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Building Performance Optimisation for the Retrofit of a Council Tower Block in London

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Abstract: This study aims to optimise the building performance of a 22-storey tower block in London Borough of Newham (LBN) using energy efficient retrofitting strategies. Initial studies show that the water ingress issues within the tower block are mainly caused by a combination of inefficient building envelope and occupants' patterns of energy consumption in their homes. The first phase of this research analysed the performance of the tower block through indoor monitoring, occupants' interviews and building simulation in the winter season. The second phase of this project, the focus of this paper, studies two retrofit approaches of the tower block by applying EnerPHit standard, and the potential retrofit approach considered by LBN. The study builds on the results from the first phase by using building simulation to examine the reduction of heating loads and the improvement of indoor thermal comfort in the winter season when applying each retrofit strategy. The results show that improving the building envelope by using EnerPHit standard through significant improvement of the building fabric and incorporating Mechanical Ventilation and Heat Recovery (MVHR) systems, decrease the building heating energy loads to more than half of the actual energy consumption while keeping the indoor thermal environment within the standard comfort range. In addition, using LBN suggested thermal insulation material as the potential retrofitting strategy to improve the External Wall Insulation (EWI), reduces the energy consumption of the building to nearly half of the original heating energy loads, nearly similar to the first retrofitting approach in this study.

Keywords: EnerPHit, energy efficiency, retrofit, building performance, thermal comfort

Introduction

Governments in many countries have put pressure to improve the energy efficiency and building performance to reduce the Greenhouse Gases (GHGs) emissions. 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 plans. The government's long-term plan is to reduce greenhouse gases by eighty percent by 2050 (CCC, 2016). The energy use in the housing sector in the UK accounts for 29 percent of the total CO_2 emissions production (DBEIS, 2017); two thirds of this energy generated by space heating demand (Palmer and Cooper, 2012). In addition, the existing UK housing stock is considered one of the least energy efficient domestic buildings in Europe and therefore, contribute to carbon emissions significantly (Neroutsou and Croxford, 2016). The significant level of global carbon emissions shows that it is essential to take rapid and effective action to reduce the energy consumption in buildings. This could be achieved by implementing energy efficient retrofit strategies, which would increase property value and improve occupants' health and comfort while reducing fuel poverty (Neroutsou and Croxford, 2016, Vilches et al., 2017, Rickaby, 2011). Many studies have found that retrofit schemes have the economic benefit due to reducing building energy costs (Galvin and Sunikka Blank, 2013, Grimes et al., 2011). As a result, the energy loads for space heating and the comfort temperature in the cold seasons have been a focus of research in the UK (Rory et al., 2016).

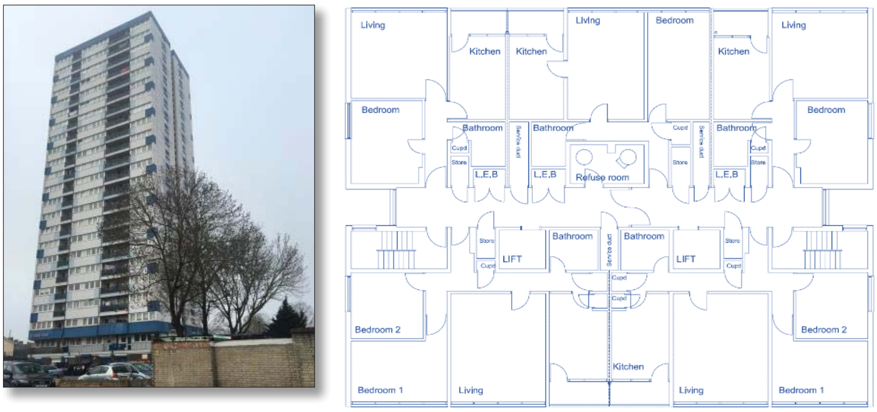
However, many studies found that the benefits from retrofitting can be compromised through the building performance gaps where expected benefits may not necessarily tie with the actual improvement (Chitnis et al., 2013, Sorrell et al., 2009). Energy efficiency studies indicate that appropriate retrofit strategies can significantly improve the building energy consumption and environmental performance. There have been successful retrofit programmes rolled out by the UK government's Department of Energy and Climate Change (DECC)– now Department of Business, Energy and Industrial Strategy (DBEIS) - to improve the energy efficiency of the buildings in the UK such as RE:FIT and RE:NEW programmes, which are two retrofitting schemes to cut the carbon emissions level in London (RE:NEW., 2012, Greater London Authority, 2017). RENEW programme is one of the relatively successful programmes which aimed to enhance the building energy performance and reduce the impact of fuel poverty in London homes (GLA, 2015) while RE:FIT scheme aimed to reduce the energy demands of the public buildings in the UK (Greater London Authority, 2017). One significant precedent is Kirklees Warm Zone (KWZ) scheme, which is one of the largest examples of such schemes completed in the UK, was the first to offer free loft and cavity wall insulation to all eligible properties (Edrich et al., 2011).

Studies show that in London Borough of Newham (LBN), there is a high rate of fuel poverty at 13.8 per cent (13,372 households) which is amongst the highest rates in the UK (Walker and Ballington, 2015b). Newham Council has been developing a plan to retrofit many of the council's residential buildings. Improving the energy efficiency of the buildings in the borough will cut the energy cost of the residential sector and reduce fuel poverty, meanwhile mitigating carbon emissions (Walker and Ballington, 2015a, Walker and Ballington, 2015b). The council's plan is to significantly reduce the number of tenants affected by fuel poverty in the domestic sector whilst achieving a minimum energy efficiency standard of B or C by 2030 (Bromley-Dery, 2015). There are also some risks associated with retrofit. The underperformance of retrofit projects can lead to major problems within the building(s) and their occupants' health. Damp, mould and condensation are the most common problems in some of the retrofitted buildings and as such, the buildings struggle to achieve indoor thermal comfort. Inappropriate building materials, lack of knowledge in the technical aspects of retrofit and inappropriate workmanship skills can lead to these problems (Deselincourt, 2015).

The current study is the second phase of the energy efficient retrofit study of one of the prototypes of LBN's council tower blocks. The 22-storey tower block comprises of 108 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 found water penetration concerns in the tower block. The first phase of this research focused on building performance evaluation and the interactions between the building performance of the flats, the occupants' energy consumption behaviour, and the indoor thermal comfort in the winter months of 2016-17 (Zahiri and Elsharkawy, 2017). This included on-site monitoring of indoor air temperature and relative humidity levels in addition to semi-structured interviews with the occupants. Along with the field studies, building simulation modelling using DesignBuilder (DB) software was performed to evaluate the building performance using the Met office weather data and the actual occupancy and energy patterns to understand possible reasons for dampness issues and the dissatisfaction of the occupants from the indoor thermal conditions. In the second stage of this study (the focus of this paper), the aim is to optimise the building performance of the same tower block, to develop guidance for LBN's planned retrofit. EnerPHit standards, and LBN recommended strategy have been tested to compare between the reduction of energy demands and the improvement of thermal comfort when using each strategy.

Case Study & Methodology

The aim of this study is to optimise the building performance of the 22-storey council tower block in LBN (Figure 1) during the winter months. The study adopts a mixed method research design based on field monitoring, semi-structured interviews, and building simulation. At first stage, the building performance evaluation was performed to identify and diagnose the possible causes of the physical issues detected in several areas of the building mainly damp, mould, condensation and water ingress. This process entailed monitoring of indoor air temperature and Relative Humidity (RH) levels of a sample of flats in the case study and building simulation modelling to assess the building performance, the occupants' energy consumption behaviour and indoor thermal comfort. Two sample flats, identified as problematic, have been selected as the exploratory sample case studies for the research, with a particular focus on the bedrooms where most complaints emerged from. Building simulation modelling using dynamic Design Builder (DB) software was also undertaken to help further understand and diagnose the issues with the building performance detected by the data loggers, observations and occupants' interviews. The results confirmed that the occupants' energy consumption behaviour and the damage to the external over-cladding are the main reasons for the damp and mould issues that consequently resulted in poor indoor environmental conditions and concerns from the occupants about their comfort, health and wellbeing.



(a) (b)

Figure 1. The case study tower block (a) and a typical floor of the case study building (b)

The second phase of the study (the focus of this paper) focuses on the building performance optimisation and methods for energy efficient retrofit. This includes building thermal and energy simulation analysis of the tower block. In this stage, two potential energy efficient retrofit strategies are investigated aiming to improve the thermal envelope and reduce the overall building energy consumption while providing a comfortable indoor environment. These recommendations can then be applicable to similar building prototypes in the UK. EnerPHit standard has been selected as one of the most efficient retrofit strategies for this tower block in order to reduce the heating energy demands. The main focus was the application of thermal insulation materials and the improvement of MVHR as well as upgrading the windows to triple glazing, which are already used in one of the recent major retrofitted council buildings in the UK; Wilmcote House in Portsmouth (Buckwell, 2012). In addition, the second retrofitting option is LBN's current retrofitting strategy to improve fit External Wall Insulation (EWI) using PermaRock thermal insulation and render system. In this study, these two strategies were applied to the simulation model separately and the results of the analysis were compared against the current energy performance of the case study to identify the better approach to reduce the building energy consumption and improve the indoor thermal comfort.

Passivhaus Standard & EnerPHit

Using the EnerPHit standard in the refurbishment and retrofit of the existing buildings can lead to extensive improvements in thermal comfort of the occupants, economic and thermal efficiency of the building and consequently reduces the carbon emissions production and energy consumption demands (Passive House Institute, 2016, Passive House Institute, 2015). Passive design of houses means a low energy and energy efficient building, which uses building architecture to minimise the energy consumption of the building and improves the thermal comfort. Based on Mikler et al (2009), the correlation of the local climate with the shape and the thermal performance of the building is one of the main consideration of passive house design. The foundation of passive house relies on natural sources of energy which consequently reduces the need for mechanical systems for indoor cooling, heating and lighting (Light House Sustainable Building Centre and Guido, 2009). Based on the passive design concepts, Passive House or Passivhaus (in German) standard depends on the low energy design concepts used in building design and construction to provide more energy efficient, comfortable and affordable places to live in. Passivhaus standard was developed by Passivhaus Institut in Germany in the 90's (Mead and Brylewski, 2010) and is one of the fastest growing, low energy standards used worldwide including the UK.

The main aim of Passivhaus standard is to reduce the heating and cooling demands of the building while improving occupants' thermal comfort. The main focus of this standard is specifically on the application of the high level of thermal insulation to the building envelope and increasing the airtightness of the building as well as incorporating MVHR (Mead and Brylewski, 2010). Because of various reasons, for the existing buildings, it is not feasible to achieve the Passivhaus standard and as a result, the Passivhaus Institut developed EnerPHit standard for certified energy retrofits with Passivhaus Components. The EnerPHit standard is the Passivhaus standard used for refurbishing and retrofitting of existing buildings (Passive House Institute, 2010). For quality assurance and verification of the specific energy values achieved, the buildings that use EnerPHit standard for retrofitting can achieve the "EnerPHit–Quality-Approved Modernisation with Passive House Components" certificate (Passive House Institute, 2010). Table 1 presents the typical EnerPHit criteria for the building components as well as heating energy demands benchmarks for cold and temperate climate zone.

Table 1. EnerPHit criterial for the building component in the cold and cool-temperate climatic regions for cold seasons (Passive House Institute, 2016)

Climate zone	Opaque envelope against ambient air		Windows (including exterior door)				Ventilation	Heating
			Overall			Glazing	Min. heat recovery rate (%)	Max. heating demand (kWh/m^2a)
	Exterior insulation	Interior insulation	Max. U-value W/m^2K			Solar heat gain coefficient (g-value)		
	Max. U-value (W/m^2K)							
Cold	0.12	0.30	0.65	0.70	0.80	Ug - g*1.0 ≤ 0	80%	30
Cool-temperate	0.15	0.35	0.85	1.00	1.10	Ug - g*1.6 ≤ 0	75%	25

Building Performance Optimisation

This paper focused on the building performance optimisation of the case study tower block during the winter season using the energy efficient retrofitting strategies. In this study, the

EnerPHit standard strategies used to retrofit of Wilmcote House (one of the tall council buildings in the UK) have been adopted to the case study building as one of the retrofitting options. Wilmcote House is one of the recent major retrofitted tall council buildings in Portsmouth (RockWool, 2016), which has the similar building structure to the case study building and also was built in the same period as the tower block. For retrofitting of Wilmcote House, the buildings envelope was improved by the application of external wall insulation materials as well as upgrading the windows to the triple glazed openings. In addition, the improved MVHR system was applied to the building. The main thermal insulation material used in Wilmcote House is REDArt system from RockWool with rendering (Robinson and Cartwright, 2016). The second retrofit strategy investigated is, LBN's current retrofitting option. LBN has suggested to improve the building's envelope by removing the existing external over-cladding and replacing it with PermaRock external thermal insulation with silicon render system (PermaROck Product Ltd, 2017).

It should be noted that the current structure of the case study tower block is in-situ reinforced concrete frame construction with floor slabs spanning between shear walls and pre-cast concrete panels covering the flank wall. The case study envelope is cladded with asbestos cement over-cladding panels. All flats have double glazed windows with UPVC panels. The internal partitions consist of the concrete blocks of 100 mm thickness and the external walls include external over- cladding of 9 mm thickness, the 80 mm air gap, the 200 mm pre-cast concrete panels and the 20 mm internal wall insulation boards and finishes. The building heating is provided by natural gas hot water boilers and also there is one extractor fan in the kitchen and another in the bathroom. The current external over-cladding system of the case study tower block was excluded from the simulation model while testing the effect of retrofitting strategies on building performance. In addition, in this study, CIBSE TM59 (CIBSE, 2017) and SAP 2012's (DECC, 2014) heating and occupancy patterns were used in the simulation modelling as the UK government's standard and CIBSE technical memorandum, which were suggested to be used for the typical UK domestic sector's occupancy and energy patterns. In the first stage of this study (Zahiri and Elsharkawy, 2017), it was successfully demonstrated that using the heating and occupancy patterns suggested by CIBSE TM59 and SAP 2012 are acceptable patterns to be used in the simulation modelling for this project.

EnerPHit Standard Strategy

In this study, the EnerPHit standard strategies used in Wilmcote House were applied to the case study tower block as one of the retrofitting options. Wilmcote social housing block in Portsmouth is one of the major Passivhaus projects in the UK that used the EnerPHit standard for retrofitting of the existing building. The Wilmcote House was built in late 60s and the building structure includes the prefabricated concrete panels, similar to the case study tower block. The building consists of three connected eleven-storey residential blocks including 107 properties and was retrofitted by Portsmouth City Council to achieve very low energy demands to meet the EnerPHit standard (Crawford et al., 2014). The original building was poorly constructed and had a poor concrete prefabricated structure and would not have been lasted long if no refurbishment was undertaken. Similar to the case study building, the openings, the roof and the building's envelope as well as the heating system were required to be replaced to reduce the building's energy and the maintenance cost. As mentioned previously, the case study tower block has the significant water ingress issues which also was the case for Wilmcote House (Buckwell, 2012). As there is a similarity in the buildings' structure and also both buildings face the same thermal and energy performance matters, it was decided to implement the Wilmcote House EnerPHit standard to the case study model in DB to assess the building's optimisation. It should be noted that Portsmouth City Council aimed to reduce the Wilmcote House annual heating and hot water demands by 90% and increase the life of the building to minimum of 30 years using the Passivhaus retrofitting strategies (Crawford et al., 2014).

For assessing the improvement of building performance of the tower block using Wilmcote EnerPHit standard strategies, it was decided to remove the existing external over-cladding system of the tower block in the simulation model and replacing it with the new insulated over-cladding using the EnerPHit standard. In addition, MVHR installation was also considered, as well as replacing the double glazed windows with the triple glazed openings to increase the energy efficiency of the building, similar to Wilmcote House. For the retrofit of Wilmcote House, the RockWool insulation products were used as EWI including RockPanel cladding façade system, a combination of REDArt External Wall systems and flat roof system, which also were considered for the case study tower block (Table 2). The REDArt external wall insulation will ensure excellent thermal performance and exceptional air tightness, reducing the occurrence of draughts, condensation and mould growth (RockWool, 2016), which are the issues of the case study.

Table 2. Specification of the materials used to improve the external wall performance of Wilmcote House (Cartwright, 2016)

Materials	Rockwool Quilt	Rockwool flexi	Cement board	REDArt system insulation	REDArt system rendering
Thermal Conductivity (w/m-K)	0.044	0.038	0.16	0.036	0.83
Density (Kg/m^3)	60	45	950	110	1800
Thickness (mm)	75	175	12	100	8

Based on RockWool limited (2016), before retrofitting of this building, more than half of the occupants were not satisfied with the indoor thermal environment and a significant number of the properties suffered from damp, mould, condensation, inefficient and expensive heating and cold draughts which affected a few occupants health. Portsmouth City Council aimed improve the buildings energy efficiency and the occupants' thermal comfort by using the EnerPHit standards for retrofitting of this building, which are the main targets of this project.

LBN Current Retrofit Strategy

The second retrofitting strategy used in this study is the application of LBN's current retrofitting option. LBN considers using PermaRock EWI system to improve the building performance in order to reduce the energy demands and improve the indoor thermal condition, which also eliminates the issues related to dampness and condensation. PermaRock systems have been designed for use on high-rise and low-rise buildings as well as traditional and non-traditional forms of construction with latest technology (PermaROck Product Ltd, 2017). In DB simulation modelling, the current external over-cladding system of the case study was replaced by PermaRock EWI with the silicon rendering (Table 3).

Table 3. Building insulation material considered for retrofitting of the case study tower block by LBN (PermaROck Product Ltd, 2017)

Components	**PermaRock Mineral Fibre Insulation**	**PermaRock Silicon K/R Finishes**
Thermal Conductivity (w/mK)	0.036	0.800
Density ($\mathrm{Kg/m^3}$)	110	700
Thickness (mm)	250	4

Results and Discussion

In this study, building optimisation of the council tower block in LBN during the winter season has been studied to provide tailored recommendation for the energy efficient retrofit for the domestic buildings in this area. The first phase of this study showed that although indoor air temperature and RH levels were in the comfort range during the winter season in 2016-17, the occupants were not satisfied with the indoor thermal condition. In addition, the initial phase of this project showed that the occupants thermal and energy behaviour have an effect on the level of dampness causing the occupants dissatisfaction. It was also suggested that improving the occupants' energy consumption behaviour can reduce this issue while reducing the total heating energy use of the building. However, the long-term solution would be energy efficient retrofit, which is the second phase of the study and also the focus of this paper.

In the second stage of this project, applying the EnerPHit standard strategies and LBN's current retrofit strategy to the case study tower block were studied using DB simulation tool to increase the building's energy efficiency in the cold seasons. Along with the council's current retrofit strategies, it was also decided to use the EnerPHit standard strategies, which were already tested in the similar type of council building in the UK; Wilmcote House in Portsmouth. This building has been retrofitted recently and the project is planned to complete in 2017. To test the case study building's performance in DB tool, the current external over-cladding system was removed from the original simulation model and the EnerPHit standard strategies and LBN's suggested retrofitting option were separately applied to the simulation model. As mentioned previously, the preferred thermal insulation material with silicon render system by LBN is PermaRock and the insulation materials used by Wilmcote House is REDArt system from Rockwool. In addition, in Wilmcote House, the building's energy efficiency was improved by applying the energy efficient MVHR system as well as upgrading the glazing to the triple glazed windows, which were both considered for the EnerPHit strategies of the case study.

Figure 2 presents the indoor air temperature of a typical middle floor of the case study tower block in the coldest week of winter 2017 after the application of EnerPHit strategies and LBN's suggested retrofitting strategy using TM 59 and SAP 2012 energy and occupancy patterns. It can be seen that the indoor air temperature was increased using both retrofitting strategies but they were still in the comfort range. Based on CIBSE Guide A (2016), the recommended comfort temperatures for the dwelling are considered between 17 °C with clothing value of 2.5 clo and 25°C with clothing value of 1clo. The EnerPHit standard resulted in more increase in the indoor air temperature mostly because of the thickness of the insulation materials as well as the use of improved MVHR and the triple glazed windows. LBN's strategy also increased the indoor air temperature comparing to the current state of the building. In addition, both retrofitting strategies reduced the indoor air temperature's fluctuation comparing against the current state of the building. This shows that the current heating energy use pattern can be modified in order to decrease the heating energy consumption while still keep the indoor air temperature in the acceptable comfort range. The most suitable modified heating patterns for this building will be studied at the later stage of this project.

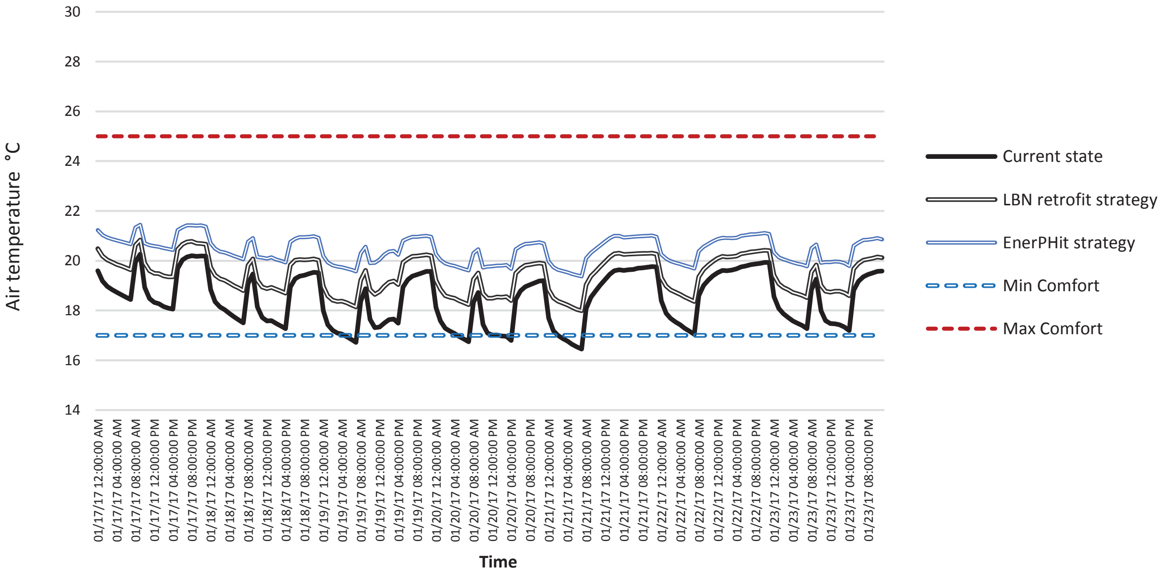


Figure 2. DB predicted indoor air temperature using various strategies in a typical middle floor of the case study tower block (Authors using DB, 2017)

Table 4 presents the U-value of the external wall using both retrofitting strategies comparing against the current state of the external wall. It can be seen that the U-value of the external wall using both strategies were improved significantly and as a result, the indoor air temperature was increased. The original U-value of the building was around 0.80 $\mathrm{W/m^2K}$ which is dropped to around 0.1 $\mathrm{W/m^2K}$ using both retrofitting strategy. However, the EnerPHit standard strategies caused more improvement comparing to the LBN's option. This also proves that the heating demand of the building can be decreased using both retrofit strategies because of having better U-value, while still keeping the indoor thermal condition in an acceptable range specially using the EnerPHit strategy.

Table 4. U-value of the case study external wall with different strategies applied to DB (Authors using DB, 2017)

Strategy	**Current State**	**EnerPHit (Wilmcote House)**	**LBN Current Retrofit Strategy**
U-Value ($\mathrm{W/m^2K}$)	0.78	0.09	0.13

Building performance enhancement in the case study building in the winter season reduced the monthly heating consumption of the case study tower block (Figure 3), which is dropped to nearly half of the estimated energy loads for the current state of the building; from over 64000 kWh to around 30000 kWh. As mentioned before, the phase one of this project proved that one of the reason of the dampness issues in the case study building, which increases the heating energy loads in the winter season, is the jet-washing of the external over-cladding that damaged the sealing between the panels facilitating a path for water to penetrate the concrete structure during periods of driving rain. This problem causes dissatisfaction of the occupants from the indoor thermal conditions in cold seasons and the increase of the energy use to improve the indoor thermal condition. Using the suggested retrofitting strategies, can improve the dampness issues as the building external envelope airtightness will be improved due to use the suggested thermal insulation materials, which will also reduce the energy use of the building and consequently reduce the energy bills. Figure 3 shows that the reduction of the energy loads of the building using the EnerPHit strategies is a bit more than using the LBN retrofitting strategy. This is because of using the triple glazed windows as well as the improved MVHR system in the EnerPHit Standard strategies along with external thermal insulation while in LBN strategy, the focus was only on improving the external wall's thermal insulation materials.

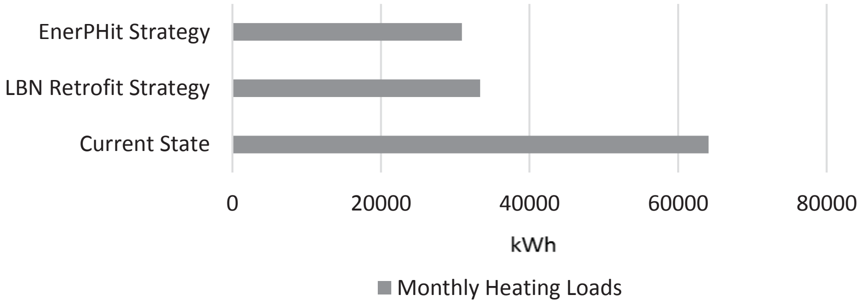


Figure 3. Monthly heating loads of the case study tower block using different retrofitting strategies in the winter months (Authors using DB, 2017)

This study also shows that both retrofit strategies reduced the heat loss of the building through the building's envelope in the cold period. Enhancing the heat balance of the building during the winter season reduces the zone sensible heating and consequently the heating loads of the building. In addition to the reduction of the heating energy loads in the tower block (Figure 3), the heat loss and the heat gain of the tower block were also improved, using the EnerPHit and LBN current retrofitting strategies, which confirms the advantage of using these two options for the retrofitting of the case study tower block. It should be noted that MVHR and triple glaze windows were considered as the EnerPHit strategies for the case study building. However, they were excluded from the simulation model using LBN strategy as the council prefers not to improve the current MVHR and glazing systems of the building. Figure 4 illustrate the heat balance of the tower block in the typical coldest day in the winter season using two retrofitting strategies comparing against the current building state. It should be noted that the heat loss and the heat gain through the floor, partitions and ceiling were excluded from the figure, as the difference between the results was very negligible.

It can be seen that the application of EnerPHit strategies decreased the heat loss through the glazing significantly, almost one third of the current state of the building which has a double glazed windows. This improvement is due to the use of triple glazed windows. In addition, adding the thermal insulation materials to the external wall of the building using both LBN and EnerPHit strategies reduced the heat loss to nearly one sixth of the current state of the building's envelope, which is very significant and consequently the zone sensible heating of the building and the heating loads reduced as well. This reduction is more than a half using EnerPHit strategies as the MVHR and glazing system of the case study building were also improved. However, LBN's strategy reduced the zone's sensible heating around one third of the original one as the focus was only on the improvement of the thermal insulation materials and the render system of the external walls. Nevertheless, using both strategies have a significant effect on the improvement of the buildings heating energy consumption and thermal condition. Based on the cost analysis of these two strategies as well as the effect of these strategies on CO2 emission level, the most suitable retrofitting strategies will be selected for the energy efficient refurbishment, which is currently studied for the final stage of this project.

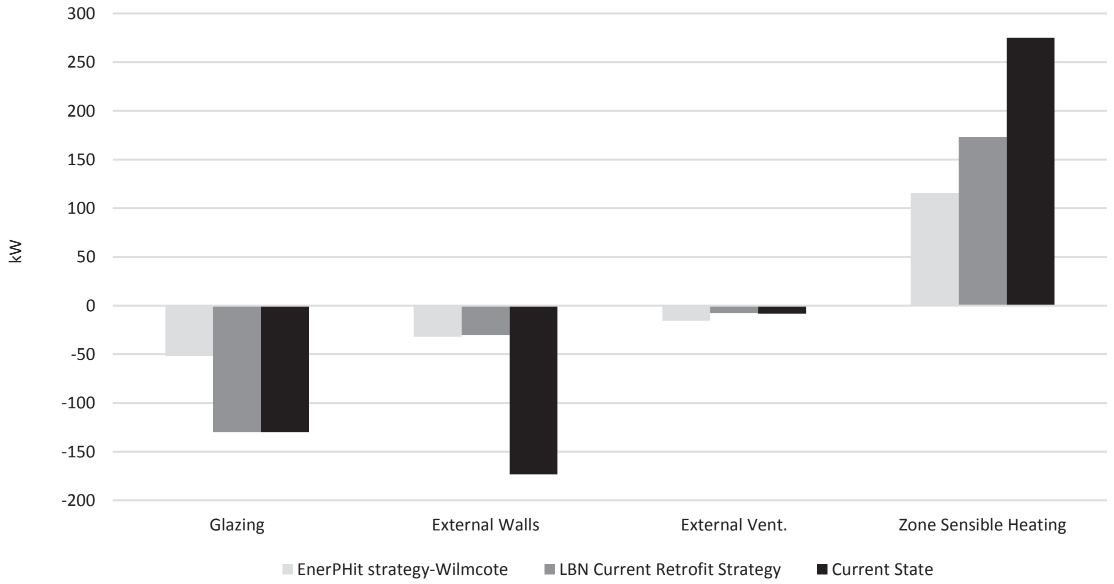


Figure 4. Hourly heat balance in the case study block in a typical coldest winter day (Authors using DB, 2017)

Conclusion

This study is the second phase of a research project which aims to improve the building performance and energy efficient retrofitting of the council tower block. Phase one of this project focused on the building performance evaluation which included field monitoring of thermal comfort variables and semi-structured interviews with the occupants concerning their energy consumption behaviour and their thermal comfort satisfaction. In addition, building simulation analysis was also performed to evaluate the case study tower block to be validated for the second phase of this project for the retrofitting of the building. One strategy was using the EnerPHit standard while the second strategy was using LBN's current retrofitting option.

To optimise the building performance, each retrofit strategy was applied to the case study tower block using DB simulation tool. Later, the effect of each strategy on thermal and energy performance of the building was assessed against the current overall performance of the building. The impact of both strategies on the heating energy demands and heating balance of the tower block were compared against the current performance of the building in the winter months. The EnerPHit system adopted used REDArt system to improve the building envelope efficiency along with triple glazing as well as incorporating MVHR system. However, LBN suggested to use its recommended insulation materials with the silicon render system as their proposed retrofitting strategy.

The results show that both strategies improved the building thermal and energy performance significantly in the winter months compared against the current building state. The indoor air temperature and the heat balance of the building during the typical winter season were enhanced, which resulted in reducing the overall energy use of the building. The study shows that the application of the external thermal insulation to the building's envelope using both strategies reduced the U-value of the external wall from around 0.8 $\mathrm{W/m^2K}$ to around 0.1 $\mathrm{W/m^2K}$ and as a result, reduced the need to mechanical heating system. In addition, the application of EnerPHit strategies decreased the heat loss through the glazing to almost one third of the current heat loss through glazing of the building due to the use of triple glazed windows and reducing it to around -52 kW. Adding the thermal insulation materials to the external wall of the building using both LBN and EnerPHit strategies reduced the heat loss through the envelope to nearly one sixth of the current state of the building's and reducing it to around -30 kW and consequently, the zone sensible heating of the building and the heating loads reduced significantly. This reduction is more than half at around 115 kW using EnerPHit strategies as the MVHR and glazing system of the case study were also improved. However, LBN's strategy reduced the zone's sensible heating around one third of the original one as the focus was only on the improvement of the thermal insulation materials and the render system of the external walls, which is around 170 kW.

As the EnerPHit standard is based on the stricter U-values, and higher insulation level, it could be an optimum alternative to reduce energy consumption. In addition, the EnerPHit strategies have more effect on reducing the heating loads, as in addition to the external thermal insulation, the double glazed windows were upgraded to triple glazed windows and the MVHR system was also incorporated for the building retrofitting strategies. Overall, both retrofit strategies could be recommended to optimise the energy efficiency of the building, reduce energy demands, and maintaining indoor comfort levels. The decision will be affected by the cost of the intervention and the council's available budget for the project. Currently, the total cost of each intervention and the payback period are under study.

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