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## **Variations of Temperature, Wind Speed and Humidity within Birmingham New Street Station during Hot Weather**

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### **Introduction**

Studies of the European heatwaves of 2003 and 2006 have shown that extremely high temperatures lead to increased mortality rates amongst more vulnerable populations such as the ill and elderly and have wider-ranging effects on health, well-being and infrastructure (Tomlinson et al., 2013). Inner-city areas are most at risk from heatwaves, as a result of the Urban Heat Island (UHI) effect whereby land use and anthropogenic heat sources raise urban temperatures to higher levels or maintain high temperatures for longer periods than in the surrounding countryside (Tomlinson, 2012a). In the West Midlands, a heatwave occurs when temperatures at a given location exceed 30 °C on two consecutive days and do not fall below 15 °C on the intervening night (Public Health England, 2013).

The BUCCANEER (Birmingham Urban Climate Change And Neighbourhood Estimates of Environmental Risk) model maps the risk associated with the current measured UHI in Birmingham and the UHI computed using Met Office climate change models, which foresee that heatwaves will become more common, with particularly adverse health impacts in built environments (DEFRA, 2009). This has been used by Birmingham City Council to inform planning decisions so as to minimise heat-health risk by reducing the exposure of vulnerable populations to high temperatures as the city develops (Birmingham City Council, 2012). The model relies on land use statistics and past satellite measurements of surface temperature to create a high-resolution map of predicted temperatures across all regions of the city (Tomlinson, 2012b). It then combines this temperature 'hazard' map with GIS models of the vulnerability and exposure of populations in each city zone to compute the overall risk of negative effects.

Birmingham New Street, which is undergoing extensive renovation between 2010 and 2015, consists of twelve underground platforms covered and surrounded by the station building, in which is located a connecting concourse, as shown in Figure 1. It is the busiest station in the UK outside London, and lies within a region of the city expected to be particularly susceptible to heatwaves, as it experienced a strong night-time UHI effect of 3.72 °C in 2006, as shown in Figure 2 (Bassett, 2013). This effect may be magnified even further in the station, which mimics to an extent the environment of London Underground, where temperatures are so high that some platforms and tunnels are to be air-conditioned and passengers advised to take water bottles (Transport for London, 2011) during heatwaves. Birmingham New Street is unlike most other, less enclosed stations, which might exhibit a greater warming extent but more rapid cooling, and to which the results presented here are not therefore applicable.

Table 1, which gives the BUCCANEER projections for New Street's zone under different climate change scenarios, implies that the UHI effect could increase significantly even under low emissions climate change scenarios by as early as 2020. It is therefore important to evaluate any extra heating likely within the station, where the high density of people adds to the heat-related health risk, particularly for vulnerable passengers and for platform staff who experience long exposures to these conditions.

Here, measurements taken at various locations within the station of temperature, ventilation and humidity over four days of especially warm weather in July 2013 are used to assess the extent to which the temperature may exceed outdoor levels, as measured directly outside and at Paradise Circus weather station (marked in Figure 2) during a heatwave and the possible reasons for any observed trend. These can inform recommendations of how the heat risk to health and infrastructure can be minimised as part of the renovation of the station and during its subsequent use.

### Method

Measurements were made at Birmingham New Street Station between the approximate hours of 11am and 6pm on each of 11<sup>th</sup>, 15<sup>th</sup>, 17<sup>th</sup> and 18<sup>th</sup> July 2013. The dates chosen all fell within a fortnight of especially high temperatures in the region, with Paradise Circus temperatures exceeding 28° C on three of the days. By measuring at a time of day when the station was simultaneously busy and warm (the early evening) and during the hottest part of the day (the mid-afternoon), the temperature variations under conditions most relevant to the health effects of heatwaves – high temperatures in conjunction with a high population density – could be explored.

Up to four transects per day were taken through the station, each taking in excess of ninety minutes and involving measurements at each of eleven locations, visible in Figure 1. Transects began at the ‘Green Wall’ outside the station, which gave an indication of the outdoor conditions. This is designed to cool its surroundings, and can be assumed to counteract any heat escaping from the station, although its effectiveness in this regard has not been verified. They then progressed to the middle of the new station concourse, followed by the eastern end, middle and western end of each of platforms 1, 7 and 12. Thus, the measurements ranged across all regions of the station where people were likely to congregate from one side to the other and encompassed both sheltered and more exposed parts of each platform studied. The Green Wall was measured again at the end of each transect, which partially compensated for the non-simultaneous nature of the measurements, although this remained a key limitation of the study.

The same quantities were measured with the same apparatus at each location. Average and maximum wind were measured over a period of 1 minute, and the temperature and humidity measured digitally, all using a ‘Kestrel 3000’ device (produced by Richard Paul Russell Ltd). Then, a whirling hygrometer (manufactured by Casella) was used to measure dry- and wet-bulb temperatures, from which the humidity was later calculated. The device was whirled for thirty seconds before the first reading at each location, and twenty seconds for each subsequent reading until two consecutive readings were in agreement to within one decimal place, the precision to which all the instruments could measure.

### Temperature Variations

A discrepancy was often seen between analogue and digital air temperature measurements, possibly owing to the complex flow of colder and warmer pockets of air particularly noticeable on the station platforms, where readings could be subject to large fluctuations. Nevertheless, the average of the two temperatures recorded at each location was taken to be the air temperature, as the standard errors (Hughes and Hase, 2010) computed in this mean were usually small, less than 1 °C. Since this study aims to compare the temperatures in different parts of the station at any given time, but the absolute temperatures in all locations varied from hour to hour and from day to day, the difference between the temperature at each site measured and the mean of the (outdoor) ‘Green Wall’ temperatures at the start and end of each transect was computed by subtracting the latter from the former.

Each set of these temperature differences was grouped according to the time of day at which the transect was taken, so as to compute the likely extent of temperature variations over time as well as space on a typical ‘warm’ (near to 30 °C) day. The results are plotted in Figure 3, which shows that the centres of the platforms tend to be warmer than the edges at all times, that the concourse temperature is generally higher than the outdoor temperature, with a roughly constant difference through the day, and that whilst all areas tend to be cooler than the Green Wall at midday, they become warmer relative to this outside temperature as the afternoon progresses, and by 6pm tend to be at a higher temperature.

Particularly relevant to heat-related health are the maximum and minimum temperatures likely to be experienced in any given place. To roughly compare the different locations studied in this respect, the maximum and minimum average temperatures obtained for each across all four days’ transects were computed, as plotted in Figure 4. The maximum temperature occurred on 18<sup>th</sup> July in most places, but on 17<sup>th</sup> July at the Green Wall and on Platform 12, which may indicate that the weather conditions most conducive to high temperatures are different in different parts of the station. The minimum in temperature occurred on 11<sup>th</sup> July for all parts of the station. Again, the centres of the platforms generally have higher minimum and maximum temperatures than the edges and the ‘outdoor’ Green Wall. The concourse appears to reach the outdoor maximum temperature, but subsequently fails to cool as easily as the open air.

These two figures illustrate that the concourse and the centres of the platforms exhibit a miniature heat-island effect relative to the outdoor, Green Wall temperature. None of these areas is specifically artificially heated or cooled. Figure 4 shows that the temperature maxima are more consistent than the minima across the different locations. This is consistent with the notion that the UHI effect tends to reduce the cooling rate in urban areas rather than affecting the maximum temperatures reached relative to greener sites (Tomlinson et al., 2013), given that the absolute minima in temperature (which may be more uniform) would have occurred close to sunrise, outside the timespan of the transects. This also explains why the station tends to be warmer than the Green Wall in the early evening, having failed to cool down after reaching a similar maximum earlier each afternoon. Indeed, Figure 3 implies that the platforms show a delayed warming as well as cooling relative to the outside.

This heat island can be attributed to a number of factors. The station is constructed of ‘urban’ materials, concrete and metal, which are slow to warm and cool by radiation relative to their surroundings, giving rise to a delay relative to the ‘rural’ Green Wall (Tomlinson, 2012a). Furthermore, extra heat is added on the platforms through the day by waiting trains and the high density of people, accumulating particularly in the centres of the platforms, and reduced ventilation beneath the station may mean that warmer air becomes trapped. Temperatures were usually but not always found to be higher on a part of the platform adjacent to a train than elsewhere, implying that whilst heat output from trains might contribute to the overall temperature elevation later in the day across all platforms, the temperature of any particular platform is not necessarily dependent on the presence of a train there.

Figure 5 plots the time at which the maximum and minimum air temperature (averaged over digital and analogue readings) was measured at each location, averaged over all four days of the study. Within the standard error (Hughes and Hase, 2010) in the mean times, it displays a marked trend for the highest temperatures to occur later in the day on the platforms than at the Green Wall. Platform 12 also displays a tendency towards delayed cooling relative to the outside air and shows the smallest variation in temperature over the time period studied, but the steady increase in the time at which the minimum temperature was observed between the Green Wall and platform 7 is a relic of the non-simultaneous measurements inherent to the transect method, and does not illustrate any fundamental trend. The maximum temperature time curve, though, shows that the peak of the heat island effect, and the greatest heat-health risk, is likely to occur at around 4pm within the station, later than the maximum temperature occurs outside (around 2.30pm according to Figure 4) and coinciding with the start of the late-afternoon peak in passenger numbers.

### Effects of Ventilation

To compare the effect of ventilation in different parts of the station, the mean wind speeds measured across all transects were averaged at each location, as plotted in Figure 6. These results suggest that the observed very light, anticyclonic winds typical of heat waves are approximately even across all the platforms and beside the Green Wall. However, the middle of platform 1 was windier than most places, and the eastern end of platform 12 less so; this may be because the curvature of the platforms increases from 1 to 12, so that predominant westerly winds are funnelled along the straight platform 1 but are blocked from the eastern end of the more curved platform 12.

Comparing Figures 2 and 5, there is no clear correlation between wind speed and average temperature at any given location: indeed, the correlation coefficient is just -0.08. All three platforms display, overall, similar spikes in temperature towards the centre despite the stronger winds on platform 1 relative to platform 12, and the anomalously high temperature in transects taken at around midday on platform 12 is more likely to be explained by the presence of trains and people than lack of ventilation, as winds were not abnormally weak there at this time of day. The mid-points of both platforms 1 and 12 exhibit temperature peaks in Figure 4, implying that neither of these peaks has much to do with ventilation.

### Humidity Variations

The relative humidity across different parts of the station at different times of day was assessed in a similar manner to the temperature. However, although exhibiting a correlation function of 0.76 when all the simultaneous digital and analogue measurements of relative humidity were compared, the digital measurements tended always to be much higher than the analogue ones, implying that there was a calibration issue with at least

one piece of equipment. Hence, the differences between the Green Wall average and the humidity at each measured location were computed separately for the analogue and digital datasets, and the average of these differences was then computed, to cancel the offset. The final average differences in humidity relative to the Green Wall are plotted in Figure 7.

The humidity tends to become lower on the platforms relative to the Green Wall as the day goes on, except at platform 12 where the humidity difference at midday is more negative than at any other time of day, corresponding to the temperature spike seen in Figure 3. In absolute terms, the humidity was found to fall in general later in the day in all locations studied, but fell more rapidly on the platforms than beside the Green Wall or on the concourse. Such a negative correlation to temperature is consistent with the moisture content of the air being roughly constant throughout the day at any one location.

All parts of the station, though, also appear to be less humid in general than the Green Wall, with the discrepancy becoming stronger as the heat island temperature effect grows, later in the afternoon. Hence, the ‘apparent’ temperature – that subjectively experienced by people – on the platforms might be expected to be similar to that in the cooler but more humid surroundings of the Green Wall, with similar levels of discomfort. To explore this possibility, the ‘humidex’ discomfort index was computed from the temperature and humidity for each observation. A higher humidex value indicates greater discomfort, with values of 30 or greater indicating ‘some discomfort’ and those exceeding 40 corresponding to ‘great discomfort’ (CCOHS, 2011). In this study, the index was computed by looking up the value corresponding to each temperature and humidity on the table provided by the Canadian Centre for Occupational Health and safety (CCOHS, 2011). It never exceeded 37 (reached at Platform 7 West on the 2pm transect on 18<sup>th</sup> July), with an overall average of 30, but these levels might be exceeded in more extreme heatwaves.

To assess humidex variation with time of day, the average humidex value at each location studied across all transects was computed beginning at around each of three different time periods; the results are plotted in Figure 8. There is no overall change in humidex value at each location over time within experimental error, implying that moisture content is indeed almost constant. However, spatial variations in the level of discomfort are masked by the large error bars. These in part arise from the fact that the index is more strongly influenced by temperature than humidity, and hence values were much lower on the slightly cooler day, 11<sup>th</sup> July, than on the other three days. Therefore, to explore the spatial variation of discomfort, the humidex values were averaged across all transects excluding those of 11<sup>th</sup> July for each location individually, as plotted in Figure 9.

This graph implies that levels of discomfort are similar to those at the Green Wall in warm conditions at the western ends of the platforms (which, like the Green Wall, are in the sun during the hottest part of the day) and on the concourse, but that the eastern ends are less uncomfortable, whilst the centre of platform 12 in particular is markedly more uncomfortable. This shows that the higher temperatures seen in the centres of platforms do translate to less healthy conditions, at least in some cases, despite the lower humidity. All parts of the station, whether under cover or exposed like the Green Wall, exhibited ‘some discomfort’ according to the humidex ratings, which grew more acute on the warmer days of the study. It is likely that discomfort will thus become problematic across the station during more extreme heatwaves.

### Comparison to Paradise Circus

To measure the station’s true ‘miniature’ heat island effect (the station’s temperature difference relative to the rest of the city, rather than the absolute UHI relative to the countryside) a comparison was made between the temperatures and humidities at each location studied with those at Paradise Circus weather station. This collects data on a minute-by-minute basis, so it was possible to compare temperatures at the exact time of each observation. The greatest absolute difference between Paradise Circus and New Street Station occurred on the coolest day, 11<sup>th</sup> July, when the Concourse was 6.2° C warmer. Figure 20 shows the difference in average temperature and relative humidity (Paradise Circus subtracted from the New Street measurements), averaged across all transects beginning at each of four approximate times of day.

The figure shows that most regions of the station – including the outdoor ‘Green Wall’, probably because it is south-facing – were generally warmer and more humid than Paradise Circus. The temperature difference increases whilst the humidity difference decreases as the afternoon progresses, in accordance with the heat island effect suggested by the above analysis. Again, platform 12 shows some deviation from the trend,

appearing to be warmer relative to Paradise circus earlier in the day, and the concourse maintains a relatively constant temperature difference. The centres of the platforms always show a tendency to be warmer than the edges, with the eastern end of platform 7 in particular being relatively cool.

The large error bars in the results derive from the limited number of readings that can be taken on a given day using the transect method. However, even within experimental error they suggest that the station platforms can be up to 3 °C and the concourse around 2 °C higher in temperature than the local weather station despite its close proximity, especially at the busiest time of the afternoon, 5-6pm. This fact must be taken into account when considering whether to take remedial action to avoid health risks at the station when outdoor temperatures approach those of a heatwave. Some of the discomfort caused by this increase in temperature over time relative to the weather station may be assuaged by the corresponding decrease in humidity visible in Figure 7, but the ‘apparent’ temperature and level of discomfort is at all times likely to be greater in the station than its surroundings, which are typified by Paradise Circus, because it is consistently higher in both temperature and humidity. The centres of the platforms, where passengers are most likely to be found, should be assumed to differ from the weather station temperature in temperatures approaching 30° C by the values given in Table 2.

### Conclusions

The measurements presented in this paper show that a ‘heat island’ effect does exist between the platforms and the outside air. The effect manifests itself as a delay in the time at which the platforms reach their maximum temperature and minimum humidity, and means that at the peak travel time (the early afternoon), temperatures beneath the station may remain very high, perhaps continuing to exceed 30°C during heatwaves, even when the surrounding city has cooled to less unhealthy temperatures. Further research is necessary to establish the exact causes of this. The platforms exhibited a temperature increase of up to  $(1.9 \pm 0.7)^{\circ}\text{C}$  relative to the outside ‘Green Wall’ average temperature during transects taken later in the afternoon. Although the humidex scale implied similar levels of discomfort within the station to those at the Green Wall, all locations were found to exhibit ‘some discomfort’ in warmer weather, and, particularly in the middle of sheltered platforms such as platform 12, this is likely to give rise to dangerously high ‘apparent temperatures’ during more extreme heatwaves.

During the warm weather, very little ventilation was observed on the platforms to dissipate the heat, and any wind recorded did not appear to correlate strongly with temperature, whilst the heating effect appeared to occur independently of the presence of a train at any given platform. But owing to the highly variable and turbulent nature of the wind currents on the platforms, the average ventilation taken over a single minute, as used here, provides only a limited picture of the winds present at each location. This study was incapable of exploring in detail the timings and causes of the observed temperature discrepancies because of the impossibility of carrying out simultaneous measurements of ventilation and temperature and contemporaneous measurements at the different studied locations under the transect method. Furthermore, it only takes into account the time period between 12pm and 6pm, that at which the risk of high temperatures is expected to be greatest. Future studies might employ sensors placed in the same locations as used here, but carrying out readings over the full 24-hour period for several warm days in order to obtain more precise times of temperature minima and maxima at the different sites and provide a more robust analysis of the effects of ventilation.

Some studies indicate that high temperatures also exacerbate the levels of air pollutants such as ozone in the atmosphere (Basu, 2009), or increase the susceptibility of people with underlying respiratory conditions to more dangerous pollutants such as nitrous oxides. It is vital that further research be done into this possibility, as regular passengers and staff will be repeatedly exposed to any fumes released from diesel engines and trapped in the enclosed station environment.

Although tentative, the results of this study show that more extensive research is required for the heat-health risk at New Street station to be properly assessed. If vindicated, they imply that passengers waiting and staff working for extended periods on the platforms may suffer from exposure to heatwave-level temperatures above those in the surrounding city zone, which is itself projected to become several degrees warmer under climate change than the present rural temperature. This will lead to associated health risks unless measures are taken to reduce temperatures.

Such measures could involve structural changes such as introducing green spaces (Birmingham City Council, 2012) or allowing a greater flow of air through the station. Or, the station might take extraordinary

measures during the periods for which platform temperatures exceed the 30 °C heatwave level, such as recommending that passengers do not descend to the platforms for any extended time. So as to be able to monitor platform temperatures, the station should therefore either be given access to real-time Paradise Circus measurements to which to add the predicted time-dependent local UHI offsets or install its own permanent sensors on the platforms, and should create a heatwave action plan to assess such possibilities. These considerations are particularly important now, when there is the opportunity to introduce risk-mitigation procedures as part of its redevelopment, and in light of climate change models predicting more instances of extreme temperatures in Birmingham – particularly pronounced in areas such as the vicinity of New Street – in the years to come.

### Acknowledgements

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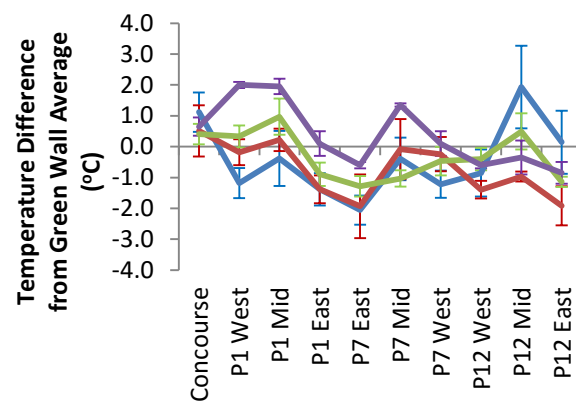
Emissions	2020	2050	2080
Low	5.53	6.43	7.03
Medium	5.53	6.73	8.01
High	5.53	7.13	9.03

Table 1: Central estimate (50% probability) BUCCANEER program predictions of the UHI extent in °C in Birmingham New Street's zone of Birmingham relative to current rural temperatures for each of 2020, 2050 and 2080 under climate change models for three possible greenhouse gas emissions scenarios (Bassett, 2013).

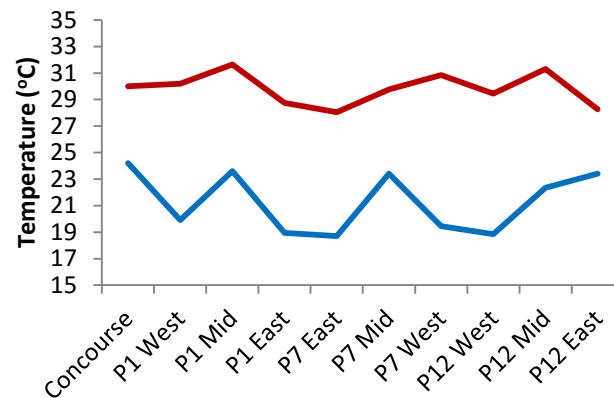
Time	Relative Platform Temperature (°C)
c.12pm	0.8 ± 0.6
c.2pm	1.1 ± 0.2
c.4pm	1.6 ± 0.5
c.6pm	1.9 ± 0.7

Table 2: The expected elevation in temperature in the middle of station platforms relative to Paradise Circus weather station in warm weather, computed by averaging the measured temperature differences at the middle of platforms 1, 7 and 12, at each approximate time of day, with standard errors in these mean values (Hughes and Hase, 2010).

Birmingham New Street Station identified in a red ('warm') zone of the BUCCANEER model map of temperature variation within Birmingham during a heat-wave (18th July 2006 at 1am); this zone was 3.72° C warmer than the countryside around the city (Bassett et al., 2013).

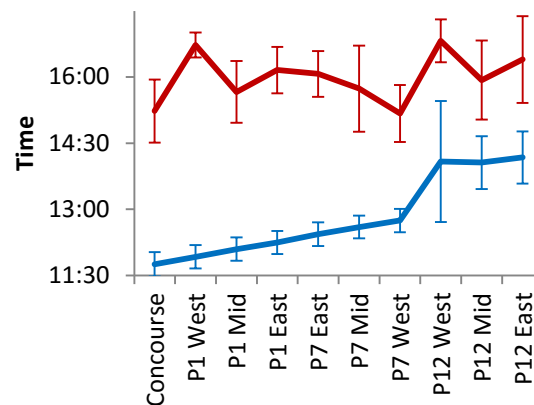
**Figure 3**

The temperature difference between each location measured and the Green Wall average at the start and end of each transect, averaged over all transects centred on 12-1pm (blue), 2-3pm (red), 4-5pm (green) and 6pm (purple), with error bars based on standard error in the mean (Hughes and Hase, 2010).

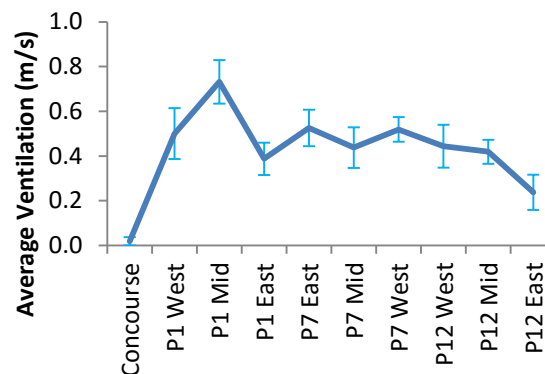
**Figure 4**

The maximum (red) and minimum (blue) temperatures recorded in each location across all transects.

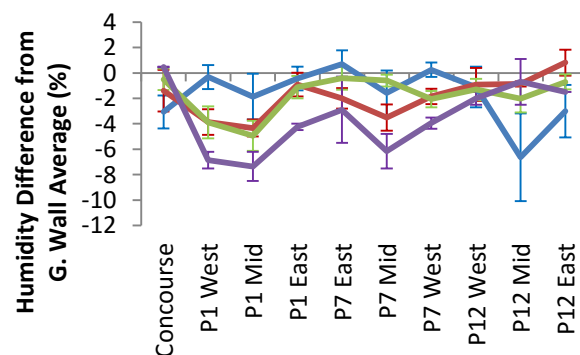


**Figure 5**

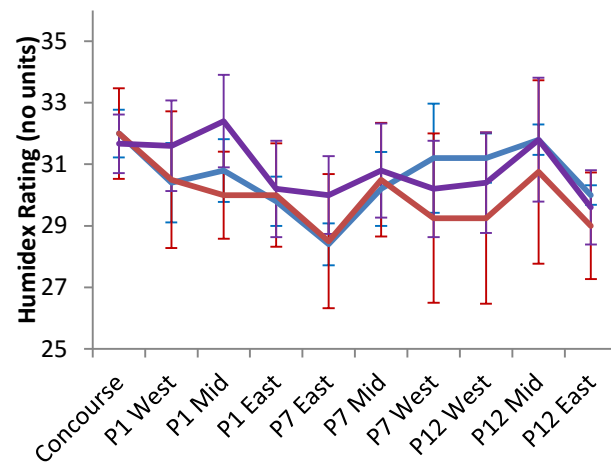
The times at which maximum (red) and minimum (blue) air temperatures were recorded at each location, averaged across the four days of the study, with error bars.

**Figure 6**

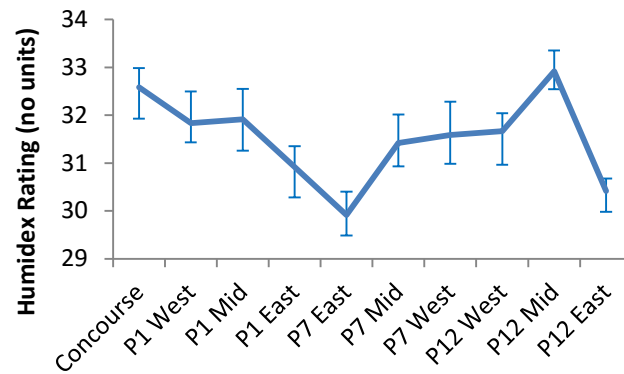
The average ventilation recorded over 1-minute intervals at each location, averaged across all transects, with error bars representing the standard error in the mean (Hughes and Hase, 2010).

**Figure 7**

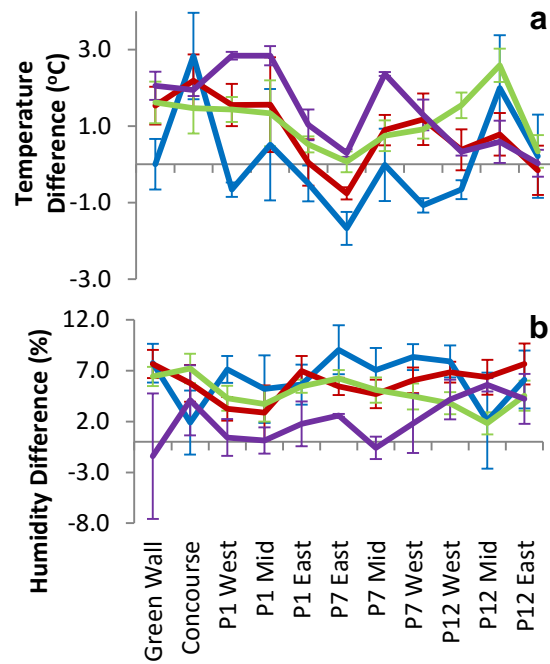
The difference in relative humidity between each location measured and the Green Wall average at the start and end of each transect, averaged over analogue and digital readings and across all transects centred on each of 12-1pm (blue), 2-3pm (red), 4-5pm (green) and 6pm (purple), with error bars based on standard error in the mean (Hughes and Hase, 2010).

**Figure 8**

Humidex values (Canadian Centre for Occupational Health and Safety, 2011) at each location, averaged across all transects beginning at approximately 12-2pm (blue), 2-4pm (red) and 6pm (purple) across all four days studied, with error bars based on standard error (Hughes and Hase, 2010).

**Figure 9**

Humidex values (Canadian Centre for Occupational Health and Safety, 2011) at each location, averaged across all transects made on 15<sup>th</sup>, 17<sup>th</sup> and 18<sup>th</sup> July, with error bars based on standard error (Hughes and Hase, 2010).

**Figure 10**

The difference in average temperature (a) and humidity (b) measured at each location in Birmingham New Street above Paradise Circus measurements taken at the same times, averaged over transects beginning at around 12pm (blue), 2pm (red), 4pm (green) and 6pm (purple), with error bars computed using standard error in the means (Hughes and Hase, 2010).