



CISBAT 2017 International Conference – Future Buildings & Districts – Energy Efficiency from Nano to Urban Scale, CISBAT 2017 6-8 September 2017, Lausanne, Switzerland

Predicting the solar energy and space-heating energy performance for solid-wall detached house retrofitted with the composite edge-sealed triple vacuum glazing

Saim Memon^{a*}, Philip C. Eames^b

^aLondon South Bank University, Division of Electrical and Electronic Engineering, School of Engineering, London, SE1 0AA, UK

^bLoughborough University, CREST, School of Mechanical, Electrical & Manufacturing Engineering, Loughborough, LE11 3TU, UK

Abstract

Triple-Vacuum-Glazing is regarded as evolutionary step in minimising the space-heating loss. This paper takes a comparative analysis approach to envisage space-heating supply required for achieving thermal-comfort temperatures and attainable solar energy gains to households with retrofit of composite edge-sealed triple-vacuum-glazing. Predictions of varying window-to-wall ratios on space-heating energy and solar energy gains for winter months are analysed. The notable winter and annual space-heating energy savings of 14.58% and 15.31%, respectively, were obtained with solid-wall detached-house retrofitted with triple-vacuum-glazed windows compared to single-glazed-windows. The heat-loss calculations show a prominent reduction from 12.92% to 2.69% when replacing single-glazed windows to triple-vacuum-glazed windows.

© 2017 The Authors. Published by Elsevier Ltd.

Peer-review under responsibility of the scientific committee of the CISBAT 2017 International Conference – Future Buildings & Districts – Energy Efficiency from Nano to Urban Scale

Keywords: Vacuum glazing; Solar Energy; Building; Thermal Modelling; Energy Savings

* Corresponding author. Tel.: +44-20-7815-7510; fax: +44-20-7815-7699.

E-mail address: S.Memon@lsbu.ac.uk

1. Introduction

A global challenge of increasing CO₂ emissions, are by now reached at an alarming rate causing fluctuating impacts on temperature and sea levels, are generally acceptable [1-2]. The UK has agreement in minimising CO₂ emissions from 1990 levels to 80% by 2050 [3]. Also there is a serious challenge particularly in the energy field of balancing the gap (a risk to security-of-supply) between peak-demand and generating capacity. This could fall to as little as 5% with a confidence de-rated margin of 0-4% in Winter 2016/17 and 3-7% in Winter 2017/18. This imposes a risk of not having enough generating capacity to meet the peak-demand as according to the OFGEM report on National Grid's Future Energy Scenarios (FES) [4]. In order to reduce such security-of-supply risk, the UK domestic housing stock is a particular focus by reason of its considerable space-heating energy consumption than in any other sector. It accounted approximately 66% of total natural-gas consumption in around 27 million houses in the UK in 2012 [5]. Over eight millions of UK solid-wall houses are so far anticipated to be hard-to-heat [6-7]. In spite of having a number of housing stock insulation methods [8] and improved heating systems as retrofitting measures which are being taken [9], there is still a scope of minimising space-heating energy that brings a need of interposition of progressive technologies, here in particular a focus is, such as triple vacuum glazing that should be consumer-acceptable. It's one thing having a triple vacuum glazing technology, in which the achievable thermal transmittance of the central glazing area is less than 0.5 Wm⁻²K⁻¹ [10, 11], and another thing to persuade the mass market to buy and install this technology. For a large area triple vacuum glazing, the use of tempered glass is beneficial; this attracts a method of the fabrication of triple vacuum glazing at temperatures below 300°C which was first developed at the University of Ulster [12]. This method uses indium or one of its alloys for airtight sealing of the edges of the glass panes at a temperature of less than 200°C. The scarcity and cost of indium are challenges in advancing indium-sealed vacuum glazing technology to the mass production level. A recent low-temperature composite edge sealed triple vacuum glazing shows promising results which was first developed at Loughborough University and reported in Memon et al (2015) [13]. In this paper, the energy and cost savings achievable by retrofitting different glazing systems to an external solid wall insulated detached house are analysed. The predicted performance of triple vacuum glazed windows is compared to a range of different window types; single, double glazed air filled, double glazed argon gas filled and triple glazed air filled windows. The influences of changing window-to-wall area ratio, from 5% to 59%, on the heat supplied and solar energy gain were analysed. The space-heating energy requirement, internal heat gains and solar gains are compared to the calculations of the steady state heat losses of the envelope having solid walls with external wall insulation are analysed by drawing heat flow diagrams.

2. Building simulation methodology

Existing retrofitting of solid wall dwellings has shown significant advantages of using external wall insulations. In this paper, a detached solid-wall dwelling with the brick thick bond having external insulation was designed and modelled [14] which have a structure of early 20th century, located in the Heathrow area of London. The occupancy of this dwelling was modelled to be a family of three adults and one child. The Dimensions of the allocated internal spaces with windows and doors and design parameters are reported elsewhere [15]. To predict the comparative performance of triple vacuum glazing with conventional glazing types in a solid-wall dwelling, the dwelling's fabric was retrofitted to a minimum 1995 building standard; insulations to external solid wall, internal ceiling and floor, loft and ground. The structural U-values used as per 1995 building regulations in the modelled detached solid-wall dwelling are detailed in Table 1. The acceptable thermal comfort temperatures for occupants, allowing natural ventilation during summer months, are between 17°C and 19°C for the winter and summer months, respectively, as per CIBSE Guide-A standard [16]. In these simulations the set-point temperatures were assigned to be 19°C. A version 4 of ASHRAE weather database was implemented to dynamically perform outdoor weather conditions throughout a year [17]. The sectional U values of each element was simulated as per standard of CIBSE Guide-A [16], it complies with the BS EN ISO 6946 [18] standard. A conventional frame material PVC was used whilst calculated their effects on overall U-value of windows following EN-ISO standard method. The k-glass used has a visible light transmittance of 0.74, G-value of 0.76 and surface emissivity of 0.9. The model structural details and U values of conventional glazed windows and triple vacuum glazed window are specified in Table 2. In the dynamic thermal simulations the calculated window U values were incorporated to envisage the winter and annual months' space-heating energy

demand. In which the solar heat gains were simulated with an assumption that solar radiation is incident on the dwelling surfaces whilst considering direct and diffuse solar radiation perpendicular and horizontal to the plane respectively, which were associated with the version 4 of APACHE weather database [17]. The solar and shading radiation heat transfers were simulated as incident on the glazing. An access of it to the interior of the solid wall dwelling was modelled with the IES Suncast shading data analysis tool.

Table 1. The structural details with their U-values used in the modelled detached solid-wall dwelling.

Structural Materials	U value $\text{Wm}^{-2}\text{K}^{-1}$
Externally Insulated Solid Wall	0.52
Internal Ceiling /Floors	1.51
Internal Partitions	1.97
Roofs	0.23
Ground contact/Exposed floors	0.63
Doors	2.56

Table 2. The structural details and U values of the conventional glazed and triple vacuum glazed windows.

Window Category	Total Thickness	Low-emissivity coating	Cavity Thermal Resistance	Centre-of-pane U values $\text{Wm}^{-2}\text{K}^{-1}$
Single	4mm	No coating ($\epsilon=0.89$)	–	5.75 [16]
Double glazed Air-filled	20mm	SnO_2 ($\epsilon=0.15-0.18$)	$0.173 \text{ m}^2\text{K}/\text{W}$	2.85 [16]
Double glazed Argon gas filled	20mm	SnO_2 ($\epsilon=0.15-0.18$)	$0.196 \text{ m}^2\text{K}/\text{W}$	2.67 [16]
Triple glazed Air-filled	36mm	SnO_2 ($\epsilon=0.15-0.18$)	$0.173 \text{ m}^2\text{K}/\text{W}$	1.89 [16]
Triple Vacuum Glazed	12.26mm	SnO_2 ($\epsilon=0.15-0.18$)	$1.42 \text{ m}^2\text{K}/\text{W}$	0.33 [13]

3. Results and Discussion

3.1. An influence of varying WWR (window to wall area ratio) on winter space-heating energy supply and solar energy gain whilst maintaining thermal comfort temperatures

When simulations were performed, with a room of wall area 8.33m^2 , all adjacent rooms to this were selected to be under the same thermal conditions. Two design features to the the retrofitting of a solid-wall house are essential: The facade facing position, determines solar heat gains; and WWR determines the amount of solar heat gains which is dependent on the type of window used. On the one hand, in a cold arid climate, increasing WWR is advantageous and on the other hand it imposes a risk of overheating. In this research work, natural purge ventilation profiles were created and simulated as the only cooling method. The type of window is important and it is for this reason an investigation of the behaviour of triple vacuum glazed window in a room under realistic weather condition is necessary. This also helps in future to improve the fabricated sample of triple vacuum glazing by utilising different low-e coatings. To evaluate the performance of triple vacuum glazed window compared to different glazed window with a range of WWR from 5% to 59%, the winter months space-heating energy supply to maintain internal thermal comfort temperatures and solar energy gain are analysed as shown in Fig. 1 and Fig. 2 respectively. It can be seen, from Fig. 6.15, whilst increasing WWR from 5% to 59% the winter months space-heating energy for a solid wall detached house with triple vacuum glazed window slightly decreases. This is due to the lower U value of the triple vacuum glazed window compared to the externally-insulated solid wall. A dramatic increase of winter months space-heating energy supply is noted with a room of single glazed window. However, due to similar U values, a little change in the supply of space-heating energy was predicted in the room for the double glazed air filled window compared to the double glazed argon gas filled window. It can be seen that solar energy gains are higher in a room with a single glazed window when compared to other window types. At WWR of 59%, a decrease in solar energy gains as compared to a room with single glazed window were predicted to be 41.4 kWh, 40.7 kWh, 71.7 kWh and 66.1 kWh for double glazed air filled, double glazed argon gas filled, triple glazed air filled and triple vacuum glazed windows. A small increase in solar gains i.e. 5.6 kWh was predicted for a room with a triple vacuum glazed window compared to a triple glazed air filled window.

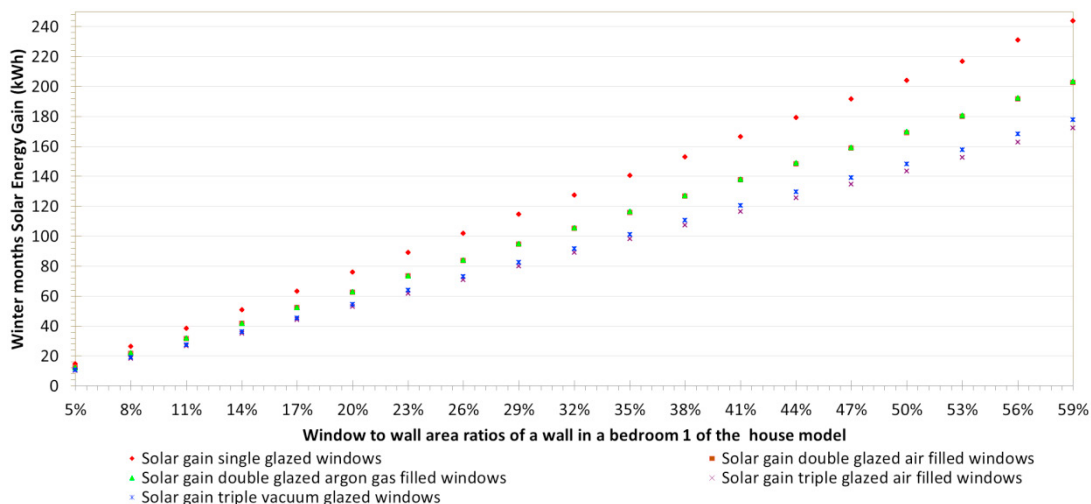


Fig. 1. An influence of varying WWR (window to wall area ratio) on winter solar energy gain whilst maintaining inside house thermal comfort temperatures.

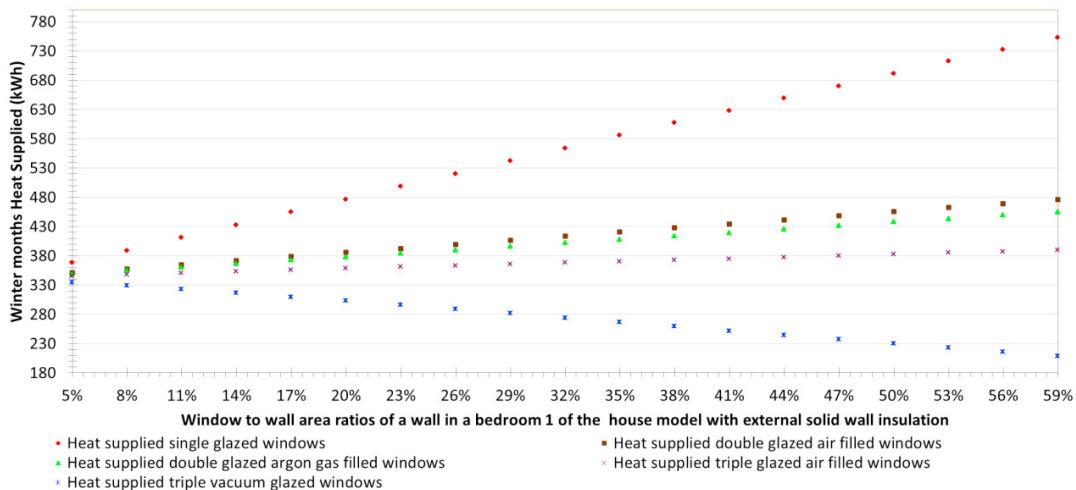
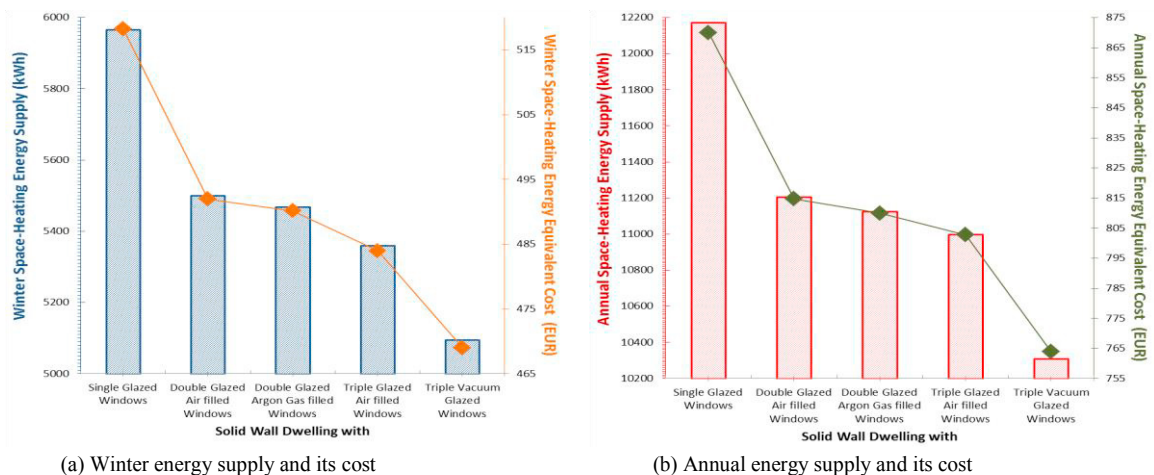


Fig. 2. An influence of varying WWR (window to wall area ratio) on winter space-heating energy supply to maintain inside house thermal comfort temperatures.

3.2. The Predictions of the Annual and winter months Energy and Cost

The space-heating energy cost calculations were based on the British Gas Standard Tariff for the London, Heathrow area (Currency Exchange Rate: 1GBP=1.43EUR) i.e. 0.124 EUR for first 2680 kWh units and then 0.0566 EUR per kWh [19]. However the tariffs vary as they are dependent on the methods of payments. It can be seen from Fig. 3 the comparative total winter months (Dec, Jan and Feb) and annual space-heating energy supplied and its subsequent equivalent cost in EUR with the use of LTHW boiler to maintain 19°C for solid wall detached house with all types of glazed windows. The notable space-heating energy savings of around 14.58% (EUR 49.2) and 15.31% (EUR 105.4) were predicted with a solid-wall dwelling retrofitted with triple vacuum glazed windows when compared to single glazed windows for winter and annual months respectively. It is debatable, yet to know, slight savings of around 7.35% (EUR 15.9) for winter months and 6.24% (EUR 39.5) for annual were obtained with triple vacuum glazed windows compared to triple air glazed windows. The savings can be more perceptible when the solid-wall insulation is improved to 2010 UK building regulations. Simulated results show an insignificant space-heating and cost savings with double argon glazed windows compared to double air glazed windows. Solar gains do contribute in reducing the space-heating load but during summer months it could cause overheating and may be inconvenient to households and

cooling is necessary in this case which again increases energy consumption. Although the advantages of triple vacuum glazing can also be realised with its thinness, this will save frame material. Also with the use of, as proposed in Memon (2013) [22], cost-effective materials the overall cost of fabrication can be reduced.



(a) Winter energy supply and its cost

(b) Annual energy supply and its cost

Fig. 3. Winter months (Dec, Jan, Feb) and Annual space-heating energy supply and its equivalent cost in EUR of the simulated solid-wall dwelling retrofitted with different glazed windows.

3.3. Analysis of Changes in Heat Flows

The dynamic thermal modelling results, of heat supplied to externally-insulated solid wall detached house, and steady state heat loss calculations were integrated to analyse the changes in heat flows with triple vacuum glazed windows and single glazed windows. The steady-state heat loss calculations show the percentage of heat loss reduction, when replacing single glazed windows to triple vacuum glazed windows, from 12.92% to 2.69%, as shown in the heat flow diagrams in Fig. 4. It is predicted from these analyses that retrofitting existing solid wall houses is important for the reduction of space-heating energy requirement with triple vacuum glazed windows. It is pertinent to mention that the heat loss due to air infiltration need to be reduced by improving the insulation and reducing air leakage through the building envelope whilst allowing the moisture vapour from the house to safely evaporate into the outside air to avoid interstitial condensation. Such measures will then exaggerate the heat loss reductions with triple vacuum glazed windows. Although the cost, stability of vacuum, ageing and degradation of vacuum glazings are the current challenges and/or hindrances in leading this technology at the manufacturing level in the UK. An approach used here has apprehended the overall performance of triple vacuum glazing in a solid-wall detached house. A more realistic approach has to be further explored when these result will be compared with the experimental results of space-heating performance when replacing single glazed windows to triple vacuum glazed windows. In these simulations the experimentally achievable thermal performance of triple vacuum glazing (as detailed in [13]) was used and its thermal performance can also further be improved in future.

4. Conclusions

This research implicates that the triple vacuum glazing, if manufactured at the mass production level with cost-effective airtight sealing materials and improved fabrication methods, is a great opportunity in reducing building energy consumption and has a potential to increase window-to-wall area ratios for more solar gains, specifically in the cold arid climates. In the building performance assessment, the heat loss calculations show a prominent reduction from 12.92% to 2.69% in overall fabric heat loss when replacing single glazed windows to triple vacuum glazed windows. However, the space-heating energy, based on dynamic thermal modelling, cost savings can be more appreciable when the solid-wall insulation is improved to 2010 UK building regulations.

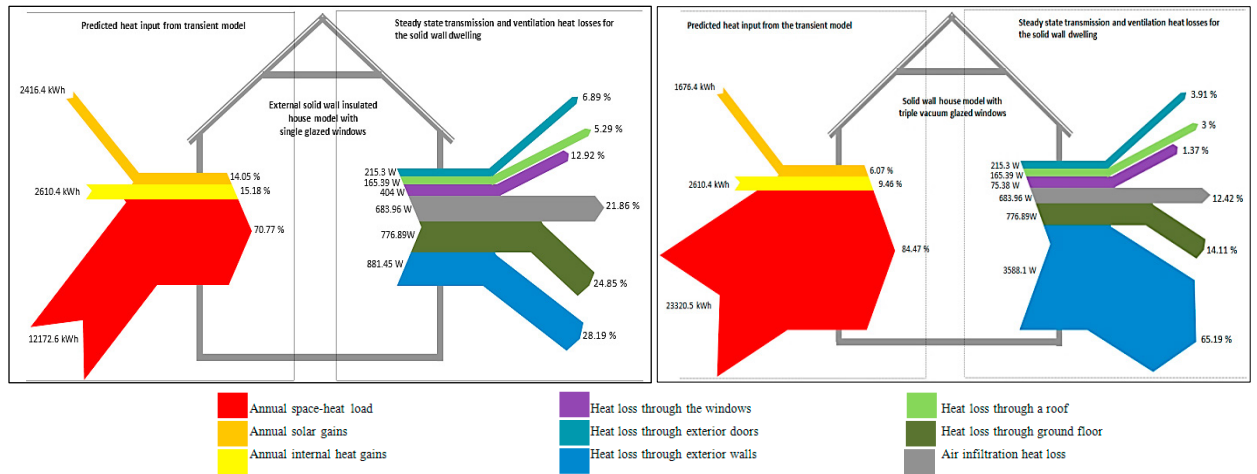


Fig. 4. Heat flow diagram for an external solid wall insulated dwelling with single glazed windows (Left) and triple vacuum glazed windows (Right) showing the simulated heat input from a dynamic model and steady state transmission heat losses through the envelope and by air infiltration.

Acknowledgement

This research work was funded by the EPSRC UK (EP/G000387/1).

References

- [1] Vanzo S, Kostro A, Gong J, Schüler A. Consequences of global warming on the energy performance of CFS with seasonal thermal control. Proc. Of CISBAT Conference, EPFL-CONF-213332, LESO-PB, EPFL, Lausanne, Switzerland, 2015; 89-94.
- [2] Hensen J, Sato M. Regional climate change and national responsibilities, Environ. Res. Lett. 11 2016; 034009.
- [3] Rogers JG, Cooper SJG, Grady AO, McManus MC, Howard HR, Hammond GP. The 20% house – An integrated assessment of options for reducing net carbon emissions from existing UK houses. Applied Energy 2015; 138: 108-120.
- [4] Marr KA. Commentary on National Grid's Future Energy Scenarios for the next three winters, ofgem, 2015. Retrieved 3rd December 2016. https://www.ofgem.gov.uk/sites/default/files/docs/2015/07/electricitysecurityofsupplyreport_final_0.pdf
- [5] Yohanis YG, Mondol JD, Wright A, Norton B. Real-life energy use in the UK: How occupancy and dwelling characteristics affect domestic electricity use, Energy and Buildings 2008; 40:1053-1059.
- [6] Xing Y, Hewitt N, Griffiths P. Zero carbon buildings refurbishment-A Hierarchical pathway, Renewable and Sustainable Energy Reviews 2011; 15: 3229-3236.
- [7] Vadodaria K, Loveday DL, and Haines V. Measured winter and spring-time indoor temperatures in UK homes over the period 1969 to 2010: a review and analysis. Energy Policy 2014; 64: 252-262.
- [8] Jelle BP, Hynd A, Gustavsen A, Arasteh D, Goudey H, Hart R. Fenestration of today and tomorrow: A state-of-the-art review and future research opportunities. Solar Energy Materials & Solar Cells 2012; 96: 1-28.
- [9] Banfill P, Simpson S, Haines V, Mallaband B. Energy-led retrofitting of solid wall dwellings: technical and user perspectives on airtightness, Structural Survey 2011; 30 (3):267-279.
- [10] Eames PC. Vacuum glazing: current performance and future prospects, Vacuum 2008; 82: 717-722.
- [11] Fang Y, Hyde TJ, Hewitt N. Predicted thermal performance of triple vacuum glazing, Solar Energy 2010; 84: 2132-2139.
- [12] Griffiths PW, Leo MD, Cartwright P, Eames PC, Yianoulis P, Leftheriotis G, Norton B. Fabrication of evacuated glazing at low temperature. Solar Energy 1998; 63: 243-249.
- [13] Memon S, Farukh F, Eames PC, Silberschmidt VV. A new low temperature hermetic dual edge seal for the fabrication of triple vacuum glazing: An experimental and theoretical analysis. Vacuum 2015; 120: 73-82.
- [14] Lofthouse P. The development of English semi-detached dwellings during the nineteenth century, Institute of Archaeology 2012; 22: 83-98.
- [15] Memon S. Analysing the potential of retrofitting ultra-low heat loss triple vacuum glazed windows to an existing UK solid wall dwelling. Int. Journal of Renewable Energy Development 2014; 3(3): 161-174.
- [16] CIBSE. Guide-A Environmental Design. (7th eds), The Chartered Institution of Building Services Engineers, London, 2006.
- [17] IES-ASHRAE. ASHRAE weather database version 4.0. APLocate User Guide. ASHRAE, 2015. Retrieved on 15th August 2015. www.iesve.com/content/downloadasset_2878
- [18] BS EN ISO 6946. Building components and building elements-Thermal resistance and thermal transmittance-Calculation method. British Standard, 2007.
- [19] British Gas, Energy tariffs standard. British Gas, 2016. Retrieved on May 2016. <http://www.britishgas.co.uk/products-and-services/energy/our-tariffs/standard.html#PriceMapFlash>