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Natural versus mechanical ventilation: Towards sustainability

Luisa Brotas and Fergus Nicol
Low Energy Architecture Research Unit, London Metropolitan University, London, United Kingdom, l.brotas@londonmet.ac.uk

Abstract
Achieving a pleasant indoor environment with low energy consumption is a major goal of good building design. With high levels of insulation to reduce fabric heat losses, heat loads associated with infiltrations in dwellings in the UK have gone up from one fifth to one third. This has made it imperative to reduce infiltration rates to a minimum consistent with good air quality. There is a trend to promote the use of mechanical ventilation with heat recovery as the way to reduce the heating loads significantly and promote good indoor conditions. But comments given by occupants in *Passivhaus* expressed concerns that opening windows will result in energy use exceeding required limits. Generally, studies have shown that occupants are not in favour of fully air conditioned or spaces with non-opening windows. This paper looks at the impact on indoor air quality and comfort levels for the occupants of natural and mechanically ventilated spaces. Results from a monitoring survey in dwellings are presented.

Keywords: natural ventilation, mechanical ventilation with heat recovery, indoor air quality

Introduction
Achieving a pleasant indoor environment with low energy consumption is a major goal of good building design. Recent concerns about greenhouse gas emissions associated with CO2 from buildings, the security of the energy supply and the rising price of oil, make reducing demand, promoting energy efficiency, diversifying the energetic resources and the adoption of renewable energies priority strategies to reduce the exterior energy dependency and reduce GEE emissions. (HMG, 2011; DECC, 2009)
More broadly, the European Commission presented the directive EPBD focussing on the energy performance in buildings. Within this context, the European Parliament resolution of 31 January 2008 on an Action Plan for Energy Efficiency: Realising the Potential "calls on the Commission to propose a binding requirement that all new buildings needing to be heated and/or cooled be constructed to passive house or equivalent non-residential standards from 2011 onwards, and a requirement to use passive heating and cooling solutions from 2008". (EPR, 2009)

With a requirement for high levels of insulation to reduce fabric heat losses the weight of heat loads associated with infiltrations in dwellings in the UK have gone up from one fifth to one third. This has made it imperative to reduce infiltration rates to the minimum levels required for air quality.

There is an increasing tendency to promote the use of mechanical ventilation to control infiltration including heat recovery as the way to significantly reduce the heat loads associated with infiltration and to promote good indoor conditions. (ZCH, 2012)

Indoor Air Quality

Indoor air quality (IAQ) and associated health problems have become much more problematic in air sealed buildings. Asthma rates are rising in industrialised countries in particular in the younger generation. High levels of pollution outdoors have certainly aggravated the situation. As people spend most of the time indoors it is fundamental to have a good ventilation system to remove combustion gases, allergens and other irritants. Damp, mouldy and poorly ventilated homes have led to an increased exposure to house-dust mites and mould spores, increasing the risk of respiratory symptoms and exacerbation of asthma. (Asthma UK, 2012)

However airborne contaminants are not present in equal measures in all buildings and depend on building materials and furnishings and occupation patterns. In the eighties The World Health Organization (WHO) identified the phenomenon Sick Building Syndrome (SBS). Some causes were associated with mechanically ventilated buildings, internal surfaces finishes, warm homogenous environment, and air tight spaces with windows that can't be opened. Inadequate fresh air was suggested as being a contributory factor to sick building syndrome. (Rostron, 1998)
Whereas this phenomenon was aggravated in non domestic buildings, it is important that mistakes leading to SBS are not repeated in the search for low carbon domestic building solutions. While buildings are becoming more airtight the source of contaminants (chemicals, biological and humidity) are also rising. Dwellings constructed mainly from natural or benign materials and surfaces with hygroscopic properties will have a better IAQ than those which are constructed from a higher proportion of synthetic materials. (Watkins, 2011)

Poor IAQ has an adverse affect on health and comfort. The effects of harmful air contaminants can range in severity from perception of unwanted odour to cancer or even asphyxiation. However groups of people such as eldery, children, pregnant women and people suffering from respiratory and cardiovascular diseases are more vulnerable to lower levels chemical concentration than those recommended in toxicological databases (SCHER, 2007; Carrer, 2009)

Ventilation in low carbon homes

It is generally recognized that uncontrolled infiltration should be minimized to avoid unwanted heat loss in winter and heat gains in summer. Air tightness standards in construction vary enormously throughout Europe, but legislation is moving towards low rates of air infiltration. In the UK sample pressure tests have become mandatory to assess air tightness in residential buildings. More stringent conditions in testing effectively tighten the requirement to prevent failures. (HMG 2010a, 2010b)

The *Passivhaus* standard, developed in Germany, defines requirements for very-low energy homes. Strategies adopted in cold climates consist of a highly insulated envelope combined with reduced air losses and a mechanical ventilation system with heat recovery. In England and Wales, level 5 of the Code for Sustainable Homes corresponds to the Passivhaus standard in terms of energy ratings. Requirements for all new homes to be zero carbon by 2016 give grounds to the development of strategies to save energy while promoting its clean generation. On-site, near and off-site carbon savings must still to be thoroughly evaluated, in particular as regards economical and technical feasibility. A clear definition of what is a zero carbon House still needs to be clearly defined. Prescriptive solutions to maintain and control very low ventilation rates are gaining currency amongst architects.

In many climates, Passivhaus requires a mechanical supply and exhaust air ventilation system with heat recovery. In this case, excellent airtightness of the building envelope is required. If the envelope is not sufficiently sealed, the airflows will not follow the intended paths, the heat recovery will not work properly, and the energy consumption will rise. In mild climates, it is possible to build Passivhaus without heat recovery systems. In such a case, if no ventilation system is present, air tightness is not quite as important. Conversely, very airtight buildings without ventilation systems run the risk of bad indoor air quality and excess humidity.

The question arises whether people feel satisfied within a domestic environment where they have no control over air-change rates. Comments given by occupants in *Passivhaus* expressed concerns about opening windows because this would disturb the air flow: this could result in energy consumption above the limits required by the standard. (Brotas, 2008)

Results from the Passive-On project showed that the Passivhaus proposal can also be less restrictive in terms of air tightness in particular on milder climates and where traditionally people are used to open windows to refresh and ventilate the spaces. Natural ventilation can be used very effectively to provide fresh air and improve comfortable and hygienic conditions for occupants. Despite the variability and difficulty in controlling natural driving forces, natural ventilation can reduce energy consumption, and the capital and running costs of mechanical and electrical plants as well as saving space for their installation. Also avoiding air conditioning units may reduce health conditions associated with poor maintenance and re-circulation of air. (Passive-On, 2012)

The adoption of passive strategies for heating and cooling, including infiltration and ventilation for cooling, is a fundamental step towards sustainability. Unfortunately, existing strategies such as solar air pre-heating have been replaced with mechanical systems with heat recovery. The adoption of a prescriptive approach such as MVHR (Mechanical Ventilation with Heat Recovery) is an easy way to comply with regulation requirements but avoids the challenge of designing the building to take account of site opportunities and constraints, and also reduces occupant control over the environment. Several studies have shown higher levels of occupant's satisfaction in office spaces where people can take action to restore their comfort levels. Generally, occupants are not in favour of fully air conditioned or spaces with non-opening windows. (Nicol, 2002; Raja, 2001; Wagner, 2007)

Towards zero carbon homes

Davis (2008) undertook a survey to homeowners and housebuilders to assess their knowledge of zero carbon homes and feasibility of building them to live in. A number of areas of concern and potential barriers to achieving the 2016 goals were raised. A significant lack of understanding of the targets proposed to reducing carbon emissions and tracking climate change is acknowledged.

The main drivers for energy efficient homes are cost savings and the return on investment. Environmental concerns are a secondary priority. Most have not taken any significant or meaningful steps to reducing their own carbon footprint. In practical terms people are not willing to compromise their lifestyle to adopt zero carbon homes. A new kitchen is a priority over energy efficiency measures. Homeowners are quite reluctant to give up gas appliances and power showers.

Technical specifications and maintenance issues are often misunderstood. There is general perception that fresh air is required to maintain the health of both a home and its occupants. Airtightness is mainly associated with drafts from windows and doors and concerns were expressed that increased airtightness may restrict access to fresh air and ventilation. 76% of homeowners would be put off by the increased airtightness that is a feature of zero carbon homes.

Conversely housebuilders are optimistic about their ability to build to required standards. However, they are concerned about the air quality, condensation and mould growth in the building, the welfare of homeowners, and the service and maintenance required by mechanical ventilation systems. With very low infiltration rates mechanical systems are likely to be required which may counteract the reduction of electrical appliances and may lead to owners switching off the system to save energy. People are also keen on opening windows to gain fresh air thereby reducing energy efficiency.

Many housebuilders do not believe that Code Level 6 homes can be built profitably by 2016 and 42% of builders expect homebuyers to have to pay more for a zero carbon home. (Davis, 2008)

The Zero Carbon Hub has recently published an interim report on mechanical ventilation with heat recovery. Stringent building regulations requiring high energy efficiency with reduced infiltration loads promotes the trend for mechanical ventilation with heat recovery as the main type of ventilation in new buildings. (ZCH, 2012)

The Ventilation and Indoor Air Quality (VIAQ) Task Group was created to address both the benefits of airtightness in reducing CO_2 emissions and the potential problems associated with indoor air quality. Their report highlights health concerns, technological problems associated with the design, installation, operation and maintenance of mechanical systems and recommends better advice for the users. Although the timeframe of 2016 for the government commitments is close and actions need to be taken to achieve the goals, a call for better evidence on these concerns is wise.
It is unfortunate that other forms of ventilation allowable under Part L and F of Building Regulations have been dropped. This effectively puts natural ventilation as well as passive strategies aside. The report acknowledges the lack of studies in indoor air quality in new homes, but expresses the worrying concerns with high levels of pollutants. This has also been reported in Europe. MVHR may achieve the proposed objectives for reducing CO2 emissions and promote good indoor quality if it is correctly operated. However, risks associated with poor maintenance and variable occupants' behaviour seriously compromises the results and may even lead to a worse

scenario in terms of energy use and healthy environment than with a simple ventilated system.

Crump (2009) reviews a series of results from existing studies on buildings throughout Europe constructed or refurbished to Passivhaus standard or with mechanical ventilation systems. In Netherlands, Hasselaar, 2008 (in Crump, 2009) refers to the indoor environment in passive houses and other low energy houses. Generally occupants were positive about the small temperature fluctuations and good acoustic shielding from the outside. Negative comments related to temperature differences between living and room, the noise from fans and airflow in dampers, the occurrence of low ventilation volumes in bedrooms, unfamiliarity with the complex system and concerns about potential maintenance costs.

Around 40% of the residents of newly constructed properties reported health complaints (nose, eye irritation, headache, tiredness and insomnia) which they associated with the heat recovery ventilation system. Ventilation capacity was generally below requirements and the quality of the indoor environment was inadequate in respect to noise, draughts, CO2, formaldehyde and high indoor temperatures in summer.

Dirty filters have resulted in 15% to 20% air reduction in the Dutch report. The frequency of cleaning of filters and units is 6 months to one year, the MVHR unit once in 8 years and ducts after 15 years or longer. Design solutions proposed included a close kitchen and drying area, filter cleaning every 2 weeks, indoor maximum acoustic levels of 28 to 30 dB(A), heat recover ventilation to be used only when heating is required and a permanent basic natural ventilation allowing safe summer and night use.

Mechanical vs natural a case study

Watkins (2011) undertook a comparison between three airtight buildings and a Victorian one with original features, assumed to have high infiltration rates.
The first case study is a Victorian terrace house, which still has its original windows and is therefore assumed to be leaky. This house relies on natural ventilation.
The second case study in Poets Road was designed by Bere Architects to be low energy and ecologically sound. It is mechanically ventilated with heat recovery.
The third case study was also designed by Bere Architects with passivhaus requirements (not tested). It is mechanically ventilated with heat recovery.
The fourth case is a refurbishment of a Victorian mid terrace dwelling in the year before the monitoring. Only the front facade of the house was retained. The house was designed using the Pasivhaus principles to achieve minimal energy use. This aim was well communicated to the builders to guarantee the success of the project. The house is mechanically ventilated with heat recovery.
Two monitoring periods include late summer (25th August and 20th September) and early winter (21st October and 23rd November) to give an indication of the conditions in warm and cool weather. Temperature and relative humidity were recorded every 15min with Thermocron i-buttons. These were tested in advance to ensure consistency of recordings.

Table 1: Details of the ventilation strategies for the case study

Case	**Name**	**Ventilation (background)**	**Ventilation (purge) geometric free area of window fully open**
1	Lavender Hill (South London) – Victorian house (Longbeach)	Whole house – unknown -leaky	3.2 m^2 (Room with 18m^2)
2	The Muse at Poets Road (North London)	Whole house - Air tightness not tested. Summer by-pass activated during monitoring period	2.1 m^2 (Room with 16.5m^2)
3	Focus House (North London)	Whole house - 4.5AC/h @ 50 Pa (96% efficiency heat recovery). Total 4.6m^3/m^2h	1.9m^2 (Room with 20.2m^2)
4	Culford Road (North London)	Whole house 1.3AC/h @ 50 Pa. Total 1.1m^3/m^2h	1.5m^2 (Room with 12.9m^2)

Figure 1 shows temperatures at the bedrooms for all cases. Case study 3 (Focus House) shows consistently higher temperatures that the other cases. It is also the case that presents higher thermal amplitudes during the day. This is surprising given the fact that amongst the three mechanically ventilated houses it is the one with possibly higher infiltration rates. Temperatures are fairly high often above 25 C. The naturally ventilated house (Longbeach House) presents the lowest temperatures throughout the summer period. However temperatures are fairly close to the Muse and Focus houses (both mechanically ventilated). Temperatures in these three houses are fairly constant during the day.

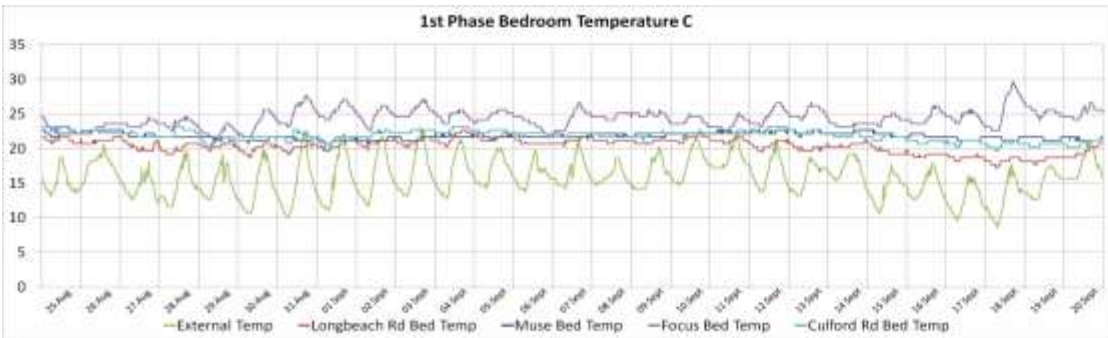

Figure 1:1st phase bedroom Temperature for all case studies (Image courtesy of Christopher Watkins)

Figure 2 presents the relative humidity for the summer period. The Longbeach house shows the higher humidity levels, which is consistent with the lower temperatures recorded. Maximum outdoor levels are quite high but all the houses show a relatively stable humidity levels within the 30% and 75% band. Humitity levels at Focus House are the lowest and show high fluctuations throughout the day.

Figure 2: 1st phase bedroom RH for all case studies (image courtesy of Christopher Watkins)

Figure 3 presents the recorded temperatures during the winter period. Outdoor temperatures range between 2 and 18˚C while the indoor temperatures are fairly constant between 14 and 27˚C. Temperatures of the Muse and Culford Houses remain quite constant during the day. The latter follows the pattern of the cold outdoor spell during the second week of November. The naturally ventilated house has around 5˚C daily fluctuations.

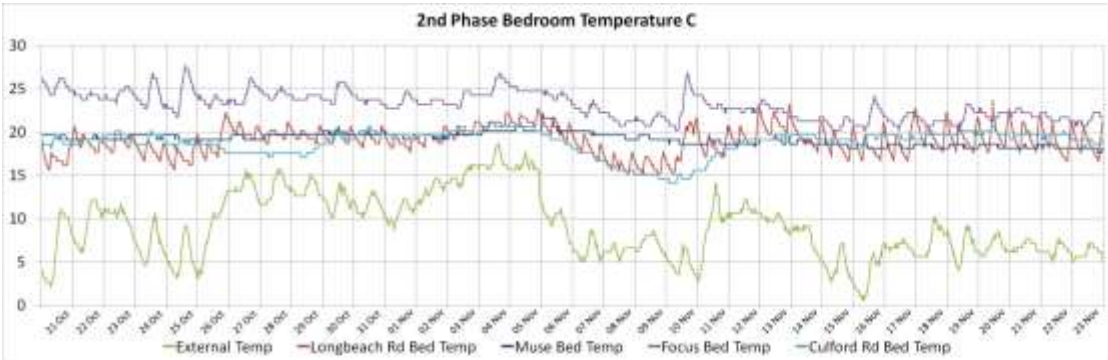

Figure 3: 2nd phase bedroom Temperature for all case studies (Image courtesy of Christopher Watkins)

The relative humidity of all houses is within recommended levels around 28 to 72% while the outdoors varies between 69 and 100%. (see figure 4) The RH of Longbeach and Muse and Focus are fairly similar and above 45%. The Focus house presents the lowest values and with higher daily fluctuations.

Figure 4: 1st phase bedroom RH for all case studies (image courtesy of Christopher Watkins)

Conclusions

There is an urgent need to effectively tackle climate change and reduce the GEE emissions from buildings. UK has set ambitious targets but needs to implement realistic mechanisms to avoid failure and compromising the comfort and health of the users of buildings.
Clearly promoting energy efficiency and minimise the heating and cooling loads is the way forward. But the occupants need to feel safe and satisfied with their environment. A debate is ongoing about whether the reduction of infiltration to minimum levels and provided by mechanical means is more effective than natural ventilation relying on passive systems. Both sides claim energy savings and improved occupants' satisfaction. However a rising number of indoor pollutants in buildings may seriously compromise both approaches. There is a need to address the toxicity of material in the design and selection of finishes and furniture. Given the trend for airtight spaces toxicity ought to be included in the assessment of buildings. Further studies in real scenarios combined with post occupancy surveys are much needed. Given the lack of studies contemplating indoor quality in low energy buildings with and without mechanical systems it seems wise to promote both mechanical and natural ventilation.
Designers, house builders and house occupants need to be clearly advised on the changes that will affect their lifestyle and the way buildings are used both in new and refurbished houses. A survey undertaken by Davis 2008 highlighted the current scenario. Occupants seem to be quite reluctant to make changes but possibly due to lack of understanding of the situation. House builders seems to be optimistic with technological innovations but the market may not reflect this. Further mechanisms to disseminate information need to be promoted.
Environmental concerns are still not embedded in society. Home owners rather spend money in fittings than on implementing energy efficient measures or renewable energies.
Analyses of temperatures and relative humidity in 3 mechanically ventilated houses with heat recovery against a naturally ventilated house are fairly similar and to not clearly justify the benefits of one system against the other. There are several factors that may contribute to this situation, one being the occupant's behaviour. It is unclear what was the energy consumed for heating during the monitoring periods therefore it is not possible to elaborate what is the low energy house.

It is interesting to note that the three houses designed to be low energy and relying on mechanical ventilation present very different pressure tests. This may be representative of the problem the building industry may face to achieve airtightness.

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