A FEASIBILITY STUDY ON INTEGRATING PHOTOVOLTAIC GLAZING INTO A BUILDINGS FACADE

Can the Integration of Photovoltaic Glazing into Existing Building Facades Advance Sustainable Energy Production and Enhance Buildings Energy Efficiency?

Karl Morris; C19458016

Technological University of Dublin

DT175 BSc (Hons): Architectural Technology

Supervisor (First): Tim O’Leary

Supervisor (Second): Kirk McCormick

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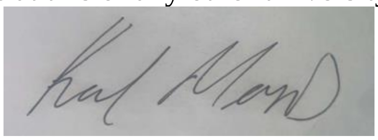
Abstract

The integration of solar photovoltaic (PV) glazing into building facades has gained increased attention in recent years as a means of advancing sustainable energy production and improving the energy efficiency of buildings. Facade integrated photovoltaics (FIPV) is a potential method for integrating solar power into the built environment, aligning with Ireland's carbon-neutral goals set for 2050. This dissertation explores the architectural issues for integrating solar PV glass into existing building facades, particularly in cases where there may not be enough roof space for traditional solar panels. The study considers topics like orientation, shading, and aesthetic integration and explores the advantages of FIPV energy production and a more environmentally friendly structure. A case study is presented, which explores the integration of solar PV glazing into an existing building facade in Ireland that did not have any previous PV installed. The building was selected based on its suitability for solar PV glazing integration, taking into consideration factors such as orientation, building design, and the amount of solar irradiation that the site receives. In this study, Revit and FormIT software's are utilised to model and evaluate the performance of solar photovoltaic (PV) glazing under various circumstances, including solar radiation and daylighting. Additionally, the Non-Domestic Energy Assessment Procedure (NEAP) software was used to evaluate the new Building Energy Rating (BER) of the case study building after the installation of the PV glazing. The results of the study provide architects and designers with valuable information on how to effectively design and position PV glazing for optimal energy production and improved energy efficiency of buildings.

Keywords: Solar photovoltaic glazing, facade integrated photovoltaics, Non-Domestic Energy Assessment, Building Energy Rating.

Declaration

I, Karl Morris, hereby declare that the work described in this dissertation is, except were stated otherwise, entirely my own work and has not previously been submitted as an exercise for a degree at this or any other university.



Karl Morris

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List of Abbreviations

PV	Photovoltaic
PV Glazing	Photovoltaic Glass/Glazing
FIPV	Façade Integrated Photovoltaic
BIPV	Building Integrated Photovoltaic
m	Meter
m2	Squared Meter
mm	Millimeters
Sq Ft	Squared Foot
°	Degree (Angle)
W	Wattage
Kw	Kilowatt
kWH	Kilowatt hours
€	Euro

Can the Integration of Photovoltaic Glazing into Existing Building Facades Advance Sustainable Energy Production and Enhance Buildings Energy Efficiency?

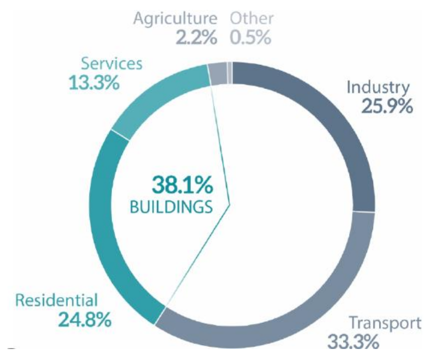
1.0 Introduction

This dissertation focuses on the integration of solar photovoltaics (PV) glazing into existing building Facades. “Collectively, buildings in the EU are responsible for 40% of our energy consumption and 36% of greenhouse gas emissions, which mainly stem from construction, usage, renovation and demolition.” (European commission, 2020). The concern about rising energy consumption promoted interest in this topic and led the focus be on the energy efficiency of structures with substantial glass facades. Existing commercial buildings are responsible for using a significant quantity of energy for lighting, heating, cooling, and the use of other energy-run equipment, which is primarily powered by fossil fuels. Fossil fuels can be replaced as an alternative by using renewable, passive energy, which is abundant, free, and has a low environmental impact. “Today, roughly 75% of the EU building stock is energy inefficient. This means that a large part of the energy used goes to waste” (European commission, 2020).

In Europe, the building industry has the highest rate of energy consumption over any other sector, accounting for 38.1% of all global energy consumption (Eurostat, 2014). This is higher than both the industrial and transportation sectors. This number could increase even more in the upcoming years due to rising demands for thermal comfort.

Figure 1

Total energy consumption by sector (Eurostat,2014)

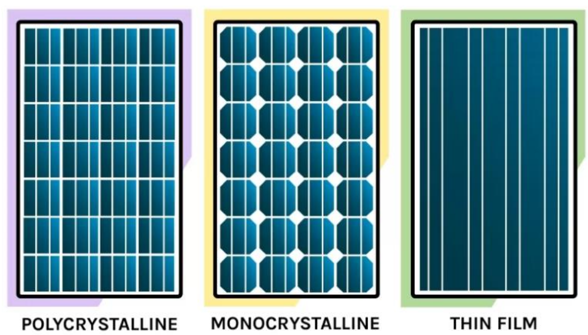


1.1 Photovoltaic Glazing

Photovoltaic technology has been around since the discovery of the photovoltaic effect in 1839. It has since evolved to become a widely used means of converting solar radiation into electricity. Typically, these systems are based on silicon and generate direct current (DC) when exposed to sunlight (Lincot, 2017). The available types of PVs include monocrystalline silicon, thin film silicon (amorphous silicon or A-Si), and polycrystalline silicon which can be seen in Figure 2. The selection of the appropriate type of PV for a specific application depends on various factors such as efficiency, cost, and the specific requirements of the building.

Figure 2

Different Solar Cells in PV glazing (Source: Hoare, 2018)



In recent years, there has been growing interest in integrating solar PV glazing into a building facade to maximize energy production while also improving the buildings aesthetic appeal. This is particularly practical for buildings where there is not enough roof space for conventional solar panel installations. By incorporating solar PV glazing into the building's facade, energy production can be increased while also reducing the building's carbon footprint.

1.2 Aims

The aim of this dissertation is to explore the feasibility and effectiveness of incorporating mono-crystalline and amorphous photovoltaic glazing units into existing curtain wall systems. I aim to investigate the potential energy generation of these PV technologies when retrofitted into an existing curtain wall system. Furthermore, I plan to develop an optimal integration strategy that considers both energy efficiency and aesthetic quality when incorporating these PV technologies into the existing building envelope. Ultimately, the aim of this research is to provide insight into the practical application of mono-crystalline and amorphous PV glazing in retrofitting existing curtain wall systems and contribute to the advancement of sustainable building practices.

1.3 Objectives

1. Assess the case study building to determine its suitability for the integration of mono crystalline and amorphous PV glazing.
2. Evaluate the optimal integration strategy for each type of PV glazing unit considered for retrofitting the existing curtain wall system.
3. Assess the impact of the proposed retrofit on the daylight performance of the existing building, considering the balance between solar heat gain and natural daylighting.

4. Measure the amount of solar exposure available on the building facade by using solar radiation modeling to estimate the energy generation potential of the installed PV glazing systems.
5. Explore the use of the Non-Domestic Energy Assessment Procedure (NEAP) to evaluate the new building energy rating.

1.4 Motivation

The main motivation for this topic was to evaluate if PV glazing can be utilised in Ireland in retrofitting existing commercial buildings. According to the European Commission (2020), “renovating existing buildings could reduce the EU's total energy consumption by 5-6% and lower carbon dioxide emissions by about 5%”. Also, in line with Irelands long term renovation strategy (2020), which states ‘one-third of commercial buildings will be retrofitted to a BER level of B by 2030” and “all commercial buildings by 2050” (SEAI, 2023). With these figures in mind, it is clear that more energy efficient designs are needed. The main motivation was to evaluate if FIPV can help Ireland towards a more sustainable building industry through the integration of PV glazing through the retrofit of façade systems. This will contribute towards achieving the goals set by EU of net zero by 2050.

Through testing this renewable energy product in Ireland, it could have a positive impact on architecture by making buildings more aesthetically pleasing, financially beneficial, and energy efficient. This testing might involve replicating prior studies, validating previous findings, or producing new findings.

1.5 Scope

The scope of this study is to investigate how solar PV glazing can improve the overall energy efficiency of commercial buildings in Ireland. This dissertation will examine the use of mono-crystalline and amorphous PV glazing units in retrofitting existing commercial buildings in Ireland, with a limited focus to one case study building.

2.0 Literature Review

Many studies have been carried out in relation to how PV glazing technologies can improve a glazed façade. Although the literature covers a wide variety of research into the topic, this review will focus on how PV glazing façade systems can be used as part of the solution to sustainable construction development. The literature review is split into separate subheadings along with a case study to provide retrofit strategies, photovoltaic glazing potential and design considerations on how the integration of PV glazing can positively affect the buildings energy consumption. compare two pieces of literature accompanied with a case study to provide design considerations and how the integration of PV glazing can affect the buildings energy consumption and overall sustainability.

2.1 Retrofit Strategies

To investigate the design potential and innovative opportunities to renovate existing building façades to make them safe, compliant to current regulations and standards, and better performing an article written by Arsenault. He gives insight into the different types of strategies. Aresnault (2015) states that “many high-rise commercial buildings exist in urban environments with façades that have become worn and deteriorated over time, producing an appearance that has become dated and unappealing”. A possible reason for the need to retrofit lies in the fact that “new curtain wall façades on existing high-rise commercial buildings can transform not only the appearance and marketability of a building, but its energy performance and longevity as well” (Aresnault, 2015). Retrofitting existing curtain walls plays a key role in the total energy consumption of a building. 10% of worldwide energy usage is directly influenced by building facades, primarily due to glazing design. “Windows are responsible for approximately 60% of the total energy consumed in a building due to the high overall heat loss and heat gain” (Hemaida, Ghosh, Sundaram, & Mallick., 2020).

The potential retrofit strategies to an existing curtain wall stated by Aresnault (2020) are a full façade replacement, over-cladding system, double-skin system, recladding, and hybrid system. These strategies can be used to improve the buildings energy efficiency and incorporate PV system into an existing curtain wall. Retrofitting of existing buildings has vast possibilities in increasing the energy efficiency of buildings, as facade design plays a crucial role in the energy consumption of a building and can offer additional benefits by incorporating possibilities of energy production. The urgent need to retrofit older buildings lies in the fact that energy use and energy related emissions from existing building stock is dominant compared to new energy efficient buildings (Lassandro & Turi, 2017).

2.2 Photovoltaic Glazing Potential

This section in the literature review will compare two separate reference works of literature and provide some background information on the reliability of the pieces. The first piece of literature is an article written by Nikolaos Skandalos and Dimitris Karamanis, titled "PV glazing technologies" which was published in 2015, in the journal "Renewable and Sustainable

Energy Reviews." Nikolaos Skandalos and Dimitris Karamanis both have a background in this field of work, and have lectured in the University of Patras, Seferi 2, 30100, Greece. The second piece of literature is by Laura Rodriguez titled "Solar glass buildings: Greatest attainable idea or science-fiction? ". Laura Rodriguez is a business development manager at Iedre S.L., a Spanish company focused on Solar Photovoltaics and Green Energy, again a reliable, knowledgeable author. These two to compare because they are relevant to my original thesis issue, contain a wealth of important material and details, testing methodology, and conclusions regarding their findings.

“According to the European Commission, buildings in the EU are responsible for about 40% of the energy consumption and 36% of greenhouse gas emissions” (Rodriguez, 2021). With the improvement of PV glazing technologies, we should significantly reduce those percentages. Rodriguez continues to state that “other markets such as Japan, Taiwan or Singapore, which have exhausted the majority of space available for rooftop or have limited space for ground-mounted projects, may find in these technologies the answer to their fight against climate change” (Rodriguez, 2021). High rise structures will be able to employ these developing technologies to not only regenerate energy but also use daylight to maintain a suitable temperature inside. Although a skyscraper can benefit from a fully glazed façade to let solar light and heat gain in, Skandalos and Karamanis claim that they can have drawbacks. “Among their benefits, glazing facades provide daylight which acts in a positive manner toward reducing the artificial lighting demand during the daytime and saving lighting energy. However, the extensive use of glass in building façades is also associated with problems such as over- heating of the building in summertime and increase of the air conditioning loads, lack of visual and thermal comfort, and increased thermal losses in wintertime. Since 33% of the average building's cooling load is related to solar heat gain through the windows, a disproportionate amount of window area in a building makes passive cooling of the building a challenging subject” Skandalos & Karamanis, 2015). A potential fix for these issues is photovoltaic glazing, which can reduce energy use per unit and assist a structure in becoming carbon neutral. PV glazing can come in different transparencies varying from, low, medium, and high. The lower transparency the more compact the solar cells are, which will produce more solar energy. Higher transparencies produce less energy and therefore “a transparent solar panel is essentially a counterintuitive idea because solar cells must absorb sunlight (photons) and convert them into power (electrons)” (Rodrigeuz, 2021). The quantity of electrical power generated by a solar cell in relation to the energy from the light shining on it determines the efficiency of solar panels. According to Rodrigeuz (2021) “the average PV module market is still working on improving its efficiencies (current average of 15-20% monofacial and 25% for bifacial modules). PV glass in comparison holds a fraction of normal modules generating capacity with something between 7% and 10%.” Essentially the more transparent it is, the less efficient it is. The PV glazing testing methodology used by Skandalos and Karamanis were evaluated by these considerations. The transparency of the PV window is a big factor as it contributes to optical and thermal properties of the window. However, by comparing different types of PV glazing in a face-to-face methodology under the same boundary and climate conditions is the best way to see which PV system is suited better. Also, the location of the building, the optical and thermal properties of the window, the electrical properties of the cell, the primary energy usage type, the cost and environmental impacts all must be considered to get accurate results. According to Skandalos and Karamanis (2015) “PV window systems should be examined under the following main aspects: electrical performance, optical performance, thermal performance and energy saving potential, cost reduction and environmental benefits”.

2.3 Case Study – Genyo Building, Granada, Spain

This building belongs to the large global pharmaceutical corporation Pfizer. Onyx Solar designed and developed the ventilated photovoltaic façade for the Pfizer-University of Granada. The facade combines three types of glass and, with a total active area of 522m2 , produces a peak power of 19,300 W, generates about 32,000 kWh of energy per year and prevents the emission of 21 tons of CO_2 emissions into the atmosphere.

From the literature review, Skandalos and Karamanis stated that PV glazing units can have drawbacks with daylighting issues. This case study used 3 different types of transparent glass at different transparencies to solve this issue. Show below in Figure 3

Figure 3

Elevation showing different transparent PV glazing (Onyx)

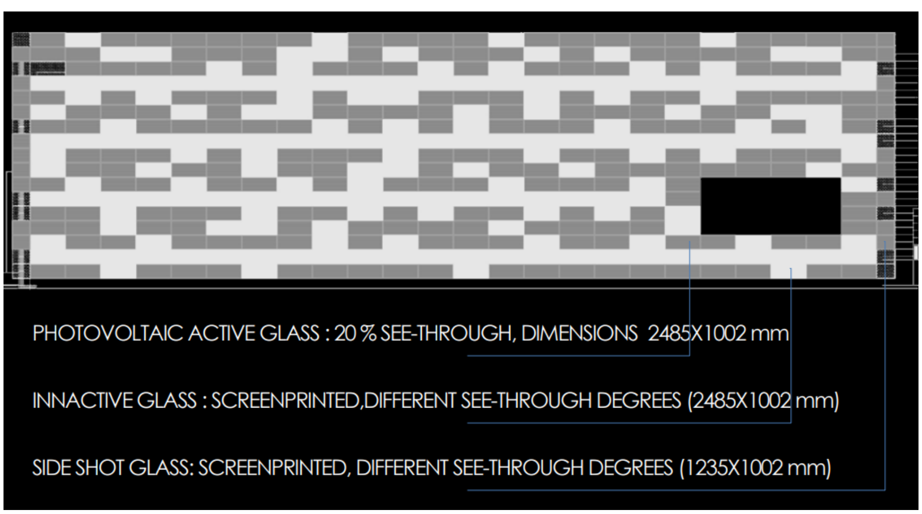


Figure 4

Application of double skinned façade (Onyx)

Figure 4 shows the application of the double skinned facade system and how it connects, while tackling issues such as daylighting and ventilation. From an Architectural Technologist perspective, the detailing that accompanies this system is simplistic yet effective, shown in Figure 5 & 6. The frame of the PV units is fixed back to the structure by a steel beam. For cable management, it was designed to be hidden and ran through the frames of the PV glazing. This case study provides insight into sustainable construction methods and tackles issues such as daylighting and ventilation by creating a double skinned façade. Similarly, in my thesis I have also taken this approach to overcome the ventilation and cable management issues.

Figure 5

Cables ran through framing system (Onyx)

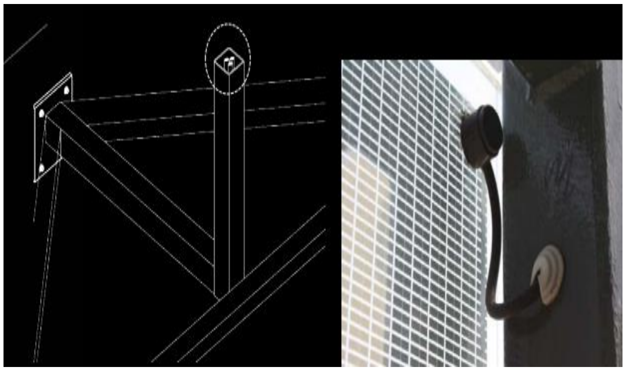
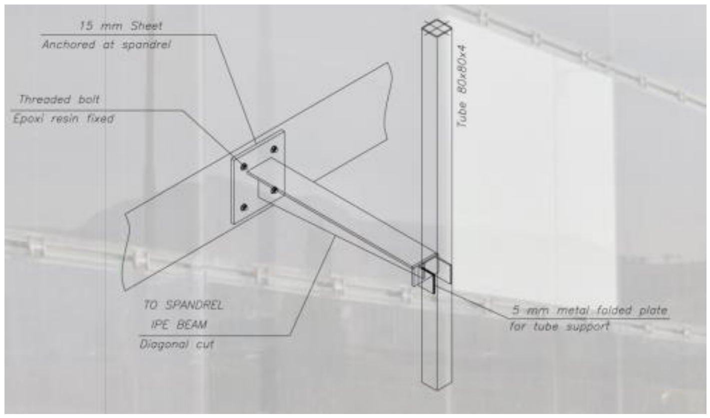


Figure 6

Steel beam connection to PV framing (Onyx)



It is evident from the literature and the provided case study that the amount of solar energy that is produced depends on how transparent the glazing system is. The energy efficiency of standard solar panels will always be higher than that of modern PV glazing components. Returning to Rodriguez's earlier discussion of high-rise buildings in Japan or Taiwan with small roof spaces, the performance disadvantage can be offset by the fact that glass has a larger surface area accessible, so lessening the disparity between the two technologies.

3.0 Methodology

3.1 Overview

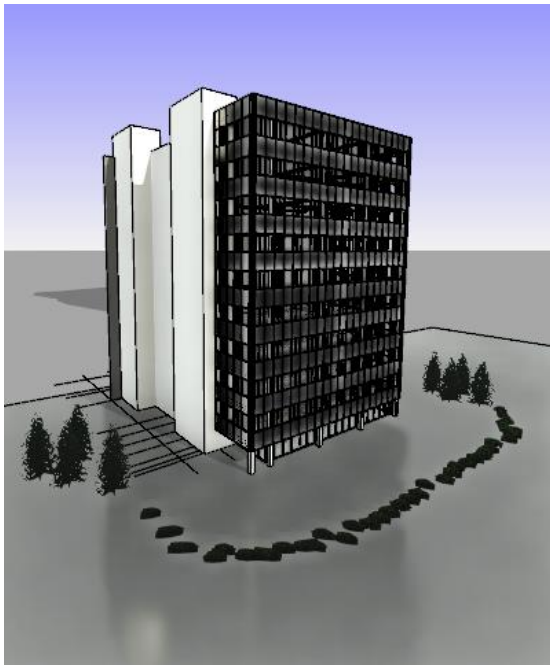
In this dissertation, I took a practical approach to researching the integration of solar photovoltaic (PV) glazing into building facades and a desktop testing approach for testing the PV units. I began by researching various literatures to identify the key factors that should be considered when using PV glazing and different types of retrofit strategies to a curtain wall system. I then carried out a case study on an existing building in Ireland to explore the practical implications of installing PV glazing. This involved working closely with the building facility manager to obtain data on the case study building. This also involved contacting a local supplier (Clear Energy) of PV glazing in Ireland for resources and information on their products via in person and online meetings, so that I could assess the feasibility of integrating PV units into my case study building. I conducted simulations using Revit and FormIT software's to evaluate the performance of the PV glazing under various conditions. Furthermore, I used the NEAP guide and iSBEM software to assess the building's energy rating after the retrofit, considering the energy generated by the PV glazing units and the upgraded U-values of the glazing unit.

3.1 Case Study- The Liberty Building

The chosen case study building for this research project is a commercial office development situated in Blanchardstown, Dublin 15. The building was constructed in 2000 by A&D Wejchert architects and has a total floor area of 10,367m2. One of the significant features of this building is that the south, south-west, and south-east facades consist of a fully glazed curtain walling system, unshaded by neighboring buildings or trees. This provided ample opportunity for the integration of PV glazing units.

Figure 7

3D camera view of Revit model from the north-west and south-west (Author)

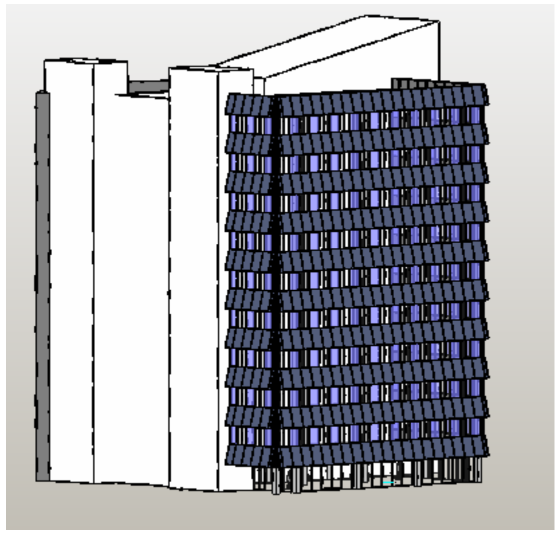


3.2 Revit Model – Daylight testing

The building was modelled in Revit, as shown in Figure 2, and the geographical location was set to provide real life conditions for the analysis, which allows for more accurate results. I then modified the model to integrate mono-crystalline and amorphous PV glazing units, and I inputted their glass properties. It is important to use the correct properties of the glass in order to produce accurate results. I used the properties from a technical data sheet, supplied to me by Clear Energy. The Revit model was an essential tool for evaluating the feasibility of the PV glazing retrofit project and for simulating different design scenarios.

Figure 8

3D view of Revit model with PV units from the north-west and south-west (Author)

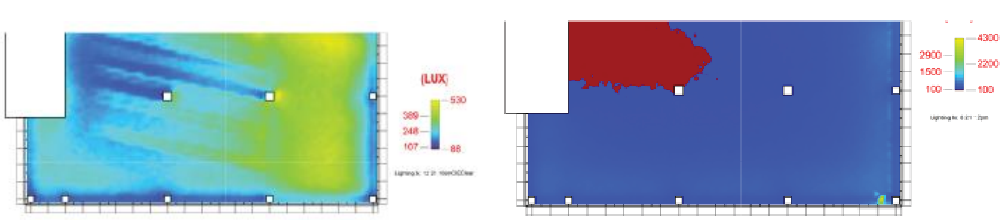


The Revit model of the case study building was not only used for showing integration of PV glazing but also for daylighting simulations.

To assess the impact of the PV glazing retrofit on the indoor environmental quality of the building, daylighting simulations were carried out using the lighting tab in Revit. The simulations aimed to evaluate the amount of natural light that would pass through the amorphous glazing units and the clear glazing units. The daylight testing was carried out on December 21st and June 21st and at three times during the day 10am, 1pm and 5pm.

Figure 9

First floor plan view of daylight simulations on Dec.21 and June.21 (Author)

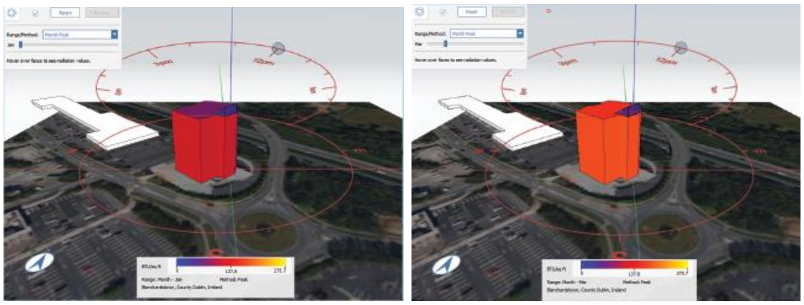


3.2 FormIT Model – Solar radiation testing

The FormIT Autodesk was used to create a detailed mass model of the case study building and its surroundings. The model was used to simulate the annual cumulative solar exposure in kWh received by the building. By accurately modeling the building's mass and context, the simulation results are more reliable. This provided a better understanding of the solar potential of the building and informing the design of the PV glazing retrofit system. To ensure the accuracy of the solar exposure assessment, the testing was carried out four times throughout each season of the year.

Figure 10

3D view of FormIT model to assess solar exposure for all seasons on the south-west and south-east facades (Author)



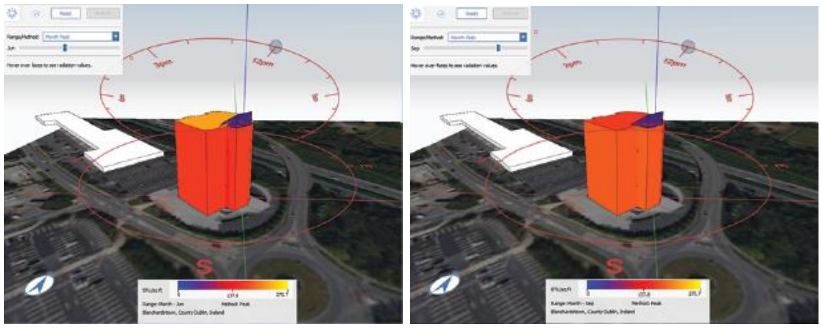
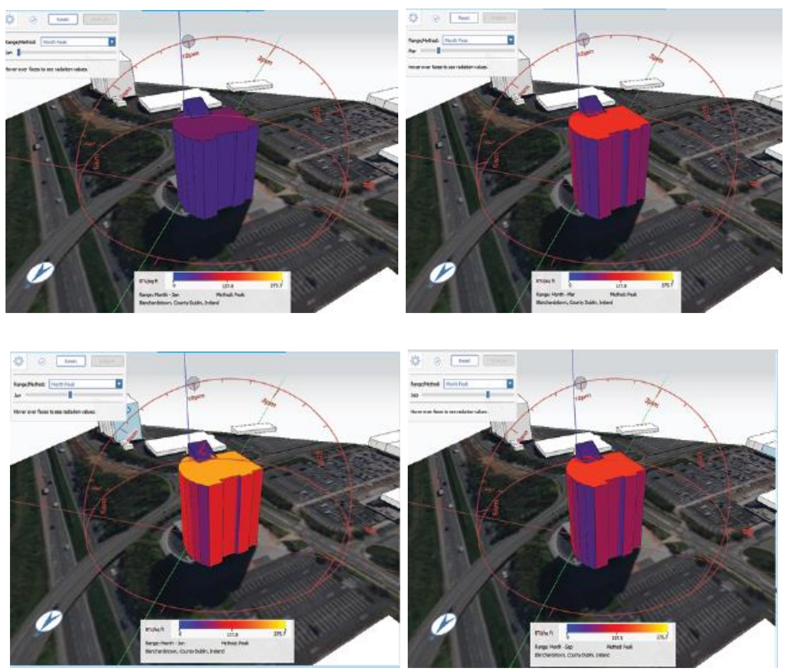


Figure 11

3D view of FormIT model to assess solar exposure for all seasons on the north-west and north-east facades (Author)



The results of the FormIt simulations, which assessed the solar exposure in kWh yearly cumulative for the case study building, were used in manual calculations to estimate the potential energy production of PV glazing retrofits. These calculations provided valuable insights into the economic feasibility of the retrofit project.

3.3 Manual Calculations

I used manual calculations to estimate PV annual production, the "NEAP" Part L calculation was used. Equation 1 highlights the formula used for manual calculations.

Equation 1

Formula used to estimate PV generation (Source: Rexel Energy Solutions, 2018)

0.80 x kWp x S x ZPV

- The 0.8 figure is a constant
- kWp (kilowatt peak) is the total kw rating of the system, the theoretical 'peak' output of the system. e.g. If the system has 4 x 270 watt panels, then it is 4 x 0.27kWp = 1.08kWp.
- S is the annual solar radiation from Table H2 (depending on orientation and pitch).
- ZPV is the overshading factor from Table H3.

Table 1 accompanies the formula. However, when doing the manual calculations, I used the figures found from my own solar testing. Table 1 is based on solar radiation figures from national climate data.

Table 1

Annual solar radiation in kWh/m2 (Source: Rexel Energy Solutions, 2018)

Tilt of collector	Orientation of collector				
	South	SE/SW	E/W	NE/NW	North
Horizontal	963				
15°	1036	1005	929	848	813
30°	1074	1021	886	736	676
45°	1072	1005	837	644	556
60°	1027	956	778	574	463
75°	942	879	708	515	416
Vertical	822	773	628	461	380

The 75 degree figures were used for the mono-crystalline units and the vertical figures were used for the amorphous units for each orientation. Table 2 further accompanies the formula. These figures were used for the overshading factor.

Table 2

Overshading factor (Source: Rexel Energy Solutions, 2018)

Overshading	% of sky blocked by obstacles.	Overshading factor
Heavy	> 80%	0.5
Significant	> 60% - 80%	0.65
Modest	20% - 60%	0.8
None or very little	< 20%	1.0

As the mono-crystalline units are not affected by any shading the value of 1.0 was inputted into the formula. As the amorphous units are slightly shaded by the mono-crystalline units the modest value of 0.8 was inputted into the formula.

By using this method, it was possible to estimate the potential annual energy production of the PV glazing units. I was further able to assess the cost savings from the solar radiation testing.

Solar heat gain calculations were used using this formula provided by Palmer (2011), the formula in Equation 2

Equation 2

Formula used to estimate internal solar heat gain (Palmer,2011)

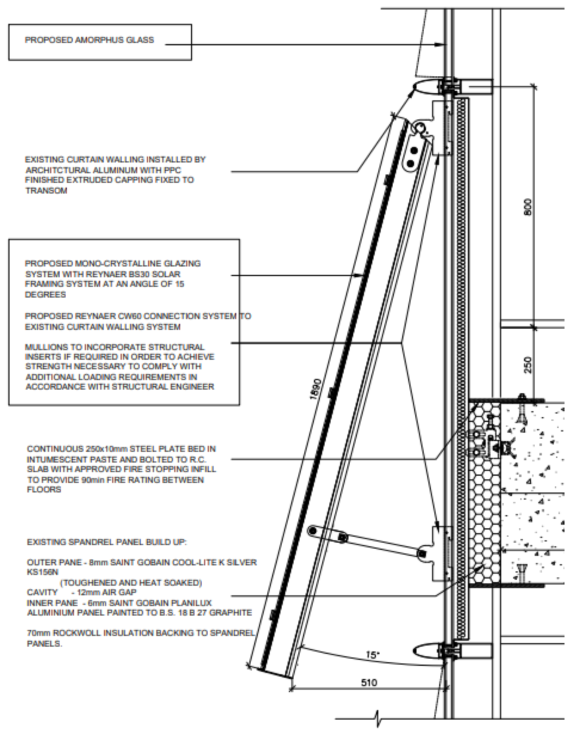
$$\text{Average Solar Heat Load per unit Floor Area} = \frac{\text{Area of Glazing x Glazing Factor x Shading Factor x Average Solar Load}}{\text{Area of Zone}}$$

3.4 Technical Design

A Raynear bracketing and framing system were used to integrate the mono-crystalline units over the existing spandrel panel. The mono-crystalline units were angled at 75 degrees to gain more exposure to sunlight. The Raynear products used were the ‘CW60 Solar’ bracketing system and the ‘BS30 Solar’ framing system. The system was specifically chosen to integrate with the building's existing facade. The brackets were attached to the existing curtain walling (assuming that the curtain walling system could tolerate the additional weight of the PV units). This integration not only improved the building's energy efficiency but also provided a sleek modern appearance.

Figure 12

Section of mono-crystalline connecting to existing curtain walling framing (Author)

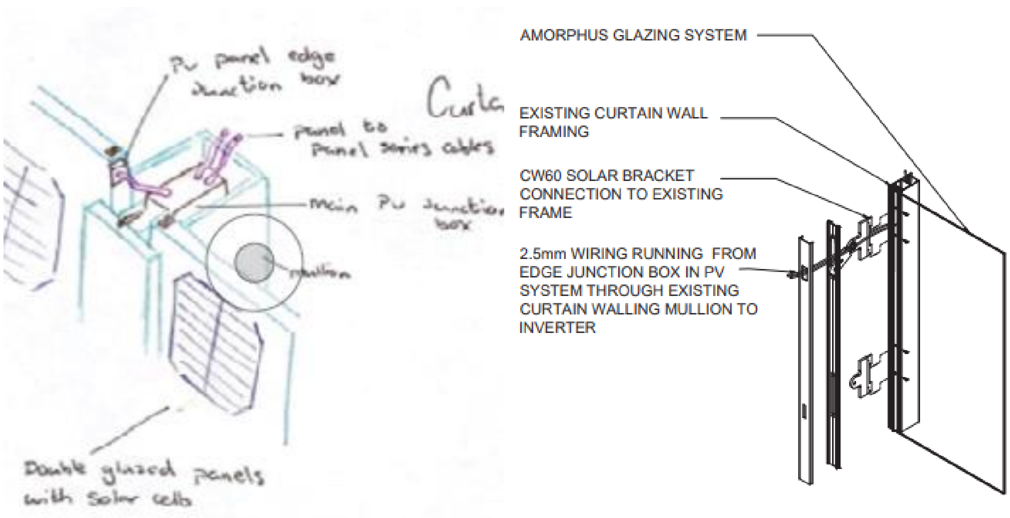


The amorphous units were integrated into the building envelope by recladding the existing glazing. The amorphous units have a upgraded U-value of 1.2W/m2K.

The eletrical connections ran through the framing system and connected to a central inveter in the building

Figure 13

Sketch and Exploded view detail of cable management (Author)



3.5 Non-Domestic Energy Assessment Procedure

To assess the impact of the retrofit on the building's overall energy performance, the NEAP guide and iSBEM software were used to calculate the new BER rating. This considered the upgraded U-values of the glazing and the renewable energy production from the PV system. By using these software tools, I was able to accurately assess the building's energy consumption and obtain the energy savings achieved through the integration of PV glazing.

4.0 Results and Discussion

4.1 Case Study Analysis

For the case study analysis, I utilised the Revit model to perform daylighting simulations and the FormIt model to evaluate solar radiation. These models were essential for assessing the effectiveness of integrating PV glazing in the building's envelope, as they allowed me to evaluate the solar exposure and natural light levels of the building accurately. The daylighting simulations provided information on the amount of natural light that entered the building, which is crucial for meeting minimum lux levels required for office buildings in Ireland. On the other hand, the FormIt model helped me to calculate the yearly cumulative solar exposure and assess the potential for energy production from PV glazing. The combination of these two models provided me with comprehensive data that enabled me to integrate the PV units to current standards and regulations.

4.2 Daylighting Results

The daylighting simulation on Revit was carried out on December the 21^{st} and June the 21^{st} to get an accurate estimation of the natural light levels of the building. Figure 9 highlights the results from December and Figure 10 shows the June results. The results shown were taken on the First floor and at 10am, 1pm and 5pm, respectively.

Figure 14

December.21 Daylighting testing results from Revit (Author)

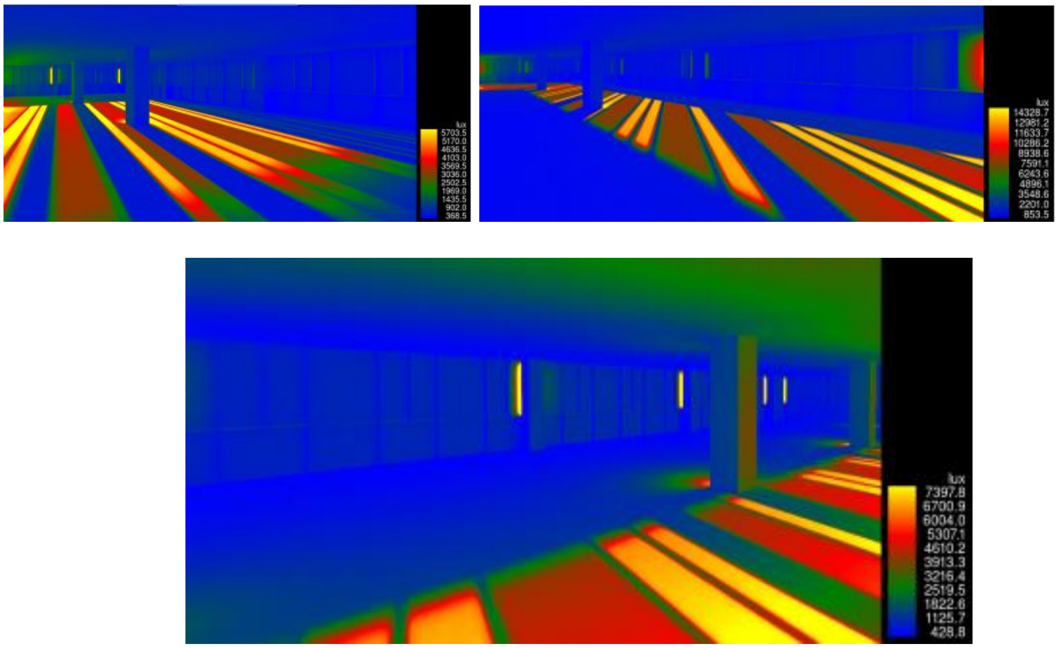
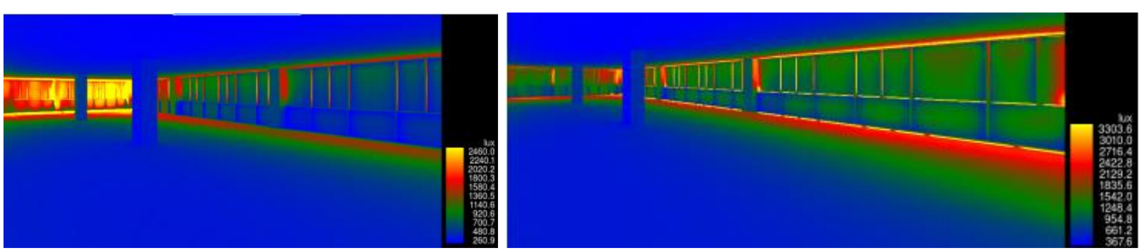
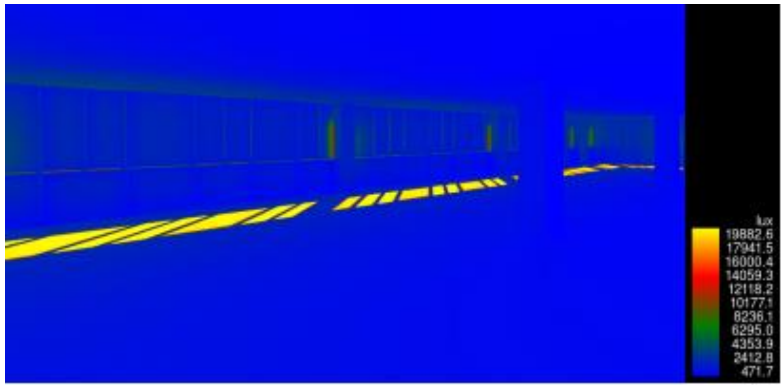


Figure 15

June.21 Daylighting testing results from Revit (Author)





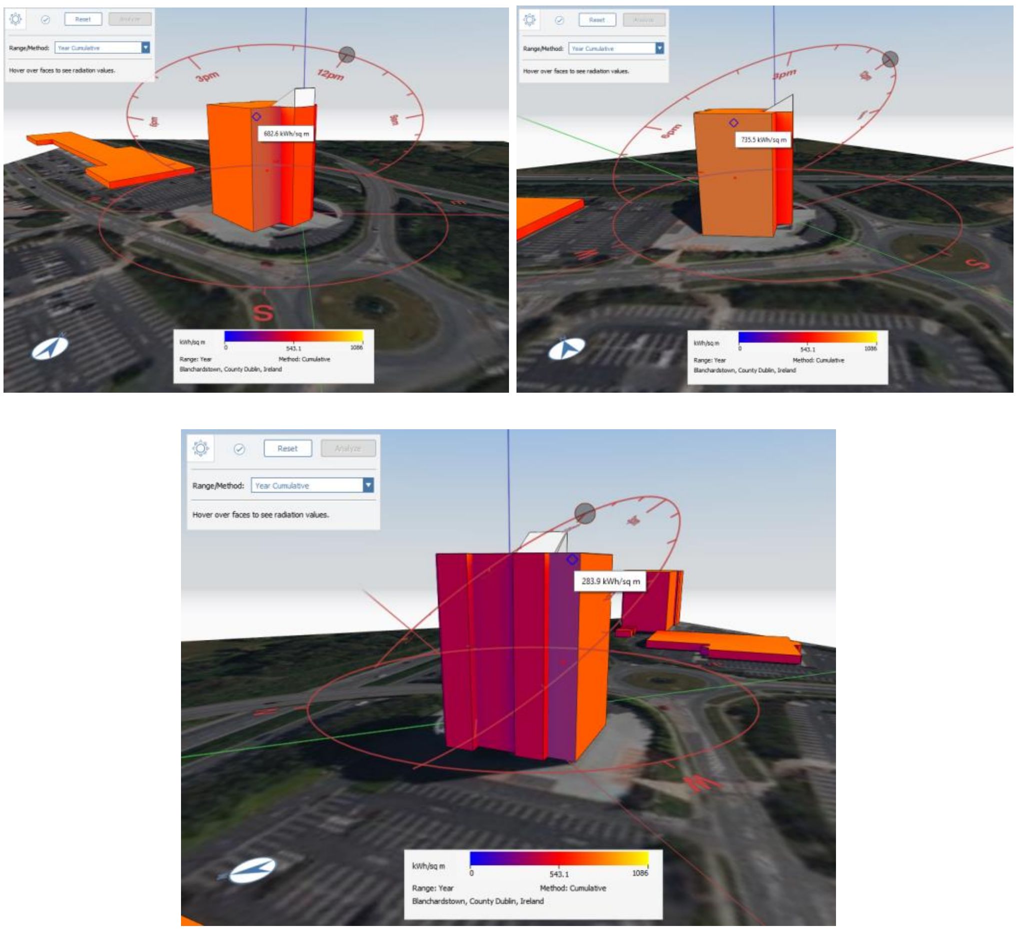
The results of the daylighting simulation show that the building received more natural daylight on December 21 than on June 21 due to the higher position of the sun in the sky during the summer months. Additionally, the mono-crystalline PV units acted as a natural shading device, reducing the amount of direct sunlight entering the building and improving the visual comfort of the occupants. The recommended maintained illuminance (lux) levels for this type of office range from 300-500 lux (CIBSE, 2014). The use of Revit for daylighting simulations was found to be effective in delivering precise and comprehensive data for the design of PV glazing retrofit.

4.3 Solar Radiation results

The results of FormIt solar radiation testing in Figure 11, which shows the yearly cumulative value in Kw/h of solar radiation received by the building's surfaces. The testing was carried out to evaluate the potential of integrating PV glazing into the building envelope. These results were crucial for estimating the total yearly energy production of the PV units on each façade.

Figure 16

FormIT Solar Radiation Testing results in Kw/h, south-east, south-west, north-west (Author)



The results show the yearly cumulative value in Kw/h of solar radiation received on each facade. The south-west facade receives 682 Kw/h/m2, the south-east facade receives 735 Kw/h/m2 and the north-west facade receives 283 Kw/h/m2.

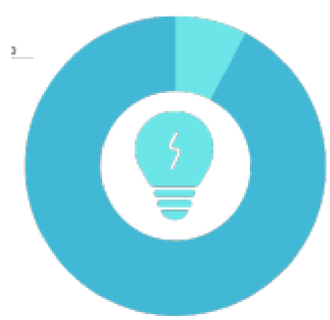
The use of FormIt software for solar radiation testing allowed for accurate and detailed analysis of the building's solar exposure, enabling me to make informed decisions about the PV glazing retrofit design.

4.4 Manual Calculations

By doing self-calculations, taking into consideration results from solar radiation testing I was able to estimate the PV annual production in kW/h/yr. The north-west facade generating a total of 9,259 kW/h/yr. The south-west facade generating 64,125 kW/h/yr and the south-east facade generating 31,307 kW/h/yr. This shows that the total yearly energy saving cost is 7.7%, which is shown in Figure 14

Figure 17

Total yearly energy saving donut chart (Autor)



By doing self calculations the aveage solar heat gain results are shown in Equation 3

Equation 3

Average Solar Heat gain calculations (Author)

$$S/E = 21.632m^2 \times .41 \times .8 \times .198W/m^2 / 78m^2 = \text{Internal Solar Heat Gain of } 18.01W/m^2$$

$$S/W = 43.72m^2 \times .41 \times .8 \times 198W/m^2 / 159.12m^2 = \text{Internal Solar Heat Gain } 17.84W/m^2$$

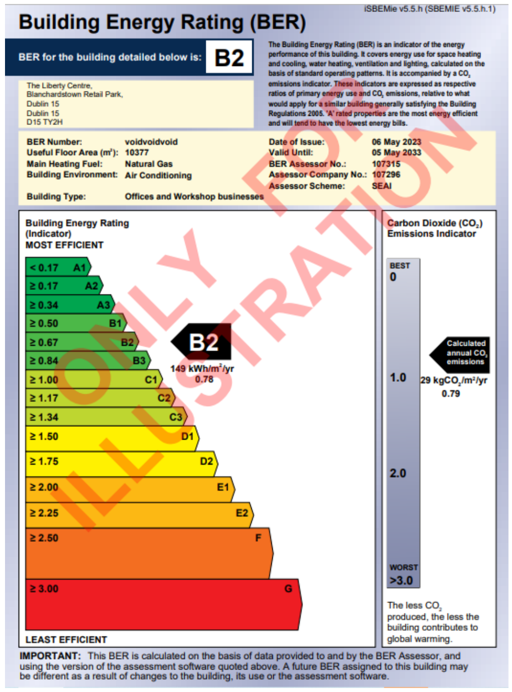
$$N/W = 10.874m^2 \times .41 \times .8 \times 160W/m^2 / 38m^2 = \text{Internal Solar Heat Gain of } 15.02W/m^2$$

4.5 Non-Domestic Energy Procedure Results

Through using NEAP guide and iSBEM software, it was evident that the retrofit design with the addition of renewable energy and upgraded glazing units with a U-value of 1.2 W/m2K could potentially upgrade the case study building's energy rating from C1 to B2. Upon using the iSBEM software for energy performance calculations, I had to rely on assumptions about the existing U-values of the building's envelope components in the absence of available data. I followed the recommendations in the NEAP guide (2019) which states that "if unable to determine whether double glazing is Low "E" or not, assume that double glazing installed before 2004 is not Low "E" and during or after 2004 is Low "E," and to "assume that double or triple glazing is air filled unless documentary evidence is provided to substantiate an alternate " (SEAI, 2019, p.). These assumptions were in line with the 1997 TGD L in line with NEAP guidance, which dictated the level of fabric performance. Therefore, I used the TGD L 1997 U-values as inputs for the software. These assumptions allowed for a more accurate assessment of the potential energy savings from the PV glazing retrofit. The existing energy consumption was 161kWh/m2/yr. The proposed retrofit energy consumption is 149 kWh/m2/yr. These calculations were carried out by also inputting the case study buildings geometry, materials, and HVAC systems, to estimate the building's energy performance. The upgraded BER certification is shown in Figure 12. See Appendix A for more information on the BER analysis.

Figure 18

Proposed BER rating of Case study building (Author)



As a result, this retrofit design has the potential to significantly improve the building's energy efficiency, reduce energy costs, and decrease its carbon footprint.

5.0 Conclusions

In conclusion, this dissertation aimed to evaluate the potential of photovoltaic glazing for the retrofit of an existing curtain wall and to develop an optimized integration strategy for the PV units. Through the quantitative data analysis described in the methodology, a greater insight into the potential of PV glazing has been gained. Through data gathering and software simulations in Revit and FormIT, I was able to assess the solar radiation and daylight exposure of the building. By incorporating a hybrid approach of over-cladding and recladding for mono-crystalline and amorphous PV units, I maximized energy production while maintaining the aesthetic and functional requirements of the building envelope. The NEAP guide and iSBEM software were used to demonstrate that this retrofit could improve the building's BER rating from C1 to B2, assuming all glazing is upgraded to a u-value of 1.2 W/m2k.

Overall, the results of this study suggest that retrofitting existing curtain walls with PV glazing can effectively improve energy performance and reduce carbon emissions in commercial buildings. However, it is important to consider the limitations of the data and assumptions made in this study, including the limited access to data on the curtain wall and the estimated u-values. Additionally, the potential challenges in implementing such a retrofit on a larger scale should be carefully considered. Nevertheless, with further research and development, the use of PV glazing in building retrofits has the potential to play a significant role in achieving Ireland's sustainable development goals. For more information on the BER analysis, see Appendix A.

5.1 Reflection and future work

I'm happy with the outcomes of this study and I feel as though I've demonstrated the positive environmental impact of retrofitting a commercial building using. However, there is always room for improvement. There is a lack of data on the existing curtain wall, which caused me to make some assumptions in my calculations. This was one of the study's limitations. In future work, it would be beneficial to gather more accurate data on a building's envelope and electrical system and explore different integration strategies and designs for the PV units. In addition, further research could be conducted on the impact of PV glazing and the potential for integrating other types of renewable energy technologies into the buildings retrofit. To conclude, I believe there is great potential for PV glazing to play a significant role in renovating existing commercial buildings to a BER rating of B, and to achieve Irelands net zero goals by 2050.

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Appendix A

SBEMIE Main Calculation Output Document

Sat May 06 13:42:35 2023 v5.5.h.1

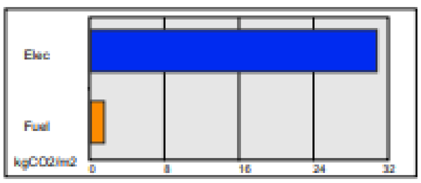
Building name

The Liberty Building

Building type: Offices and Workshop businesses

SBEMIE is an energy calculation tool for the purpose of assessing and demonstrating compliance with Building Regulations (Technical Guidance Document - Part L for the Republic of Ireland) and producing Building Energy Ratings. Although the data produced by the tool may be of use in the design process, **SBEMIE is not intended as a building design tool.**

Building Energy Performance and CO2 emissions

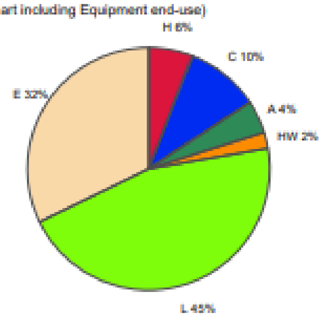


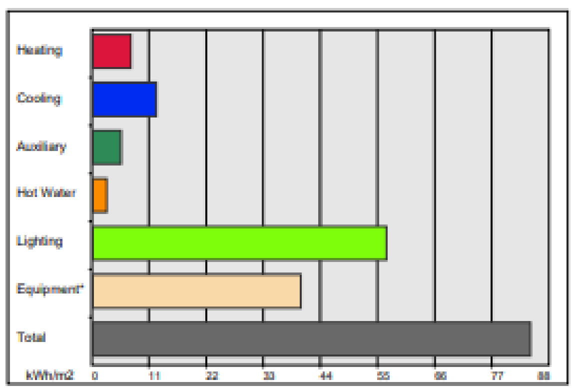
3 kgCO2/m2 displaced by the use of renewable sources.

Building area is 10377 m2

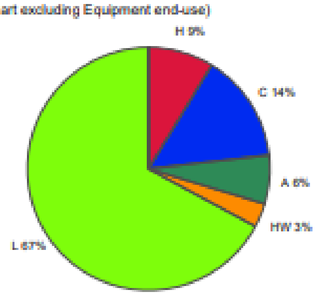
Annual Energy Consumption

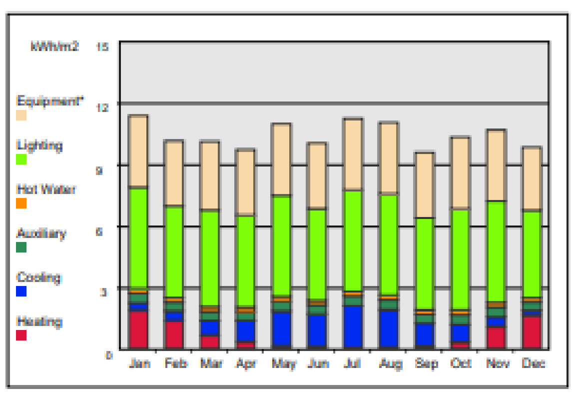
(Pie chart including Equipment end-use)



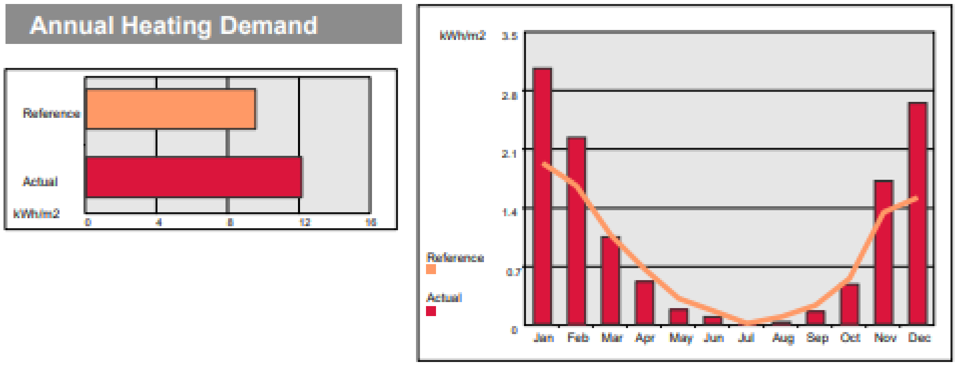


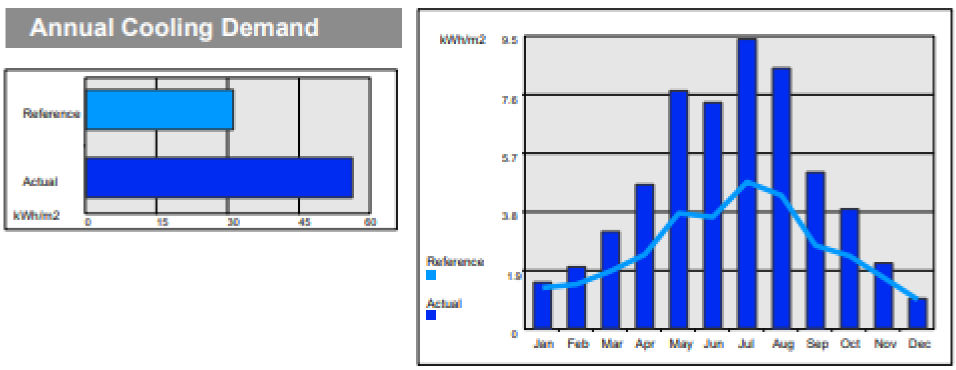
(Pie chart excluding Equipment end-use)





(*) Although energy consumption by equipment is shown in the graphs for information, this end-use has not been included in the total results of the building or the calculation of the ratings.


Annual Heating Demand
Reference
Actual
kWh/m2
0
4
8
12
16
kWh/m2
3.5
2.8
2.1
1.4
0.7
0
Reference
Actual
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


Annual Cooling Demand
Reference
Actual
kWh/m2
0
15
30
45
60
kWh/m2
9.5
7.6
5.7
3.8
1.9
0
Reference
Actual
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec