RETROFITTING OF A HISTORIC PUBLIC BUILDING FOR ENERGY EFFICIENCY: EXPLORING MEASUREMENTS AND ATTITUDES FOR HERITAGE CONSERVATION PROFESSIONALS

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Abstract
During the last few decades, there has been a trend toward enhancing energy performance and improving indoor comfort conditions of heritage buildings. Architectural heritage and aesthetic values do not allow typical retrofit interventions. Governmental and planning directives mainly focus on saving energy in existing buildings and do not extend to historic buildings. Architectural heritage bodies must act to determine energy retrofit measure types that can be applied to historic buildings to conserve their values. There is a need to enhance the energy efficiency and environmental sustainability of historic buildings. This study aims to reduce a heritage building's energy use through technical interventions and selection of specific retrofit measures. Each of these interventions is then evaluated using sustainable tools. Designing energy retrofits for existing buildings has environmental, economic, social, and health benefits. This study describes a methodology for adopting Integrated Environmental Solutions–Virtual Environment (IES–VE) tools as energy and environmentally conscious decision-making aids. A methodology was developed to monitor buildings for potential improvements and support the retrofit strategy development. We present a case study of a banquet hall renovation project titled “The Banqueting Hall in Jesmond Dene, Newcastle Upon Tyne” that implements IES–VE approaches to energy retrofits to a historic public building. To generate energy savings, several improvements were added to the building. For each alteration, building energy consumption and mean radiant temperature were examined, and the results indicate that with all improvements applied to the building there is a potential to reduce total energy system demand by 45%. Restoration of historic buildings is of paramount interest for preserving a locality's character and history. Environment-friendly retrofitting helps reduce the footprint of old energy-inefficient structures. Simulations of various energy-efficient retrofitting methods are of paramount interest for planners to decide optimal strategies for improving building performance. Although several articles have been published in this area, each new building comes with unique challenges and is therefore unique and highly significant.

Keywords: Energy efficiency, energy conservation measures, public building simulation, retrofit measurement, sustainable refurbishment.

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INTRODUCTION

Retrofitting is the process of improving building energy efficiency performance and addressing environmental concerns through technical interventions. This process also involves changes in occupant lifestyle and includes an ongoing repair and maintenance program (Syngellakis, 2013). Retrofitting existing buildings has been shown to be extremely eco-friendly, especially when considering economic factors (Dixon, 2014). It can also help extend building lifespan, especially in the case of historical buildings, and can provide solutions for optimizing the energy performance of these buildings and extend the heritage value life (Dixon, 2014; Kok *et al.*, 2012). A main focus of retrofitting is reducing heat losses through the building fabric (i.e., walls, doors, windows, floors, and roof), thus minimizing heating costs, CO_2 emissions, and overall energy consumption.

Traditional buildings perform differently from modern buildings because of differences in building materials and structural form (Ascione *et al.*, 2011). Traditional buildings provide vernacular character and are related to the memories of people and the past, bringing aesthetic and community benefits. Thus, heritage buildings cannot be replaced because they have great links to locality and history and reach into the past (Ma *et al.*, 2012). Responsible retrofitting requires compromises between different values to deliver continuous energy use reductions at minimal environmental influence, enhance traditional construction, and positively contribute to human health (May, 2015).

Public building rehabilitation plays an important role in transforming the public sector for many reasons. First, these buildings are old and thus do not correspond with modern directives, but by applying technical solutions, traditional buildings can gain a high energy-saving potential. Additionally, worker productivity is directly influenced by indoor thermal conditions and air quality. Last, public buildings represent reference components in establishing sustainable bridges to future smart cities. Because public buildings account for more than 40% of final energy consumption, particularly for heating and cooling, improving building energy consumption lead to saving energy togather with supporting economic growth, sustainable development, and job creation (ibid). Greater use of energy-efficient appliances and technologies, combined with the adoption of renewable energy, are cost-effective ways to enhance energy security. However, conserving energy and reducing costs are not the only reasons for retrofitting existing buildings; they can also create high-efficiency buildings by applying an integrated, whole-building design process.

According to Einaudi (Einaudi,2015), retrofitting existing historical buildings introduces a great opportunity for reducing building energy consumption and greenhouse gas emissions. Building construction and operation contribute to a large proportion of total worldwide energy use (Beiter and Tian, 2015). In the building sector, energy is consumed mainly by existing buildings as opposed to new building construction, which is approximately 1.0%–3.0% (Ma *et al.*, 2012). The building sector consumes about 40% of energy in the United States and Europe and about 25%–30% in developing countries (Berardi, 2015). Therefore, rapid energy efficiency improvements in existing buildings are vital for timely global energy use reduction and environmental sustainability. Lucchi (Lucchi, 2011) reported that retrofitting is a radical approach to future-proofing historic buildings that works by integrating conservation, design, and operation. Nowadays, there are many retrofitting technologies available on the market; however, there are many constraints and limitations that affect the decision of choosing the best technologies for a particular project, which has been summarized by the study of Ma et al. (Ma *et al.*, 2012), these constrains are : specific building characteristics, project targets, available budgets, building services and efficiency, and building fabric.

A study by (Lucchi, 2011) Lucchi divides the building retrofit process into five major steps (Figure 1). This project deals mostly with the second and third steps.

Figure 1: Building retrofit process.

First, an energy audit is performed to understand building energy use using sustainable rating system performance indicators. To predict reliable energy savings yielded by proposed retrofit measures, simulation parameters can be calibrated using energy audit data (Ascione *et al.*, 2011). Second, building performance assessment and diagnostics are used to provide a building energy use benchmark, identify system operational problems, and identify energy conservation opportunities (ibid).

For this research, a banquet hall was chosen as a heritage public building. The alterations that would be added to the building would bring life to this building and to the Jesmond Dene, which would give visitors a destination to walk to. This is an approach to transform this building into a sustainable building by reducing total energy demand during each step of the alterations. This project aims at reducing a traditional building's energy use through the choice of systematic retrofit strategies.

Traditional construction differs significantly from modern construction, using different materials, construction methods, and designs. Many traditional buildings have had alterations, additions, or other changes made to their fabric, services, and use over the past century (May, 2015). Therefore, there is a vital need to understand historical building characteristics, traditional construction methods, and local techniques; otherwise, reconstruction and retrofitting strategies will face technical challenges or even cause physical damage and potential legal claims (Lucchi, 2011).

To decide which simulation software to use, a literature research was conducted together with a survey of the available data. Building performance simulations have played an important role in high-performance building design and operation and have aided the development of policies to achieve energy reduction goals. Building energy modeling is defined as the use of mathematical models to present the physical characteristics, proposed operation, and control strategies of a building and its energy systems. Calculations in these models include building energy flow, air flow, energy use, thermal comfort, and other indoor environmental quality indexes such as glare (Tianzhen Hong, 2018). This study indicates that simulation techniques offer possible solutions allowing efficient retrofitting or modification decisions for a whole building within a manufacturing facility. Such solutions should aim to identify potential options for reducing energy use while maintaining or improving facility productivity (Garwood *et al.*, 2018). The simulation tool used in this study is Integrated Environmental Solutions–Virtual Environment (IES–VE), which has many advantages such as being commercially available for simulating a whole building. IES–VE has a range of features including good integration with BIM for fast model import and generation. It can also simulate heating, ventilation, and air conditioning (HVAC) systems as well as environmental thermal influence, occupant schedules, air flow, and lighting design (IES, 2018). A study by Attria and de Herde (Attia and De Herde, *2011*) compared 10 simulation tools that have been mostly used in research based on a scheme of five criteria: usability, intelligence, interoperability, and accuracy. Usability and accuracy were the main strengths for IES–VE, which has several distinctive input options and allows users to generate an overwhelming amount of information and output. Additionally, the results sufficiently support architects in decision-making processes, which play an important role in choosing optimal retrofitting strategies (Attia and De Herde, 2011).

Research done by Reeves and Olbina (Reeves and Olbina, 2012) validated the precision and accuracy of three building modeling tools (Autodesk (Ecotect 2011), Autodesk Green Building (Studio 2011), and (IES–VE 2011)) for simulating heating, cooling, and overall energy use for two retrofitted buildings. Their main results show that IES–VE had the second-most accurate measurements of overall energy consumption for the first building and was the most accurate for the second building. Additionally, it was argued that IES–VE achieved the most accurate readings for monthly average heating energy use. Overall IES–VE simulations were accurate in three out of six analyzed simulations. Research by Attiaa et al. (2015) discussed that there is a wide gap in priorities between architects and engineers, in that architects prefer selecting an IES–VE plug-in with an 85% accuracy because it is adaptable for use during different design phases and can be used and read by different design team members, especially engineers. IES–VE is also preferable for its friendly graphs that enable easy reading and simple information management. The above research concluded that both Energy Plus and IES–VE (IES 2016; (Ingram, 2013; Mcnally, 2014; Memon, 2014) are suitable software for modeling and simulating historical building energy efficiency. IES–VE was chosen as it has already been validated by several studies on building retrofitting. It also allows the simulation of multiple scenarios on the same model, thus enabling comparative analysis of the interventions. Furthermore, it offers a more user-friendly interface and requires less coding skill than Energy Plus (Menconi *et al.*, 2016).

This research focuses on how to determine general principles for retrofit measures in the light of energy concerns while accounting for the impact on heritage values of historical public building in a conservation area.

The scope of the research is to define methodology and methods to enhance historic building energy efficiency and sustainability using energy modeling and simulations of a historic public building (HPB) while considering constraints related to the high historic and aesthetic values of the existing building and its contents.

To achieve these research aims, the following objectives must be satisfied during the study's different stages:

-Identify actual energy use, heating and cooling energy demand, CO_2 emissions, and other related environmental impacts of an HPB.

-Define a methodology to suggest appropriate combinations of retrofitting solutions to apply to the HPB with respect to performance, legislation, regulations, heritage values, and cost implications, thus taking an overall sustainable approach to such measures.

LITERATURE REVIEW

HPB Characteristics

Retrofitting strategies for historic buildings differ from those for buildings without historic value. For example, many different regulations must be considered before executing any retrofit approach. The heritage value of a protected building is one of the most important aspects in retrofitting strategies, and it must be determined to what extent retrofitting measures would compromise that value. Therefore, a holistic approach is essential for making reasonable selections toward creating an energy-efficient building with low emissions. This approach assesses benefits and weighs them against the heritage value (Grytli *et al.*, 2012). Thus, a careful investigation of planning laws, heritage laws, and scientific literature shows which measures are most appropriate for a historical building retrofit.

Literature reviews agree on the significance of a good understanding of building envelope construction, which is used mainly for heat loss calculations ((Barnham *et al.*, 2008; Ingram and Jenkins, 2013; Örn, 2018). One of the most important terms in the conservation of historic buildings is preserving the building's original fabric and characteristics. Heritage building methods differ from modern building motheds in ways that produce different functional characteristics. Some examples include moisture barriers, damp-proofing, cavity walls, and insulation (Heritage Buildings and Sustainability, 2009). Another important difference is that heritage buildings, due to their thermal properties (masonry construction and timber floor), can provide natural ventilation and thus reduce dampness, whereas modern buildings rely mainly on mechanical ventilation. Historical building materials such as good response to air and moisture prevent condensation because of their permeability and softness (WORKS, 2008). Additionally, the higher thermal mass of older solid walls retains heat better than modern cavity walls, and this can help control the temperature of the space (cool in summer and warm in winter). In contrast, heritage buildings are less thermally efficient than structures built using current building standards (WORKS, 2008). Older buildings can often be drafty and can leak heat due to large window size and the predominance of sash and case windows that lead to a greater area of low-efficiency glazing and greater potential for drafts. Another reason why HPBs consume more energy is the size of the spaces (e.g., larger rooms and higher ceilings with no insulation), which increases energy demand for heating the space (English Heritage, 2013; Almeida, 2014).

Legislation

Historic building construction materials, structures, and methods have architectural and historic importance. It is important to consider building preservation before renovating it to understand the risk of losing cultural heritage (Advies, 2011b). A study by Grunewald et al. (2010) cited by Pilzer (Pilzer, 2016) assessed consideration of retrofitting strategies based on the value of preserving the building, retrofitting benefits, and the amount of changes justified because of these advantages. Some of building modifications can lead to changes in building function and role, and some retrofitting options can change building appearance characteristics, which could later lead to a failure to recognize its construction history. Therefore, any retrofit strategy should be reversible to avoid issues regarding legislation (Pilzer, 2016). Another point to be considered is that historic building materials and construction techniques may not be compatible with new construction materials as they can have mechanical or chemical reactions that could lead to building destruction (Advies, 2011a). A report by the Westminster City Council (Westminster City Council, 2013a) divides historic buildings into three categories, which are as follows:

- unlisted properties in a conservation area,
- listed properties, and
- unlisted properties outside a conservation area.

For each case, there are measures that require permissions, that are unlikely to require permission, and that are unlikely to be permitted (Retrofitting Historic Buildings for Sustainability, 2013a). On the basis of this, project managers, planners, and architects must decide independently whether any retrofit strategy needs a permit. If any alterations are not in line with legislation, permission from a heritage agency should be optioned to assess whether proposed retrofit options are acceptable.

Relevant Studies

Some studies have referred to understanding experimental approaches taken by other scientists in this field. Research by Piselloa et al. (Piselloa *et al.*, 2014) defined holistic methodologies for improving energy use in existing buildings using simulation tools for a building “pilot case study” in Italy. The aim of his study was to reduce building heating and cooling load demands by implementing specific retrofits. The study adapted an Energy Plus simulation for the new integrated building energy loads, and the plant was consisted of ground heat pumps and a water storage tank connecting underground vertical boreholes as heat exchangers. The main results indicated a total building energy saving of 50%.

Another studying was conducted by Mancinia et al. (Mancini *et al.*, 2016) to improve the thermal performance and thermal bridge of a building in Rome using a simplified dynamic simulation with thermography analysis that was reliable with an error of approximately 5% compared with real measurement data. The results of this research demonstrate that short-term interventions strongly affect current energy costs. Another important report on progress in the development of retrofitting guidelines for historical public buildings relative to energy and water efficiency was conducted by Sahin et al. (Sahin *et al.*, 2016). This study mainly presented the existing retrofit guidelines of different countries and dose not show every aspect of the building retrofit process and the risks involved in the retrofitting process.

A study by Dascalki and Santamouris (Dascalaki and Santamouris, 2002) investigated energy savings possibilities for five building types in four different climate regions for different European retrofitting strategies. The study methodology included changes to the building envelope, integration of passive heating and cooling components, and HVAC and artificial lighting systems. The results indicated that these alterations affected the performance of the buildings; however, the conclusions drawn from this study could not be generalized because of different building types and varieties of climate conditions. However, an analysis of the results revealed common trends in the energy performance of different building types and extracted information on the most suitable retrofitting interventions for each type.

A study by Ardente et al. (Ardente *et al.*, 2011) presented the results of an assessment of energy and environmental effects of a set of retrofit actions implemented in a European Union project titled Bringing Retrofit Innovation to Application in Public Buildings. The most important finding of this study is that enhancing envelope thermal insulation has a great energy savings potential. Representation of insulation materials, lighting, and glazing components provided very efficient solutions. In all case studies, introducing HVAC and lighting systems provided great energy benefits. Additionally, both solar and wind plants generally overestimated energy production at the design stage relative to monitored results, with lower energy savings and higher payback indices than what was predicted.

METHODOLOGY

Background

The banquet hall being studied has a unique architectural design, and a comprehensive approach was adopted for determining the base case's initial energy. An extensive independent inspection of the building was conducted to develop a clear overview of initial conditions and gain a clear insight into which building retrofit measures might be. Additionally, detailed architectural plans of the building were retrieved from Newcastle University. The material and thermal properties of the entire building are shown in the methodology and building description. All previously mentioned data are merged in IES–VE software to simulate the base case and assess identified retrofitting measures and packages. Building elevations and plans are shown in Appendix A.

Building Description

The banquet hall was built by Sir William (later Lord) Armstrong as an entertainment building for him and his wife and was given to the citizens of Newcastle upon Tyne in 1883. The building is in the Jesmond Dene valley, which has exotic trees and shrubs and is surrounded by a natural conservation area that forms an oasis of natural beauty in an urban setting (Figure 2). The building is set on the western bank of the Ousburn River and was designed by John Dobson to generate power from the water. In the 1870s, there were alterations, and an extension was added to the banquet hall (Newcastle City Council, 2005). The building is a listed building within a conservation area and is of architectural and historic interest The buildings are in poor condition and in need of comprehensive repair and refurbishment to ensure they do not deteriorate further.

Figure 2: Aerial view of the banquet hall site.

Modeling and Measurement

To understand an energy demand analysis on the case study and assess the potential to reduce primary energy demand and carbon emissions, a simulation program that models all building characteristics is used. The first step in this process is simulating the building's initial situation as a base case. This base case simulation represents the building envelope, and all simulations of measures and packages build up directly on the base case. The energy simulation workflow toward the base case is a 3D perspective of the historical building directly produced in IES–VE software. An orientation relative to the north axis is simulated, and shading surfaces and other geometries are replicated. The outline defining the surfaces, various constructions, and different space types (e.g., main hall and kitchens) is shown in Appendix B.

Improving building envelope thermal performance has the potential to significantly reduce energy demand (i.e., heating and cooling load). This is commonly achieved by replacing and enhancing walls, windows, and ceilings with materials with better U-values (Şahin *et al.*, 2015). Each of these retrofit areas is tested using a variety of measures to identify the most appropriate solutions for the different targets. Maintaining indoor climate at a preferably low energy demand is the main use for thermal energy. Choosing glazing type also plays an important role in the retrofitting process as more than 60% of a building's total energy loss originates from its windows. As a result, low U-value glazing products have tremendous potential to provide energy savings (Jelle *et al.*, 2012; B. P., 2007). Typical glazing products are single-layer and multilayer-glazing; vacuum glazing; electrochromic glazing; solar cell glazing; aerogels; and low-emissivity (low-e) coatings, frames, and spacers (Cuce and Riffat, 2015). Another important factor in retrofitting strategies is the use of insulation material as historic building walls, roofs, and floors are outdated and do not meet modern thermal requirements (Saio *et al.*, 2017).

Base Case Modeling

The building has been badly neglected, and the banquet hall's original structure is roofless; therefore, there have been several changes to the base case's thermal model. The model's characteristics are as follows:

1. The building's external cavity wall consists of natural stone (0.22 m) and red brick work (0.075 m) with a 40 mm cavity of rubble.
2. Banquet hall walls have tall arches for windows in which the (4 mm) glass has been assumed to be single-glazed. Additionally, the same glazing has been used for roof skylights in the reception hall and the original window in the artist hall.
3. Simple uninsulated construction was added to the banquet hall roof, which consists of a layer of timber and slate tiles. This was assumed to be the roofing construction for the whole building; however, the artist roof was left as its original construction.
4. Uninsulated cast concrete floors were assumed for the building.
5. Several no net heating transfer adjustments were added around the building for the back and left side of the base case model to give the same effects as the natural surrounding hillside.
6. The same adjustments were added under the staircase and in the upper level rooms. Appendix B further details the build-up model.

Base case room conditions are without a heating system and thus reflect building temperatures. However, people used the building, especially the artist room, for sculptures and arts purposes and can access the building 24 h a day during working days. Thus, the base conditions were modified to have a 60% occupancy profile from 8 am to 7 pm year round. With an infiltration rate of 8 ach, the building's annual temperature will be highly affected by external temperatures (Figure 3). The site plan is provided in Appendix A.

The annual temperature does not satisfy building regulations for thermal comfort of people, which has building temperatures ranging from 25 to −5 across the year.

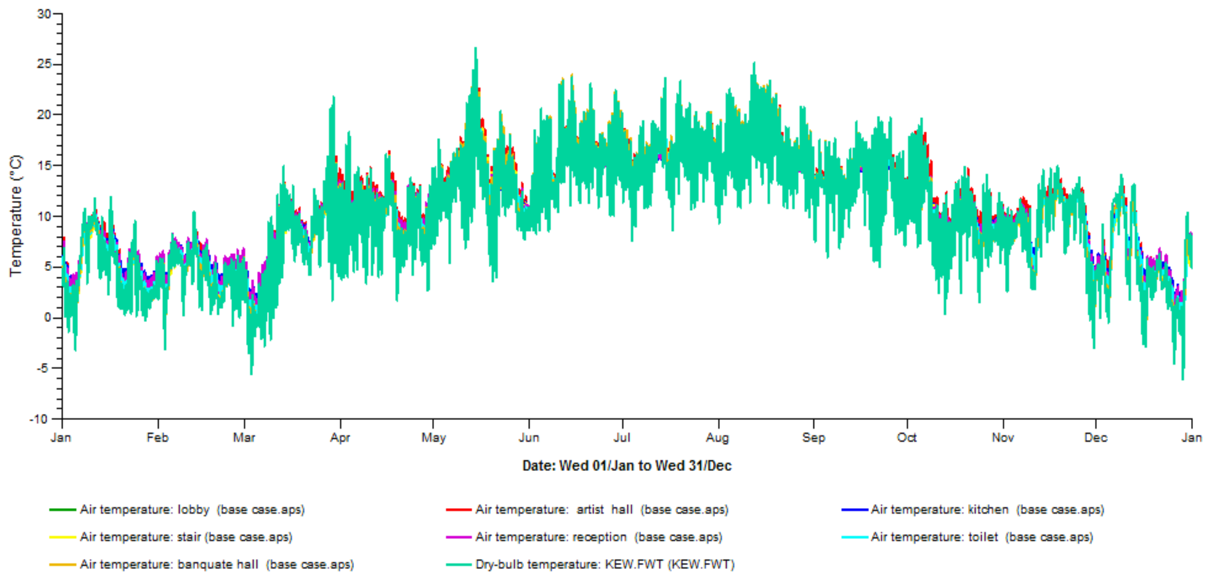


Figure 3: Annual internal air temperatures with respect to external temperatures without heating.

Building Heating and Cooling

Heating was thus introduced to the base case using a natural gas heating boiler with a 90% seasonal efficiency and 86% mean delivery efficiency. However, the heating profile operates from 8 am to 7 pm on all days, including weekends. This will affect room conditions. To achieve a degree of thermal comfort requires an annual boiler load of 616 MWh[1] with a total energy system annual requirement of 684 MWh[1].

An average temperature profile will be introduced for the banquet hall (Figure 4) and the reception hall and lobby (Figure 5).

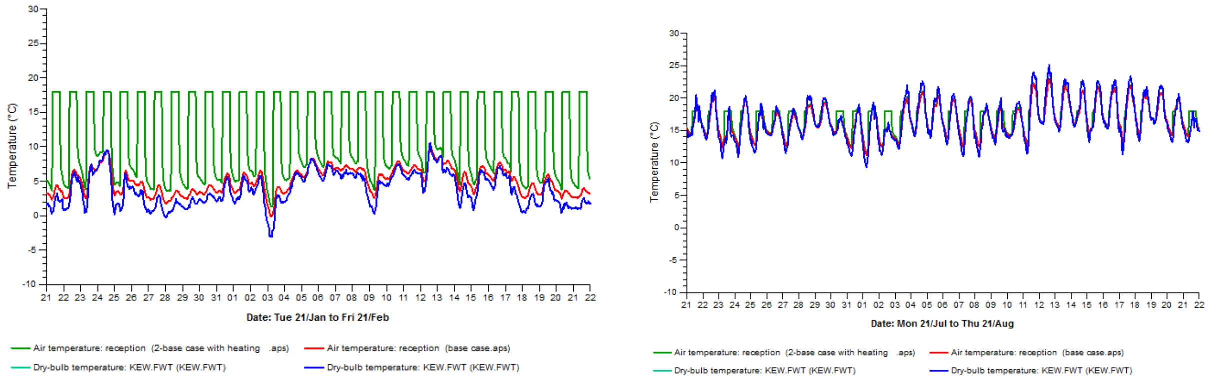


Figure 4: External and internal air temperatures during peak winter[2] and peak summer[3] for the banquet hall.

[1] -Table for heating plant loads and energy will be combined in Appendix C

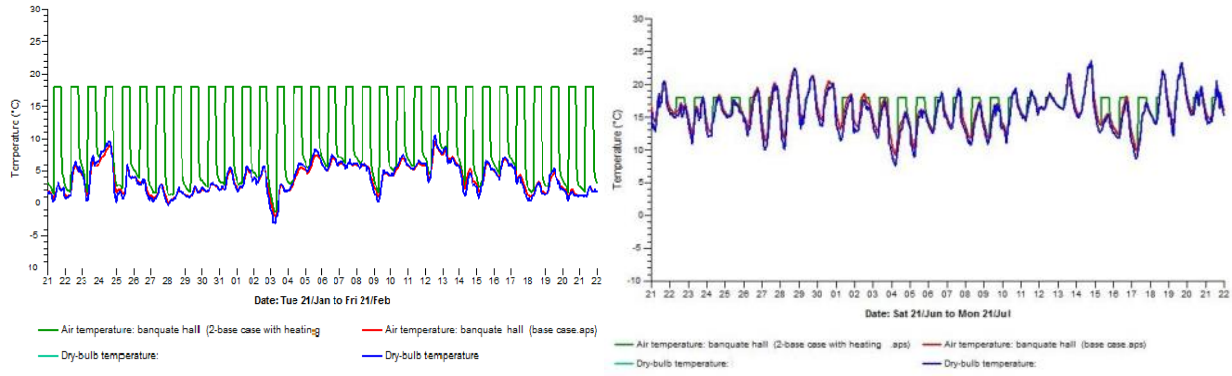


Figure 5: External and internal air temperatures during peak winter[2] and peak summer[3].

These diagrams illustrate that there are dramatic changes in internal temperatures; however, large amounts of energy are required to achieve comfortable thermal conditions. Thus, a series of improvements will be applied to the building to achieve thermal comfort while reducing energy consumption through examination and analysis of different material and building system conditions.

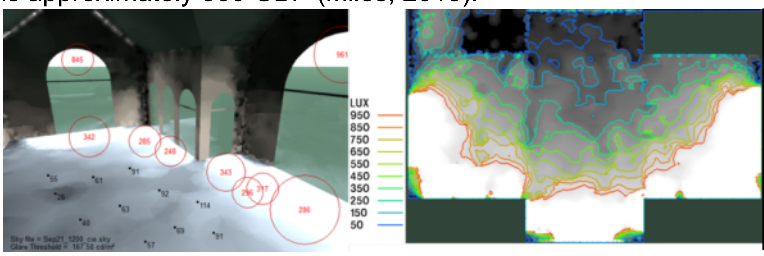
RESULTS AND DISCUSSION

Glazing

A significant amount of heat is lost through the glass and gaps in and around the frames of windows. The current windows consist of single glazing with 4 mm sheets, and glazing replacement will be introduced to external windows in the banquet hall, lobby, and artist room and in the roof skylight of the reception area, which is the only existing source of daylight for this room. Two types of glazing, double and triple glazing, will be selected. Double glazing is less competitive with respect to U-values but is widespread and economical. Similarly, triple glazing has highly advanced thermal properties but comes at a higher price (SANCO, 2014). A study by Ardente et al. (Ardente *et al.*, 2011) illustrated that by improving envelope insulation and lighting through different glazing types will achieve the most significant advantage in terms of energy consumption assessment. The cost of replacement double- or triple-glazed window is a significant investment, but if it returns a window to its original appearance, it may add value to a property (Miles, 2013).

Double Glazing

A glazing specification for double glazing has been provided (Pilkington Architectural, 2011), which consists of clear 4 mm Pilkington Optifloat glass and Pilkington Insulight glass that consists of a 4 mm Pilkington K Glass S inner pane and 16 mm 90% argon-filled cavity, and has a U-value of 1.2 W/m^2 k. Simulation results indicate no changes in thermal performance in any rooms; however, there is a significant decrease in the building's annual total system energy of 6.7%. Figure 7 illustrates the illuminance levels for double-glazed windows. The average cost for replacing 1 m^2 of double glazing is approximately 360 GBP (Miles, 2013).



[2]Peak winter is from 21 January to 21 February.

[3]Peak summer is from 21 July to 21 August.

Figure 7: Illuminance levels on 21 Sept. for the banquet hall (left). Illuminance contours on 21 Sept. (right).

Triple Glazing

To meet the required high levels of air tightness, a building would typically use triple-glazed windows rather than double-glazed windows. Figure 8 illustrates the triple glazing's effect on illuminance level. Triple glazing following Pilkington's specifications was used to obtain a U-value of 1.03 W/mk (Pilkington, 2012b). Triple glazing can reduce energy in the study sample by 8% on average, which is in line with research done by El-Darwish and Gomaa (El-Darwish, 2017). Building historical value can be significantly influenced by alterations to windows, as introducing double-glazed or triple-glazed windows can improve thermal performance and provide security and acoustic benefits (N. Miles, 2013b).

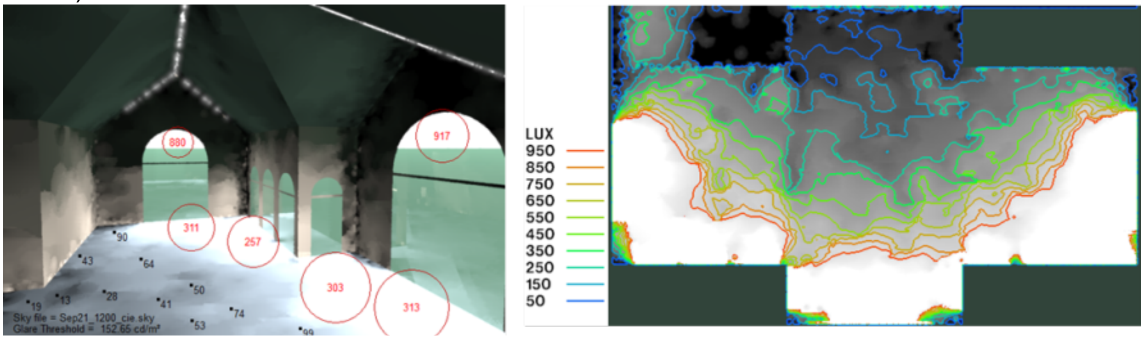


Figure 8: Illuminance levels on 21 Sept. for triple glazing in the banquet hall (left). Illuminance contours on 21 Sept. (right).

Introducing Wall Insulation

The existing wall construction consisted of a cavity wall composed of 220 mm of natural stone, 400 mm of rubble, and 75 mm of red brickwork. Figure 9 shows the building's external and internal materials. Many factors must be considered when adding insulation. A study by Pickles (Pickles, 2012) identified three main ways in which cavity walls can be insulated. The first of these is external insulation; however, as a building's external façade has its specific characteristics, the first way has been neglected as it also will be less effective, cost more, and have harmful effects on natural surroundings.

Figure 9: Picture from inside the banquet hall shows external wall details. Source: (blogspot, 2012).

The second method is adding insulation within a cavity. This method has some advantages, as it can improve thermal performance without affecting a wall's appearance or characteristics. With this method, the cavity should be clear to add insulation by (a) injecting or blowing insulation or (b) adding rigid insulation.

For this method, it has theoretically been assumed that the cavity is clear of rubble; however, injecting or blowing insulation material can have significant technical effects on the wall and also negatively impact the wall. Filling the cavity with non-rigid insulation can introduce moisture to the brick leaf regardless of the material type. Another effect for this kind of material is that it may leave unfilled air pockets that can result in “cold bridging to the inside wall, which may attract condensation” (Pickles, 2012). For this reason, method (a) is not introduced for this simulation work. Adding rigid insulation to the cavity has the advantage of cavity insulation and will adequately overcome moisture and cold bridging risks. For this simulation, two different materials were introduced for insulating within the cavity. Material selection is influenced by the most common type available in Newcastle and England overall. Although external solid wall insulation has a higher capital cost, the costs of solid wall insulation significantly vary on the basis of property type, wall area, finish, and number of installations and can be estimated as 156 GBP per m^2 unit (Miles, 2013).

The effects of two insulating methods, within cavity and interior insulation, with three insulation types were tested and compared against the baseline case (i.e., no insulation) to determine the most effective insulating method.

Kingspan Insulation

The first type of insulation tested was a double layer of Kingspan Kooltherm K8 Cavity Board insulation (Kingspan Insulation Ltd, 2018). These boards were 125 mm thick, and each had a thermal conductivity of 0.020 W/mk. This installation left a 200 mm air cavity between the board and the external leaf, which would provide several advantages. The cavity serves to separate the inner and outer wall layers, which helps prevent moisture from passing through the wall into the building, leading to dampness and structural decay.

Rockwool Insulation

The second insulation setup used two layers of Rockwool energy saver (Rockwool uk,2009b) insulation and an air cavity. The first layer was 115 mm thick and had a thermal conductivity of 0.035 W/mk. The second layer was 85 mm thick and also had a thermal conductivity of 0.035 W/mk. There was also a 200 mm air gap between the insulation and external leaf, which would provide the same benefits as mentioned previously.

Internal Insulation

The third type of insulation tested was the use of internal insulation, that is, insulation applied to the interior wall surface. This overcomes technical issues related to reconstructing the building and the need to keep the same construction. However, it also might influence the building's internal appearance, which consists of red brick with arches and decks in the wall used for placing statues as shown in Figure 9.

This method used a 100 mm thick layer of Kingspan Kooltherm K118 insulated plasterboard, and in this case, rubble would be left inside the wall cavity.

Insulation Performance Evaluations

Energy Consumption

Figure 10 shows a small reduction in annual sensible load for room with heating using two layers of Kingspan cavity insulation. However, Rockwool do not have a noticeable effect in reduction heating load and that may return to the high conductivity the material has 0.035 W/m2 k.

[4] -Full detail of material in Appendix F

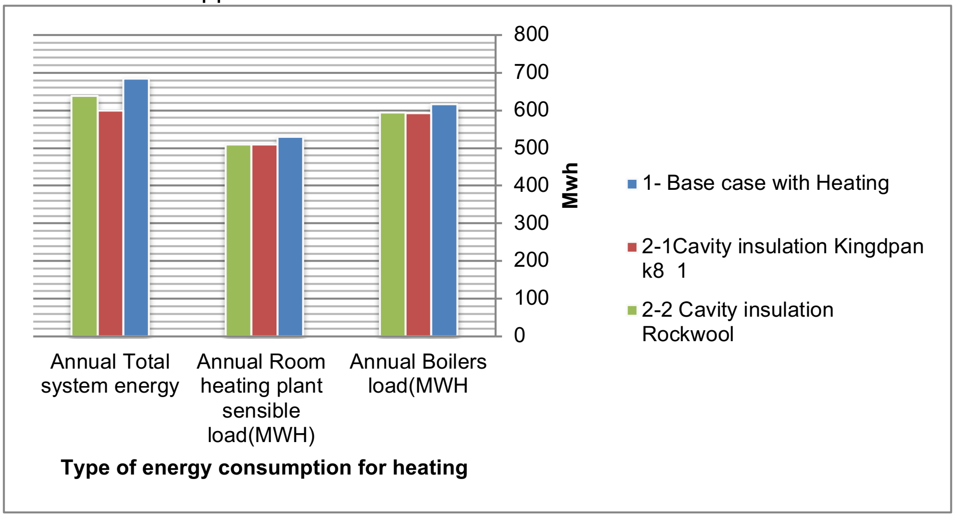


Figure 10: Annual energy consumption before and after adding cavity insulation

In contrast, internal insulation has a greater effect at reducing heating energy demand with a reduction of 450 MWh (18%) compared with the base case as shown in Figure 11.

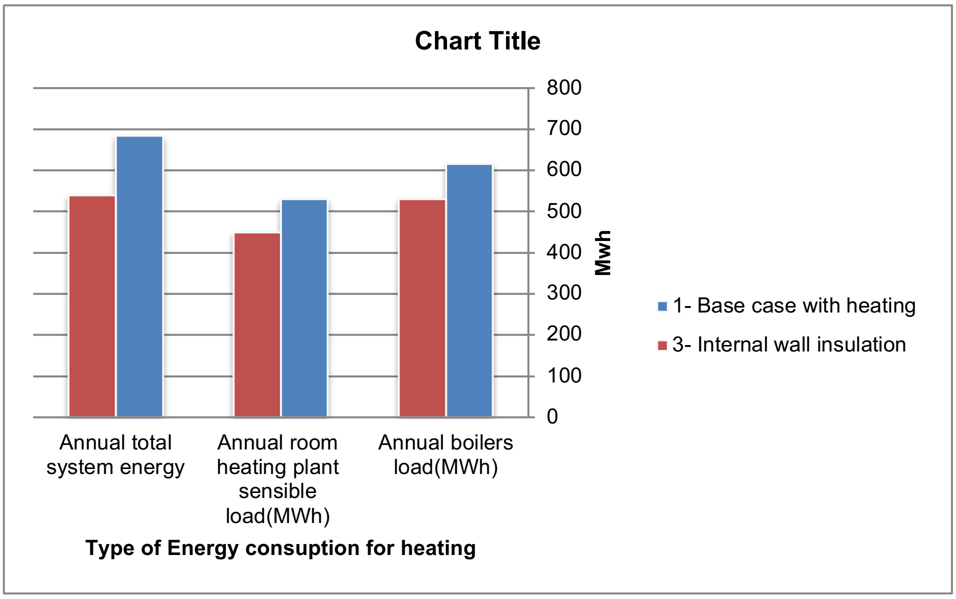


Figure 11: Annual energy consumption for internal insulation compared with the base case.

Indoor Air Temperature

As shown in Figure 12, the banquet hall's air temperature has not been changed dramatically by introducing different insulation materials. However, internal insulation can increase the annual total time with air temperatures between 18° and 25° by 3%.

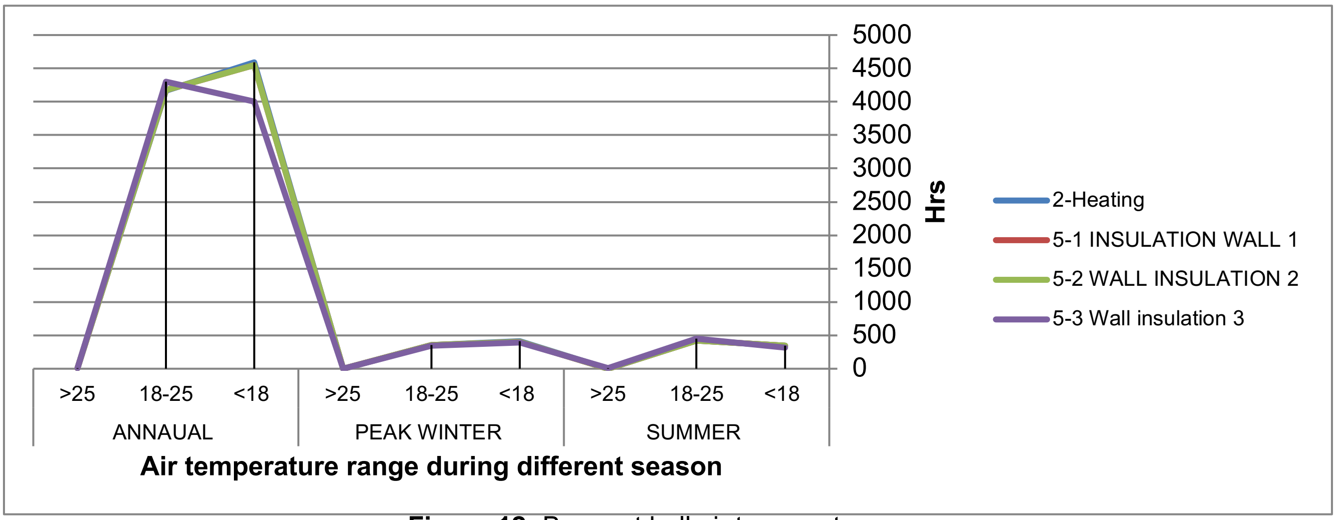


Figure 12: Banquet hall air temperatures.

This slight air temperature increase was also seen in other rooms when introducing cavity insulation. However, internal insulation increases mean radiant temperatures as shown in Figure 13.

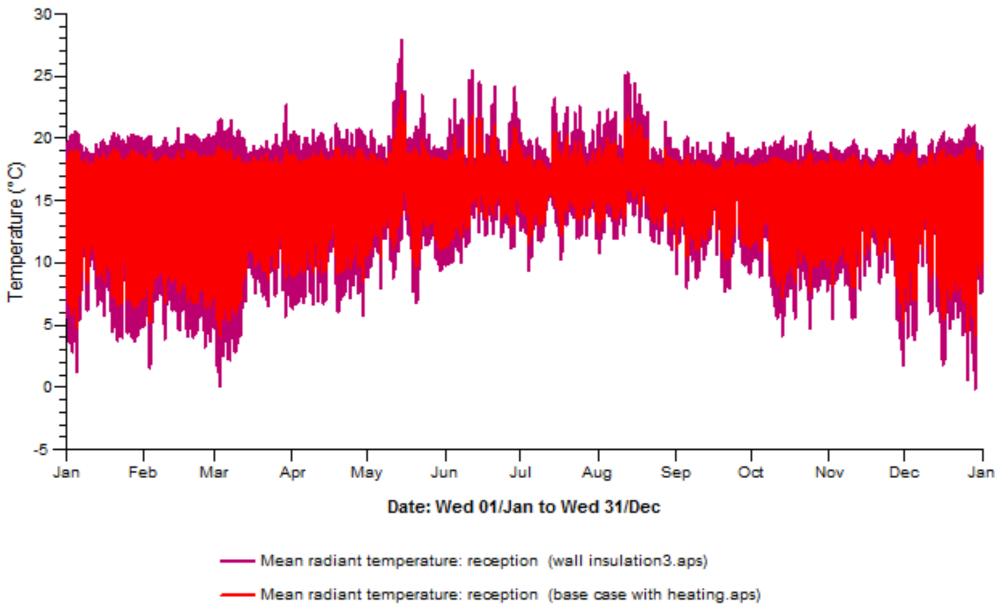


Figure 13: Annual, peak winter, and summer mean radiant temperatures for the reception area.

Changing Occupancy Level

The current predicted occupancy level is one person per 20 m^2 and changes this level to one person per 10 m^2, with an occupancy profile of 60% throughout the day at different times. Changing occupancy level in this manner increases annual internal gain to 3.5% (Figure 14). Another factor that is affected by increasing the occupancy level is the CO_2 concentration. Figure 15 indicates a CO_2 concentration doubling during the winter and summer peaks in the reception area. Increasing internal gain and CO_2 concentration due to increased occupancy may lead to higher mean radiant temperatures as cooling energy demand will be increased.

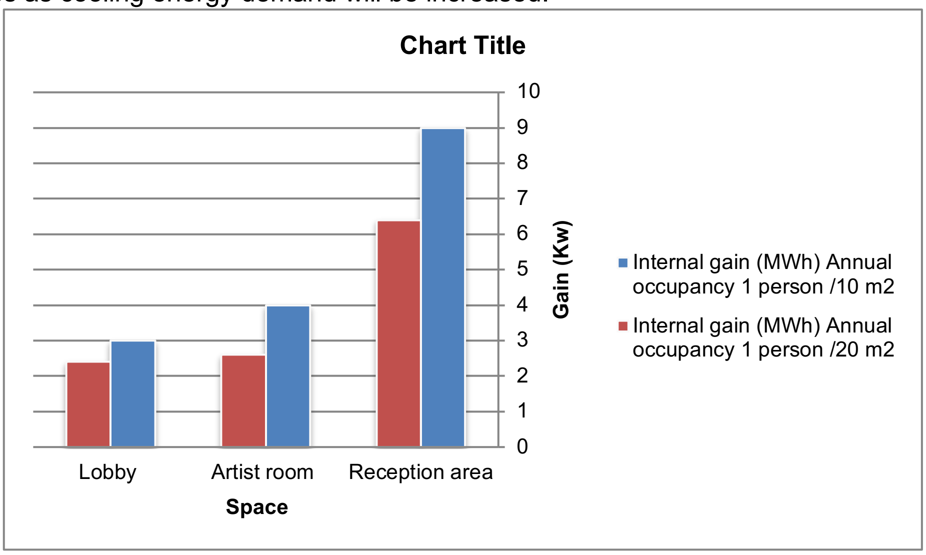


Figure 14: Annual internal gains for different occupancy levels in different spaces

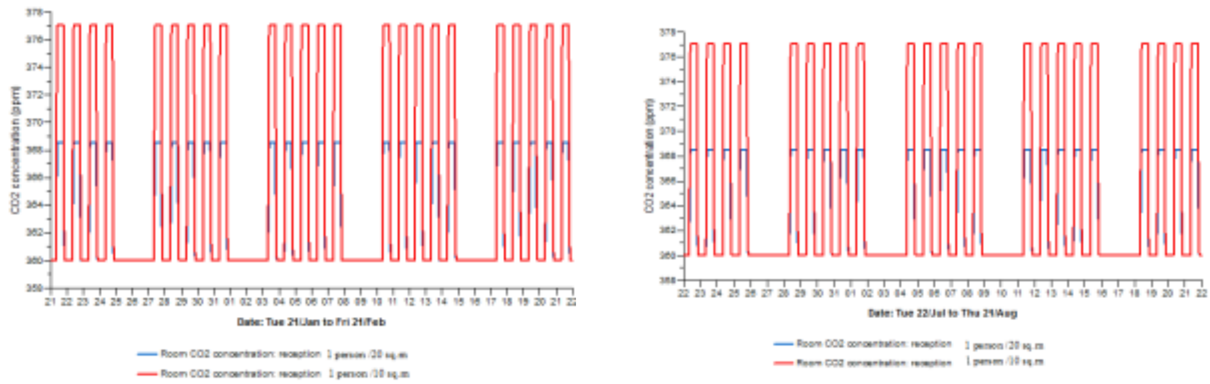


Figure 15: Peak CO_2 concentrations in the reception area for winter (left) and summer (right).

Introducing Roof Insulation

The base case roof is a warm roof with simple construction consisting of timber with a thickness of 25 mm and slate tile covering 25 mm thick. Adding insulation to the roof will need to consider historical building criteria such as roof and roofing felt performance that "reduces the risk of tiles being blown off in stormy conditions" (Heritage, 2012), and Heritage (2012, p. 17) states that there are different ways in which insulation can be introduced, with each having some positive and negative aspects (Heritage, 2012). Adding insulation under roof rafters was selected for this project. A 100 mm thick layer of Kingspan Kooltherm K7, which has a thermal conductivity of 0.02 W/mk is added and finished with a dense 12.5 mm thick layer of plaste. This was added to the whole roof of the building with the exception of the artist room as it already had insulation and the stair ceiling as IES–VE software will not permit application there. Annual boiler loads are reduced to 580 MWh, which is a 6% reduction in annual energy use. Roof insulation increases the number of hours with annual mean radiant temperatures of 18° to 25° by 3% in the reception area (Figure 16).

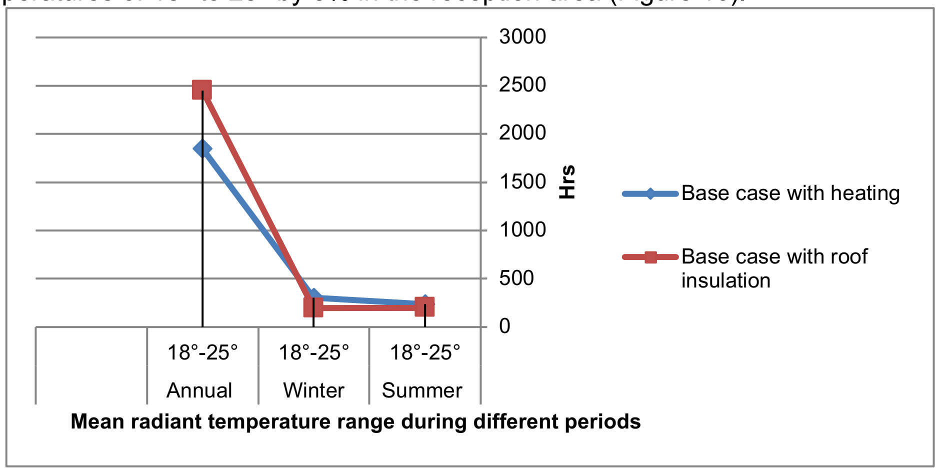


Figure 16: Annual mean radiant temperature for the reception area..

Additionally, the insulation considerably reduces the rate of dissatisfied people by 2% as shown in Figure 17.

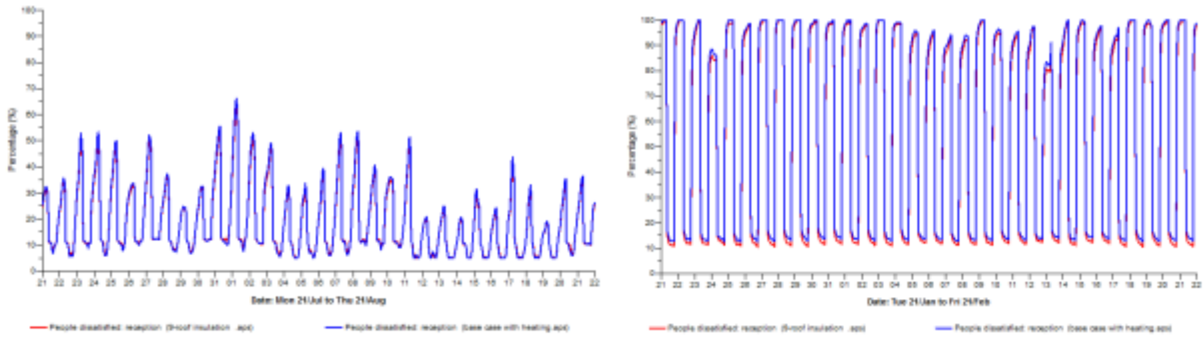


Figure 17: Peak winter and peak summer dissatisfaction levels in the banquet hall for the base case and added roof insulation.

Introducing Insulated Wooden Shutters
Wooden shutters with a thermal resistance of 0.5 W/mk were added to the external windows and sky light as internal shading devices. A profile was made for shutters to be open when the building is occupied from 8 am to 7 pm on work days and closed during the night throughout the year. That led to significant changes in solar gain, which were decreased twice as much when compared with the base case for all rooms with external windows, including the reception area.

Floor Insulation
The existing floor for the base case model is constructed of a simple layer of dense concrete (10 mm thick (Figure 18). Floor insulation is added to enhance the floor's energy efficiency and reduce the amount of heat transfer. The floor is currently badly neglected as it has been left exposed and has a notable rate of slope in the banquet hall. To improve floor heat loss and protect the floor from harmful effects of moisture and salts, two different insulation materials were added to the floor. The first insulation material consists of a layer of Kingspan K3 floorboard with a 100 mm thickness and thermal conductivity of 0.02 W/mk. This layer is then covered with a dense layer of plaster 70 mm thick. The second insulation configuration consists of a 105 mm thick Rockwool floorboard with a thermal conductivity of 0.038 W/mk on top of the existing dense concrete and topped with a 70 mm thick layer of timber flooring.

Figure 18: Photograph of the banquet hall interior shows the slope of the exposed floor. Source: (blogspot, 2012).

The effects of introducing floor insulation to the building are described in the following.

Boiler and Energy Loads
Figure 19 illustrates that installing Kingspan insulation on the floor reduces annual energy consumption to 632 MWh, which is a decrease of 8% in total loads. The second type of insulation also decreases sensible heating loads of the building by the same rate of 8%.

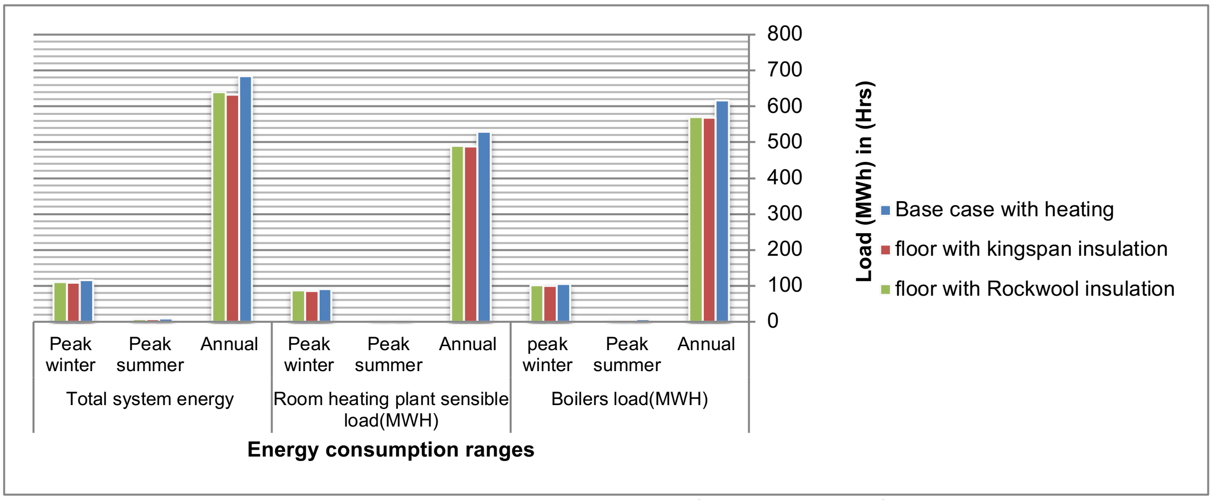


Figure 19: Annual, peak winter, and peak summer loads after introducing floor insulation.

Air and Mean Radiant Temperature

The banquet hall air temperature is reduced by 1% after providing floor insulation, which is nearly the same ratio for both selected insulation materials (Figure 20).

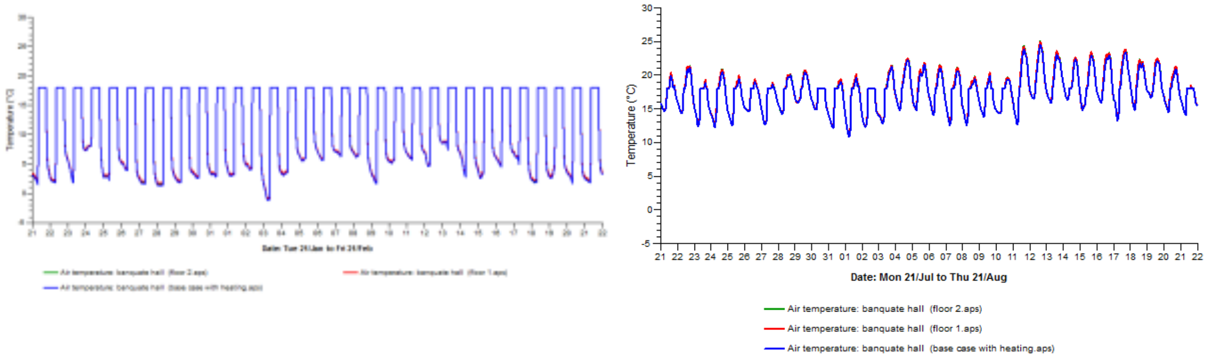


Figure 20: Peak winter and peak summer banquet hall air temperatures after introducing floor insulation

Reception Mean Radiant Temperature

Hours of mean radiant temperature between the 18° and 25° throughout-the-year increase when providing floor insulation. This minimizes heating sensible loads to 149 MWh, which is a 7% decrease. The load and mean radiant temperature changes are the same for both insulation types as shown in Figure 21.

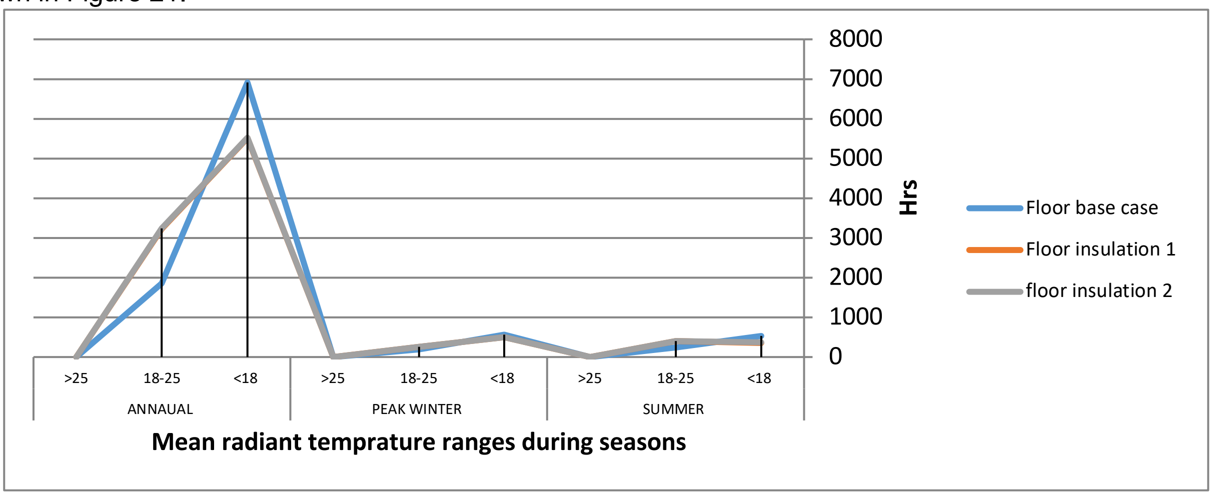


Figure 21: Mean radiant temperatures of the reception area after introducing floor insulation.

Integrating All Optimum Improvements

To enhance building performance in terms of energy consumption and thermal comfort, several improvements were applied:

1- Introduce triple glazing to the external window and sky light.
2- Adopt internal insulation for the external wall using Kingspan K18 material.
3- Maintain predicted occupancy level of 1 person per 20 m^2.
4- Introduce selected roof insulation.
5- Introduce shutters to the external windows.
6- Introduce floor insulation with a Kingspan layer.

Total Energy Performance Reduction

Table 1 shows the effects of applying all improvements to the building, which led to a 45% reduction in energy demand compared with the base case model.

Table 1: Annual energy loads before and after alterations.

	Room heating sensible load (MWh)	Boiler load (MWh)	Total system energy (MWh)
Base case	530	620	685
Building with integrated improvements	370	430	485

CONCLUSIONS

This paper demonstrated how applying specific actions for energy retrofits of existing buildings can decrease annual heating and cooling energy demand without compromising the aesthetics and architectural and historical value of a historic building. To conclude, retrofitting strategies such improved window glazing reduced energy demand in the study sample by an average 6.7% for double glazing and an average 8% for triple glazing. Wall insulation was introduced to the building using three methods and different materials. The best results were achieved using technologies that can assist with alternative solutions and test many variables to choose the strategy with the best potential to obtain energy savings through large-scale use. Internal insulation led to an 18% reduction in energy load. An annual energy demand reduction of less than 5% resulted from the use of two-layer insulation material (Kingspan), whereas Rockwool had almost no energy reduction effect. Additionally, using good insulation materials in the roof and floor led to annual energy system demand reductions of 6% and 7.5%, respectively. This study covered retrofit measures that strongly affect energy consumption through building envelope parameters. The influence of retrofit measurements on human comfort and overall energy consumption is crucial in terms of sustainable development and must be addressed through several recommendations, guidelines, and special measures. During retrofitting of historic buildings, there must be compromise between economic impact and thermal comfort and the preservation of the building's architectural and historical value, which can be achieved with the help of simulation tools, visualization methods, and measurements. The recommendations from this research can encourage the development of advanced building envelope retrofit technologies that can reduce cooling and heating energy demands. Additionally, retrofit measures can target visual comfort and other human comfort issues and can note how such interventions on a heritage building influence people's feelings and perceptions.

Bibliography

"Kingspan Insulation," Kingspan Insulation Ltd (2018) [Online]. Retrieved from https://www.kingspan.com/gb/en-gb/about-kingspan/kingspan-insulation.

" Rockwool I nsulation," ROCKWOOL (2009b) [Online]. Retrieved from https://www.rockwool.co.uk/.

"Heritage Buildings and Sustainability," Heritage Council of Victoria (2009a).

"JESMOND DENE CONSERVATION AREA CHARACTER STATEMENT," Historic Environment Section (April 2005). *Urban* Design & Conservation Group, Planning & Transportation Division, Newcastle City Council.

"Kingspan insulation," Kingspan Insulation Ltd. [Online]. Retrieved from https://www.kingspan.com/irl/en-ie/product-groups/insulation/insulation-boards/kooltherm/kooltherm-k7-pitched-roof-board. [*Accessed* 2019].

"Retrofitting Historic Buildings for Sustainability," Westminster City Council (January 2013a). *Built Environment*. City Hall: Westminster Publications.

"SANCO," SANCO-Glasbuch [Online]. Retrieved from https://www.sanco.de/en/glass-book/read-the-glass-book-online.html, *201*.

Advies, O. *Toolkit Energieduurzaamheid voor Historische bebouwing* (2011a) .

Advies, O. (2011b) *Toolkit Energieduurzaamheid voor Historische bebouwing Uitgangspunten en toelichting*.

Almeida, S.L.G.D. (2014) *Retrofitting and refurbishment processes of heritage buildings: application to three case studies*.

Ardente, F., Beccali, M., Cellura, M. and Mistretta, M. (2011). Energy and Environmental Benefits in Public Buildings as a Result of Retrofit Actions . *Renewable and Sustainable Energy Reviews.* 15(1):460-470.

Ascione, F., De Rossi, F. and Vanoli, G.P. (2011). Energy Retrofit of Historical Buildings: Theoretical and Experimental Investigations for the Modeling of Reliable Performance Scenarios. *Energy and Buildings.* 43(8):1925-1936.

Attiaa Sh., et.al., "Selection criteria for building performance simuation tools: contrasting architects' and engineers' needs," (2015). *Building Performance Simulation.* 5(3):36.

Attia, S. and De Herde, A. (*2011 ,* November). Early Design Simulation Tools, for Net Zero Energy Buildings: Buildings: A Comparison of Ten Tools *Conference proceedings of 12th international building performance simulation association*, *2011*.

B. P. (Incorporated) J. D. A. a (2007). C. K. *Arild Gustavsen*, "State-of-the-Art Highly Insulating Window Frames – Research and Market Review," SINTEF Building and Infrastructure.

Barnham, B., Heath, N. and Pearson, G., "Technical Paper 3. Energy Modelling Analysis of a Traditionally Built Scottish Tenement Flat *techniqual conservation Group*. Edinburgh: Historic Scotland (2008).

Beiter, P. and Tian, T. (2015) *Renewable energy data book*. United States Department of energy.

Berardi, U. (2015). Building Energy Consumption in US, EU, and BRIC Countries. *Procedia Engineering.* 118:128 – 136.

Best Practices on Public Building and District Retrofitting. project funded by the european community in the 7th framework programme *2013*.

blogspot (2012). Photographs of Newcastle [Online]. Retrieved from http://newcastlephotos.blogspot.co.uk.

Cuce, E. and Riffat, S.B. (January 2015). A State-Of-the-Art Review on Innovative Glazing Technologies. *Renewable and Sustainable Energy Reviews.* 41:695-714.

Dascalaki, E. and Santamouris, M. (2002). On the Potential of Retrofitting Scenarios for Offices. *Building and Environment.* 37(6):557-567.

Dixon, T. (2014). "Commercial property retrofitting : What does “retrofit” Mean, and How Can We Scale Up Action in the UK Sector? *Journal of Property Investment and Finance.* 32(4):443-452.

Einaudi, F.L. OPEF, Osservatorio sulla Politica Energetica [Online]. Retrieved from http://www.opef.it.

El-Darwish, I. Gomaa, Mohamed , " Retrofitting Strategy for Building Envelopes to Achieve Energy Efficiency,". *Alexandria Engineering Journal .*

English Heritage (2013) *English Heritage annual report & accounts*. London: TSO (The Stationery Office). The Stationery Office .

Garwood, T.L. , Hughes, B.R., Oates, M.R. , O’Connor, D. and Hughes, R. (January 2018). A Review of Energy Simulation Tools for the Manufacturing Sector. *Renewable and Sustainable Energy Reviews.* 81(1):895-911.

Grytli, E., Kværness, L., Rokseth, L.S. and Ygre, K.F. (2012). The Impact of Energy Improvement Measures on Heritage Buildings. *Journal of Architectural Conservation.* 18(3):89-106.

Heritage, E. (2012). Energy Efficiency and Historic Buildings. *Energy Efficiency and Historic Buildings: Early Cavity Walls.* 30(3).

Hong, Tianzhen, Langevin, J. and Sun, K. Building Simulation: Ten Challenges. *Building Technology and Urban Systems Division,* no. Berkeley, California 94720. USA (2018).

Ingram, V. and Jenkins, D. (2013). "*Historic Scotland Technical Paper 8: Energy Modelling of the Garden Bothy Dumfries House*." Edinburgh: Historic Scotland.

Ingram, V.J.D. (2013) *Evaluating energy modelling for traditionally constructed dwellings*. Edinburgh: Historic Scotland.

institute of education sciences (2018). Integrated Environmental Solutions Virtual Environment (IES VE) [Online]. Retrieved from https://www.iesve.com .

Jelle, B.P., Hynd, A., Gustavsen, A., Arasteh, D., Goudey, H. and Hart, R. (2012). Fenestration of Today and Tomorrow: A State-Of-the-Art Review and Future Research Opportunities. *Solar Energy Materials and Solar Cells.* 96:1-28.

K. I,[" 1 May 2007]. *Ltd*, "Kingspan Insulation [Online]. Retrieved from http://www.kingspaninsulation.com/.

Kok, N., Miller, N.G. and Morris, P. (2012). The Economics of Green Retrofits. *Journal of Sustainable REAL Estate.* 4(1):4-22.

Lucchi, E. (2011) *"Energy Efficiency in Historic Buildings: a Tool for Analysing the Compatibility, Integration and Reversibility of Renewable Energy Technologies," low-energy architecture (LEA):*9.

M. S., "Analysing the potential of retrofitting ultra-low heat loss triple vacuum glazed windows to an existing UK solid wall dwelling," nternational Journal of Renewable Energy Development, [S.l.] (October 2014)*, 3*, no. ISSN 2252-4940:(161-174)..

Ma, Z., Cooper, P., Daly, D. and Ledo, L. (2012). Existing Building Retrofits : Mthodology and State -Of -The- Art. *Engry and Building.* 55(12), no. 889-902:27.

Mancini, F., Cecconi, M. , De Sanctis, F. and Beltotto, A. (2016). Energy Retrofit of a Historic Building Using Simplified Dynamic Energy Modeling. *Energy Procedia.* 101:1119 – 1126.

May, N.G.N. (2015) *Planning responsible retrofit of traditional buildings StBA, UK: Sustainable Traditional Buildings Alliance*.

Mcnally, Y. (2014) "*An investigation into energy saving via retrofit compared to replacement housing*.," [*Thesis*] *(Ph.D.). Ulster University*..

Menconi, M.,Painting, N. and Piroozfar, P. (December 2016). Responsive Retrofit Measures for Traditional Listed Dwellings: an Investigation into a Mixed Methods Approach, in *5th international conference on zero Energy Mass Customised Housing.* Kuala Lumpur, Malaysia: *ZEMCH*.

Miles, N. (January 2013). "Retrofitting Historic Buildings for Sustainability (Retrofitting Guide)," Westminster City Council. *Built Environment, London*.

Örn, T. (2018) *Energy efficiency in heritage buildings, conservation approaches and their impact on energy efficiency measures*. Edinburgh: Luleå University of Technology. Historic Scotland.

Performance and energy efficiency of traditional building , Gap analysis study (2012a). london: English Heritage.

Pickles, D. (march 2012). ENERGY EFFICIENCY and HISTORIC BUILDINGS: Insulating Early Cavity Walls. *Historic England, London*.

Pilkington Architectural (2011b) [Online]. Retrieved from http://www.pilkington.co.uk/planar. Pilkington Press.

Pilkington, "Pilkington Architectural," Pilkington (1 August 2012b) [Online]. Retrieved from www.pilkington.co.uk/planar.

Pilkington, "Pilkington Architectural," Pilkington Building Products - UK, First October 2011 [Online]. Retrieved from http://www.pilkington.co.uk/planar.

Pilzer, B. *Retrofitting of historical buildings for carbon emission reduction: A case study in Utrecht, the Netherlands Faculty of Geosciences Theses* (2016).

Piselloa, A.L., Petrozzia, A. and Castaldoa, V.L. (2014). Franco, "Energy Refurbishment of Historical Buildings with Public Function: Pilot Case Study,". *Energy Procedia.* 61:60-663.

Reeves, T. and Olbina, S. (2012). Validation of Building Energy Modeling Tools: ECOTECT™, Green Building STUDIO™ and IES<VE>™. *Proceedings of the Winter Simulation Conference:*12.

Retrofitting Historic Buildings for Sustainability (January 2013b). *Built Environment*. Westminster City Council.

ROCKWOOL (April 2009). Rockwool I Nsulation [Online]. Retrieved from http://www.rockwool.ie/.

Attia, S., & De Herde, A.*"Early design simulation tools for net zero energy buildings: A comparison of ten tools,"* (2011a).

Şahin, C.D., Arsan, Z.D., Tunçoku, S.S., Broström, T. and Akkurt, G.G. (2015). A Transdisciplinary Approach on the Energy Efficient Retrofitting of a Historic Building in the Aegean Region of Turkey. *Energy and Buildings.* 96:128–139.

Sahin, Dr O., Bertone, Dr E. and Morshed Alam, Dr M.D. (May 2016). "Retrofitting Public Buildings for Energy and Water Efficiency: Part 2 Retrofitting Guidelines," Sustaianble. *Built Environment*. Queensland: National research centre.

Saio, C., Nocentini, K., Tagliafico, L.A., Biwole, P.H. and Achard, P. (2017). Application of Advanced Insulating Materials in Historical Buildings, in., *International Journal of Heat and Technology 2nd AIGE/IIETA international conference and 11th AIGE 2017 Conference on "Energy Conversion, Management, Recovery, Saving, Storage and Renewable Systems", Genoa (Italy)*. 35(Special Issue1):S345–S352.

Syngellakis, S. (2013) *Retrofitting of Heritage Structures, Design and evaluation of strengthening techniques*. UK: Wessex Institute of Technology.

Tianzhen Hong, J.L.K.S. (2018). Building Simulation: Ten Challenges. *Building Simulation.* 11(1, March) .

Winter in the Dene (2012c) *Available: graph paper press* [Online]. . [*Accessed* (22 january 2013c).

Works, C. (2008) *Energy Heritage: A guide to improving energy efficiency in traditional and historic homes*. UK.