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Building Performance Evaluation for the Retrofit of Council Housing in the UK: A case study of a tower block in London

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Abstract: The energy consumed in the domestic sector in the UK accounts for more than one fourth of the total CO_2 emissions in the country. Retrofit programmes aiming to improve energy efficiency of buildings have been initiated in the UK for more than two decades to achieve 80% reduction in greenhouse gas emissions by 2050. Building retrofit is a cost-effective way to reduce energy demand of existing buildings and improve thermal comfort. This research evaluates the building performance of a council tower block in London. Initial field surveys highlighted the serious damp and mould issues in several flats. This leads to health concerns caused by a combination of inefficient building envelope and partial unawareness of the occupants concerning efficient use of their homes. The research focuses on the interactions between the building performance, the occupants' energy consumption behaviour and thermal comfort in winter. In phase one of the project, building monitoring and simulation analysis were undertaken to assess the building performance and indoor thermal conditions. The second phase of the project focuses on the building performance optimisation and methods for energy efficient retrofit. This includes simulation analysis and a questionnaire-based survey to define the occupants' energy consumption behaviour and thermal comfort.

Keywords: Building performance, retrofit, council housing, simulation modelling, field monitoring

Introduction

Improving the energy efficiency of the built environment is one of the major priorities of the UK government in order to reduce energy demand and deliver on the carbon emission reduction plan. The energy use in the housing sector in the UK accounts for more than twenty five percent of the total CO_2 emissions produced in the country (Low Carbon Innovation Coordination Group, 2012). The significant amount of carbon emission levels in the country show that there is a need to take initiatives to reduce the buildings' energy consumption and consequently mitigate the impact on climate change. Energy efficiency studies indicate that the suitable retrofit techniques can improve the building energy and environmental performance. Building retrofit also facilitates better indoor thermal comfort, health and wellbeing of the occupants while reducing the energy demands of the building (Vilches et al., 2017, Rickaby, 2011). However, the energy consumption of buildings is not always reduced by energy retrofit particularly in fuel poverty conditions (Vilches et al., 2017).

There have been major retrofit programmes rolled out by the UK government's Department of Energy and Climate Change (DECC) – now Department of Business, Energy and Industrial Strategy - to improve the energy efficiency of the buildings in the UK to achieve 80% reduction in CO_2 emissions by 2050 (Department of Energy and Climate Change, 2012). One major programme introduced is RENEW programme which aims to enhance the building energy performance and reduce the impact of fuel poverty in London (Mayor of London, 2015). Studies show that in London Borough of Newham (LBN), there is high rate of fuel poverty at 13.8% (13,372 households) which is amongst the highest rates in the UK (Walker and Ballington, 2015b). Newham Council has been actively developing a plan to retrofit many of the existing domestic buildings particularly council housing. Improving the energy efficiency of the buildings in LBN, will cut the energy cost of the residential sector and reduce fuel poverty, while decreasing the carbon footprint of the properties (Walker and Ballington, 2015b, Walker and Ballington, 2015a). LBN's Council plan is to significantly reduce the number of fuel poor domestic buildings whilst achieving minimum energy efficiency standards of B and C by 2030 (Bromley-Dery, 2015). The Council also incorporates the UK national's best practice of the fuel poverty scheme in the borough's plan (Walker and Ballington, 2015b). However, there are some limitations in incorporating all the recommendations to the programme to improve the LBN's building energy efficiency. These limitations include low income levels of the households, high number of problematic private rented sector as well as health and age-related problems (Walker and Ballington, 2015a). Despite these barriers, Newham Council makes all the effort to increase the external funding for more support to the schemes.

The current study evaluates the building performance of a few of the typical problematic flats in one of the council tower blocks in LBN, planned for retrofit in the short term. This 22-storey tower block comprises of 108 properties; a combination of 1-bedroom and 2-bedrooms flats. The initial field surveys conducted by the LBN Community and Infrastructure team highlighted some major damp and mould issues within many flats (Medhurst and Turnham, 2016). The survey also confirmed water penetration issues in the tower block, which consequently resulted in poor indoor environmental conditions and concerns from the occupants about their comfort, health and wellbeing. The research focuses on the interactions between the building performance of the flats, the occupants' energy consumption behaviour and lifestyle, and the indoor thermal comfort in the winter months.

Methodology

The aim of the study is to investigate the building performance of the 22-storey tower block in LBN with the purpose of reducing the building energy consumption and to improve indoor thermal performance by providing tailored recommendations for energy and cost-efficient retrofit. The study adopts a mixed method research design that includes field monitoring and a questionnaire-based survey. The project is being undertaken over two phases. The first phase of the project, the focus of this paper, is the building performance evaluation to identify and diagnose the possible causes of the physical issues of damp, mould and condensation. This process entails building simulation modelling and case study monitoring of indoor air temperature and Relative Humidity (RH) levels of a sample of flats in the case study identified as problematic to assess the building performance, the occupants' energy consumption behaviour and indoor thermal comfort. Flat A and Flat B have been selected as the exploratory sample case studied for the research, with a particular focus on the bedrooms. Both flats are located in the south-east orientation of the building in the middle floors of the block with similar damp, mould and condensation issues. Two zones were selected in each property to be monitored, the small bedroom representing a non-problematic bedroom and a master bedroom, which suffers from cold, mould and condensation. Building simulation modelling using dynamic DesignBuilder (DB) software was also performed to help understand and diagnose the issues with the building performance.

The second phase of the project focuses on the building performance optimisation and methods for energy efficient retrofit. This includes building simulation analysis and a questionnaire-based survey distributed to all flats of the block to understand the occupants' energy consumption behaviour and indoor thermal comfort and satisfaction. In this phase, the most sustainable and cost-effective practical recommendations for heating, cooling, and ventilation of the properties will be proposed. In addition, the most effective retrofit strategy will be recommended to improve the thermal envelope and to reduce the building overall energy consumption while providing a comfortable indoor environment. These recommendations can then be applicable to similar building types in the UK.

Case Study: Tower block in London Borough of Newham

The case under study is a council housing tower block located in London Borough of Newham. The 22-storey tower block was constructed in 1966 (Medhurst and Turnham, 2016) and consists of 108 2-bedroom and 1-bedroom properties. The structure is in-situ reinforced concrete frame construction with floor slabs spanning between shear walls and pre-cast concrete panels covering the flank wall. Externally, the building envelope is fitted with asbestos cement over-cladding panels. All flats have double-glazed windows with UPVC panels and internal wooden doors. The internal partitions consist of the concrete blocks of 100 mm thickness and the external walls include external over- cladding of 9 mm thickness, an 80 mm air gap, 200 mm pre-cast concrete panels and 20 mm internal wall insulation boards and finishes. Floors consist of 150 mm concrete slabs as well as floor and ceiling finishes. There is one extractor fan in the kitchen and another in the bathroom. The building heating is provided by natural gas fuelled hot water boilers.

From a survey undertaken by Newham Council in 2016 to diagnose the water penetration problems; it was found that 25 flats (23% of the tower block) experienced severe damp, mould and condensation issues (London Borough of Newham, 2016). In addition, an internal damp survey was carried out with the aid of a damp meter to identify the cause of damp penetration in the two sample flats (Figure 1) in the south-east corner of the tower under this study, flats A and B (Figure 2).

(a) (b) (c) (d) (e)

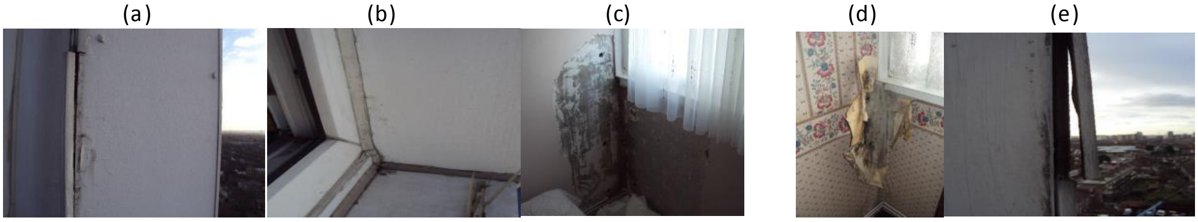

Figure 1. Damp and mould problems in Flat A (a, b, c) and Flat B (d, e) in the tower block in LBN

Based on the Newham survey results (Medhurst and Turnham, 2016), the building external over-cladding facades were jet washed in 2012 which may have damaged the sealing between the panels facilitating a path for water to penetrate the concrete structure during periods of driving rain. The second phase of this research will assess potential long-term solutions and will introduce the most cost-effective recommendations.

Monitoring

To evaluate the thermal and environmental performance of Flats A and B, the indoor air temperature and the Relative Humidity (RH) levels of the two main bedrooms of flats A and B (Figure 2) were monitored in the winter; from 25/11/2016 to 23/3/2017 using data loggers. Data loggers were fitted in each bedroom with the logging intervals of 15 minutes to collect indoor climatic data (air temperature and RH levels). They were located away from the heat source and any direct solar radiation. Interviews with the occupants of the properties demonstrated they each have different lifestyles, various schedules for ventilation, heating, lighting and domestic hot water usage which have direct impact on the indoor air temperature and RH levels, as well as the energy consumption of the properties. In Flat A, the heating is turned on by a young family (2 adults and 3 children) from 8:00 pm until 7:00 am in both bedrooms whilst it is turned off in all other zones in the flat during a typical winter day. Both bedrooms are usually naturally ventilated for at least one hour every day. On the other hand, in Flat B, one elderly occupant keeps the heating off in both bedrooms whilst keeping the heating on from 8:00 am until 10:00 pm in all other zones of the flat and the occupant never opens any windows during the winter season for ventilation purpose. It should be noted that the master bedroom in both flats have apparent water ingress issues while the second bedrooms in both flats have no such issues. The on-site measurement results provides important data to identify and highlight issues regarding the thermal performance of the properties.

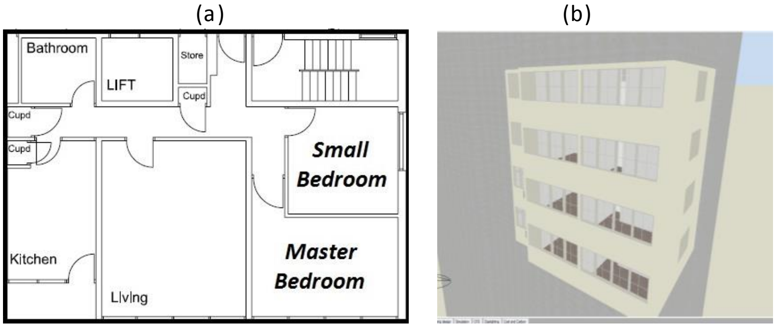

Figure 2. Floor plans of south-east flats (a) (London Borough of Newham, 2007) and the model on DB tool (b)

Building Simulation Modelling

In addition to the on-site monitoring, the building performance of the two properties, Flat A and Flat B, was studied using the building simulation modelling, in this case DesignBuilder software (DB). Building performance of the two sample flats was assessed to provide more in depth understanding of the possible reasons for the mould and damp within the building fabric and the potential correlations with occupants' lifestyle and energy consumption behaviour. There has not been detailed information available about the building materials for the case study tower block in LBN. Therefore, the characteristics of the typical council housing tower blocks in London and in the UK, in the 1960s, were adopted to create a more accurate simulation model in DB. This will help to investigate the operational performance and enhance the energy consumption of the properties more accurately while improving the indoor thermal comfort. The most typical material used in this type of building in 1950s/1960s in the UK was pre-cast reinforced concrete panel designed for a life of at least 60 years (Malpass and Walmsley, 2005, Harrison and De Vekey, 1998, Colquhoun, 2008). Table 1 shows the U-values of the case study building components.

Table 1. U-values of the building envelope components of the case study tower block

Building Elements	**Internal Partition**	**External Wall**	**Internal Floor**	**Glazing**	**Roof**	**Internal Doors**
U-value W/m^2K	2.93	0.78	1.82	2.67	0.28	2.82

To validate the building simulation analysis, the outdoor weather data obtained from the UK Meteorological Office (Met Office) for Gravesend weather station was incorporated into the simulation model's hourly weather file in DB, as well as the actual schedules for heating, ventilation, lighting and the domestic hot water usage in both flats. Later, the software was validated and assessed against the field monitoring data from the flats that were modelled in DB. The measured indoor air temperature and RH levels in both flats were compared against the simulation results in DB. At this stage, the focus was on the coldest week of the winter season in 2016-2017 (17/1/2017 – 23/01/2017).

Results and Discussion

The on-site monitoring results for the small bedroom and the master bedroom of flats A and B were gathered in order to assess the building performance and the environmental conditions as well as to analyse the damp and condensation issues. Figures 3 and 4 present the weekly mean indoor air temperature and RH levels of the measured rooms against the outdoor air temperature and RH. The results show that the indoor air temperature and RH levels in the measured bedrooms were usually within the acceptable comfort ranges in the winter. Generally, the RH range between 40% and 70% is acceptable for the sedentary occupancy while the indoor air temperature for the dwelling recommended to be between 17 °C and 19°C in bedrooms for winter conditions with clothing insulation of 1 clo and between 23 °C and 25°C for the summer conditions with clothing insulation of 0.5 clo (CIBSE, 2016). However, both flats have damp, mould and condensation issues in the master bedrooms, although the RH levels were usually in the acceptable range in the measured period. As discussed previously, the jet-washing of the building's external over-cladding facades might have damaged the sealing between the panels providing a path for water to penetrate the concrete structure where the impact might be magnified with the existing thermal bridges that can lead to internal condensation, damp and mould (Hopper, 2012).

Building simulation analysis were also performed on flats A and B during the coldest week of the winter season (17th-23rd January 2017) to represent the winter season for the simulation analysis. This is to assess the building performance and environmental conditions of the cases in more details (phase one) and to recommend the energy efficient retrofitting strategies which will result in reducing the dampness and the building's energy consumption (phase 2). Table 2 presents the mean, maximum and minimum climatic data measured with the data loggers during the coldest week of the measurement period.

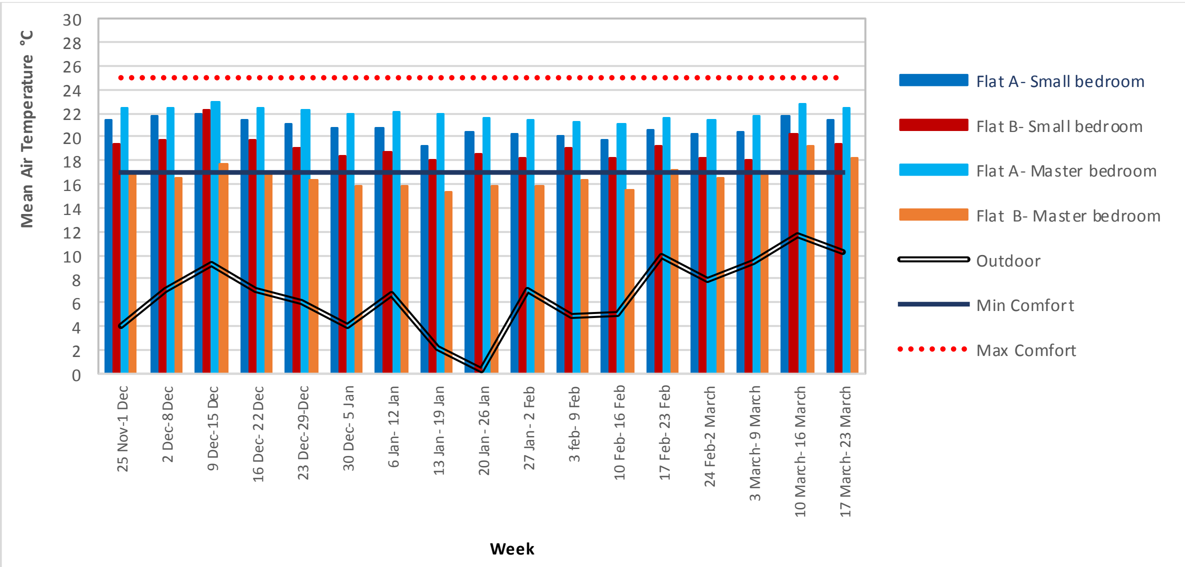

Figure 3. Weekly mean indoor air temperature against outdoor air temperature in small and master bedrooms in flats A & B

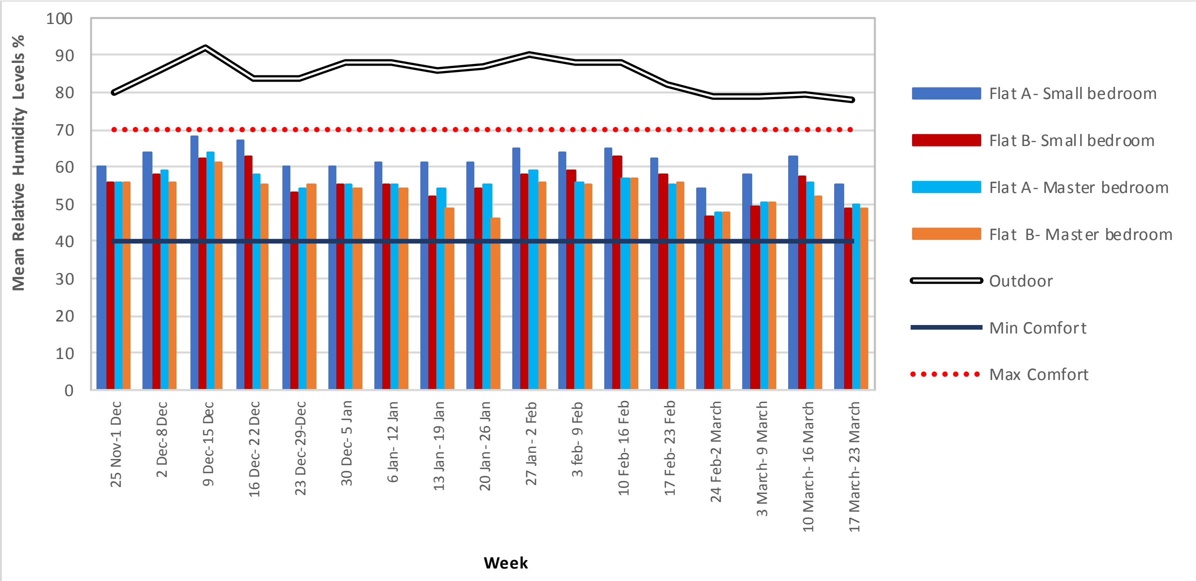

Figure 4. Weekly mean indoor RH levels against outdoor RH levels in small and master bedrooms in flats A & B

Table 2. Min, Max, Mean indoor air temperature and RH levels of the measured flats during the coldest week of winter, 17th Jan 2017 until 23rd Jan 2017.

Flats	Bedrooms	Temperature			RH Levels		
		Min	Mean	Max	Min	Mean	Max
Flat A	Small	19.1	20.6	21.6	47	63	76
	Master	20.2	21.9	23.2	40	57	70
Flat B	Small	16.7	17.1	20	48	54	65
	Master	14.5	16	19	42	46	51
Outdoor		-6.8	-0.2	6.8	48	85	100

Figures 5 and 6 illustrate the measured indoor air temperature and relative humidity levels against DB simulation results during the coldest week of the monitoring period. It can be seen that there is an acceptable correlation between the measured indoor air temperature and DB software generated air temperature. This proves that DB can be used as a valid software to perform the simulation modelling for the second phase of the project. In addition, this shows that the predicted building materials for the case study building (based on the 60s building material for the pre-cast concrete block) are also acceptable. Moreover, the measured indoor RH levels in all bedrooms were generally higher than the predicted results. Apart from the software and data loggers' accuracy, the water ingress issue in the flats might be one reason, is caused by the damaged external over cladding. Studies show that dampness can lead to mould growth on the building surfaces and the decrease in the effectiveness of the thermal insulation (Trotman et al., 2004) which is the case of the base case flats. The water also can be entrapped in the building materials and the indoor moisture can be appeared on the building fabric behind the insulation during the cold period as the building is internally insulated (De Selincourte, 2015). The occupants' lifestyle also has a significant impact on this issue, for example showering a few times a day in Flat A and once a day in Flat B and using washing machine every day in both flats. Although the bedrooms in Flat A are ventilated for one hour every day, the relative humidity levels are higher than Flat B as this property is occupied by a young family of five but Flat B has only one occupant.

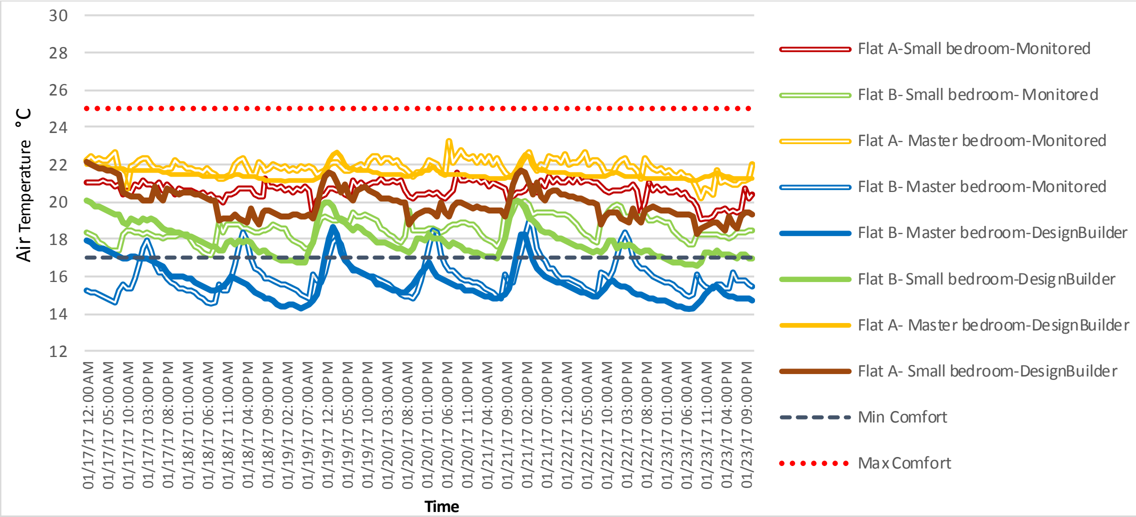

Figure 5. Indoor monitored air temperature against DB software predicted results in flats A & B bedrooms

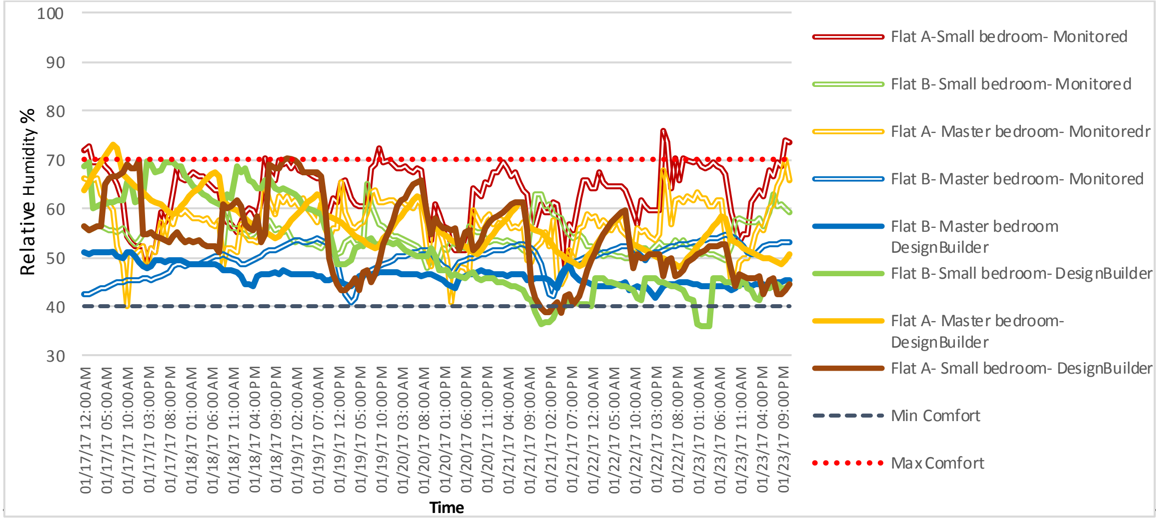

Figure 6. Indoor monitored RH levels against DB software predicted results in flats A & B bedrooms

The building simulation analysis shows that the average daily heating energy consumption of the small bedroom (non-problematic) and the master bedroom (problematic) of Flat A are 4 KWh and 10 KWh. This shows that the heating energy consumption in the master bedroom is higher than the small bedroom, probably to reduce the level of damp and condensation. In addition, 1.7 KWh of this energy in the master bedroom and 0.8 KWh in the small bedroom lose through infiltration because of the poor building fabrics. Moreover, as the total area of the master bedroom is 13 m^2 and the small bedroom is 10 m^2, the problematic room uses more energy for heating to keep the indoor air temperature in an acceptable range. However, the energy consumption and the system loads in Flat B bedrooms are zero as the radiators are turned off because of the occupants' health issues although it is turned on in the rest of the flat during the day-time in the winter season. In addition, the heat loss from infiltration in this flat is 1.1 KWh in master bedroom and 0.6 KWh in small bedroom.

Conclusion

This paper studies the thermal performance of a tower block in London Borough of Newham in two typical properties of the block as a sample. Field monitoring and simulation analysis were performed to assess the building performance (phase one). The focus of this research was on the master and small bedrooms. Both flats have the water ingress issue in the same corners of the flats which is significant in the master bedrooms. The results of this research supports the argument that the dampness issues in the case study flats may be caused by the poor construction materials of the external walls. This is further elucidated as both indoor air temperature and RH levels of the rooms within both flats were usually in the acceptable range during the field monitoring period. However, the occupants were generally unsatisfied with the indoor environmental conditions. In addition, the occupants are unaware that their energy consumption behaviour and lifestyle might indeed add to this problem during the winter season. Raising awareness of occupants concerning energy consumption behaviour and the important role of programmed natural ventilation can reduce many of the issues experienced. However, the long-term solution is the energy efficient retrofit, which can essentially reduce damp and mould in the properties, while reducing the energy consumption of the block and providing a comfortable indoor environment. The second phase of this project focuses on the building performance optimisation and provides feasible and cost-effective recommendations for energy efficient retrofit for the domestic sector in LBN.

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References

Bromley-dery, K. 2015. Home Energy Conservation Act (HECA) Return London.

CIBSE 2016. Environmental Design, CIBSE Guide A. London, UK: Chartered Institution of Building Services Engineers.

Colquhoun, I. 2008. *RIBA Book of British Housing: 1900 to the Present Day,* Oxford, Architectural Press.

De Selincourte, K. 2015. The risks of Retrofit. *Green Building Magazine,* 25**,** 28-37.

Department of Energy and Climate Change 2012. International aviation and shipping emissions and the UK's carbon budgets and 2050 target. London: The Department of Energy and Climate Change.

Google. 2017. *The Site of a Tower Block in London Borough of Newham*. Google.

Harrison, H. W. & De Vekey, R. C. 1998. *BRE Building Elements: Walls, Windows & Doors,* London, BRE Press.

Hopper, J. 2012. Evaluating the Installation of Retrofitted External Wall Insulation - CIAT Student Award, Technical Report. London, UK: CIAT.

London Borough of Newham 2007. Typical Floors Plans of the Tower Block in LBN. London: London Borough of Newham.

London Borough of Newham 2016. Water Penetration Survey. London.

Low Carbon Innovation Coordination Group 2012. Technology Innovation Needs Assessment (TINA)- Domestic Buildings- Summary Report.

Malpass, P. & Walmsley, J. 2005. *100 Years of Council Housing in Bristol,* Bristol, UK, Faculty of the Built Environment, University of West England.

Mayor of London 2015. RE:NEW- Helping to make London's homes more energy efficient. London: Mayor of London.

Medhurst, J. & Turnham, C. 2016. Damp Survey for London Borough of Newham. London.

Rickaby, P. 2011. GUIDE 1: introduction to the low carbon domestic retrofit guides. *Building Opportunities for Business.* 1 ed. London: Institute for Sustainability.

Trotman, P., Sanders, C. & Harrison, H. 2004. *Understanding Dampness,* Watford, BRE Bookshop.

Vilches, A., Padura, Á. B. & Huelva, M. M. 2017. Retrofitting of homes for people in fuel poverty: Approach based on household thermal comfort. *Energy Policy,* 100**,** 283-291.

Walker, S. & Ballington, R. 2015a. Domestic Energy Efficiency in Newham Annual Report 2013-4. London.

Walker, S. & Ballington, R. 2015b. LBN Annual Fuel Poverty Report 2013-14. London.