Findings from a Post Occupancy Evaluation of adaptive restoration and performance enhancement of a 19th century ‘Category B’ listed tenement block in Edinburgh

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Abstract:
This paper describes the findings of a post occupancy evaluation that examined the user satisfaction and energy performance of a recently completed (2008) adaptive rehabilitation project of a traditional 19th Century sandstone tenement block in Edinburgh city centre. At design stage this project sought to incorporate low carbon technologies and high thermal performance into an existing and historic structure, including internal insulation, a ground source heat pump with underfloor heating, sunspaces and MVHR. Since completion the project has won several awards for its approach to sustainable design.

The paper discusses key outcomes of this performance evaluation, which identified some problems occurring with systems and users interaction with these, leading to incidences of poor environmental quality and high-energy use. The paper concludes by identifying limited improvements which could be made to this structure and future design considerations that could improve both retrofit and new-build housing stock

Keywords:
Tenement, refurbishment, monitoring, performance, energy efficiency.

1 Introduction

In an attempt to mitigate the damaging effects of greenhouse gas emissions, international governance has for the reduction of energy use and CO_2 emissions. In Scotland (the setting for this research) the Government has identified target reductions in domestic regulated energy use, compared to 2007 technical standards, of 30% by 2010 and 60% by 2013 and the ambition of whole life zero carbon by 2030 (Sullivan, 2007). A low carbon economy is now a strategic priority for the Scottish Government. As domestic energy use represents 30% of total national energy use (Shorrock et al, 2003) there can be little doubt over the role this sector has to play in helping to achieve the targeted reductions. Moreover, as an estimated 70% of the stock currently in existence will still be standing and in use by 2050 the role that existing dwellings will have to play in helping to meet these ambitious targets cannot be underestimated.

In Scotland the single largest housing typology, - 23% of all dwellings (Clarke et al, 2005), - is that of the tenement. This form exists in all dense urban Scottish areas and has been constructed in a recognisable guise from the 1800s through to the present day. Accordingly this typology constitutes a valid topic for research to understand how the performance of such buildings can be adapted to reduce CO_2 output.

As an ever-growing toolkit of energy conservation measures becomes available to Architects the successful use and integration of these technologies into existing buildings more challenging than in new build scenarios. With the Scottish tenemental vernacular this challenge is often made all the more demanding by the age of the stock and the nature of the construction. Many of these buildings exist in designated conservation areas or have a 'listed' status. Even outwith these criteria there is a, well-founded, perception that it is worth preserving the character of the stock. Ultimately, the reverence paid to these buildings limits physical upgrades to those which have no visual effect on the exterior; best practice approaches to energy efficiency are not always achievable in such circumstances.

With the above knowledge, this paper describes the building performance evaluation of an adaptive rehabilitation project on a Category B listed 19th Century stone tenement located within the World Heritage Site of Edinburgh's Grassmarket. Working within the constraints of its historical significance and limited budget (a registered social landlord as Client) and end user group, this project has sought to create an energy efficient solution for its sustainable rehabilitation.

To assess the performance of this building the Mackintosh Environmental Architecture research Unit (MEARU) undertook a programme of monitoring and evaluation over a three-week period during March 2011. Environmental monitoring was supplemented with an analysis of energy demand and acquisition of qualitative data through semi-structured interviews of the occupants, and observations by the surveyors to provide an overview of building performance that would go beyond the purely empirical.

Due to the nature of the funding, this project was undertaken over a limited, albeit very focussed, period. As such the information derived provides a 'snapshot' of building performance, rather than a more extensive review of performance over the course of an annual climatic cycle. The study collected data on 6 properties (5 dwellings and 1 small office) out of a potential 17 properties. Within this context the scope of the study and associated limitations should be acknowledged.

Notwithstanding these limitations, this investigation has identified several key outcomes relative to the physical performance of the building fabric, the user interaction with the properties and the fraught relationship that can exist between these two, sometimes opposing, factors. These key areas relate to:

- Specific issues for resolution with this particular development which, if implemented will benefit both the building end users and the Social Landlord
- Understanding of user behaviour and identification of gaps in their knowledge which result in reduced comfort and increased energy use

- General design improvements which will benefit future building projects from the Client, Architect and the profession as a whole through dissemination of this paper and other project outputs.
- Specific areas of further potential study on this development and more general topics of suggested study which could benefit the process of building design, procurement and construction overall.

2 Design Context

The measures used in the refurbishment of the block incorporate specific approaches to design and specification which were included to reduce the on-going environmental impact of the building and to improve the living conditions of the potential residents.

2.1 Construction

Working within the constraints (both physical and statutory) of the existing blonde ashlar and random rubble sandstone façade and structural cores, a new internal layout was constructed to provide flatted accommodation. The new insertions in this masonry skin essentially represent a contemporary approach to lightweight timber construction with a high thermal response.

2.2 Energy Strategy

The thermal performance of the building was improved by bringing the fabric up to contemporary standards through a process of internally dry lining and insulating to achieve a U-value of $0.25W/m^2K$. The thermal performance of the historic, timber sash and case windows was also improved through the use of secondary internal glazing improving U-values to $1.8W/m^2K$. Both of the above strategies adhered to the design principles dictated by the building's historic status in that they did not materially affect the principal elevation. To the rear a south facing, semi-glazed (approx. 50%) sunspace with an average U-value of circa $1.0W/m^2K$ has also been incorporated into 12 of the dwellings to provide additional amenity and to make use of passive solar gains.

The principle active technology employed throughout the development is a vertical ground source heat pump (GSHP) which, along with an electric back up heater, provides for the hot water and space heating demands of the full building. Delivery of the space heating is through a wet under-floor heating system. Due to constraints on the construction this is provided within proprietary insulated trays rather then being contained in a screed.

As noted below, the ventilation of 13 of the dwellings also allows for the use of heat recovery through proprietary mechanical ventilation with heat recovery (MVHR) units.

2.3 Ventilation Strategy

In the office space and 1 bed apartments (without sun spaces) a conventional system of opening windows, background trickle ventilators and mechanical extraction from wet spaces has been installed. Elsewhere a whole house MVHR system is in use. Note that MVHR relates to an energy strategy but is viewed primarily as a ventilation aspect with the heat recovery aspect being secondary.

2.4 End Users

The building has three distinct groups of occupants, all of whom were represented in the data collection process. The first user group is that of the mainstream social rent tenants. They occupy one of the building's two closes. The second user group, occupying the second close, is made up of residents who require supported living. The third group of users are the care staff who occupy the building's office space and provide support to user group two.

2.5 Project Inception

Following completion and occupation of the building there were reports from residents of poor performance or failure of the heating system. Through a process of further commissioning and alteration this system was brought up to a standard where resident complaints were dramatically reduced but where continued problems were evident. Anecdotal evidence suggested over-heating was common and this was be supported by visual inspections of window openings.

In response to these issues MEARU was asked by the Architects to undertake a building performance evaluation identify issues relative to the building performance in general with a specific focus on internal comfort. The project was funded by the CIC Start Online academic consultancy fund.

3 Research Methodology

Research into the building performance and user satisfaction was undertaken using a variety of approaches and techniques for data collation and analysis. This was designed to primarily provide a resource of quantitative (empirical) data but which was supported by qualitative data providing a greater depth to the analytical process.

3.1 Building Performance – data collection

Over a 3½ week period (from 17.03.11 to 12.04.11) the internal temperature, relative humidity and CO_2 concentration were monitored in all apartments, the hall and kitchens of five flatted dwellings and throughout one office space (noting that in each case the bathrooms/ WCs were omitted). Measurements of these parameters were made at 1 minute intervals using Eltek GD-47 transmitters, placed in each dwellings space, and recorded as a 10 minute mean value on Eltek RX250AL data loggers. In the case of hall spaces, temperature and relative humidity only were monitored using Gemini Tinytag Ultra data loggers with data calibrated to the same time intervals as the Eltek equipment. Data on internal surface temperatures was recorded using thermographic imaging on a Flir ThermaCAM B360.

Although not a longitudinal study there were, significant benefits in a short, intense period of monitoring. The relatively brief duration led to limited intrusion on the occupants, ensured continuity in data collection relative to both dwellings and occupants and allowed a fine granularity which helped to identify specific events within the flats.

3.2 Energy Use – data collection

A key question was the relationship between the building's simulated and as built performance levels. The simulated performance was taken as the space and water heating loads identified by the design stage SAP calculations. This figure was then compared to the energy draw of the heat pump installation through review of its separate electrical meter.

A more thorough investigation in the regard of true regulated energy would have been desirable but separate sub-metering was not installed in each flat and so this was not possible. As the suspected problems with the dwellings related predominantly to thermal comfort this approach was deemed to be suitable.

Limitations in terms of physical access and willingness of the housing association to have additional equipment installed meant that the electrical demand of the MVHR systems and the heat output of the GSHP were not monitored. Sufficient information has, however, been gathered to subsequently assess the efficacy of these systems if not their efficiency.

3.3 User Satisfaction – data collection

At the time of equipment installation, a semi-structured interview was conducted with residents and office users to query patterns of occupancy, user behaviour and comfort.. Ultimately this was reviewed on a case by case basis and this additional layering of information was used to support or confound findings suggested by the empirical analysis. Generally the analytical process was undertaken from a macro to micro level working from broad based values, derived over the full monitoring term, to specific daily values and events that affected the internal environs

4 Findings and Discussion

4.1 Thermal Comfort / Energy use

Due to the anecdotal evidence on overheating, this became the principle focus of initial research. A review of physical data at the macro level (ref. Table 1) confirmed that the mean and absolute maximum temperatures within all apartments (office space excluded) were - often significantly - beyond the accepted comfort range. The mean values confirmed the suspicions held at the project outset but did not provide any information on cause or potential solutions. To identify this, a more focussed review was undertaken of each dwelling relative to the profile of physical parameters on a diurnal basis.

Table 1. Mean and absolute maximum thermal conditions over project duration

(Source for comfort temperature standards, BS 5449:1990)

Room	Mean Temp (^oC)	Comfort Temp (^oC)	ΔT^1 (^oC)	Absolute Max (^oC)	ΔT^2 (^oC)
Living Rm	22.62	21.00	+1.62	28.00	+7.00
Kitchen	22.87	18.00	+1.87	29.10	+11.10
Hall	23.45	18.00	+5.45	31.20	+13.20
Sun Space	21.24			40.90	
Bedroom 1	22.58	18.00	+4.58	27.20	+9.20
Bedroom 2	21.41	18.00	+3.41	26.20	+8.20

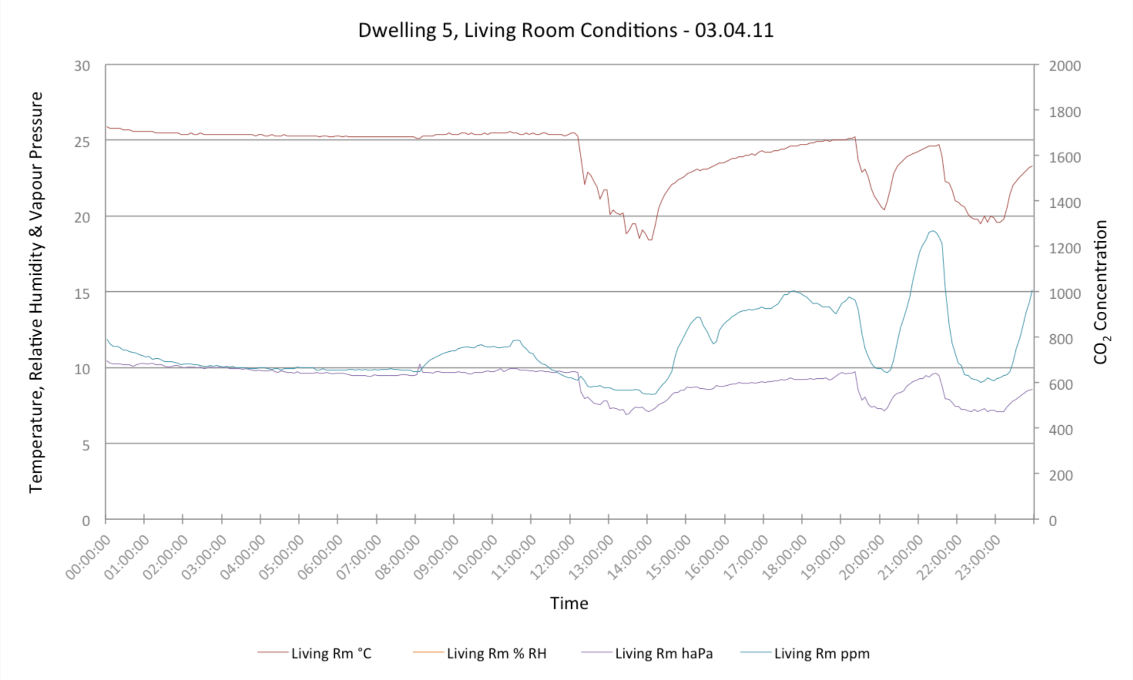

Figure 1. Physical parameters in Dwelling 5 living room – fluctuating thermal comfort

Figure 1 illustrates one daily example where a monitored living space is heated to a degree of discomfort and then is rapidly cooled by the occupant behaviour of liberal window opening. This behaviour was found to be repeated throughout the development and was supported by the survey responses in which 60% of residents noted they opened windows every day throughout the year.

Recorded data from an unoccupied dwelling had shown that a relatively stable temperature profile could be maintained internally and it was reasonably assumed that, despite its high thermal response nature, the fabric itself was not at fault and was capable of facilitating thermal comfort. Further investigation using thermal imaging provided an insight to problems of frequent overheating. Figure 2. shows the surface temperature of a typical apartment floor. At the time of photography the thermostat was set at its lowest level yet a temperature of 28.9°C was evident. Immediately after this image was taken the thermostat was turned to it's highest setting with the same image being taken one hour later (ref Figure 3).

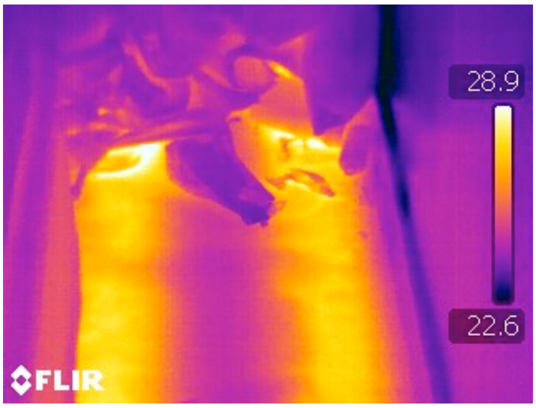

Figure 2. Floor surface temperature T^1

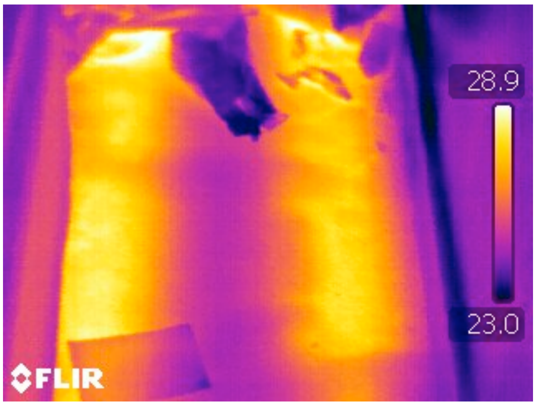

Figure 3. Floor surface temperature T^2

The level of the initial reading suggested that the control of the heating system was ineffective. This was confirmed by the lack of response over the subsequent sixty-minute period. Poor performance of heating controls, allied to a poor user interface, were identified as factors that consistently resulted in the creation of sustained internal temperatures exceeding the comfort range. In addition to this, the lack of thermal mass in the structure, an outcome of the approach to thermal upgrade of the historic fabric, results in high rates of heat gain and loss; a process which is difficult for residents to stabilise once the cycle of window opening has commenced. Ultimately the poor control of this leads to an increase in the energy required for space heating and undermines the thermal efficiency of the building. This also provides an explanation for the disparity in predicted and measured energy loads for space and water heating.

Further analysis identified that user behaviour was not the only explanation of the disparity between simulated and actual performance levels. The inclusion of sunspaces to the southern elevation of dwellings was intended to provide increased amenity to the dwellings as well as providing a thermal benefit of 5 – 10% through passive gains.

The desire to extend the amenity of each dwelling was the primary design driver but this has come at the expense of the overall performance as a design decision was taken to provide under floor heating to these volumes. As the external walls of the sunspaces have U-value of circa 1.0W/m^{2}K as opposed to 0.25W/m^{2}K, to other external walls, there is a risk of increased heat loss which is exacerbated by limited thermal separation between the main volume of the dwelling and the sunspace which were seen to take on unwanted heat gains when already above the recognised comfort temperatures.

While the intent of these spaces was to offset the space heating energy demand it appears that they have, in fact, actually added to the primary energy demands. They were not designed as buffer spaces (which would have been more appropriate) but this is how they are behaving, but without the combination of thermal and ventilation benefits this can afford. This design element would be greatly improved if the desire was simply to create a captured outdoor space, without artificial heating but with the incorporation of significant thermal mass to allow thermal buffering and to create a suitable mid range temperature environment mediating between internal and external temperatures for the purposes of ventilation and improved internal air quality.

4.2 Internal Air Quality (IAQ)

Monitoring identified several spaces with very good IAQ. Given the prevalence of window opening this result was hardly surprising, but will of course have a thermal penalty. In circumstances where window opening was common, the use of an MVHR system was not only ineffective but is also additional primary energy burden on the dwelling as the fan continues to run at the same rate regardless of IAQ conditions. Where window opening was not prevalent, maximum values of CO_2 concentration were frequently found to rise and be sustained above recognised maximum desirable levels of 1000ppm (Appleby, 1990). Figure 4 illustrates a particular situation from Dwelling 2 over the monitoring period but this is one which was often repeated in monitored apartments throughout the project

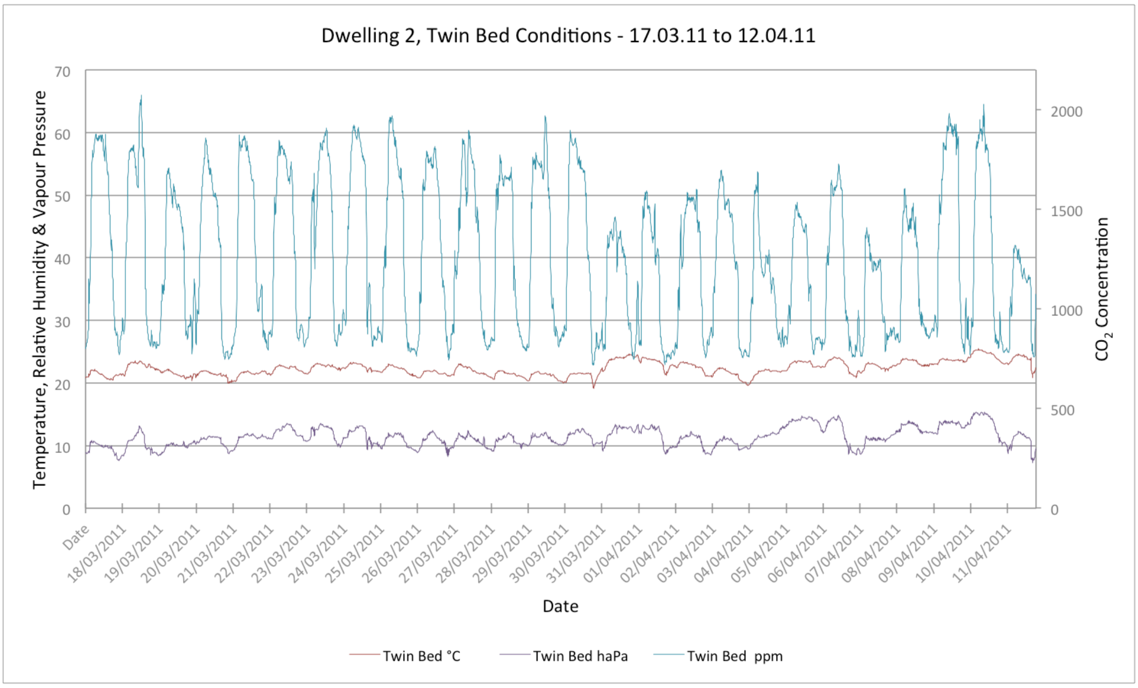

Figure 4. Physical parameters in Dwelling 2 twin bedroom – high CO_2 concentrations

The effects of CO_2 itself are generally limited, but its importance as an environmental indicator is invaluable. Where concentrations greater than 1000ppm are experienced the rate of air change is insufficient and the potential for culmination of internal pollutants is increased with an associated impact on occupant health. Examples within domestic contexts include Radon, which is estimated to account for 9% of European lung cancer deaths and VOCs which act as allergens and respiratory and dermal irritants (Crump et al, 2009). With low air change rates there is also a well defined risk of interior moisture vapour build up which brings with it its own set of health implications. Vapour pressures over 1.13kPa have been identified as promoting the growth of dust mite populations (Platts-Mills et al, 1989) which have, in turn, have been found to have a causal relationship with development of asthma in susceptible children (IoM, 2002). With exceptionally high vapour pressures there is also an associated risk of fugal growth and an increase in the levels of fungal spores, microbial bodies and other pathogens which can be detrimental to the health, particularly to the ever increasing atopic portion of the population. In addition to this, increased relative humidity has also been found to increase health impact from non-biological aerosols as it increases the rate of off gassing of water-soluble chemicals such as formaldehyde (Arundel et al 1986).

A contributory factor is the layout of the system, with the two air delivery registers focussed into the hall space only. The theory behind this design appears to have been that air would migrate from this central location into adjacent apartments. The data appears to confirm that the supplied air pressure is not sufficient to overcome tightly sealed room entrances which incorporate, due to legislative requirements, self-closing fire doors and smoke seals. The situation appears to have been exacerbated post-construction, as carpet installation has further reduced the air spaces under doors.

With the potential health impacts, the importance of good IAQ cannot be a secondary concern and it must not be undermined by attempts to improve thermal efficiency and air tightness. Not withstanding this position, the level at which poor air quality is perceptible has the potential to cause occupants to manually seek improved ventilation. With a CO_2 concentration of 1000ppm poor air quality is perceptible to humans with the stress initiated behavioural response invariably being one of window opening and the result being, as was evidenced with the poor thermal control, one of high energy loss. Instances of this were identified through in the monitoring of this project and the outcome of poor air quality is, again, behaviour which counteracts the approach to energy conservation central to a contemporary design ethos

5 Conclusion and Further Research

This paper presents a specific case study focussing on just one building which has a relevance in application throughout a huge proportion of the Scottish housing stock which will likely still be in existence for the foreseeable future (due to conservation) and, one which has a significant role to play in aiding the achievement of legislative energy conservation targets.

Although the period of fieldwork described was limited in terms of duration and number of dwellings monitored, the depth of information collated and number and significance of findings identified, many of which are not presented in this paper, suggests that this type of intense monitoring can be an exceptionally useful tool in understanding building performance. This suggests suitability in terms of an approach to BPE which could be incorporated into new and retrofit contracts to ensure that design targets are being met and help to identify where improvements can be made.

A literature review for this project has highlighted a significant gap in the understanding of the standards of IAQ in energy efficient dwellings and this is a key area for further study. This is relevant to new build energy efficient dwellings and particularly to retrofit schemes as contemporary approaches may actually reduce IAQ and undermine attempts to improve thermal efficiency and reduced CO_2 output.

The degree of complexity required to design high performance buildings, combined with the interrelated nature of design, construction, ventilation, heating and occupancy leads to an argument that current fee levels do not allow the time to form this understanding, and leads to a fragmented reliance on specialists and manufacturers.

These questions have wider implications for the profession and identify areas for further research if we are to achieve the desired sustainable future.

6 Acknowledgement

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