World Renewable Energy Forum, WREF 2012, Including World Renewable Energy Congress XII and Colorado Renewable Energy Society (CRES) Annual Conference, 6, pp.4636-4643.

HEAT LOAD AND SOLAR GAIN PREDICTION FOR SOLID WALL DWELLINGS RETROFITTED WITH TRIPLE VACUUM GLAZING FOR SELECTED WINDOW TO WALL AREA RATIOS

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ABSTRACT

In much of the developed world there is a large stock of solid wall dwellings that require intervention to improve their energy performance. Heat loss through the windows of solid wall buildings is one of the factors contributing to high energy consumption for space heating resulting in excessive carbon emissions which lead to climate change. In this paper the heat load and solar gain are analysed for a room in a solid wall dwelling with single, double air filled, triple air filled, double vacuum and triple vacuum glazings at 5.49%, 12.36%, 13.19%, 20.6%, 24.72% and 32.96% window to wall area ratios (WWR's). Simulated results are presented and the influence on energy required for space heating and solar energy gain in winter months (Dec, Jan and Feb) are analysed. The costs for space heating energy are calculated and show that replacing single glazed windows with triple vacuum glazed windows in the simulated room of a solid wall dwelling could save £36.07 annually. Assuming a dwelling consists of 6 simulated rooms, considerable energy and cost savings could be realised. It was also shown that for low heat loss glazings it is possible to significantly increase the window to wall area ratios with little increase in room heat load.

1. INTRODUCTION

Demand side carbon reduction and energy efficiency of buildings and dwellings are currently major concerns due to links with climate change. Energy efficiency can be improved by using a high performance window, high levels of wall insulation and changes in window to wall area ratios, efficient appliances leading to reduction in fuel use and carbon dioxide (CO_2) emissions. The window to wall ratio has a significant effect on dwellings for both energy required for space heating and solar gain. By using triple vacuum glazing it is possible to increase the window to wall area ratio (WWR) with little penalty in terms of heat load required to heat the rooms of a solid wall dwelling. Heat loss through glazings was estimated to contribute to 11.3-11.7 % of the CO_2 emissions from buildings (Peacock *et al*, 2007). Replacing standard air filled double glazing with vacuum glazing will reduce the U value from 2.75 down to approximately 0.8 W/(m^2.K), reducing the heat loss by more than three times. Further reduction in heat loss to less than 0.5 W/(m^2.K) can be achieved by using triple vacuum glazing, this will enable switching off or turning down of radiators reducing power consumption and the use of fossil fuels. This research forms part of the CALEBRE (Consumer Appealing Low energy Technologies for Building Retrofitting) project that has the aim of establishing a robust refurbishment package for reducing UK domestic carbon emissions resulting from solid wall dwellings.

2. METHODOLOGY

2.1 Modelling and Simulation Approach

The room of a solid wall dwelling was simulated with single, double air filled, triple air filled, double vacuum and triple vacuum glazed windows comprising 5.49%, 12.36%, 13.19%, 20.6%, 24.72%, and 32.96% of the area of the external wall illustrated in figure 1. The room is part of a building having properties of floor, roof, solid wall and door constructions detailed in table 1 with dimensions of 6.5mx6.5mx2.8m.The heat load and solar gain is simulated using the IES simulation software (IES, 2011). The energy consumption of a LTHW boiler to provide space heating and the solar energy gain are simulated to determine the heating load in the winter months (Dec, Jan and Feb) to maintain a set point temperature of 21°C. The annual energy consumption is also calculated and the cost based on domestic gas tariff prices in the UK calculated and compared to that for a room with triple vacuum glazed windows. The annual energy consumption, cost based on domestic gas tariff prices, and the energy savings are compared with a single glazed window room for the different glazing systems where the reduction in energy costs are calculated.

The inside heating set-point temperature of the room is 21°C. The outdoor weather conditions used are from the ASHRAE design weather database v4.0 with a default location of London/Heathrow. The outdoor profile is illustrated in figure 2. For all of the solid wall dwellings modelled for peak summer time conditions, external air temperatures can lead to overheating as the set point temperature is fixed and the outside temperature at various times is greater than this. The control is set so that heating is switched on when the indoor temperature is under 21°C. The maximum outside air temperature is approximately 28°C, this would lead to the indoor air temperature increasing to higher values than this due to solar and casual heat gains in the room. The selected cooling system in the model is natural ventilation. The maximum outside air temperature only occurs for a short period of time during which the heating system will be turned off automatically. During the months of May to the middle of August there is a minor increase in the indoor room temperature due to a sudden increase in the outside temperature and the inadequacy of the natural ventilation to maintain the 21°C temperature as shown in figure 2.

The detailed design parameters for the simulations are given in table 1. The main focus of the reported work is on the performance analysis and comparison of single, double and triple vacuum glazed windows. The standard EN-ISO U values are incorporated for single glazing, double air filled glazing, and triple air filled glazing. For the double and triple vacuum glazing; It has a vacuum inside the cavity between the panes a thermal resistance value is used. The single glazed window (a glass sheet without low e coating) is used as a baseline for comparison. Vacuum

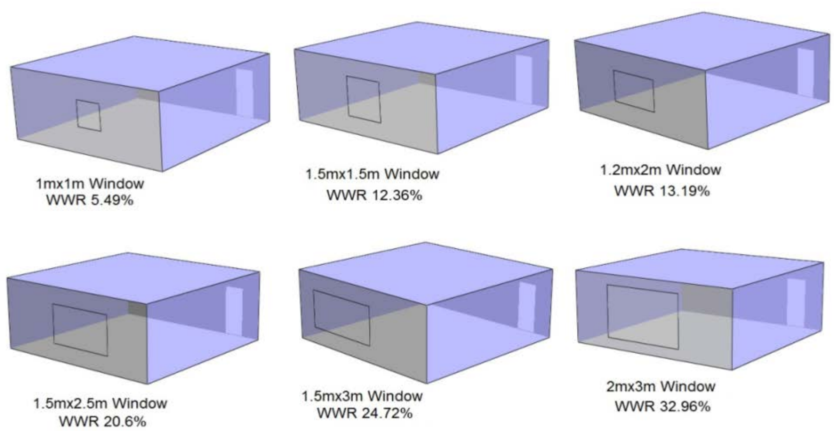


Fig. 1: A schematic diagram of the room modelled with 5.49%, 12.36%, 13.19%, 20.60%, 24.72%, and 32.96% window to wall area ratios.

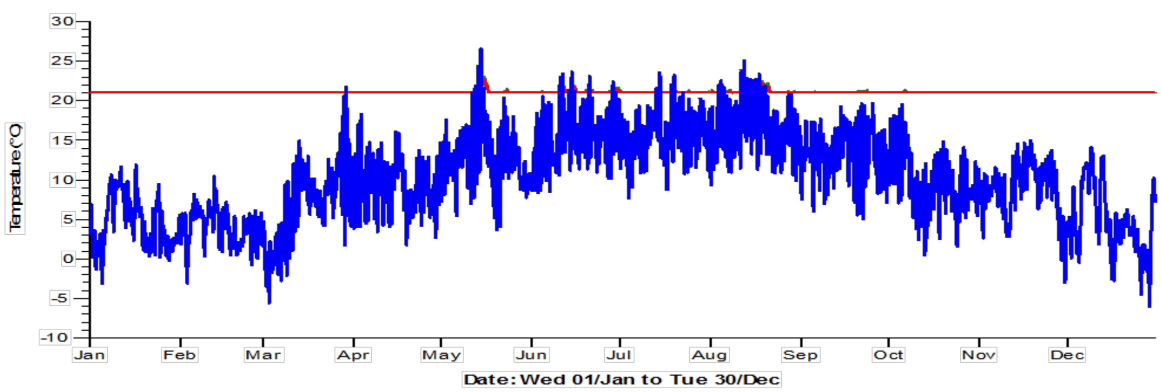


Fig. 2: Annual inside set-point temperature and outside temperature simulated using the ASHRAE database temperature profile for London/Heathrow UK.

glazing can reduce the heat loss compared to the standard glazing systems; essentially a thin vacuum gap of around 0.15mm width with a gas pressure of less than 0.1Pa is used to suppress gaseous conduction and convection. Using the IES software construction tool, double and triple vacuum glazings were simulated by increasing the thermal resistance of the cavity to give U values of 0.85 and 0.46 W/(m^2.K) respectively. The use of a standard wooden frame with a U value of 1.98 W/(m^2.K) decreases the U values of single and double air filled glazed window while increasing the U values of the triple air filled, double vacuum and triple vacuum glazed window because frame has a higher heat transfer coefficient than the glazing. The use of vacuum glazings on their own or together with solid wall internal surface insulation, can reduce heat losses significantly, in this work solid wall internal surface insulation is simulated to provide total U value of 0.35 W/(m^2.K). The advantages of this are that it reduces by almost one-third the energy loss through the wall, doesn't require planning permission and is cheaper than external insulation; the disadvantages are that the life span is short, up to 7 years, overheating can be an issue since it changes the building's response rate leading to larger swings in internal temperature and relative humidity by sorption/desorption causing overheating and moisture distress (Loveday *et al*, 2011). The reason for not simulating external wall insulation is that it changes the external appearance of the building and thus requires planning permission from the local area council (relevant to conservation areas) and is more expensive, however its expected life is greater than 12 years. The room heating conditions are implemented as hot water radiators using

TABLE 1: DESIGN PARAMETERS

Glazed Windows					
Parameters	*Thickness*	*Type of coatings (Emissivity)*	*Cavity Thermal Resistance*	*Frame*	*U values (glazing) & (with frame)* W/(m^2.K)
Single glazed Window	4mm= 1x4mm(glass)	No coating	–	(a) Material Hardwood	(5.7546) & (5.3779) (EN-ISO)
Double Air-filled Glazed Window	20mm= 2x4mm(glass) 1x12mm(cavity)	Two Tin Oxide hard (0.15-0.18)	0.173 m^2K/W	(b) Area Occupy 10%	(2.8525) & (2.7660) (EN-ISO)
Triple Air-filled Glazed Window	20mm=36mm 3x4mm(glass)- 2x12mm(cavity)	Three Tin Oxide hard (0.15-0.18)	0.173 m^2K/W	(c) Resistance 0.3332 m^2K/W	(1.8962) & (1.9053) (EN-ISO)
Double Vacuum Glazed Window	8.13mm= 2x4mm(glass)- 1x0.13mm(cavity)	Two Tin Oxide hard (0.15- 0.18)	1.00 m^2K/W	(d) U value 1.9873 W/(m^2.K)	(0.8492) & (0.963) (EN-ISO)
Triple Vacuum Glazed Window	12.26mm= 3x4mm(glass)- 2x0.13mm(cavity)	Three Tin Oxide hard (0.15-0.18)	1.00 m^2K/W		(0.4584) & (0.6113) (EN-ISO)
Visible light normal transmittance is kept constant *Solar reflectance is kept constant* *Inside/outside surface emissivity and (Resistance)*			0.76 0.69 0.9 / 0.9 (0.13 / 0.04 m^2K/W)		
Room Construction					
Roof U value		0.2497 W/(m^2.K) (Stone chippings, felt/bitumen layers, cast concrete, glass_fibre quilt, cavity, ceiling tiles- 6500mmx6500mmx409.5mm)			
Solid wall with internal insulation		0.3495 W/(m^2.K) (Brickwork [outer leaf], dense eps slab insulation, concrete block, gypsum plastering- 6500mmx273.5mmx2800mm)			
Floor U value		0.2499 W/m^2.K (London clay, brickwork [outer leaf], cast concrete, dense slab insulation, chipboard, synthetic carpet-6500mmx6500mmx1198.5mm)			
Door U value (Construction)		2.1944 W/m^2.K (Pine-762mmx1981mmx40mm)			
Room Conditions					
Simulated Heating set-point		On continuously 21°C			
Outside Temperature		Weather temperature ASHRAE database.			
Heating System		Central Heating water radiators using LTHW (Low temperature Hot Water) gas fired Boiler. Hot water supply temperature is 60°C			
Cooling System		Natural Ventilation			

LTHW boiler (Low Temperature Hot Water). A gas fired boiler provides hot water at a supply temperature of 60˚C. The boiler could be replaced by gas fired heat pumps or air source heat pumps but for consistency with the current domestic dwelling practices in the UK a LTHW gas fired boiler is used.

2.2 Simulation Methods of Heating Load and Solar Gains

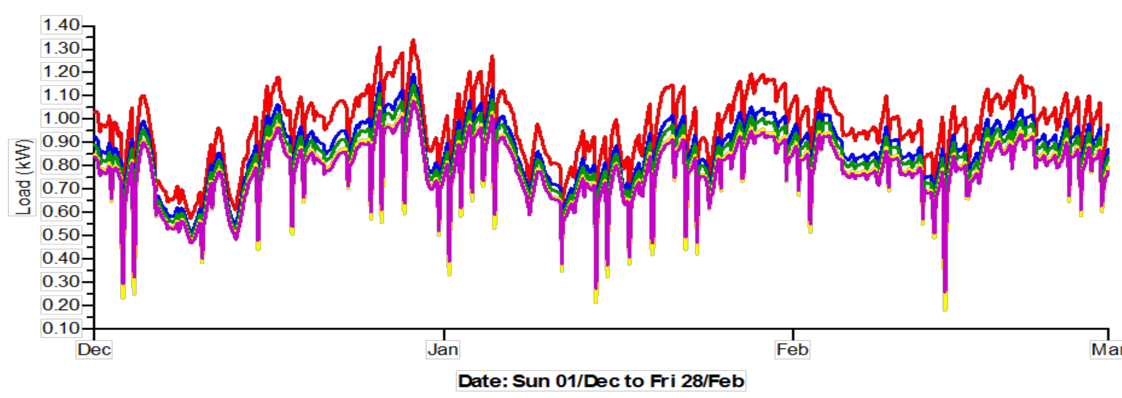
ASHRAE procedures are followed for the heat load calculation using the Apache thermal simulation tool (IES, 2011) in the IES software environment for the detailed simulation of a room in a domestic dwelling. The simulation was performed with a real weather data profile allowing heat load to be evaluated from periods of a day to a year required to maintain the inside room heating set point temperature of 21°C. Conduction in the room model element (wall, roof, ceiling, and floor) is assumed to be one-dimensional (IES, 2011) & (CIBSE, 1999). Air gaps or vacuum gaps of the windows are modelled as thermal resistance. For the interior surface of the room, CIBSE based constant convective heat transfer coefficient values of 3W/(m^2.K) are used. For the exterior surfaces of the room external forced convection was used with heat transfer coefficients based on wind speed calculated from McAdams empirical equation (CIBSE, 1999). Solar heat gain is the solar energy incident on the glazing transmitted to the room interior. Hard glazing coatings (Tin oxide) are used on the glazing surfaces in the simulations. The solar gains throughout the year transmitted through the glazing were determined using the Suncast shading data analysis tool. The detailed calculations are given in section 2, appendix 5A.2 and 5.A7 of the CIBSE guide (1999) & (IES, 2011).

3. RESULTS AND DISCUSSIONS

3.1 Winter Heat Load and Solar Gain Analysis

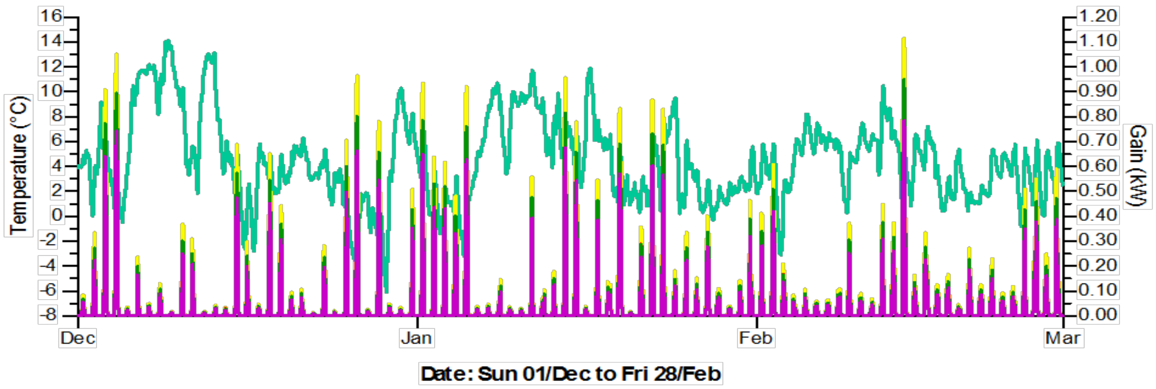
The room was simulated for the winter months (Dec, Jan and Feb) to calculate the heat load and solar gain in kW for single, double air filled, triple air filled, double vacuum, and triple vacuum glazed windows that maintains the internal air temperature at 21°C with the outdoor temperatures shown in figure 2. The results presented are based on a single room in a solid wall dwelling having window to wall area ratio of 13.19% (1.2m x 2m window) with the standard room design parameters detailed in table 1. It is clear that there is a compromise between solar heat gains and thermal transmittance, using low e coated triple vacuum glazing reduces solar gain and reduces thermal transmittance, which is beneficial during the winter season.

Figure 3 presents for the winter months (Dec, Jan and Feb) heat load comparison for the different windows (1.2m 2m size) of a solid wall dwelling at window to wall area ratio of 13.19%. It can be seen that the maximum heating power is consumed in December, specifically on the 29th in the morning, with 1.34kW consumed to maintain 21°C with a weather side temperature of -6.1°C for the case of a single glazed window, compared with a triple vacuum glazed window the heating required at that particular time is 1.08kW, a reduction of 260 watts. It can also be seen that the double and triple vacuum glazing performance is similar but at certain period the double vacuum glazed window room heat load is reduced than the room with triple vacuum glazed window because solar heat transfer is more on that timings of winter months using double vacuum glazing as compare to triple vacuum glazing.



Single Glazed Window Room Double Glazed Window Room Triple Glazed Window Room
Double Vacuum Glazed Window Room Triple Vacuum glazed Window Room

Fig. 3: Winter Heat load simulation for a single room with a window (1.2mx2m) of a solid wall dwelling using different types of windows for a window to wall area ratio 13.19%.



Single Glazed Window Room ——— Double Glazed Window Room ——— Triple Glazed Window Room ———
Double Vacuum Glazed Window Room ——— Triple Vacuum Glazed window Room ——— Weather side Temperature ———

Fig. 4: Winter Solar gain simulation for the single room (1.2mx2m) of a solid wall dwelling using different types of windows for a window to wall area ratio 13.19%.

From Figure 4 it can be seen that the maximum solar gain of 1.115kW is received though the single glazed window compared to a solar gain through the triple vacuum glazed window of 0.785kW, a difference of 0.33kW due to the lower solar transmittance of the triple vacuum glazing. The difference in peak solar gain compared to the single glazing for the other types of glazing double air filled, triple air filled and double vacuum glazed windows are 0.21kW, 0.314kW and 0.166kW respectively.

The heat required and solar gain for the winter months in kWh was calculated for the different glazing types. Figure 6 presents the calculated heating requirements for comparison for the different window types. It can be seen that the total heating energy required when using a double air filled glazing is 1849 kWh compared to that for the triple vacuum glazed window of 1674.3 kWh, this gives an energy saving of 174.7 kWh. When compared with single, triple air filled and double vacuum glazed windows energy savings are 398.2 kWh, 109.1 kWh, 12.9 kWh respectively.

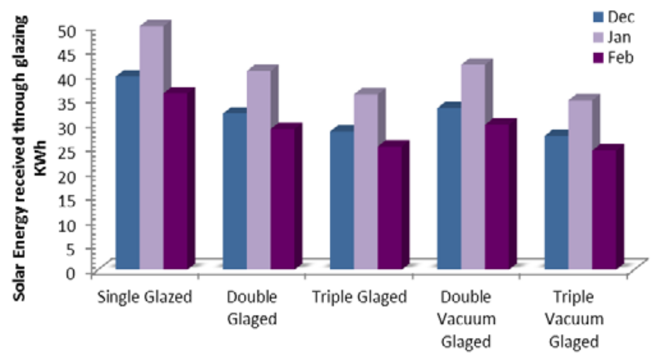


Fig. 7: Monthly solar gain in kWh through the different glazing types for the winter months Dec, Jan and Feb.

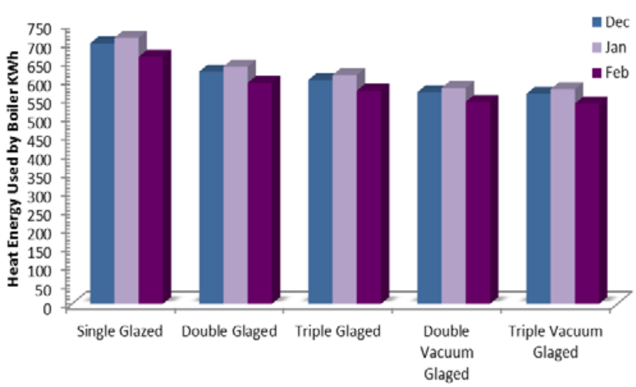


Fig. 6: Monthly heating required in kWh for the months Dec, Jan and Feb for rooms with different glazing types.

Figure 7 shows the calculated solar gain through the different glazing types that work to reduce the heat load of the LTHW boiler required in order to maintain the internal room temperature at the set point of 21°C. The total solar gain in the three winter months for the single glazed window is 126.5kWh for the triple vacuum glazed window 86.7 kWh a difference of 39.8 kWh. The reduction in solar heat gain compared to the single glazing for double air filled, triple air filled and double vacuum glazed windows are 24.7 kWh, 36.9 kWh and 21.4 kWh respectively.

3.2 Energy Consumption, Energy Costs and Financial Savings

The simulations performed predict the total energy required to maintain 21°C inside the room during the winter months, Dec, Jan and Feb. The annual energy requirement calculated assuming cooling in summer was achieved by natural ventilation with no energy requirement for cooling. If the temperature in the room increases above 21°C the boiler automatically switches off and when the temperature falls below the set point 21°C then the boiler switches on. A significant reduction in the energy load met by the LTHW boiler is obtained by using triple vacuum glazing, the reduction in solar gain is disadvantageous during the heating session. During the summer months, the heat load required to maintain 21°C inside the room is more than for the other window types. Solar gains during summer months can be disadvantageous since they increases the inside room temperature above that desired and thus require an active cooling system that increases energy consumption. In this work, cooling is considered to be met by natural ventilation and does not include any active cooling load. The focus of this paper is on the energy consumed for heating only resulting from different glazing systems.

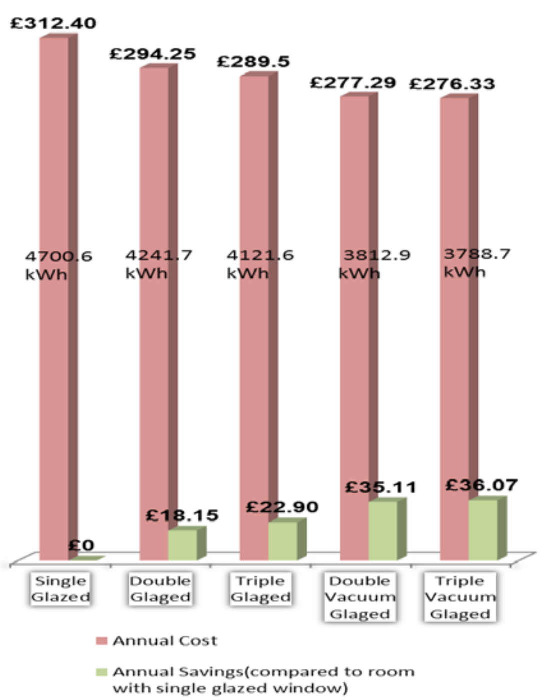


Fig. 8: The predicted annual energy consumption by the boiler in kWh, energy cost and energy savings resulting from replacing single glazing with double air filled, triple air filled, double vacuum and triple vacuum glazed windows in the modelled room of a solid wall dwelling.The standard gas tariff used (First 2680 kWh per year costs 8.675 pence and susequent consumption charged 3.955 pence).

The predicted annual energy required from the LTHW boiler throughout year can be seen from Figure 8, the annual savings for the triple vacuum glazed window compared to a single glazed window is £36.07 which is the saving for one simulated room. Similarly double air filled, triple air filled, and double vacuum glazed windows annual energy cost savings are £18.15, £22.90 and £35.11. Assuming a dwelling consists of 6 simulated rooms the cost saving could be hundreds of pounds. Simulations were undertaken for a single room with heat loss through an exterior wall, roof and floor, and a heating set-point constant at (21°C) which is not normal in most domestic dwellings because consumers allow the temperature to fluctuate and do not normally have the heating system switched on for 24 hours. In this work it is assumed that heating is provided if the temperature goes below the set-point of 21°C.

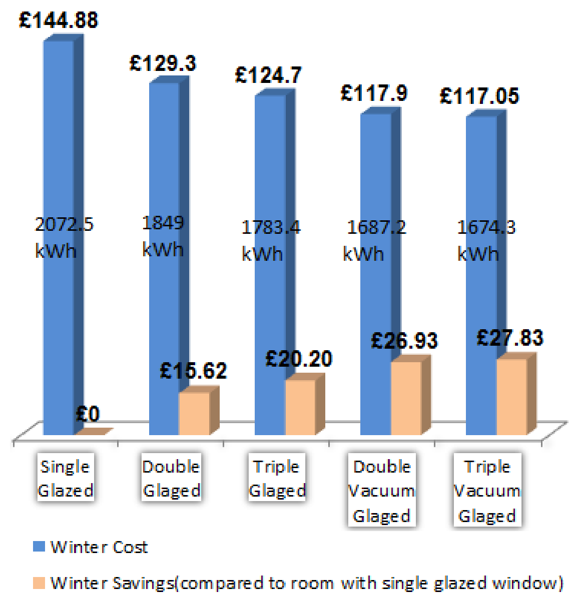


Fig. 9: Energy consumption for the winter months, energy cost based on standard monthly tariff 6.991 pence per kWh, and cost savings compared to single glazed window.

Figure 9 illustrates that the peak energy consumption in the year occurs in the winter months, Dec, Jan and Feb, it can be seen that more than 50% of the heating energy consumption throughout the year occurs in the winter months. In the winter replacing single glazing with triple vacuum glazing results in a cost saving of £27.83. Both annual and winter energy consumption tariffs are chosen as standard (British Gas, 2011) costs. The calculations show very little difference between double and triple vacuum glazed window energy consumption and cost saving difference for this case due to the large heat loss through the remainder of the fabric.

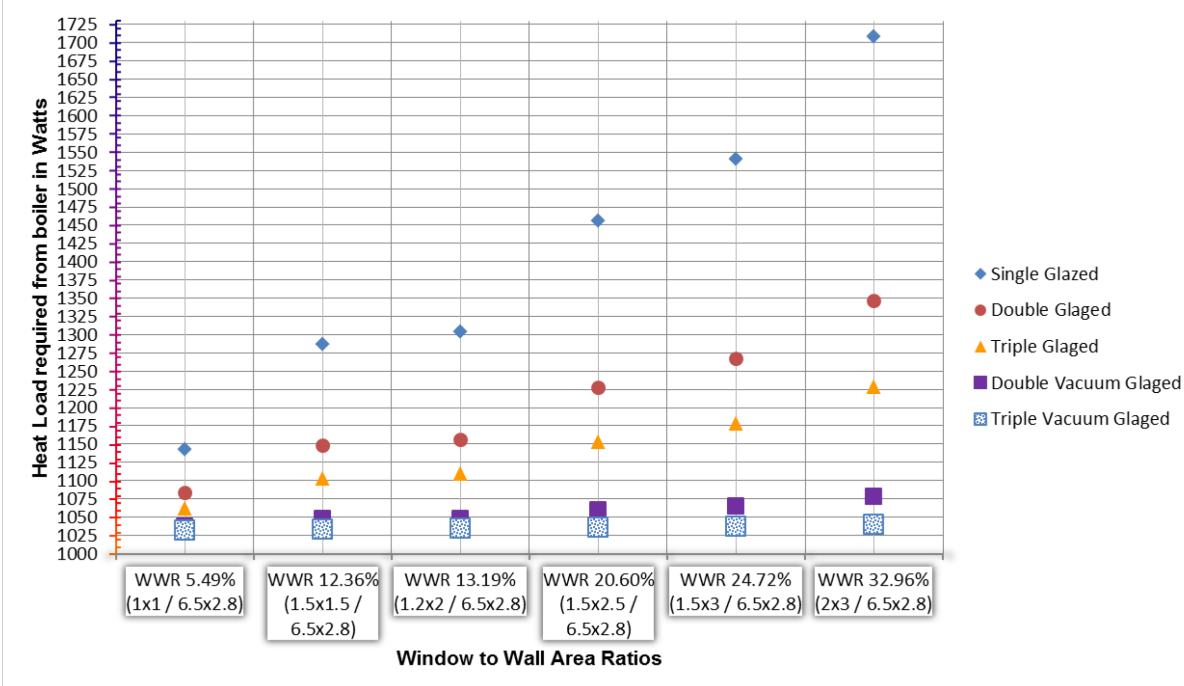


Fig 10: Predicted heat load for a room in a solid wall dwelling with different glazing types with window to wall area ratios of 5.49% 5.49%, 12.36%, 13.19%, 20.60%, 24.72% and 32.96% of window to wall area ratios.

3.3 <u>Heat Load Performance Analysis of Glazings at Different Window to Wall ratios</u>

Two significant factors need to be considered in the construction of solid wall dwellings. One is the location of the window which determines the solar gain another is the window to wall area ratio (WWR). To assess the performance of the different glazings for different window to wall area ratios simulations were performed for the previously described room. The outdoor temperature for these simulations was a constant value of -6.10°C, the indoor set simulations was 21°C.

From figure 10 it can be seen that increasing the window to wall area ratios increases the heat load requirement from LTHW boiler. For the double and triple vacuum glazed window, the difference in heat load requirement as compare to single, double air filled, and triple air filled glazed windows is small. Comparing the performance of double vacuum glazed window at WWR 5.49% the heat load is 1037 watts and 1078 watts at WWR 32.96% which gives an increase in the heat load of 41 Watts. Similarly comparing the performance of triple vacuum glazing at WWR of 5.49% requires a heat load of 1032 watts and at WWR 32.96% require heat load 1040 Watts, an increase of 8 Watts. This shows that increasing the window to wall area ratio does not make a significant difference in heat load if using triple vacuum glazing since both the wall and the triple vacuum glazed window have almost the same thermal transmittance.

4. <u>CONCLUSIONS</u>

A model for a room in domestic solid wall dwelling was developed to simulate heat load and solar gain when using single, double air filled, triple air filled, double vacuum, and triple vacuum glazed windows for a constant window to wall area ratio 13.19%. Winter heat loads and solar gains were analysed and it was predicted that the heat load can be reduced significantly by using either double or triple vacuum glazing. Predictions of the costs of energy and potential financial savings resulting from replacing single glazing by more energy efficient glazing systems were made. It was also shown that for low heat loss glazings it is possible to significantly increase window to wall area ratios with little increase in room heat load.

5. <u>ACKNOWLEDGEMENT</u>

Work supported by Engineering and Physical Sciences Research Council (EPSRC) of the UK (EP/G000387/1) as a contribution to the Work Package 3.4 of the CALEBRE (Consumer-Appealing Low Energy Technologies for Building Retrofitting) project.

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