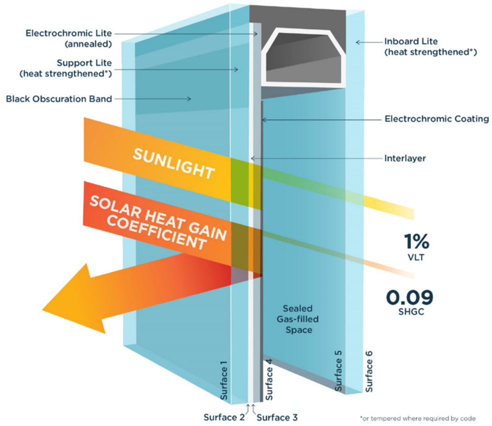
Suppliers

Traditionally, mechanical shades are used to prevent excessive solar heat gain and glare in buildings. Smart or dynamic glass can automatically reduce light transmittance from fully transparent to near-fully dark. This enables a higher level of control, while maintaining outside views and visual appeal of a high-glass façade. **Saint-Gobain** subsidiary **SageGlass**, and competitors such as **View Inc.**, **iGlass Technology**, **ChromoGenics**, and **Kinestral**, all offer smart glass solutions.

Swiss International Scientific School Dubai, UAE, with zoned **SageGlass** coating. Source: ©SageGlass A. Romero



Smart window pane construction. Source: ©SageGlass

Unique Selling Proposition

Smart windows offer a high level of control over light transmittance into a building, allowing building management systems to maximise daylight influx and unobstructed views to the outside, while minimising solar heat gain. This helps to reduce cooling energy consumption from 5% to potentially 50% – depending on local climate and building façade – improve daylighting, reduce glare and artificial lighting needs, and enhance occupant comfort and productivity.

Technology

Mechanical shades or blinds are effective and affordable solutions to block solar radiation, yet they do have some drawbacks. Mechanical shades block outside views for occupants, only partially prevent solar heat gain if used internally, require additional fitting structures in the external or internal walls that can interfere with building design, require maintenance due to dirt, corrosion, or wind damage, and allow only a limited level of control for intermittent shading.

Some window panes can darken under bright light (photochromic, which is used in sunglasses) or high temperature (thermochromic), yet this does not allow direct control by building management systems or occupants. Electrochromic (EC) windows darken in response to a signal, using materials that change color in response to electricity (typically 1.5 V to 3 V DC).

EC smart windows incorporate a proprietary material (such as tungsten oxide, nickel oxide, or EC polymer) sandwiched between electrode layers, and two transparent conductive layers (often indium-tin-oxide, or ITO) wired to control systems. While some companies offer flexible EC films that can be applied as a retrofit film to existing windows (e.g. iGlass), most companies integrate the EC layer between the layer of double-paned glass to maximise durability and seamless integration with the building design.

G-value expresses the solar energy transmittance through building materials, which contributes to internal heating. The maximum regulated G-value differs by region and a building's glass-to-total surface ratio. Dubai Green Building Regulations and Abu Dhabi Estidama Pearl rating 2 promote a G-value of 0.3. Modern buildings often combine high glass ratios (e.g. >80%) with high energy efficiency. Glass' limited thermal insulating properties can make this challenging.

Smart windows can integrate with building energy management systems (BEMS). These are increasingly advanced, using machine learning software to integrate data from factors such as HVAC systems, occupancy and usage preferences, weather forecasts, time-specific energy cost, and more, to optimise energy and create drastic cost reductions. The ability of smart windows to shade gradually, or independently shade specific sections in a single pane (e.g. shading top-section to reduce glare while maintaining direct outside views), creates an additional and highly impactful level of BEMS control.

To this end, **SageGlass** develops software to optimise the control strategy and ensures system compatibility with all BEMS communication protocols, while enabling user control through programs like smartphone apps and **Amazon** Alexa voice control.

Digital models allow architects and engineers to model a smart window's thermal and light impact during the building design stages with Building Information Modeling (BIM).

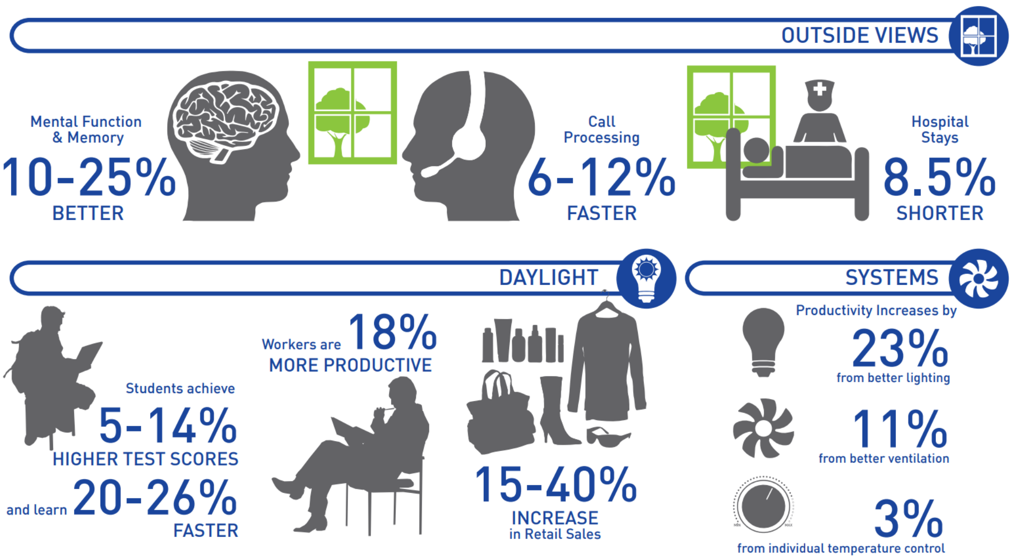
Commercial aspects

Due to still limited economies of scale, relative expensive EC materials, and complex manufacturing methods, smart window glass can cost US$400 - US$800 per m^2, an order of magnitude more than conventional, low-emission (low-e) coated glass combined with mechanical shades or blinds. Payback periods are well within a building lifetime, typically 10 years or more. However, smart windows add additional benefits to compensate upfront capital costs:

- **LEED building energy-efficiency credits:** Any shading system contributes to credits for the energy efficiency category. The functional benefits a building gains through its smart windows qualify it for additional credits in the category of Energy and Atmosphere, as it provides optimised, targeted, and faster levels of shading control, as well as the categories of Indoor Environmental Quality, Daylight and Views, and Controllability of Systems, thereby increasing a building's overall LEED score.
- **Higher rents from an improved exterior and interior with reduced heat-buildup near the windows:** While mechanical shades can interfere with an architect's premium design, shades can obstruct impressive views from premium high-rise skyscrapers or seaside office or living spaces.
- **Improved occupant comfort and productivity:** Though exact impact of daylight quality, outside views, and better temperature and air quality control are challenging to quantify, surveys from the **World Green Building Council** (see infographic) indicate significant gains on a number of factors that can directly translate to higher productivity of workers.
- **Detailed levels of control:** With increasing usage of advanced building energy management systems (BEMS), smart windows' high level of control over heat gain and daylight quality create an additional and impactful level of BEMS control. By preventing excessive heat gain, building designers can also choose to downsize AC chillers.

Innovations to Watch

- **Faster switching times:**
Improving switching times from a typical 10 minutes to less than 1 minute improves occupant comfort, and allows for more energy optimisation by instant switching depending on room occupancy. **Stanford University** demonstrated < 1 minute, while **MIT** (in collaboration with **Masdar Institute of Science and Technology**, now a part of **Khalifa University of Science and Technology**) demonstrated ~ 7 seconds switching times.
- **Cost-reducing materials or manufacturing methods:**
Current capital costs of up to 10x that of mechanical shades have limited the uptake of smart glass technologies despite strong benefits to occupants' comfort and building aesthetics. However, innovations and production methods are helping reduce costs. This is demonstrated by **Stanford University**'s EC polymer injected between panes, and the **University of Cincinnati**, **HP**, and **Merck**'s jointly demonstrated novel e-ink derived material and roll-to-roll micro-patterning production.
- **Smart building integration**:
Advanced control using machine learning to integrate weather patterns, historical data, room occupancy, personal preferences, and AC power requirements, enables further energy reductions, and potential revenue from bidding in demand response programmes. **SageGlass** and other technologies only require power during the transition phase. Development of integrated solar power generation using materials like perovskite or suspended magnetic particles, combined with wireless control, can further help building integration by removing the need for wiring for control systems.



Productivity and comfort gains achieved through window and ventilation technologies. (Source: World Green Building Council)

SMART WINDOWS: ELECTROCHROMIC WINDOWS FOR BUILDING OPTIMISATION

KEY DEVELOPERS

Name	Founded	Visual light transmittance (G-value)	Switching time	Main differentiator
SageGlass (Saint-Gobain)	1989, U.S.	62% to 1% (G-value 0.4 to 0.05)	~8 to 10 minutes	Subsidiary of **Saint-Gobain** since its 2012 acquisition. Gives access to world-class glass manufacturing facilities and markets for cost reductions.
View Inc.	2009, U.S.	58% to 0.5% / 1% (G-value 0.41 – 0.09)	~10 to 30 minutes	Closed US$200 million funding round in June 2017, bringing total investment to US$700 million. Completed ~400 projects since company was founded.
iGlass Technologies	2014, U.S.	65% to 5% (G-value n.a.)	~20 seconds	Produced EC polymer film and control bar, which can be mounted onto existing window glass
Chromo-Genics	2003, Sweden	70% to 2% (G-value n.a.)	~10 to 30 minutes	Uses roll-to-roll manufacturing method to produce ceramic EC layer between transparent polyester films
Kinestral	2013, U.S.	~63% to ~2% (G-value ~0.43 to ~0.08)	~3 minutes	Global joint-venture with **AGC Asahi Glass**; claims faster switching times than competitors
ITN Energy Systems	1995, U.S.	>70% to 3% (G-value n.a.)	~30 seconds	Lab-scale development of roll-to-roll deposition process onto flexible transparent PET film

Note: n.a. – not available

Typical impact of smart windows	
Costs	Typically US\$400 - US\$800/m^2. Economies of scale may reduce this further. Payback times are highly variable depending on climate, location, and building design and usage, with typical payback times estimated at 10 years or more.
AC energy	Depends on local climate, building glass-to-wall ratio, and building usage. Claimed reductions range from 5% to 50%. A **SageGlass** commissioned study in Copenhagen, London, Frankfurt, and Madrid showed energy use decreases from 5% (Copenhagen) to 18% (Madrid) compared to external shading.
Lighting energy	Reductions up to 60%, due to retained visibility to outside and ability to apply different levels and specific zones of smart window shading.
Comfort & productivity	Though quantitative research is still limited, **World Green Building Council** highlights benefits of ample natural light without excessive glare or heat gain to worker productivity. **Cornell University** showed 51% drop in eyestrain symptoms and 63% drop in headaches in facilities with ample natural light. **Lux Research** found daylighting impacts productivity more than thermal comfort.

Relevance to the UAE

With the UAE's extreme solar gain conditions, AC loads can be 50% or more of a building's energy consumption, especially in the desirable, high-glass premium buildings. In comparison to other regions, the UAE construction and building sector can realise significant benefits from smart windows on AC load reductions and occupant comfort. In this environment, the performance of the **SageGlass** smart windows being installed in the Masdar Visitor Centre and other buildings in the UAE, gives readers valuable insight in the performance benefits to the UAE, to help develop best-in-class building systems for energy efficiency and comfort.

Takeaway and Recommendations

Smart windows have been around for several decades, but adoption has been hindered by high costs, limited recognition of building energy-efficiency needs, and low penetration of building digitalisation (BIM, BEMS). Also, the building owner paying more for construction is typically not the building operator who benefits from resulting energy savings, making overall financial payback less obvious until higher energy efficiency can be recouped in higher rents. With each of these factors starting to change, the ROI on smart windows becomes more quantifiable, as smart window cost reductions and improved building energy efficiency drive shorter payback periods. **Masdar**'s recently announced project to build the first "Multi-Comfort House" in the Middle East through a partnership with **Saint-Gobain** will drive best-in-class development of these systems to help drastically reduce the large building energy consumption in the region.

Technology value: Medium	Though smart windows allow higher levels of control and additional benefits, conventional shades will offer a good solution in many cases, with lower direct upfront capital cost.
Momentum: Low	Smart windows have been around for several decades and have only recently started showing more adoption as digitalisation of building control increases and more value and certification systems emerge for energy efficiency.
Maturity: Medium	Leading developers like **SageGlass** or **View Inc.** offer industry-standard levels of transparency and high shading. However, cost reductions from lower-cost materials, and faster switching times, can still add differentiating value.
Risks: Low	Leading developers have dozens of projects with successful integration of smart windows. This helps demonstrate ROI to building owners, through quantifiable energy efficiency credits passed on to the building operators' through rent.