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Towards energy-efficient retrofit of council housing in London: Assessing the impact of occupancy and energy-use patterns on building performance

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ABSTRACT

This study investigates an energy-inefficient council housing tower block in London, due for retrofit, by exploring the correlations between occupancy and energy consumption patterns, thermal comfort and building energy performance in the winter. The aim of this study is to evaluate the building performance and develop a reliable building simulation model to be employed in the second phase of the study for developing an energy-efficient and cost-effective retrofit strategy to support the council's plans. The research seeks to demonstrate the significance of using dominant occupancy and energy use profiles as opposed to relying on standardised profiles when calculating building energy consumption using building simulation software. The paper reports on the results from the first phase of the study where a quantitative methodology; including a questionnaire, structured interviews, indoor monitoring, and building simulation modelling was adopted. The results provide evidence that occupants' socio-demographic characteristics have a considerable impact on household energy consumption and fuel bills. The results also show that indoor environmental issues experienced in many flats are partly attributed to the thermally inefficient building envelope and partly due to occupants' patterns of operating their homes with evidence of excessive heating energy use in attempts to alleviate the indoor issues experienced.

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1. Introduction and research context

Improving energy efficiency of buildings is one of the UK government's targets to mitigate greenhouse gas (GHG) emissions informed by the United Nations Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA) [1]. Energy efficiency in the domestic sector has also been the focus of much research in recent years due to its significant impact on carbon emissions [2]. Energy consumption in the UK housing sector accounts for 29% of the total Carbon Dioxide (CO_2) emissions production [3], where two thirds of this energy is used for space heating. Enhancing the energy performance of residential buildings can significantly contribute to achieving the UK government plans in carbon emissions reduction of 80% by 2050 [4]. It has been asserted that a steady rate of improvement in energy efficiency of the domestic stock has been achieved nationally between 1996 and 2012, hence the average Standard Assessment Procedure (SAP) rating of dwellings increased by 14 SAP points from 45 to 59 [5]. This is mainly due to the multiple retrofit programmes delivered by the UK government's Department of Energy and Climate Change (DECC) – now the Department of Business, Energy and Industrial Strategy (BEIS) – to improve the energy efficiency of buildings in the UK [4].

The UK policies aiming at improving energy efficiency and reducing CO_2 emissions from the domestic sector have undergone significant changes in recent years including programmes that have been run by local authorities and at community levels [6,7]. One of the successful programmes delivered is RE:NEW programme, introduced in 2009 to reduce carbon emissions and energy bills of London's domestic sector [8]. The main approach of RE:NEW programme is to find ways to cut energy bills by improving the building performance of the domestic sector to tackle fuel poverty [9] (households spending more than 10% of their income on heating energy services are considered to be in fuel poverty [10]). Based on the UK BEIS [11], 11% of households in England were in fuel poverty In 2017, at around 2.5 million. This is a significant number as occupants struggle to keep their homes warm whilst not achieving indoor thermal comfort during the cold winters, which may exacerbate the quality of life and cause health issues. RE:NEW scheme supports London boroughs and housing associations to develop and complete retrofit projects to help mitigate fuel poverty and achieve carbon emissions reduction targets

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[8]. So far, at least 127,000 residential buildings in London have been improved, which in turn, contributes to saving 46,000 tonnes CO_2 emissions annually [8]. Retrofit schemes have a significant impact on reducing domestic energy use hence achieving economic benefits from the reduced energy costs [12,13]. However, retrofit programmes also require wider engagement to generate positive and effective uptake and delivery for both, providers and end users, which can be achieved if programmes are adequately promoted. A survey of 500 households in Kirklees Warm Zone (KWZ) scheme in England confirms that promoting retrofit schemes effectively particularly by a trusted provider, may enable wider participation and uptake [6].

In addition, retrofitting domestic buildings helps improve health and comfort of occupants besides meeting the energy and fuel poverty reduction targets [6]. As a result of the thermal and economic benefits of retrofits, energy loads for space heating and thermal comfort levels in cold seasons have become recently much of the focus of research in the UK [14]. However, many studies have found that the benefits from retrofitting can be compromised through shortfalls in the building performance where achieved benefits may not necessarily resonate with the expected outcomes of the interventions [15,16]. One of the challenges for retrofit is adopting the most appropriate retrofit approach, which ensures the optimum thermal comfort of occupants and improved energy performance for particular building prototypes [17]. The extent of energy required to achieve the satisfactory level of comfort also varies from one building to another across various building typologies [18,19] and consequently might be different to the national average [7]. This is partly due to the particular physical characteristics of a building as well as occupants' energy consumption behaviours and occupancy patterns, which play an important role in the overall building energy load [20].

Energy consumption of buildings may not be significantly reduced by energy upgrade alone, particularly in areas with high fuel poverty levels where behavioural change interventions are required to support retrofit scheme delivery [21]. Studies assert that occupants' energy consumption behaviour and socio-demographic factors may have a significant impact on the intensity of energy used in buildings [22]. The intensity of energy consumption is highly associated with the energy use patterns related to occupants' presence within the buildings [23]. In fact, one of the main factors of uncertainty in predicting the building performance is occupancy and energy use schedules associated with energy consumption [22–25]. According to Song et al. [26], there are a few barriers to predicting the building energy performance using occupants' energy use data. These include occupants' diverse demographic and socio-economic characteristics as well as the various energy consumption patterns adopted either to achieve comfortable indoor environments or to reduce the intensity of indoor environment issues such as damp and mould. Considering occupancy and energy use profiles in energy simulation supports realistic building energy performance calculations. However, there is a lack of consensus regarding approved methodologies of occupants' energy use patterns to be incorporated into building simulation tools [27,28]. One study [29] investigated the effect of occupancy schedules and users' behaviour on the energy consumption of a building in order to define an approach for building simulation. In this study, the occupancy patterns of more than 3400 Belgian households studying the detailed activities of around 6500 occupants where seven occupancy profiles, with three states, were identified to be used in the simulation tools. These states are; "home and awake", "sleeping" and "absent". However, it was found that these schedules were quite general and far too simplistic to be applied to the simulation modelling and concluded that there is a lack of information concerning the interaction between the occupants and the internal spaces during specific periods not included in the three defined states. Another study [23] also investigated the occupancy profiles, and schedules for lighting and appliances and input data to a building energy simulation tool to develop new energy calculation methods. The identified profiles were applied to 10 different building typologies, which included one to three space categories, including weekdays and weekends that were then applied to the simulation tools. The space categories were used to group the similar rooms to a larger zone, where possible, for a quicker simulation analysis. The hourly occupancy, appliances and lighting patterns were also explored to study the impact of occupants' behaviour on cooling and heating energy use. The study showed that using the actual average hourly patterns in the simulation tool increased the peak energy loads of the buildings between 12% and 30%, which is realistic, and highlighted the importance of realistic hourly schedules for different building typologies. Song et al. [26] also examined how occupancy-related behaviours have significant impact on the prediction of building energy performance. A prediction model was developed to adopt the building thermal behaviour and to apply representative end-user groups. The model provided more insight into the daily peak energy demand, daily energy use, as well as general energy use patterns which showed that the occupants' energy-related behaviours provide more accurate predictions of building energy performance.

The current study evaluates the building performance of one of the typical social housing tower blocks in London Borough of Newham (LBN), which is planned for retrofit in the short term. In LBN, there is a high rate of fuel poverty at 13.8%, with 13,372 households identified as experiencing fuel poverty, which is among the highest rates in the UK [30]. Hence, LBN Council set a plan to significantly reduce the number of tenants affected by fuel poverty whilst achieving minimum energy efficiency standards (SAP) of B and C by 2030 for the social and private housing [10]. Improving the energy efficiency of residential buildings in the borough has proven to significantly cut energy bills for both council and private housing stock [5,30]. Concerning the research case study, initial field surveys conducted by LBN's Community and Infrastructure team in 2016 highlighted significant damp and mould issues in at least one quarter of the tower block flats which affected the occupants' thermal comfort and led to relatively high heating energy demands in the winter months [31]. This study investigates the interactions between the building performance, occupants' energy consumption behaviour related to thermal comfort in the winter months, and occupants' socio-demographic characteristics. The aim is to explore feasible occupancy and energy consumption profiles to be applied to the building simulation model that will help explore energy-efficient and cost-effective retrofit strategies for this tower block and similar prototypes in the second phase of the study. Considering realistic and dominant occupancy and energy use patterns in building energy simulation analysis may yield reliable outputs for retrofit interventions [32] and may help reduce the gap between the predicted and the actual building energy performance [33].

2. Research methodology

The research project is undertaken over two phases; the first phase of the project, the focus of this paper, is the building performance evaluation to identify the current energy performance of the building and develop a reliable building simulation model for the second phase. This includes understanding the underlying causes of the issues reported from occupants; mainly high energy bills and issues with indoor thermal comfort. The study adopts a quantitative research design based on a survey questionnaire, structured interviews, indoor monitoring, and dynamic simulation modelling. The questionnaire seeks to understand the correlations between the occupants' energy use patterns, the ex-

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