

TECHNICAL ARTICLE

Evaluation of Retrofit Approaches for Two Social Housing Tower Blocks in Portsmouth, UK

Victoria Aragon*, Despoina Teli*† and Patrick James*

The UK aims to reduce its carbon emissions focusing on the renovation of its existing building stock, particularly on the residential sector. Within this group, social housing is an excellent candidate for retrofits, but faces specific challenges. The cases presented in this study are social housing tower blocks in the City of Portsmouth, which are destined to be retrofitted but present particularities within its architecture, heating system, and occupants' behaviour and comfort perception. This study presents an analysis of the thermal performance of these buildings after different retrofit intervention scenarios were undertaken to evaluate heating loads, comfort and overheating. A dynamic simulation model was developed using the software TRNSYS and included performance evaluation under future climate change scenarios. Firstly, the buildings were modelled under different occupier energy profiles and the results in all cases, show that the physical properties of the building lead to a high level of energy consumption and discomfort. Moreover, the simulation of possible retrofits demonstrated that improving the building envelope to meet 2010 Building Regulations or stricter standards would result in a decrease of more than 80% of the heating load but would result in overheating if no adequate shading is installed. The analysis indicates that the best performing retrofit corresponded to a mixed system of MHRV for heating and natural ventilation during the summer. The paper concludes that (a) existing buildings are inefficient and a retrofit would result in a complete change in their energy performance and (b) that a thorough economic appraisal is required to select the best environmentally and economically viable interventions.

Keywords: social housing; retrofit; storage heaters; thermal comfort; overheating

1. Introduction

As part of its emission reduction goals, the UK is improving the energy performance of its built environment resulting in a large number of refurbishment projects. Social housing represents 17% of the residential sector (HM Department for Communities and Local Government, 2017, page 2); additionally, its public ownership allows for ease of management making it an excellent candidate for retrofits. Moreover, targeting this sector coincides with the government's goal of tackling with fuel poverty (Brenda Boardam 2007, page 7). A problem encountered in building retrofits is what is known as the "performance gap" (Brown et al. 2014) meaning the difference between the actual and the expected results after a retrofit. There are three main factors that affect a building's performance: building thermal characteristics, occupant behaviour and climate. The interaction between these will determine both the comfort of the residents and the energy con-

sumption of a building (Gupta et al. 2014). Consequently it is paramount to analyse each of these aspects to diminish the performance gap. Studies such as building simulation and comfort surveys are key analysis for developing an understanding of building performance and user behaviour.

1.1. Occupant behaviour and thermal comfort

Buildings are designed to provide protection and safety to its residents, assuring indoor comfort conditions. The first thermal comfort model was developed by P.O. Fanger (Nicol & Spires 2013, page 6). It predicts the comfort level of a room based on characteristics such as people's clothing, metabolic activity and indoor conditions. The model was based on measurements in climate chambers and laboratories where participants reported their level of comfort when exposed to different thermal conditions. The extensively used CIBSE Guide A (CIBSE 2006) utilises Fanger's model for defining what indoor conditions maximise occupants thermal comfort. Additionally, standards such as the American ASHRAE Standard 55 or the European CEN BS EN 15251 are based on Fanger's comfort predictions as well but add a differentiation between 'standard' and more 'vulnerable' occupants presenting three categories of users based on their vulnerability (Brager & de

* Sustainable Energy Research Group, Faculty of Engineering and the Environment, University of Southampton, Southampton SO17 1BJ, GB

† Department of Civil and Environmental Engineering, Chalmers University of Technology, SE-412 96, Göteborg, SE

Corresponding author: Victoria Aragon (V.Aragon@soton.ac.uk)

Dear 1998, page 88). This helps to represent reality more accurately, as for example, occupants such as elder or sick people who have low activity levels will prefer higher temperatures than others (Guerra-santin & Tweed 2013).

These standards and guidelines are intended for systems designs to estimate cooling and heating loads of HVAC units. However, both ASHRAE and European guidelines also present adaptive comfort models for naturally ventilated buildings in the summer based on the relationship between outdoor and indoor operative temperatures. Although the aforementioned models are useful for building design stages they are not so much for existing buildings where other factors such as people's interaction and familiarity with the building play an important role. Additionally, other variables may affect thermal comfort as it is subjective; it can vary according to the type of person, climate and habits (Amin et al. 2016).

Besides considering thermal comfort, standards for indoor conditions are also set in relation to health risks to reduce mortality induced for exposure to excessively cold or warm homes. For cold weather, the UK Government has set a Cold Weather Plan limiting indoor temperatures to a minimum of 18°C (Public Health England 2014, page 57) and the WHO recommends a minimum of 21°C for in the case of vulnerable or elderly population (World Health Organization 1987, page 7).

Regarding warm weather, CIBSE Guide A defines overheating in naturally ventilated buildings as when the indoor operative temperature overpasses 26°C in bedrooms or 28°C in living areas in more than 1% of occupied hours. The most advanced criteria for overheating is defined in CIBSE TM 52 (Nicol & Spires 2013) based on the adaptive comfort model BS EN 15251. In contrast to CIBSE Guide A, temperature limits are not fixed values but vary according to the outdoor running mean temperature. Additionally, overheating is defined by a combination of three different criteria: (i) a temperature limit that should not be overpassed more than 3% of the year's occupied hours; (ii) evaluation of continuous exposure to elevated temperatures throughout a day, (iii) an absolute temperature limit that should never be exceeded. If any two of the three criteria is not fulfilled then the space is considered to be overheated.

Overheating has become a relevant issue in the UK in the face of climate change where an increase of temperature as well as a higher frequency of extreme weather events, such as floods and heat waves, is expected (Jenkins et al. 2009). This can be very dangerous for vulnerable occupants, such as elderly or disabled, particularly when strategies that are normally successful to cope with high temperatures during summer such as opening windows, might not work during a heat wave (Mavrogianni et al. 2015). Changing climate added to increasing population and urbanization presents a need for cities to adapt to new conditions and develop resilience in order to provide comfort for inhabitants (Carter et al. 2014).

1.2. Social housing retrofits

Social housing is defined as affordable housing for people on a low income (Department for Communities and Local Government n.d.). Regarding its demographics, the most

commonly observed age band is over 65 years of age, and 34% of residents of social housing are considered inactive or unemployed. What is more, the social housing sector is not dynamic; people do not tend to move but stay in the same place for a long period of time. Moreover, an important goal of providing social housing is to avoid fuel poverty, meaning that residents should be able to live in adequate comfort conditions and be economically capable of meeting the energy bills (Palmer & Cooper 2013). Hence, building performance is a key aspect to address.

A characteristic UK social housing building is the 1960's prefabricated concrete tower block which represents approximately 10% of the existing social housing building stock. This type of construction, which was seen as promising for a sustainable future, with time and lack of proper maintenance, proved to be energy inefficient and of poor quality; thus needs to be refurbished. The focus in tower blocks refurbishment is on passive techniques such as natural ventilation and solar gains, and avoiding active or mechanical measures in order to diminish energy consumption (Shabha 2003). The performance gap observed post retrofits in social housing is mostly attributed to social aspects, meaning occupant behaviour which depends on the occupants' profile, their cultural background, age and lifestyle. Additionally, It is generally observed that there is a rejection and lack of interest of occupants to engage with new technologies and building systems (Brown et al. 2014).

An example of a future retrofit project is the one of two social housing tower blocks in the city of Portsmouth: Towers A&B. The objective of such is to diminish the energy consumption of the blocks and improve the living conditions of the residents. As this project aims to have a significant impact in the building's performance and considering the large number of residents affected, a deep analysis of the situation is required. A first evaluation has been performed by the Sustainable Energy Research Group at the University of Southampton (Teli et al. 2016) showing elevated indoor temperatures during heating season and a high level of comfort experimented by residents. This study is a continuation of that research and aims to assess the thermal conditions and the energy performance of Towers A&B before and after different retrofit measures through thermal simulation, under current and future climates. The objective of this paper is to provide useful conclusions for the renovation project. This report is structured as follows: section (2) presentation of the case study, (3) methodology, (4) analysis of current occupants' behaviour, (5) analysis of simulation results including contrast of different users under existing building conditions and comparison of retrofit scenarios and (6) simulation under future climate.

2. Case Study

The buildings analysed in this paper are two identical social housing tower blocks, A&B, in the city of Portsmouth. The towers host 'vulnerable' residents, the majority are either over 65 years of age, unemployed or retired and receive some type of benefits for being disabled or ill. The buildings have 17 floors of 8 flats each, two-bedroom (approx. 70 m²) and one-bedroom apartments (approx.

50 m²) distributed towards East and West at a 5 degree angle (**Figure 1**). Regarding thermal properties, both towers have poor U-values that do not comply with current Building Regulations (Office of the Deputy Prime Minister 2006). **Table 1** shows a summary of each element U-values; Tower A recently had its roof insulated resulting in a lower U value than Tower B. Also, there is no mechanical ventilation, occupants rely only on single pane windows in lounges, bedrooms and kitchens.

The particularity of the towers is their heating system. Heating is electrical and is managed and paid by the City Council. Electricity for heating is provided during the heating season, approximately from October to May/June. Initially the buildings had underfloor electric heating, but then storage heaters were installed in almost all of the flats; consequently a small number of flats still have underfloor heating or a combination of both systems. Storage heaters are meant to be used under ‘Economy 7’ tariff, charging during night hours when lower electricity prices are offered, and release heat throughout the day. However, this is not the case in towers A&B where due to some flats still having underfloor heating, electricity for heating has to be provided both during day and night. This, in combination with a lack of occupants’ engagement with heating controls, leads to storage heaters being charged during the day resulting in high costs for the City Council.

3. Methodology

First, a literature review and collection of information was developed. This includes indoor monitoring of temperature and relative humidity in 21 flats for eight months and thermal comfort surveys implemented in 2014 by the University of Southampton Sustainable Energy Research Group. In addition, heating electricity usage records were provided. The data was used to analyse the characteristics of existing conditions in the towers, such as indoor temperatures in winter and summer as well as occupant preferences, use of heating controls and occupancy.

Secondly a model of a middle floor was developed in the dynamic simulation environment, TRNSYS (Anon n.d.). In each flat, the bedroom, the lounge and the kitchen were modelled as separate zones whereas the hallway and the toilet were joined as one zone. Thirdly, simulation of the towers, as they are today, was performed utilising an occupant profile based on existing residents as well as a ‘standard’ occupant profile. The ‘standard’ resident is considered as someone who is responsible for his/her own heating bills thus tries to minimise energy consumption while maintaining comfort conditions within the household. This allowed evaluating the impact of occupants and the existing heating scheme on energy demand and building performance. Fourthly, three different retrofits were defined and modelled with the ‘standard’ user profile. Finally, the best performing retrofit or retrofits were selected and modelled under future climate conditions obtained from morphing current weather files (University of Southampton n.d.) for the year 2050. The existing building was simulated with future climate as well.

All simulations were performed utilising CIBSE weather files from the neighbour city, Southampton. Test Reference Year (TRY) were used for evaluating winter building performance, and Design Summer Year (DSY) for summer. Finally, three criteria were used for quantifying building performance: (i) annual heating demand, (ii) thermal comfort in winter and (iii) thermal comfort in summer. Comfort analysis was based on BS EN 15251 temperature limits for Category I (vulnerable occupant), considering fixed limits in winter and adaptive ones in summer for a

Table 1: Fabric properties of towers A and B.

U Values (W/m ² K)	Tower A	Tower B	UK 2010 Building Regulations
Exterior walls	3.4	3.4	0.3
Windows	2.5–3	2.5–3	0.18
Roof	0.5	3.2	2.0

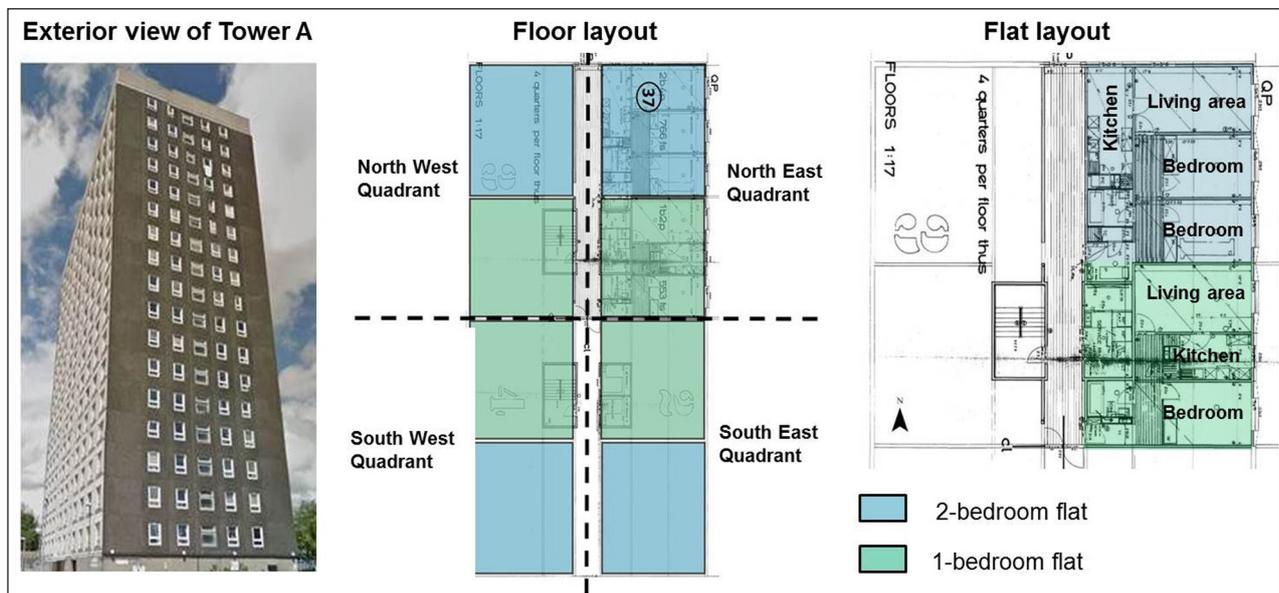


Figure 1: Characteristics of case study, social housing tower blocks A&B in the city of Portsmouth, UK.

naturally ventilated building. Overheating was calculated based on TM 52 criteria.

4. Analysis Of Current Occupant Behaviour

Data loggers were installed in 21 occupied flats within both towers measuring indoor temperature and humidity, at 5 minutes intervals, from February to October 2014. The loggers were placed in different types of flats, one and two bedrooms, and in varied floors and orientations. In addition, a questionnaire survey was asked to the residents of monitored flats to evaluate Post Occupancy Comfort, behaviour patterns and engagement with controls, as well as their understanding of the heating system.

Firstly, indoor temperatures were evaluated showing mean temperatures of 23.5°C in bedrooms and 24°C in lounges during the winter season and 23.6°C and 24.2°C during the summer season respectively. This means that occupants live in similar conditions across the entire year; there is almost no seasonal effect on indoor conditions. Moreover, indoor temperatures were more uniform across flats in the summer than during winter. In summer, as there is no active cooling, only natural ventilation, temperature varies very little across each type of flat. In winter, usage of heating controls and temperature set points can lead to different heating patterns; indoor temperature patterns may vary according to each individual preference and heating usage. Moreover, both during the heating and non-heating seasons temperatures were over 21°C in all but two flats and in at least 10 flats bedroom and lounge temperatures were above 25°C during the heating season. **Figure 2** shows the temperatures in each flat for the heating and non-heating periods in bedrooms and lounges.

Interestingly, the comfort survey showed that the majority of people were comfortable with current conditions throughout both winter and summer in bedrooms and lounges. During winter, a few would like to have warmer bedrooms but cooler lounges, whereas the opposite in

summer. Additionally, most people declared to never engage with storage heaters' controls, neither input or output, for both bedrooms and lounges. Also, they stated to open windows and utilise fans often in the summer.

Under the current situation, occupants live in high temperatures all year long and show elevated levels of comfort. Making residents responsible for their heating bills could have negative consequences. It could be that people will not be able to meet the cost of heating their houses to the high temperatures they are used to and result in high dissatisfaction. Residents would have to manage their storage heaters efficiently if they do not want to incur in high costs. This implies a change in their current behaviour as they would have to engage with the controls of their heating system. It is necessary to analyse the building's thermal performance to understand both the impact of occupants in the heating demand and how a retrofit would contribute to maintaining comfort and reducing energy costs.

5. Simulation Results

Figures 3, 4 and **5** contain the results of all scenarios simulated. **Figure 3** presents a comparison of the heating demand for each case. **Figure 4** shows the distribution of indoor temperatures during winter and summer months against thermal comfort limits. It was chosen to show the results for a one bedroom South West flat as a case with the highest risk of overheating and a two bedroom North West flat as an example of a flat with high heating demand; the profiles for the remaining flats showed very similar distributions. Finally, **Figure 5** shows the outcome of evaluating overheating under TM 52 criteria.

5.1. Existing buildings under 'current' and 'standard' occupant profiles

As stated in the methodology section, the simulation of the existing building was done under two occupant profiles: 'current' and 'standard'. The main difference between the

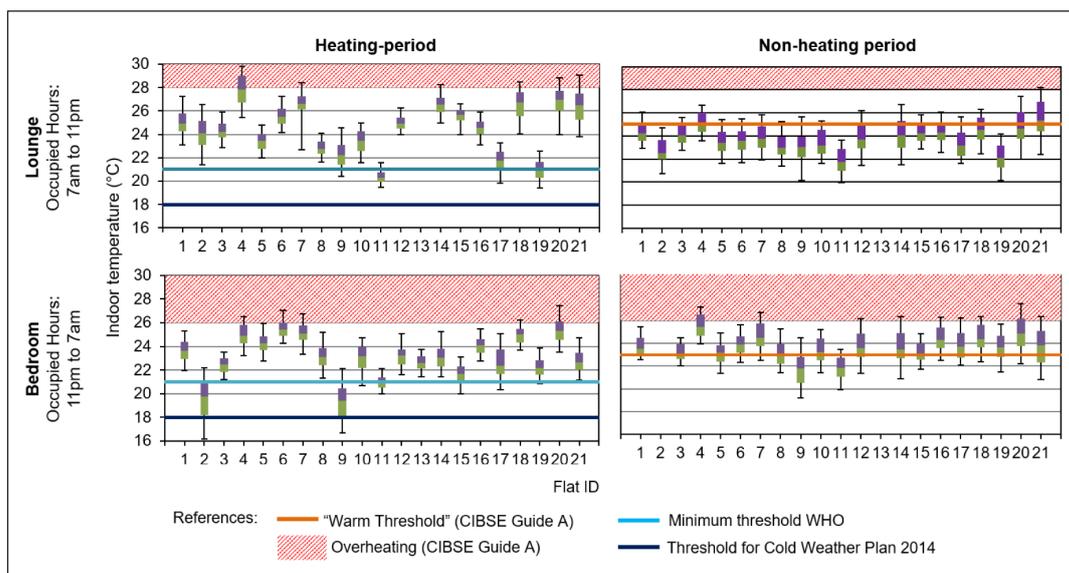


Figure 2: Indoor temperatures in bedroom and lounges during occupied hours in 2014. The heating period covers February to May and the non-heating period, May to September.

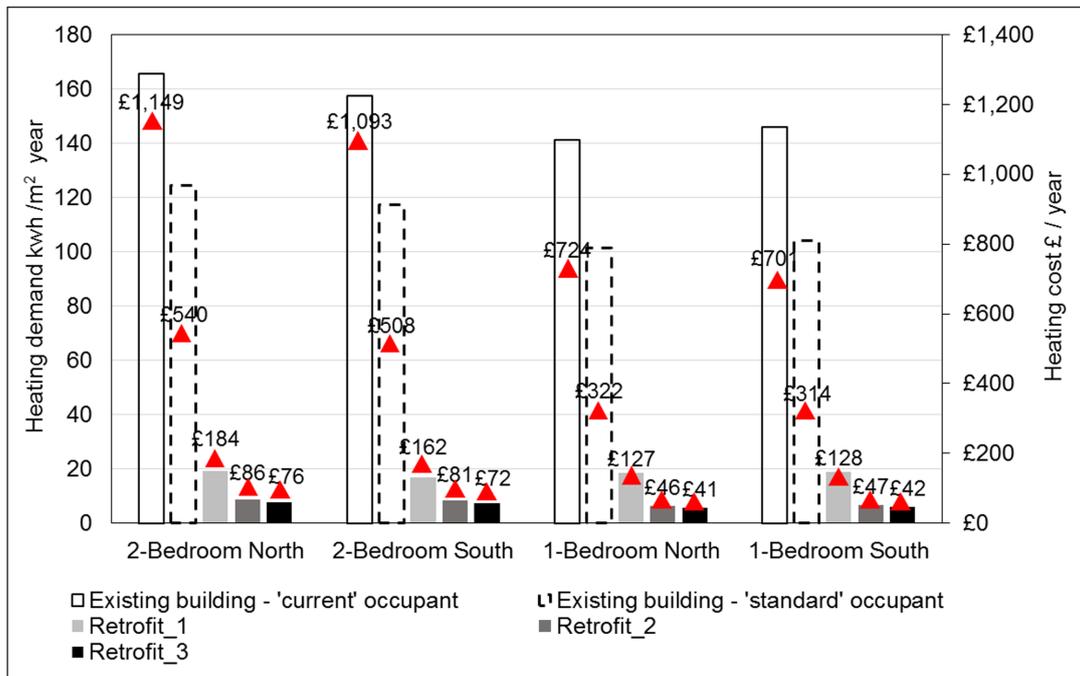


Figure 3: Heating demand in existing and retrofit scenarios. East and West flats were merged into one category utilising the average of both, as the difference in the heating demand between each was less than 1%. Cost estimations were performed considering that: ‘current’ users consume half of the electricity during off-peak hours – 23 pm to 7 am- and the other half during peak hours; Standard users consume only during off-peak, considering the Economy 7 multiple tariffs of 13.64 p/kwh and 6.2 p/kwh for peak and off-peak hours respectively (SSE 2016).

two is how they manage and control their heating system. The ‘Current’ occupant heats all rooms continuously maintaining the heaters at maximum output capacity all day and only turning them off when indoor temperature is over 25°C. Charging occurs during night and day. In contrast, a ‘standard’ occupant utilises storage heaters according to the ‘Economy 7’ criteria; keeps input controls closed during the day and open at night to charge them. Output controls are managed to minimize heat release during the night and heating takes place twice per day, in the morning and in the evening. This user turns the heating off when indoor temperature is over 22°C. The same occupancy patterns were used for both profiles, considering that people spend the entire day in the house as they are mostly retired or unemployed.

The level of accuracy of the model was evaluated comparing the heating demand against 2014 values. The model resulted in 30% more than 2014, which for this study was considered valid. Concerning the results of the simulation, as shown in **Figure 3**, the type of user has a significant effect on the heating demand, ‘standard’ users showing a lower demand. However, given the current physical conditions of the building, the heating demand is high –125 kWh/m²/yr. even with a ‘standard’ user. As a comparison, the average heating demand for a terraced house in England that is compliant with 2010 Regulations is of 60 kWh/m²/yr (Pelsmakers 2012). Tower blocks are expected to have a lower heating demand than terraced houses, given the compact shape and high occupancy density (AUTODESK SUSTAINABILITY WORKSHOP 2011). Furthermore, when comparing across flats, double bedroom flats show the highest heating demand per square

meter. Within them, North flats 32% more than the South ones, due to minimum solar gains in North oriented flats.

On the subject of thermal comfort, the distribution of indoor temperatures of occupied hours of Lounges and Bedrooms was evaluated under the two types of user. **Figure 4** shows the results for a two-bedroom North West flat and a one-bedroom South West one. Under a ‘current’ user, indoor temperatures during the heating season are within the comfort range for two bedroom flats with some degree of overheating; higher temperatures can be expected for all the remaining flats as North ones are the coldest. In contrast, with a ‘Standard’ user, a considerable number of hours fall below the 18°C threshold, which questions the adequacy of the current buildings to provide comfort for a Standard user in the winter.

During the non-heating or summer period, there is no relevant difference between the thermal performances of the towers under each type of user. Concerning the floor layout, West zones show higher overheating than East (**Figure 5**), which can be attributed to the occupancy schedule and the fact that West oriented flats reach maximum solar exposure in the afternoon. Moreover, internal one bedroom flats experience higher temperatures than two bedroom flats, and all the southern flats are more overheated than the North ones. Finally, a wide range of temperatures is observed during the summer: hours below minimum and comfort levels, even surpassing Category III limits.

In conclusion, with the current thermal properties of the buildings, having a Standard user, meaning one responsible for his or her heating bills, is not a promising situation. Heating would cost the same as for a house even

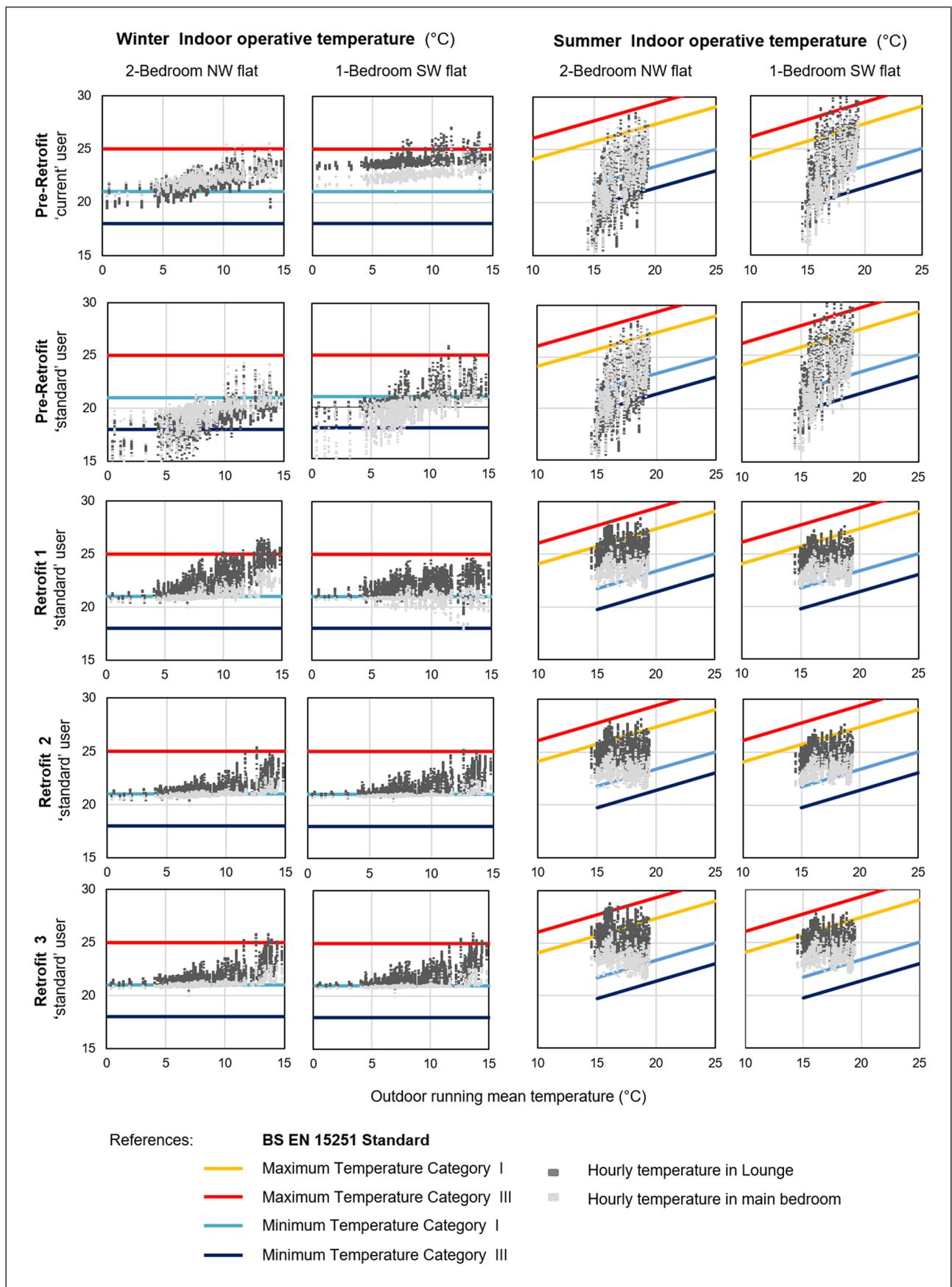


Figure 4: Indoor operative temperatures during occupied hours. Bedrooms are considered occupied from 11 pm to 7 am; Lounges from 7 am to 11 pm. BS EN 15251 Category I corresponds to spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons. Winter temperature limits are fixed values whereas summer vary with on the outdoor running mean temperature as stated in adaptive comfort model for naturally ventilated buildings.

when using Economy 7 tariffs and still it would not assure temperatures above the minimum threshold (18°C). What is more, the wide temperature variation throughout the entire year could result in a high degree of discomfort.

5.2. Retrofit scenarios under existing and ‘standard’ occupant profile

Three retrofit scenarios were chosen (Table 2): (1) improve building fabric to meet UK Building Regulations, (2) improve building as in (1) and replace storage heaters by a MHRV system, and (3) replace storage heaters by MHRV and improve building fabric to EnerPhit Standards, Passivhaus Standards for building retrofits (bre n.d.). All were modelled with a ‘standard’ user profile. After a first simulation, all three scenarios resulted in indoor operative temperatures over 30°C even during winter. This shows that given the building’s layout, orientation and the lack of cross flow ventilation, any improvement in the fabric without the addition of adequate shading, would result in extreme overheating. For this reason, the next step was to add shading in the form of fixed vertical panels on each side of the windows for East and West windows, and fixed horizontal overhangs on South facing windows.

Regarding heating demand, results show that under all retrofit scenarios, the reduction in the electricity demand for heating is of more than 80% compared to the pre-retrofit situation. The resulting demands fall

below EnerPhit limits (25 kWh/m²yr) and no case shows temperatures under 18°C during summer or winter. Additionally, during the heating season, indoor temperatures are more uniform after retrofits (2) and (3), which include MHRV, than after retrofit (1), which includes storage heaters.

Regarding indoor temperatures during the non-heating season, the performance of the building after the retrofits contrasts to the current situation: one bedroom flats overheat less than two bedroom ones and lounges overheat more than bedrooms (Figure 5). Despite this variation along the floor layout, it was chosen to show the operative temperatures for the same type of flats as in the previous section, two-bedroom North West (2B_NW) and one-bedroom South West (1B_SW) flats, to provide a comparison with the initial results. Finally, scenarios (1) and (2) result in more hours within comfort limits than (3), which fails the overheating criteria even with shading included (Figure 5).

6. Future Climate Analysis

Based on the previous results, the best performing retrofits were (1) and (2). Retrofit (2) shows uniform indoor temperatures but involves installing a MHRV system, whereas (1) does not require a change in the original system. Consequently, as each involves different costs and benefits, it was chosen to simulate under future climate

Table 2: Characteristics of Retrofit scenarios.

	Current scenario	Retrofit 1	Retrofit 2	Retrofit 3
External Wall Insulation	U- Value: 3.42 W/m ² K	U- Value: 0.28 W/m ² K	U- Value: 0.28 W/m ² K	U- Value: 0.15 W/m ² K
Window Replacement	U- Value: 2.83 W/m ² K, g: 0.755	U- Value: 1.4 W/m ² K, g: 0.622	U- Value: 1.4 W/m ² K, g: 0.622	U- Value: 0.8 W/m ² K, g: 0.622
Heating system	Storage Heaters	Storage Heaters	MHRV 85% efficiency	
Ventilation system	Window opening by user	Window opening by user	Mixed system: MHRV during heating season and window opening during the non-heating season	
Infiltration	1 ac/h	0.6 ac/h	0.6 ac/h	0.6 ac/h
Shading	No shading	Vertical shading in East and West windows Horizontal shading in South windows		

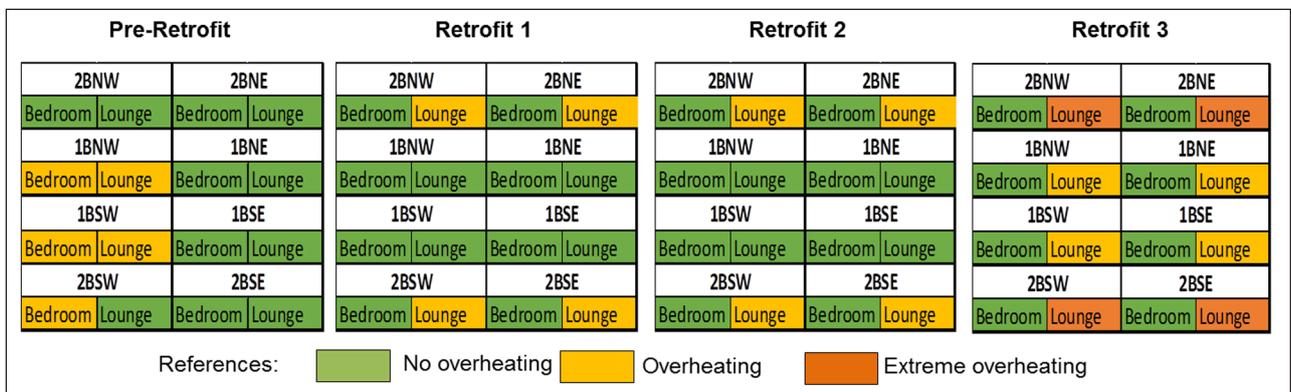


Figure 5: Overheating analysis by floor layout. Results of TM 52 analysis for occupied hours during the summer season in lounges and bedrooms under current climate. A space was considered ‘overheated’ when at least two out of the three criteria specified in TM 52 failed. ‘Extreme overheating’ was considered when at least two out of the three criteria showed high overheating value: (i) more than 10% of occupied hours above comfort threshold, (ii) more than 20 days with a temperature weighted exceedance of more than six, (iii) more than 10 hours with temperature records above the maximum limit.

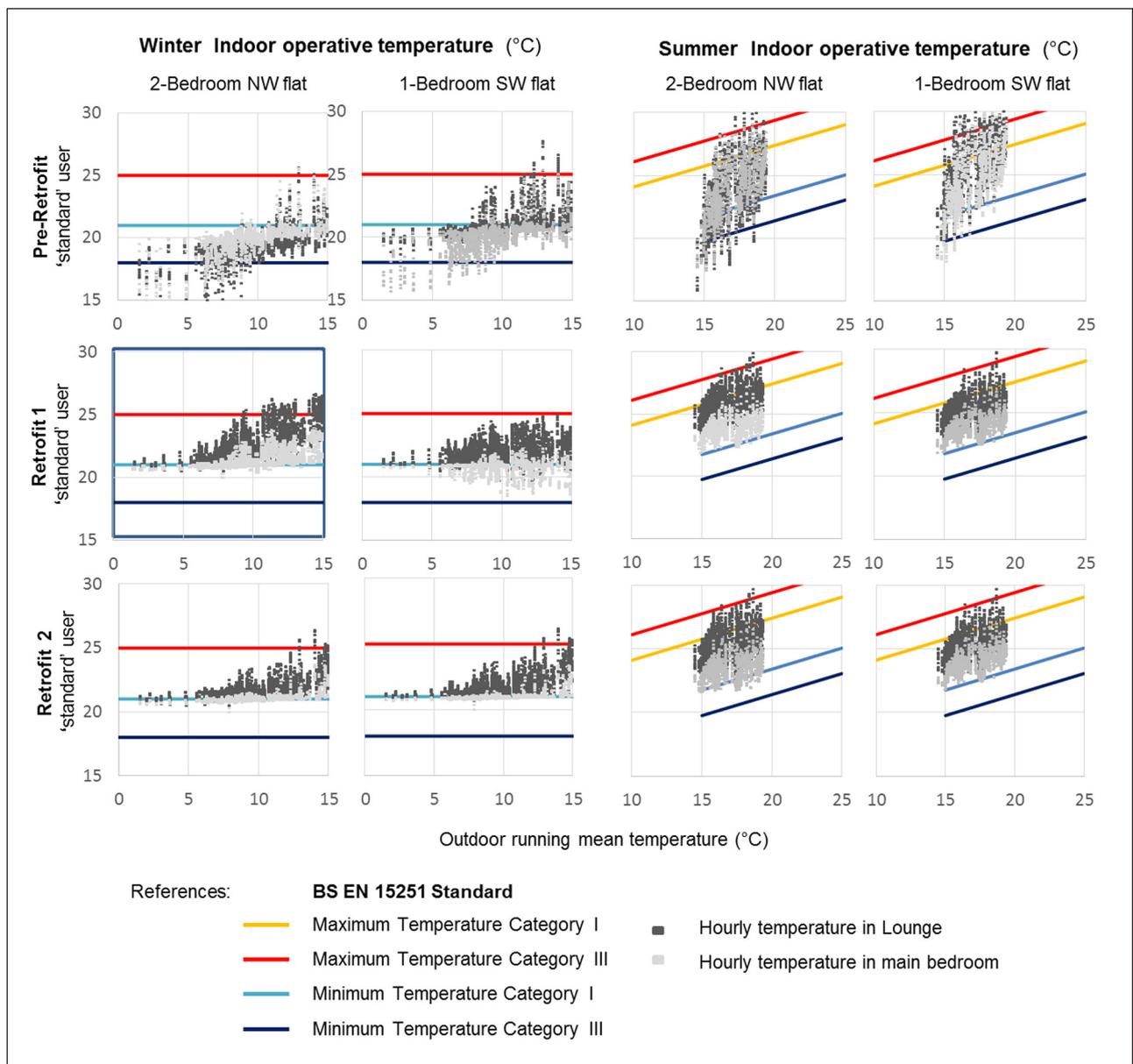


Figure 6: Indoor operative temperatures during occupied hours under 2050 climate. Bedrooms are considered occupied from 11 pm to 7 am; Lounges from 7 am to 11 pm.

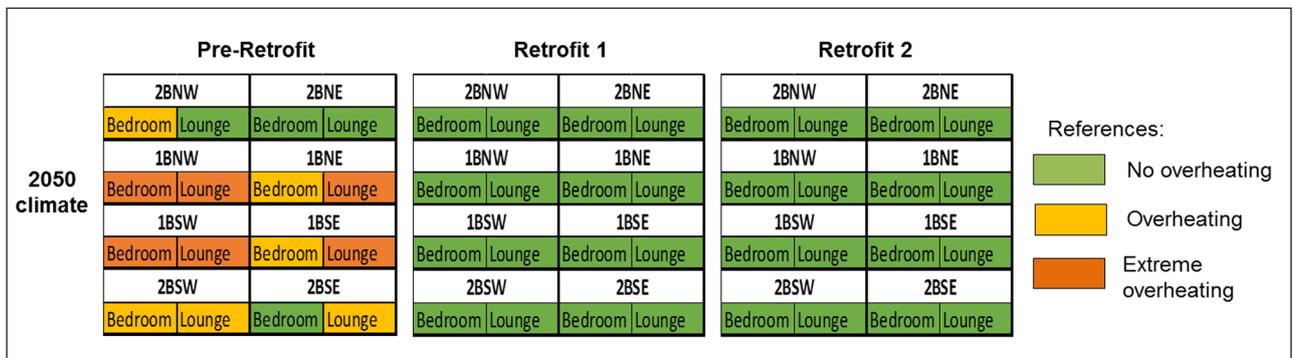


Figure 7: Overheating analysis by floor layout under 2050 climate. Results of TM 52 criteria for occupied hours during the summer season in lounges and bedrooms. A space was considered 'overheated' when at least two out of the three criteria specified in TM 52 failed. 'Extreme overheating' was considered when at least two out of the three criteria showed high overheating value: (i) more than 10% of occupied hours above comfort threshold, (ii) more than 20 days with a temperature weighted exceedance of more than six, (iii) more than 10 hours with temperature records above the maximum limit.

conditions for a further evaluation. The pre-retrofit scenario was simulated as well to assess how the current building would perform in the future. All were evaluated with a 'standard' user profile.

In a pre-retrofit scenario in the year 2050, the temperature distribution during the heating season shows fewer hours below 18°C than with current climate (**Figure 6**) as expected. Both retrofits show a slight increase in indoor temperatures during the heating season as well, with even some overheating under retrofit (1). During the summer or non-heating season, the pre-retrofit scenario shows temperatures over the maximum comfort limits, some reaching 32°C.

Based on the overheating analysis (**Figure 7**), the building as it is in 2050 would experience a high level of overheating if no shading is installed. In contrast, both retrofits show excellent summer performance across the floorplan. It is important to consider that as BS EN 15251 is an adaptive comfort model; it can be used for comparing comfort levels under a same climate, but not across different ones. One would be inclined to think that under a hotter climate, overheating would be higher; but because the climate changes, so do the outdoor running mean temperature and the thresholds. Also, it is reasonable to expect that people will adapt to higher temperatures in time.

In summary, the building as it is, even with higher comfort limits, would overheat in the summer without the addition of shading due to the thermal properties of the building and its layout. Moreover, during the heating season, the indoor temperature range would still go below and above comfort limits. As for the retrofits there is no one which shows a better performance than the other under 2050 climate.

7. Discussion And Conclusion

The present study analysed different types of retrofits of towers A&B to provide useful conclusions for a future renovation project. Several remarks can be made about the results.

First of all, in relation to the buildings' current performance, it is clear that given the existing envelope's physical properties, a retrofit is necessary. Clearly the existing envelope is very poor and making residents responsible for their heating bills before an upgrade could result in fuel poverty. Current users and their comfort requirements push the heating demand to high levels, and even with a responsible or 'standard' user, the heating load would still be higher than what expected for the type of construction. What is more, if users would manage their heating under the Economy 7 criteria, they would experience temperatures under 18°C, the minimum required by the WHO. On top of that, during the non-heating period residents would experience a wide temperature range; during nights, when temperature goes down, indoor operative temperatures in living areas go below the minimum threshold; during the day overheating is experienced. This situation can be very detrimental to health, particularly for vulnerable residents such as the ones in these towers.

Regarding possible retrofits, it was shown that all cases analysed would result in a large decrease of the heating demand but would, with no exception, require installation of shading to avoid overheating. The existing physical properties are so poor that any improvement would result in a considerable change in the performance. This can also be attributed to the buildings' architecture, as tower blocks were designed with a compact and high-density layout to minimise heat losses. However, this design which is advantageous for minimizing heating, combined with the buildings' orientation, results in high levels of overheating, particularly when insulating to EnerPhit standard. The floor layout does not allow for cross flow ventilation and as the main facades are oriented to East and West they receive extensive solar radiation during occupied hours. Thus the main issue in view of a retrofit becomes overheating, even with a current climate.

Scenarios (1) and (2), where insulation is improved to meet UK Building Regulations, were identified as the best performing. After retrofit (2), which includes a MHRV system, the distribution of indoor operative temperatures is uniform and there are fewer hours over the maximum limit than when utilising storage heaters (retrofit 1). This can mean greater comfort for residents as they are currently used to fairly constant temperatures and little variation. Nonetheless, besides the comfort improvements it can offer, installing MHRV implies the costs and difficulties of replacing the heating system in an occupied building, which feasibility needs to be evaluated. The improvement of indoor temperatures needs to be weighed against the costs of installing a new heating system.

Furthermore, the analysis under future climate showed that even without implementing any retrofit, the buildings would experience a high degree of overheating if no shading is added. Once again, shading becomes a key element to address to improve living conditions in both towers. Finally, the use of an adaptive comfort doesn't allow to directly compare the overheating evaluation for two different climates, as it implies that people accommodate their comfort standards in relation to the outdoor temperature. Based on this, the results showed that after retrofits (1) and (2) the buildings would perform very well during the summer season with natural ventilation in a 2050's climate.

In conclusion, the analysis shows that a retrofit of towers A&B is required and it should involve installing shading under any retrofit scenario. Also, the best performing of the retrofit options analysed was aiming for compliance with current Building Regulations and installing a MHRV system, however economic feasibility needs to be evaluated.

8. Limitations of the study

Regarding overheating analysis, Category III of BS EN 15251 Comfort Standard could have been used for overheating calculations instead of I as it is suggested for existing buildings. However, Category I was chosen due to the vulnerability of current occupants. Moreover, the results are limited to the occupancy profiles defined in this study

(full day time occupancy). This was chosen so as to simulate the worst possible scenario, given the vulnerability of current residents.

Further studies could focus on the type of shading to install, its efficiency and people's perception, and on other evaluating other heating options. What is more, it would be of interest to simulate the building under a heat wave to accurately evaluate the performance under a future climate.

Acknowledgements

This work is part of the activities of the Energy and Climate Change Division and the Sustainable Energy Research Group at the University of Southampton (www.energy.soton.ac.uk). It also has some support from EPSRC grants: EP/J017698/1, Transforming the Engineering of Cities to Deliver Societal and Planetary Wellbeing, EP/N010779/1, City-Wide Analysis to Propel Cities towards Resource Efficiency and Better Wellbeing and EP/K012347/1, International Centre for Infrastructure Futures (ICIF).

Competing Interests

The authors have no competing interests to declare.

References

- Amin, R**, et al. 2016 The influence of a student's "home" climate on room temperature and indoor environmental controls use in a modern halls of residence. *Energy and Buildings*, 119: 331–339. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S0378778816301657> [Accessed June 5, 2017].
- Anon** TRNSYS—Transient System Simulation Tool. Available at: <http://www.trnsys.com/>.
- AUTODESK SUSTAINABILITY WORKSHOP** 2011 Building Massing & Orientation. Available at: <http://sustainabilityworkshop.autodesk.com/buildings/building-massing-orientation>.
- Brager, G S** and **de Dear, R J** 1998 Thermal adaptation in the built environment: a literature review. *Energy and Buildings*, 27(1): 83–96. Available at: <http://www.sciencedirect.com/science/article/pii/S0378778897000534> [Accessed June 4, 2015].
- bre** PASSIVHAUS Basic Principles. Available at: <http://www.passivhaus.org.uk/page.jsp?id=17> [Accessed August 8, 2015].
- Brenda Boardman** 2007 *HOME TRUTHS: A low-carbon strategy to reduce UK housing emissions by 80% by 2050*. Available at: www.foe.co.uk/hometruths, <http://www.eci.ox.ac.uk/research/energy/downloads/boardman07-hometruths.pdf>.
- Brown, P, Swan, W** and **Chahal, S** 2014 Retrofitting social housing: reflections by tenants on adopting and living with retrofit technology. *Energy Efficiency*, 7(4): 641–653. Available at: <http://link.springer.com/article/10.1007/s12053-013-9245-3/fulltext.html> [Accessed February 26, 2015].
- Carter, J G**, et al. 2014 Climate change and the city: Building capacity for urban adaptation. *Progress in Planning*, 95: 1–66. Available at: <http://www.sciencedirect.com/science/article/pii/S0305900614000397> [Accessed July 15, 2014]. DOI: <https://doi.org/10.1016/j.progress.2013.08.001>
- CIBSE 2006 CIBSE Guide A: Environmental Design**. Department for Communities and Local Government Definitions of general housing terms. Available at: <https://www.gov.uk/guidance/definitions-of-general-housing-terms> [Accessed June 5, 2017].
- Guerra-santin, O** and **Tweed, C** 2013 Summer post occupancy evaluation of a Passivhaus care home in the UK. *PLEA 2013: Sustainable Architecture for a Renewable Future*.
- Gupta, R, Barnfield, L** and **Hipwood, T** 2014 Impacts of community-led energy retrofitting of owner-occupied dwellings. *Building Research & Information*, 42(March 2015): 446–461. Available at: <http://www.tandfonline.com/doi/abs/10.1080/09613218.2014.894742>. DOI: <https://doi.org/10.1080/09613218.2014.894742>
- HM Department for Communities and Local Government** 2017 English Housing Survey. Headline report, (8010). Available at: <https://www.gov.uk/government/collections/english-housing-survey>.
- Jenkins, G J, Perry, M** and **Prior, M J** 2009 *The climate of the UK and recent trends*. Available at: http://ukclimateprojections.defra.gov.uk/images/stories/trends_pdfs/Trends.pdf.
- Mavroggianni, A**, et al. 2015 Urban social housing resilience to excess summer heat. Available at: <http://www.tandfonline.com/doi/abs/10.1080/09613218.2015.991515#VTTtoSSEveaE> [Accessed April 20, 2015].
- Nicol, F** and **Spies, B** 2013 The limits of thermal comfort: avoiding overheating in European buildings TM52.
- Office of the Deputy Prime Minister** 2006 The Building Regulations 2006 L1B Conservation of fuel and power in existing buildings. *Changes*, (April): 35. Available at: www.thebuildingregs.com.
- Palmer, J** and **Cooper, I** 2013 *Housing Energy Fact File*.
- Pelsmakers, S** 2012 *The Environmental Design Pocketbook*. London: RIBA Publishing.
- Public Health England** 2014 *Minimum home temperature thresholds for health in winter – A systematic literature review About Public Health England*.
- Shabha, G** 2003 A low-cost maintenance approach to high-rise flats. *Facilities*, 21(13/14): 315–322.
- SSE** 2016 SSE 1 Year Fixed v4 Terms and Conditions. (May), 4–5.
- Teli, D**, et al. 2016 Thermal adaptation to high indoor temperatures during winter in two UK social housing tower blocks. In *9th Windsor Conference: Making Comfort Relevant*.
- University of Southampton** Climate Change World Weather File Generator for World-Wide Weather Data – CCWorldWeatherGen. Available at: <http://www.energy.soton.ac.uk/ccworldweathergen/> [Accessed May 5, 2015].
- World Health Organization** 1987 Health impact of low indoor temperatures. *Report on a WHO meeting*, 27.

How to cite this article: Aragon, V, Teli, D and James, P. 2018 Evaluation of Retrofit Approaches for Two Social Housing Tower Blocks in Portsmouth, UK. *Future Cities and Environment*, 4(1): 4, pp. 1-11, DOI: <https://doi.org/10.5334/fce.8>

Submitted: 17 October 2017

Accepted: 20 December 2017

Published: 26 January 2018

Copyright: © 2018 The Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC-BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited. See <http://creativecommons.org/licenses/by/4.0/>.

]u[*Future Cities and Environment*, is a peer-reviewed open access journal published by Ubiquity Press.

OPEN ACCESS 