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Investigation into the interaction between indoor climate, activity and passive cooling on occupants of low energy buildings.

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ABSTRACT: This paper explores different conditions arising through a series of ventilation air flow rates in low energy 'free running' buildings. The air flow rates have an interaction with occupant levels and activity within the building. One climate file is used to gauge a variety of scenarios in a single floor of a low energy office building. These scenarios are tested in a hygrothermal whole building simulation modelling software that allows interaction between a set indoor climate condition with varying occupancy levels and activities. The impact on the building occupant is the main area of assessment, to address potential issues/areas of concern when applying such a passive design strategy for future building solutions and closing the gap in energy performance from inception to occupancy.

Keywords: energy, thermal comfort, hygrothermal, passive cooling

INTRODUCTION

Since recent EU legislation to improve building performance, and recent debate in the UK on defining zero carbon [1], enormous focus has turned to ventilation and building fabric in construction. There are still areas of research needed to interpret occupant satisfaction of living/working within these improvements, building on studies referenced in this paper [2, 3, 4, 5] and on occupant health. Much has been written in relation to standards of thermal comfort, adaptive thermal comfort, health of building occupants, and risk of mould/condensation on building fabric [6, 7, 8, 9, 24]. A large amount of these findings have been based on standard thermal comfort and occupancy values, or standardized energy rating software assumptions that don't convey true reflection of the interaction of all parameters in one model [10].

Recent developments in numerical hygrothermal simulation have lead to the development of whole building 3D simulation [11]. This takes into account heat, moisture and energy calculations. This paper attempts to examine scenarios based on a non-mechanical ventilated approach in a storey level of a low heat demand office building in this way. In an era where embodied and operational energy are being examined in the context building performance, the impact on the occupant and how this may influence our future use of these buildings is of huge importance [12].

LITERATURE REVIEW

Nicol & Humpheys et al [13], and their term 'adaptive thermal comfort', challenge that a constant temperature energy standard such as Passivhaus doesn't allow for user control of occupants own thermal comfort. They emphasise the benefits of 'free running' naturally ventilated buildings. 'If a change occurs so as to produce discomfort, people

react in ways which tend to restore their comfort' [14] gives rise to their proposal of a need to control thermal comfort on an individual basis. This is at odds with other such studies as the CEPHEUS study in Germany documenting the satisfaction levels of Passivhaus occupants [15]. The Passivhaus approach deals with thermal comfort on an 'index' basis [14] expressing the thermal state of the body, looking at the five classic parameters: temperature, humidity, air movement, clothing levels, and activity [16, 17].

With occupant interaction with ventilation, deDear and Brager cite occupant 'expectations' differing when it comes to naturally and mechanically ventilated buildings [18]. Nicol & Humphreys counter that it is the temperature that people expect and not the ventilation approach in a particular building situation [14]. The user interaction and number of occupants affect both approaches. It seems there are two belief systems in place for low energy buildings and ventilation strategies. The Passivhaus approach demands a constant fresh air supply and also temperature is supplied on an hourly basis to their low energy building model [19]. Nicol et al propose that more energy savings existing in design whereby one ability to adapt their thermal comfort more freely [13].

Previously [12] it has been outlined that there is difficulty at design stage identifying interaction between a predicted indoor climate and occupant interaction with this in reality. In a previous study on a low energy building, the occupant activity was not defined when investigating the differences between ventilation methods [10]. To illustrate passive cooling effects, particularly in low energy buildings where both solar gain and internal gains have higher impacts in the overall energy balance, the nature of occupancy is important in relation to the adaptive thermal comfort approach.

Indoor humidity depends on three variables: the building use, thermal conditions (i.e. solar gain, temperature) and ventilation conditions (main ventilation strategies) [11]. Humidity internally is the cause of many issues in buildings, a potential 'hazard' to health that ventilation strategies can impact on [21]. WUFI®plus is a room climate model which connects the energy building simulation and the hygrothermal (heat and moisture movement) calculation, developed by the Fraunhofer Institute of Building Physics Holzkirchen Germany. It allows for specific data to be entered about cooling, heating, occupancy, and this can be regulated according to months of the year/time of day. Occupancy and activity rates can also be entered, allowing for room by room heat and moisture behaviour to be analyzed [11]. A site specific outdoor climate is also assigned within the model. It is a significant developing software alongside the more established stable of WUFI Pro 1D and WUFI 2D [11].

METHODOLOGY

A single compartment of an upper floor of an office building is modelled with WUFIPlus. The floor plate is 96m^2 and main orientation is south west facing. There is a typically large glazed unit on this elevation, with smaller openings to the north. The south eastern wall is fully exposed, whilst the north western wall is a party wall to a room with the same inner climate conditions as that which is being modelled. The building fabric and air tightness are designed close to the Passivhaus standard in relation to U Values etc.

An adult, at rest, gives off 43 $g.h^{-1}$ of moisture, 36 W of radiant heat, 65 W of convective heat and 30.3 $g.h^{-1}$ of CO_2. At middle activity, these figures change significantly to 123 $g.h^{-1}$ 47 W 158 W and 60.5 $g.h^{-1}$ respectively. The interaction of ventilation rate and occupancy levels with the activity impacts on the optimum temperature, moisture and CO_2 levels required for comfort and health in any indoor climate. Two varying flow rates of ventilation (natural) are modelled, based on recommended figures from other sources. Two activity levels at resting position and in middle activity are evaluated. Other internal gains are not included in this paper. The outputs analysed are relative humidity and temperature levels, with CO_2 concentration tabulated separately. By graphing these results in a clear format, any relationship between air flow, occupancy and potential health/comfort 'hazards' will be examined.

The recommended ventilation rates for offices that are naturally ventilated for this area, according to CIBSE Guide A [25] are 10 $l.s^{-1}$ per person (3 $ach.hr^{-1}$ approximately). In a smoking area, this increases to 45 $l.s^{-1}$ per person. The Passivhaus recommends a minimum air change rate of 0.3 air changes per hour, which is less than 1 $l.s^{-1}$. The Passivhaus model is different to the approach being tested in this paper, as it is a temperature constant approach, and involves strict criteria about using controlled mechanical ventilation with heat recovery to ensure a controlled amount of ventilation is maintained [19].
Based on some of this information, the chosen flow rates for this paper are 3 and 10 $l.s^{-1}$ per person, based on the typical recommended value and a sample reduced value to examine. They are called ventilation rate A and B in the results section respectively. In summer as a free running building capable of adaptive thermal comfort the model assumes a purge ventilation level of 500 $l.s^{-1}$ from 8am to 6pm between the 01/06/12 and 01/09/12 as a representation of possible overheating in summer being passively dealt with by the occupant. This was constant in both sample ventilation rates. The model is simulated over 8760 hours (12months) from 1st October 2012-1st October 2013. A heat source of 20kW is handling heating load for the heating period.

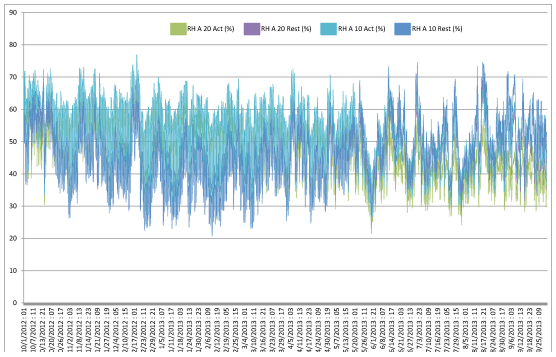
RESULTS

Air flow rate A: 3 $l.s^{-1}$ per person

For the lower air change rate the relative humidity stays broadly between 30-70%. There are large weekly swings consistently for all occupancies and activity levels in summer. The resting occupancies have lower relative humidity in summer than the rest of the year where much of the time is above the 50% threshold. The temperature is above 20°C for all occupancy levels and activity rates apart from some weeks in December/January for the occupants at rest. For 70% of the year excluding summer the resting occupancies stay below the 25°C threshold and are moderately comfortable. This combined with large swings of RH is not comfortable as defined by EN7730.

For the 10 resting and active occupants, the result ranged from 16.2-31°C and 17.4-35.8°C respectively. The RH values ranged from 20.8-74.5% and 22.2-76.9% respectively. The overheating temperature went up but the RH stayed within approx 2.5% difference. For the 20 resting and active occupants the temperature range was 15-33.3°C and 17-42.5°C respectively. The RH was 23.2-71.3% and 21.5-71.3% respectively. There

was a much larger overheating swing in these results but practically no change in RH levels (fig 1).
The heat loads annually are much lower in ventilation rate A than in vent rate B. The corresponding CO_2 concentration was much higher above 1200 to 2630ppm (fig 2).



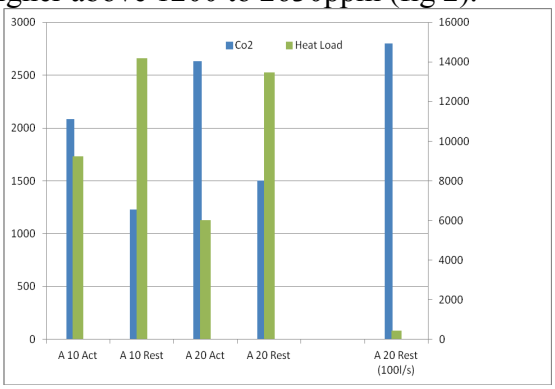
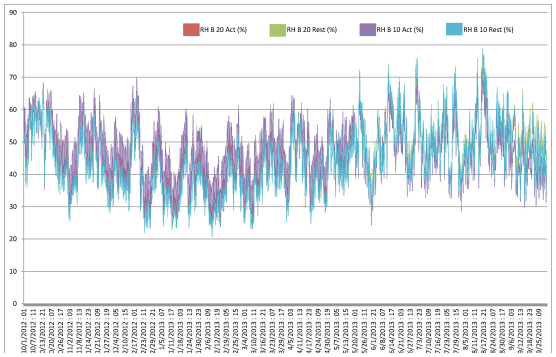


Fig 1: Ventilation rate A showing Relative humidity for the year
Fig 2: Ventilation rate A showing CO2 and annual heat load levels

Air flow rate B: 10 $l.s^{-1}$ per person
The highest relative humidity is both occupant numbers at rest by a margin of about 5% in the summer, but these are lower than the active occupancies at for the other months in the year. The relative humidity peak is approx 78% for a limited number of days in august, and drops again. This surprisingly is not the hottest temperature in the office in the same period of days. There is frequently a period of dry air for the resting occupants in the winter months as low as 21% for the lower occupancy. The temperature builds up to a high for both active occupancies of 34°C. From March there is frequent overheating with the current natural ventilation strategy approach (fig 6&7).
For the 10 resting and active occupants the temperature range is 16.2-30 and 17.4-34.1°C respectively. The RH ranged from 20.8-78.9% and 22.2%-70.7% respectively. The overheating maximum temperature increased, but the humidity decreased. For the 20 resting and active occupants the range for temperature was 15-31.2°C and 15.2-32.1°C respectively. Similarly the RH was 22.5-75.5% and 23.5-73.8% respectively. The temperature only increased marginally, but the RH reduction gap was smaller for the higher occupancy (fig 6&7).
The heat loads are higher in air change B in some cases by nearly 50% compared to air flow rate A. The CO_2 concentration range was 750-900ppm in all cases (fig 8).



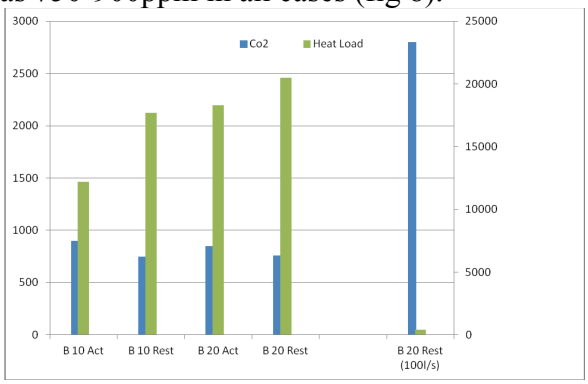


Fig 3: Ventilation rate B showing relative humidity

Fig 4: Ventilation rate B showing CO2 and annual heat load levels

CONCLUSIONS

Air flow rate A

The temperature is above 20°C for all occupant levels and activity rates apart from some weeks in Dec Jan for the 10 and 20 people at rest. This combined with large swings of relative humidity is not comfortable as defined by EN7730 [16]. The amount of ventilation naturally supplied to this room is not enough for activity or occupancy. The heat load figures were much improved due to less ventilation heat losses in the building, but there was a 200% increase in the CO_2 concentration levels between 20 people active at this air flow rate versus B. When factoring in other pollutants NOT included in this study such as furnishings etc, this could easily reach beyond the recommended 1000ppm threshold limit for office buildings and classrooms in ASHRAE 55 [17].

Air flow rate B

The heat load lowers with increasing occupancy. Other studies have shown that a reduced temperature with high humidity for longer than 8 hours within a day can lead to mould spores over a period of time. Healthy RH should be between 40-70%. The relative humidity values for air flow rate B stayed 85% of the year between these two figures. We could infer that more natural ventilation air flow allows for the humidity of external climate to have an impact more on the internal climate. Higher heat load figures due to increased ventilation losses also lead to a healthier CO_2 ppm level within the office floor, so a net loss for energy but a gain for health and indoor air quality.

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