Assessing the effect of retrofit strategies on thermal comfort and energy performance in social housing

Recently, 30 percent of the final energy consumption in the UK is attributed to residential buildings. Besides, social housing accounts for around 5 million residential properties in the UK playing a major role in implementing energy efficiency retrofit policies in the country. This sector is home to some of the most vulnerable groups in society who are more at risk of thermal discomfort, fuel poverty, and poor environmental conditions. Hence it is crucial to consider a comprehensive approach not only to address energy efficiency but also to understand the effects of retrofit on summer/winter thermal comfort conditions. The aim of this study is to assess the effects of retrofit strategies on energy performance and thermal comfort conditions in a case study flat in the social housing sector in the UK. A building survey was conducted followed by dynamic thermal modeling in IES (VE) to evaluate the effects of upgrading the building fabric to the Part L of the UK building Regulations as well as to the passive house standards. Moreover, CIBSE TM59 and PMV guidelines have been applied to the model to assess its thermal comfort and energy consumption. The results revealed that although a high level of insulation and airtightness can reduce annual energy consumption by up to 60 percent, they could simultaneously increase the risk of overheating.

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Keywords
Thermal Comfort; buildings' energy modeling; CIBSE TM59 guideline, passive house standard, Part L standard

1. Introduction

In the past decade, population growth, technological developments, and higher living standards have led to a substantial increase in energy consumption worldwide. Meanwhile, in the UK, implementing energy efficiency policies and regulations has played a crucial role in curbing energy demand growth in the country. In fact, the UK's energy consumption has declined from 150 million tonnes of oil equivalent in 2010 to 120 million tonnes in 2021 [1]. Since Buildings account for almost 30 percent of energy demand in the country, implementing energy efficiency policies in this sector enables the country to sustain this trend in the coming years.

With the current annual replacement rate of 180,000, of around 28 million housing stock in the UK; retrofitting seems to be the only viable approach to improve the energy performance of buildings [2]. Retrofitting in buildings refers to the upgrading of the fabric, systems, or controls of a property without fundamentally altering its original design or structure. Retrofitting measures may include improving insulation, upgrading HVAC (heating, ventilation, and air conditioning) systems, replacing windows with more energy-efficient ones, utilizing renewable energy resources, etc. Hence, retrofitting is a common practice to transform older or less efficient buildings into more energy-efficient ones [3].

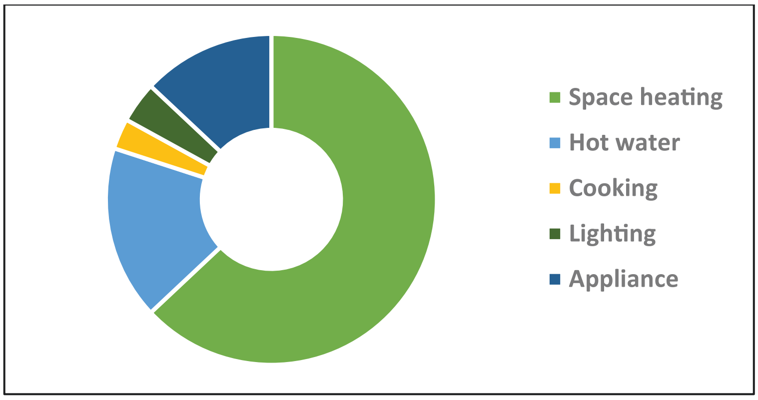

Figure 1. Breakdown of energy consumption in existing homes [4]

The initial stage in implementing effective retrofit strategies for improving a building's energy performance is analyzing the energy flow of the case study to provide insights into the contribution of each section to the building's overall energy consumption. According to statistics in existing homes, as shown in Figure 1, space heating is the dominant driver of energy consumption (making up 63% of annual energy consumption), followed by hot water demand (17%) and appliance demand (13%) [4]. As a result, Numerous initiatives have been undertaken to decrease the energy required for space heating in residential buildings by upgrading the building envelope to minimize heat loss and improving overall thermal efficiency.

In order to organize and coordinate these initiatives and efforts toward energy efficiency in buildings, guidelines and regulations have been developed, referred to as a framework for implementing energy-saving measures. Amongst these regulations and codes, "part L: Conservation of fuel and power" and "passive house" are widely known in this scope in the UK.

Approved Document Part L specifically focuses on energy efficiency and aims to improve the thermal and energy performance of buildings by setting requirements for insulation, air tightness, heating, cooling, and lighting systems. Besides, the passive house standard is a rigorous guideline for energy efficiency developed in Germany in the late 1980s [5]. The principle behind the passive house is to create buildings that require a very small amount of energy for heating and cooling, and this is achieved through a combination of orientation design, shading system, super insulation, triple glazed windows, and a controlled ventilation system [6].

In this regard, many studies have been conducted to evaluate the effects of implementing energy-saving measures in existing buildings and their effect on overall energy consumption. Evanglisti et al. [7] assessed the impact of applying retrofits (e.g. utilizing double-glazed windows, and adding thermal insulation to the roofs and walls) on energy performance in a building constructed during the 1950s in Rome. The result showed a reduction of up to 40% in energy consumption. A similar study by El Darwish [8], in a case study building in Egypt, showed a reduction of 33% in annual energy consumption.

Hyeon Jo et al. [9] implemented retrofits with a focus on improving openings in building envelopes by changing entrances and windows and reducing thermal bridges on the building envelope, in a case study building in South Korea, which reduced the annual energy consumption by 10 percent. Zhou et al. [10] analyzed the effect of window-to-wall ratio according to building orientation on energy consumption in a case study building in China. The results of this study revealed the relation between window-to-wall ratio in different orientations on the building's overall energy consumption, and effectively utilizing this strategy can reduce the consumption by up to 4%.

Although applying these strategies significantly reduce energy consumption, it is important to also consider their impact on thermal comfort, particularly for vulnerable populations. Currently, in the UK, social housing accounts for approximately five million out of 28 million housing stock [11]. To achieve the best results, any effort to reduce energy consumption in residential buildings should also consider thermal comfort and indoor air quality. In this regard, many studies have been carried out to evaluate the occupants' thermal comfort before and after implementing energy efficiency retrofit.

Kim et al. [12] assessed the effect of energy efficiency retrofit on occupants' thermal comfort. They coupled retrofit in the building envelope with improving the HVAC system, which decreased energy demand and the percentage of dissatisfied occupants in the case study building. The same results have been achieved in other case study buildings in Germany and Sweden by Gartner et al. [13] and Liu et al. [14]. Although utilizing mechanical ventilation alongside improving the building envelope can result in lower energy consumption and better summer/winter thermal comfort, it may not be economically feasible in many cases, including in social housing[12], [15]. To this end, this study intends to assess the effects of retrofit strategies on both energy consumption and summer/winter thermal comfort in a case study building in the social housing sector of the UK.

2. Materials and Methods

A 2-bed, southwest-facing, naturally ventilated flat (Figure 2, 69 sqm) in Newham, London, UK, was selected as the case study flat. The case study building was built in 1965 and renovated during the 1990s. Simulations were conducted in IES(VE) to assess the energy performance and summer/winter thermal comfort condition in the case study building for the base case and retrofitted scenarios explained below in section 2.2.

The heating set points for the different zones of the case study flat are considered according to the "CIBSE guide A" recommended comfort criteria as follows: 18°C bedrooms and kitchen, 21.5°C halls/stairs/landings, 22.5°C living room and 21°C for bathroom [16]. These set points are linked to the occupancy profile of the zones, in which the rooms are considered to be occupied 24/7, while the living room and the kitchen are occupied from 9 am to 10 pm. The energy supply system in the building is all-electric, and the flats are heated with electric radiators. In terms of material used, the building has solid concrete walls (150mm thickness) and internal roofs/floors with double-glazed windows. The details of the current status of building elements are presented in Table 1.

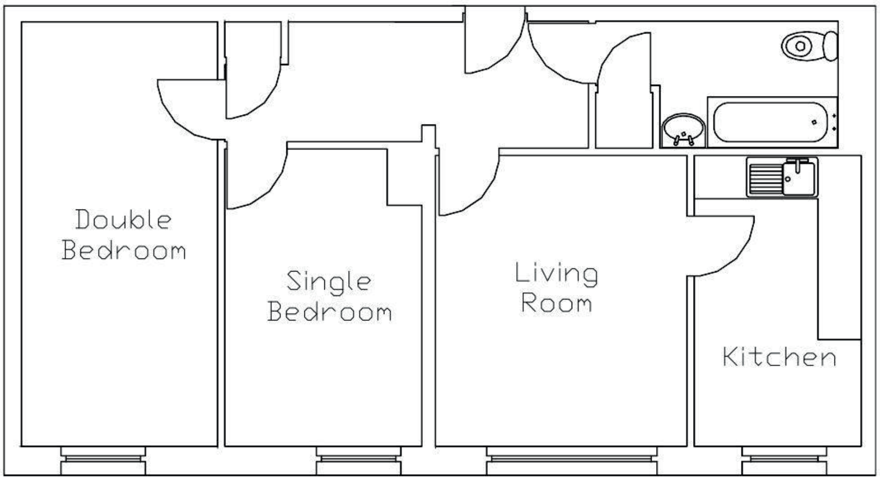

Figure 2. Floor plan of the case study flat .

2.1 Thermal comfort assessment

CIBSE TM59 provides a standardized method to assess the risk of overheating in naturally ventilated residential buildings during the summer period. The following criteria must pass from May to the end of September in order to avoid the risk of overheating in buildings [17]:

1. For the living room, kitchen, and bedrooms, the number of hours during which (operative temperature – comfort temperature) [18] is greater than or equal to one degree (K) shall not be more than 3 percent.
2. For bedrooms only: the operative temperature in the bedrooms from 10 pm to 7 am shall not exceed 26°C for more than 1 percent of annual hours.

It should be noted that windows should be modeled as open when both the internal temperature exceeds 22°C, and the room is occupied. Moreover, internal doors are left open in the daytime but are assumed to be closed when occupants are sleeping. Furthermore, PMV [19] is a widely used approach to assess thermal comfort in indoor environments, and it is utilized in this research to analyze the thermal comfort of occupants from October to the end of April (heated periods). This method calculates an index value on the basis of four measurable parameters (air velocity, air temperature, mean radiant temperature, and relative humidity) and two expected variables (clothing and metabolism rate). This index value ranges from +3 (indicating feeling too hot) to -3 (feeling too cold), and the thermal acceptability criterion is considered between 0.5 to -0.5 [19], [20]. In order to conduct a simulation on IES VE, CIBSE design summer year (DSY1) and IES London city airport weather files were utilized to assess summertime overheating analysis and PMV index, respectively.

2.2 Retrofit strategies classification

Two sets of retrofit strategies, mainly focusing on improving the building fabric, air tightness, and windows' thermal transmittance, were considered in order to meet part L of the UK building regulations and passive house requirements; and Three scenarios were considered as follows:

- Base case (current situation).
- Retrofit to Part L standards.
- Retrofit to Passive House standards.

Table 1 provides detailed information regarding the retrofit strategies in the building.

Table 1. Building characteristics before and after retrofit strategies.

Building element	Passive House	Part L	Current situation
External wall U-value (W/m2K)	0.15	0.3	2.2
Windows U-value (W/m2K)	0.77	1.4	2.29
Windows G-value	0.55	0.4	0.4
Internal ceiling (W/m2K)	1.25	1.25	1.25
Airtightness (ACH)	0.05	0.5	0.7
Roofs (W/m2K)	0.15	0.15	2.1

3. Results

This section is focused on assessing occupants' thermal comfort in the current situation and after implementing part L and passive house retrofit strategies. Furthermore, the impact of these retrofits on energy consumption, and specifically space heating, has been quantified.

Figure 3 shows the operative temperature in the living room and bedroom from May to September to assess the risk of overheating in summer according to CIBSE TM59 guidelines. In the base scenario, the living room's maximum operative temperature has reached 33°C, which is almost the same in part L and passive house retrofits. However, the average operative temperature is lower in the Base scenario. For example, the bedrooms' average temperature in the Base case, part L, and passive house retrofits is around 21,22, and 23°C, respectively.

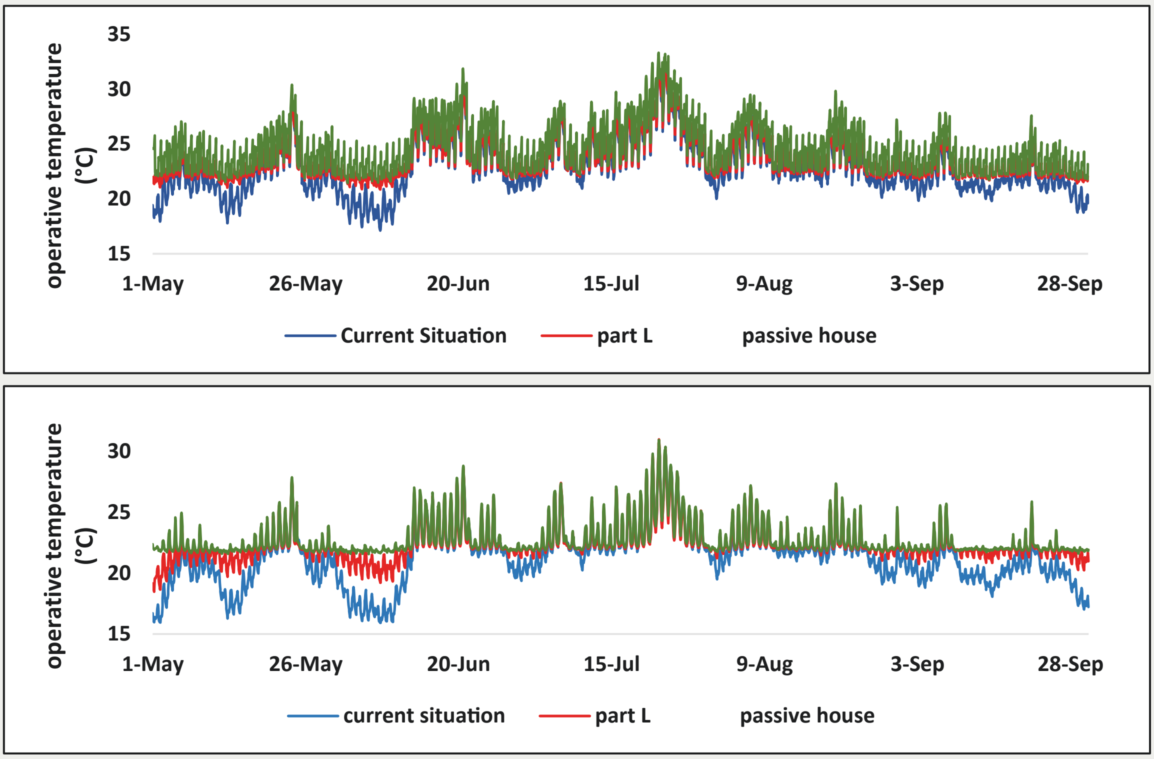

Figure 3. Operative temperature in (top) Living room (bottom) bedroom during May-September

In the kitchen, where there is more internal gain due to cooking, the maximum operative temperature reached 35°C during late July in passive house retrofit, and the average is almost 24.5°C in both part L and passive house scenarios. Furthermore, more than 12% of hours (operative temperature – comfort temperature) is greater than or equal to one degree (K), which shows the high risk of overheating in the kitchen when applying passive house requirements to this flat. This variable is almost 2 and 3.5 percent in the base case and part L retrofit.

Overall, between four occupied zones (bedrooms, kitchen, and living room), the living room and kitchen cannot meet the CIBSE TM59 requirements in the passive house scenario. According to simulation results, the living room has passed the assessment in part L, where 1.1 percent of hours, overheating has been reported. Finally, Bedrooms are the least problematic zones, and only in less than 1 percent of hours, TM59 requirements are not met in all scenarios.

During winter, PMV index assessment shows that occupants are likely to experience a warm sensation (PMV index of around 1) in passive house retrofit (Figure 4). Passive house retrofit is recommended to be coupled with mechanical ventilation in order to supply fresh air. Although in this model, occupants will open windows when the indoor temperature reaches 25°C, applying a high level of insulation and airtightness, and relying on natural ventilation, can result in thermal discomfort during winter, as shown in Figure 4. This however needs more investigation to assess the effects of applying mechanical ventilation on energy consumption and thermal comfort.

On the other hand, the case study's current situation does not provide a comfortable indoor condition during winter since the PMV index is less than -0.5 in 20 and 50 percent of hours during winter in the living room and bedroom, respectively. Moreover, part L retrofits show a better indoor environment in terms of thermal comfort, where the PMV index in bedrooms and living room is ranged between 0.5 and -0.5 in almost 85 percent of hours.

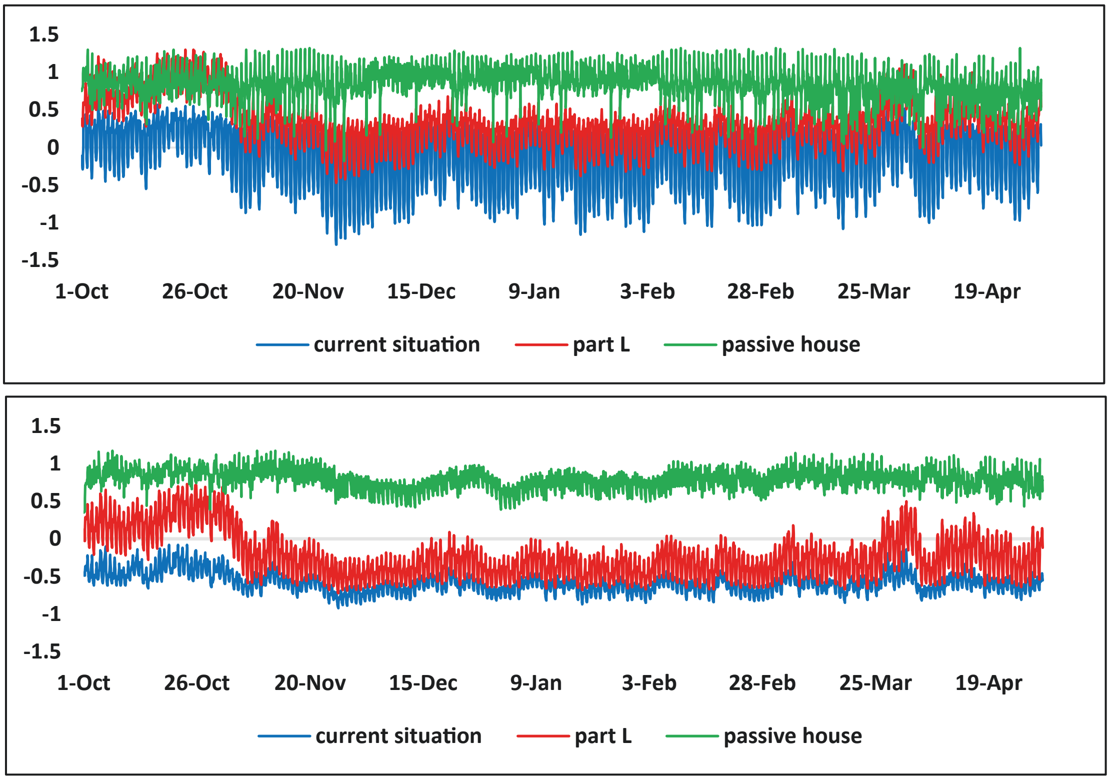

Figure 4. PMV index in (top) Living room (bottom) bedroom from October to the end of April.

Regarding energy consumption, the case study flat consumed 155 KWh/m2 before implementing retrofits, which is almost 20 percent higher than new domestic flats in the UK [21]. Around 60 percent of the energy has been consumed for space heating purposes, which matches typical UK scenarios [4]. Applying strict standards for building envelope insulations, such as Part L and passive house, can reduce energy demand for space heating by up to 90 percent in the case study. Figure 5 shows that improving exterior wall insulation and utilizing triple-glazed windows can save almost 60 percent of total annual energy consumption. Hence, as expected, applying passive house standards achieved better results decreasing total energy consumption to 63 kWh/m2, which matches the monitored performance of implemented passive house buildings in the UK [22, 23].

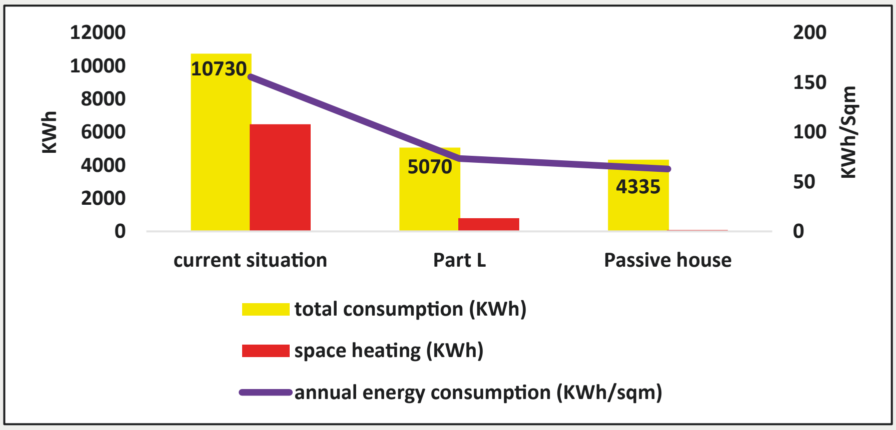

Figure 5. Yearly energy consumption and share of space heating.

4. Conclusions

Almost 30 percent of energy in the UK is consumed in the domestic sector, which highlights the importance of energy efficiency measures in buildings. There are more than 5 million social housing properties, mostly occupied by vulnerable populations, that require more consideration while applying energy efficiency measures. Two sets of retrofit strategies were simulated in IES (VE) to comply with the Part L and passive house standards in a case study building to assess its performances in terms of thermal comfort and energy consumption.

The results indicate that implementing a high level of insulation and airtightness in buildings can increase the risk of overheating during the summer, particularly in zones with higher internal gain, like kitchens. Furthermore, during winter, part L retrofit resulted in a better performance, where the PMV index was between 0.5 and -0.5 in 85 percent of hours. Finally, in terms of energy consumption, there is a 60 percent energy-saving opportunity in the case study building, utilizing triple-glazed windows and exterior wall insulation. This paper purely focused on building fabric retrofit strategies by improving U-Values to the Part L and Passive House standards. Further studies are required to assess the effects of other strategies such as shading, ventilation, thermal mass, occupants' behaviours, orientation, other weather scenarios, etc. on the energy performance and thermal comfort in the case study building.

Acknowledgments: This research is funded by the Newham Council and University of East London. The research team would like to thank all the staff and residents who supported this study.

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