AFFECT: ADAPTIVE FENESTRATION FOR EMISSION-FREE CLADDING TECHNOLOGY

Brian Norton
Dublin Institute of Technology
Aungier Street, Dublin 2, Ireland
Phone 00353 1 402 7135, Email president@dit.ie

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Abstract

A combination of technologies when applied to glazed fenestration can realise highly adaptive energy-efficient facades providing good thermal comfort to building occupants. “Adaptive Fenestration for Emmission-free Cladding Technology” (AFFECT) employes vacuum glazing, electrochromic coating, luminescent solar energy concentration, photovoltaics and in-build antennae and battery to create a cladding system that mediates between indoor and outdoor environmental conditions to ensure indoor comfort conditions are maintained.

1. Introduction

Utilising and responding to external environmental factors, innovative passive, photovoltaic (PV) and controlled “smart” (Swords et al, 2008) building cladding systems influence the energy and equipment required to maintain internal building comfort (Shanks et al, 2006). Building envelopes can provide thermal insulation, daylighting, ventilation, passive solar gains, PV electricity, and interact via a telecommunication antennae with a building so as energy management (BEM) system to adapt to diverse and changing building functions and weather conditions. The adoption of these innovations in building cladding will reduce significantly greenhouse gas emissions even if the technical reductions achievable are mitigated by occupant behaviour (Yohanis et al, 2008).

Adaptive Fenestration For Emissions-free Cladding Technology (“AFFECT”) is a combination of building cladding innovations that coherently and optimally integrates five key attributes as show in figure 1.

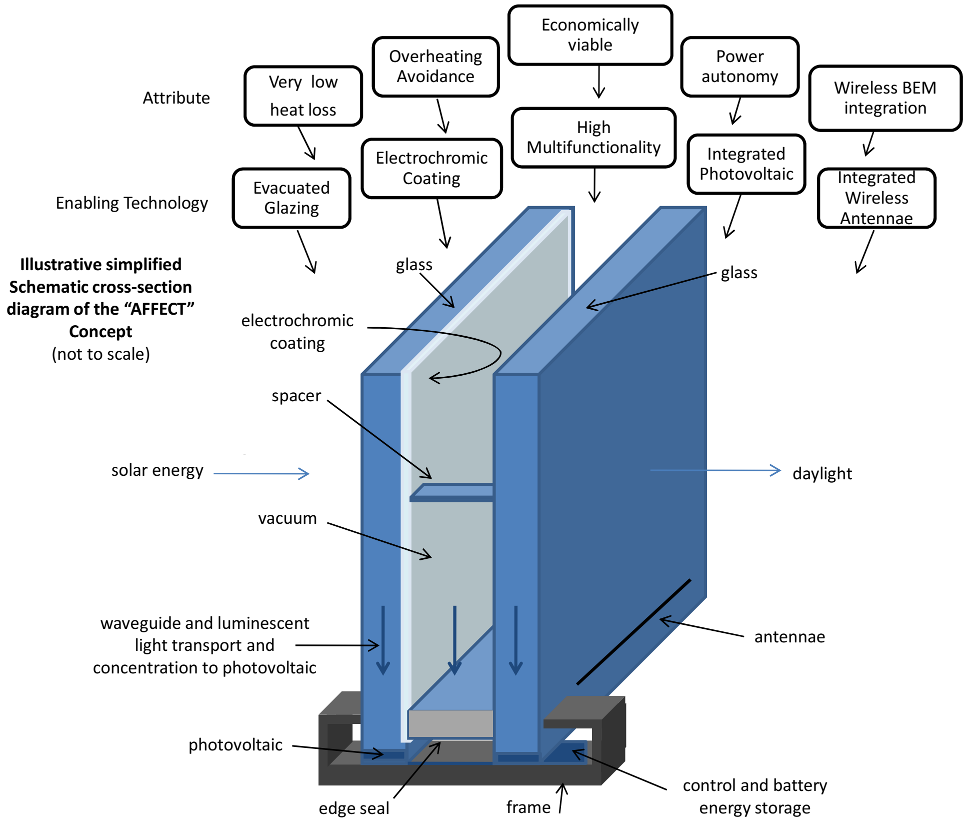

Figure 1 Overview of the generic "AFFECT" cladding concept.

This concept builds on multidisciplinary research on innovative building cladding (Zacharopoulos et al., 2000, Mallick et al, 2004a, 04b, 06, Mondol et al, 05, 06a, 06b, 07a, 07b, 07c, 08, 09, Norton et al , 2011), and their thermal management (Huang et al, 2004, 06a, 06b, 07), the conception and development a very highly insulating patented evacuated glazing (Griffiths et al., 1998, Griffiths et al, 2006 Hyde et al., 2000 Fang et al, 2005, 06, 07a, 07b, 08, 10, Waide and Norton 2003), solar energy conversion, (Zacharopoulos et al., 2000, Eames et al., 2000; Kothdiwala et al., 1995, 99, Eames & Norton, 1993a, 93b, 95, 98), and low energy and sustainable buildings, (Waterfield et al., 1996, Lo & Norton, 1996, Norton & Harris, 1992, Lo et al., 1994 Yohanis & Norton, 1998, 99a, 99b, 2000, 02a, 02b, 02c). Use of the first detailed experimentally-validated transient thermophysical analysis of solar energy collection that gave equally detailed and complete consideration to both optical and heat transfer behaviour (Eames and Norton 1993a, 93b) has allowed detailed simulation of both direct and diffuse solar radiation absorption in heterogeneous three-dimensional transparent systems, conduction in (and between) all system elements taking full account of their thermophysical properties with both short-wave and long-wave radiation exchange. Convective and radiative heat transfer from external surfaces is also modelled. This model has been applied to design and develop a non-imaging concentrator for PV that achieves a concentration ratio of 2.5 without any tracking requirement (Eames et al., 1997), analysis showed that in excess of 70% of diffuse skywards insolation for this system reaches the PV material. Work, (Eames et al 1997, Mallick et al, 04a, 04b) has lead to designs for a range of non-tracking relatively-thin PV planer concentrating elements for vertical façade mounting that require only 40% of the PV material per unit power output compared to standard systems. These elements are non-imaging and by the use of total internal reflection have excellent optical efficiency. Due to their wide acceptance angle they can utilise all direct insolation and the majority of diffuse insolation without tracking (Eames et al. 1997). Previous research has led to improved understanding of the thermophysical behaviour of quantum dot solar concentrators (Gallagher et al, 2004, 07a, 07b, Kennedy et al, 2009) that provide luminescent concentration in the AFFECT system. The interaction of solar radiation optics and heat transfer at the building façade affects internal building comfort that in turn (Yohanis and Norton 2002b) influences building energy efficiency. The consequential production of unwanted greenhouse gas emissions over the total life cycle determines overall environmental impact (Yohanis and Norton, 2002a, 2006) and economic viability of any developed system.

2. Components

2.1 Electrochromic glazing

Electrochromic (EC) vacuum glazing (ECVG) windows, the glazed component of which is shown in figure 2, are an active building component that can control the solar radiation penetrating into buildings whilst reducing heat lost considerably (Fang et al, 2008, 2010). It can therefore reduce space heating or cooling loads and improve thermal comfort in buildings.

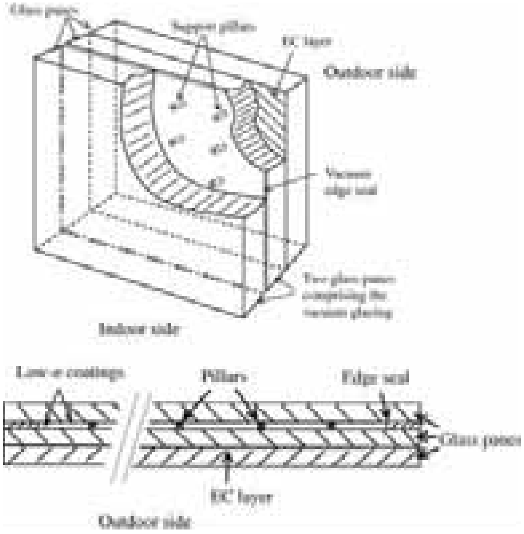

Figure 2 Schematic diagram of an EC VG. The third glass pane coated with EC layer is combined with vacuum glazing.

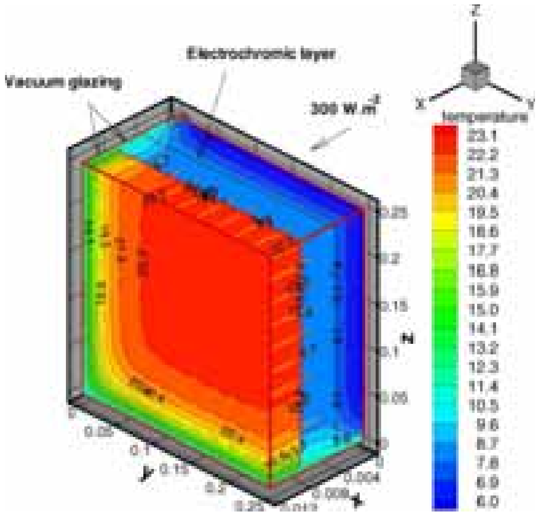

Fig. 4. Under 300 W m^{-2} insolation and opaque state, predicted isotherms for an EC VG with the EC layer facing the outdoor environment with the two glass pane surfaces within the vacuum gap coated with two low-e coatings with emittance of 0.18 within the vacuum gap. (Fang et al, 2008)

Work has developed detailed three-dimensional heat transfer simulations of electrochromic vacuum glazing. An example of this is shown in figure 3.

An EC window does not impede visibility through the window (as with blinds and curtains), reduces glare, has no moving parts (and as a result, minimum maintenance cost), can be integrated into the central power management of the building, block both direct and diffuse solar radiation (unlike passive shading devices), can become transparent during the early morning and afternoon hours to improve natural lighting conditions (unlike tinted glass) and as it requires low voltage power can be powered by photovoltaics. EC devices have only been produced recently and thus comprehensive long-term operational data is not yet available. Due to complex interaction of the many parameters involved, there remain opportunities for both significant performance improvement and design for lower initial cost. The EC devices fabricated thus far are integrated into insulating windows that consist of double glazings with low emittance coatings separated by an argon-filled gap. A much lower overall heat loss coefficient would be achieved with the use of evacuated double-glazing, in conjunction with the EC device resulting to a triple EC evacuated window.

2.2 PV thermal management

A challenge when employing solar energy concentration is that the more intense energy flux gives a larger temperature rise at the PV surface. Incident insolation absorbed by the photovoltaic (PV) cell that is not converted to electricity produces heat, leading to PV temperatures in excess of 75°C being recorded regularly. At 75°C PV cell efficiency is approximately 75% of that at 20°C. The effectiveness of media and techniques used to-date to cool PV cells are inherently limited. The aim is to develop cost-effective techniques to increase these limits to maintain PV temperature closer to ambient thereby improve cell efficiencies to at least 90% of that of a cell operating at ambient temperature. Research will therefore be undertaken on the development of systems in which concentrating PV operate at lower temperatures. For building integrated PV systems, water-cooling is not viable and natural convective air-cooling is the general approach adopted to date. The design and physical realisation of new highly efficient, cost-effective photovoltaic systems for building integration will include advanced thin film coatings, innovative ventilative cooling techniques (Mallick et al, 2007a) and phase change materials. The use of phase change materials with a phase transition in the temperature range 25°C to 35°C with building integrated PV systems, can significantly increase diurnal and annual solar to electrical conversion efficiency by reducing PV cell temperature rise (Huang et al, 2004, 2006a, 2006b, 2007 Hasan et al, 2010). To accommodate the full thermal load from the PV, significant quantities of phase change material are required along with effective methods of transferring the heat from the PV to the phase change material. In addition, adequate thermal discharge of the phase change material is essential between solar heat gain cycles. The proposed generic cooling approach consists of augmenting/adapting a standard PV panel so that an air flow passage is produced at the back of the panel in which an array of hexagonal or circular hollow tubes filled with phase change material are located. The phase change material moderates the PV temperature rise and the array of tubes and back-plate both provide an extended heat transfer surface area. If phase transition has not taken place, the cooling air (at the exit from the air space) will be at a temperature less than the phase transition temperature and suitable for building heating in autumn, winter and spring. In the summer period, direct venting to ambient would ensue. At suitable times of the year the rates of convective heat transfer could be improved by using the building ventilation system to draw the air volume required to meet air change requirements through the airspace at the rear of the PV system.

2.3 Luminescent concentration

For all but the lowest concentration ratios, conventional optical concentration techniques require solar tracking, which is expensive, and utilises only the direct component of radiation, rendering them unsuitable in the cloudy conditions prevalent in the U.K. A non-tracking PV concentrator will use integrated quantum dot technology (Barnham et al., 2000; Gallagher et al, 2004a, 2007b, Kennedy et al, 2009). A quantum dot solar concentrator is shown in figure 5.

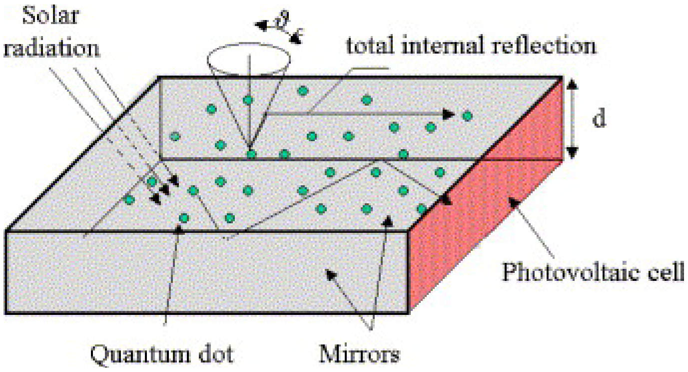

Fig. 5. Principle of the QDSC (Gallagher et al, 2004)

Two means of incorporating luminescent concentration of solar energy onto edge-mounted pv in evacuated glazing will be investigated.

- the inner surface of that pane of the evacuated glazing not EC coated will be coated in a thin film containing quantum dots
- a pane of the evacuated glazing will be seeded with quantum dots as shown in figure 1

Insolation is absorbed by a quantum dot and then re-radiated isotropically, ideally with high quantum efficiency, and trapped within a sheet by internal reflection. The trapped light is converted at the edge of the sheet by a PV cell with a band-gap just below the luminescent energy. Experiments will be undertaken for the full range of solar incident angles to quantify reflection losses on the absorptance of direct and diffuse insolation components. Thermal effects on system efficiency will be measured. Particular attention will be paid to the possible degradation of the performance under enhanced UV illumination. The systems will also be characterised using the outdoor test cell and the south facing test façade of the laboratory under real environmental conditions and under controlled conditions. Particular attention will be given to near-infra-red (NIR) absorbing quantum dots as these show promising efficiency as can be seen from figure 6 (Kennedy et al, 2009).

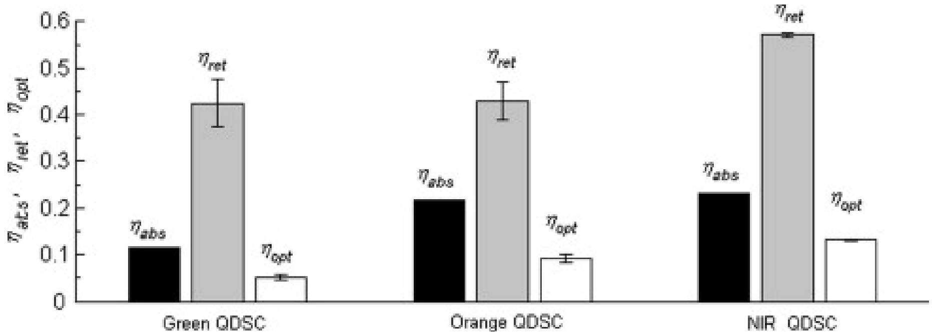

Fig. 6. Predicted optical efficiency (η_{opt}) of 60 × 60 × 3 mm QDSCs containing green, orange and NIR emitting QDs. $\eta_{opt} = \eta_{abs} \times \eta_{ret}$, where the retention efficiency, $\eta_{ret} = 1-$(escape cone loss) (Kennedy et al, 2009).

2.4 Integrated power supply

Integrating power supply and control into a switchable window avoids the need for electrical connections. This reduces installation time and cost whilst also giving high long-term reliability. The integrated power supply best suited to this application is photovoltaics (PV). To optimise the PV system size and thus economic viability the factors shown in figure 9 are taken into consideration.

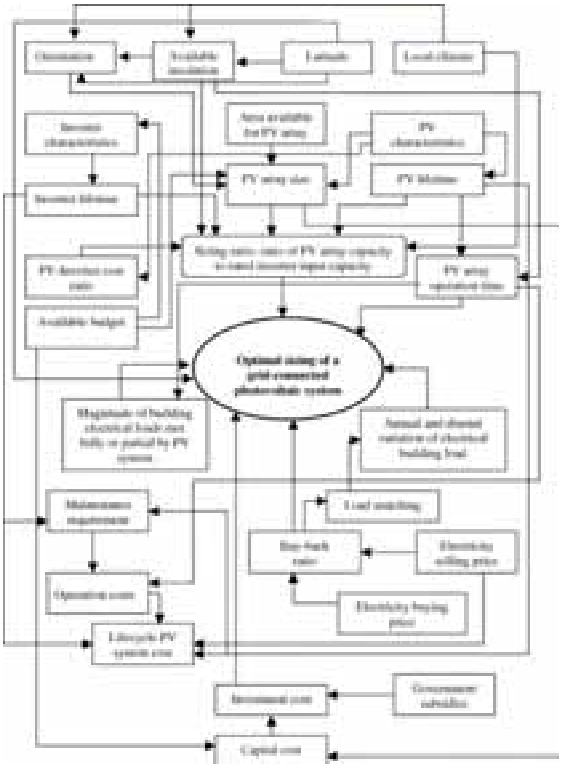

Fig. 6. Interactions of influences on PV system sizing (Mondol et al, 2005)

2.5 Self-powered wireless connectivity

The radio spectrum is a scarce commodity with commercial pressure to increase capacity while increasing service bandwidth. Networks operating between 1900 MHz and 2170 MHz will offer high bandwidth services and in urban areas, will operate small-area microcells requiring a high density of base-station installations. Microcellular systems are designed to restrict coverage in an effort to improve frequency re-use and increase capacity and are thus highly suited to wireless BEM systems. In high-density urban areas this will result in increased use of building-mounted antennas and back-haul using radio or optical fibre. An advantage of this approach is that limited range base-station and handset transmitters operate at lower power levels, reducing mean population exposure to electromagnetic fields. The placement of microcell antennas on buildings, however, can lead to concern over visual amenity, vandalism and maintenance.

Vertical façades usually have a flat external profile that can integrate a low-cost microcell antenna element or array. The microcell transceiver can, with an appropriate integrated battery, be PV powered. There has been previous interest in combining antennas with solar panels, particularly within the field of satellite communications, (Pozar and Targonski, 1998), where an integrated panel can yield significant cost savings where the antenna array and solar panel are the same structure, (Vaccaro et al., 2000). However the use of PVs themselves as antenna elements has the potential to be a significant innovation particularly if good impedance matching is achieved. Recent work (Shynu et al, 2008, 2009; Roo Ons et al, 2009) has developed,

(i) Solar cell acting as ground plane for micro strip antenna, (ii) Inset-fed micro strip facing the front contacts of the cell, (iii) High gain micro strip antennas integrated with PV, (iv) Quarter-wave metal plate solar antennas, (v) Proximity coupled-fed micro strip facing the back of the cell, (vi) Solar cell as reflector for dipole antenna, (vii) Optically transparent antennas on PV, (viii) Integration of a-Si solar cells with microwave antenna, (iix) Parabolic concentrator solar antenna and analysis has been undertaken of currents induced by the patch in metallic layers of solar cell and of the influence of solar heating on gain and bandwidth (Roos Oons et al, 2010).

3. Conclusion

An illustration of the complex interactions between the enabling technologies is shown in Figure 7.

Figure 7 Interactions between the technologies enabling AFFECT.

The attributes of the system are;

- very low heat loss; achieved via an evacuated space between contiguously-sealed glazing panes trapping re-emitted long-wave radiant energy.
- overheating avoidance; very high annual solar fractions of total space heating can be achieved with very low heat loss glazings combined with appropriately deployed and controlled local heat storage in walls and floors. As this can lead to overheating (particularly in summer), electrochromic coating will be employed to control solar gain.
- power autonomy; the electrochromic glazing requires the application of an electrical potential to change between transparent and opaque. This will be provided by a photovoltaic cell giving the system resilience to power failure/outages and reduced installation cost and time by obviating the need for power cables. (This would also be an enabling system facilitating the introduction of future equipment and services such as photovoltaic/battery powered lighting and use of cable-less motion/light energy harvesting wireless information technologies).
- wireless building energy mangement (BEM) system integration; this involves a pv powered antennae integrated in the BEM system linking the control of each AFFECT cladding element with others in the same and other facades of the building and linking all the AFFECT cladding elements to activities modulating natural ventilation. Solar radiation, ambient temperature and wind-speed would be monitored locally to provide BEM data. The BEM system can then by varying the solar energy collection and ventilation behaviour of different facades diurnally seek to ensure no fossil fuel energy use together with acceptable comfort conditions.
- economically-viable; via multifunctional integration of the enabling technologies in a single cladding system. Each glazing pane will either be seeded, or coated with a thin film, of appropriate quantum dots so that it will also be a luminescent concentrator and waveguide that will avoid absorption in the visible range. The proximity of the antennae to the pv will seek to use the latter as a ground plane. Control electronics and battery storage will be located in the frame. (Battery storage is required to for example initiate operation on some AFFECT panels from opaque to transparent early on cloudy days when instantaneous pv output may be insufficient).

Within the European Union it has been estimated that buildings consume about 40% of energy, produce over 30% of the carbon dioxide emissions, generate 40% of waste materials (Norton and Skates, 2000) and can adversely affect air quality (Lo et al, 2001). The adoption of new cladding technologies will provide significant annual savings in primary energy and CO_2.

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