An update of the UK's test reference year: The implications of a revised climate on building design.

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Abstract

Average weather years have been used around the world for testing buildings to ascertain their likely energy use using thermal modelling software. In the UK, the Test Reference Years which are in current use were released in 2006 but generally consisted of data from 1983 to 2004. In this work, revised test reference years will be proposed which are based on a new climatic period from 1984 to 2013. The differences between the two years will be highlighted and the implications for building design will be discussed.

Practical Application

Test Reference years are integral to building design to assess the performance of buildings at design stage. Specifically they are used to assess energy use in buildings as well as for compliance purposes with Part L of the Building Regulations.

Keywords: Test Reference Year, building design, weather data, energy use

Introduction

Typical weather years are widely used by professionals to assess the performance of buildings at design stage using thermal modelling software. The weather files are essential in the development of passive, energy efficient buildings that are also resilient to current and future changes in climate and extreme weather events. In Europe these typical reference years usually take the form of Test Reference Years (TRYs) such as those used in the United Kingdom[1] or Germany[2], Typical Meteorological Years in America[3] and Design Reference Years in Denmark[4]. Each file type contains an hourly time series of important weather variables which are relevant to building simulation. Each reference year has been sorted from a multiyear weather series using statistical methods with Finkelstein-Schafer statistics[5] the most common.

There are a number of methods for generating the most average weather files with the most common being the Sandia method[3] and the ISO method[6]. The Sandia method selects a typical month based on nine daily indices consisting of the maximum, minimum, and the mean dry bulb and dew point temperatures; the maximum and mean wind velocity; and the total global horizontal solar radiation. The ISO method is much simpler and considers three primary daily indices consisting of the mean dry bulb temperature, total global horizontal radiation and mean relative humidity with wind speed considered as a secondary variable. Previously in the UK a slight modification was made to the ISO method considering mean wind speed as a primary variable rather than relative humidity[7].

In the UK the TRY has long been established for the determination of average energy usage in building design. Previous research has found the underlying method to be robust at producing the average energy use over the climate from which the reference year was produced. Kershaw et al.[8] modelled the baseline weather series and the generated TRY for two locations and 15 building types including schools, various housing types and offices. It was found that in general the TRY produces the representative average for a range of building types and any location. Further work[9] showed that the methodology could produce weather files which generated the average energy use from the thousands of weather years from the UKCP09 weather generator. Similarly Jentsch et al.[10] found that the TRY mean monthly temperature sits within the centre of the long-term data as would be expected.

Whilst it is clear that the TRYs are representative of their baseline data for each location, the current datasets are developed based on the baseline 1984 to 2004, which does not include the more recent representations of the changing climate. The use of past weather is common place for assessing buildings. However, using weather derived from a series where the most recent data is from over a decade old is questionable. It is therefore necessary to update the TRYs to a more recent baseline to reflect observed changes in the climate and therefore better represent the UK weather. In this work new TRYs will be presented to replace the set released in 2006. The method for creating updated TRYs will briefly be described, the new base line data and cleaning algorithms will be presented and the implications of the new data sets on the built environment will be discussed.

Method for creating new Test Reference Years

The method for selecting candidate months for the TRY has long been established and as described above the method has been found to be robust[8–10]. Although the method is detailed formally elsewhere[1,6], for completeness the method will be briefly described.

The most average months that are used within the weather file are those whose weather patterns are closest to the long term trend over the observation period. The most average months are chosen using the FS statistic to compare the cumulative distribution functions of the daily mean values determined from the hourly weather parameters[5]. The FS statistic sums the absolute difference between the values for each day in an individual month's cumulative distribution function and the overall cumulative distribution function for all the months considered for a weather variable given by,

$$\mathrm{FS}_{m,y} = \sum_{i=1}^{N_m} \left| \mathrm{CDF}_{i,m,y} - \mathrm{CDF}_{i,m,N_y} \right| , \qquad (1)$$

where $\mathrm{FS}_{m,y}$ is the FS statistic for month *m* in year *y*, $\mathrm{CDF}_{i,m,y}$ is the cumulative distribution function for month *m* in year *y* and day *i*, and $\mathrm{CDF}_{i,m,Ny}$ is the cumulative distribution function for month *m,* and day *I,* over all years N_y.

The months with the smallest overall FS statistic are chosen as the most average. The Finkelstein-Schafer statistic is a method which compares the cumulative distribution for a given weather variable and a given month with the cumulative distribution for the whole data series for the same weather variable. The most average month is then chosen to represent the data series. The Finkelstein-Schafer statistical method is superior to using just means alone to choose the most average months as it chooses months with less extreme values that have a cumulative distribution function closer to that of all the years considered. Hence, the average month chosen using the Finkelstein-Schafer statistic can be considered representative of all the years. This process is followed for each month of the year for each parameter in turn. For each month, *i*, the candidate, most average months for the TRY are assessed from the sum, $\mathrm{FS}_{m,y}$, from their FS statistics, FS_i , to give a weighted index for selection combining all weather parameters which have been determined as important for building simulation, given by

$$\mathrm{FS}_{sum,i} = w_1 FS_1 + w_2 FS_2 + w_3 FS_3 + \cdots , \qquad (2)$$

where w_1, w_2 and w_3 are the weighting factors and FS_1 , FS_2 and FS_3 are the respective FS statistics for weather parameters 1, 2 and 3. The weighting factors add up to unity and the exact values are chosen depending on each parameter's relative importance. As the candidate month with the lowest FS_{sum} for one variable might not have the lowest FS for another the sum is taken. The most average month is the one with the lowest FS_{sum}, and hence the most average for all the weather parameters considered. This is done for each month of the year in turn. The ISO selects the representative months using air temperature, humidity, and solar radiation with wind speed as a secondary parameter[6]. Here this ISO method is applied to the observed data where by the primary variables are used to find the three months with the lowest ranking. The month with the lowest FS statistic for the wind speed is then chosen as the representative month for that location. For the TRY files created for the UK, the weighting factors for the primary weather parameters are identical and set to 1/3.

Revised observations and Test Reference Years

The original baseline dataset used for generating the TRYs was not complete and varied between locations[7]. Using updated observations does not solve this problem and the number of complete years used for the analysis was complicated by the availability of data at many weather stations. The original baseline and the updated baseline locations and duration of the observed period at that location are displayed in Table 1. For some locations such as Edinburgh and Glasgow the original baseline was from 1978 to 1999 as the weather stations stopped recording data after this point. In this case data from a slightly earlier period was required to produce the requisite number of years for the analysis. For Leeds the baseline was from 1985 to 2001 due to the limited lifetime of the weather station. Other locations such as Manchester and Norwich the weather stations have since stopped recording.

The analysis and reference year creation was further restricted by the availability of data with many months missing. For some locations such as Birmingham, Nottingham, Southampton and Swindon very few complete years were available with July often missing[7,11]. Again, updating the weather baseline to more recent observations (1984-2013) is not immune to such problems. The same issues were found during the update of design data presented in CIBSE guide A[12]. In this analysis a similar approach will be taken to compile the required observations. To ensure enough data is available for the analysis of design weather conditions, new sites are combined with the original locations where appropriate. For example, observations from Glasgow Bishopton are included into the analysis after April 1999 and Edinburgh Gogarbank is included after December 1998. For Leeds, Church Fenton is added to the observed data but due to the number of incomplete months, Leeds Weather Centre has been included for the period 1989-2002 whereas guide A used Church Fenton only[12]. For Swindon, the original weather station was placed at Boscombe down. Brize Norton weather station is approximately 68 km north of the Boscombe Down but is only approximately 27 km north east of Swindon. However Brize Norton weather station has a much more complete dataset with only 49 missing hours over the whole time period compared to 18545 hours for Boscombe down (10% of the total) which would lead to many missing months. A robust solution is to use Brize Norton weather station for this analysis. Similarly for Southampton and Norwich, the observations are now sourced from Hurn and Marham respectively.

Updating the observation dataset and including new weather station data does not solve all issues with data availability and the observations will still not be complete. Like previous work, missing data is interpolated where appropriate[1]. If more than 20 % of the month is missing for any variable then the month is considered invalid and removed. However, if for a given month, the weather is recorded on a bihourly basis, this data is interpolated to ensure a large selection of months is available for the analysis[6] – contiguous months are much more important than contiguous years for this analysis. The maximum number of consecutive missing hours is 60 which is equivalent to two and half days to ensure that a valid time series is produced which do not allow large blocks of missing data. Where missing data is interpolated, a linear interpolation algorithm is used for wind speed, wind direction (rounded to the nearest 10 degrees) and cloud cover (rounded to the nearest Okta). Air pressure, dry bulb temperature and wet bulb temperature are interpolated using a cubic spline algorithm. In the case of temperature an extra algorithm is used to linearly interpolate the daily maximum and minimum temperature and the time of the occurrence using valid maxima and minima either side of the gap. These interpolated points are included in the overall spline interpolation algorithm.

The revised TRY months are listed in table 2. Despite a slight change in the methodology to select the new TRY months and an updated baseline, there are a few instances of repeated months with a maximum of four for Birmingham and three for Manchester i.e. a month which was average from the 1983 – 2004 baseline remains average for the 1984 – 2013 baseline. For Norwich, Swindon and

Southampton such comparisons are less meaningful as the baseline data set for all years has been sourced from a new location. For all locations the average of the selected months is six years further into the future than the original dataset with a maximum of 15.5 years for Southampton and a minimum of -3.75 years for Newcastle. For locations such as Edinburgh (14.5 years), Glasgow (8.4) and Southampton (15.5) the difference in the average of the year of the month selected reflects the change from the original baseline starting at 1978 which is five years earlier than most other locations.

Comparison of the new Test Reference Years temperature characteristics

The external temperature is the primary driver for the amount of energy a building will use when occupied, so this section will examine differences in the key temperature characteristics. This work concerns the implications of a change in the TRY weather files which consist of the most average months in the dataset. As such, the discussion of extremes within the data is outside the scope of this work. Mean temperatures for key percentile ranges for all locations with both the original and updated TRYs are listed in table 3. Table 3 lists the mean temperature of all temperatures cooler than the 10th percentile and mean temperature of all temperatures warmer than the 90th percentile to demonstrate the differences between the extremes of the two temperature distributions and the mean of the 10th to 90th percentile to show the mean temperature excluding the extremes. The mean temperature excluding the extremes (between the 10th and 90th percentiles) is very similar for all locations and the absolute difference between the original and new TRYs is less than 0.5°C. For the lower tail of the distribution (less than the 10th percentile) nine of the locations have an absolute difference greater than 0.5°C with most updated TRYs cooler than the original. The upper tail is much more similar for both distributions with only five locations having an absolute difference greater than 0.5°C and there is an even split between locations which are warmer and cooler after the update. Even though some temperature distributions for some location appear similar it is found that statistically Glasgow is the only location where the distributions of the original and updated temperatures are from the same continuous distribution using a two sample Kolmogorov-Smirnov test at the 5% significance level showing that there are significant differences between all locations which need to be explored further.

Figure 1 displays the yearly mean temperature, figure 2 displays the heating degree days with a base temperature of 15 °C and figure 3 displays the cooling degree days with a base temperature of 21 °C for both the original TRYs and the updated TRYs. Although statistically the distributions of the new and original distributions are found to be different, there is little difference between the two sets of weather files for all three measures for most locations. There are six locations with an increased yearly mean temperature and eight with a reduced yearly mean temperature. The largest difference in the yearly mean temperature is found to be in Southampton at 0.6°C colder. For all other locations the difference is much smaller at 0.3°C or lower and for three locations (Cardiff, Nottingham and Plymouth) there is no change. For all locations there is little difference between the heating degree days of both data sets with an average increase of 28 degree days. The largest changes are found for Southampton (+10%), Newcastle (+5%), Leeds (+4%) and Edinburgh (-4%). Similarly there is little difference between the cooling degree days for both data sets in terms of the absolute number with the average across all locations equal to -0.3 degree days. The largest percentage increase is found for Norwich (100%), Cardiff (45%) and Edinburgh (50%); however, this only amounts to a difference of 25, 5 and 2 cooling degree days respectively.

Some of the differences in the temperature statistics might be explained by changes in the observation locations with five locations using an additional weather station in combination with the original dataset, and three locations, Norwich, Southampton and Swindon, only data from different weather stations is used. In the case of Newcastle a new location is included to provide the most up to date observations from 2003 to 2014 at Albemarle. Albemarle is on an airfield some 17km north-west of the city in a rural setting surrounded by fields[12]. It is likely that the temperatures at Albemarle will be lower at all times of the year due to this fact which is likely to reduce the temperature of the selected months. In the case of Norwich the weather observations are now obtained from Marham. Marham is an RAF airfield 45km west of Norwich, 55km from the original weather station (Coltishall) and is 25km from the coast (Norwich is also 25km from the coast). While the mean temperature for the whole of East Anglia is between 9°C and 10.5°C[12], for which both the new and current TRYs sit towards the upper end of this range, the updated TRY has a slightly warmer summer and could reflect a change in the underlying weather at this new location.

Comparison of energy use within buildings using the new Test Reference Years

From figures 1, 2 and 3 it would seem unlikely that a building design will be largely perturbed by an update in the TRY weather files for most locations. However, it was found that the underlying distributions of the new weather files do not have statistically the same distribution as the original TRYs. This could have a bigger impact on building design especially where the distribution of the warm or cool events within each year has changed. It is difficult to know what the changes in the observational period and the updated weather files will make to the outputs of building thermal models and therefore design decisions without carrying out building simulation for a vast number of buildings. Depending on the location, building construction and use, the weather files are likely to have very different impacts. A highly glazed construction is likely to be more susceptible to overheating during the day from solar radiation while a heavy weight construction can store that excess of heat, but in this situation, the building must be able to purge this heat at night. To investigate the impacts of the new weather files it is possible to generate a number of standard building types and run a dynamic thermal model and compare the key output statistics such as the total energy use or occupied hours with the internal temperature above a threshold as used within CIBSE TM36[13]. This approach would be as limited as the total number of building types selected. In this study the focus has been put on dwellings; however, as many parameters representing characteristics of the buildings have been left random one could think that the results obtained here are transferable to other building types. For each building type there are also many possible building construction parameters which can be configured in many different ways. These construction parameters are not limited to the total floor area, the aspect ratio, the number of party walls, the wall construction materials, the roof construction materials, the percentage of glazing, the type of glazing, the construction and area of internal walls, the exposed surface area of the walls (external shading), internal gains and ventilation provision. It should be noted that the characteristics of the buildings have been selected such that they provide a broad set of cases with respect to the heating and cooling demand; it is for that reason that one may find the lower bound of the infiltration too low. It has been intended to represent highly efficient buildings with mechanical ventilation and heat recovery (such as a passivhaus) in which the heat loss due to infiltration is very low. In this work a single building form is considered consisting of a single story with a footprint of 100m^2 and a height of 2.8m. The underlying built form is north-south rectangular. There are 159m^2 of internal partitions but the entire building is treated as a single zone. For simplicity the zone was conditioned to maintain the room temperature to 21°C for all occupied hours with an idealised plant load so that a fair comparison could be made across the entire range of building configurations. As electrical gains pay an important role in the heat balance the annual electricity demand are varied following the distribution as suggested by the Energy Savings Trust[14]. To make sure that the time series representing the instantaneous electric load was realistic, a profile from a real dwelling was used which was monitored in the Micro CHP Acceleration project of the carbon trust[15]. Occupancy was also included in the models but metabolic gains are less influential in the heating demand. However, it is important to know when the building was occupied to model the heating and cooling schedules. As the electricity profile was taken from the real world, this profile was used to calculate the occupancy profile. Using visual inspection, it is most likely that the building is occupied during periods where the electricity consumption goes up. A threshold filter was used to derive a binary series to generate an occupancy schedule. The same profiles are used for every simulation with a total of 7116 either partly or fully occupied hours.

To compare the impacts of a large range of buildings, with varying building parameters, a large sample of the parameter space is required for a reasonable trend to be established. To represent a large proportion of buildings five parameters have been selected; the aspect ratio, the U-value of the walls, the U-value of the roof, the infiltration rate and the glazed percentage. Details of the range of the parameters are listed in table 4. The construction U-values have been approximately centred on limiting values within part L1A of the building regulations[16] as it is most likely that a new set of TRYs will be used to design new buildings with the most up to date building regulations. At the upper end of the parameter range it has been assumed that the as built building parameters may not be as good as predicted to increase the range of buildings considered. Although the range in parameters considered here is beyond what might be found in practice[17]. The building constructions are listed in table 5. The overall U-value of the roof and wall constructions is achieved by changing the thickness of the insulation layer. The U value of the floor is 0.19 $Wm^{-2}K^{-1}$. The windows are placed on all walls with a U value of 1.39$Wm^{-2}K^{-1}$ and g-value of 0.586. The glazed percentage is given as the percentage of the floor area distributed across all external walls. As thousands of buildings are required for all 14 locations, Kriging algorithms are used in R[18] to create the meta-model in this analysis. Kriging models have been shown to perform well to predict energy use in thermal building models[19]. The meta-model is designed using fifteen samples per input variable giving a total of 75 simulations generated using an optimised Latin Hypercube design[20]. From these meta-models, 10,000 buildings are then created with parameters sampled from table 4 using a uniform distribution to ensure the entire parameter space is covered.

For each building at each location, the total heating load, total cooling load (as a proxy for overheating) and the total exergy is modelled using both the original and updated weather years in Energy Plus[21]. The cooling load could be met (at least in part if not totally) by natural ventilation but this is not the focus of this work. The distribution of the percentage difference between the two weather years energy loads is displayed for the locations of Edinburgh (figure 4), London (figure 5), Manchester (figure 6) and Plymouth (figure 7). In each case a positive change implies the new weather file uses more energy and a negative change implies less energy.

In the case of Edinburgh (figure 4) a building simulation is likely to predict a design will use less energy in total. All configurations considered here are predicted to use less heating energy while most configurations will require more cooling energy to maintain the temperature to 21°C. The heating load is reflective of figure 2 which shows fewer heating degree hours. Figure 4 shows that the change in cooling load is small (near zero) but increased for many configurations. This is contrary to table 1 which shows that the original TRY has a more extreme tail. On closer inspection, the revised weather file has on average a lower coincident cloud cover for hours on which the temperature is greater than 21°C which would contribute to the cooling load. In all cases in absolute terms, the change in the predicted cooling load is small.

The updated London weather file shows that the cooling energy would be expected to increase for all building configurations (figure 5). The cooling energy dominates the total energy usage with the correlation between cooling energy and total energy being approximately linear ($R^2=0.85$). The heating load is distributed around a small decrease but the absolute change is small (between -2% and +1%). In this case the updated London file has a greater number of heating degree days, but generally shows lower heating energy, implying cooler but sunnier weather for the updated file.

For Manchester (figure 6) most building configurations are predicted to use less heating energy and less energy in total. While the change in total energy is correlated to a change in heating energy, it is also correlated to a change in cooling energy. The percentage change in cooling energy for each configuration is much higher, between -6% and 7% compared with -4 and 1% for heating energy. However, the absolute difference is much smaller which is reflected in the total change in energy.

For Plymouth (figure 7) the heating load is expected to increase for all building configurations. However, the cooling load is expected to increase by a similar magnitude but this corresponds to a change of between 20% and 53%. The change in total exergy is distributed around approximately 0 kWh and is correlated to the change in the cooling load.

For all locations the absolute change in heating energy and total exergy is small (less than 10%) and clearly heating energy is the dominant energy source for both the original and the new weather files.

The cooling energy can change by up to 100% but in absolute terms this change is small in comparison to the change in heating energy.

The results for the predicted energy use for modelled buildings for all locations can be summarised as: most building configurations are expected to have less modelled heating energy; most buildings are expected to have more modelled cooling energy; total exergy is highly correlated to the heating energy for Eight locations (Belfast, Birmingham, Edinburgh, Glasgow, Manchester, Newcastle, Nottingham and Swindon); total exergy is highly correlated to the heating energy for Eight locations (Cardiff, Glasgow, Leeds, London, Manchester, Norwich, Plymouth and Southampton); Newcastle is the only location where the total exergy is predicted to increase in all modelled building configurations and is correlated to the heating load.

The previous analysis suggests that updating weather files may have consequences for building design but does not show what the implications of an individual design are. The heating energy, cooling energy and total exergy for all 10,000 building configurations modelled using the new London TRY against each building's total heat transfer coefficient is shown in figure 8. The heat transfer coefficient is calculated as the sum of the fabric (each external surface's area multiplied by its U value) and ventilation losses. Again, the plant is used to maintain the internal temperature at 21°C across the year. For heating energy, cooling energy and total exergy, a building which has a lower heat transfer coefficient generally uses less energy and conversely a building which has a higher heat transfer coefficient generally uses more energy. The 50 buildings which use the least total energy (as shown by the black circles in figure 8) also are among the buildings which use the least heating and cooling energy. However in this case the buildings which use the least heating energy do not appear within this set and it is clear that some configurations of buildings which have relatively low heating energy do not have relatively low cooling energy. The same results can be found for all locations using both the original and updated TRY weather files with only the magnitude of the energy changing depending on location. In this case, regardless of the weather file used when designing a building, an energy efficient building (in average conditions) will remain an energy efficient building but the modelled absolute energy use will change.

Summary and conclusion

In this work new average weather files (Test Reference Years) using an up-to-date baseline for use with building simulation have been presented using the ISO method[6]. The baseline has the benefit of including any recent changes in the UK weather including the cooler winters of the late 2000s and the warm periods of 2006 and 2013. However, in general, the updated files are very similar to the original set in character in terms of the temperature distribution and the number of heating and cooling degree hours (figures 1, 2, 3 and table 1), even with the changes in location and an updated and extended time period.

Using a simple test building with a large range of possible configurations (10,000 of them) the heating energy, cooling energy and total exergy was estimated for both the original weather files and the updated files. The difference between these energy demands was investigated (figures 4, 5, 6 and 7). The building was considered to have an ideal plant maintaining the internal temperature to a constant 21°C with no other heat gains. It is found that the modelled heating demand is predicted to decrease, the modelled cooling demand is predicted to increase for most buildings at most locations and the modelled total exergy demand depends on which of the two demands were greatest in magnitude which in turn depends on the location. For some locations this is in contrary to statistics shown in figures 1, 2 and 3. For example for London, the new weather file has a lower mean temperature, more heating degree days and fewer cooling degree days. However, the modelled heating load would be expected to decrease for most buildings and the modelled cooling load would be expected to increase by a few per cent for all buildings. This is probably due to the effects of solar radiation consistent with the warmer temperatures increasing the plant loads during occupied hours. Furthermore the choice of building and occupancy schedule may have influenced these results but using this building choice has reflected the trend in the difference in underlying weather between the new and the original weather files. All results here provide a more general discussion with regards to what is the effect to the base line energy use for a building using an updated weather file. Up to the release of a new set of weather files, reflecting an up-to-date climate, industry would use the original weather files to model how a design would use energy and to refine the design. After the weather file release, it is clear that the building design's predicted energy use, the characteristics of the energy use and when it will use this energy to condition the building will change. This could lead to different design decisions to minimise energy use. Figure 8 shows a building which uses less total exergy with average conditions will use less heating energy and less cooling energy although the buildings which had the lowest heating energy did not appear within this set. All buildings with the lowest total exergy are found to have low wall U-values and low glazing percentages. This result is independent of the weather file used and therefore the location as the same result is found for both the updated and original weather files for all locations. Therefore a well-designed, low energy building will remain low energy regardless of a change in location and weather file under which it is being evaluated. It is the magnitude of the average energy use which will change using an up-to-date weather file. It must be remembered though that the building considered here is relatively simple in design, only considers a subset of the potential parameters and uses perfect controls.

The provision of weather files is essential in the development of passive, energy efficient buildings that are also resilient to the current climate. Providing up-to-date weather files which reflect observed changes in the climate is crucial to this aim. The TRYs created in this work will be made available from CIBSE.

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Location	Original baseline			Updated baseline (1984-2013)		
	Station SRC ID	Start date	End date	Station SRC ID	Start date	End date
Belfast	Aldergrove	1983	2005	Aldergrove	1984	2013
Birmingham	Elmdon	1983	1997	Elmdon	1984	1997
	Coleshill	1998	2004	Coleshill	1998	2013
Cardiff	Rhoose	1983	1997	Rhoose	1984	1997
	St Athan	1998	2005	St Athan	1998	2013
Edinburgh	Turnhouse	1978	1999	Turnhouse	1984	1998
				Gogarbank	1999	2013
Glasgow	Abbotsinch	1978	1999	Abbotsinch	1984	1999 (Apr)
				Bishopton	1999 (May)	2013
Leeds	Leeds WS	1985	2001	Church Fenton	1984	1988
				Leeds WS	1989	2002
				Church Fenton	2003	2013
London	Heathrow	1983	2005	Heathrow	1984	2013
Manchester	Ringway	1983	2005	Ringway	1984	2003
				Woodford	2004	2012
Newcastle	Newcastle (1)	1983	1990	Newcastle (1)	1984	1990
	Newcastle (2)	1991	2001	Newcastle (2)	1991	2003 (Feb)
				Albemarle	2003 (Mar)	2013
Norwich	Coltishall	1983	2005	Marham	1984	2013
Nottingham	Watnall	1983	2004	Watnall	1984	2013
Plymouth	Mountbatten	1983	2004	Mountbatten	1984	2013
Southampton	Southampton	1978	2000	Hurn	1984	2013
Swindon	Boscombe Down	1983	2004	Brize Norton	1984	2013

Table 1. The original and updated baseline weather data observation site and durations used for determining Test Reference Years.

Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Belfast												
Original	2003	1985	1993	1998	1997	1997	2001	1999	2001	1988	1989	1985
Update	2000	2005	1993	1995	1988	2000	2008	1996	1997	1988	1984	2012
Birmingham												
Original	2000	2004	2004	2000	1995	1983	2001	1996	1995	1988	1991	2000
Update	2003	2005	2004	2006	1988	1984	2010	1996	1995	1988	2007	2007
Cardiff												
Original	1988	2003	1993	1988	2000	1983	1996	1996	1996	1988	1995	1983
Update	1986	2005	1993	2006	1988	1986	1997	1991	2010	2002	2008	2007
Edinburgh												
Original	1988	1982	1981	1985	1997	1999	1996	1980	1990	1988	1998	1979
Update	2003	2005	2004	2010	2013	1993	1987	2007	2013	2010	2008	1984
Glasgow												
Original	1986	1985	1978	1998	1997	1979	1996	1998	1997	1988	1998	1984
Update	1988	1999	2008	1988	1988	1998	1997	2005	2010	2010	1998	1996
Leeds												
Original	1995	1993	1993	1996	1997	2001	2001	1994	1995	1991	1990	1985
Update	1995	2005	2010	1995	2003	1993	2005	2013	2013	2000	1991	2007
London												
Original	1988	2004	2004	1992	2000	2001	1991	1996	1987	1988	1992	2003
Update	2011	2001	2004	1988	2004	1994	2005	2000	2007	2009	1991	2003
Manchester												
Original	1999	1992	2004	2000	1985	2001	1996	1996	1996	1986	1987	1987
Update	1999	2004	2001	1988	1985	1984	1996	1998	1989	1988	2007	1991
Newcastle												
Original	1988	1999	1992	1998	1997	2000	1996	1998	1996	1985	1989	1984
Update	1992	2001	1988	1998	1985	1998	1987	1984	1985	1988	1987	1984
Norwich												
Original	2004	1999	2004	1995	1993	1990	2002	1996	1985	1987	2001	1998
Update	2000	2005	2004	2005	2003	2005	2001	2012	2007	2002	2012	2003
Nottingham												
Original	1995	1999	1993	1998	2003	1984	2001	1994	1987	1999	1987	1994
Update	2003	2005	2004	1999	1988	2000	2008	2007	2007	1988	1990	2012
Plymouth												
Original	2004	1999	2001	2004	2000	2000	1994	1996	1988	1983	1984	1983
Update	1994	1999	2005	2006	2012	1994	1994	2000	2007	1986	2001	2003
Southampton												
Original	1982	1999	1983	1988	1985	1995	1981	1987	1988	1987	1987	1982
Update	2013	2004	2004	2008	1997	2013	1985	2000	1995	2002	2012	1997
Swindon												
Original	1988	1999	1993	2000	2000	1988	1996	1996	1996	2002	1987	1983
Update	2003	2005	2004	1995	1993	2008	2005	1987	1987	1985	2001	2007

Table 2 Individual months selected for the original and updated test reference years for all 14 locations

Location	Mean temperature < 10th percentile		Mean temperature 10th – 90th percentile		Mean temperature >90th percentile	
	Original	Updated	Original	Updated	Original	Updated
Belfast	-1.22	0.31	9.22	9.30	18.87	19.11
Birmingham	-1.29	-1.43	9.80	9.79	22.63	21.96
Cardiff	0.82	0.60	10.41	10.34	20.69	21.26
Edinburgh	-1.12	-1.50	8.77	9.06	19.36	18.70
Glasgow	-2.93	-1.43	8.72	8.79	19.30	19.60
Leeds	-0.33	-0.85	10.08	9.88	22.22	22.27
London	0.74	0.72	11.35	11.22	23.84	23.67
Manchester	0.14	-1.47	9.91	9.80	21.58	20.80
Newcastle	0.70	-0.46	9.50	9.24	20.21	20.33
Norwich	0.05	-0.52	10.00	10.04	22.00	23.73
Nottingham	-0.57	-0.89	9.50	9.51	21.99	21.67
Plymouth	1.78	1.83	11.11	11.10	20.19	20.29
Southampton	-0.29	-1.80	10.95	10.47	22.34	21.82
Swindon	-0.42	-1.29	9.76	10.06	22.26	22.25

Table 3. Mean temperatures for key percentile ranges for of all locations for both the original and updated TRYs.

Building parameter	Parameter minimum	Parameter maximum
Aspect ratio	0.33	3
Wall U Value ($Wm^{-2}K^{-1}$)	0.05	0.5
Roof U Value ($Wm^{-2}K^{-1}$)	0.05	0.5
Infiltration (ACh^{-1})	0.05	0.5
Glazing percentage	10	60

Table 4. Minimum and maximum values for the five variable building parameters.

	Material Thickness (mm)	Conductivity (W/m.K)	Density (kg/m3)	Heat Capacity (J/K)
External Wall				
Brick	106	0.89	1920	790
Insulation	36-586	0.03	43	1210
Brick	106	0.89	1920	790
Plasterboard	12.5	0.21	700	1000
Ground Floor				
Insulation	110	0.025	700	1000
Concrete	100	2.3	2300	1000
Cavity	100	-	-	
Chipboard	20	0.13	500	1600
Carpet	10	0.04	160	1360
External Roof				
Clay Tile	12.7	0.84	1900	800
Membrane	0.1	1	1100	1000
Insulation	69-594	0.03	43	1210
Plasterboard	12.5	0.21	700	1000
Internal Walls				
Plasterboard	12.5	0.21	700	1000
Brick	0.005	0.89	1920	720
Plasterboard	12.5	0.21	700	1000

Table 5. Building surface construction parameters.

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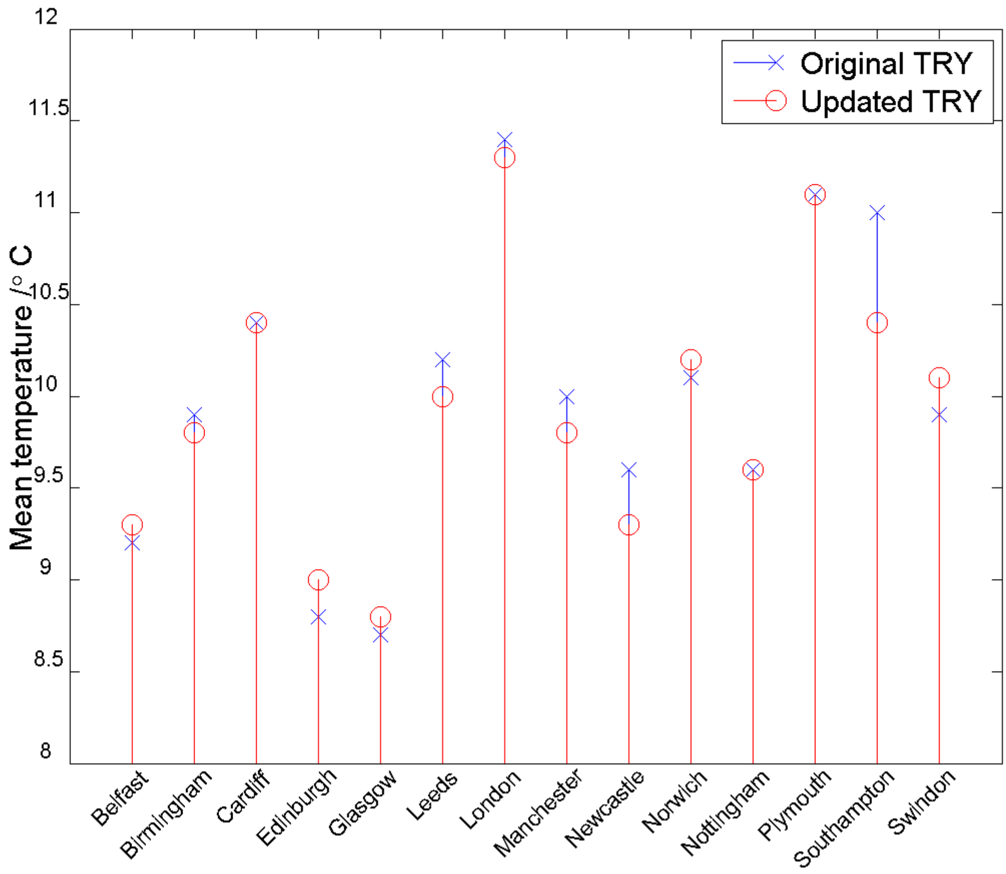

Figure 1. Mean Temperature of the original and updated TRYs

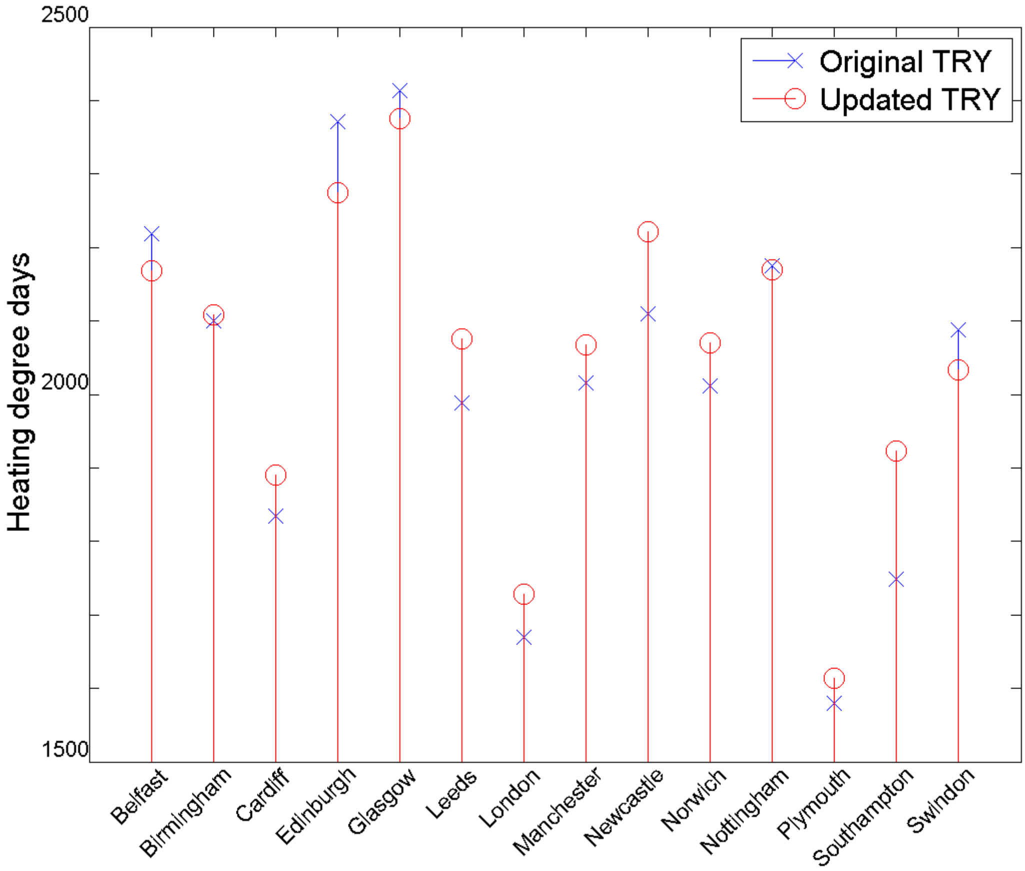

Figure 2. Heating degree days of the original and updated TRYs with a base temperature of 15 °C

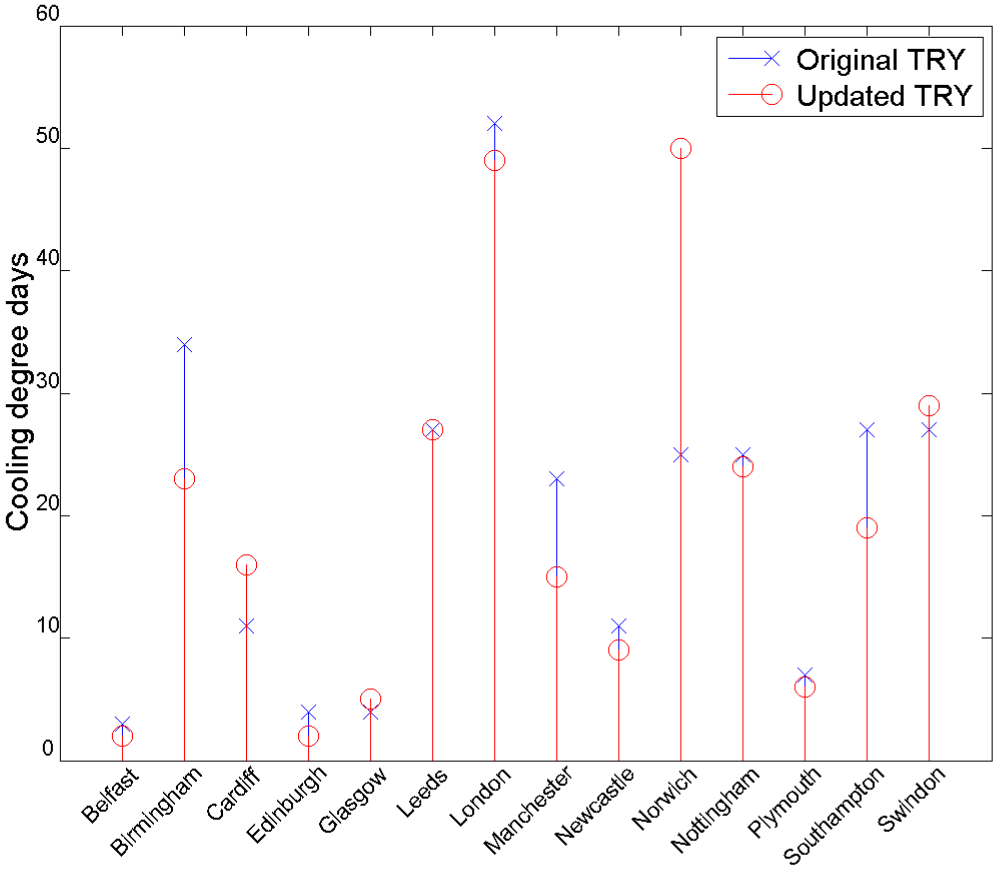

Figure 3. Cooling degree days of the original and updated TRYs with a base temperature of 21 °C

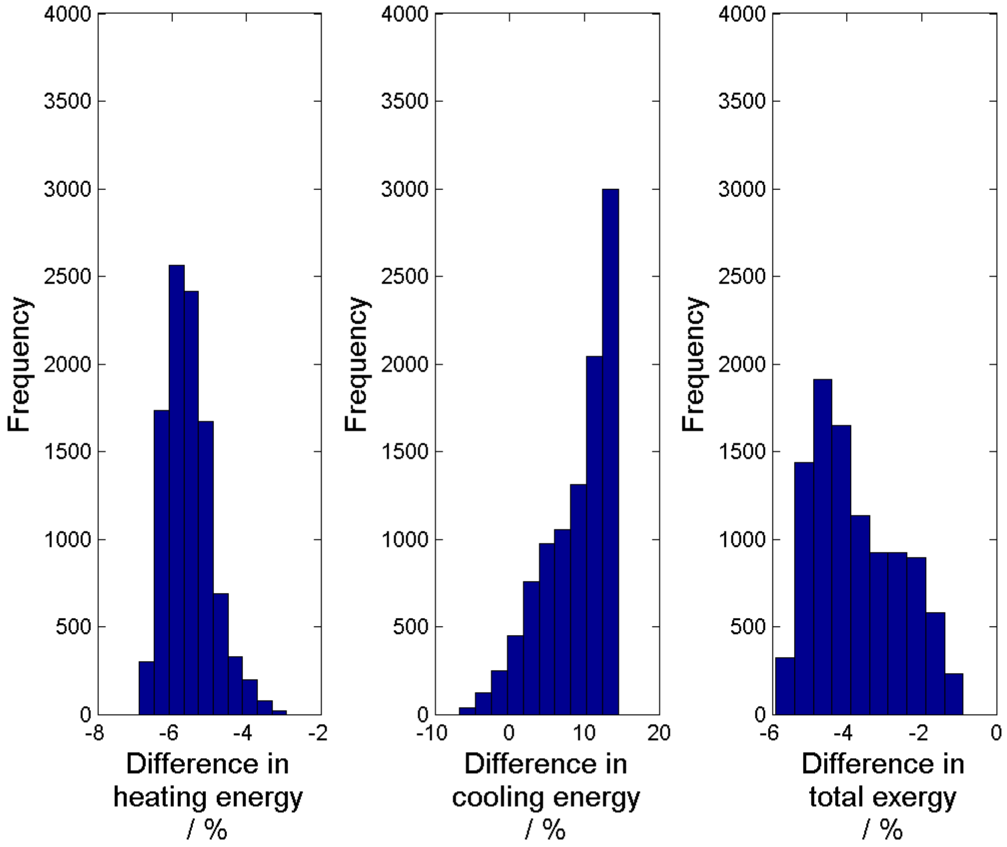

Figure 4. Distribution of the percentage change of the difference between the new and original test reference years for heating energy, cooling energy and total exergy for Edinburgh.

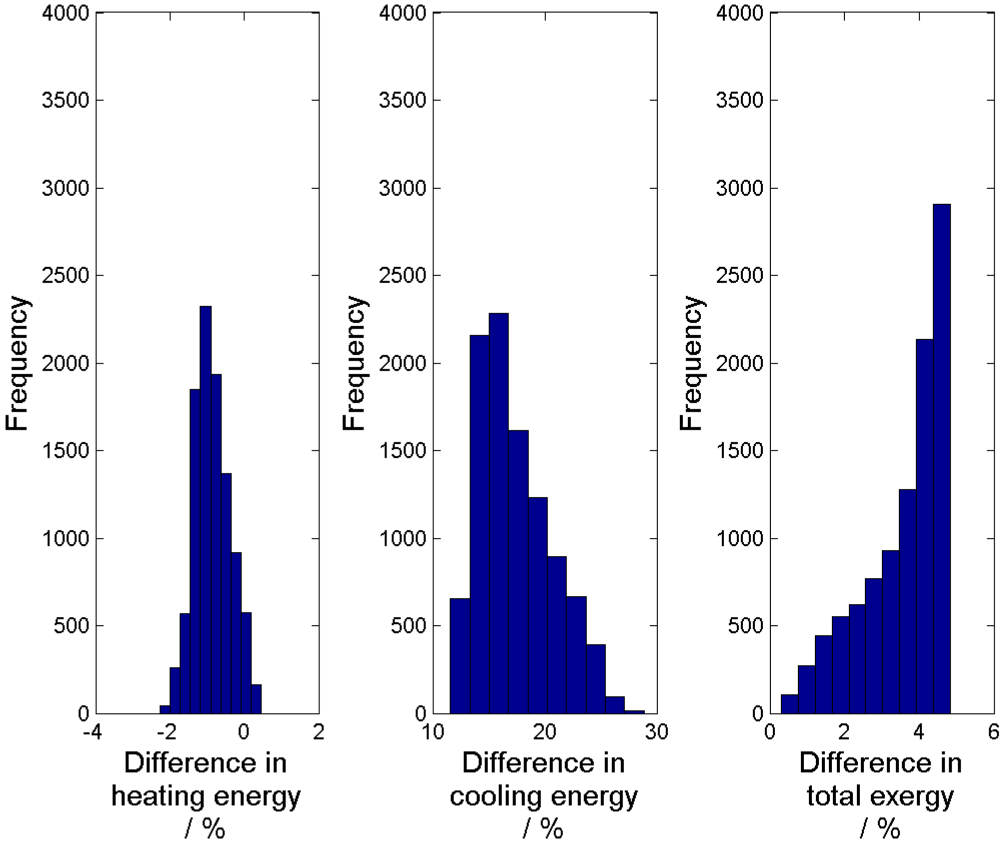

Figure 5. Distribution of the percentage change of the difference between the new and original test reference years for heating energy, cooling energy and total exergy for London.

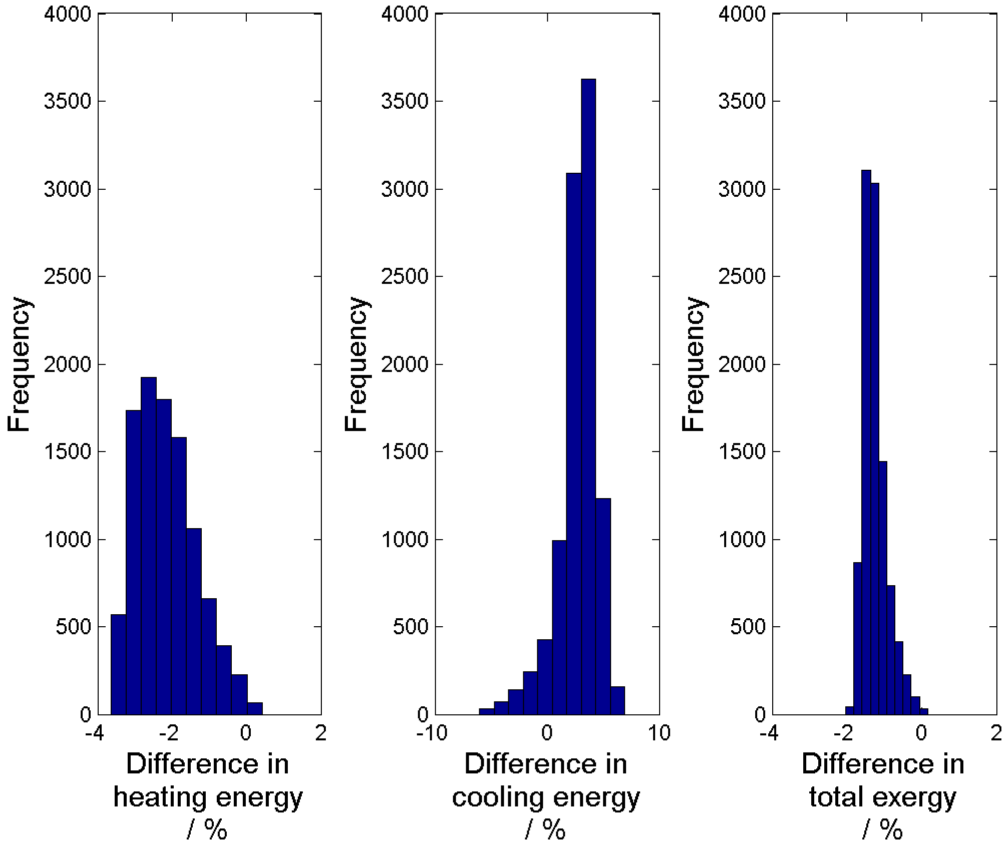

Figure 6. Distribution of the percentage change of the difference between the new and original test reference years for heating energy, cooling energy and total exergy for Manchester.

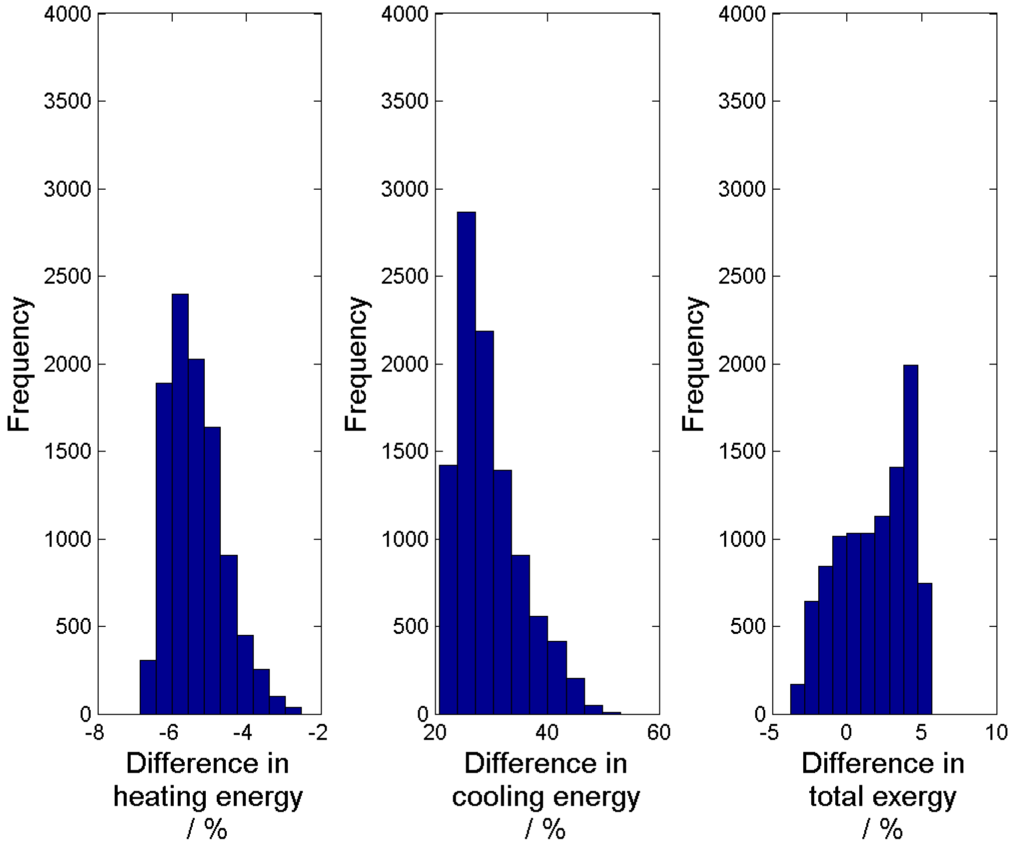

Figure 7. Distribution of the percentage change of the difference between the new and original test reference years for heating energy, cooling energy and total exergy for Plymouth.

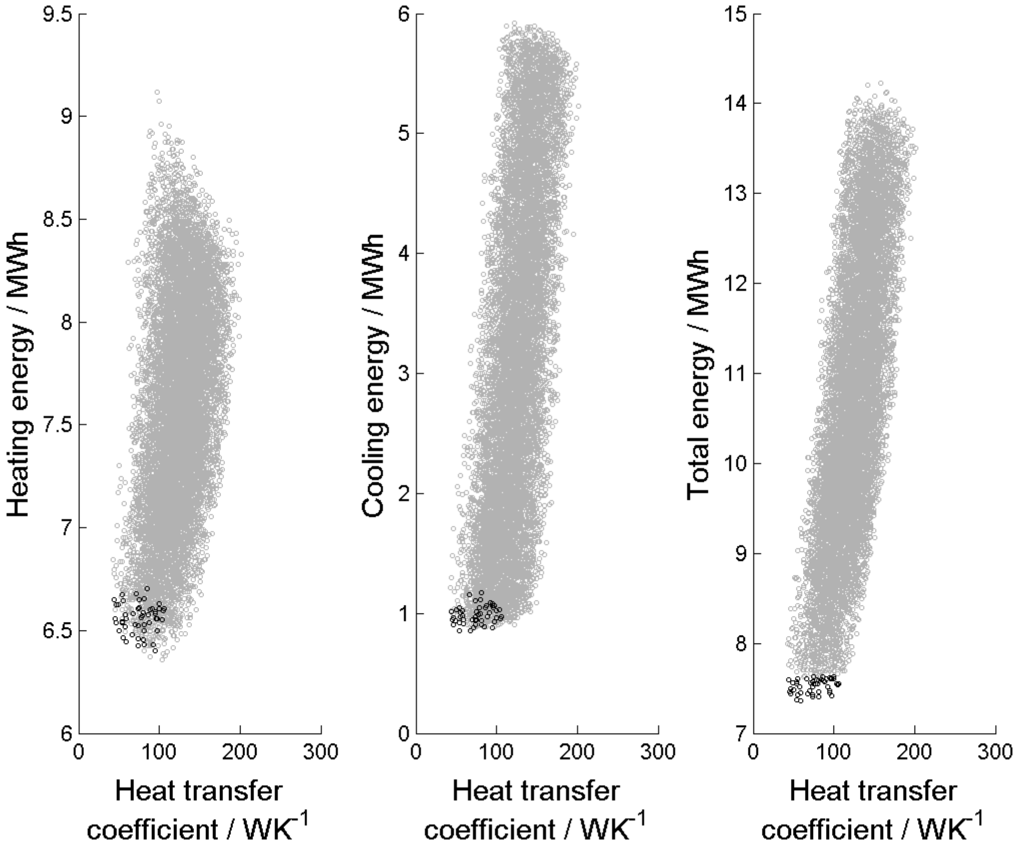

Figure 8. Heating energy, cooling energy and total energy for all 10,000 buildings using the new London TRY against the building's heat transfer coefficient. The 50 buildings which use the least total energy are highlighted by black circles.