



Investigating Net Zero in UK Commercial Buildings: Its Impact on Climate Change and Cost Management

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Abstract. This research identifies the optimal combination of insulation and glazing materials for commercial buildings to achieve the United Kingdom's (UK) net-zero 2050 target in terms of energy savings and cost-effectiveness. Twelve insulation and glazing materials are critically evaluated using the Analytic Hierarchy Process and assigned a score based on the data. The top-ranked materials are applied to a building model in EDSL TAS software for simulation. The average U-values, energy consumption, total emissions, and energy performance asset ratings of the four specific conditions in eight selected locations of the UK are analysed and compared. Results show that Glasgow has the highest value in every parameter, while Plymouth has the lowest, indicating regional weather variations. It is also observed that the lowest average U-value comes from vacuum-insulated panels (VIP), which is 0.18, and for glazing, it is 0.56, obtained from triple glazing with lower solar gain (TG LSG). Both results meet the standard set by Building Regulations 2010. The combination of VIP and TG LSG gives the U-value of 0.09 indicating improved thermal insulation. It also reduces energy consumption by 40.98% and total emission by 26.45% compared to the worst combination. This set is 42.26% more expensive than the baseline; nevertheless, it offers annual energy savings of 49.16% per m². The average yearly saving is £6,082.50, and the payback period is 35 years under current conditions. Net present value of this combination is £-66,750.50, which can be improved if the unit price of materials decreases through mass production, along with government incentives and subsidies. From a carbon-saving perspective, this combination reduces, on average, 20.07 tCO₂eq of operational carbon footprint, exceeding the baseline by 31.90%, and saves £839.90 in potential carbon penalties annually, promoting long-term resilience and economic feasibility. The study's findings offer valuable insight to policymakers to pursue sustainable envelope design.

Keywords: climate change, building regulations, insulation, glazing, U-Value, EDSL TAS, energy performance, cost management, sustainability, policy.

1. Introduction

Research Background

One of the foremost challenges in the built environment is the energy performance of the new and existing UK constructions, and the corresponding unfavourable impacts on global warming (Kayleigh *et al.*, 2018). The government has set the Net Zero Strategy in 2021 to fight the potential consequences from climate change. It is to be noted that the UK experienced two of the hottest years on record in 2022 and 2023, with heatwaves, droughts, wildfires, and floods severely affecting many local people (Ministry of Justice Climate Change and Sustainability Strategy, 2024). The need of an improved building element is greater than ever before. Mansoor Kazerouni (2023) pointed out five critical elements that ensure the desired sustainability goals and tackle climate change, which are site selection, control over construction method, design and development of high-performing building envelope, such as glazing and insulation, employment of passive design principles, and lastly a clean energy high-performance HVAC (heating, ventilation, air conditioning) system. This research focuses solely on building envelope to ensure energy efficiency. These elements require more attention to achieve net zero target set by the government (Cohen *et al.*, 2021 and Charisi, 2017)

The choice of insulation and glazing plays a vital role in terms of energy saving and promote resilience. Ali, Issa, and Elshaer (2024), outlined the classification of various insulating material along with advantages and drawbacks. The choice of insulation depends on multiple factors, including demand, cost, demographic context, population density, weather data, and the availability of the material. Keeping environmental protection and sustainability in mind, preference is given to those materials that minimize carbon footprint, while also being cost-effective. On the other hand, Michael *et al.* (2023) gave a detailed classification of established glazing technologies as well as emerging innovations. The choice of glazing depends on numerous factors such as daylight availability and requirement, local weather patterns, building function and demand from the occupants, obligation to maintain privacy, and lastly, availability, life cycle, and maintenance cost. This paper highlights both insulation and glazing as best combination can result in significant difference in reduction of operational carbon. There are many authors who found suitable insulation or glazing materials in general. However, they did not address both the materials together within one framework. Additionally, while selecting the best combination, it is equally important to consider the cost for long term benefits

and ensuring sustainability. This paper understands these issues and thus focuses on both the performance as well as related cost of insulation and glazing materials. It also validates the justification of the cost and contributes on environment resilience through the analysis of embodied and operational carbon in the long term.

Research gap in evaluating both the performance and the cost of materials

Many articles and journals give a comprehensive overview and the evaluation of building materials, as well as recent trends for energy conservation in buildings. Ali, Issa, and Elshaer (2024) gave a thorough description focusing on various thermal insulation materials, their applications, pros and cons, etc, for enhancing energy efficiency in buildings; however, they did not conduct a comparative assessment. Kumar *et al.* (2020) focused on comparative analysis of material properties (thermal, hygroscopic, acoustic, reaction to fire, environmental, and cost) and the optimization criteria for selecting the best materials (energy, environment, economic, and comfort). But it also does not conclude which insulating materials are the best in terms of performance and cost.

A similar limitation is discovered for the glazing system as well. Michael *et al.* (2023) provided a meticulous review of established and emerging glazing materials based on previous publications as well as the thermal and optical properties, together with opportunities and limitations, but there was no mention of the best glazing materials. Moghaddam *et al.* (2023) wrote an article where four critical perspectives (EThCE: Energy performance, Thermal comfort, cost-effectiveness, and lastly environmental impact) were considered and mentioned that general recommendations for the selection of glazing materials may not be practical due to many factors. While the paper noted it correctly, it did not consider those things to identify the recommended materials in terms of performance and cost. Moreover, no article discusses both the performance and price of insulating materials and glazing materials together. This paper addresses this requirement, making an all-inclusive discussion for a building that may help to identify key elements for a sustainable net-zero structure.

CIBSE TRY weather data and The Building Regulations 2010

This research paper uses the CIBSE Test Reference Year (TRY) weather file to specify the multiple locations of the UK. TRYs are created by compiling a yearly weather dataset, discarding the extremely high or low air temperatures to arrive at the most average months and standard climate patterns, and to calculate the average energy demand or annual energy assessments in building calculations (EDSLUK weather data guide, 2021 and Amoako-Attah and Jahromi, 2016).

This paper aimed at the UK commercial buildings and thus follows the UK Building Regulations 2010, approved document Part L: Conservation of fuel and power, Volume 2: 2021 edition. Section 4: Limiting heat gains and losses is the primary focus, as the objective is to assess the thermal transmittance and reduce it by adding insulation and glazing components.

2. Methodology

Research Methods

In this investigation, the best materials from broader categories of insulation and glazing components are critically appraised by following the analytic hierarchy process (AHP) and weighted sum model (WSM). A range of parameters is used to find the top five materials from each unit. The materials are specified in a 3D model of a building, assumed to be an office building based on the construction type and floor area. The CIBSE weather data is used for individual conditions. The simulation is done in four conditions-baseline, assigning only insulation or glazing, and lastly a combination of both insulation and glazing materials. The results are obtained by using the above states and analyzed further to find out the best set of the external envelope.

Selection of locations and materials

This research aims to be representative of every location in the UK. For this purpose, the chosen locations are Newcastle upon Tyne, Manchester, Birmingham, London, Plymouth, Cardiff, Glasgow and Belfast, which have distinct weather patterns.

To understand which materials are the most suitable options, various parameters are checked. For example- to critically assess the insulated material, thermal conductivity, resistance, bulk density, fire resistance etc. are evaluated (H is for Home Harbinger, 2025, Grazieschi, Asdrubali, and Thomas, 2021, Villasmil, Fischer, and Worlitschek, 2019). On the other hand, for glazing parameters, data like U-value, solar heat gain coefficient, visible transmittance, emissivity etc. are considered (Emissivity, 2025, para 1, Guardian Glass, 2025, Window insulation', 2025, para 3, Li and Wu, 2022, Santana *et al.* 2019, Cuce and Riffat, 2015). Additionally, from the sustainability perspective, the embodied carbon and unit cost is taken into consideration for both building envelopes. All the data is given a score based on the performance and efficiency (Budak *et al.* 2019). Table 1 provides the criteria that are examined for scoring, and the weightage is also provided. It is to be noted that higher weighting of certain criteria is given based on previous literature, importance and lastly judgement based on the objective of the study.

Table 1: Criteria selection and their weightage for the selection of best insulation and glazing material

Insulation Material		Glazing material	
Criteria	Weighting Percentage (%)	Criteria	Weighting Percentage (%)
Thermal Conductivity	20	U-value	25
Thermal Resistance	18		
Embodied Carbon	18	Solar Heat Gain Coefficient	20
Cost	15		
Fire Resistance	12	Visible Transmittance	18
Durability	6	Embodied Carbon	15
Specific Heat	5	Cost	12
Bulk Density	4	Window frame	6
Vapor Diffusion Factor	2	Emissivity	4
Total	100	Total	100

This scoring helps to identify the better materials when it is multiplied with the criteria weightage, and total score is obtained. Figures 1 and 2 show the material score according to the criteria and weightage. The score is given based on the performance. Figure 1 shows that VIP has the highest score from insulation material and Figure 2 identifies that electrochromic glazing has the highest score from glazing materials. It is also shown that the top material matches with the findings of previous literature. (Zukowski,2025, Rashidzadeh and Matin,2023 Lu and Memari, 2019, Schiavoni *et al.*,2016)

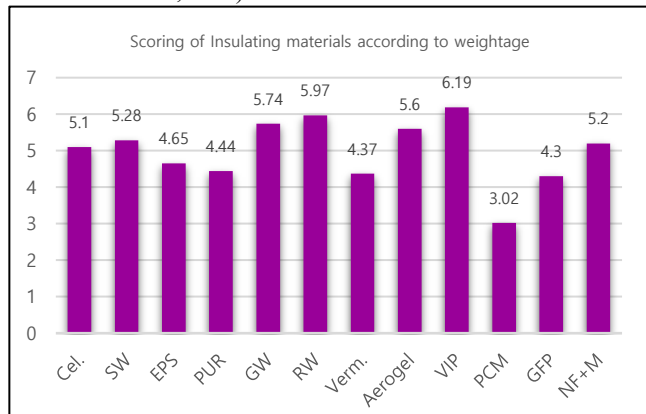


Figure 1: Insulating materials according to weightage. Here, Cel. =Cellulose SW=Sheep Wool, EPS=Expanded polystyrene, PUR= Polyurethane, GW=Glass Wool, RW=Rock Wool, Verm. =Vermiculite, VIP =Vacuum Insulation Panel, PCM= Phase Changing Material, GFP=Gas Filled Panel, NF+M=Natural Fiber Reinforced Mycelium Composite

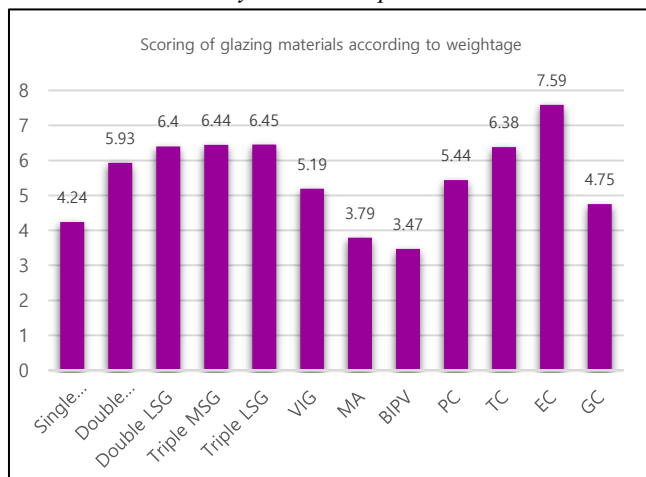


Figure 2: Glazing materials according to weightage. Here, MSG=moderate solar gain, LSG=lower solar gain, VIG=Vacuum Insulated Glazing, MA=Monolithic Aerogel, BIPV=Building Integrated Photovoltaic, PC= Photochromic, TC= Thermochromic, EC= Electrochromic, GC= Gasochromic

EDSL TAS software

Thermal analysis software TAS is used as a dynamic virtual experiment to model and represent the thermal properties of the building. The software version 9.5.6 was pioneered by Environmental Design Solutions Limited, also known as EDSL, in 2023. This component-based plant modelling tool

has full accreditation for energy performance certificate (EPC) and the UK building regulations Part L 2021 and is approved by the Department of Communities and Local Government (DCLG). TAS offers a comprehensive solution by creating 3D geometry, performing daylight and climate-based modelling, simulation, and generating various reports for understanding multiple scenarios, such as optimizing the built environment, energy performance, energy consumption due to heating, etc. (Amoako-Attah and Jahromi,2016).

Figure 3 represents a commercial building which is a multi-storied structure with a floor area of about 6330 m². The building has windows on each floor, allowing enough sunlight and reducing electricity. It is assumed that the model building represents a standard commercial building with real world functional layout. It is presumed that internal conditions are applicable every day. For internal condition, A345 version 6.1.b is used, which is designated in each zone. The layout is drawn in AutoCAD, and the DWG file is exported to the TAS 3D Modeler. Once the internal condition and zone assignment are complete, the weather and material allocation are provided for each location. The baseline uses only weather data while the three conditions use materials according to conditions.

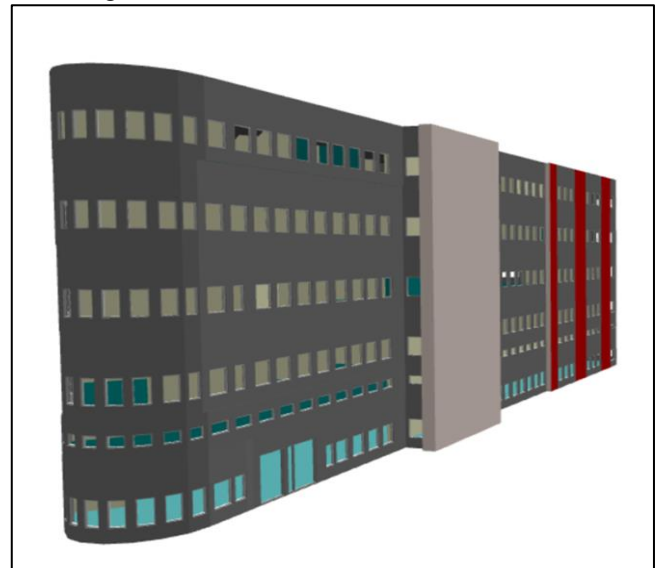


Figure 3: 3D view of the model building in TAS

Thermal simulation for baseline, only insulation or glazing and combination

The first simulation is done using the baseline, meaning there is no consideration of glazing and insulating material. However, in the original TBD (TAS building data) file, glazing and insulation are given by default, the insulation in external wall is mineral wool quilt, and the glazing is double glazing in baseline condition. In the baseline, only the weather TRY data is changed for various locations, checking the internal condition and zone.

In the beginning, the internal condition, zone, and TRY weather data are given in the TBD file. When the top 5 insulating materials are fixed from the critical appraisal (VIP, Rockwool, Glass wool, Sheep wool, Aerogel), they are assigned in the TBD file for the advancement of simulation. In the NCM Opaque materials under the construction database, there are many insulation materials ready for use.

If the material is not available, the insulation material is to be created by clicking on a new opaque material and specifying conductivity, specific heat density, vapor diffusion factor, and thickness.

After applying the new materials, it is assigned in the individual TBD file, replacing the previous insulating material. Here, the total simulation for only insulation will be 40. (5 insulation materials in 8 locations).

While keeping the zone, internal condition, and TRY weather checked, like insulating material, the glazing materials are applied. Glazing consists of two things: frames and panes. To assign a window frame in the TAS model, the NCM frame materials section is used, where the type of window frame, its conductivity, and the thickness are assigned. The top 5 best glazing materials (Electrochromic glazing, Triple glazing lower solar gain, Triple glazing moderate solar gain, Double glazing lower solar gain, and Thermochromic glazing) that were obtained from the critical appraisal of glazing material selection are assigned. The thickness of glass is aligned with the SHGC value. The materials are specified by delegating glass and gas from the NCM transparent material. In terms of assigning gas, Argon gas is selected for its abundant, cost-effective, and non-toxic nature. The total simulation is 48 considering electrochromic glazing as both double-glazing unit (DGU) and triple glazing unit (TGU). (6 glazing materials in 8 locations).

UK building regulation studio process for result generation

Only insulation or glazing material does not give a proper result, as it only shows one outcome. To avoid the problem of over simulation, the top best performing four insulating materials along with five glazing materials are considered in eight locations and total simulation is 160. Figure 4 shows the flowchart of the methodology from 3D modelling to thermal simulation and finally result generation from BRUKL (Building Regulations UK Part L) report production.

When the TBD file is updated with newly assigned materials, the 3D file is generated to merge with the new TBD file, and the shading calculation option is enabled for sunlight control. In the TAS manager building regulations Studio 2021, a new ttpl file (file extension for TAS) is clicked to add the newly delegated TBD file. In this simulation, a new HVAC system is used, where it is modelled as central heating using water, radiators, and ventilation is incorporated as a natural air configuration, and DHW (daily hot water) demand is stipulated by the supply of natural gas.

EDSL TAS generates two reports. From the reports, the below parameters or results are taken for further analysis and discussion.

- Average U-values [$W/(m^2 \cdot K)$] from building global parameters
- Energy consumption by end user due to heating
- Total emission from Energy and CO₂ summary and
- Energy performance asset rating.

The values of the above parameters for different conditions in various locations are further analysed to identify the best combinations of sustainable insulation and glazing materials as building envelope.

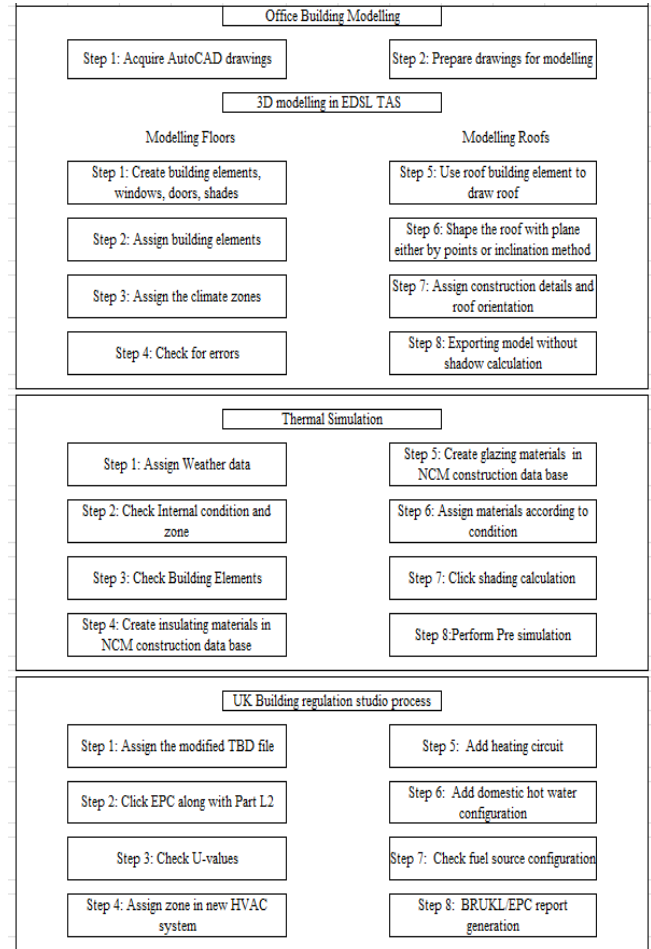


Figure 4: Flow chart of the research methodology

3. Results Analysis and Discussion

This paper focuses on the result of the combination as the aim is to identify the suitable pair of insulating and glazing materials rather than single parameter in terms of thermal performance and return on investment.

Simulation result of the combination of glazing and insulation

Average U-values

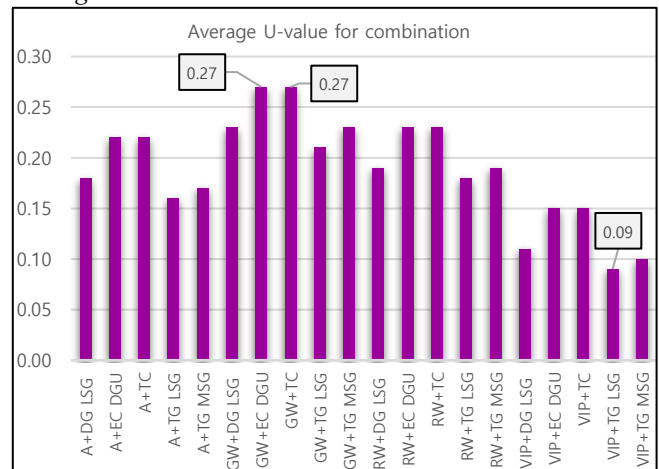


Figure 5: Average U-value for combination. Here A=aerogel, DG=double glazing, TG=triple glazing

Figure 5 portrays the average U-values for the various combination. The highest U-value is 0.27, which comes from the combination of GW and EC DGU and GW and TC. The value decreases up to 66.67% when VIP and TG LSG is used, carrying the lowest U value of 0.09.

Energy Consumption

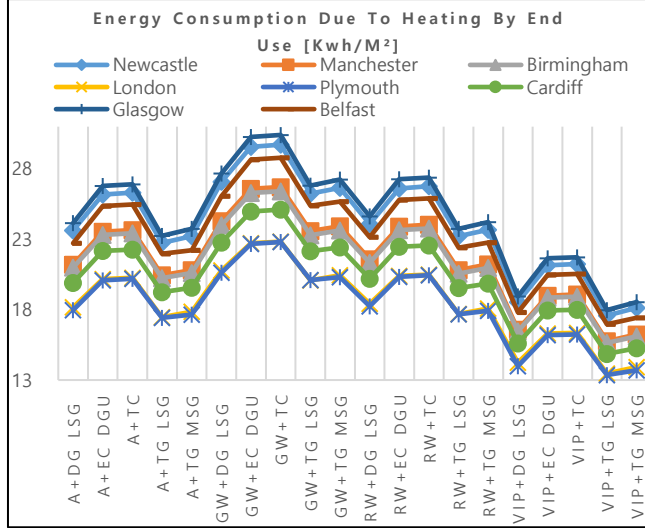


Figure 6: Linear graph of energy consumption (heating) by end use, considering the combination

Figure 6 depicts the energy consumption in different combination for the selected eight locations which is expressed as kWh/m². It also identifies that Glasgow shows the highest energy consumption in every combination due to the location and weather conditions. London and Plymouth show almost the same fluctuations in every combination, and so do Manchester and Birmingham (Snugg, 2023). It is observed that if a construction firm changes the combination from GW and TC to VIP and TG LSG, the average reduction of energy consumption by end use due to heating will be approximately 41%.

Total Emissions

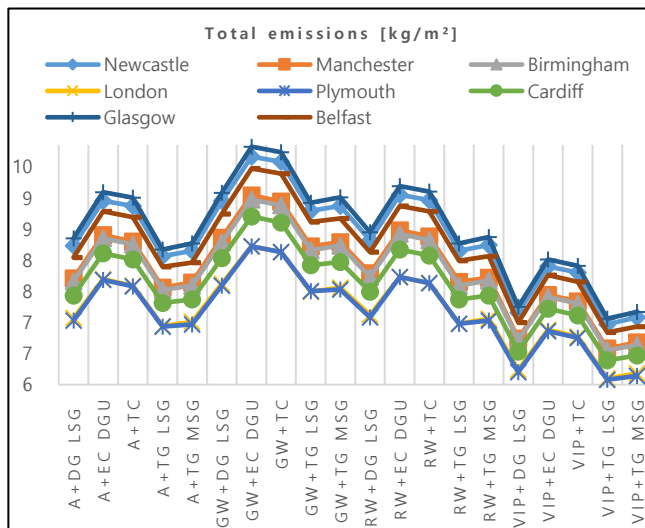


Figure 7: Linear graph of total emissions, considering the combination.

Figure 7 illustrates the total emission for using the various combinations which is expressed as kg per square meter. It is shown that the total emissions of Birmingham and Manchester is almost same. London and Plymouth also have the same; London being the lowest emitter (Exploring Regional Weather Disparities: North vs. South in the UK, 2024). As usual, Glasgow emits the most CO₂ per square meter for the location and weather patterns. Results show that if a contractor changes the combination from GW and EC DGU to VIP and TG LSG, the average reduction of CO₂ emission will be 26.45%.

Energy Performance Asset Rating

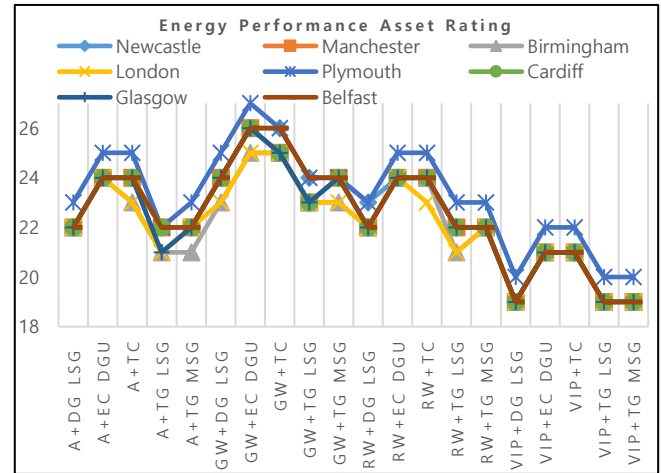


Figure 8: Linear graph of energy performance asset rating for the combination

Figure 8 is a representative illustration of energy performance certificate (EPC). It is clearly outlined that Plymouth gives a slightly higher value for each pair than the rest of the locations, and for every set of configurations, while the asset rating values are almost the same in the other places. The lowest value occurs with the pairing of VIP and DG LSG, VIP and TG LSG, and VIP and TG MSG. Table 2 summarizes the complete analysis of U-values, energy consumption and CO₂ emission along with the best material and improvement of performance.

Table 2: Comparative analysis for different parameters for the only insulation, only glazing and the combination

Parameters checked	Type of simulation	Worst Material	Best Material	Average decrease for switching (%)
U-value	Only insulation	Sheep Wool	VIP	45.45
	Only glazing	EC(DGU), TC	TG LSG	20.00
	Combination	GW and EC(DGU), GW and TC	VIP and TG LSG	66.67
Energy Consumption	Only insulation	Sheep Wool	VIP	30.20
	Only glazing	EC DGU	TG LSG	11.55
	Combination	GW and TC	VIP and TG LSG	40.98
Total Emission	Only insulation	Sheep Wool	VIP	19.60
	Only glazing	EC TGU	TG LSG	9.10
	Combination	GW and EC DGU	VIP and TG LSG	26.45

Embodied Carbon

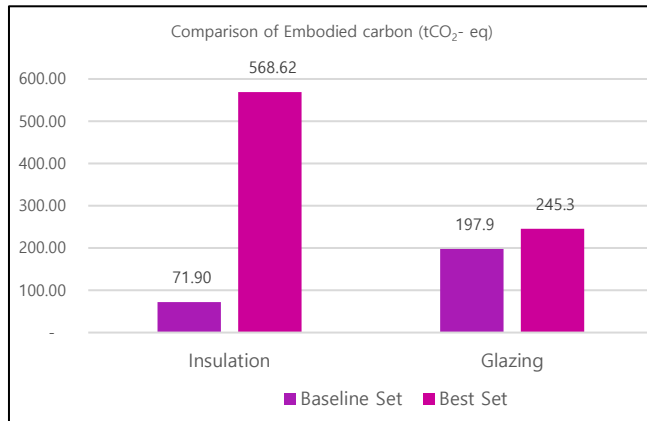


Figure 9: Comparison of Embodied carbon between baseline and best combination

Figure 9 in the above shows a comparative illustration of embodied carbon of insulation and glazing in baseline and the best condition. The embodied carbon is associated with the production, transportation and manufacturing of a material. It is seen that the total embodied carbon is 544.05-ton CO₂-eq higher in the best pair than in the baseline. It is because VIP is an advanced material compared to rock wool. Again, triple glazing has an extra coating and layer of glass that emits more carbon than the double-glazing material; thus, the result is logical.

Cost-Benefit Analysis

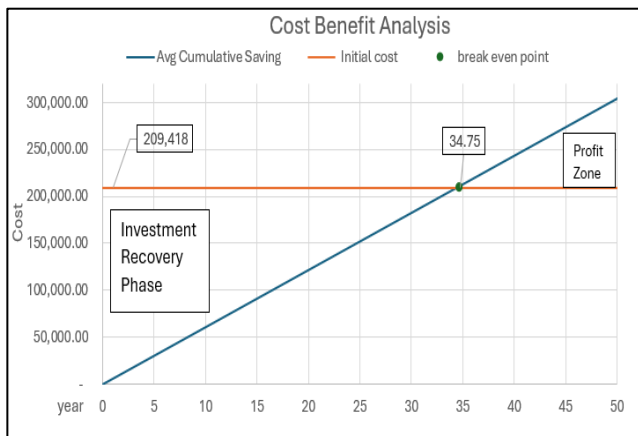


Figure 10: Cost-Benefit-Analysis of best set (VIP and TG LSG)

After identifying the best combination of insulation and glazing, it is equally essential to understand the associated cost. Figure 10 demonstrates the cost benefit analysis for the optimal pair together with investment recovery phase and profit phase. The cost benefit analysis scenario compares with the baseline and best combination which is VIP and TG LSG. Adopting the best combination, it is found that the additional incremental capital expenditure (capex) is £0.209 million, representing a 42.26% increase in cost. However, it also saves 15.18 kWh/m² annually, which is 49.16% lower than the average annual consumption from the baseline set. Multiplying with the floor area and unit price of gas, it is found that, the annual savings across the eight locations of the UK range from £5,285 to £6,928, with an average of £6,082.5 (Ofgem,2025), and the payback period ranges from

31 to 39 years, with an average of 35 years under the 50-year service life of a commercial building (Designing Buildings,2023). The incremental capital expenditure (capex) and the payback period can change significantly improve if the unit price of VIP and TG LSG is decreased. This is possible reality in future as demand of VIP and TG LSG is increasing for their sustainable and advanced features. Again, market growth also plays important role for mass production which results in reduction in unit price.

Net Present Value Analysis

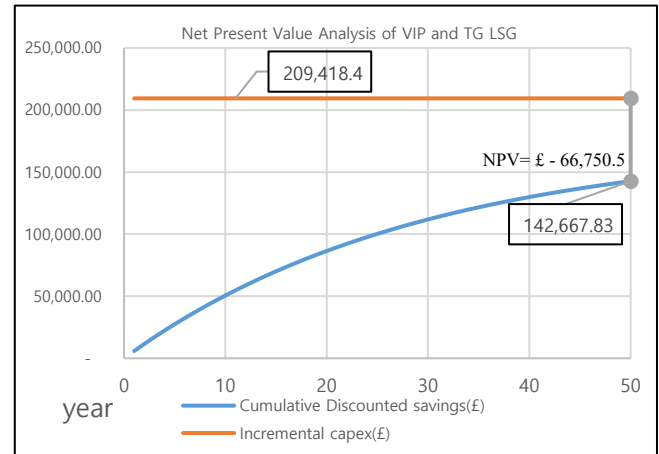


Figure 11: Net Present Value Analysis of best set (VIP and TG LSG)

From the above Figure 11, it is observed that the straight line shows the initial capital expenditure and gradually increasing curve explains the cumulative discounted savings of the best combination where discount factor is assumed 3.5% (HM treasury,2025). Additionally, it noted that the value of net present value is =£-66,750.5 which is negative, meaning the cumulative discounting savings is less than the incremental capital expenditure. This graph implies that this option is financially unviable under the current scenario. This occurs due to the extremely high unit cost of VIP and TG LSG. In the future, to meet the climate urgency, sustainable products will be in high demand. As a result, technological advancements are expected to increase the production of VIP and TG LSG, leading to a decrease in unit cost. Additionally, the unit price of gas is volatile due to various factors, including new sources, availability, events such as demand and supply, power generation, oil prices, and geopolitical conditions, as well as sanctions and conflicts. If the unit price of gas rises, the total annual savings increase, thus changing the net present value.

Cost in terms of Carbon

VIP and TG LSG have higher embodied carbon as both the materials are advanced, require extra coating, manufacturing technology. Thus, it results in higher embodied carbon, and the cost of embodied carbon is higher in best combination than the baseline combination. It is found that about 544.05-ton embodied carbon worth of £22763.24 is higher in best combination. It is derived from using the carbon price in civil penalties (UK Emissions Trading Scheme,2024). However, embodied carbon is one time cost. The best combination saves operational carbon throughout the service life of a building.

Figure 12 shows the annual operational savings if a construction firm switches to VIP and TG LSG combination. It is observed that switching to the best combination from baseline saves 31.90% of operational carbon annually per square meter of a building. The annual operational carbon savings across the eight locations range from 17 tCO₂eq to 23 tCO₂eq, with an average of 20.07 tCO₂eq. Glasgow saves the highest annual operational carbon saving whereas both Plymouth and London give same and the least value. It is a potential carbon penalty savings that occurs annually and thus outweighs the embodied carbon cost, promoting sustainability.

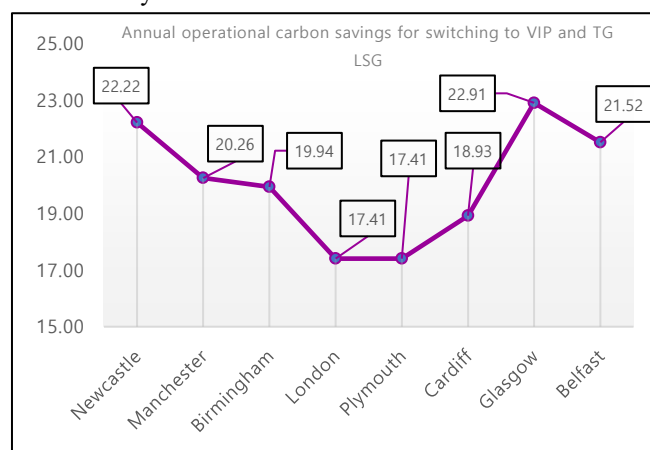


Figure 12: Annual Operational Carbon savings for switching to best combination

Although the NPV is negative under current conditions, the combination of VIP as an insulation material and TG LSG as a glazing material is a sustainable and appropriate solution that supports the net-zero goal set by the UK.

4. Conclusions

Concluding remarks:

Irrespective of the case -whether it involves only insulation, glazing, or a combination -Glasgow has the highest energy consumption and CO₂ emissions, while Plymouth has the lowest. The result occurs due to the location, weather, and climate conditions of the corresponding places. The best insulation solution is VIP, and for glazing, it is TG LSG. The U-value while using VIP only is 0.18. On the other hand, the lowest U value is 0.56 when only TG LSG is applied. According to the Building Regulations 2010, Part L, the U-value of the wall is 0.26 and the window is 1.6, both of which fall below the standard value, which is desirable. Again, when both VIP and TG LSG combinations are used, the average value becomes 0.09, which is also very low compared to the building regulations.

In terms of energy consumption, the highest combination occurs in the GW and TC set. When a building firm uses VIP and TG LSG pair, the energy usage drops by a mean value of 40.98%. Birmingham produces the lowest percentage decrease (40.78%), while Plymouth has the highest percentage depletion in energy consumption (41.40%).

For total emissions, the highest contributors are GW and EC DGU, while the best combination remains the same as before (VIP and TG LSG). When shifting from GW and EC DGU to VIP and TG LSG, the emission decreases on average by

26.45%. The highest decrease in emissions occurs in Glasgow (27.54%), while the lowest emission rate is observed in London (25.18%).

The energy performance asset rating also shows that the lowest value occurs with the combination of VIP and TG LSG paired with VIP and TG MSG and VIP and DG LSG, with a value of 19 for all locations except Plymouth, where the value is 20.

According to Cost benefit analysis (CBA), the cost increases by approximately 42.26% when switching to the best combination, whereas annual consumption decreases by approximately 49.16%. The average annual cost saving is £6,082.5 and the payback period ranges from 31 to 39 years, with an average of 35 years across eight locations in the UK. Lastly, the NPV value of TG and LSG is £-66,750.5, indicating an impractical option under the present conditions. However, with the advancement of technology, policy incentives, subsidies, and even the rise of gas prices, the NPV may change in the future, making this combination the best suited for UK commercial buildings.

From the perspective of carbon savings, total embodied carbon in the best combination is 544.05 tCO₂eq higher than the baseline. However, the operational carbon is 31.90% tCO₂eq higher per square meter that results in average 20.07 tCO₂eq decrease or £839.90 potential saving from carbon penalty. This pair is a green project that will attract the investor in the long run.

The study proposes the following recommendations for future investigation and practice.

- Further research should include the inspection of a broader range of construction materials to develop viable solutions.
 - During the assessment, other key parameters, such as availability, durability, recyclability, end-of-life impact, and maintenance requirements, should also be evaluated.
 - Extensive experimentation is advised to identify novel combinations of insulation and glazing materials. This approach will address current data gaps and encourage market growth. Additionally, this may reduce costs and promote feasibility.
 - The study concentrated on eight locations in the UK; it can be expanded to include more locations, thereby providing a more thorough view of the results.
- To mitigate climate change and reduce costs in achieving the net-zero goal, business partners and policymakers can be encouraged by the study's findings and adopt a holistic approach to sustainable building envelope design.

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