Examining the Interrelationships of Microclimate, Construction Performance and User Behaviour to Inform Design Strategies

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ABSTRACT: Clear indications of climate change have established an increased interest in reducing CO2 emissions. The UK government has responded by introducing higher legislative standards and also a performance rating 'Code for Sustainable Homes' intended to introduce step changes towards its stated goal of carbon neutral dwellings by 2016.

It is becoming clear that there is a mismatch between design intentions and standards actually achieved in most buildings. In an effort to address this mismatch, the Good Homes Alliance in the UK requires that their developer members monitor a sample of all completed building units for a minimum of two years following handover. This strategy is intended to contribute to the development of sustainability by identification of both good and problematic strategies which can inform the ongoing design process.

This paper presents preliminary data collected from the first year of a two year post occupancy study of a semi detached house, built to EcoHomes Excellent standards. The research project aims to identify a minimum level for monitoring which can reliably indicate the building performance and can produce comparable data.

The house is well insulated and passed the pressure test but the relative humidity levels were initially unexpectedly high. The relationship between site microclimate, construction, building management, user behaviour and design of openings is examined and critical implications discussed.

Keywords: hollow clay blocks, relative humidity, window openings, microclimate, user behaviour, post occupancy

INTRODUCTION

There is increasing awareness of the significant part energy use in buildings contributes to our global carbon emissions. Of the UK's annual emission of around 155 tonnes of carbon, [1] around half is associated with building use and that half splits fairly equally between domestic and non domestic buildings. There is speculation about the levels of reduction required to contain climate change, but there is general agreement that home energy use, which accounts for around one quarter of an individual's CO2 emissions should be reduced to zero. This commitment is expressed in the provisions of the Code for Sustainable Homes (CSH) which commits the UK government to the target of all new homes achieving zero carbon emissions in use though step changes in the Building regulations by 2016 (fig 1). The Code for Sustainable Homes supersedes the Ecohomes standards. It includes new areas of sustainability and also, on top of the basic requirements, tradable standards to achieve the star ratings.

Date	2010	2013	2016
Energy efficiency improvement of the dwelling compared to 2006 (Part L Building Regulations)	25%	44%	Zero carbon
Equivalent standard within the Code	Code level 3	Code level 4	Code level 6

Figure 1: Diagram from the government publication, 'Greener Homes for the Future' [2]

POST OCCUPANCY STUDIES

The housing project was designed to Ecohomes Excellent standard, about the same as level 3 Code for Sustainable homes. It is widely understood that unless more investigation is made into measured building performance, there is little hope of achieving the goal of zero energy as there is a very significant mismatch

between anticipated and achieved performances in building. Bill Bordass demonstrated in 'Energy Performance of non-domestic buildings, closing the credibility gap' that the design estimation was wrong by a factor of 4 when compared to actual energy use over two years [3].

Overall, the post occupancy study reviewed in this paper pursues the goals of monitoring and evaluating homes in the development to compare results to other houses and national benchmarks and to make recommendations to improve practice. A secondary goal is to develop a robust post occupancy evaluation (POE) approach that minimises the information collection whilst providing maximum understanding of the performance of the project.

Post occupancy studies should confirm that the design intent has been met in full, and the AECB (the Association for Environmentally Conscious Building, UK) in the forum discussions around the Code for Sustainable Homes on their web site go further to suggest that the completion certificate should not be given until the house is monitored and its performance confirmed [4]. The Charter of the Good Homes Alliance requires members to undertake two years post occupancy monitoring following the completion of a building. In the UK, although it is still considered a brave and altruistic move to carry out post occupancy studies, they are increasingly undertaken.

The alignment of the reasonable expectations of both the building supplier and the occupier is an issue explored by Bill Bordass [3] and in DTI study at Stanford Brook [5].

THE MONITORED HOUSES

The nine houses are built on a disused quarry in a very pretty Oxfordshire village. They were marketed on the strength of their low energy use and healthy internal environment. The developer chose to use a single ziegel block wall to achieve the required thermal performance. Ziegel blocks are a new introduction to the UK from Germany (though Ibstock, in 2009, is developing plant to make the blocks in the UK); they are thin walled cellular clay blocks (fig 2). Their chief advantages are perceived to be the speed of laying, the breathable construction and quick drying, and the reduction of risks from interstitial condensation. They have a low embodied energy in comparison to a regular masonry construction and achieve a good thermal performance (u-value of 0.23 W/m^2K) with a single block 365mm thick, plastered internally and rendered externally. The blocks are made from clay that has been mixed with sawdust particles so that these burn to form a micro porous structure when they are fired. They are thin bedded, effectively glued together, and because of the lack of a forgiving mortar

bed they are planed to very close tolerances after firing. They are quite brittle in use so tradesman must be careful to avoid damaging them before the surfaces are rendered or plastered.

METHOD

It was intended two houses would be monitored intensively over two years. The aim is to combine qualitative and quantitative analysis and be able to spot weaknesses in house design through its use, by measuring actual performance and comparing this to the user experience.

Figure 2: Ziegel walls blocks showing cellular construction [6]

The first occupant took over the house in December 2007 and the first monitored data was collected in April 2008.

The study comprises interviews with the occupants, a weekly log of their activities and monitoring of energy and water flows to confirm the success of the design. Additionally monitoring of internal conditions, temperature and relative humidity (RH), has been undertaken to establish the relationship between the design intentions and those conditions pertaining in the house. Monitoring devices were set up in four positions- living room, bedroom, kitchen and main bathroom. The loggers were mounted at 1500 mm. A weather station was also set up outside to record local RH and temperature.

ISSUES ARISING FROM THE MONITORING

It was anticipated that the monitored data in this case study would be particularly detailed; pulsed electronic monitoring every minute was planned for all power circuits, gas, water, temperatures and relative humidity to provide an extensive picture of the building performance. A range of difficulties arose in practice:

- the collection system for the environmental data is not yet sufficiently developed to be as reliable as a battery operated sensor.
- two house owners have resisted the installation of electronic equipment, one on issues of noise - the hum of the computer terminal and another because of concerns about additional radio waves in the house.
- there were problems with the modem link being severed several times, resulting in considerable loss of data.

For these reasons, at the close of the first year of monitoring, only one house had been monitored in detail. During the year the project reverted to monitoring energy use directly from metered information and collecting information about temperatures and RH levels using computer programmable battery operated sensors ('hobos'). Because there was considerable interest in the performance of the passive stack ventilation in the dwellings in relation to dissipating the relative humidity arising from use of showers/cooking /washing activities, the data was originally collected at intervals of one minute. This generated huge data sets and, when hobos were used, proved to be inconvenient because of the limited data sets recordable from each programming. Data was subsequently collected at 10 minutes intervals which was sufficient to record fluctuations in temperature and relative humidity relating to the activities in the building.

THERMAL IMAGING

At building completion the first house to be monitored was investigated using a thermal imaging camera, following an air tightness test and just before occupation. The thermal imaging was carried out in December, at daybreak to both maximise the temperature difference between inside and outside (a temperature difference of 15K is recommended [7]) and to avoid any interference of solar radiation on the building elevations.
A number of interesting observations were made:

- the ziegel blocks need particularly careful detailing in areas where they have been cut- for example into the gable. This observation was confirmed by observation on other sites using ziegel blocks. The thermal image of the front elevation (fig 3) shows the greatest heat loss to be at the apex of the gable where the blocks are cut and a complicated junction, with large surface heat loss area, is made with the barge boards and rafters. The window frames are also a significant heat loss area, performing less well than the glazing.
- Some areas of the internal walls, particularly into the internal corners were cold. (fig 4)
Subsequently some mould was noted in areas which have little air movement, for example wardrobes. This suggests that the transfer of moist air through the ziegel blocks was not working as well as had been anticipated,

perhaps because drying out was only partial or lack of air circulation in the house.

DISCUSSION

The first months of monitoring were of a family house that was occupied by a single man who was often away. It had been anticipated that monitoring two of nine dwellings would report on typical patterns of family life, maybe full occupancy of the dwelling and the subsequent increased use of all facilities. However as the number of one person households stands at 29% of all households in the most recently published data [8], it might be that the

Figure 3: Thermal image of stone clad gable, the light areas show areas of significant heat loss at apex of roof

Figure 4: Thermal image of external corner of east bedroom, first floor; the dark areas show cold internal corners,

definition of typical occupation should be reviewed. It is expected that four houses in total will be monitored in the second year of the project, in the anticipation of

recording a wider range of patterns of energy use and general performance of the houses.

Various user issues were raised by the house owner in relation to thermal performance that could usefully be addressed in subsequent designs- -
- improve induction process to ensure that all novel systems are fully explained to occupant
- include illustrated section in handbook on principles of ventilating the home including section diagrams showing air flow
- revise window specification to have more opening options which are secure (windows can only be securely opened to about 10mm)
- investigate humidity issues – ventilation options, drying out, and location
- incorporate internal cool storage cupboard on outside wall of kitchen (underfloor heating makes all kitchen cupboards very warm)
- source thermostat valve controls with more accurate temperature settings (1-3 K variation in controls)
- provide adjustable showerhead for family bathroom shower (height and angle)
- improve specification of shower screen in family bathroom to stop water leakage onto floor
- ensure that skylights are easy to reach and open

The record of temperatures and relative humidities confirmed that the house temperatures were very steady at around 20K (fig 5) with temperatures varying by less than 2 K over a typical week, but that it suffered with high humidity in its first months of occupation.

As the construction had been particularly chosen to achieve a healthy environment, the generally high internal RH was a source of concern, particularly since the user activity was minimal in relation to shower use, cooking, washing and other activities that might raise relative humidity levels. However the passive stack appears to be effectively reducing the relative humidity peaks following showering to the ambient RH conditions (fig 5). Figure 6 indicates the high summer values of RH (typically above 70% in the living room) which started to reduce into the autumn 2008 (fig 7).

DESIRABLE RH LEVELS
It is generally believed that relative humidity levels are best in dwellings at levels between around 35-55% RH though the optimum RH relates to the internal temperature. Cunningham [9] suggests ambient RH should be kept below 45% at 21degC, temperatures fairly typical in the monitored house. Concern about healthy buildings and RH levels arise from increases in asthma and other respiratory diseases that have become particularly prevalent in the most recent generations of children. Asthma is believed to be associated with the presence of dust mites in the atmosphere and these thrive

in temperatures achieved in modern centrally heated houses, particularly where there are high humidity levels [10].

The mucous membranes which are part of the bodies defence mechanism against upper respiratory illness set the desired lower limits of RH as they are adversely affected by levels lower than around 35-40% RH [11].

The breathable qualities of the ziegel blocks, intended to average out relative humidities may be helpful in the winter heating season. Studies in Finland of 170 detached houses in a variety of constructions, some breathable and some traditional, indicated that the effect on the RH was negligible when the furnished houses were monitored in use [12]; this contrasts with the results obtained in a single dwelling using an unfired 'Errol' brick [16].
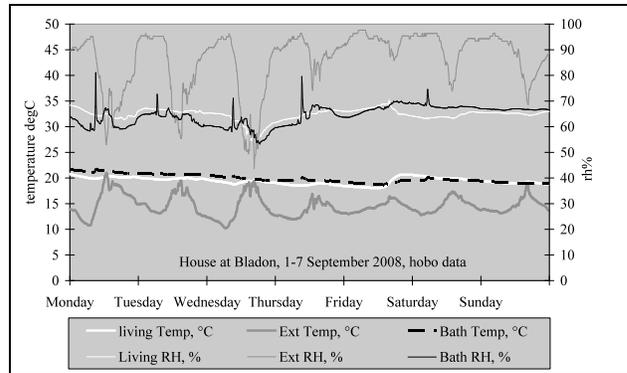
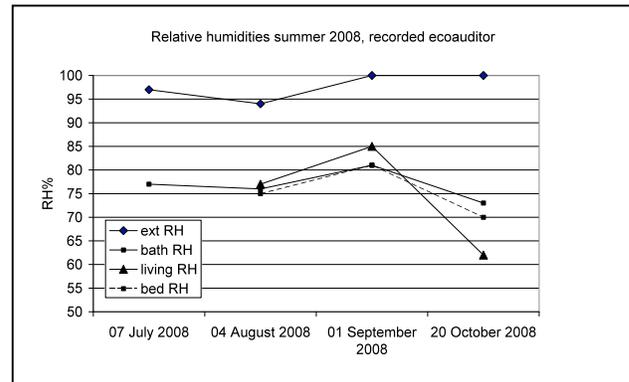*Figure 5: Temperatures and RH, September 2008*

Figure 6: RH recorded summer 2008
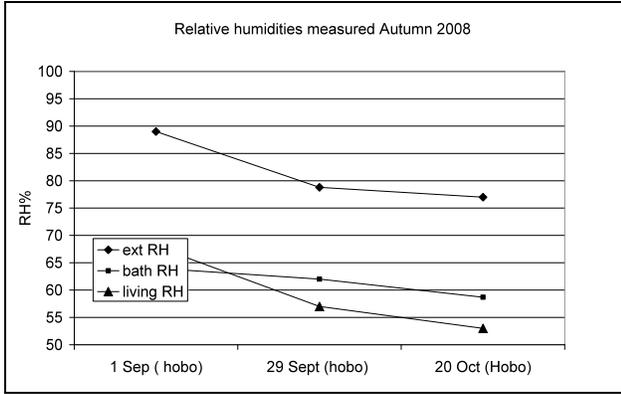
Relative humidities measured Autumn 2008

Figure 7: Relative humidity recorded Autumn 2008

As well as psychrometric strategies to reduce dust mites, other control strategies were employed including the designing out of fitted carpet environments to reduce dust mite habitats: these houses were designed with timber floors and stairs.

MICROCLIMATE AROUND THE SITE

Southern England is a relatively densely populated region, and the quarry site available in the Oxfordshire village is typical of the type of brownfield site that is available for development within village boundaries. The houses sit into a deep quarry that limits exposure to the prevailing south westerly winds, with relatively little wind-driven ventilation as a result. Relative humidities recorded externally at the site are high in damp conditions because of this. Passive stack ventilation was installed in the bathrooms but there is evidence that natural ventilation systems are not adequate when houses are very well sealed. With hindsight, the poor opportunities for wind driven ventilation could have been offset by provision of other ventilation modes, using MVHR (mechanical ventilation with heat recovery) rather than passive ventilation. However this observation must be set against the fact that only one house has been monitored extensively and it was very poorly ventilated due to windows and vents not being opened as much as might reasonably have been anticipated.

CONSTRUCTION TECHNIQUES AND DRYING OUT

A disadvantage of the ziegel blocks is their very porous nature and it seems likely that in the wet building season of summer 2007, the blocks absorbed a large amount of water. It is usual to wet plaster the blocks internally and this, along with the application of a 75mm screed, has the implication of a considerable drying out requirement. Drying out was made more difficult by the requirement of the local planning authority to provide a stone cladding to match the surrounding Cotswold stone buildings. Drying out is also made more difficult generally by the high levels of air sealing that is required

in modern low energy buildings. In this case the ventilation rate was down to 4 ach@50Pa. The choice of plaster finish is important. The manufacturer specifies the use of a mineral plaster which the architect believed had been replaced with a gypsum plaster. This may have resulted in the unexpected mould growth in the wardrobes because of the reduced vapour permeability.

Until recently there has been little published for many years on drying out factors in buildings because dry finishes, plasterboards for example, have been widely used. The combined requirements of thermal mass and well sealed buildings, characteristics which can be particularly associated with the application of wet finishes, have raised the discussion of drying out times and strategies again.

The Building Research Establishment (BRE) [13] discusses three phases of drying out in their digest, 'Drying out Buildings'. Firstly, free water evaporates from the surface, secondly water from the large pores is lost by water vapour working its way through the labyrinth of pores to the surface of the material and thirdly, over a period of years, water is lost from the fine pores or cells. The drying out process is concerned with the second phase. The traditional rule of one month per inch, now translated to one day per mm, of thickness to be dried in good drying conditions is qualified by the comment that this is often insufficient. Recent research by Rantala and Lelvo [14] suggests that to be precise about minimum drying times, slab moisture content needs to be established by measurement within the body of the slab as the surface moisture content can be misleading.

The block manufacturer [15] points out that in Germany a slower hand over process is traditionally followed, and that it is considered good practice for external render to be applied only when all wet trades have finished internally, encouraging the drying process. Could it be, perhaps as a side effect of the ongoing recession, that it becomes common practice that houses are handed over less quickly, and have more time for the wet trades to thoroughly dry before the first occupant moves in?

BUILDING OCCUPANT BEHAVIOUR

Occupants have a very significant effect on the actual energy use within housing compared with the estimated energy use. Work by Stevenson et al [16, 17, 18} has shown that user behaviour can undermine energy systems because they have not been properly inducted into their function and how to use them correctly. Furthermore, as shown in this study and others [18] thermostatic controls are notoriously inaccurate and can lead the user to raising them unnecessarily in order to get a response. Occupant interaction with windows is another major area of

research in energy use in housing. [19, 20] In low energy houses, ventilation systems are designed for very low air-change rates. If the occupants decide to open the windows frequently in order to receive 'fresh air', this can increase the energy use considerably. In this study, the opposite situation occurred. The occupant in one house was reluctant to open his windows very much at all because he perceived there to be a security risk in doing so, even if this may not have been the case in reality. This has contributed towards the excessive humidity levels experienced in this home, and raises the question as to whether low-energy homes can in fact rely on passive ventilation systems alone, if occupants refuse to open windows.

It also highlights the very important relationship that exists between occupant perceptions and their behaviour.

GENERAL CONCLUSIONS AND FUTURE WORK

The high relative humidities experienced in the first few months following handover appear to be the result of several influences- the difficult microclimatic conditions on the site, the lack of awareness of the drying required in these well sealed houses and the occupant perceptions and behaviour. From the start of the winter heating season 2008/09 the relative humidities have started to drop and it is believed that the units are settling into the performance anticipated at the design stage. Does it matter that for the first few months of a building use the RH levels tend to be high? Because of the unfortunate effect of sensitising children to allergies if large populations of dust mites are present, it seems important to avoid high humidities internally at all times. In addition high levels of RH can lead to the building fabric and finishes being adversely affected as well. Special instruction should perhaps be provided in an induction handbook: lack of induction and instructions on how to use the building was one of the issues noted in the occupant study.

Mark Way and Bill Bordass [21] refer to the helpful presence on site during the first weeks of occupation of a design and construction team representative and it can be noted that an informed representative on site might have helped to fine tune the buildings.

It is hoped that the second year of monitoring will include a larger a larger sample of units to try to achieve a range of occupancy patterns.

Could monitoring be carried out for just a single year when the building has settled down? Experience with this project would suggest that the results in the first year will possibly not represent typical operational conditions, in either internal performance or energy use. However considering the first year as a pilot study and using it to identify issues that should be addressed seems a worthwhile proposal.

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