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Architectural design of an advanced naturally ventilated building form

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Abstract

Advanced stack-ventilated buildings have the potential to consume much less energy for space conditioning than typical mechanically ventilated or air-conditioned buildings. This paper describes how environmental design considerations in general, and ventilation considerations in particular, shape the architecture of advanced naturally ventilated (ANV) buildings. The attributes of simple and advanced naturally ventilated buildings are described and a taxonomy of ANV buildings presented. Simple equations for use at the preliminary design stage are presented. These produce target structural cross section areas for the key components of ANV systems. The equations have been developed through practice-based research to design three large educational buildings: the Frederick Lanchester Library, Coventry, UK; the School of Slavonic and East European Studies, London, UK; the Harm A. Weber Library, Elgin, near Chicago, USA. These buildings are briefly described and the sizes of the as-built ANV features compared with the target values for use in preliminary design. The three buildings represent successive evolutionary stages: from advanced natural ventilation, to ANV with passive downdraught cooling, and finally ANV with HVAC support. Hopefully the guidance, simple calculation tools and case study examples will give architects and environmental design consultants confidence to embark on the design of ANV buildings.

Keywords: Low energy buildings; Advanced natural ventilation; Ventilation areas; Case studies; Downdraught cooling

1. Background

The imperative of reducing the emission of greenhouse gases, and in particular CO_2, caused by the burning of fossil fuels has stimulated interest in the design of low energy buildings. In the 20 buildings monitored by Bordass et al., in the well known UK PROBE Studies [1] there was a factor of 6 difference in the CO_2 emissions produced for space conditioning and lighting a given floor area (Fig. 1). Nine of the 10 highest CO_2 emitters were air-conditioned (AC) or mixed mode (MM) (these used chilled beams, with displacement ventilation, etc. rather than full AC), and 9 of the 10 lowest emitters were naturally ventilated (NV) or advanced naturally ventilated (ANV). The term 'advanced natural ventilation' was coined to encompass buildings which utilised the stack effect to drive an air flow and so has been adopted for the buildings which are the subject of this paper. In the AC and mechanically ventilated buildings, the CO_2 emissions resulting from the fans and pumps required to move air (and water and refrigerant) accounted for up to 50% of the emissions associated with space heating and cooling. Because AC buildings tend to be deep-plan, the CO_2 emissions for artificial lights were also substantial. Buildings which are particularly densely occupied, with long periods of usage and with high internal heat gains (e.g. from computers and other equipment) might justify the use of AC, but as the PROBE results show, some relatively lightly used buildings nevertheless had AC.

NV and ANV buildings utilise naturally occurring wind pressures, and/or the buoyancy force generated by internal heat sources, to drive an air flow, thereby avoiding the use of fans. Admitting cool night air into a building, to purge daytime heat accumulated in exposed thermal mass, can avoid the need for mechanical cooling entirely or, in warmer locations, reduce cooling loads, energy use and associated CO_2 emissions. Shallow-plans, which typify simple NV buildings, or the use of atria and lightwells in deeper-plan buildings, can improve the use of natural light reducing the CO_2 emission associated with artificial lighting.

Whilst global warming is seen as a treat to NV and ANV buildings, the overheating risk can be overstated. Current

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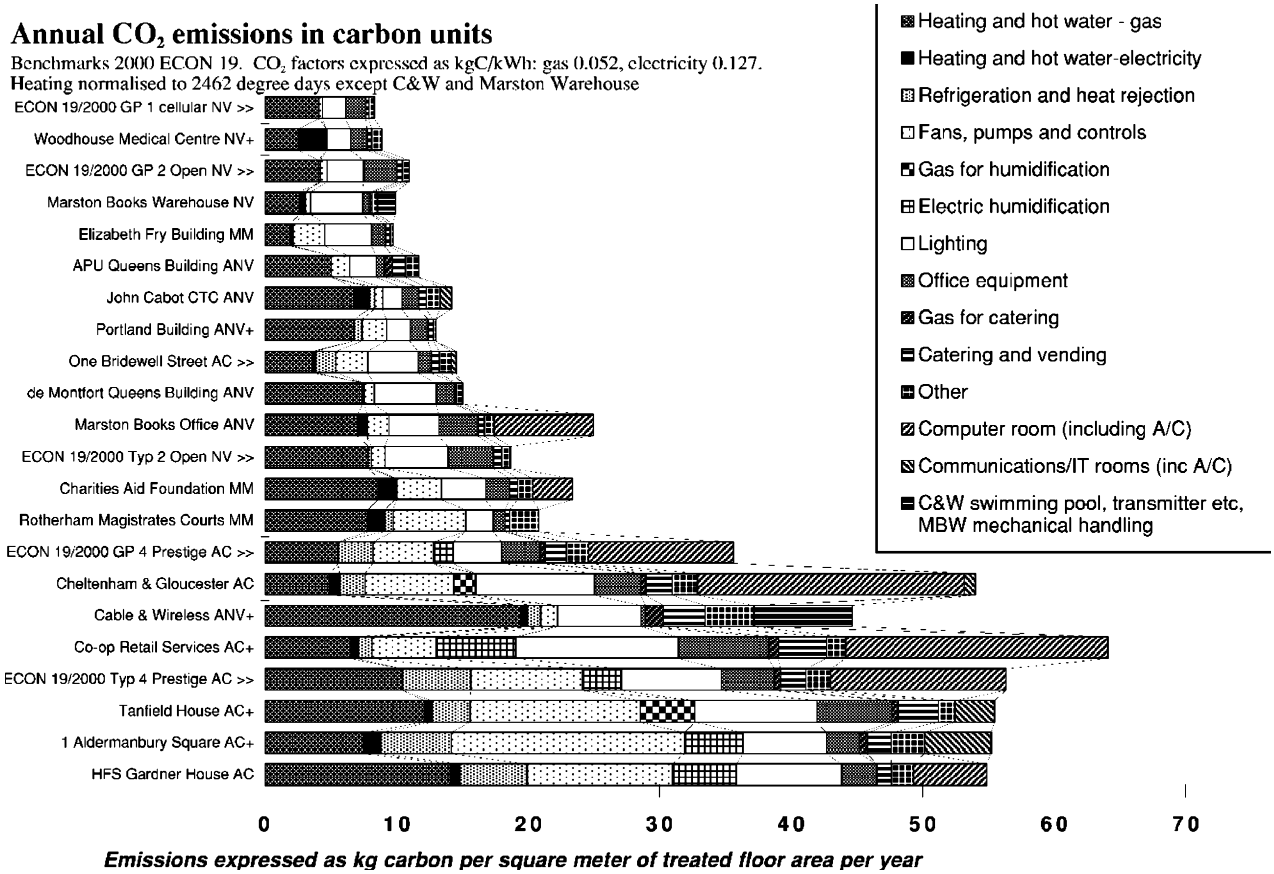

Fig. 1. The CO_2 emissions from 20 buildings and ECON19 [32] benchmarks.

evidence for the UK, although rather weak, suggests that ANV can keep buildings comfortable though the next century in all but the hottest (London) region [2,3].

Conventionally conceived NV buildings are shallow plan with an extended perimeter, and façade openings which provide the fresh air inlet and exhaust air outlet (Table 1). These features can be incompatible with the planning constraints imposed by tight urban sights and the noise and pollution in city centres. The use of manually operated windows can compromise security, increasing concerns about theft by building occupants (a particularly important consideration for library buildings of the type described in this paper). Mechanically controlled perimeter windows enable night ventilation but the building may then be vulnerable to break-in or other malicious acts.

At the design stage an ability to reliably predict the likely internal conditions in a building, for example by using dynamic thermal models and computational fluid dynamics programs, can be reassuring and it is important to have a clear idea of how the internal conditions in the finished building will be controlled. Relying, as they do, on variable and ill defined pressure differences set up across the building by the wind, the likely performance of simple NV buildings is hard to predict and control.

ANV buildings that utilise the stack effect, in which air warmed by internal sources of heat drives the air flow, do not necessarily rely on wind pressures. If properly designed and controlled, an air flow can be assured at all times when there is an internal source of warmth, including at night. In fact, in an unconstrained displacement flow regimen, where heat sources generate isolated plumes of warm air, the flow rate is directly proportional to the strength of the source, and the interface between the cooler air the warm air above remains fixed [4]. With heat sources distributed over a surface, the air flow is also dependent on the source strength in steady state conditions [5]. This happy coincidence, between heat input and air flow rate, enables rather simple but robust control of air flow and makes prediction of performance at the design stage comparatively reliable. Further, the interface between the cool and warmer air can be designed to lie above head height.

The benefits of control-ability and predictability, which stack driven natural displacement ventilation offers, can be lost if wind pressures begin to dominate the flow. An inability to harness these pressures is not a disadvantage; after all it is during still warm summer conditions when it is most difficult to keep ANV buildings thermally comfortable. Therefore, designing the buildings to be 'wind neutral' is a useful guiding principle.

In a recent paper [2] a taxonomy was proposed, in which stack ventilated buildings were divided into four main types (Fig. 2). The edge-in, centre-out approach (E-C) is exemplified by the Queens Building at De Montfort University, Leicester, UK [6–9] and the edge-in, edge-out strategy (E-E) by the UK Building Research Establishment's (BRE) Energy Efficient Office of the Future [10].