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Simulation investigation of heating load for solid wall house retrofitted with Vacuum Insulation Panels

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ABSTRACT

Energy efficiency for the purpose of sustainability is being taken up increasingly at present. Increasing the energy efficiency of buildings is being taken more seriously; consequently the demand for energy efficient buildings has risen.

Heat losses can be reduced by lowering the heat transfer coefficient (U-value) of the building fabric by applying insulation in the building envelope, and so vacuum insulation panels (VIPs) can play a vital role in reducing the heat loss in buildings. VIPs represent a high performance thermal insulation material solution, offering an alternative to thick wall sections and large amounts of traditional insulation in modern buildings. Recently several researchers have carried out work to improve the performance of VIPs for building applications.

The purpose of this paper is to investigate the heating load of proposed retrofitted solid wall houses with VIPs compared to the existing solid wall houses in the UK. Solid wall houses in Nottingham have been chosen as a case study for this paper. The main goal of this simulation is to investigate the energy performance and cost effectiveness of a retrofit strategy that could be used for solid wall houses in the UK.

1 INTRODUCTION

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 highly insulated building fabrics, high levels of wall insulation and efficient appliances leading to reduction in fuel use and carbon dioxide (CO_2) emissions.

The interest in vacuum insulation panels (VIPs) has risen in the building and construction sector in recent years. There are many advantages as well as challenges associated with the application of VIPs in the building and construction sector. Solid wall houses are generally considered to be amongst the most difficult to treat for insulation since insulation can only be placed in two possible locations, either internally (in which case the room sizes are reduced and there is considerable disruption to interior décor and services), or externally (where changes to the appearance of the building may be unacceptable and where other structural modifications, such as roof extensions at the eaves, etc., may be required to facilitate the installation).

2 ENERGY IN BUILDINGS:

In the developed world, about 20-40% of all energy consumed used is accounted for by the built environment. For instance, in 2004 in the UK, 39% of total energy consumed was attributed to use in buildings and in Europe as a whole this figure was 37% [1] .

Carbon emissions from non-domestic and domestic buildings account for about 17% and 27% respectively of total carbon emissions in the UK [2] . 73% of the figure for domestic consumption is due to water and space heating (see Figure 1). According to the Energy Saving Trust, two tons of CO_2 emission can be saved if the homes are made energy efficient [3]. Heat loss in buildings is due to fabric heat loss and ventilation heat loss. The former can be reduced by the use of highly efficient thermal insulation materials. Heat is lost through the building envelope (e.g., windows, walls, roof and doors) through radiation, conduction and convection [4]. The CIBSE

Guide F states 'a less thermally massive building would have shorter preheat periods and use less heating energy' [5].

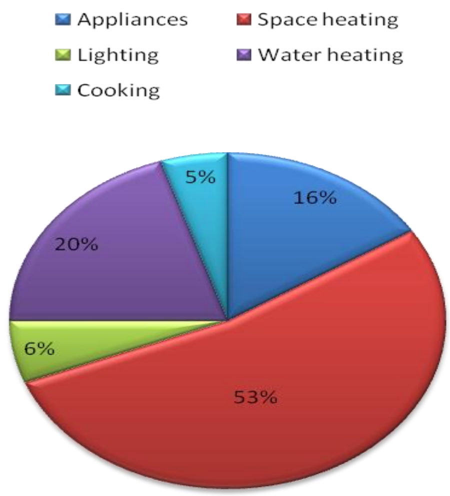


Figure 1: Domestic carbon emissions by end use. Redrawn from [1, 3, 5]

3 CODE OF SUSTAINABLE HOME

Many standards and guidelines have been published for sustainable buildings. The most important of these is the Code of Sustainable Homes (CSH) which stated that walls, floors and roofs should have U value 0.11 W/m2K. This has the target of all new domestic buildings being zero carbon by 2016 and non-domestic buildings by 2019 [1]. The level of sustainability of a building is assessed by its point score across 9 categories. Choice of building materials is an important category and there are strict requirements in terms of minimum insulation level, elemental U values and design standards. Buildings with super insulated fabric have low energy consumption. The choice of insulation needs to take into account specific thermal transmission resistance, space requirements, compression resistance, material ecology and service life, moisture resistance and vapour permeability

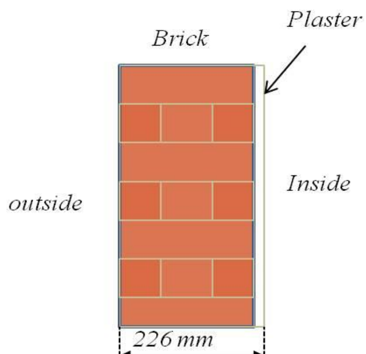
4 SOLID EXTERNAL WALL HOUSES

The types of external walls which were built before 1920 are probably solid rather than cavity walls. Solid walls, unlike cavity walls, have no such gap, so they let through more heat.. Solid walls can be insulated – either from the inside or the outside. This will cost more than insulating a standard cavity wall. For this paper, one house in Nottingham has been taken as a case study. The baseline house is semi-detached and comprises two ground floor living rooms, a pantry, hallway, a store cupboard under the stairs, a coal store and a kitchen, with three bedrooms, a landing and a bathroom upstairs. It has a floor area of 108m2. The total external wall is 126 m2; the external opening area is 32.8 m2.

Figure 2: axonometric of the case study

4.1 Solid wall optimization

Solid wall houses are generally considered to be amongst the most difficult to treat for insulation since insulation can only be placed in two possible locations, either internally (or externally, as previously stated. Calculations to establish the thermal performance of the existing solid walls found that the U-values were 2.23 W/m2K (see figure 3), indicating that in their present condition they were allowing an unacceptable level of heat energy to escape.



Layer description		*Thickness*	*Conductivity*
		(m)	*w/(m·k)*
Brick	*(outer*	*0.22*	*0.84*
Plaster	*board*	*0.006*	*0.16*
Total resistance			*0.476*
U-value w/m²·k			***2.1304***

Figure 3: the existing solid wall

There is clearly a significant need to optimize the external wall to meet Level 6 of the Code of Sustainable Homes (CSH). Equation 1 has been used to identify the required thickness of retrofitted walls with different insulation to show how thick the wall needs to be in order to meet level 6 of the CSH.

$$\text{L insu.} = \text{k insu.}[(1/(\text{U-value})) - ((\text{L}B\,(\text{mm}))/(\text{k}B))\times 1/1000 - ((\text{L}P\,(\text{mm}))/(\text{k}P))\times 1/1000\,]\times 1000 \quad (1)$$

Where :
L*B*: thikness of insulation
k*B*: thermal conductivity of insulation
L*B*: thikness of Brick
k*B*: thermal conductivity of Brick
L*P*: thickness of plaster
k*P*: thermal conductivity of Plaster

The above calculation shows that VIPs have the lowest thickness which will help to increase house space. Figure 4 illustrates the different thickness between Expanded, Polyurethane and VIP with outer brick and plaster to meet the CSH target in 2016 for wall U-value (0.11 W/(m2K)).

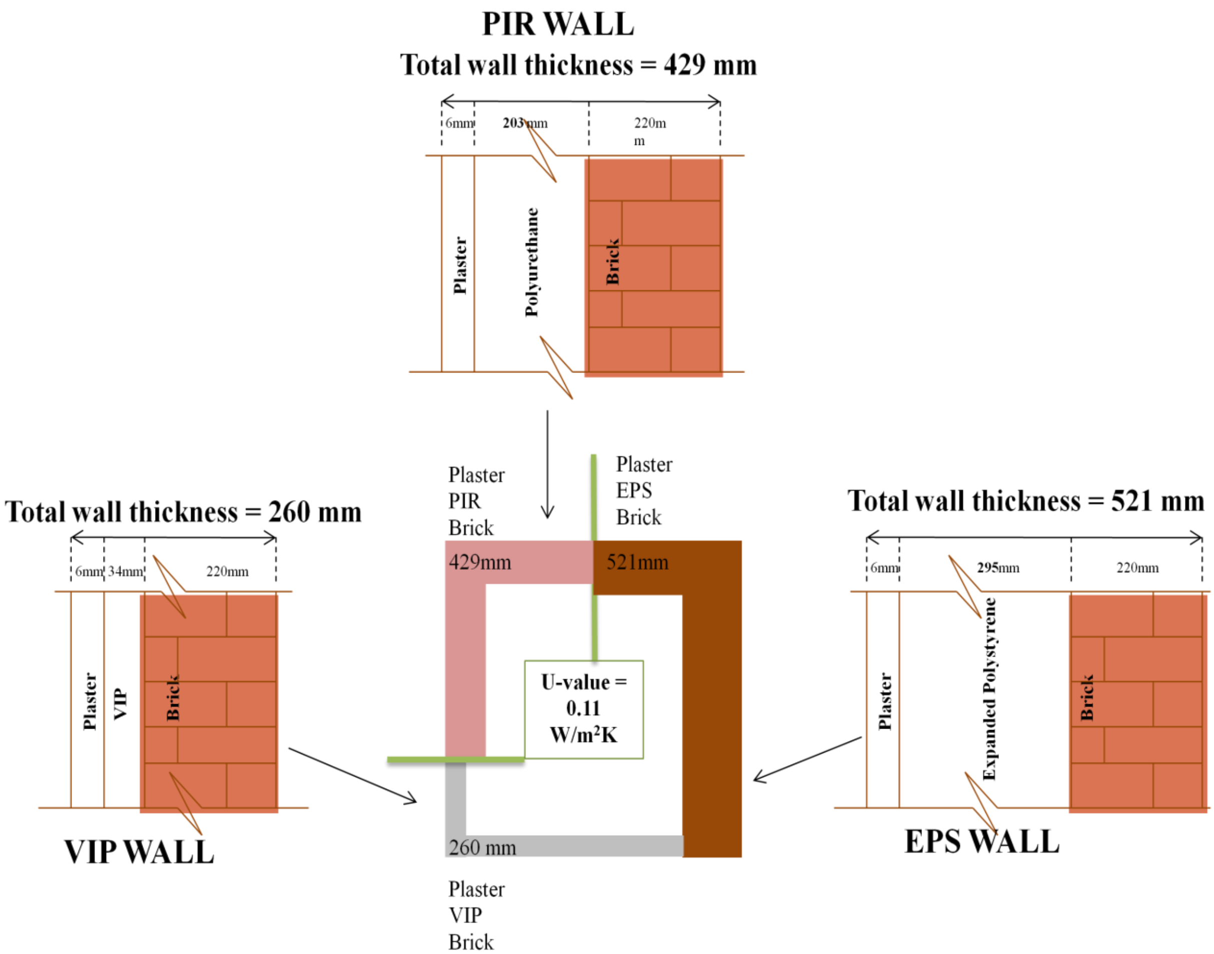
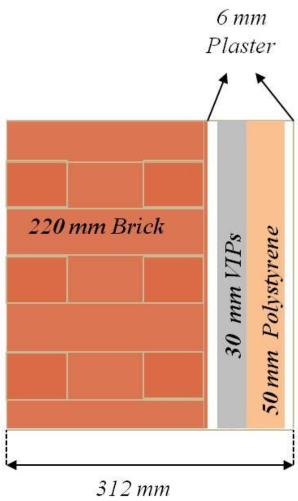


Figure 4: Required thickness to meet CSH level 6 (0.11 W/(m2K)) with different types of insulation

With VIPs the wall thickness can be reduced by about 50% compared to EPS and 60% compared to polyurethane insulation. Use of VIPs can make it easier to improve the thermal insulation in walls with minimal additional thickness. Retrofitting of houses using VIPs may therefore be done without large changes to the house, e.g. extension of the protruding roof and fitting of windows. At the same time, U-values low enough to fulfil the standards of zero carbon houses. VIPs are today mainly installed directly in the construction on site; however, using VIPs as insulation requires a protective outer to save VIPs from any damage. Without protection the envelope of VIPs is highly sensitive to mechanical impact, especially to point loads e.g. by sand grains, bricks or stone fragments, or other sharp objects including tools and corners of other panels. Once installed in a workmanlike manner, failure risks are observed to be low.

The required thickness of retrofitted solid walls will be 312 mm with 30mm VIPs insulation and 50 mm polystyrene as a protective outer (see figure 5).



Layer Description	Thickness m	Conductivity W/(m·K)
brickwork (outer leaf)	0.22	0.84
plasterboard	0.006	0.16
VIP	0.03	0.004
polystyrene	0.04	0.03
plasterboard	0.006	0.16
Total Resistance	9.347	
U-Value W/m²·K	**0.11**	

Figure 5: shows section of proposed retrofitted wall

4.2 House simulation:

The house has its properties of floor, roof, solid wall and door constructions detailed in the table. The heat load and solar gain are simulated using IES simulation software [6]. The energy consumption of the heating system and the solar energy gain are simulated to determine heating load in the winter months based on weather analysis to maintain a set point temperature of 19°C. The required input data includes weather data based on the house location, data detailing the layer-by-layer thermophysical properties of house fabric elements, sensible and latent gains from lights and occupants, according to the CIBSE guide [7] and Setting the occupied time of house. (See table 1).

Table 1: Design parameters for house simulation

HOUSE FABRICS	U VALUE W/m^{2}K	
Windows	5.17	
Doors	5.7	
Roof	4.0	
Ceiling and floors	2.28	
Existing solid walls	2.13	
Optimized solid walls	0.11	
ASSUMPTIONS		
House location	Nottingham	
lighting		
Occupancy	2 people	
Occupied time	Morning	6:00 to 8:00
	Afternoon	16:00 to 22:00
Simulated Heating set-point	19	
Outside temperature	Weather temperature ASHRAE database.	

4.2.1 Weather analysis

The house is located in Nottingham, UK and Sheffield provides the nearest hourly weather data available. This data is used for dynamic thermal simulation and other modelling applications in assessing the heating load for this house.

To make a prediction of when cooling and heating is required, the hourly heating degree days (HDD) cooling degree days (CDD) are calculated using equations 1.0 and 2.0 respectively. These give an indication of the variation of the average temperature from a base temperature. The base temperature used here is 15.5oC. The results of this have been plotted by month (see figure 6):

$$HDD = \text{Temparature base} - ((\text{Temparature max} + \text{Temparature min}))/2 \qquad (2)$$

$$CDD = (\text{Temperature Max} + \text{Temperature Min})/2 - \text{Temperature base case} \qquad (3)$$

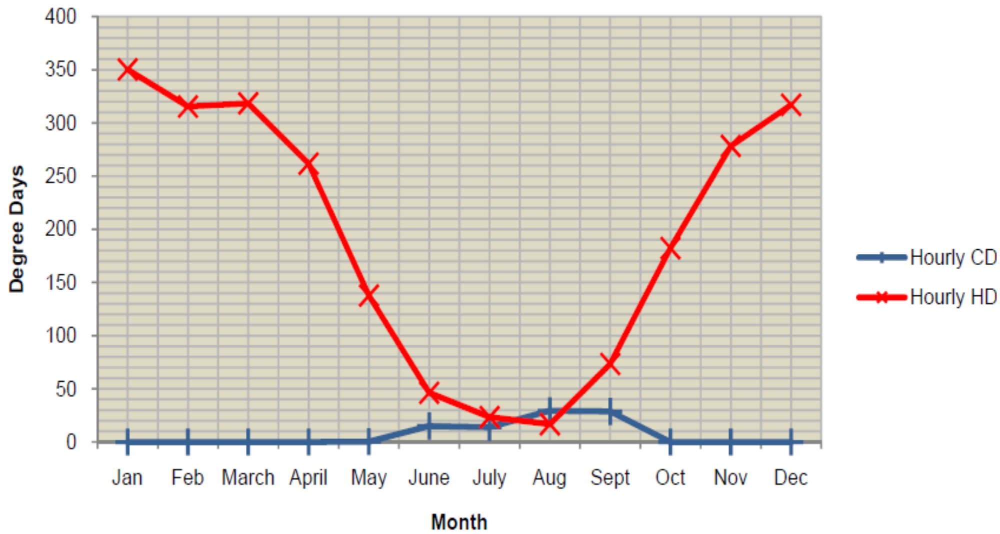


Figure 6: heating and cooling degree day plots for Sheffield by month

4.2.2 Heating load result

To assess the impact of using high performance insulation materials upon the heating load, the heating load of the house is simulated with solid walls (existing walls) first; then another simulation is carried out with optimized solid walls. If the temperature in the house increases above 19°C, the heating system automatically switches off and when the temperature falls below the set point 19°C then the heating system switches on.

Figure 7 presents a comparison of the heating load of all the year for solid walls and optimized walls. It can be seen that there is high demand for heating in Jan, Feb, Mar, Nov and Dec. The maximum heating load is consumed in January for both wall types. The sum total of heating load for optimized walls is 14.45 MWh and 20.18 MWh for existing solid walls. From the result it can be seen that the heating load can be reduced by 30% with optimized external solid walls which meet level 6 of the CSH. Further reduction can also be delivered by optimizing all home fabrics (roofs, floors, windows and doors).

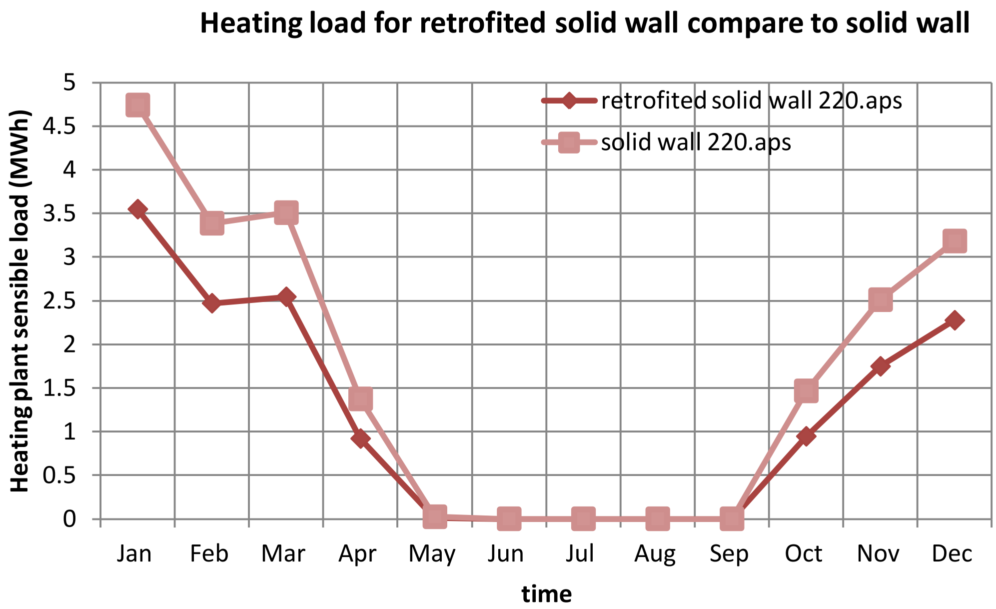


Figure 7: heating loads for proposed wall and solid wall.

4.3 Economic analysis

The simulations performed predict the total energy required to maintain 19°C inside the house during the winter months. The annual energy requirement calculated assuming cooling in summer is achieved by natural ventilation with no energy requirement for cooling. The annual energy consumption of the house with existing solid walls is calculated and the cost based on domestic electricity tariff prices in the UK calculated and compared to optimized walls, as table 2 and figure 8 show:

Table 2: The heating load of proposed retrofitted and existing solid walls

Heating plant sensible load (MWh)	**proposed retrofitted solid wall**	**exsiting solid wall**
Total heating load in kw	14452.9	20184
The heating cost £/ Kwh per year	2312.464	3229.44

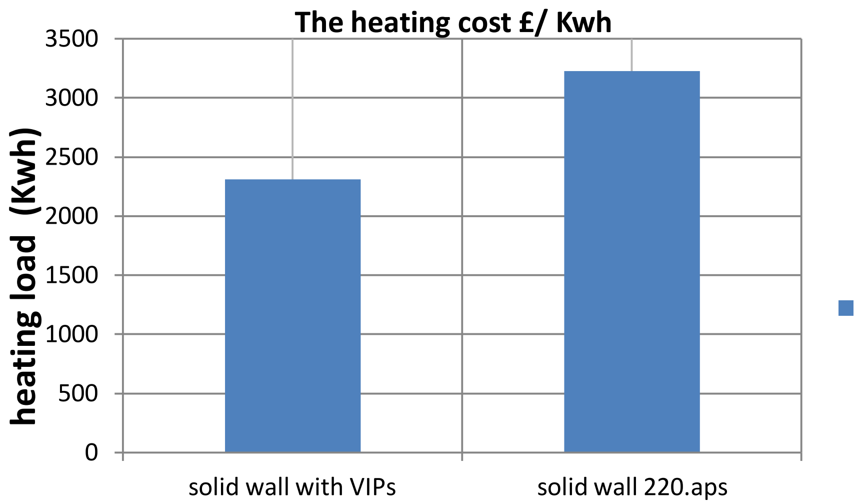


Figure 8: shows the heating cost of existing walls and retrofitted solid walls

The calculated payback period of retrofitted solid walls with VIPs is 15.8 years, as table 3 shows. This may seem relatively expensive but if we take into account the economic advantages of space saving, the VIPs will be a valuable choice as insulation for solid walls. There will also be a shorter payback period when the economic value of the potential space saving due to thinner VIP is considered, as Alam et al [8] finds in his analysis.

Table 3: The payback period of retrofitted solid wall

External wall (m^2)	93.5
Cost of VIPs £ 80 /m	7480
Cost of Ps £ 25 / m	2337
labour cost £ 50 /m^2	4675
total cost of suggested retrofitting	14492
The payback period (year)	**15.8**

5 Summary

By applying the VIPs to the external surfaces there is minimal disruption to the building occupants: the room sizes remain unaffected. Analysis of calculations predicts that the heat load can be reduced significantly by using VIPs, 30 vacuum insulation panels and 50mm polystyrene. Predictions of the costs of energy and potential financial savings resulting from optimising solid walls have been made. The calculated payback period of retrofitted solid walls with VIPs is 15.8 years. This may appear relatively expensive, but if we take into account the economic advantages of space saving then the VIPs will be a valuable choice as insulation for solid walls.

6 References

1. Government, D.f.C.a.L., *Sustainable New Homes(CSH), The Road to Zero Carbon Consultation on the CSH and the Energy Efficiency standard for Zero Carbon Homes.* 2009.
2. H. Simmler, S.B., U. Heinemann, H. Schwab, K. Kumaran, Ph. Mukhopadhyaya, D. Que´ nard, H. Salle´ e, K. Noller, E. Ku¨ cu¨ kpinar-Niarchos, C. Stramm, M.J. Tenpierik, J.J.M. Cauberg, M. Erb *Vacuum Insulation Panel Properties and Building Applications, summary* IEA/ECBCS Annex 39., 2005.
3. Callister, W.D.J., *Materials Science and Engineering - An Introduction.* John Wiley & Sons, Inc. , 2008.
4. A., L., *Materilas Architects and Builders.* Oxford: Elserier, 2010(4th edition,).
5. CIBSEGuide F, S., CIBSE, 2004: p. p4-4.
6. IES (Integrated Environmental Solutions Ltd), *ApacheSim Calculation Methods-User guide, IES Virtual Environment 6.4.* 2012.
7. CIBSE, *Guide Environmental Design, The Chartered Institution of Building Services Engineers, London.* 1999.
8. Alam, M., H. Singh, and M.C. Limbachiya, *Vacuum Insulation Panels (VIPs) for building construction industry – A review of the contemporary developments and future directions.* Applied Energy, 2011. **88**(11): p. 3592-3602.