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High efficiency non-residential buildings: concepts, implementations and experiences from the UK

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ABSTRACT

The UK has a national target to cut CO₂ emission by 80% of the 1990 figure by 2050. This paper reflects on over 20 year of work into the design and operation of advanced naturally ventilated (ANV) buildings. The alternative forms of ANV building are described and measured CO₂ emissions presented. The resilience of ANV buildings to anticipated changes in the UK climate are discussed.

KEYWORDS

Non-domestic buildings, advanced natural ventilation, carbon emissions, internal temperatures, future climate.

INTRODUCTION

The UK has a target to cut CO₂ emissions by 80% of the 1990 levels by 2050 (TSO, 2008a). In developed European countries, a substantial proportion of CO₂ emissions are due to buildings and the activities within them; in the UK commercial¹ and public² building account for 15% of all direct CO₂ emissions (Carbon Trust, 2009). The Committee on Climate Change (CCC), which sets the

¹ Buildings that are not homes, such as offices, warehouses, shops, etc.

² Public buildings include schools, hospitals, and administration buildings.

UK's five-yearly carbon budgets (TSO, 2008b), sees reduced dependency on centrally supplied energy to heat, cool and light buildings as a key component of the nation's carbon reduction pathway.

The UK building regulations (ODPM, 2006) place limits on the allowable CO₂ emissions control for conditioning, ventilating and lighting non-domestic buildings (so-called regulated energy); unregulated emissions arise from equipment within buildings (computers, lifts, catering etc). Looking forward, the UK government has an *aspiration* that all new non-domestic buildings will be zero-carbon by 2019 with new public buildings leading the way by being zero-carbon by 2018. Consultation documents (HM Government, 2008; CLG, 2009) seek comment on the plausibility of such an aspiration.

When designing buildings without mechanical cooling it is important to assess the risk of summertime overheating. Recently it has become necessary to consider the risk of overheating under the conditions that might be encountered in a future, warmer UK (CIBSE, 2005).

This paper reflects on 20 years of work into the design, realization, commissioning and monitoring of advanced naturally ventilated public buildings, primarily university library and teaching buildings. The CO₂ emissions and internal temperatures of completed buildings are presented and also the predicted resilience of the ANV design concept to a warmer UK climate.

ADVANCED NATURAL VENTILATION

The term advanced natural ventilation (ANV) has become associated with buildings that utilise the stack effect for ventilation, and other passive devices, primarily night ventilation, exposed thermal mass and solar

shading, for summer cooling (Fig 1, Fig 2). Winter heating is usually by low-pressure water-based boilers and emitters. The whole is controlled by a building management system.



Figure 1. The Frederick Lanchester Library, Coventry, UK.



Figure 2. Judson College Harm A. Webber Library, nr. Chicago, Illinois

The present author has acted as the energy and environment consultant to the design teams of more than nine ANV buildings, most with architects Short and Associates. These have used four distinct ANV concepts (Fig 3). The Queens building at De Montfort University, completed in 1991, used the E-C concept and heralded a renewed interest in ANV in the UK (BRECSU, 2000; Asbridge, 1996).

Later ANV buildings included the larger, very deep-plan, Frederick Lanchester Library, in Coventry (2001, C-E and C-C) (Cook et al. 1999; Krausse et al, 2007) (Fig 1). and The Garrick, Lichfield's civic theatre (2003, E-C) (Cook and Short, 2008). More recent buildings have seen the emergence of hybrid ANV concepts; the School

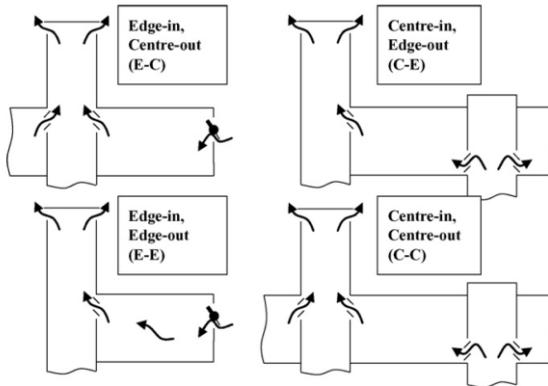


Figure 3, Schematic diagrams of the four ANV concepts

of Slavonic and East European Studies (SSEES) in central London, (2005, C-E) (Short et al. 2004; Short et al. 2009) includes passive downdraught cooling to combat the higher summertime temperatures encountered in the centre of London, whilst the more extreme climates found overseas have seen the integration of ANV with full air-conditioning: the Harm A Weber Library in Elgin, near Chicago, Illinois, USA (2007, C-E and E-E) (Lomas et al. 2006; Short and Lomas, 2007; Lomas et al. 2009) (Fig 2) and the Science and Technology Museum Project of Green Buildings in Hangzhou, China (2009, E-C) (Ji et al. 2009).

In the late 1980's and early 1990's clients tended to commission ANV buildings through a desire to demonstrate concern for the environment and to reduce future operating costs. Much of the design work and analysis was focused on assessing the risk of summertime overheating: it is this consideration that determines the size and location of the ventilation stacks (Lomas 2007).

CO₂ EMISSIONS AND ANV BUILDINGS

The energy benefit of naturally ventilated (NV) buildings in the UK climate was illustrated clearly by the PROBE³ Studies (Bordass et al. 2001). Of 20 UK buildings monitored, 9 of the 10 highest CO₂ emitters were air conditioned (AC) or mixed mode (MM) (these used chilled beams, with displacement ventilation etc.) and 9 of the 10 lowest emitters were NV or ANV. Across all buildings there was a factor of 6 difference in the CO₂ emissions for space conditioning and lighting a given floor area. In the AC and MM buildings the fans and pumps used to move air, water and refrigerant accounted for up to 50% of these emissions and, because AC buildings tend to be deep-plan, the CO₂ emissions from artificial lights were also substantial. Although heat recovery is not possible in NV and ANV buildings, the CO₂ emissions associated with space heating was invariably less than that in the AC and MM buildings. The Lanchester library monitoring illustrated the CO₂ reducing benefits of ANV (Krausse et al. 2007); after accounting for differences in the period of occupancy, emissions were equivalent to 25 kgCO₂ per m². This is around 25% of the benchmark value, used in the UK for the EU energy ratings of university campus buildings.

The hybrid ANV buildings (SSEES and Judson) highlighted the need for thorough commissioning to achieve acceptable performance, but this is often neglected due to the time pressures imposed by the construction programme, and exposed the poor performance and unreliability of some conventional

³ Post-Occupancy Review of Buildings and their Engineering (PROBE) was a research project which ran from 1995-2002. See <http://www.usablebuildings.co.uk/>

actuators and louvers (Short et al. 2009; Lomas et al. 2009). Such problems are a substantial barrier to achieving zero-carbon buildings with performance that does not degrade over the building's life span.

Inefficiencies creep inexorably into complex systems, thereby degrading their overall performance, and AC and MM buildings tend to have complex and hidden energy systems and controls. In contrast NV buildings, tend to be relatively simple with visible, robust and accessible controls – windows, dampers and louvers. Heating is by well-understood low-pressure hot water heating and there is no refrigeration system. Energy management is less onerous and time consuming.

INTERNAL TEMPERATURE & ANV BUILDINGS

The Lanchester library was monitored from June 2004 to June 2005. Because of the exposed thermal mass and the night ventilation, warm days caused minimal rise in internal temperatures. Even during a prolonged hot spell, which included outside air temperatures up to 35.4°C, the internal temperature did not exceed 26.4°C. The building therefore comfortably met the prevailing CIBSE thermal comfort criterion that there should be no more than 1% of occupied hours with a dry-resultant temperature above 28°C (CIBSE, 2006). An occupant survey indicated that the library operated very successfully and was popular with its users. Above all, occupants expressed satisfaction with the indoor air quality (Krausse et al. 2007).

The resilience of ANV buildings to the likely future climate in London and Manchester was assessed by predicting the dry-resultant temperatures in a simple, rectangular, 26m² space that had an E-E ventilation concept (Lomas and Ji, 2009). The ANV designs were compared to a space with simple natural ventilation

(SNV). The analysis included variations in the exposed thermal mass, window area, window type, orientation, ventilation opening areas⁴, orientation, glazing type and internal heat gain (Table 1). The energy use and CO₂ emissions for heating, fans, lights and equipment was compared to figures for a mechanically ventilated, but not AC, space. The risk of overheating was assessed by comparing the predicted internal temperatures with the boundaries defined by the European adaptive thermal comfort standard (BS EN 1251, 2008)⁵.

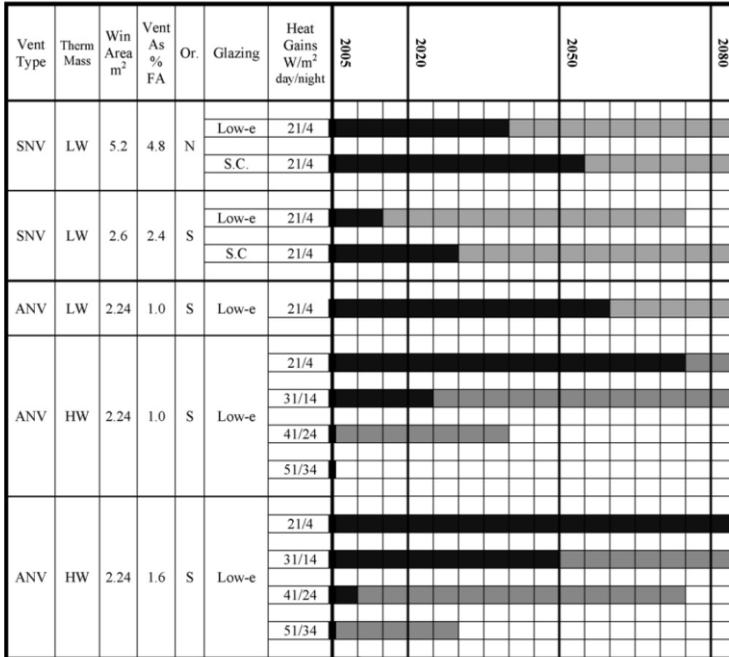
The typical future weather was constructed using a morphing algorithm that shifts and stretches current weather data files based on projected mean monthly temperatures for 2020, 2050 and 2080 (CIBSE 2005)⁶. In 2080 the peak temperatures are 6K higher than at present in London and Manchester; the projected peak temperature in London in a *typical* 2080 year was 36°C.

The simulations showed that the ventilation area needed in ANV buildings was much less than in buildings with SNV. The concept of ‘life-expectancy’, i.e. the time before the overheating risk becomes unacceptably high,

⁴ Vent. opening area was expressed as a % of the floor area (FA), ceilings were either exposed concrete or light-weight tiles (HW), window glazing was either of low-emissivity (Low-e) or high performance solar control, high light transmission (SC).

⁵ The work firstly entailed defining an indicator of unacceptable overheating risk as the standard doesn’t provide such a figure. This was taken as 130hrs outside the Cat 1 comfort boundary.

⁶ TM36 (CIBSE 2005) uses mean monthly temperatures generated for the UK Climate Impacts Programme 2002 for a medium-high global emissions scenario called National Enterprise. This yields temperatures towards the upper end of all the temperature rises projected by various development scenarios, but not the highest.



Bars extending to right of 2080 hours indicates space has less than 130 hours over the adaptive temperature limit even in 2080. Data plotted to nearest 5 years.

Fig 4. Impact of design on future overheating risk: the bars indicate the time before the risk of overheating becomes unacceptable in London (dark bar) and Manchester (light bar). Source: Lomas and Ji, 2009.

was introduced to evaluate the effect of future climates. Life expectancy depended primarily on location, internal heat gains, ventilation area and exposed thermal mass, in this order. For a well designed ANV building predicted life expectancy in the London area was around 45 years (i.e. until 2050) for an internal gain of 31 W/m² and a ventilation area of 1.6% FA. In the Manchester area this extended to over 75 years. Additional gains of 10 W/m²

reduced life-expectancy in both Manchester and London by 40 to 50 years.

The CO₂ emissions associated with even a modest internal electrical load (15 W/m²) represented as much as 60% of all the emissions from the well designed and controlled ANV space. This fraction increased as heating energy use declined in the warming climate.

CONCLUSIONS

Analysis and experience over a 20 year period led to some useful conclusions with regard to ANV buildings in a low-carbon and warmer world.

1. Well designed ANV public buildings are capable of providing summertime thermal comfort in all areas of the UK, except, perhaps, London and inner cities that have a substantial urban heat island.
2. ANV buildings tend to have much lower CO₂ emissions than AC, MM or mechanically ventilated buildings. Control of ventilation openings is crucial to achieving this low-carbon performance.
3. The promises of lower heating energy use offered by the heat recovery and energy management systems of mechanically ventilated buildings do not seem to materialise in practice.
4. The poor performance and lack of durability of key components, and the difficulty of understanding, commissioning and managing complex systems contribute to increased CO₂ emissions.
5. In NV buildings, the risk of overheating in a future, warmer UK climate is significantly influenced by location, internal heat gains, ventilation area and thermal mass.

6. Controlling internal heat gains, especially electrical loads has an important, and increasing, role to play in mitigating, and adapting to, climate change.

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