Proceedings of 2nd Conference: ***People and Buildings*** held at Graduate Centre, London Metropolitan University, London, UK, 18th September 2012.

Network for Comfort and Energy Use in Buildings: http://www.nceub.org.uk

Overheating risk in night cooled buildings within London's urban heat island

Elinor Huggett[1]

1 MSc Environmental Design and Engineering, University College London, UK, elinor.huggett.11@ucl.ac.uk

Abstract

A building 'overheats' when its occupants find internal conditions uncomfortably hot, and feel a need for cooling. Overheating risk is currently assessed using the 'design summer year', a warm past weather year. The whole London area uses Heathrow data, but, as a result of the urban heat island effect, overnight temperatures do not fall so far in the city centre as in its rural surroundings. This may have an effect on overheating, particularly in night cooled buildings.

CIBSE has now produced data for London Weather Centre, in the city centre, and London Gatwick, a rural site. This research casts doubt on the current overheating assessment procedure, using the new data to show that the presence of the urban heat island has a considerable effect on overheating risk, and that the external climate can be used as a proxy for internal overheating behaviour.

Keywords: urban heat island, overheating risk, night cooling

1 Introduction

Traditionally in the UK, buildings have been designed to provide their occupants with warmth during the winter. However, recently a combination of factors has increased the frequency of uncomfortably high internal temperatures in summer: this is referred to as 'overheating'. On average, London's urban heat island results in overnight city centre temperatures being 4-6°C warmer than its rural surroundings (GLA, 2006). This may be expected to have an effect on overheating in the city.

At present, overheating risk is assessed using the design summer year (DSY), a warm past weather year. This is selected as the year sitting in the middle of the upper quartile of available weather years, when they are ordered according to mean temperature. CIBSE recommends that the overheating risk of a naturally ventilated building should be measured according to time spent over 28°C during the DSY. This risk is considered acceptable if fewer than 1% of occupied hours fall above this boundary when a building is modelled using thermal simulation software. There are DSYs available for 14 different locations in the UK, and the DSY for the whole London area is selected from weather data between 1982 and 2004 at London Heathrow.

The heat balance of the urban landscape is affected by a number of factors, the relative importance of which is not well understood. The surface properties of the urban landscape are very different from those in a rural environment, the rough urban surface reduces wind speeds which may otherwise remove excess heat, and the reduced sky view factors limits the quantity of heat re-emitted (Oke, 1987). These result in a damping of the diurnal swing, by reducing the rate of overnight cooling of the landscape (Oke, 1982). The surface albedo is altered, possibly reducing reflection of heat from the urban surface (Kolokotroni et al, 2008).

It is accepted that the presence of an urban heat island leads to an increase in overheating risk, but little is known about the magnitude of this impact. This research investigates the value of using site specific data files for buildings in the London area, using new CIBSE weather data.

1.1 Metrics of overheating

Currently, the DSY is chosen using mean temperature across a year's overheating period (1st April - September 30th). This research investigates two alternative metrics of annual overheating risk: climatic cooling potential (CCP) and weighted cooling degree hours (WCDH).

CCP, as proposed by Artmann et al (2006), is a metric designed to assess how appropriate night cooling is for a site. It is the only metric in the literature attempting to relate a location's external climatic characteristics to its overheating risk. Essentially, it considers how far below the building temperature the external temperature drops overnight, and calculates a cumulative cum of these differences, giving a degree hour figure, as shown in Equation 1.

$$CCP = \frac{1}{N}\sum_{n=1}^{N}\sum_{h=h_i}^{h_f} m_{n,h}\left(T_{b,n,h} - T_{e,n,h}\right) \quad \begin{cases} m = 1\ h\ if\ T_b - T_e \geq \Delta T_{crit} \\ m = 0\ \ if\ T_b - T_e < \Delta T_{crit} \end{cases} \tag{1}$$

WCDH is a metric proposed by CIBSE (2012), which reflects the increased likelihood of overheating when the temperatures are considerably higher than predicted comfort temperatures (Nicol et al, 2009). It uses a conceptual free running building with a very high ventilation rate as a reference point. The WCDH figure for a year is the cumulative squared difference between the predicted comfort temperature and the internal operative temperature, whenever the latter exceeds the former - see Equation 2.

$$WCDH = \sum_{\substack{all\ hours \\ \Delta T > 0}} \Delta T^2,\ where\ \Delta T = T_{op} - T_{comf} \tag{2}$$

1.2 Data and modelling

CIBSE has produced weather data for London Weather Centre, in the city centre, and London Gatwick, a rural site, in addition to London Heathrow. These data were used to calculate annual figures for mean external temperature, CCP, and WCDH for each site. They were also used as input to a dynamic thermal model of a night cooled building at each location, for the whole data period.

In the work described in this paper, EDSL Tas was used to give a realistic idea of how much a building overheats in any given year, allowing comparisons to be made between modelled overheating and predicted risk according to the different metrics.

The selected case study is an office archetype developed by Steadman et al (2000) as part of their work cataloguing the UK's non-domestic stock. For the purposes of this research it was optimised for night cooling, using Kolokotroni's work on night cooled buildings as a reference. Therefore it incorporates a lot of exposed thermal mass, 60% glazed facades using low G-value glazing, and external insulation to reduce solar heat gains. Internal gains were taken from CIBSE Guide A (CIBSE, 2006).

The building is ventilated between 6pm and 8am, whenever the internal temperature exceeds 14°C, up to a maximum of 25 ACH when 18°C is reached. During the day, ventilation switches on if the temperature exceeds 18°C, reaching its maximum if the temperature reaches 21°C. Ventilation reduces to 1 ACH for fresh air if the external temperature exceeds the internal.

2 Results

The graph shown in Figure 1 clearly describes the effect of the urban heat island on mean temperature, with a clear gradient between Gatwick and London Weather Centre. Both figures seem to be rising with time, and peaks in the two measures seem generally to coincide.

Furthermore, the annual overheating is consistently lowest at London Gatwick, although in earlier years it is often highest at Heathrow, which is unexpected. London Weather Centre overtakes as the 'hottest' location from the mid 1990s, but the earlier results cast doubt on the integrity of mean external temperature as an indicator of internal overheating risk.

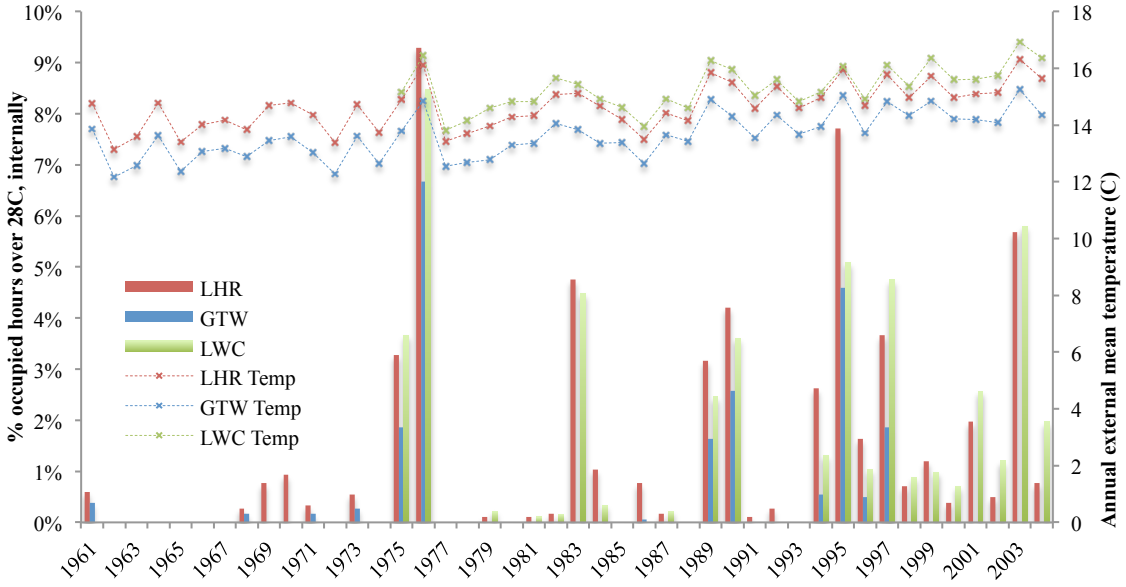

Figure 1: mean external temperature and internal overheated hours

Table 1 shows the difference between the sites according to all the different metrics. Gatwick is consistently the 'coolest' site, apart from in the case of weighted cooling degree hours. However, none of the proposed metrics reflect the intensity of the UHI effect on overheated hours: there is only a 13% increase in mean temperature from Gatwick to LWC, but an 80% rise in internally overheated hours.

Table 1: overall means and variation between locations

	GTW		LHR		LWC	
MEAN T	13.6	(100%)	14.7	(108%)	15.3	(113%)
TOTAL CCP	27989	(100%)	24905	(89%)	22404	(80%)
WCDH	564	(100%)	767	(136%)	734	(130%)
INTERNAL HOURS > 28	27.3	(100%)	44.6	(163%)	49.3	(180%)
EXTERNAL HOURS > 28	16.4	(100%)	27.8	(170%)	30.3	(185%)

Table 2 shows the DSYs picked out by the different metrics, from the new CIBSE data. In the cases of LHR and GTW, 44 years of data were assessed, while at LWC 30 years were assessed. The convention of selecting the DSY as the year in the middle of the upper quartile is retained, although this is usually done for around 20 years of data. Therefore at LHR and GTW the DSY is the fifth 'hottest', and at LWC the fourth.

Table 2: DSYs predicted for the locations by the different metrics

	GTW	LHR	LWC
MEAN T	1976	1997	1999
CCP	1998	1997	1995
WCDH	1975	1989	1995
INTERNAL HOURS > 28	1997	1990	1997
EXTERNAL HOURS > 28	1975	1983	1990

There is no incidence of complete agreement across all locations for any given metric, or conversely any complete agreement across all metrics for any given site. The year that appears most frequently across all locations is 1997, but at each location, no given year appears more than twice. The present DSY is selected from London Heathrow weather data from 1982 - 2004, and is 1989. This year is picked out as DSY only by WCDH at Heathrow.

The metrics were examined for correlations, and Table 3 shows the pairs ranked by strength of correlation. This process suggested that either external temperature or WCDH gave the best indication of overheating risk in any given year. The case study building was free running, with a high ventilation rate, so it follows that the metrics best predicting its temperature are those more reliant on external temperature extremes.

The mean temperature and the CCP gave the weakest correlations with internal overheating, casting doubt on the suitability of either of these as a metric for prediction of risk. Both of these metrics are constructed to reflect temperature lows, rather than highs, which may explain this.

Table 3: correlations between different metrics, ranked by strength

RANK	RELATIONSHIP	r
1	MEAN vs CCP	-0.98
2	INT vs EXT	0.97
3	EXT vs WCDH	0.96
4	INT vs WCDH	0.92
5	EXT vs MEAN	0.70
6	MEAN vs WCDH	0.69
7	INT vs MEAN	0.68
8	EXT vs CCP	-0.61
9	INT vs CCP	-0.60
10	WCDH vs CCP	-0.60

3 Discussion

The results indicate quite strongly that London's UHI has a significant effect on overheating risk. The Tas model overheated most of all when weather data from LWC was used: an average of 49.3 hours each year were over CIBSE's threshold of 28°C, 80% higher than Gatwick's average of 27.3 hours, and Heathrow's figure of 44.6 hours was 63% higher than the rural site.

Although the UHI is predominantly an overnight phenomenon, the increased minimum temperature results in the early part of the occupied period at an urban location being much warmer than at a rural site. There is little difference between the temperature peaks, but the diurnal range is much smaller in the city centre. This means that generally there are fewer warm hours externally at GTW than the other sites, with LWC having the most hot hours. Since it appears that the internal temperature is very affected by external conditions, probably as a result of its high ventilation rate, the presence of the UHI will indeed have a large influence on overheating risk. This should probably be taken into account during the design process for passively cooled buildings, since it is clear that in the UK, outside air provides a useful source of cooling.

When the weather years were ranked for the different locations, the range of suggested DSYs showed a very high level of variability, with no metric exhibiting agreement across locations. This supports the hypothesis that a building's location has a significant effect on the way in which it overheats. The current DSY of 1989 was not highlighted as a particularly hot year, which casts doubt on the suitability of this as a year for testing a building's reaction to temperature extremes.

All of the metrics reflected the UHI's presence, with differing intensity. The strongest correlations occurred when external overheated hours and WCDH were tested, suggesting that the case study building's temperature generally tracked the external temperature, particularly on hot days. It may therefore be reasonable, even in the case of a night cooled building, to use external temperature as a proxy for internal behaviour.

The metric that best predicts the level of overheating experienced in the building appears to be the WCDH. However, this metric gives strong emphasis to times of particularly

high temperatures, but attributes little importance to prolonged periods where temperatures are just slightly above the predicted comfort temperature. This means that Heathrow, a semi-urban site with a large diurnal range and high temperature peaks, has a consistently higher WCDH score than the urban site, where temperature peaks are damped. A similar effect is noticeable at the building level, with higher WCDH externally than internally, due to the damping effect of the building's structure.

4 Conclusions

Given these results, the author would recommend that the selection process for design summer years in urban areas should undergo a review. At present, it seems likely that the overheating risk assessment in these areas is understating city centre buildings' chances of overheating, while overstating the risk in rural areas: the intensity of overheating in the city centre was considerably higher than at London Heathrow, and Gatwick's figure similarly reduced from Heathrow. This could result in uncomfortable internal environments or inefficient retrofitting of cooling systems. In order to prevent this, it would be worth the effort of assessing buildings using site specific data.

Although all of the metrics investigated had different strengths, the main result was that the magnitude of external overheating was the best indicator of internal overheating risk in the case study building, whether hours over 28°C or WCDH were used. Therefore, while more time is being spent on using site specific data, less time could be used on the production of complex assessments of weather data: external temperature metrics could be used as a proxy for internal conditions.

References

Artmann, N., Manz, H., & Heiselberg, P. (2007). Climatic potential for passive cooling of buildings by night-time ventilation in Europe. *Applied Energy*. 84(2), 187-201

CIBSE (2006). *Guide A: Environmental Design*

CIBSE (2012) *TM49: Probabilistic Design Summer Years for London*

Kolokotroni, M., Giannitsaris, I., & Watkins, R. (2006). The effect of London's urban heat island on building summer cooling demand and night ventilation strategies. *Solar Energy*. 80(4), 383-392

Mayor of London. (2006) *London's Urban Heat Island: A Summary for Decision Makers*

Oke, T. R. (1982). The energetic basis of the urban heat island. *Quarterly Journal of the Royal Meteorological Society*. 108(455), 1-24.

Oke, T. R. (1987). *Boundary Layer Climates*. Methuen, USA

Steadman, P., Bruhns, H. R., et al (2000). An introduction to the national Non-Domestic Building Stock Database. *Environment and Planning B: Planning and Design*. 27(1), 3-10.