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Low-cost solar thermal based adaptive window: Combination of energy-saving and self-adjustment in buildings

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Abstract

New high-tech smart windows have a great impact on reducing heating and cooling costs in buildings in comparison with the conventional window systems. However the initial costs of these windows are rather too much. This paper demonstrates two new methods for constructing low-cost smart windows that can respond to the level of thermal condition according to basic laws of thermodynamics. The first method is based on the variations in pressure of a trapped gas at different temperature conditions which can move up and down a thin layer of a colored liquid as a sunshade, and the second one is a two phase liquid–liquid (transparent–translucent) fluid with different thermal expansion coefficients that allows one phase to rise or sink faster than the other one, in response to temperature variations, and thus casting or retracting an opaque light filter. The calculations and results of experimental tests showed that not only the incoming light can be adjusted without the use of electricity, but also the initial costs of construction can be reduced.

Keywords: Adaptive windows; Low-cost technology; Daylighting control; Thermal expansion coefficient; Sustainable building

1. Introduction

Adaptive window (also known as switchable/dynamic/smart window) technologies are capable of intelligently modulating their light transmission properties in response to changing external climate such as light, heat or electricity (Lampert, 1998; Gao et al., 2012; Favoino et al., 2015). Smart window technologies have improved considerably over the past 40 years and there is a wide variety of optical switching devices for smart glazing in the market nowadays, which includes micro blinds (Lamontagne et al., 2009), Low-E coatings (Ren et al., 2011; Sadineni et al., 2011; Cuce et al., 2015) and switchable reflective devices including electrochromic windows (Granqvist et al., 1998; Piccolo et al., 2009; Zalewski et al., 2012; Aldawoud, 2013; Jelle, 2013), thermochromics windows (Parkin et al., 2008; Kamalisarvestani et al., 2013; Long and Ye, 2014; Long et al., 2015; Zheng et al., 2015), Suspended-Particle Devices (Lampert, 2004), gasochromic windows (Wittwer et al., 2004)and liquid crystal glazing (Wilson, 1992; Baetens et al., 2010) (Table 1). Smart windows are judged on several specific factors including material costs, installation costs, energy consumption, operating voltage and operating temperature range and also functional features such as their transmittance modulation range in the

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Table 1
Types of smart glass in architecture.

Type	Mechanism	Advantages	Disadvantages
Thermochromic	• Changes its reflectance and transmission properties at a specific critical temperature (Kamalisarvestani et al., 2013) • Adapts directly to changing sunlight intensity with no electricity consumption (Long and Ye, 2014)	• No power supply required (Kamalisarvestani et al., 2013) • Continuously adapts tint to sunlight • Easy installation (same as traditional windows) (Long and Ye, 2014)	• Cannot be manually controlled • Enough heat from direct sunlight should be absorbed by the glass to act well (Parkin et al., 2008)
Electrochromic	• Very little electrical current creates chemical reaction causing window to tint (Aldawoud, 2013)	• No electricity is needed for maintaining the particular shade • Can be manually controlled (Piccolo et al., 2009)	• Power supply required (Jelle, 2013)
Micro-blind	• Rolled thin metal blinds on glass • Micro-blinds stretch when a potential difference is applied (Lamontagne et al., 2009)	• Remarkable speed • UV durability • Customized appearance and transmission (Lamontagne et al., 2009)	• Power supply required (Baetens et al., 2010)
Low-E	• Glass treated with invisible metallic coating to reflect or trap light and heat (Ren et al., 2011)	• Limits UV rays • Reduces energy consumption and sound levels in building (Cuce et al., 2015)	• More costly than regular glass • Cannot be manually controlled • Visible light cannot be controlled (Cuce et al., 2015)
Liquid crystals	• When a voltage is applied to the glass, causes the liquid crystals to align, allowing light to pass (Baetens et al., 2010)	• Privacy at the flip of a switch • No window coverings needed (Wilson, 1992)	• Does not conserve energy • Power supply required (Wilson, 1992)
Suspended particles devices	• A thin laminated film of nano-scale particles suspended in a liquid (Lampert, 2004) • When power is on, the particles align and light passes and when the power is off, the particles are randomly oriented blocking the light	• Very high switching speed • Can be manually controlled (Lampert, 2004)	• Power supply required for both switching and maintenance (Lampert, 2004)

visible and the whole solar spectrum, expected lifetime and number of achieved cycles with or without minor degradation and switching time for coloration and bleaching.

There exists a noticeable body of research on the smart window technologies in architecture and other sciences but cost, warranty, switching time, glare and color rendering issues cause some restrictions on the marketability of these glazing technologies (Sadineni et al., 2011). From the energy point of view, energy saving, heat loss (gain) reduction and low-cost fabrication are the most important aspects of selecting a glazing system (Hassouneh et al., 2010). The qualities and performances of glazing are proportional to the costs, as the initial costs of the dynamic glazing products are considerably higher than prevalent glazing systems, and there are some constrains on their use in common buildings. Therefore, it is more rational to install these systems in higher performance buildings such as commercial buildings (Hee et al., 2015). This paper introduces two new low-cost solar thermal based smart windows which can dramatically reduce the cost of production based on a simple low-tech method with no power supply required. In contrast to most contemporary approaches to smart glazing systems, which require high-tech materials and technologies, these concepts are based on basic laws of thermodynamics that could be easily constructed with simple tools and common materials. Reducing manufacturing costs can encourage the use of these smart windows more widely in common buildings.

2. Research goals and method

The aim of this study is to find simple low-cost methods of constructing new adaptive windows which can respond to solar heat (no power supply required) for dynamic daylight and solar energy controlling. This work offers two ways based on basic laws of thermodynamics to deal with the issue. In each method, a physical model based on calculations is made and the accuracy of implementation is studied under laboratory conditions.

2.1. The first method: Trapped gas and fluid membrane

In the first method, the glass is divided into two parts: (a) the trapped gas and (b) translucent liquid as a simple gas thermometer. As illustrated in Fig. 1, a transparent surface is placed in a glass brick which divides the glass brick into two parts (tanks). According to the ideal gas law (applicable at low pressures such as this experiment), when the temperature of the trapped gas (air) experiences an increase in temperature equal to ΔT, the translucent fluid