The Fourteenth International Conference on Construction in the 21st Century (CITC-14)
Rio de Janeiro, Brazil | **September 2-5, 2024**

Improving Energy Efficiency in Heritage Buildings – A Case of "Palazzo Farnese", Italy

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Abstract

Historic or heritage buildings are an important component of the building stock that necessitates energy efficiency interventions. About 14% of EU27 building stock dates before 1919 and 12% dates between 1919 and 1945 (with considerable national differences). With a significant proportion of the total building stock, and high potential for energy savings or at least high enough to warrant scrutiny from an energy efficiency perspective, heritage (listed and non-listed) buildings have become a focus of special attention in Europe. The main objective of this study is to examine the potential for energy efficiency in historic buildings in Italy through the case study of *'Palazzo Farnese' (a 16th Century palace converted into a musuem)*. The key retrofit interventions considered in this study are external wall insulation, gypsum board for external walls and triple glazing. The results show that combining wall, window, and roof retrofitting resulted in a significant reduction in energy consumption. The total energy use intensity (EUI) decreased from 175.0 kWh/m^2 in the Business As Usual (BAU) scenario to 151.5 kWh/m^2 in the simulataneous retrofit scenario. In addition, the results reveal that wall retrofitting is the most effective individual intervention for lowering total EUI. This research demonstrated how optimal energy efficiency measures could be successfully implemented in museums while taking both conservation requirements and people's thermal comfort into account. The most influential intervention in decreasing the total EUI is wall retrofitting. The findings of this study can be useful not only for conservation architects but also for city governments and historical buildings used as museums.

Keywords

historic buildings, energy retrofit, preservation, energy efficiency, cost savings, payback period.

1. Introduction

Buildings account for nearly 40% of the total energy consumption and a quarter of global greenhouse gas (GHG) emissions. Energy efficiency in buildings is therefore key to achieving net zero and addressing rising energy costs. Heritage or historic buildings are an important part of the building stock that requires energy efficiency interventions. Statistics show that 14% of buildings in the EU-27 were built before 1919, and 12% were built between 1919 and 1945 (with considerable national differences) (IEA, 2007). However, historic buildings are frequently overlooked in energy efficiency retrofit policies and initiatives due to the widespread misconception that energy efficiency retrofits can have an impact on the irreplaceable value of such buildings (Martínez-Molina et al., 2016). Although examples from European legislative frameworks show that historic buildings can be exempt from mandatory targets, they are still "under significant pressure to reduce carbon emissions" (Galatioto et al., 2017). Since historic buildings make up a significant proportion of the total building stock, and the potential for energy savings is high or at least high enough to warrant scrutiny from an energy efficiency perspective (Martínez-Molina et al., 2016), the topic of energy efficiency in heritage (listed and non-listed) buildings has recently become a particular focus in Europe (IEA, 2007).

In this context, the main objective of this study is to analyse the potential for energy efficiency in historic buildings in Italy using the case study of *'Palazzo Farnese'*. Palazzo Farnese is one of the prominent monuments of the Italian city of Piacenza and is also listed among the Civic Museums and the State Archives. The building was designed by Jacopo Barozzi, known as Vignola, but was never fully built and remains unfinished. Although incomplete, it is one of the greatest examples of 16th century royal residences in Italy and is often referenced by contemporary architects. Over the centuries, since construction was first interrupted in 1602, the building has changed its function several times, each time being modified and transformed. Today, Palazzo Farnese houses various museum sections with artifacts and art of excellence (Marmo et al., 2018).

2. Literature review

2.1 Energy efficiency strategies for historic buildings

In the recent years, a considerable body of literature has looked at improving energy efficiency in historic buildings and concluded that improving the energy performance of historic buildings is based on achieving a balance between indoor comfort, material conservation, energy savings and preservation of architectural character (Camuffo et al., 1999; Corgnati et al., 2009; Pavlogeorgatos, 2003; Saïd et al., 1999). Two key approaches are identified for improving energy efficiency in historic buildings: a) Objectivist value approach and b) Relative value approach. The objectivist value approach focuses on alterations and additions that do not destroy or alter the building's original materials and design. For example, in an objectivistic value approach, new windows would have a contemporary design that blends in with the overall appearance of the original building (Martínez-Molina et al., 2016). On the other hand, the relative value approach permits alterations in materials and design if they are intended to enrich or enhance the heritage significance of the building (Martínez-Molina et al., 2016). However, a broader notion of heritage significance is also embedded in the relative value approach, especially when considering adaptations to design and architecture. This approach allows for the implementation of energy efficiency measures for the envelope, including insulation and new windows (Martínez-Molina et al., 2016). Despite the notable differences, both approaches can improve energy efficiency without compromising the heritage significance of the building.

The choice of approach and interventions depends on a range of factors such as existing materials and their physical and chemical compatibility with new materials, and the impact of the intervention on the building (Pavlogeorgatos, 2003). An in-depth review show that improvements in insulation, use of high-efficiency windows (glazing and frames), design of smart and high efficiency lighting components, retrofitting of heating and cooling systems and their integration with natural ventilation, and implementation of renewable energy sources such as wind or solar (only if they have minimum impact on architectural value) are some of the possible energy retrofit options for historic buildings in Europe. However, the most suitable combination of interventions is found to be the replacement of existing windows with low-emissive windows, the application of thermal insulation plaster, and insulation for walls and roof (Bernardi, 2008).

2.2 Factors affecting energy efficiency in museums

A small body of literature has reviewed the possibilities for energy conservation in museums and the key factors that must be considered when considering museum energy retrofit interventions. For example, Ucar & Doering (1983) recommended following heating, cooling, and humidity control guidelines and conducting energy audits for all museum buildings (Ucar & Doering, 1983). Humidity control is important as excessive humidity can compromise the life of the building and the artifacts contained within it (Corgnati et al., 2009; Saïd et al., 1999). Similar evidence was found by monitoring indoor environmental conditions at a museum in Ottawa, Canada (Saïd et al., 1999). Pavlogeorgatos (2003) found that, along with humidity and pollution, the temperature of exhibition halls and storage areas is one of the most important factors contributing to the deterioration of artworks (Pavlogeorgatos, 2003). Due to the wide variety of works of art housed in museums and the array of materials that comprise them, special attention must be paid to microclimate control. A methodology for microclimate assessment is described in a study on field monitoring of environmental parameters and microclimatic quality evaluation (Corgnati et al., 2009). A microclimate assessment is important as heating and air conditioning systems designed for human well-being are not suitable for building conservation and can lead to unfavorable temperature and humidity fluctuations (Camuffo et al., 1999, 2001). Camuffo et al. (1999) analysed the indoor microclimate of a museum in Venice, Italy, paying particular attention to the influence of heating and cooling systems in summer and winter (Camuffo et al., 1999), and determined that pollutants were more prevalent in summer, when windows and doors are opened more frequently.

Maahsen-Milan and Simonetti (2011) examined three cases of architectural and historic significance in Torino, Italy and suggested that improving envelope performance can be a key strategy for achieving optimal levels of energy efficiency and thermal comfort. Wang et al. (2014) performed multiple simulations of the impact of different energy efficiency solutions (3 types of glazing for skylights, insulated timber roof structure, and adaptive controls) on the quality of indoor environment in a national gallery project. The results show that energy savings could be increased by 28% through improved glazing and a further 20% through increased roof insulation. The article concluded that a combination of all suggested solutions could have a 60% energy consumption reduction. Likewise, Farreny et al.

(2012) analysed the energy profile of 28 museums in Spain and found a correlation between water, energy consumption and building services. Relevant influencing factors include building size, activity rate, number of visits and hours of operation.

Drawing on the existing literature, the key retrofit interventions considered in this study are a) external wall insulation b) gypsum board for external walls and c) triple glazing. This study also acknowledges the importance of achieving optimal values of the building physical parameters (Corgnati et al., 2009). Importantly, this study aims to address the problem of achieving optimal indoor microclimate conditions (spatial distribution of relative humidity, temperature, air velocity, etc.) in museums by using architectural modelling (Martínez-Molina et al., 2016).

3. Methods

3.1 Case Study – Palazzo Farnese, City of Piacenza, Italy

Palazzo Farnese was selected as a case study for the application of energy efficiency interventions. The building is located in the center of Piacenza, in a dense residential area near the Po River (Fig. 1). The building is open on all sides, and has a courtyard and a garden. It consists of two different interconnected buildings with three floors above ground and a mezzanine. The basement houses the museum space, with thick thermally resistant walls. The walls are mainly made of solid brick, while the floors are mainly made of masonry vaults and the attic is covered with wood. Windows vary in size, with wooden frames and single or double glazing.

Fig. 1. Location of Palazzo Farnese and its surroundings

The analysis of the potential for improving energy efficiency in Palazzo Farnese is based on the following steps: i) collection of existing information of the building through desk study (historical background, geometrical layout, photos, etc.); ii) inspection of the site for verification of the secondary information and the acquisition of additional data required for analysis; iii) collection of information on loads, room functions and building construction for 3D simulation (Fig. 2 and 3); iv) building 3D models using building modelling software; v) categorisation of rooms into four categories (exhibition, office, storage, and cicrulation space) so that standard loads and schedules can be applied to them; vi) application of suitable retrofits; and vii) analysis of results.

3.2 Building Energy Modelling

In order to optimise the design of each specific retrofit measure applied in the museum, simulations were carried out in Rhino V7 software. These simulations helped to assess the internal comfort of visitors and display materials, and calculate the distribution of indoor temperatures, as well as the energy required for heating and cooling. The model was produced taking into account building characteristics (dimensions, orientation, building materials), occupancy profile, and lighting, cooling and heating loads. The calibration of the model in the simulation software was performaned by constructing opaque and transparent components of the real building. Subsequently, different thermal zones were defined in the museum.

The building consists of three floors above the ground and one basement. It contains a total of 163 zones. These zones are divided into four thermal zones: Category 1: Exhibition/ Gallery/ Classrooms/ Entrance Hall; Category 2: Office/ Laboratory; Category 3: Storage/ Closet/ WC and; Category 4: Corridor/ Staircase/ Elevator. Tab. 1 provides the structural input data used in this study. It contains all energy constructions used to create the energy model. The key retrofit measures considered are: a) external wall insulation. The building's exterior walls were not insulated, and the primary analysis revealed significant thermal losses in all exposed walls. b) 8cm fiber board plus 3cm gypsum board to the external walls. c) upgrading windows from double glazing to triple glazing.

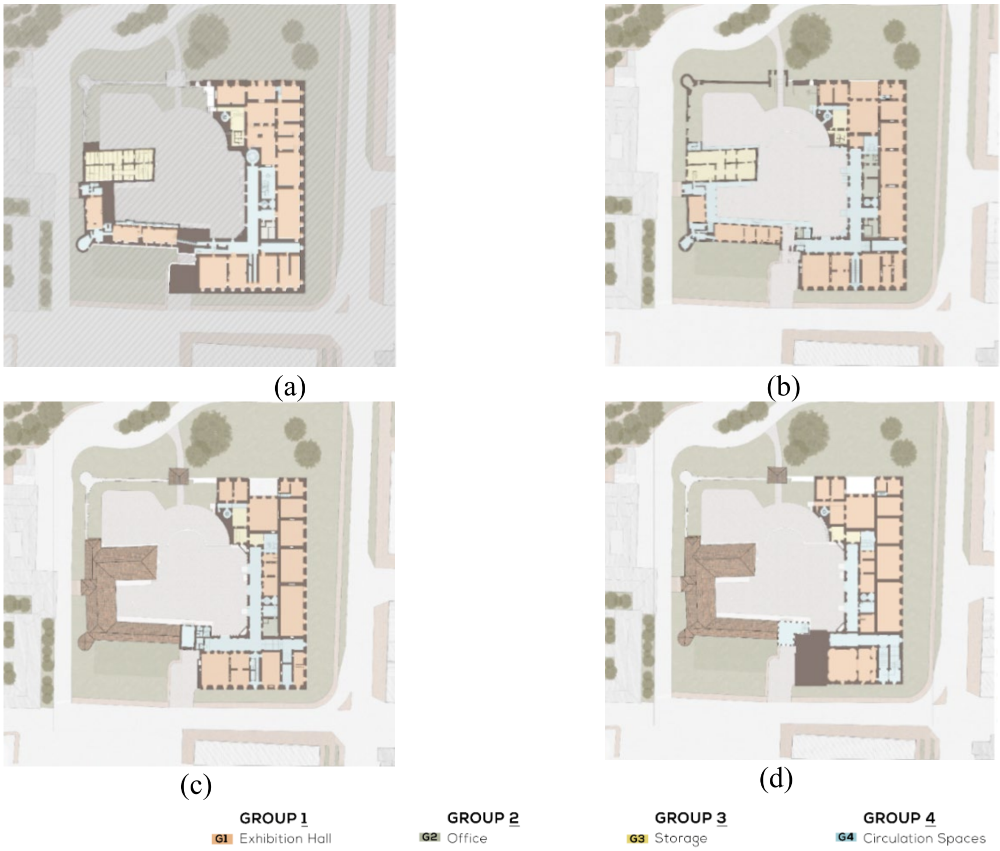

(a) (b) (c) (d)

Fig. 2. Floor plans of Palazzo Farnese [(a) Underground FL (b) Ground FL (c) First FL (d) Second FL]

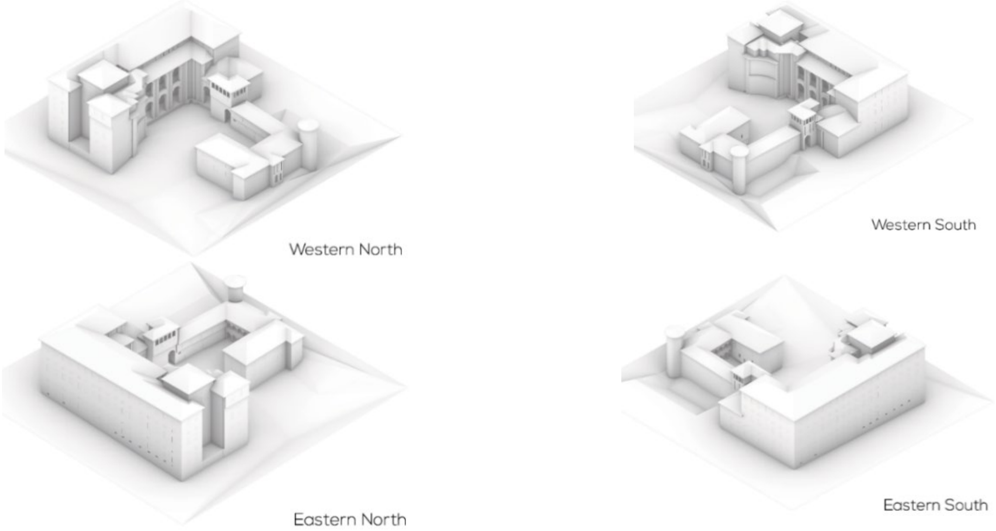


Fig. 3. 3D model view of Palazzo Farnese

Table 1. Construction set of Palazzo Farnese.

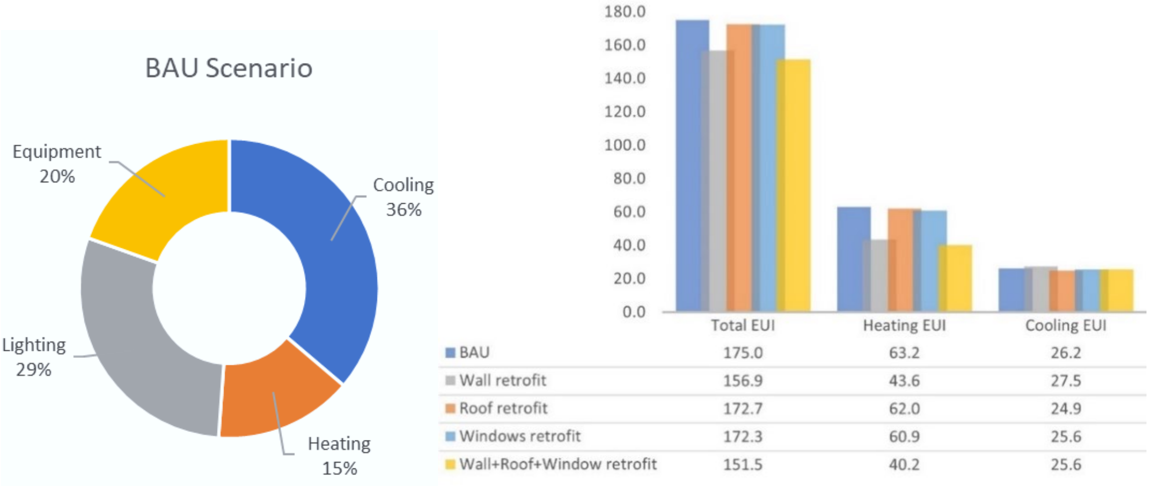
	Thickness (cm)	**Conductivity (W/m^2-k)**	**Density (kg/m^2)**	**Specific Heat (J/kg-k)**	**Solar Absorption**	**Thermal Absorption**
Roof						
Clay Tile	10	1.3	2400	880	0.7/ 0.4	0.4
Concrete	05	1.4	2400	800	0.7	-
Wood	40	0.265	802	871.5	-	-
External Wall						
Brick	170	1.273	2049	1288.7	-	-
Plaster	05	1.208	278	972	-	-
Insulation	***08***	***0.038***	***160***	***840***	***-***	***-***
Gypsum Board	***05***	***0.253***	***623***	***603.3***	***-***	***-***
Internal. Wall						
Brick	120	1.273	2049	1288.7	-	-
Plaster	05	1.208	278	972	-	-
Floor/ Ceiling						
Stone	0.5	2.440	3146	2139.8	-	-
Cement	05	0.438	1340	811.3	-	-
Wood	20	0.265	802	871.5	-	-
Gypsum	05	0.253	623	603.3		
External Window						
		U-Factor (W/m^2-k)		Solar Heat Gain Coefficient	Visible Transmittance	
Double Glazing		2.8		0.8	0.51	
Triple Glazing		***1***		***0.6***	***0.41***	

Note: retrofit measures considered in this study are highlighted in bold italics

4. Results

4.1 Overall performance

Under a business-as-usual (BAU) scenario, the museum's total energy use intensity (EUI) was 175.0 kilowatt-hours per square meter (kWh/m^2). The energy demand after each retrofit application was then analysed (Fig. 4). In the first step, when the roof was retrofitted, the total EUI dropped by 3 units to 172.7 kWh/m^2. The total EUI after wall retrofit further decreased by 18 units to 156.9 kWh/m^2. The total EUI after window retrofit was similar to that of roof retrofit at 172.3 kWh/m^2. This shows that the individual intervention with the greatest impact on reducing the total EUI was wall retrofitting. The simultaneous application of the different retrofit measures resulted in a reduction in energy consumption of about 20 units to 151.5 kWh/m^2.



	Total EUI	Heating EUI	Cooling EUI
BAU	175.0	63.2	26.2
Wall retrofit	156.9	43.6	27.5
Roof retrofit	172.7	62.0	24.9
Windows retrofit	172.3	60.9	25.6
Wall+Roof+Window retrofit	151.5	40.2	25.6

Fig. 4. Total EUI comparison in different retrofits

4.2 Cooling and heating performance

The heating EUI was reduced from 63.2 kWh/m^2 in BAU to 40.2 kWh/m^2 after the roof, windows and walls were retrofitted simultaneously. The most effective measure was wall retrofit, which reduced the heating intensity from 63.2 kWh/m^2 to 43.6 kWh/m^2. In contrast, the least impactful measure was the roof retrofit, which reduced the heating EUI from 63.2 kWh/m^2 to 62.0 kWh/m^2. Heating EUI was reduced from 63.2 kWh/m^2 in BAU to 60.9 kWh/m^2 after window retrofit.

The cooling EUI reduced from 26.2 kWh/m^2 to 25.6 kWh/m^2 after the three optimised scenarios are implemented together. Neither the increase with wall retrofit nor decrease with roof and window retrofits are significant impacts on cooling EUI. For each roof and window retrofit, the cooling EUI was reduced to 24.9 kWh/m^2 and 25.6 kWh/m^2 respectively. But in the case of wall retrofit, the cooling EUI increased by 1.3 kWh/m^2 relative to the BAU. This shows that none of the individual retrofit measures had a significant impact on the cooling EUI.

5. Conclusions

Italian energy policy determines important strategies for building energy efficiency codes and their application throughout the country. However, much work remains to be done to achieve energy efficiency goals. In this regard, historic buildings can provide significant opportunities for energy efficiency and net zero targets. This study analysed the energy efficiency potential of historic buildings in Italy by applying a series of specific retrofit measures to the case of the "Palazzo Farnese" museum.

The results revealed that the study of energy efficiency of historic buildings is a complex task that should consider technical and management measures as well as conservation issues. In addition, this work demonstrated how energy efficiency measures can be successfully applied, taking into account energy saving requirements and thermal comfort. Based on the findings, the total EUI in the BAU scenario is 175.0 kWh/m^2 with an opportunity to reduce it by 20 kWh/m^2 through wall, window, and roof retrofitting. Wall retrofit showed the highest energy saving potential (by 18 kWh/m^2) while roof and window retrofits provided savings of only 3 kWh/m^2 relative to the BAU scenario. The retrofit reduced the heating EUI from 63.2 kWh/m^2 in BAU to 40.2 kWh/m^2 while the observed savings in cooling EUI were insignifcant. Wall retrofit played key role in reducing the heating EUI to 19.6 kWh/m^2. Window and roof retrofits could only offer heating EUI savings upto 2.3 kWh/m^2 and 1.2 kWh/m^2, respectively.

The observed cooling and heating performance patterns can be related to the museum's indoor microclimatic conditions (Fig. 5). In winter, the heat transfer through the envelope varies between -14.56 and 46.30 kWh/m^2 under the BAU scenario, while in summer, the observed heat transfer is between -62.5 and 154.82 kWh/m^2. Here, negative heat transfer represents heat loss, while positive represents heat gain. Due to the large diurnal variability of the climate, a pattern of more heat loss at night and more heat gain during the day was observed. After the roof retrofit was applied, the heat transfer of the building in winter was reduced by about 2 kWh/m^2. No significant heat transfer was observed in summer. By replacing double glazing with triple glazing as a retrofit measure, the heat gain was reduced from 154.82 kWh/m^2 in summer to 125.95 kWh/m^2. However, the required heat gain in winter also dropped from 46.3 kWh/m^2 to 45.53 kWh/m^2 after the window retrofit. After the wall renovation, the heat loss was reduced by 20 kWh/m^2, saving the energy required for heating. The insulation stored internal heat gain (occupants, lighting, and equipment) and contributed to indoor thermal comfort conditions. In summer, however, internal gains come at the expense of increased cooling energy consumption. Since the heating coefficient of performance (COP) is smaller than that of cooling, the annual heating energy saving is higher than the cooling energy consumption.

Museums represents an important sector in the field of energy efficiency in historic buildings. Due to the air conditioning requirements of generally large exhibition halls and spaces, and due to the large number of visitors and high air change rates, they have a high energy usage. Museums are also often high energy consumers due to the need to provide strict humidity control and often have specific and/or different heating and cooling requirements. For historic buildings used as museums, it is important to ensure both the thermal comfort of the occupants and optimal internal hygrothermal conditions. However, these two goals (thermal comfort of occupants and protection of museum collections) are not always fully compatible. This study was able to assess the internal comfort of visitors and the preservation of exhibits by calculating the spatial distribution of indoor temperatures and the energy required for heating and cooling. The findings of this study can be useful not only for conservation architects but also for city governments and historical buildings used as museums.

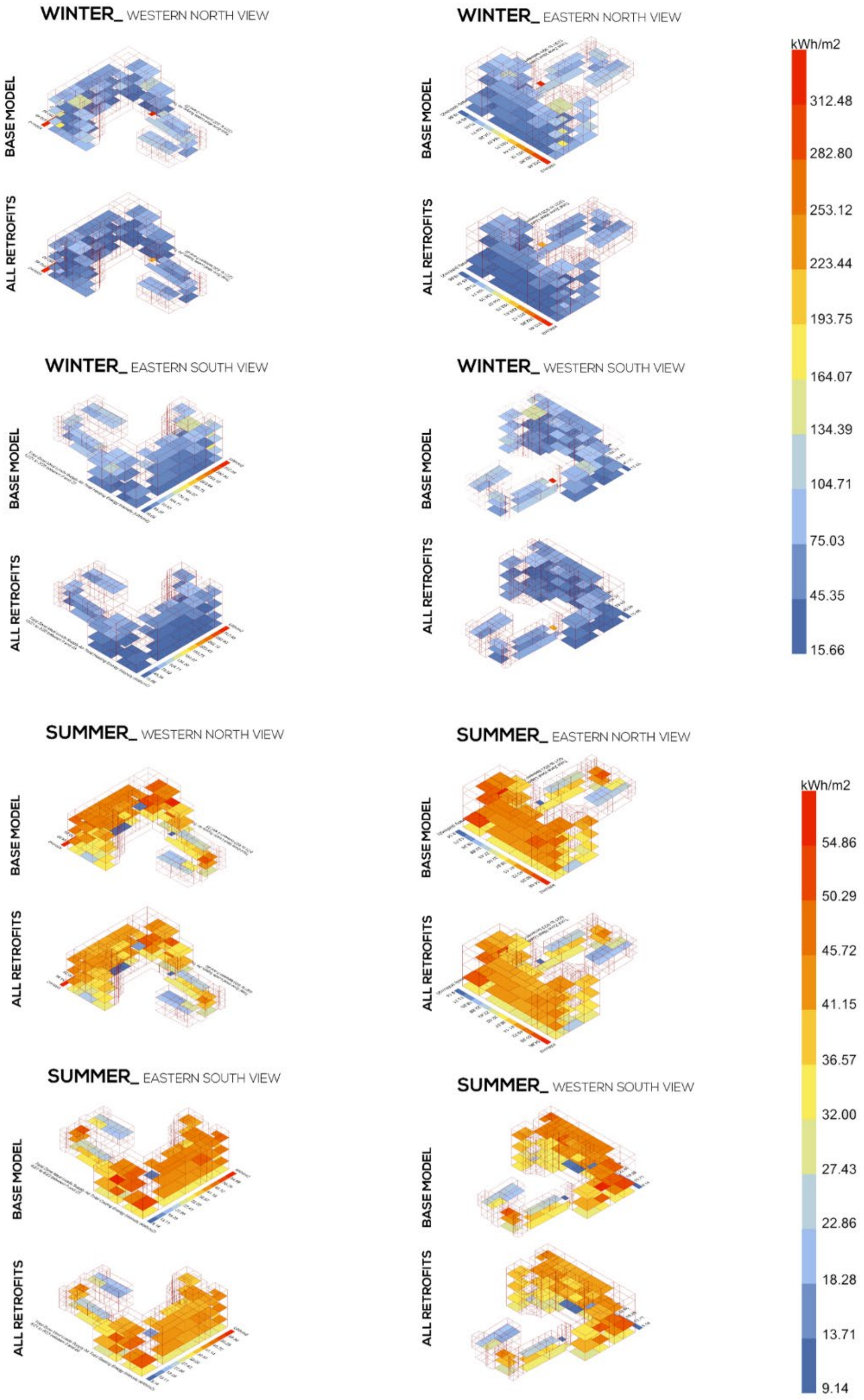


Fig. 5. EUI comparison in different retrofits

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