Comparison of Measured Indoor Environment for Social Housing in West Yorkshire, UK

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ABSTRACT: The study is part of a project aiming to investigate the energy efficiency within the most deprived communities across six local authorities in Yorkshire and the Humber region in the UK. A post occupancy evaluation is performed on four dwellings before refurbishments are undertaken to investigate the indoor environmental conditions and to compare the measured levels with the accepted standards. The results have shown that one home in Kirklees almost complied with the range of winter internal temperatures in living room, and similarly all bedrooms in Kirklees and Leeds complied with the guidelines in winter season. In addition, relative humidity levels were almost in the acceptable range under both summer and winter conditions. The average indoor CO_2 levels were also measured in four homes, indicating inadequate ventilation during the monitoring period. A random day was chosen to visualise CO_2 concentration behaviour in the same homes and it was found that the CO_2 level followed a pattern that rising during the morning, evening and night times in response to human indoor activities. Moreover, there was a direct correlation between CO_2 and air temperature levels showing that there is a dilemma of keeping windows closed with stale indoor air in the four dwellings.

Keywords: energy innovation; deprived communities; indoor environments; social housing; post occupancy evaluation

INTRODUCTION

The BIG Energy Upgrade (BEU), also known as the Energy Innovation for Deprived Communities (EIDC), is a project aims to investigate the energy efficiency within the most deprived communities across six Local Authorities (LAs) in Yorkshire and the Humber region in the UK. A post occupancy evaluation has been carried out by the Building Environments Analysis Unit (BEAU) at the University of Sheffield on a sample of dwellings (i.e. two in Kirklees and two in Leeds areas) in the region (West Yorkshire in England, UK) before their refurbishments have been undertaken as part of the BEU partnership, with £14.9 million funding that is part financed by the European Regional Development Fund (ERDF) programme 2007 to 2013.

Currently, the existing buildings contribute around 45% of the UK's overall annual carbon dioxide (CO_2) emissions with more than a quarter coming from domestic buildings. For the country to meet its 80% CO_2 reduction target by 2050, there needs to be an extensive refurbishment throughout the existing building stock to improve their energy efficiency [1]. Refurbishment option could be seen as more modest and simple at the first glance referring to demolition/dismantling and new development, but the results of improving energy performance of housing in Belgrade showed efficiency in energy savings and CO_2 emission reductions, as well as improved housing quality and standards. By improvement of thermal insulation and replacement of windows, contribution to energy savings and upgrading of the building appearance have been achieved [2].

The indoor environment is an influential factor to environmental quality. People spend a majority of their time in buildings and therefore the indoor environment is the main setting for many; consequently certain conditions of this environment can have a profound effect on the quality of the environment and the occupants' health [3]. Studies have highlighted that at present many people live in conditions that are considered 'unhealthy' because of the high levels of mould growth, damp and dust mite concentrations. Approximately 20% of all dwellings in England suffer from mould growth and dampness to some degree [4].

Oreszczyn and Pretlove indicate that a key parameter in house dust mite survival and mould growth is Relative Humidity (RH). Relative humidity is a function of both moisture and temperature, which are dependent on many other interrelated factors of the indoor environment, including fabric insulation, occupants activities within the home (i.e. number of occupants, hours of occupation, ability to pay fuel bills and amount of moisture generating activities), the heating system (i.e. efficiency, control and distribution), ventilation and external climate. Using these factors they have developed a model to identify the risk of mould growth in dwellings [2, 6].

Ucci et al investigated the links between asthma and low ventilation rates in housing because of the fact that the trend towards the reduction of domestic ventilation rates for energy efficiency had resulted in poor indoor air quality which may represent a causal factor for the high asthma prevalence in the UK [5]. Sick Building Syndrome (SBS) is a type of illnesses related to poor

Indoor Air Quality (IAQ) in buildings and it has contributed to the awareness of poor health associated with a poor indoor environment. SBS can be defined as the discomfort or sickness associated with poor indoor environments with no clear identification of the source substance [7, 8].

This study has been undertaken as part of the BEU programme with an aim to deliver a new approach to energy efficiency and renewable energy projects within a minimum of ten of the most deprived communities in the UK. The properties will be assessed by energy efficiency experts and then brought up to modern standards with a range of measures including so-called smart electricity meters and heating systems upgrades to boilers, wall and loft insulation, double glazing, insulated cladding and even solar panels where appropriate. It is therefore important for the success of the EIDC project that both detailed monitoring and post occupancy evaluation are performed on a sample of dwellings before rolling out a wider refurbishment. The aim of this study is to investigate the indoor environmental conditions of four selected homes in Kirklees and Leeds areas at Yorkshire and the Humber region in the UK, before refurbishment, and to compare the measured levels with the widely accepted standards.

METHODOLOGY

Indoor air temperatures and relative humidity levels were measured at four selected homes using HOBO U12-012 and U10-003 data loggers. Indoor carbon dioxide levels were also recorded in four deprived community homes using Telaire 7001 CO_2 meters. Although CO_2 is not toxic, it is commonly used as an indicator of air quality, and high levels of CO_2 indicates inadequate ventilation in a space.

All HOBO U12-012 data loggers and CO_2 meters were placed in the living room in each home, specifically in the breathing zone of a person sitting on a sofa (approximately 1.5 metre above the floor level) and away from open windows. In addition, participants were requested to behave as normal within their homes during the monitoring period in order to obtain realistic data. HOBO U10-003 data loggers were placed in the bedroom in each home.

The aim of the post occupancy evaluation carried out was to monitor indoor air quality and to gain an insight into indoor conditions within deprived community homes to be able to compare their indoor environmental conditions i.e. air temperature (°C), relative humidity (RH%) and carbon dioxide (CO_2), with the recommended standards (i.e. CIBSE and ASHRAE). Average levels of each variable were collected in 15-minute intervals over a 24-hour period for periods of two weeks.

RESULTS AND DISCUSSION

The monitoring process has been undertaken before any refurbishment to be completed in the four selected dwellings. Results have been compared to the published standard guidelines by the Chartered Institution of Building Services Engineers (CIBSE) and the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE).

Below, Table 1 describes the home type, home age, tenure, ventilation condition, window type, cooker type, number of occupants and their ages.

Table 1: General description of sampling location in Kirklees and Leeds (West Yorkshire).

Description	Dwelling K*1	Dwelling K2	Dwelling L**1	Dwelling L2
Type of building	Semi-detached	Semi-detached	Terraced	Terraced
Home age (yr)	65	65	40	40
Dwelling – Tenure	Rented	Owned	Rented	Rented
Window Type	Fully double glazed	Fully double glazed	Fully double glazed	Fully double glazed
Cooker Type	Electric	Electric	Electric	Electric
No. of Occupants and Ages	4 (67, 65, 38 and 37 years)	3 (60, 57 and 33 years)	2 (69 and 68 years)	2 (58 and 61 years)
Type of Ventilation	Natural - at least one window open every day	Natural - at least one window open every day and night	Natural - at least one window open every day and night	Natural - at least one window open every day and night

K*= Kirklees L**= Leeds

Figure 1 shows the average indoor air temperature for each of the monitored dwellings in Kirklees and Leeds areas. The dashed line in Figure 1 is the internal air temperature of 22°C recommended in living room. In comparison with the standard guidelines, it is clear that one home (K2) did not comply with the CIBSE's recommendation for the range of internal temperatures

(22-23°C) in living room, and both L1 and L2 also do not comply with this standard guideline.

Figure 2 on the other hand, shows the average relative humidity (RH%) levels for the living rooms, and in this case, both rooms do comply with the standard guidelines for the four selected homes in Kirklees and Leeds. The recommended level of indoor relative humidity should be between 40-70% [9].

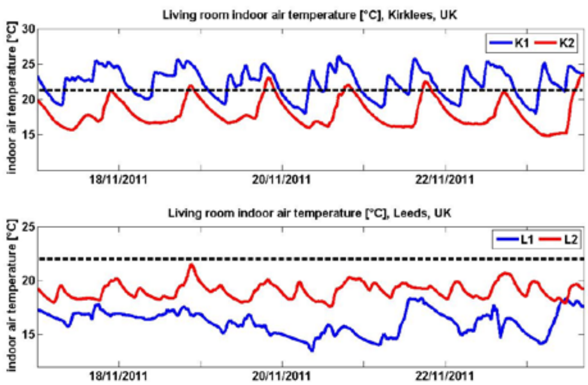

Figure 1: Daily indoor temperature for the living rooms in four homes in Kirklees and Leeds.

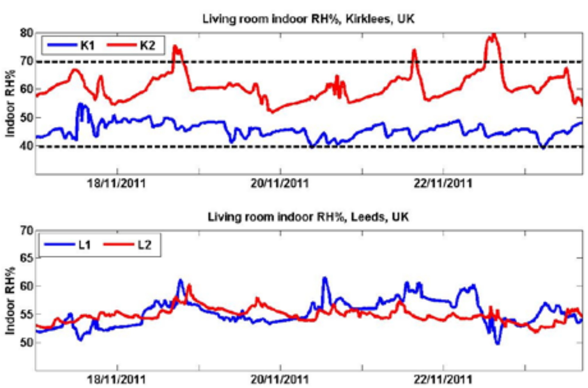

Figure 2: Daily indoor RH% for the living rooms of four homes in Kirklees and Leeds.

Carbon dioxide (CO_2) is present in the natural environment, being produced by combustion of biological processes, and it is present at typical levels of about 360 ppm in the ambient urban environment though this can rise substantially inside occupied buildings. Currently, there are no UK CO_2 standards for indoor air, while the ASHRAE recommends that carbon dioxide levels should not exceed 1000 ppm inside a space [10]. Figure 3 shows the indoor CO_2 levels of the living room of four deprived community homes for one week in Kirklees and Leeds areas. As a result, it can be seen that the levels are fluctuating around the recommended value for indoor space.

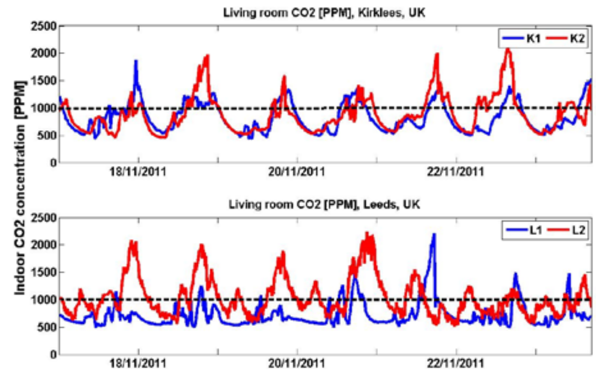

Figure 3: Level of CO_2 in the living rooms of four homes during one week in Kirklees and Leeds.

19th November 2011 was chosen as a random date to plot the CO_2 concentration against time to investigate the behaviour of carbon dioxide during the selected day over a 24-hour period. Figure 4 indicates that the indoor CO_2 levels followed a pattern in the four deprived community homes. Levels were seen to be under 1000 ppm during early morning and day time, later rising at evening and night time due to the increase of human activity and the lack of ventilation.

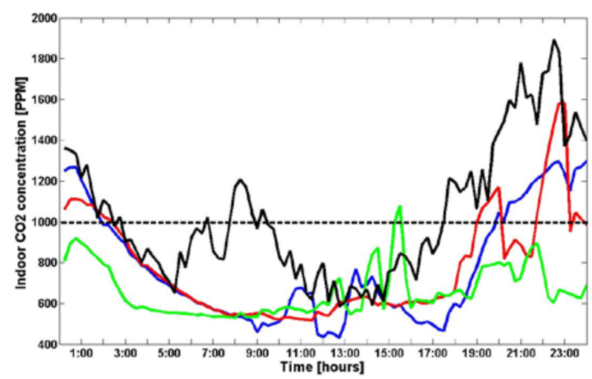

Figure 4: CO_2 concentration of four homes in Kirklees and Leeds for one day (19/11/2011).

The indoor temperature and relative humidity of four bedrooms were plotted against the standard guidelines (shown dashed lines). Figure 5 shows that participant K2 does not comply with the standard guideline for indoor air temperature for the bedroom which is 17°C to 19°C [9]. In Leeds, participant L1 does not comply with the same guideline either. Figure 6 shows that relative humidity levels comply with the standard guidelines in the bedrooms as well as in the living rooms for both location homes.

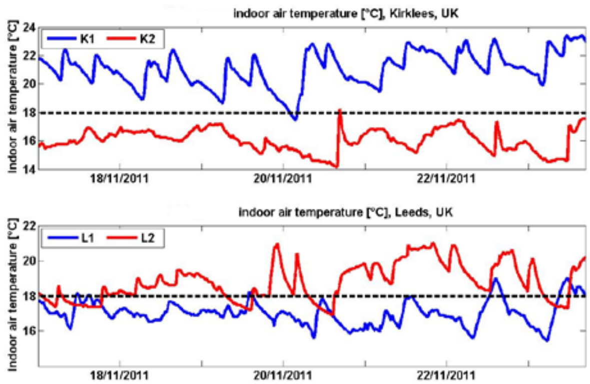

Figure 5: Daily indoor temperature for the bedrooms of four homes in Kirklees and Leeds.

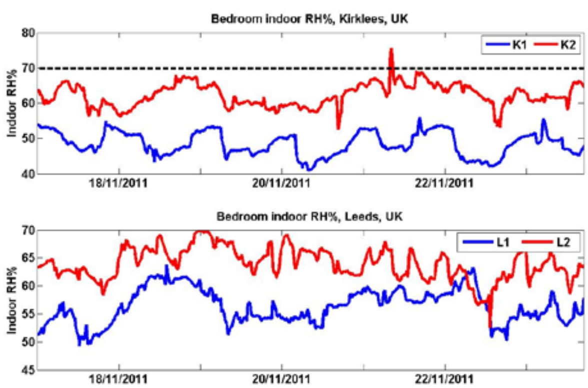

Figure 6: Daily indoor RH% for the bedrooms for four homes in Kirklees and Leeds.

Daily indoor air temperatures and daily CO_2 levels of the four selected homes were correlated with statistically significant results (r =0.676, p =<0.05), (r =0.498, p =<0.05), (r =0.390, p =<0.05), and (r =0.599, p =<0.05). Figure 7 shows this direct (positive) relation between indoor temperatures and CO_2 levels for four deprived community homes. These results may indicate that the warmer spaces have lack of air ventilation rates and therefore the CO_2 levels are higher, and it also reflects the dilemma of achieving proper ventilation and indoor thermal comfort.

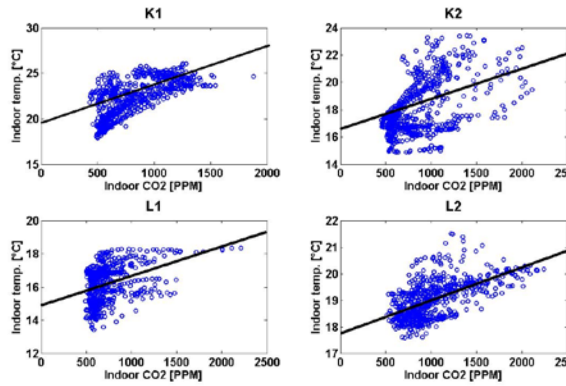

Figure 7: Correlation of daily carbon dioxide and daily temperature for four homes.

Figure 8 shows the average indoor air temperature of the living room for Kirklees home which was 2.6°C higher than the average indoor temperature of the living room for Leeds home. In addition, it also shows the mean of indoor temperature of the bedroom for Kirklees home was 0.6°C higher than the mean of indoor temperature of the bedroom for Leeds home. Moreover, a t-test analysis showed that the mean air temperatures were statistically significant and that their t-test results are as follows:

$t = 2.43$, $p =< 0.05$ and $t = 0.80$, $p= < 0.05$

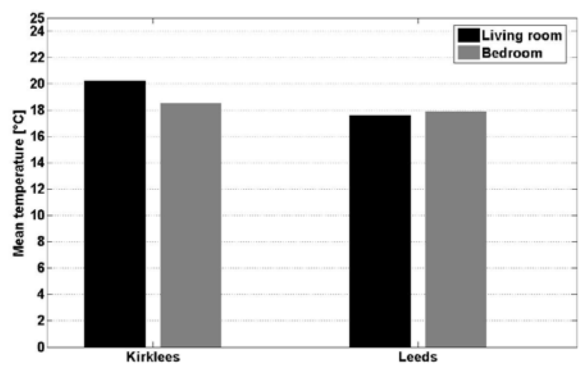

Figure 8: Difference of mean temperatures for the living rooms and the bedrooms of four homes in Kirklees and Leeds.

Figure 9 shows the carbon dioxide levels were compared with mean of the two living rooms for Kirklees and Leeds homes. The t-test analysis showed that the mean CO_2 levels were statistically different (25 ppm) which was significant and their t-test result is as follows:

t 0.040, $p < 0.05$

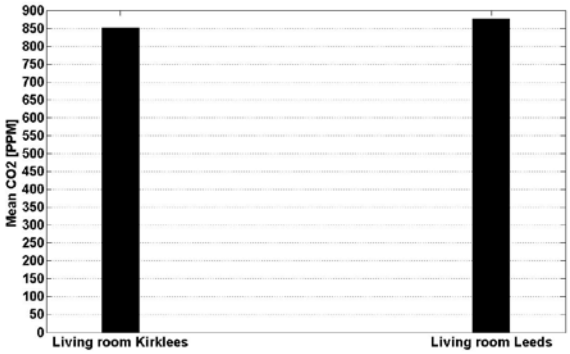

Figure 9: Difference of CO_2 levels between the living rooms for Kirklees and Leeds.

CONCLUSION

The study aimed to investigate the indoor environmental conditions, i.e. air temperature, relative humidity and CO_2 levels, of four deprived community homes in Kirklees and Leeds areas at West Yorkshire in the UK before refurbishment to compare with the widely accepted standards. The conclusions from this study are based on a limited number of samples (in this case, four homes from deprived communities). To further generalise the results, it would be necessary to do more sampling on a larger population which will be the future work. From this limited data, the measured values of indoor temperature levels have been found not to comply with the standard guidelines in both locations whereas the measured values of relative humidity levels have been found to comply with the recommended standards in four selected homes. It was found that there is a direct and a positive relation between indoor air temperatures and CO_2 levels which reflected the dilemma of achieving proper ventilation and indoor thermal comfort in these deprived community homes. Moreover, the results have indicated that the warmer spaces have lack of air ventilation rates and therefore the CO_2 levels are higher, which confirms the same dilemma of achieving proper ventilation and indoor thermal comfort conditions.

ACKNOWLEDGEMENTS

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