Energy Efficient Retrofit of a Protected Building of Historical Significance

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ABSTRACT: In the UK, historically or architecturally significant buildings that are of special interest are protected by the English Heritage that makes every effort to preserve them. There are over 370,000 listed buildings in the country, and over 92% of them are considered 'Grade II'. This means that any building work will require planning consent to prevent indiscriminate demolition and damage, and very little change is allowed specially on external elements. The majority of the Grade II listed buildings in the country are pre-1930s and consequently very energy inefficient, but are, nevertheless, occupied.

In this paper, the authors present a study of architecturally sensitive energy efficient upgrade measures applied to a dwelling in the Royal Standard House, a Grade II listed building located in Nottingham, designed by Evans, Cartwright & Woollett and opened in 1923. Firstly, on-site field work gathered qualitative and quantitative data, such as comfort of occupiers, indoor daylight distribution, temperature variation and infrared thermography images. Secondly, the building was dynamically simulated with step-by-step envelope improvements considering different scenarios, and their impacts on comfort and energy performance were noted. Daylight distribution was also analysed to evaluate the impact of the building envelope changes on the daylit environment. The energy performances of the different scenarios were compared in order to evaluate the impact of the different refurbishment measures for existing buildings.

The findings show that over 50% reduction on energy use can be achieved with no impact on the external character of the facade and with a minimum impact in the interior space. It was concluded that the fabric energy efficiency category of the Code for Sustainable Homes (CfSH) standard, normally applicable only for new-build, can be taken as a benchmark for a refurbishment. The results have also shown that a balance between optimum daylight distribution and thermal performance can be achieved with a holistic design approach.

Keywords: sustainable refurbishment; energy-efficiency retrofit; grade II listed dwellings; energy performance; daylighting analysis

INTRODUCTION

The 'historic building' can be defined as containing "architectural, aesthetic, historic, documentary, archaeological, economic, social and even political and spiritual or symbolic values" [1]. In the UK; 'listed buildings' is a sub-group for the protection of historic buildings in legal terms, which is classified as 'Grade I, II and III' by the "increasing levels of protection based on their comparative values and conditions" [2]. The English Heritage, which is an institution responsible from the listed buildings, indicates that there are over 370,000 listed buildings in the country, and over 92% of them are considered 'Grade II' [3]. 'Listed Building Consent' should be taken "for any works of alteration or extension – both external and internal – which would affect a building's character" for Grade I and II buildings [4].

The majority of the Grade II listed buildings in the country are pre-1930s [5] and consequently very energy inefficient, but are, nevertheless, occupied Therefore, application of energy efficient upgrade measures to Grade II listed buildings are significant in terms of sustainability. Sustainable refurbishment can happen on different scales: in the urban scale, it means restoration of 'an historical and architecturally significant building' as a vital indication of sustainable urban design [6]. In building scale, sustainable refurbishment may include 'increasing daylight through roof or facade, upgrading thermal insulation and increasing natural ventilation' [7]. The cavity of exterior wall may be insulated and double glazing with low emissivity glass may be applied to the windows [8].

This paper presents a study of architecturally sensitive energy efficient upgrade measures applied to a dwelling in the Royal Standard House, a Grade II listed building located in Nottingham. At first, on-site field work has been conducted both qualitatively and quantitatively focusing on the comfort of occupiers, indoor daylight distribution, temperature variation and infrared thermography images. Afterwards, the building was dynamically simulated with step-by-step envelope improvements considering different scenarios, and their impacts on comfort and energy performance were noted. Daylight distribution was also analysed to evaluate the impact of the building envelope changes on the daylit environment considering a holistic design approach.

RESEARCH CONTEXT & METHODOLOGY

The Royal Standard House (in Nottingham, UK) was designed by Evans, Cartwright & Woollett as the 'Memorial Nurses' Home' (Fig. 1), as an addition to the Nottingham General Hospital, and opened in 1923. The architectural elements of the building belong to the

Classical period, such as “symmetrical facade with projecting centre and end bays, central portico that is 3 storeys with giant Ionic columns and sash windows with rubbed brick heads” [9].

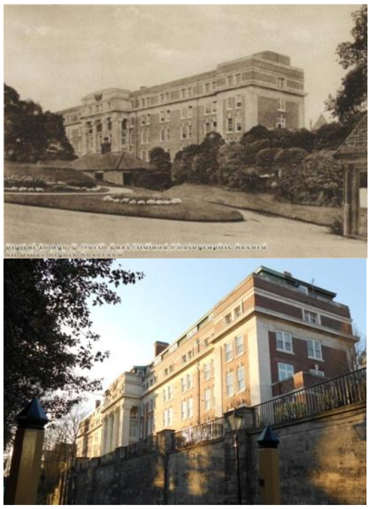


Figure 1: Royal Standard House (formerly known as Memorial Nurses’ Home) from the Castle ground in 1920s as above [10] and current appearance as below (author’s image).

The location of the Royal Standard House is on the north of the Nottingham Castle and is close to the city centre (Fig. 2). In the frame of micro-climate analysis, the sun-path diagram shows that the building is orientated towards south-east and north-west. Nottingham’s climate present cold but relatively mild winters, indicating that minimising heating load through an well-insulated building envelope is an appropriate strategy. Summer dry-bulb temperatures may go over 25°C indicating that overheating risks should be taken into consideration.

The original building had a longitudinal plan with a corridor in the middle and nurses’ bedrooms on both sides. The building was listed as Grade II, nationally important and of special interest. A refurbishment project by Maber Associates turned this Grade II listed building into a 30-flat residential building in 2000 and divided it into three wings, which are served by three separate circulation cores. In the scope of this research, Flat 30 has been selected for this study. It is a roof flat on the 4th floor orientated towards south-east, south-east and north-west (Fig. 3).

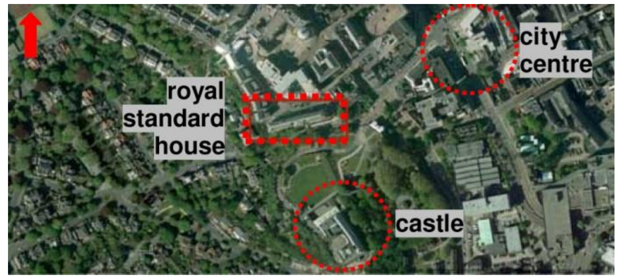


Figure 2: Site analysis (graphically represented by the author on the Google Earth image of Nottingham).

Figure 3: Plan of Flat 30 in Royal Standard House (redrawn by the author, based on the information from the Nottingham City Council planning department [11] and current flat layout).

Figure 4: Infrared thermographic image of the Royal Standard House and Flat 30 on the upper floor.

This research aimed at investigating the potential reduction in energy use to be achieved in the dwelling in a Grade II listed building with no impact on the external character of the facade and with a minimum impact in the interior space. The impact of different scenarios related to the upgrade of building envelope was compared. The 'Code for Sustainable Homes' (CfSH) is an assessment method, which is used in the UK to enhance sustainability in the new built environment. As an addition in this research, the CfSH was investigated as a benchmark for sustainable refurbishment.

On-site field work has been conducted in order to collect qualitative and quantitative data regarding to the visual and thermal comfort of occupants and personal review on energy use. Measurements related to indoor daylight distribution and temperature variations were conducted and infrared thermography images were taken (Fig. 4). The building was dynamically simulated with step-by-step envelope improvements considering different scenarios using Bentley TAS software, and their impacts on comfort and energy performance were noted. Daylight distribution was also analysed to evaluate the impact of the building envelope changes on the daylit environment by daylight factor simulation using Autodesk Ecotect / Radiance software.

ENERGY EFFICIENCY UPGRADE MEASURES

A simulation matrix was created with each case changing only one parameter and all other parameters remaining constant. Except for Case 4, each case contained the application of upgrade measures onto the internal side of the envelope. For U-Values, building data and sustainable design and refurbishment guidelines were taken into consideration (Table 1).

- **Case scenarios**

Pre-Base Case: As built in 1923, the window is single-glazing timber frame. The envelope has uninsulated external wall and uninsulated roof which are both consisted of green slate mansard roof [12].

Base Case: The Base Case represents the current envelope. During the refurbishment project in 2000, the window was changed to double-glazing timber frame. The external wall and roof was internally insulated with fibre glass.

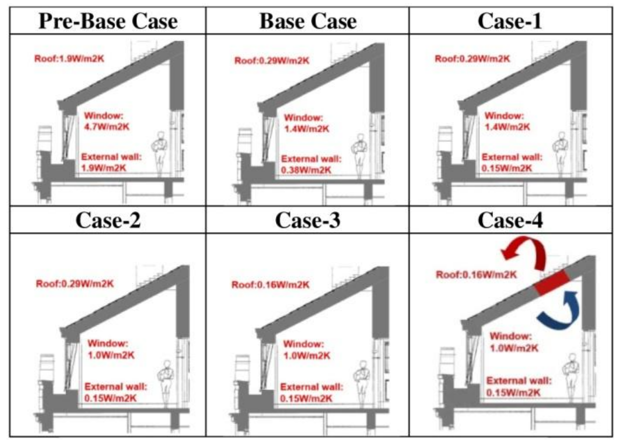
Case 1: While the window and roof were kept as in Base Case, additional internal insulation layer was applied to the external wall [13] (Fig. 5).

Case 2: While the roof and external wall were kept as in Case 1, a secondary glazing (also double-glazing) was integrated internally, 15cm away from the current double glazing [14] (Fig. 6).

Case 3: While the external wall and glazing system were kept as in Case 2, additional internal insulation was applied to the roof [12].

Case 4: While the envelope was kept as in Case 3, this case enhanced the daylight distribution of the living and dining spaces through the addition of a rooflight. This case also enhanced natural ventilation by stack ventilation through the rooflight in living and dining spaces, and through single-sided ventilation in other spaces.

Table 1: U-Values (W/m2K) of simulation cases shown on the section of Flat 30.



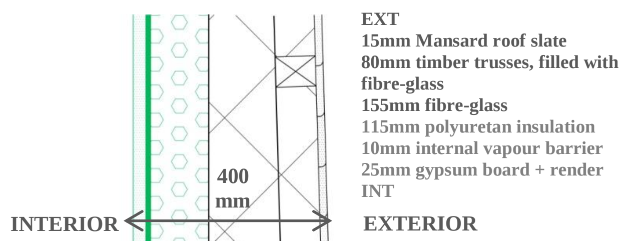


Figure 5: The detail of the external wall after additional insulation as in Case 1. Detail inspired by [14], and adapted to the project by the author.

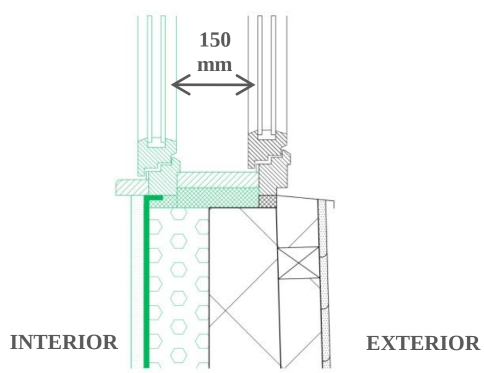


Figure 6: The detail of the window after secondary glazing as an addition to the external wall as in Case 2. Detail inspired by [14], and adapted to the project by the author.

- **Assumptions**

Five thermal zones were created in the simulated flat: Zone 1: Living & dining room, Zone 2: Workspace & hall, Zone 3: Bedroom 1, Zone 4: Bedroom 2 and Zone 5: Entrance hall (communal space). In winter; Zone 1, Zone 2, Zone 3 and Zone 4 were heated spaces. For these heated zones, the winter operative temperatures indicated in *CIBSE Comfort Guide* were taken into consideration for the temperature of spaces [15]. In the simulations, the indoor temperature for winter was assumed as 22°C for Zone 1 and 19°C for Zone 2, Zone 3, Zone 4. Zone 5 was considered as unheated as electric heaters in communal spaces are switched off.

For the simulation calendar, months from January to May and from October to December were defined as winter. Months from May to October were defined as summer. In the heated zones, heating hours were based on the *SAP 2009: Government's Standard Assessment Procedure (SAP) for Energy Rating of Dwellings 2009* as SAP calculations are used in the CfSH assessment and indicated as 7am-9am and 4pm-11pm for weekdays and between 7am-11pm for weekends [16]. Internal and occupancy gains were inputed in the simulations in Zone 1, Zone 2, Zone 3 and Zone 4; however, were not assumed in Zone 5 as it is a circulation space.

In the Pre-Base Case and the Base Case, the infiltration rate was assumed as 0.5 ACH at atmospheric pressure. In Case 1, as the external wall was additionally insulated with the assumption of being well-sealed, infiltration rates were decreased to 0.3 ACH. In Case 3 and Case 4, as the roof was additionally insulated and assumed that it would be well-sealed; infiltration rate was decreased to 0.2 ACH.

ANALYSIS OF THE RESULTS

- **Occupancy survey**

The occupancy survey revealed that majority of participants thought that heating was needed in terms of comfort both in flats and in communal spaces (Fig. 7). In contrast to this, most of participants thought that energy consumption could be cut with better insulation and double-glazing. Therefore, energy efficiency upgrade measures can be applicable in the Royal Standard House as occupants are conscious about energy-efficiency and demand less energy consumption, but also want to keep the indoor temperatures in the comfort range.

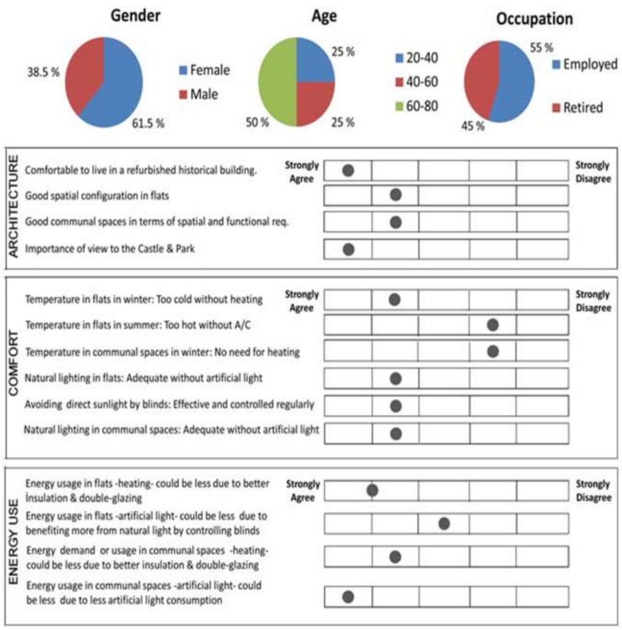


Figure 7: Occupancy survey results.

- **Thermal performance & Energy use**

In the hottest week, the lowest indoor temperatures were observed in the living and dining rooms in the Pre-Base Case. From Base Case towards Case 3, the room had more solar gains due to lower U-Values and indoor temperatures gradually increased (Fig. 8). On the hottest day, which was day 229, overheating occurred with temperatures more than 26°C for 67% of the time in Case 3. Nevertheless; in Case 4 temperatures dropped significantly due to natural ventilation. Similar temperature patterns were seen in the workspace, bedroom-1, bedroom-2 and entrance hall presented for the hottest week.

Winter performance was evaluated in terms of heating loads of each zone. The largest heating requirement was in the Pre-Base Case and decreased gradually towards Case 4, which required the least heating for living & dining room due to better performance of building envelope (Fig.9). The external temperature directly affects the heating loads as lower external temperature caused higher heating loads. It was evaluated that better envelope performance of Case 4 caused heating loads to drop significantly when compared with Pre-Base Case in entire winter, with a similar pattern in the other heated spaces as well (Fig. 10).

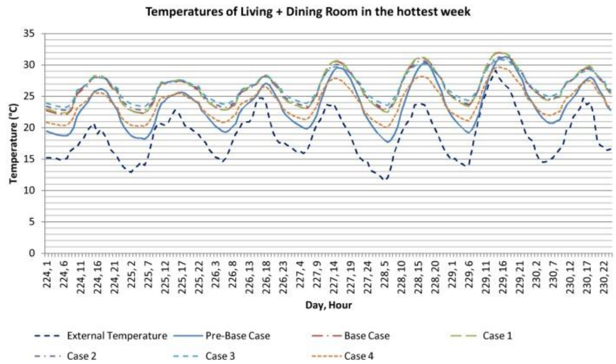


Figure 8: Temperatures of the living + dining room in the hottest week for all cases.

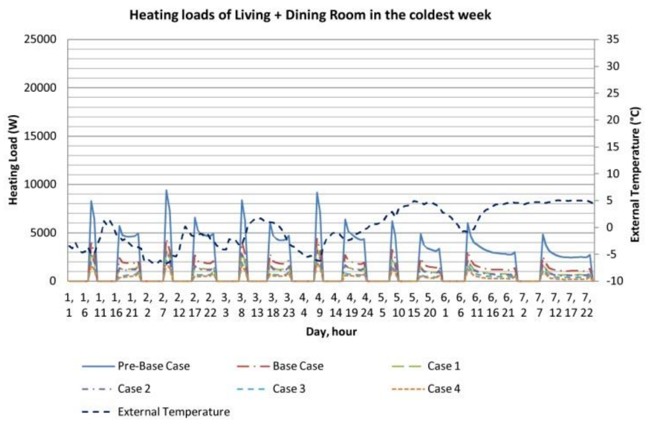


Figure 9: Heating loads of the living + dining room in the coldest week for all cases.

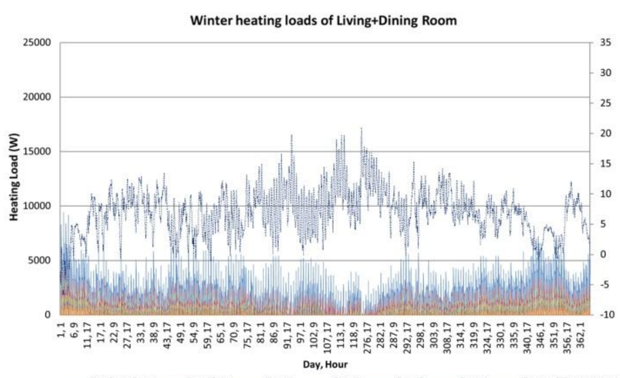


Figure 10: Heating loads of living + dining room in entire winter for all cases.

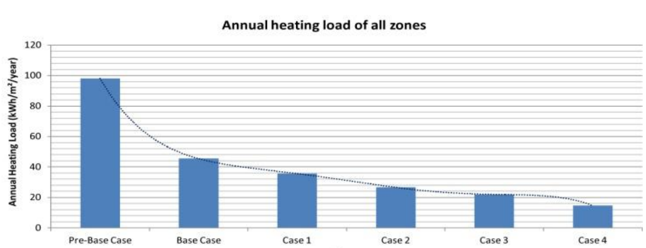


Figure 11: Annual heating loads of all zones.

In the CfSH, the limitation of the annual heating and cooling load in order to achieve Level 5/6 is 39kWh/m²/year. In order to assess the convenience of CfSH as a benchmark in a sustainable refurbishment study, the annual heating loads of all cases have been compared (Fig. 11). As the entire building envelope was insulated in the Base Case, the annual heating load decreased sharply. Better performing external wall decreased the load below the benchmark as in Case 1. The addition of secondary glazing to the Case 2 showed a similar change. The impact of additional roof insulation in Case 3 was quite low when compared to Case 1 and Case 2. In Case 4, the rooflight had an impact on the solar gains by increasing them slightly and decreasing the annual heating loads accordingly. The point details of the building envelope were drawn within the frame of this study, in order to observe the insulation and second glazing additions to the external wall according to related cases.

- **Daylight performance assessment**

As Case 4 contains a rooflight that would directly affect the daylight distribution of the living & dining room, a daylight performance assessment study has been conducted to evaluate the impact of rooflight on the indoor daylight distribution in comparison to the Base Case. It has been observed that rooflight increased the average daylight factor from 1.64% in Base Case (Fig. 12) to 2.45% in Case 4 (Fig. 13). As average daylight factor should be minimum 2% in order to be a daylit space for most part of the year with supplementary artificial light when needed according to the SLL Lighting Handbook, it is possible to say that rooflight achieved to decrease the artificial lighting consumption due to enhancing daylight distribution in the living & dining room [17]. The spatial quality of space also increased due to a better daylit environment.

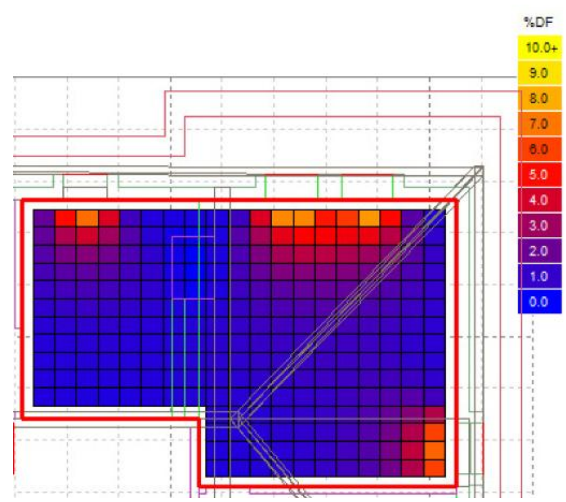


Figure 12: Daylight factor isolux plot of living & dining room as in Base Case.

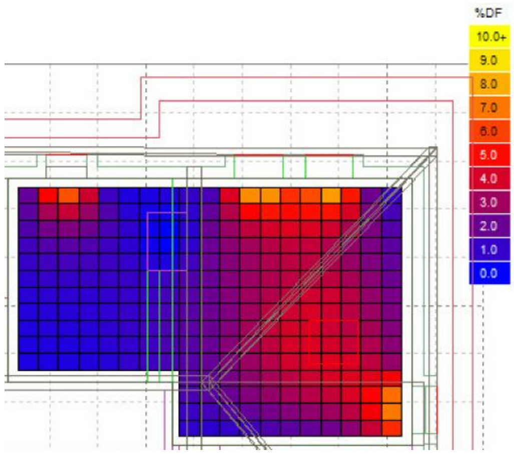


Figure 13: Daylight factor isolux plot of living & dining room as in Case 4.

CONCLUSION

Through this research the authors have demonstrated that over 50% reduction on energy use can be achieved with no impact on the external character of the facade and with a minimum impact in the interior space, when Base Case and Case 3 were compared. In winter, the annual heating load can be significantly decreased resulting in a better energy performance with the application of energy efficient upgrade measures on the building envelope. Although overheating in summer may occur due to higher insulation, the integration of natural ventilation can minimise this impact. In terms of environmental design, it is possible to conclude that a balance between optimum daylight distribution and thermal performance can be achieved with a holistic design approach.

This study also showed that the fabric energy efficiency category of the Code for Sustainable Homes assessment system, which was designed for new buildings, may be taken as a benchmark for sustainable refurbishment projects. Although the results cannot be generalised to other projects, the method used by the authors can be implemented in other sustainable refurbishment projects.

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