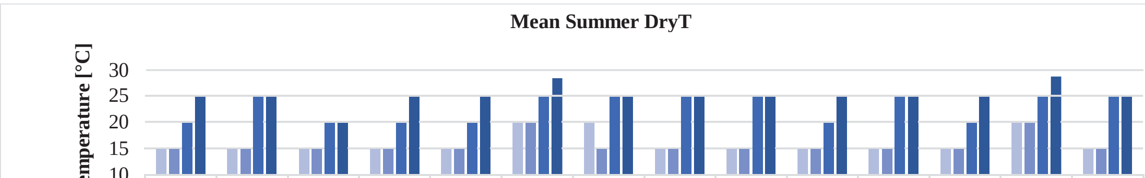



Figure 2 Mean summer DryT difference between CIBSE DSY and control year HSY for fourteen UK locations

In Figure 3, the mean summer DryT from future HSY is apparently increased for all of the fourteen UK locations relative to current years i.e. DSY and control year HSY. According to the absolute difference of mean summer DryT between current year and future years, mean summer DryT increases up to 8.4°C (Southampton) in 2050s and 11.9°C (Birmingham) in 2080s respectively. In 2050s, mean summer DryT is overall higher than 20°C except Belfast (19.7°C), Cardiff (17.3C), Edinburgh (18.5°C) and Norwich (19.5°C). In 2080s, Birmingham, Heathrow, Southampton and Swindon see the highest mean summer DryT greater than 27°C.




| | 01 Belfast | 02 Birmingham | 03 Cardiff | 04 Edinburgh | 05 Glasgow | 06 Heathrow | 07 Leeds | 08 Manchester | 09 Newcastle | 10 Norwich | 11 Nottingham | 12 Plymouth | 13 Southampton | 14 Swindon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CIBSE DSY | 14,4 | 16,6 | 16 | 14,9 | 15,3 | 18,5 | 17,2 | 15,8 | 14,8 | 16,3 | 15,6 | 16,3 | 17,2 | 15,8 |
| HSY_cntr | 14,3 | 15,8 | 15,3 | 14,4 | 14,6 | 17,7 | 15,9 | 15,6 | 14,9 | 15,9 | 16,3 | 16,4 | 17,6 | 16,3 |
| HSY_2050s | 19,7 | 22,7 | 17,3 | 18,5 | 20,6 | 25 | 22,5 | 22,5 | 21,3 | 19,5 | 23,6 | 20,8 | 26 | 23,2 |
| HSY_2080s | 21,6 | 27,7 | 19,6 | 24,1 | 23,3 | 28,5 | 25,9 | 26,4 | 25,24 | 25,6 | 25,3 | 24,4 | 28,8 | 27,2 |

Figure 3 Comparison of mean summer DryT between current and future years

## 4. Overheating risk prediction for UK Dwellings

### *4.1. Thermal modelling for the existing typical UK dwelling*

There are five main types of dwellings in the UK which are detached house, semi-detached house, terraced house, bungalow and flat. Semi-detached house which has two blocks with one side attached to each other is selected since it is the most common type according the English Housing Survey Headline Report 2012-13. The dimension, construction and thermal properties of this model are defined according to the Building Environmental Performance Analysis Club (BEPAC) Technical Note 90/2 [12]. This is a naturally ventilated dwelling with south facing orientation and is assumed unshaded by surroundings as shown in Figure 4. EnergyPlus, a validated building energy modelling program produced by US Department of Energy is used to do dynamic thermal comfort simulation with DSYs and HSYs. The main bedroom in the first floor is supposed to gain the most solar radiation in that it is facing south and has a large single glazing window. Thus, this room is likely to be under higher risk of overheating than other rooms. Overheating risk is assessed according to the static criterion from CIBSE Guide A [8]. For the bedrooms, the percentage of annual occupied hours with operative temperature above 26 °C should be no more than 1%.

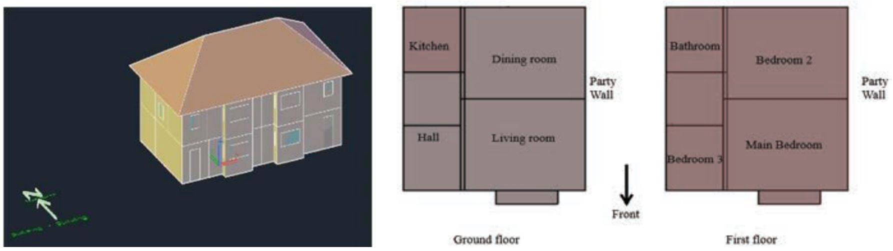



Figure 4 Semi-detached house model

*4.2. Results and discussion*

Figure 5 shows that overheating occurs in Heathrow (1.37%) and Leeds (1.02%) when DSY is used in dynamic thermal comfort simulations but no overheating happens when the control year HSY is applied. In addition, overheating risk resulted by DSY is slightly higher than the one resulted by control year HSY for most of the locations except Glasgow, Newcastle, Nottingham and Swindon. As the static overheating assessment criterion considers hourly discomfort temperatures, it indicates that there would be variations in hourly DryT between the weather data used for DSY and HSY. In addition, the difference of overheating risk might partially arise from the different sources of weather data used for creating DSY and HSY. Moreover, the new approach for creating HSY might make the resultant overheating risk different from that resulted by DSY.

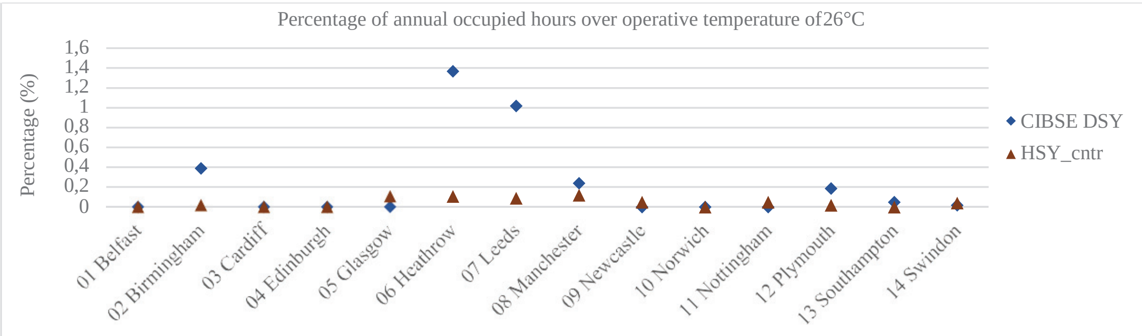
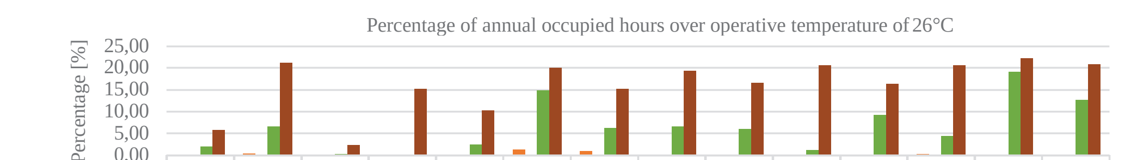



Figure 5 Overheating risk caused by CIBSE DSY and control year HSY

In addition, the overheating risk increases significantly in future year. According to the results of overheating risk shown in Figure 6, for 2050s HSY, although most of the locations exceeds 1% of occupied hours with operative temperature above 26 °C, Cardiff (0.17%) and Edinburgh (0.26%) are under lower risk of overheating compared to other locations. For 2080s, however, all of fourteen UK sites exceed the recommended overheating risk criterion. Birmingham, Heathrow, Plymouth, Southampton and Swindon are under the highest overheating risk. The percentage of overheated hours is greater than 20% of annual occupied hours indicating that it is likely to lead to heat related mortality if no appropriate adaptations are applied to the existing dwellings.

## 5. Conclusion

HSYs for fourteen UK sites have been created based on weather data produced by UKCP09 weather generator and the mean summer PET to predict overheating risk of naturally ventilated buildings during April to September. The mean summer DryT is calculated from DSY and HSY respectively. According to the comparison, there is little difference of mean summer DryT (less than 1°C) between DSY and HSY. However, the resultant overheating predictions from control year HSY are different from the ones from DSY for most of the cities particularly for Heathrow and Leeds. In addition, under a changing climate, most of the locations exceeded the static overheating risk criterion recommended by CIBSE Guide A [8]. As the climate warms, the change of overheating risk in Belfast and Cardiff is smaller than any other locations. In short, in order to assure a comfortable indoor environment against climate change, the appropriate and sustainable adaptation is necessary for the UK dwellings. Orientation and the obstruction around the buildings will be taken into consideration in the future work as they might have an important impact on realistic overheating risk. In addition, indoor PET will be calculated as it is also suitable for assessing the indoor thermal comfort.




| | 1.Belfast | 2.Birmingham | 3.Cardiff | 4.Edinburgh | 5.Glasgow | 6.Heathrow | 7.Leeds | 8.Manchester | 9.Newcastle | 10.Norwich | 11.Nottingham | 12.Plymouth | 13.Southampton | 14.Swindon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CIBSE DSY | 0,00 | 0,39 | 0,00 | 0,00 | 0,00 | 1,37 | 1,02 | 0,24 | 0,00 | 0,00 | 0,00 | 0,19 | 0,05 | 0,02 |
| cntr_HSY | 0,00 | 0,02 | 0,00 | 0,00 | 0,11 | 0,11 | 0,09 | 0,12 | 0,05 | 0,00 | 0,05 | 0,02 | 0,00 | 0,04 |
| 2050s_HSY | 2,08 | 6,58 | 0,17 | 0,26 | 2,44 | 14,91 | 6,30 | 6,65 | 6,01 | 1,25 | 9,35 | 4,50 | 19,17 | 12,67 |
| 2080s_HSY | 5,82 | 21,25 | 2,27 | 15,24 | 10,34 | 20,07 | 15,24 | 19,32 | 16,59 | 20,65 | 16,41 | 20,66 | 22,29 | 20,87 |

Figure 6 Comparison of overheating of UK dwellings between fourteen UK locations for current and future time periods

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