The Sustainability Benefits of Suspended Particle Device (SPD) Light-Control Technology: Energy Efficiency, Individual Well-Being, and Security

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ABSTRACT

Buildings and vehicles are among the leading users of energy worldwide, and as such, contribute significantly to carbon emissions and energy expenses. Architectural and transportation products made with suspended particle device (SPD) light-control technology – windows, skylights, partitions, sunroofs and others – can reduce energy use and advance individual well-being and security objectives. These "smart glass" products use SPD film that contains a coating of microscopic, orientable particles whose alignment and light transmission properties can be varied with an electrical interface. By regulating the voltage to the SPD film, users can manually or automatically control the amount of light, glare and heat entering the building or vehicle. This paper summarizes the technical features of SPD light-control technology and discusses its sustainability benefits which include energy savings, individual-well-being and security.

BUILDINGS AND VEHICLES

Energy is required to power industries, advance standards of living, and spur economic development. The world's need for energy continues to grow. The U.S. Energy Information Administration reports that world energy consumption will reach 739 quadrillion Btu by 2030, a 49% increase from 2007. Carbon dioxide emissions, a focal point of the climate change debate, are projected to increase 43% over this time period [1].

Buildings consume significant amounts of energy and exert a strong influence on carbon emissions and environmental quality. In the United States, residential and commercial buildings account for 39% of the country's total energy consumption [2]. The U.S. Green Building Council reports that U.S. buildings represent 72% of the nation's electricity use and contribute 39% of aggregate carbon emissions [3]. United States buildings have several defining characteristics. At more than 250 billion square feet, the size of the building stock is substantial [4]. The nation's building stock also is old. According to the U.S. Department of Energy, 76% and 85% of commercial and residential buildings, respectively, in the country were built before 2001 [5]. Consistent with the overall growth in energy consumption, energy-related expenditures in U.S. buildings are staggering and on the rise. These expenditures in the U.S. exceeded $400 billion in 2006 and are expected to grow on an inflation-adjusted basis approximately 25% by 2030. Electricity-related costs are rising at a particularly fast rate [5]. Buildings in the U.S. generally also have wide variations in their use of even the most basic approaches to energy efficiency. To illustrate this point, while nearly ninety percent of residential and non-residential glass products currently sold in the United States are thermally efficient insulating glass units (IGUs) [5], approximately forty percent of all windows in use in U.S. buildings are made with thermally inefficient single-glazed (i.e. non-IGU) panes [6].

A number of legislative initiatives are aimed at reducing the energy used in buildings. In the United States, chief among these is the Energy Independence and Security Act of 2007. The Act requires that new commercial buildings in the U.S. must reach a "zero net energy" goal by 2030 and existing such buildings by 2050 [7]. According to the National Renewable Energy Laboratory, a zero-energy building (ZEB) is "a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies" [8]. Other mandates exist at the state (e.g. California Title 24 [9]) and local (e.g. Los Angeles Green Building Code [10]) levels.

The worldwide transportation sector is large and diverse. Despite the recent recession, global production of passenger cars and commercial vehicles still totaled 61.7 million in 2009 [11]. In 2008, there were a total of 255,917,664 registered vehicles in the U.S., 137,079,843 (54%) of which were passenger cars. In addition, there were 228,663 general aviation aircraft in the active fleet and 7,856 air carrier aircraft in operation [12]. Total vehicle miles in the U.S. transportation sector exceeded six trillion during 2008 and are expected to surpass eight trillion in 2030 [11]. The transportation sector represents 29% of total energy consumed in the country [13] and 33% of the United States' gross carbon dioxide emissions [14].

There is a strong regulatory push in the transportation sector to improve energy efficiency. For example, in the United States, Corporate Average Fuel Economy (CAFE) standards are intended to improve the fuel economy of passenger cars and light trucks sold within the country. In April 2010, the National Highway Traffic Safety Administration (NHTSA) and the United States Environmental Protection Agency (EPA) (co-administrators of the CAFE standards) announced new federal rules to improve vehicle fuel economy and reduce

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greenhouse gas emissions. These new rules are expected to achieve an estimated 34.1 miles per gallon for the industry-wide fleet by 2016 and reduce carbon dioxide emissions by approximately 960 million metric tons [15]. CAFE standards appear to be having a favorable effect. The United States Energy Information Agency projects the fuel efficiency of the vehicle stock of light-duty vehicles in the country will increase 34% from 2009 to 2035 [16].

SMART GLASS

Smart glass is glazing whose light-control properties change in response to a stimulus. Referred to in a number of ways – dynamic glazings, chromogenic glazings, smart windows, variable tint glass, switchable glass and others – smart glass products produced and offered today include windows, doors, skylights, partitions and sunroofs. There are two main categories of smart glass – passives and actives. The light-control properties of passive smart glass change in response to changes in a non-electrical stimuli such as ultraviolet light or heat. The light-control properties of active smart glass are varied using an electrical stimuli, and as such offer users much greater control of their smart glass products when compared to passives.

Smart glass is not new and until recently, sales have been predominated by small-area applications. Self-dimming automotive mirrors have been offered commercially for more than twenty years. In 2010, worldwide demand for these mirrors exceeded 20 million units [17]. Self-dimming eyewear also has been offered for some time. These lenses now account for approximately 18% of all eyeglass lenses sold in the United States today [18].

The smart glass industry is evolving from one serving primarily small-area applications such as eyewear and automotive mirrors to one now able to serve large-area applications in the architectural, automotive, aerospace and marine markets. This trend toward larger smart glass products is opening up a wider range of potential uses for smart glass, thus increasing demand. In the United States, smart glass demand is forecasted to grow at 10% per year through 2017, a rate approximately twenty times greater than that for flat glass overall [19]. Interest also is high among architects, specifiers and other green building professionals. A study of U.S. Green Building Council LEED Accredited Professionals found that 88% would recommend or specify smart glass for a project if costs were reasonable and the smart glass met performance requirements [20].

SUSPENDED PARTICLE DEVICE (SPD) LIGHT-CONTROL TECHNOLOGY – OVERVIEW

Suspended particle device (SPD) light-control technology is developed and licensed by Research Frontiers Inc. (Woodbury, New York). It is an active smart glass technology that gives users the ability to control the amount of light, glare and heat passing through glass or plastic products such as windows, skylights, doors, partitions, sunroofs and other widely used products.

Products made with SPD light-control technology are produced by laminating SPD film between panes of glass or lightweight polycarbonate, or a combination of each. In some applications such as architectural partitions and retrofits, the SPD laminate is a finished product. For other products such as exterior architectural windows, the laminate is fabricated into a thermally efficient insulated glass unit. Within the SPD film are randomly oriented microscopic particles. When no electrical voltage is present, the particles absorb light and block it from passing through the film. When an electrical voltage is applied, the particles align so that light can pass through. By regulating the voltage with a simple switch or other control device, users instantly regulate the amount of light, glare and heat transmitted through products such as windows [21].

Research Frontiers has licensed several companies to produce SPD film. Among these is Hitachi Chemical Company, Ltd. Hitachi Chemical has announced annual production capacity of SPD film of 400,000 m^2/year [22], the largest known announced capacity in the smart glass industry. SPD film offers very dark tinted states and is able to block more than 99.5% of incoming visible light. In its most light-transmissive state, optical clarity is achieved and visible light transmission can be as high a 65% [23].

SPD products have many distinctive features. Unlike other smart glass products such as those based on liquid crystal or electrochromic technologies, products based on SPD technology are tunable in seconds to any level of light transmission between tinted and clear. Light-control changes occur uniformly regardless of the size of the glazing. SPD products reject over 99% of harmful ultraviolet light at all times. Powered using AC voltage, SPD products use no power when completely tinted and consume only nominal amounts (e.g. 0.06 watts/ft2) when in their fully light-transmissive state [21]. They are available in flat or curved surfaces, and can be produced in virtually any custom shape. In addition, as a laminated system, SPD products also can be fabricated with special characteristics such as impact-resistance.

SUSPENDED PARTICLE DEVICE (SPD) LIGHT-CONTROL TECHNOLOGY – BENEFITS TO USERS OF BUILDINGS AND VEHICLES

Architectural SPD products – windows, skylights, doors and partitions – are available now as laminated panels or insulated glass units for new construction, replacement and retrofit projects. These products offer a distinctive blend of energy efficiency, occupant well-being and security.

With regard to energy efficiency, the main sources of solar energy are infrared light (53% of the total), visible light (44%) and ultraviolet light (3%) [24]. SPD products offer exceptional control (i.e. rejecting or harvesting) over the amount of solar energy entering buildings and vehicles. This control can lower heating and cooling requirements in buildings and vehicles, decrease the size of mechanical systems, cut energy-related costs and reduce carbon emissions. Several independently conducted tests highlight the solar control properties of SPD light-control technology. Tests by DSET Laboratories found that SPD insulating glass units can reject up to 94% of incoming solar energy (i.e. solar heat gain coefficient = 0.06) in their tinted state [25]. Testing conducted by Mercedes-Benz in Death Valley, California shows that the sunroof made with SPD technology now being offered in the 2012 Mercedes-Benz SLK can reduce sun exposure to 1/20th of direct exposure levels (from over 1,000 watts/square meter to less than 50 watts/square meter). In addition, when compared to conventional automotive glass, Mercedes-Benz reports that the use of SPD-SmartGlass significantly reduces the temperature inside the SLK by up to 18ºF/10ºC [26]. This reduction can lower the amount of fuel required to cool a vehicle after it has been sitting in the sun for a period of time. A recently released University of Cambridge study reports that windows with SPD technology can reduce solar heat gain by as much as 90%. It further noted "SPD glass holds great energy saving potential and is a technology that can really help to reduce energy wastage of glass facades" [26]. Collectively, SPD products' dynamic light-control control capabilities can reduce energy consumption and carbon emissions.

Daylighting is a design and operations strategy to illuminate interior spaces using natural light, thus reducing the cost for artificial lighting. In the architectural market, the New Buildings Institute reports that daylight harvesting can yield 35% to 60% annual savings on lighting energy [27]. With regard to energy-saving daylight harvesting strategies, SPD products are superior to static film tints and conventional shading systems because of their ability to precisely regulate the amount of visible light entering a building or vehicle and because SPD products integrate very well with building automation systems. Using basic control devices such as photosensors and occupant sensors, SPD products can be tuned to more light-transmissive states during periods of the day such as the morning when the sun's intensity is not at its peak and available natural light is limited. As the day progresses and the sun's intensity increases, the light transmission of the SPD product can be regulated to more tinted levels to best satisfy interior lighting needs and occupant preferences while also reducing energy used for artificial lighting.

The presence of natural light also has many individual well-being and productivity benefits. It has been shown to increase learning rates in schools [29] and generate higher sales in retail environments [30]. Worker performance also is improved when window views are preserved and when glare from windows is reduced [31] – all conditions supported by SPD products and the infinite number of light-control levels they offer.

Material-intensive shading products in buildings and vehicles (e.g. conventional blinds, shade and curtains) are difficult to clean and prone to accumulating particulates and germs. The outer surfaces of SPD products are made with smooth glass or polycarbonate substrates, and as such are much easier to clean and less likely to accumulate particulates and germs and. This can improve indoor air quality in buildings and vehicles. Improving indoor air quality is especially important in health care environments because patient risk and the costs to health care facilities are associated with nosocomial infections. SmartGlass International Ltd. (Dublin, Ireland and London, England) offers a number of smart glass products and recently introduced its SmartGlass Medical division to offer SPD light-control products and others to address these needs in the healthcare sector [32].

SPD products support user well-being in additional ways. For example, the sunroof using SPD technology on the new Mercedes-Benz SLK is 110 pounds lighter than when the vehicle has no sunroof [33]. Reducing the weight of the roof of an automobile not only decreases fuel consumption and lowers carbon emissions, it also can give the car more stability because it is less top-heavy.

SPD products are offered in a growing number of high-performing fabrications that improve security. For example, in 2009 GKN Aerospace was awarded a $425,000 contract by the Combating Terrorism Technical Support Office (CTTSO) of the U.S. Department of Defense to develop instantly dimmable bullet-resistant windows using SPD light-control technology [34]. In the architectural market, various high-performing fabrications of SPD products are offered commercially in addition to standard SPD laminates and insulated glass units. LTI Smart Glass, Inc. (Pittsfield, MA), for example, offers fabrications of SPD products that have blast-resistant, ballistic-resistant, and anti-eavesdropping capabilities [35].

CONCLUSION

Buildings and vehicles support people's quality of life and advance commerce. They're also leading users of energy and contribute substantially to carbon dioxide emissions. Smart glass is a growing category of glazing products whose light-control properties are variable. SPD light-control technology is a film-based technology that offers many exceptional performance characteristics and benefits.

Now available for many applications – windows, sunroofs, skylights, partitions, sunroofs and more – SDP products are unique when compared to other smart glass products such as those based on liquid crystals or electrochromics in that they

are the only smart glass system that can instantly, precisely and uniformly control light transmission to any level between dark and clear. This control offers many opportunities to save energy by managing solar heat gain (i.e. rejecting or harvesting as needed) harvesting daylight to reduce use of energy for artificial lighting. SPD products also offer many benefits for individuals, including protection from harmful ultra-violet light, privacy, improved indoor air quality and positive feelings of connectedness to one's environment. The many benefits of their potential are now being realized on a global scale.

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