CURRENT AND LIKELY FUTURE PERFORMANCE OF ADVANCED NATURAL VENTILATION

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ABSTRACT

Advanced natural ventilation (ANV), often characterised by the use of dedicated ventilation stacks, shafts and other architecture features such as atria, light wells, has gained popularity for natural ventilation design in recent decades. In this research, a prototype ANV system is proposed, and the likely thermal performance in a range of UK climatic conditions predicted using dynamic thermal simulation. The simulations showed that ANV has greater resilience to future climatic conditions in the north of the UK than in the south-east and that, for the assumed internal heat gains, the design studied is unlikely to maintain comfortable conditions in the southeast of England beyond the middle of this century.

INTRODUCTION

Buildings and activities within them are a key contributor to greenhouse gas emissions, for example, in 2000, the energy consumed in buildings accounted for 46% of the UK's total energy consumption (CIBSE 2004), and about half the nation's carbon emissions are associated with energy use in buildings (BRE 2006). It is now almost universally accepted that climate change, one of the most significant concerns facing mankind, is caused by the accumulation of greenhouse gases in atmosphere. Reducing the carbon emissions in building stocks is one way to tackle this global concern.

Of the many techniques and technologies that can be used to reduce carbon emissions of buildings, natural ventilation (NV) is one that can be readily implemented today using conventional construction methods and expertise. Such buildings tend to consume much less energy for space conditioning than typical mechanically ventilated buildings. The PROBE studies (Bordass et al., 2001) reported the monitored energy use and CO_2 emissions of 20 public and commercial buildings and compared these to the Typical and Good practice benchmarks reported in ECON 19 (BRECSU 2000). The results showed that nine of ten highest CO_2 emitters were air-conditioned or mixed mode, and nine out of the ten lowest emitters were naturally ventilated or used advanced natural ventilation (ANV).

ANV, which is often associated with architectural features such as atria, lightwells, and stacks, has made natural ventilation possible for modern non-domestic buildings with large deep plans, and sealed façades. As described in Lomas (2006), ANV strategies can be classified as Edge-in, Centre out (E-C), Centre-in, Edge-out (C-E), Edge-in, Edge-out (E-E) and Centre-in, Centre-out (C-C). Existing examples of ANV buildings which have used one or more of the above ventilation strategies include: the Queens Building at De Montfort University, Leicester, where the E-C strategy was used (BRECSU 1997, Bunn 1993); and the Frederick Lanchester Library at Coventry University where the C-C and C-E strategies were used (Field 2000, Pidwell 2001). The Harm A Webber Library for Judson College, Illinois, near Chicago, uses a hybrid approach, in which both the C-E and E-E strategies are used in combination with mechanical cooling to combat the warm humid summers and the cold winters (Lomas et al., 2007).

Buildings also need to withstand the changing climate throughout their life cycle. Whilst a design may cope with the existing climate it may not be able to cope with future climatic conditions. It is therefore important to know, particularly at the building design stages, how a building is likely to perform in the future. One way to do this is to use dynamic thermal simulation.

In this research, dynamic thermal simulation is used to predict the current and likely future temperatures inside alternative ANV buildings. A hypothetical ANV building is described and a brief introduction to the current and future weather conditions of the UK is given. The modelling methods and the results are described and discussed. Conclusions are drawn about the likely risk of overheating in ANV buildings due to climate change in different parts of the UK.

THE MODEL

The prototype model was simulated using IES Virtual Environment, a well-established dynamic thermal simulation program for analyzing the dynamic responses of a building based on the hourly input of weather data (IES 2007). Figure 1 shows the plan of the model, which incorporates all four of the ventilation strategies mentioned in the introduction.
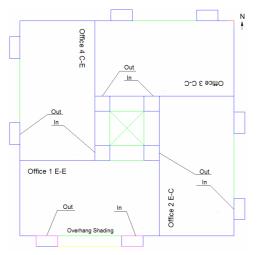
Figure 1 plan view of the model

The model has four identical office spaces with dimension width × depth × height of 13.0m × 7.0m × 3.6m (internal). The perimeter of the central atrium is 6.0m×6.0m in plan with projection area 10m^2 for the roof light glazing. Four stacks/shafts are embedded within the atrium space serving as either the inlet or outlet of an individual office. Internal glazing with an area of 11.4m^2 connects the office spaces and the atrium. Each office space has two vertical shafts on its long external perimeter serving as both extruded shading for the external glazing and as a potential airflow path. The external glazing area is 12m^2 and right above the glazing there is a shading overhang. The office spaces are on level 2 and only the external window and surrounding wall are exposed to ambient conditions; all other surfaces are connected to internal spaces. For each floor, the total height is 4.0m (finished floor level (FFL) to FFL). The total height of the stacks and shafts is 15.0m, which gives a 3.0m stack height above the notional roof level.

The model setup enables one to test different ventilation strategies under the same modelling conditions. For example, the E-E strategy currently has a south-facing window and the other spaces are 'switched off' thereby only testing the office and its connection to the adjacent atrium and stacks; this is the case used for this paper. When one wishes to test the E-C strategy, the model is turned 90 degree clockwise, which 'switches-on' office 2 and 'switches-off' the other offices. In sequence, it is possible therefore to test all four ANV strategies using the same modelling set up.

An axonometric view of the model when the C-C strategy is used, is shown in Figure 2. The two vertical shafts at the external perimeter now serve as external shading only. One may argue that these shafts and stacks (ref. also Fig 1) do not seem useful. Here however, the aim is to test the different ANV strategies under the same shading conditions. Preserving the stacks is just a convenient way of doing this.

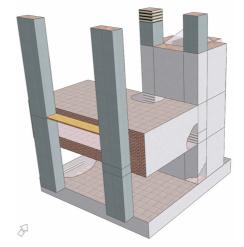External shafts are fed directly by ambient air but the central shafts are fed by an under floor plenum. In the

Figure 2 axonometric view of the model showing C-C ANV strategy

C-C strategy (figure 2), air enters the under-floor plenum, then the vertical shaft on the right, and into the office space at low level. Warmed exhaust air leaves the office space at high level, into the stack on the left, and then out through the outlet at the top of the stack. The free opening area along the airflow path used in this work is 1.4m^2, which is 1.5% of the total floor area of the office space. This percentage is taken from the work of Lomas (2006) where the four ANV strategies were discussed in detail.

Table 1
Construction details of the proposed model

PARTS	CONSTRUCTION	U VALUE
External Wall	Brickwork 100mm + EPS insulation 58.5mm + Concrete Block (medium) 100mm + Plastering 15mm.	0.35 W/m^2 K
Internal partition	Plaster 13mm + Brick work 105mm + plaster 13mm.	1.69 W/m^2 K
Ceiling (Heavy)	Plastic tile 3mm + Screed 75mm + Cast Concrete (dense) 200mm.	1.88 W/m^2 K
Ceiling (light)	Plastic tile 3mm + Screed 75mm + Cast Concrete (dense) 100mm + Cavity 400mm + Ceiling tile 10mm.	1.22 W/m^2 K
Roof light	Suncool glass – Plkington K 6mm + Cavity 16mm + Clear float 6mm	1.2 W/m^2 K
Glazing	Standard clear low-e double glazing	1.98 W/m^2 K
Stack and shaft construction	Aluminium 3mm + Dense EPS insulation 300mm + Aluminium 3mm.	0.08 W/m^2 K

Although the U-values for internal partitions and ceilings are relatively large, they are surrounding spaces that are 'turned off' in the model, which gives them an adiabatic condition.

The internal heat gains for lights are $12W/m^2$ and the same gain is used for the equipment. The offices have 6 occupants and each one has a maximum of 90W sensible gain and 60W latent gain; adding averaged lighting and equipment gains, the total internal heat gain is therefore $30W/m^2$. These heat gains were applied during working hours; 9am to 5pm, without lunch breaks, 5 days a week.

The background infiltrate rate was set at 0.25 ach^{-1}; which is an average for all strategies given in the CIBSE Guide A, table 4.13 (CIBSE 2006). The ventilation control was deliberately simple; during working hours (9am to 5pm), the ventilation openings were fully open. Outside these hours, the venting openings were either fully closed or fully opened depending on whether night-time ventilation was modelled or not. It is worth noting that in the UK, even in the southeast, the night-time ambient temperature is rarely over 24°C and so passive night-time cooling in summer is nearly always effective.

The airflow model used in this work is the MacroFlo in IES. It allows users to carry out studies of natural ventilation, infiltration, façade analysis and mixed-mode design. MacroFlo uses a fast multi-zone thermo-fluid solver to simulate the interactions between airflows, pressures and thermal conditions. For a natural ventilation system, the lack of wind can be the worst scenario for ventilation. In this work, only buoyancy-driven force was considered by sheltering the ventilation openings in MacroFlo.

When the interior is cooler than ambient, it is possible for fresh air flows to be too low, or for the flow direction to reverse. Therefore, in the model, a low speed fan provided a minimum volume of fresh air (60l/s in total, i.e. 10l/s per person). The fan only operated when the CO_2 concentration fell below 950ppm or when $T_o - T_a \leq 2.0K$ (where T_o is office air temperature and T_a is the ambient air temperature).

WEATHER DATA

The hourly weather data used in thermal simulation models represents a single complete year. In the UK, such typical year is called a test reference year (TRY) and is select from a set of 12 months, where each one is the most representative month over the past 20 years (CIBSE 2002). A TRY weather data set is useful for predicting a building's typical energy consumption and CO_2 emissions.

In order to evaluate the possibility of over-heating in naturally ventilated buildings the CIBSE (2002) have developed design summer years (DSYs). A DSY is the third warmest, according to the April-September average temperature, from a sequence of 20 years. Thus the DSYs represent much more extreme conditions than TRYs.

The DSYs are used in association with the overheating criterion given in CIBSE (2006), which is that the number of hours over the operative temperature of 28°C should not be more than 1% of the annual occupied hours (equivalent to 20 hours in this work). The guidance also states that between 25°C and 28°C an increasing number of occupants may feel uncomfortable and have lower productivity. In this work, the current overheating risk was assessed using the DSYs for London, Birmingham, Manchester and Edinburgh as given in the CIBSE 2005 release (CIBSE 2006).

It is also important to evaluate the performance of a NV building design when influenced by climate change. To do this it is necessary to generate weather data that are representative of the future. In this paper the morphing algorithm described in Belcher et al (2005) was used to generate future weather data under the UKCIP02 medium high scenario (UKCIP 2002). Both TRY and DSY weather data were generated for London and Manchester for the year 2020, 2050 and 2080 (figure 3).

Year	Temperature threshold (°C)		
	25	27	28
2005	106	42	28
2020	217	102	58
2050	339	193	128
2080	608	372	285

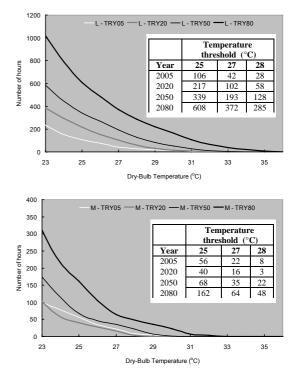| Year	Temperature threshold (°C)		
	25	27	28
2005	56	22	8
2020	40	16	3
2050	68	35	22
2080	162	64	48

Figure 3 Total hours above stated ambient dry-bulb temperature in a current typical year, the CIBSE 2005 TRY, and in typical future years 2020, 2050 and 2080 TRYs: (a) London and (b) Manchester

By 2020 the London TRY has 58 hours with a dry-bulb temperature over 28°C, which is similar to the current London DSY05 (not shown in figure 3), and by 2080 there are around 285 hours over 28°C. By 2050 the Manchester TRY has about the same number of hours over 28°C as London has today.

MODELLING METHODS

The first phase of the modelling work sought to develop standard modelling conditions. To do this the E-E strategy was selected starting from a base case (Case 1). The base case does not have any overhang, the inlets from the shaft and the outlet to the stack are only open during working hours; i.e. there is no night-time ventilation, and there is a light weight ceiling (see table 1). The second case (Case 2) is with the overhang shading while Case 3 is the same as the second but with night ventilation to cool the building fabric outside working hours. Case 4 is based on the third case but with heavy weight ceiling. The current London DSY data (LonDSY05) was used for this phase of the simulations.

The second phase of the work used the conditions for Case 4 to simulate four geographic locations in the UK (London, Birmingham, Manchester and Edinburgh) using the current DSYs 2005 data.

In phase three, the likely future performance of the E-E ANV strategy was evaluated using the future projected weather data for London and Manchester.
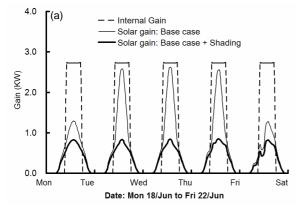
Finally, the other ANV strategies were briefly considered and wider considerations discussed.

RESULTS AND DISCUSSIONS

Phase 1: developing the modelling conditions

The solar gains for the base case (Case 1) and Case 2, with the overhang, during a working week in June using the current London DSY data are shown in figure 4a. Clearly, the 1.0m overhang substantially reduces the solar gains to the office space; without the shading, the solar gain could be as much as the total internal heat gains. On days 2 to 4 during the middle of the day, when the sun is in the south, the sky is relatively clear which leads to high direct solar radiation that the overhang effectively shades (Fig 4b). On day 1, which is cloudy, the diffuse radiation is higher leading, co-incidentally, for the shaded case, to a similar total heat gain to that on days 2 to 4.

The total solar gain from May to September inclusive was 2.09MWh for the base case, while for Case 2 the solar gain was just 1.24MWh; a 40% reduction.
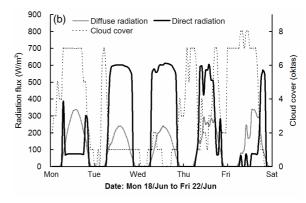
Figure 4 Internal heat gain, solar gains for the base case and the base case with 1.0m overhang shading (a) and the external solar radiation and cloud cover conditions (b).

Figure 5 shows the internal dry resultant temperature (DRT), i.e. the average of the radiant and dry-bulb temperature, with and without night-time ventilation.

Without night ventilation (Case 2) the DRT in the office space remained high - the night-time infiltration and conductive heat loss brought the DRT down by only about 3°C. In contrast, with night-time ventilation (Case 3), the DRT decreased by about 7°C from its daytime peak. This meant that during occupancy, the DRT with night-time ventilation is always lower than without night ventilation.
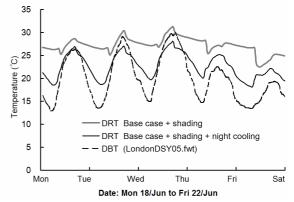
Figure 5 Comparison of resultant temperatures (DRT) for Case 3 with -, and Case 2 without, night cooling.

The effect on the indoor DRT of the ceiling construction, is shown in Figure 6. The heavy weight construction has a greater ability to prevent a rise in the DRT increase during the daytime.
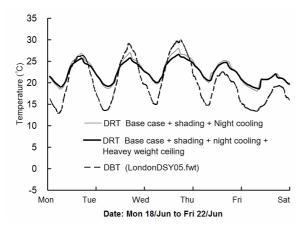
Figure 6 Comparison of dry resultant temperatures (DRT) for Case 3 with a light weight ceiling and Case 4 with a heavy weight ceiling.

Although the difference was only up to 1°C or so for the days shown in the figure, the annual affect on the number of hours of elevated temperatures is notable.

The predicted numbers of hours over certain temperatures for the four cases investigated in phase 1 are shown in Figure 7. Compared with the base case, the introduction of shading, night cooling and a heavy weight ceiling construction all contributed to reducing the indoor DRT. The ceiling construction has a marked effect for elevated temperatures in the range 25°C and 26°C, but when the temperature is 28°C or over, the difference between the lightweight and heavyweight ceiling is reduced.
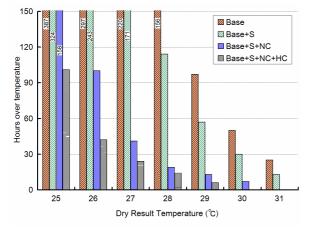

Figure 7 Number of hours over certain internal dry-resultant temperatures for all four cases.

Considering the CIBSE overheating criterion, the office with the lightweight ceiling has 19 hours over 28°C and the office with the heavyweight ceiling 14 hours over 28°C; both these offices, with the E-E strategy and night-time ventilation, thus satisfy the over heating criterion.

Phase 2: different geographical locations

Using E-E strategy with shading, night ventilation and a thermally heavyweight ceiling (Case 4), simulations were carried out for four locations – London, Birmingham, Manchester and Edinburgh,

using current DSY weather data. The daily mean ambient temperatures for the four locations during July are shown in figure 8, these data indicate that London is the warmest and Edinburgh the coolest. The other two locations are in between.
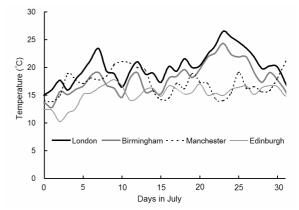

Figure 8 Daily mean external dry-bulb temperatures in July for London, Birmingham, Manchester and Edinburgh (DSYs 2005)

The predicted number of hours for which the internal DRTs exceeded various values (figure 9) indicated that there was no over heating at any of the locations other than London; i.e. the indoor DRTs was never above 27°C for more than 20 hours. In Manchester and Birmingham, there were fewer than 5 hours over 27°C and in Edinburgh, the highest predicted DRT was less than 24°C.

In more northerly latitudes, it is possible that the ventilation openings could be smaller without the space overheating, e.g. 1%, and in Edinburgh perhaps ANV is unnecessary and simple NV alone is adequate to maintain interior conditions.
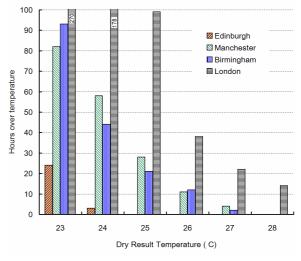

Figure 9 Predicted number of hours for which the internal DRT, when using E-E strategy, will exceed certain values at four locations in the UK: current (DSY 2005) weather data

Phase 3: future performance of ANV

The future projected weather data were used to investigate the likely thermal performance of the E-E strategy (Case 4) for both London and Manchester.
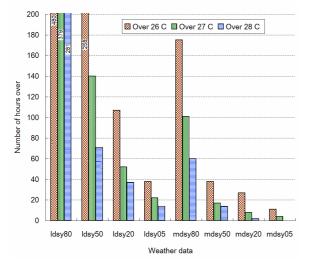

Figure 10 Predicted number of hours for which the internal DRT exceeds various values: current and future DSYs for London and Manchester

Figure 10 shows the predicted number of hours over various DRTs when using the future London and Manchester DSYs. It is evident that the design is able to meet the CIBSE overheating criterion in the current London climate, but not during an extreme (DSY) year of the 2020s. The ANV design is, however, much more resilient to the future climate of Manchester; here the internal DRT exceeds 28°C for less than 20 hours right up to the 2080s.

The thermal response of the ANV design in typical future years is shown in figure 11. In Manchester, the indoor DRTs rarely exceed 28°C even in 2080s, while in London there are more than 20 hours over 28°C by 2050; and by 2080 the overheating risk is severe even in this typical year.

It is evident therefore that, with the assumed internal heat gains, the ANV (E-E strategy) is unlikely to provide an acceptably low overheating risk in southeast of England from around the 2020s onwards.

One solution would be to develop a hybrid design in which the basic ANV approach is supported by mechanical cooling which is strategically used to combat only the hottest conditions; as in the designs of Judson College Library in the US (Lomas et al., 2007) and the Science and Technology Museum Building in China (Ji et al 2008).
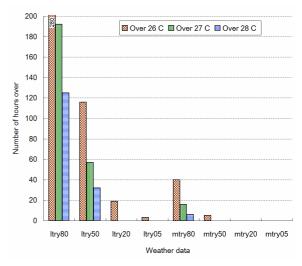

Figure 11 Predicted number of hours for which the internal DRT exceeds various values: current and future TRYs for London and Manchester

Discussion

One of the intentions of this paper was to evaluate the potential differences of the four ANV strategies using the same modelling conditions (heavy weight ceiling, with 1.0m overhang shading, and night cooling, with the London DSY weather data). In fact the preliminary simulation results showed that the edge-in strategies performed rather similarly (figure 12).

The centre-in strategies included an under floor plenum, the construction, volume and inlet area of which, all influence the temperature and volume flow of the air to the offices. Such a plenum was used in the Braunstone Health Centre (Cook & Short 2005). In theory, the plenum will add extra thermal mass into the airflow path, potentially stabilizing the incoming fresh air temperature. The reduced temperature of the air in the plenum, as predicted by the model, is illustrated in figure 13. However, the plenum also puts extra airflow resistance into the system, potentially reducing the airflow. The initial simulations indicate that it would be rather difficult to understand easily the generic performance of such plena and that more work is needed: for example to explore the influence of alternative plenum designs. These matters will be the subject of future work.
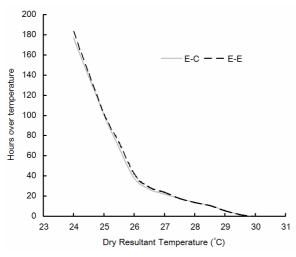
Figure 12 Number of hours over certain temperatures for the edge-in strategies.
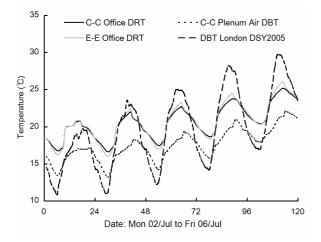

Figure 13 Office DRTs for both C-C and E-E strategies illustrating the effects of plenum.

The overheating criterion used in this work is from CIBSE (2006). This guide also suggests that the risk of overheating may be evaluated by an adaptive approach in which the overheating threshold temperatures varies with the changes in external ambient temperature. The method may more realistically take into account the effect of climate change on the perception of thermal discomfort. It is therefore worthwhile to revisit the work presented here using the adaptive method.

CONCLUSIONS

This paper has evaluated the thermal performances of advanced natural ventilation (ANV) using dynamic thermal simulation tools. A hypothetical ANV design with four commonly used strategies was proposed and simulated. Modelling conditions were developed using the E-E strategy and the current London DSY weather data. The E-E strategy was then used to test the influence of geographic locations and to evaluate the risk of overheating in the future climates of London and Manchester.

The following conclusions can be drawn.

- In ANV designs, the use of sufficient shading, night-time passive ventilation and a heavy weight ceiling can all improve the thermal performance. Overall, the first two of these were predicted to have largest potential to reduce the internal dry resultant temperature (DRT). The heavy weight construction was predicted to have a relatively big impact when office DRTs were in the range of 25°C to 26°C.

- The ANV design was more resilience to the future climate in the north of the UK than in the southeast. Reduced ventilation openings may be possible in the north due to the cooler summer conditions.

- The evaluation of the future anticipated climate has shown that the proposed ANV design and associated internal gains is unlikely to retain an acceptably low overheating risk in the warmer summers in the southeast of England after the middle of this century. The modelled ANV design was however able to maintain thermal comfort until beyond the 2050s in Manchester.

More work is needed in order to address the performances of the two proposed centre-in strategies; which incorporated a thermally massive plenum.

ACKNOWLEDGEMENT

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