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Investigating the Opportunities to Improve the Thermal Performance of a Case Study Building in London

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ABSTRACT

This study was carried out to investigate the opportunities of improving thermal performance by focusing on envelope effects of a building located in London. Firstly, through a broad literature review of the previous conducted case studies, an investigation of all the building envelope aspects and parameters influencing the thermal performance of the building was conducted to provide critical information of thermal performance of the envelope components within the UK buildings. Then, onsite measurements were carried out to obtain the building's base case heating load using the standard CIBSE GUIDE A 2017 heat load calculation methodology. Neglecting thermal bridging in the heating calculation showed 8% reduction in the building's total heating load. Also, 17% reduction in energy consumption and CO2 emissions was achieved by applying polyurethane-foam and polystyrene-boards as cavity and external wall insulations, respectively. Moreover, the effect of applying both insulation in the energy consumption, CO2 emissions, cost and payback period analysis was analysed.

KEYWORDS

CO2 Emission, Energy Consumption, Heat Transfer, Sustainability, Sustainable Energy, Thermal Comfort, Thermal Insulation, Thermal Load

INTRODUCTION

In this paper the assessment of opportunities to improve envelope performance and to provide thermal comfort for a case study building located in London, would be carried out using manual calculation method provided by CIBSE GUIDE A 2017. The building comprises 25 (1-bedroom) studio flats built in 1970.

The doctrine of environmental sustainability assessments is based on reducing the energy consumption and carbon dioxide emissions; reducing the growth of environmental emissions (Farsi, et al., 2017; Hosseinian_far, et al., 2010). One of the most disturbing problems with which all the countries around the world are struggling is the global warming which is a consequence of climate change and the CO_2 emitted mostly by human activities and purposes. Almost all the emitted CO_2 in the environment comes from the energy consumption by the industries, transportation and housings.

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In order to decrease the greenhouse gas and CO_2 emissions, the UK government has decided to reduce 60% of the carbon dioxide emissions by 2050 as of the levels in year 1990 (Hosseinian-Far, et al., 2017).

However, there are still some unclear points left about the different divisions' involvement and the financial instruments of reducing CO_2 emissions from the atmosphere after 2020. The building sector has had a considerable contribution in 0.7% of the total energy consumption reduction from 142,174 (ktoe) to 141,175 (ktoe) in the UK in 2017 (ECUK, 2018). Moreover, since 1970, the domestic sector has followed the transportation division in terms of the consumed energy by 28%. In this paper, the main focus will be on optimizing thermal comfort and the energy consumption of the case study building by taking the envelope influence into consideration. Compared with the other countries around the world, the UK has almost the oldest building stock. Due to an absence of building standards in the past, nowadays housing sector is one of the most insufficient energy consumer divisions. This problem means almost 45% of the total CO_2 emissions within the UK is resulted from the buildings (Hosseinian-Far, et al., 2017; Daneshkhah, et al., 2017; Government, 2018; HM Government, 2010). A huge amount of studies have been carried out during the last decades, especially after applying building regulation since 1970, to investigate the amount of energy consumed in the buildings. The envelope assessment has been considered as a valuable tool to save energy in buildings. This paper investigates the effects of the envelope in the energy consumption of a case study building by taking two important factors of thermal transmittance (U-Value) and admittance (Y-Value or thermal bridging) into account through load calculations validated by CIBSE guides. Housing sector in the UK have a high potential for application of energy efficiency improvements. The energy consumption of the UK housing in 1997 has been reduced by 4569 (ktoe) and reached 40,116 (ktoe) in 2017 (ECUK, 2018). The high potential of the energy saving in the building sector has been shown by previous studies. Although, there has been a significant improvement implemented by the UK government, still the domestic sector has a potential of 32% of carbon emission reduction among the other divisions regarding 5th carbon budget (Rosenow, et al., 2018).

The UK housing have 3 major divisions: flat or bungalow, detached and semi-detached or terraced house (Palmer & Cooper, 2011). In order to meet the 80% CO_2 emission reduction and energy consumption target, the UK government has produced a Standard Assessment Procedure for Energy Rating of Dwellings (SAP, 2012) to classify the new and existing buildings and provide regulatory measurement for designing and retrofitting purposes.

"The state of mind which expresses satisfaction with the thermal environment is defined as the thermal comfort". This condition varies in terms of the climate, occupants clothing, activity level of people inside the building, nature of the body and type of the building (Tasssou & Jouhara, 2017).

The factors affecting the thermal comfort are divided into two main categories: environmental factors and personal factors. The environmental factors include, the sun light, air temperature, mean radiant temperature, relative air speed and humidity. However, metabolic heat production and the type of occupants' clothing form the personal factors influencing the thermal comfort (CIBSE GUIDE A, 2017).

In a study, (Myhren & Holmberg, 2008) defined the thermal comfort as a range of air temperature around 37 °C associating skin temperature between 32-32 °C which the human body performance is in the best position. Moreover, the thermal comfort can be described as the anticipation of a suitable condition inside the buildings for the occupants which relates directly to the time and place (Chappells & Shove, 2005). In a study (Derks, et al., 2018), analysed nurses' perception of the thermal comfort within the hospital ward. The results showed that by taking seasonal and oriental conditions into account, the easiest way to provide better thermal condition is to design different zones in the hospital wards as the perception of thermal comfort of staffs differs from the patients considerably. In addition, in a further study (Luo, et al., 2018) assessed the indoor thermal comfort of four college-aged subject groups in different locations where lived only in northern, migrated from south to the north, lived only in south and had moved from north to the south in China. The results illustrated that the geographical location has a significant impact on feeling neutral within the buildings for those migrated from north to the south and vice versa.

Therefore, following the discussed points, this research identifies the vital elements of affecting buildings' envelope contributing to overall thermal performance, in order to provide thermal comfort for occupants. Although, other papers through literature have illustrated the significance of applying state-of-the-art technologies to meet requirements and maintain buildings thermal performance in an acceptable level; this research emphases on envelop performance improvement effects through a coherent designed methodology of applying standard calculations to analyse energy demand, greenhouse gasses emissions and capital investment payback period. And the aim is to identify the most efficient way of improving buildings envelop thermal performance and determine both potential energy and cost savings along with meeting environmental sustainability principles.

This paper consists of 5 main parts. In the first part (Introduction), the significance of studying global warming as a consequence of growing energy demand and greenhouse gasses emissions is discussed. Moreover, thermal comfort fundamentals, the energy demand within buildings and the importance of improving building thermal performance to provide thermal comfort is discussed within the first part. Having introduced the importance of conducting the research within the first part, the paper expands in the second part through a through literature review in order to identify the key influential elements within buildings envelop to provide indoor comfort. The findings within literature are incorporated to an integrated methodology of analysing the key identified aspect through a thorough methodology in the third part. Base case scenario is applied in order to provide both solid understanding of current situation and as a reference to the degree of improvements. The findings are represented in the fourth part along with appropriate discussions, tables and figures. In the fifth part a holistic view of the study considering the obtained results is represented and concluded.

LITERATURE REVIEW

The heat can be defined as the transforming energy due to temperature variations and include three types: heat flow by conduction, convection and radiation. The heat transfer by conduction occurs between two adjacent molecules as the result of temperature difference. However, in heat transfer by convection, presence of a fluid, either gas or liquid, transferring the energy is compulsory. Moreover, the heat transfer by radiation occurs between two substances having different surface temperatures which the sun is the main source of this type of heat transfer (Karayiannis & Ratcliffe, 2016). The factors affecting the heat transfer and thermal comfort within the buildings are called thermal load. Mostly these loads belong to the artificial lighting within the building, loads of the equipment such as computers, occupants load, ventilation load in the new constructed buildings, infiltration mostly in the old buildings and solar gains (Irsyad, et al., 2017).

In another study, (Yoshino, et al., 2017) realised 6 main factors affecting the building thermal load, according to the international energy agency assessment, including: local weather, building's façade features, building energy management, internal design requirement, type of occupants activities and the building performance.

In order to provide optimised thermal comfort within buildings the amount of consumed energy by the Air-Conditioning system should be taken into account. Moreover, the more energy is consumed, the more CO_2 will be emitted into the environment. The 30% of emitted CO_2 comes directly from the consumed energy in the building sector which has taken 40% of global energy consumption around the world (Yang, et al., 2014). Currently, awareness of the global warming and climate change danger has been increased and is about three factors of economic growth, energy use and associated environmental pollutants. This has caused to attempts in trying to decrease the fossil fuels usage (Lean & Smyth, 2010; Hosseinian-Far, et al., 2017; Farsi, et al., 2017). Moreover, although, the residential building in Malaysia contribute to 19% of total energy consumption, utilizing Air-Conditioning systems during the warm seasons affects this amount that will increase continuously (Cheung, et al., 2005).

THE EFFECT OF BUILDING ENVELOPE ON THERMAL COMFORT AND ENERGY CONSUMPTION

Although currently a large number of researches and studies have been carried out to investigate the energy consumption reduction while providing thermal comfort within the buildings, most of them have considered using sustainable energies such as wind power, solar thermal and PV panels, and less attention has been brought into envelope performance of the buildings. In the UK, many buildings exist from many years ago especially some of them belong to the Victorian era. Therefore, the UK is likely to have older buildings in comparison with the other European countries. This shows that most of the buildings have poor insulation resulting in more energy consumption (ECUK, 2018).

LIGHTING LOAD WITHIN THE BUILDING

The lighting load is considered as an internal load. Location, orientation and type of the lights have significant influence on bringing the heat to internal surfaces. In order to provide between 150 to 800 lux illuminances within the buildings, the amount of the lighting load for the buildings built in 1970s and 1980s was around 30 W/m^2. However, in the new buildings by using modern methods in manufacturing and building thermal load designing, it has reduced by around 15 W/m^2 to provide 500 lux illuminance (CIBSE GUIDE A, 2017). The energy consumed within the buildings by HVAC systems to provide thermal comfort and satisfy the occupants takes about one third of the total energy consumed in the world. In addition, the amount of the electricity consumed to provide artificial lighting has been estimated around 19% of the total electricity consumed in the world (Baloch, et al., 2018). Thus, it is clear that lighting load has a significant impact on the thermal load which should be considered during designing stages by building services engineers.

SOLAR HEAT GAINS WITHIN THE BUILDINGS

During the last decade many studies have been carried out to investigate the effect of the solar radiation on the internal heat loads. According to the table 5.19 CIBSE GUIDE A, 2017, heat gains by solar radiation are divided into 4 categories: the direct transmitted heat to the environment, the heat absorbed by the glazing, the amount of absorbed heat by the shades inside the building and the absorbed heat by building façade (walls, roof and floor). Solar heat gains should be considered during summer for calculations of the cooling load specially in buildings where a broad area of the envelope consists of glazing (Lu, et al., 2017).

In order to build high efficiency buildings, the amount of the glazing area to the envelope should be considered which plays the most important role in solar gains within the buildings. The radiated solar energy to the Earth is divided in 3 parts: 4% ultra-violate radiation which the human is unable to recognise, 47% can be seen as the natural light by human eyes and nearly 50% of this energy is infrared radiation (Ahmed, et al., 2017). Although this radiation affects the heat gains, utilizing natural light of the sun can reduce using the amount of artificial lighting produced by the lights and consequently reduction in the cooling load as well (Bodart & Herede, 2002).

THE EFFECT OF THE WALLS ON ENVELOPE PERFORMANCE

In 2016, out of 27.7 million properties in the UK, around 70% (13.3 million) of the properties have cavity walls, the number of buildings with 125mm loft insulation was 15.8 million (66%) and 718,000 buildings (around 8%) had solid wall insulation, (BEIS, 2017). The External walls usually consist of different layers. The outer surface of them normally is constructed by heavy weight materials such as brick works. However, the inner and middle surfaces include lightweight materials and insulations such as plater and mineral wool (Leccese, et al., 2018). Although, the approach of using heavy wright and low thermal performance materials in external walls has changed, a huge number of existing buildings in the UK have low thermal performance materials in their walls such as brickwork the usage of which goes back to 1970s. In the historic buildings the external walls mostly are constructed by brickwork (Calle & Bossche, 2017). The problem is moisture; water has harmful influence on the brick works, resulting in mould growth, condensation and undesirable heat loss specially when the raindrops heat the outer surface of the external walls of building. These issues can be solved by increasing thermal insulation (Abuku, et al., 2009). However, adding more insulation to overcome heat loss in the winter may cause overheating in summertime. (Tink, et al., 2018).

Although currently, the amount of unfilled voids by mortar has been reduced, still historic buildings suffer from this issue due to absence of data (Guizzardi, et al., 2015). They carried out a test to investigate the Hydrothermal performance of an extensive wall exposed to the moisture. The test showed that moisture movement is faster within the outer surfaces of the wall comparing to the inner side.

Wall insulations are divided into 3 categories such as internal wall, cavity wall and external wall insulations. Wall thermal insulations can result in increasing the wall thermal resistance, air tightness, thermal comfort and reducing the energy consumption (Rovers, et al., 2017).

One of the most common ways to reduce the energy consumption to provide thermal comfort within the building is applying external wall insulations, especially in solid wall and cavity buildings. Reduction in the probability of inside surface condensation would be a good result of external wall insulation. Moreover, this would not cause significant problem for the building residents during retrofitting (Tingley, et al., 2015).

The selection of materials to be used in the building fabric plays a significant role in the energy consumption. Uninsulated external walls can contribute to almost 35% of the total heat loss. However, filling the cavities of the external walls or applying other type of insulations can prevent around 60% of the total heat loss (EST, 2010). In another study, (Kontoleon & Giarma, 2016) which examined passive thermal behaviour of buildings, has found that the thermal transmittance of each multi-layered wall is responsible for its thermal performance.

THERMAL BRIDGING INFLUENCE ON HEAT LOSS THROUGH THE FABRIC

One of the most important factors influencing the heat transfer and temperature fluctuation through the building envelope is thermal bridging. The surface temperature reduction resulting from heat transfer through the envelope layers should be diminished. The high potential parts of the building facade which can play as a thermal bridge are roof eaves, window and door frames and the junctions at the end of each surface. The reason that the thermal bridging has not been taken into account was that its effect is negligible comparing to the total heat loss by transmission (CIBSE GUIDE A, 2017). This issue can cause a major problem of mould growth. However, this can be significantly reduced by applying a minimum layer of insulation to the walls (Fantucci, et al., 2017).

In old buildings, ventilated envelope is a well-known fabric design technique specially those made by aluminium. By using this technique, the building will benefit in terms of the heat loss through linear thermal bridging, moisture problems, fire protection, and noise annoyance (Theodosiou, et al., 2017). There are different types of thermal bridging within the building envelope. The most complex thermal bridging in the window system buildings occurs in the windows as their thermal performance depends on the thermal performance of the frame as well (O'Grady, et al., 2018).

METHODOLOGY

In this section, the methodology which was followed to investigate the energy consumption of the building and acquire the best solution to improve the level of energy consumption along with providing thermal comfort is designated. The effect of external wall layers and glazing on the heat loss and energy consumption will be investigated through U-Value and Y-Value calculations. Moreover, the effects of infiltration heat loss in the consumed energy will be analysed as the building is old and infiltration heat losses have not been considered during designing stages due to lack of standard methodology or legislative designing approaches. At the next stage, application of 30 (mm) Extruded Polystyrene-Board as an external insulation and calculation of filling the cavity between the external wall by closed cell Polyurethane-Foam would be carried out in order to select the best option of optimising the building energy performance. Once both filling the cavity and PCM application is done, the lower heat loss in the building between each one would be selected considering the best case scenario and cost analysis would be carried out in order calculate the application costs and energy consumption by the boilers to provide thermal comfort within the building. Therefore, the standard heat load calculation methodology provided within the CIBSE GUIDE A 2017 was followed in order to conduct required calculations and discover the best solution.

According to the monthly energy bills, cost of the heating source was considered 0.0338 (£/kWh) for the gas fuel boilers. Moreover, capital cost of both the insulations are to be calculated. Although both the insulations are well known and broadly provided in the market, due to lack of sufficient data about the labour costs, the prices of both the insulations will be taken from them (BEIS, 2017). The price of external wall insulation has been provided £55 per m^2 of the wall area including material and labour; while for the cavity wall insulation it is £5 per (m^2) of the wall area. Then as the building is occupied by the people who are 60 years old or more, the UK government suggests VAT of 5% instead of the normal 20%, in case of energy improvement retrofitting (GOV.UK, 2018). Last but not least, the obtained saved money in a month will be multiplied by 12 in order to achieve the approximate annual saving. Once the capital costs of both methods are calculated, the payback period will be analysed using the annual saving and capital cost of applying Polyurethane-Foam and Polystyrene-Boards insulations.

THE CASE STUDY BUILDING CHARACTERISTICS

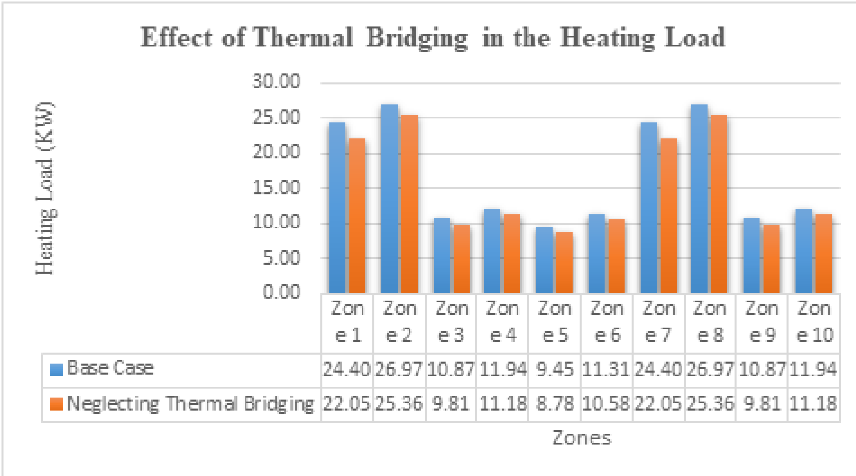
The case study building is a 2 story 25 flats retirement housing building, including 1 bedroom for each unit, built in 1972, and consisting of sold red bricks in the external walls, flat roof and double-glazed windows. Currently is used by old people and those who need extra care. The total net floor area was measured 737.5 m^2 on site and was compared with the Google earth software tools in order to get the most accurate data. Moreover, the total height of the building has been measured 5.6 (m) from the ground. Therefore, each floor height is obtained 2.8 (m).

The building comprises 3 main parts, two residential blocks facing to the west (western block) and east (eastern) respectively where have the same shape and a middle passage block which is used as connection between the two main residential blocks. Each of the residential blocks include 12 units 6 on each floor and 1 unit in the middle block (zone 5). The building does not have an air conditioning system and is naturally ventilated by openable windows. During the winter thermal comfort within the building is satisfied by heat emitters located in each flat. Heat emitters are fed by central plant using three atmospheric conventional gas fired boilers, each one having an output of 67 (KW) which gives total output of 201 (KW) all together.

ZONING

Due to absence of building plan schematics, the aim was to take the best decision to calculate the most accurate thermal loss from the building. Therefore, the first step of carrying heat loss and heat load calculations is zoning. According to the shape and location of the building which includes 3 blocks, it will be divided into 10 individual zones. The western and eastern blocks will be divided to 4 zones for each one and the middle block will be divided in two zones which gives 10 zones all together. The main entrances and receptions in the western and eastern blocks are considered as

Figure 1. Case study building's ground floor



unconditioned spaces due to absence of heat emitters in those areas. Figures 1 and 2 illustrate simple schematic of building zoning divisions.

THE EXTERNAL WALL OPTIMIZATION APPLYING 30 (MM) EXTRUDED POLYSTYRENE-BOARD AS EXTERNAL INSULATION

In order optimise the building envelope performance 30 (mm) Extruded Polystyrene-Board Figure 3. was chosen as an external insulation for the external walls. It has the ability of being fully recycled

Figure 2. Case study building's first floor

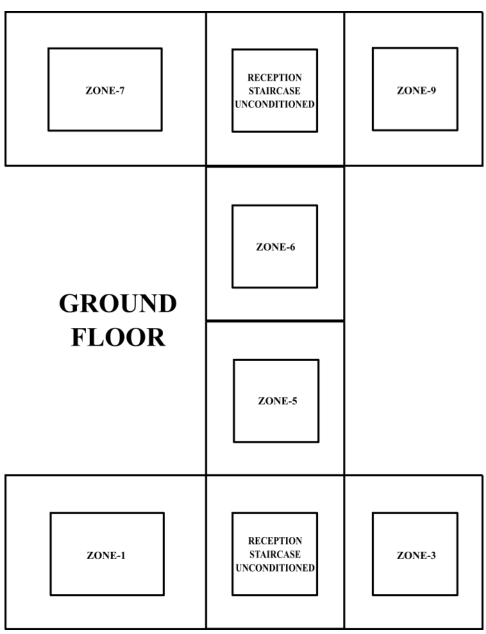
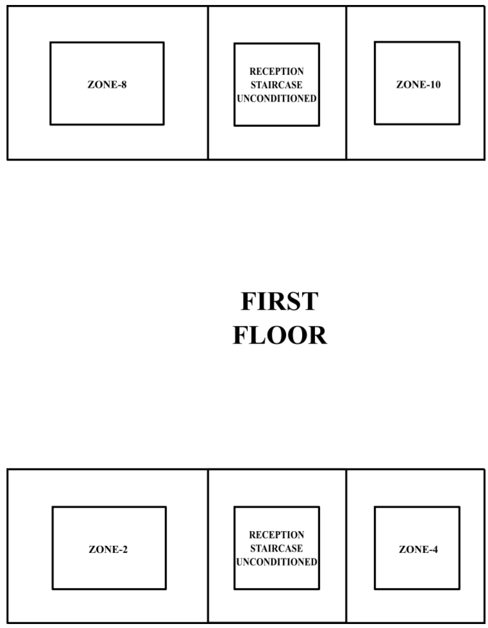


Figure 3. Extruded polystyrene external wall insulation



and environmentally friendly. This insulation is a good choice for the places with severe weather conditions like the UK due to its strength and resistance. There are many types of this insulation in the market and it has been widely used to optimise the building envelope performance as external wall, roof, internal wall and floor insulation specially in the UK.

The selected insulation has a length and width of 1200 (mm) and 600 (mm) respectively and for the 30 (mm) thickness it can provide thermal conductivity of 0.034 (W/m K). This Extruded Polystyrene-Board can be applied to the building without causing annoyance to the occupants. Moreover, it has high resistance against the water and there is no need for special tools to set up and cut off the insulation from the wall.

CAVITY EXTERNAL WALL INSULATION BY APPLYING CLOSED CELL POLYURETHANE-FOAM

As the second option to optimise the building's envelope performance, application of closed cell Polyurethane-Foam Figure 4, will be examined. This type of insulation has been used widely in the old buildings to improve the envelope performance. This foam has density of 40 (kg/m^3) and thermal conductivity of 0.022 (W/mK) and is going to fill 50 (mm) air space between the external wall.

RESULTS AND ANALYSIS

In order to start the analysis, the building's base case heat loss was calculated according to the onsite measurement. The Table 1 gives a summary of total calculated base case heating load through the building incorporating each individual zone.

Figure 4. Closed cell polyurethane foam

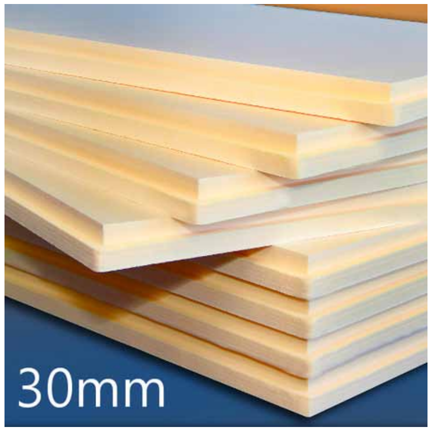


Table 1. Base case calculated heating load

Onsite Measurement	
Description	**Heating Load (kW)**
Zone 1	24.40
Zone 2	26.97
Zone 3	10.87
Zone 4	11.94
Zone 5	9.45
Zone 6	11.31
Zone 7	24.40
Zone 8	26.97
Zone 9	10.87
Zone 10	11.94
Total Load (without diversity factor)	169.11
Applying heating diversity factor	135.29

HEATING LOAD CALCULATIONS AFTER APPLYING THE EXTRUDED POLYSTYRENE-BOARD EXTERNAL INSULATION

The selected insulation has been provided to the industry in different categories in terms of the thickness and thermal conductivity. At the first step using the given data of 0.034 (W/mK) thermal conductivity and 30 (mm) thickness the new U-Value of the wall was calculated as shown in the Table 2.

Since the external wall insulation was applied to external wall, the U-Value was reduced by 1.671 from 1.7 to 0.029 (W/m^{2}K). Once the results were obtained, it was observed that a significant amount of the heating load was reduced by approximately 18% from 169.11 to 139.73 (KW). The data of each individual zone comparing with the base case heating load is illustrated in Figure 5.

Considering zones 1, 2, 7 and 8 which included more external walls comparing the other zones, the heating load was reduced by approximately 19%; whereas, for the zones 3, 4, 9 and 10 which

Table 2. Optimised U-Value by applying extruded polystyrene-board

Optimized U-Value by External Insulation Polystyrene Board							
Component	**Description**	**R_i (m^2K/W)**	**R_o (m^2K/W)**	**Thickness (m)**	**Thermal Conductivity (W/mK)**	**R_T (m^2K/W)**	**U-Value (W/m^2K)**
	30mm Extruded Polystyrene Board			0.03	0.034		
External Wall		0.13	0.04			33.91	0.029
	Exposed Brick			0.105	0.77		
	air space			0.05	0.42		
	Exposed Dense Concrete			0.1	1.87		

Figure 5. Heating load data before and after applying extruded polystyrene-board

cover a little bit less external wall surfaces decreased by around 22%. It should be considered that the heating load of the zones 5 and 6 where are located in the middle block of the building had a very small difference compared with the base case data as these zones are mostly covered by the glazing.

CLOSED CELL POLYURETHANE-FOAM (PUF) U-VALUE ANALYSIS

Using the given thermal conductivity of 0.022 (W/mK) by the manufacturer the new U-Value after applying the insulation was calculated which is shown in the Table 3.

Applying the cavity insulation gave a U-Value of 0.028 (W/m^2K) for the external wall. Comparing the new result with the building's base case there was a reduction of 1.74 (W/m^2K); around 98%. In addition, percentage reduction in the new calculated U-Value was applied to the base case which

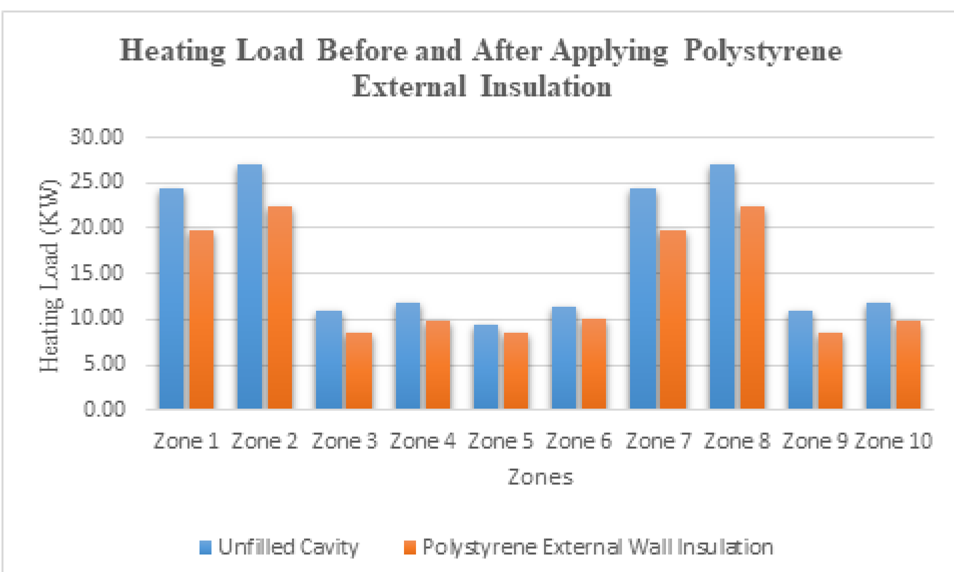
Table 3. The new calculated U-Value of the external wall after filling the cavity by closed cell polyurethane foam

Optimized U-Value by Polyurethane Foam							
Component	**Description**	**R_i (m^2K/W)**	**R_o (m^2K/W)**	**Thickness (m)**	**Thermal Conductivity (W/mK)**	**R_T (m^2K/W)**	**U-Value (W/m^2K)**
External Wall	Exposed Brick	0.13	0.04	0.105	0.77	35.178	0.028
	Cavity Filled by Polyurethane Foam			0.05	0.022		
	Exposed Dense Concrete			0.1	1.87		
	Dense Plaster			0.013	0.57		

for example gave a reduction from 2347 (W/K) to 2336 (W/K) in the zone 7. Although the obtained U-value was lower than the Polystyrene-Boards, there was little difference which can be neglected.

The results show that a significant amount of the heat loss through the building was cut due to improving the external wall cavity, considerably in the zones 1, 2, 7 and 8 where include more external walls. Then, the differences between the base case and the cavity heating loads after filling were compared which are illustrated in the Figure 6. Considering the four zones mentioned above, the heating load after applying the cavity insulation has been reduced around 5 (KW) in each zone. Regarding Zones 3, 4, 9 and 10, they experienced approximately 3 (KW) heating load reduction in each zone. Considering the four zones mentioned above, the heating load after applying the cavity insulation has been reduced around 5 (KW) in each zone. Regarding Zones 3, 4, 9 and 10, they experienced approximately 3 (KW) heating load reduction in each zone. By taking zone 6 into

Figure 6. Heating load of individual zones before and after applying polyurethane foam



consideration where has a similar reduction to zone 5, the zone's south face is covered by glazing and the north face was considered as an internal wall.

Still the effect of applying external cavity wall insulation can be seen by having a reduction of 1 (KW). This is because the polyurethane foam can even fill the unfilled tiny holes during construction by mortar, resulting in reducing the effect of thermal bridging in the zone junctions.

EFFECT OF THERMAL BRIDGING IN THE BUILDING HEATING LOAD

After calculation and examination of applying the Extruded Polystyrene-Boards and Closed Cell Polyurethane-Foam insulations to the external wall of the building, the effect of heat transfer through the thermal bridging in the envelope junctions was analysed, comparing to the calculated base case heat load. Although, the effect of heat loss through the thermal bridges in each zone was negligible, the total heating load became 156.17 (KW) by a reduction of around 13 (KW). Figure 7 shows the effect of neglecting thermal bridging heat loss through the building.

ENERGY CONSUMPTION ASSOCIATING CO2 EMISSIONS ANALYSIS

Since all the heating load analysis were obtained, the amount of energy consumed by applying both thermal insulations to the external wall associating the emitted CO_2 was calculated. Examining application of both the insulations gave 17% reduction in the consumed energy and emitted CO_2. Multiplying the amount reduced CO_2 by 12, gave annual reduction of 518.16 ($KgCO_2$). The obtained results are shown in the Table 4.

THE ENERGY CONSUMPTION AND SAVINGS

Considering that the building is fed by 3 gas fuel boilers, the cost of daily and monthly energy consumed by the boilers according to the heating loads of all three cases (Base case, with Extruded

Figure 7. Effect of neglecting thermal bridging heat loss through the building

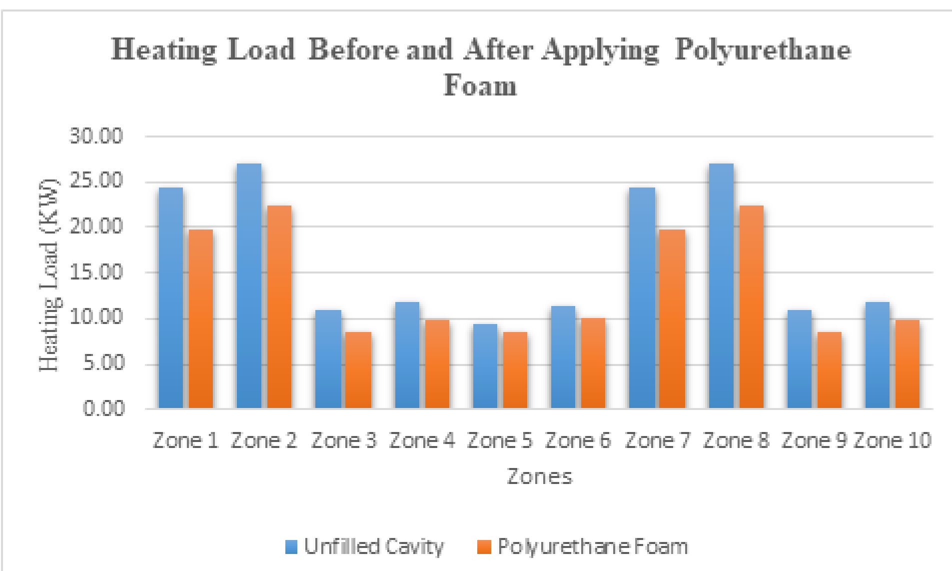


Table 4. Energy consumption and associated carbon dioxide CO2 emission

CO_2 Emissions Investigation Considering the Energy Consumption					
Description	**Total Heat Loss (KW)**	**Energy Consumed (kWh)**	**Conversion Factor**	**CO_2 Emitted ($KgCO_2$)**	**Saving (%)**
Base Case	169.11	1352.92	0.184	248.88	-
Polyurethane Foam in the Cavity	139.77	1118.16	0.184	205.70	17
Polystyrene Board as External Insulation	139.79	1118.29	0.184	205.72	17

Polystyrene-Board and Closed Polyurethane-Foam) to satisfy thermal comfort within the building was calculated which is shown in the Table 5.

Moreover, the amount of the daily and monthly cost saving was obtained for both the insulations which is shown in the Table 6.

CAPITAL COST AND PAYBACK PERIOD

The capital cost of both the applied insulations according to the material price, labour cost per (m^2) and VAT factor was calculated in order to analyse and examine the benefits of these investments. Moreover, the payback periods of applying both the insulations were obtained using the approximated annual saving provided by both insulations which are shown in Table 7.

The results showed although both methods provide same amount of cost saving, there is a huge difference in the total capital cost between them. The total capital cost of applying the Extruded

Table 5. The energy consumption cost analysis

Energy Consumption Cost						
Description	**Total Heat Loss per Day (KW)**	**Energy Consumed (kWh) 8 hr/day**	**Fuel Consumption Rate (0.0338 £/kWh)**	**Applying 5% VAT**	**Total Energy Cost per Day (£/kWh)**	**Total Energy Cost per Month (£/kWh)**
Base Case Heat Loss	169.11	1352.92	45.73	2.29	48.02	1440.45
Polyurethane Foam in the Cavity	139.77	1118.16	37.79	1.89	39.68	1190.50
Polystyrene Board as External Insulation	139.79	1118.29	37.80	1.89	39.69	1190.64

Table 6. Cost saving analysis after applying both the thermal insulations

Energy Cost Savings			
Description	**Per Day (£)**	**Per Month (£)**	**Saving (%)**
Polyurethane Foam in the Cavity	8.33	249.95	17
Polystyrene Board as External Insulation	8.33	249.81	17

Table 7. Total capital cost and associated payback period

Total Capital Cost and Payback Period							
Description	**Material and Labour (£)**	**Area (m^2)**	**Cost (£)**	**VAT (5%) (£)**	**Final Cost (£)**	**Annual Saving (£)**	**Payback Period (Year)**
Polyurethane Foam in the Cavity	5	673	3365	168	3533	2999	1.2
Polystyrene Board as External Insulation	55	673	37015	1851	38866	2998	13

Polystyrene-Boards obtained £38,866 which is around 11 times bigger than total capital cost of applying Closed Cell Polyurethane-Foam. The analysis of applying the Polyurethane-Foam became £3533 resulting in less than 1.5-year payback period. Whereas, the mentioned above capital cost of Polystyrene-Boards gave a period of 13 years to return the invested money in improving the energy efficiency of the building.

CONCLUSION

In conclusion, the analysis showed that a significant amount of heat loss can be prevented by U-Value measurement and using exposed wall insulations (cavity or external). Moreover, the results of this paper showed that by applying other envelope component such as roof, ceiling, ground floor thermal insulations and triple glazing windows significant amount of heating load, consumed energy and emitted CO_2 will be reduced. Furthermore, neglecting thermal bridging can lead to underestimating the heating load and more energy consumption and more CO_2 emissions.

In conclusion Although the Extruded Polystyrene-Board is completely recyclable, using Closed Cell Polyurethane-Foam as the cavity insulation was found more cost effective. As the focus of this research is on the effect of building envelope on the thermal loads, suggestions and recommendations are related to the topic of the study. However, during site visit it was observed that building suffers from lack of efficient HVAC systems:

- In order to get the most accurate results, the building’s schematic plans, hot water and piping details of the building should be provided to the investigators, which can help them use an analyser software such as IES VE and Energy Plus.
- Although, applying external wall insulation has a significant effect on the energy consumption, and using roof and floor thermal insulations can add more energy saving.
- Moreover, using triple glazing windows can contribute to energy saving due to their lower U-Value comparing to the double-glazed windows.
- In addition to the thermal insulation that reduces probability of occurring the condensation, the main impact of condensation in the buildings is due to lack of efficient air conditioning system. While there is no air conditioning system in the building, electrical dehumidifiers can be used in order to help reduce the chance of condensation within the building.
- It is better to recognise the materials used in the building fabric by the envelope experts to calculate each component’s thermal resistance.
- Providing party wall insulation to the internal walls adjacent to the staircases can improve the energy efficiency of the building in addition to the other envelope components.

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APPENDIX

Table 8. Glossary

Abbreviations	Description	Unit
VAT	Value Added Tax	n/a
SAP	The Governments Standard Assessment Procedure	n/a
CIBSE	The Charted Institution of Building Services Engineers	n/a
ktoe	Kiloton of Oil Equivalent	n/a
CO_2	Carbon Dioxide	n/a
$KgCO_2$	Kilograms of CO_2	n/a
f	Decrement Factor	n/a
N_p	Number of People	n/a
Ɛ	Emissivity	n/a
M^2	Meter Square	n/a
M^3	Cubic Meter	n/a
C^o	Temperature	Celsius
K	Temperature	Kelvin
k	Thermal Conductivity	w/m.K
w	Power	W, KW
U-value	Thermal Transmittance	w/ M^2K
Y-value	Thermal Admittance	w/ M^2K
R_T	Total Thermal Resistance	M^2/K.W
R_i	Inside Surface Resistance	M^2/K.W
R_o	Outside Surface Resistance	M^2/K.W
T_i	Inside Temperature	C^o
T_o	Outside Temperature	C^o
λ_g	Thermal Conductivity	w/m.K

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