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# Vacuum tube window technology for highly insulating building fabric: An experimental and numerical investigation

Erdem Cuce*, Saffa B. Riffat

*Department of Architecture and Built Environment, Faculty of Engineering, University of Nottingham, University Park, NG7 2RD Nottingham, UK*

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ABSTRACT

A novel vacuum tube window technology is introduced, and its thermal performance efficiency is both experimentally and numerically investigated. Heat transfer inside the window is modelled via a reliable commercial computational fluid dynamics software ANSYS FLUENT. For various vacuum tube diameters (28, 50, 70 and 80 mm), an excellent accordance is observed between experimental and numerical data. The *U*-value of vacuum tube window is determined for different values of design parameters such as pane thickness, tube thickness, tube diameter and argon gap. As a consequence of thermal performance characteristics, cost, lightness and aesthetic issues, the optimum vacuum tube diameter is found to be 60 mm. It is concluded from the results that the vacuum tube window technology has a *U*-value below 0.40 W/m$^2$ K, which corresponds to five times better thermal insulation performance than commercial argon filled double glazed windows with low-e.



## 1. Introduction

Global energy consumption rapidly grows day to day as a consequence of the remarkable growing trend of world population, increasing demand for transportation and building services, and rising comfort levels with technology, bringing with it serious environmental impacts such as ozone layer depletion, global warming and climate change [1]. Today, there is a global consensus among scientists that the existing energy resources will be exhausted in the near future [2]. Both this reality and growing significance of environmental issues prompt developed and developing countries to recheck their energy policies regarding energy production and consumption [3,4]. Especially following the decades of 1973 oil crisis, numerous attempts are made to alleviate the domination of fossil fuels in global energy consumption by focussing the world's attention on renewables. However, recent reports indicate that the renewable energy sources currently can meet only 14% of the global energy demand [5], which is not sufficient for a decisive measure. Therefore, energy minimization and its efficient use at global scale are crucially required.

Recent research of International Energy Agency on global sectoral energy consumption clearly reveals that domestic sector plays a role on global energy use, and hence greenhouse gas emissions [6]. Kolokotsa et al., [7] report that the energy consumption in buildings accounts for 40% of the energy used worldwide. In another work, Zhao and Magoules [8] note that the buildings in Europe are responsible for 40% of total energy consumption and 36% of total $CO_2$ emission. Sadineni et al., [9] emphasize that the situation is almost the same in the USA. About 39% of the total primary energy in the USA is consumed by buildings. These dramatic scenarios can be attributed to the poor thermal insulation characteristics of existing building fabric technologies. In this respect, building sector is considered one of the most promising ways to be able to reduce primary energy consumption, and thus to mitigate greenhouse gas emissions [10].

Windows are indispensable components of building envelope which provide vision, air ventilation, passive solar gain, daylighting and the opportunity to leave the building in extreme situations. On the other hand, they play a dramatic role in heating and cooling loads of buildings in winter and summer, respectively due to their notably higher *U*-values compared to the other components of buildings as illustrated in Fig. 1. Windows are responsible for about 60% of the total energy loss of a building [11]. Hence, developing windows with low thermal transmittance can substantially contribute in reducing energy costs of buildings, and can provide large energy savings.

Currently, the window market in the world is predominated by double glazing technology, and a great majority of houses that are

* Corresponding author. Tel.: +44 (0) 115 951 4882.
*E-mail address:* laxec5@nottingham.ac.uk (E. Cuce).

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**Fig. 1.** Typical *U*-values of building elements.

built now have double glazing fitted as standard. However, windows are still responsible for almost half of heat loss from building envelope [12]. The ability to construct highly efficient buildings will only be achieved if measures are taken to decrease fabric *U*-values and incorporate efficient window technologies. Windows however do not comprise merely of the glazing component but also the frame, which has aspects of both heat transmission and air tightness to consider. In this regard, it is important to identify appropriate technologies to manufacture energy efficient windows, which will also improve the visual and thermal comfort of the occupants.

This study aims at introducing an extraordinary window technology called vacuum tube window for low-carbon buildings. Several attempts are made in literature to improve overall performance parameters of vacuum glazing. Eames [17] presents an overview of vacuum glazing technology and outlines the future prospects through the latest reports on commercial products. Zhao et al., [18] develop a method to prepare transparent supporting spacers for vacuum glazing. Transparent glass spacers between the glass sheets are found to be very efficient to improve appearance and light transmittance. Schultz and Jensen [19] combine monolithic silica aerogel and vacuum concept into a single glazing and investigate the thermal insulation performance. Their results indicate that an evacuated aerogel glazing with 20 mm glass distance can yield a *U*-value below 0.5 W/m$^2$ K. It is concluded from the previous works on vacuum glazing that the fabrication cost is still very high and attractive *U*-values for low/zero carbon buildings are very difficult to achieve. Therefore in this research, a unique design of vacuum glazing is introduced. This novel window is based on vacuum phenomenon and provides highly thermal insulating ability via its thermally optimized design. Within the scope of this research, experimental and numerical investigation of vacuum tube window are presented to justify its efficiency, reliability, practicality and sustainability for both retrofitting of existing buildings and new-build applications. For the tube diameters of 28 and 70 mm, the average *U*-value of the window is analysed both experimentally and numerically, and an excellent agreement between the results is achieved. Similar accordance is observed for the tube diameters of 50 and 80 mm for the readers' interest.

## 2. Vacuum tube window technology

Vacuum tube window technology can be summarized as the combination of a particular amount of evacuated glass tubes at optimized dimensions, and integration of them into a double glazed frame as illustrated in Fig. 2. The evacuated tubes at a particular vacuum pressure are fixed between two glass window panes and for the external connection between vacuum tubes, an insulating adhesive is utilized. However, evacuated tubes can also be installed separately to eliminate potential thermal bridges through the adhesive. The surrounding enclosure between the vacuum tubes and the window panes is filled by argon as inert gas.

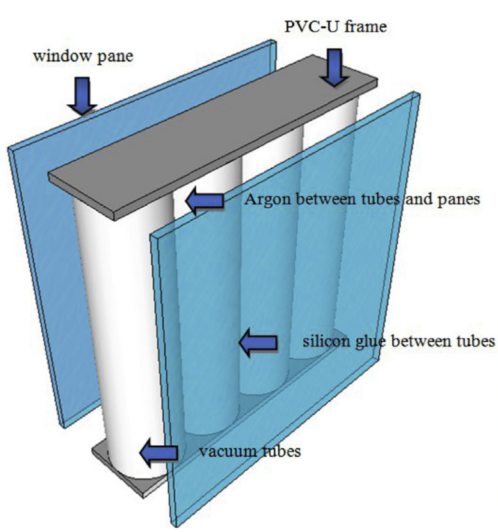


**Fig. 2.** Schematic of the vacuum tube window (on the left) and the sample developed (on the right).