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Report on barriers for new solar envelope systems

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SOLAR ENVELOPE SYSTEMS FOR HVAC AND LIGHTING

Report on barriers for new solar envelope systems

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Contents

1 Introduction

This report is a result of extensive discussions within Task 56 of the Solar Heating and Cooling Programme (SHC) of the International Energy Agency (IEA). Innovative solar envelope technologies face multiple barriers, which prevent some of these innovations from contributing significantly against climate change. This report presents the barriers that the experts of Task 56 are aware of. The aim is to provide a comprehensive view (as much as possible) that developers of new integrated solar envelope systems could benefit of, at an early stage of their planning phase.

In addition to this report, a separate report DB.2 will be published, which provides examples and recommendations of strategies towards the commercial success, despite the possible difficulties described in this report DB.1.

The structure is based on [1] and discusses the technical challenges first, and then human-related barriers from regulations, to software quantifying the benefits of integrated solar envelope systems, to architectural, economic and social barriers.

2 Technical barriers

2.1 Mounting

Over the course of time, the organizational structure of the construction industry has developed into several specialist disciplines, with different trades and subcontractors at the construction site, responsible for e.g. masonry, carpentry, joinery and interior/exterior finishing. With integrated solar envelope systems, many of these disciplines come together, and these envelope systems additionally often need to accommodate plumbing, HVAC and electrical engineering tasks. This blurs the boundaries between these disciplines and the subsequent allocation of responsibilities and tasks are not always clear, leading to potentially inefficient construction processes or sub-optimal systems. Regular and effective communication between the multiple parties (i.e. speaking a common language) is therefore of primary importance to achieve high-performance buildings [2].

Many solar envelopes are designed as dedicated, tailor-made systems that need to be carefully assembled and installed. Irrespective of whether the system is pre-fabricated or assembled on-site, there tends to be a large need for customization and ad-hoc solutions. This can make the mounting process a cumbersome and time-consuming task, with a relatively large risk for errors. Modularity and plug-and-play solutions offer potential to reduce these costs [3].

Many solar technologies were originally designed for environments other than building Integration. Still today most active solar systems are installed in large settings over metallic substructures in building roofs or over flat land. Under these conditions, maintenance and repair of solar systems, and its individual components is relatively easy. With the increased integration level of active solar systems in buildings, the access to components can become more complex.

In the case of façade-integrated systems, maintenance & repair operations need to be planned carefully. Specific areas need to be delimited at floor or roof level to place auxiliary elevation devices and avoid personal injuries due to falling objects. This results in cost for specially trained employees, safety measures and machinery. In the case of space problems at floor level or due to corporate image policies, distortions caused by maintenance processes might need to be limited to certain periods of the day or year.

In roof-integrated systems, some of the aforementioned issues are no longer so relevant, but different issues appear. Operations on sloped roofs require special training. In some cases of building integration such as active glazed roofs, systems are incorporated into the roof itself. The replacement of solar components in this context implies that the inner volume of the building is weather-exposed during the period of substitution. This applies also to facade-integrated systems, but their orientation is less critical regarding rain. Similar to facade-integrated solar systems, distortion caused by these processes should be limited to specific periods and the possibility of injuring people by falling objects needs to be excluded. Highly skilled staff and redundant safety measures are required for this operation. Therefore, the maintenance costs can be substantially higher depending on which installations and employees would be used without a solar building envelope and on the ease of maintenance of the specific solar envelope technology.

Overall, in order to mitigate the aforementioned issues, integrated solar systems usually need to be designed for robustness, considering substantially longer substitution cycles than those in regular solar components, and mechanical properties specified for building envelopes. In order to facilitate maintenance & repair processes, designers should focus on disassembly and replacement processes.

Some of more advanced construction systems are already designed considering these issues. In many curtain wall solutions, the replacement of glazed assemblies is facilitated by design, and glazed elements can be disassembled individually. Similarly, some rain screen systems allow for the substitution of individual items of the external shield.

These designs need to be “ported” to solar activated variants of these systems. While maintaining already proven solutions for modulation and disassembly, solutions are required for electrical and hydraulic junctions.

2.2 Peak temperatures

The highest temperatures in solar envelope systems typically occur with solar thermal components that use a spectrally selective absorber and cover glass pane. Bergmann and Weiß [4] investigated 14 facade-integrated solar thermal installations with flat-plate technology. Although temperatures of 200 °C may occur, the installations can offer long service lives as long as materials are used which can withstand the temperatures and a design that takes care of the thermal expansion of the materials [1].

2.3 Vapor transfer

If a solar building envelope includes larger areas that are tight regarding vapor such as glass panes and metal sheets, then it needs to be checked that no moisture issues can appear.

In the case of building-integrated solar thermal collectors, Bergmann and Weiß [4] investigated that the absorbed heat can dry the building envelope, if materials are used between the absorber and the building interior, which are open for vapor. For cases in which a vapor-tight layer is needed in between the absorber and the building interior, special insulation concepts are available which combine low thermal transmittance with vapor transport around the vapor-tight areas [5]. Rear-ventilation is also an option. As it bypasses a part of the building envelope, this part cannot contribute to the insulation of the building.

Moisture in the facade can degrade thermal performance and even lead to health problems (mold growth) and even to complete failure of the façade (structural damage). Hence, integration of active (chillers, heat pumps) and passive components (pipes, ducts, heat exchangers) for ventilation and cooling into the façade with temperatures below dew-point need to be designed with care in order to avoid moisture accumulation inside the façade. Airtight construction and diffusion tight insulation can be used for this.

In case of maintenance openings, protection against driving rain must be secured.

2.4 Hydraulics

When solar envelope systems use a heat transfer medium, the Tichelmann concept[1] should be used to ensure homogenous flow through all parts. Inhomogeneous flow typically leads to a higher energy demand. When several units of different sizes are being connected together, the pressure needs to be equalized by valves to ensure an equal flow distribution.

Such technologies also need to assess the cases with the highest temperatures. The heat transfer medium can evaporate as long as an expansion vessel is properly installed in this fluid circuit, the materials are temperature-stable and the component can empty completely with the vapor pressing all fluid out of the component.

2.5 Shading

It is important to assess any shading effects through the entire year at each location of a solar envelope system in order to avoid disappointments: simple hardware and software tools can be used.

In the case of building-integrated photovoltaics (BIPV), shading needs to be analyzed carefully, because even partial shading can reduce the photovoltaic yield significantly, if the cells and modules are not connected in the proper way.

Sometimes however compromises on the energy performance have to be accepted when a strong architectural integration is on focus. An example is the International School in Nordhaven, Copenhagen, Denmark (see Figure 1), where the whole façade of the envelope is made of BIPV - even the parts that are in shade most of the time. The BIPV parts that are in shade have of course contributed to a poorer payback time but the architectural value has been estimated to be more worth than the saving that could have been achieved by changing the material of the facade. While the photovoltaic technology is getting cheaper and closer to the standard materials which are used for the envelope, this solution might be seen more often in the future.

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[1] Planning and Installing Solar Thermal Systems: A Guide for Installers, architects and engineers, Earthscan, 2010.

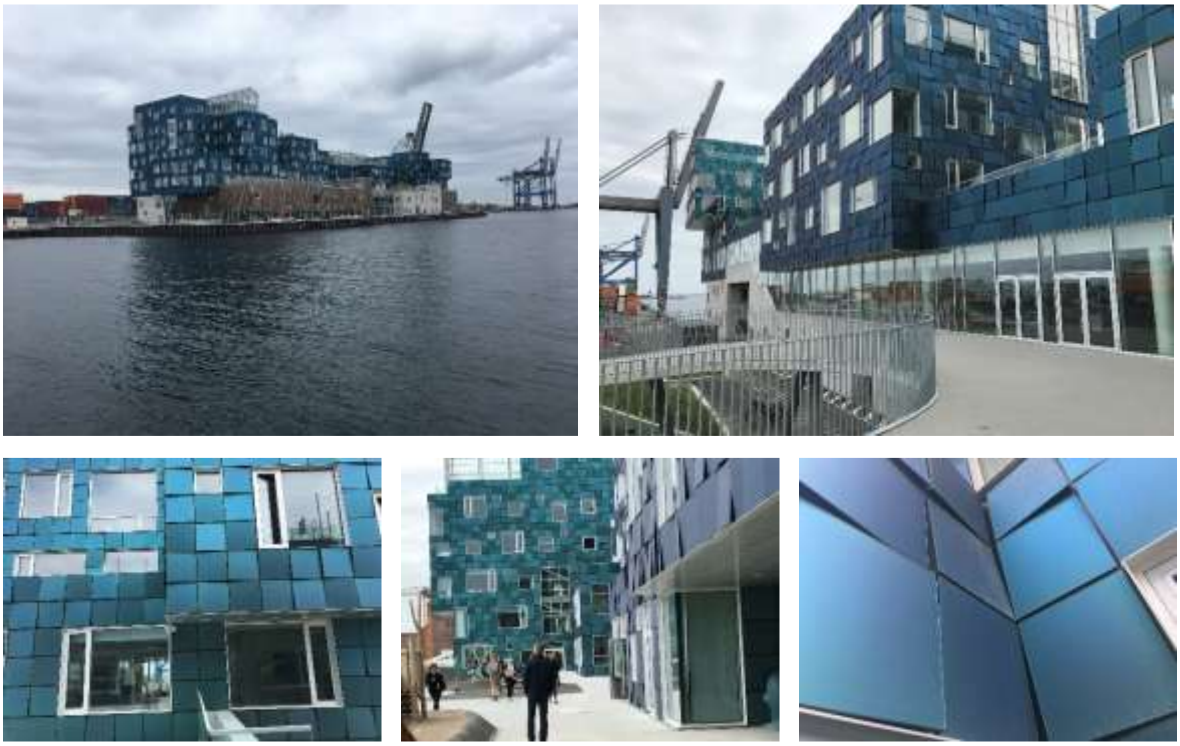

Figure 1 Photos of the International School in Nordhaven, Levantkaj 4-14, 2150 Nordhavn, Copenhagen, Denmark.

2.6 Control

One barrier is sometimes found in the difficult interoperability of electric devices and controls. The modern technology for solar envelope systems is usually combined with a control strategy to influence or improve the physical conditions of the indoor environment. For example the shading is controlled by a sensor that detects the irradiation on the façade. In case of high irradiation the shading system will be closed in order to reduce glare and overheating in the building. The communication between the sensors and the actuators of the building automation is realized with different control protocols (for example BACnet, DALI, KNX, ZigBee,… [6]).

A lot of new technologies for solar envelope systems promise benefits like high-energy efficiency or good user acceptance. But for decision makers an easy handling is also one of the crucial selection points. At the moment there is still a lack of interoperability, which imposes extra work on architects, facility managers and other decision makers [7], [8]. A simple Plug & Play is not possible in most cases, which means that the architect or the facility manager needs an expert to install the system and connect it to the building automation. The problem of the interoperability is even more important for building renovation, where only parts of the building technology are renewed. In this case, a new technology has to be implemented into an existing and already working system. Existing actuators have to be controlled by new sensors or vice versa, in this case it must be ensured that the new installation will work with the old system [9].

When all components can be operated together, still it is a challenge to develop a good control system: the mere addition of controllable components to the building envelope does not directly guarantee successful operation [10]. It is essential to take appropriate control strategies into account already during the design phase. One could say that it involves the design of a 'process' rather than the design of an 'artifact' [11]. This is in contrast with conventional building envelopes that are typically passive.

3 Regulations

Building codes apply to integrated solar envelope technologies. Moreover, innovative integrated products need to comply with test methods developed for conventional products, while standards do not consider large wall or roof integrated designs. Due to limited edge effects the real solar thermal performance of solar thermal building envelopes have been underestimate by up to 25%.

Stakeholders in the building and solar energy industry stress the need for updated standards for building integration, considering reputable references and state-of-the-art available technologies in the market [12]. It is vital to match both construction and solar energy industry standards and develop appropriate codes to adapt to the prompt development of building-integrated solar technologies and accommodate the design and construction needs [13]. Such standards would facilitate the integration of solar envelope technologies in several countries, where varying building codes and regulations hinder the consolidation of one standardized product, and would increase the level of certainty of those wanting to implement such technologies [13].

It is almost by definition that codes and standards lag behind the latest state of innovation in technology. The introduction of innovative systems that go beyond the current status quo is therefore likely to face legal barriers. Developers of such technologies would need to work with policy-makers to make sure that their product gets included in the standards in an appropriate way. In addition, new versions of standards should be written open enough to allow possible future developments.

Building regulations are also susceptible to change. Uncertainties about how laws and regulations (e.g. feed-in-tariffs or tax exemptions) might change in the near future may withhold investors from choosing for solutions that are perceived as more risk-prone but with higher possible rewards. However, the mere number of regulations to keep track is a barrier especially for small companies with ambitions to supply different markets. Policy makers should keep in mind that each change of regulations generates costs within the companies active in this field.

4 Design support tools

Suitable design support tools are needed in order to bring architects closer to technical issues during early design stages. Solar technologies need to be incorporated into the façade design and construction process from earlier stages, allowing for closer collaboration between the different disciplines involved [12,14]. Due to the novelty of the technologies, there are currently few reliable design guides or rules-of-thumb available. Studies also emphasize the importance to integrate solar envelope systems in advanced simulation tools and energy performance monitoring platforms [13].

Most software programs for building design support lack extensive capabilities for complex solar envelope systems, which commonly include energy generation components and shading control [15,16]. Simulation tools do not include features to allow for example to treat direct and diffuse light in a different manner. This lack of performance prediction tools makes it difficult for architects, designers and engineers to assess or guarantee the performance of the products, as it is very difficult or sometimes hardly possible to model their behavior.

This paucity of performance prediction tools comes hand in hand with the lack of integration in computer aided design (CAD) tools such as Autodesk Revit or Grasshopper for Rhinoceros. In order to be able to reach the mass-market, it is important that solar envelopes' components become part of the designers' standard routine. Seamless integration in CAD environments, especially through building information model (BIM) libraries is essential to this end.

Another challenge is to make the design support tools so easy to use that the barrier to start using them decreases. This still requires large research and development effort, but can contribute to lower costs for high-performance buildings.

5 Architectural barriers

Many solar building skins have a disruptive impact on the exterior appearance of the building. In certain cases, this recognizable look is desired to create an iconic building that attracts attention [17]. However, in order to reach the mainstream market, it is important that solar envelope systems blend in with the urban landscape and get beyond the stage of being considered as gadget solutions. The argument of conforming with the urban surroundings is of particular importance for cultural heritage sites [18], but there are currently not many tools available that can quantify the visual impact of solar facades in the design phase [19]. Some contemporary high-end solar envelope systems [20,21] have a distinct appearance that carries the signature of the architect who designed it.

Transparency is a key factor in building design and is especially advocated in façades for daylight utilization and enabling a visual connection between the occupant and the outside world. Energy harvesting facades usually benefit from maximum solar absorptance, often manifested in the form of large opaque surfaces. This leads to a competition between interests, because the available façade surface is limited [12].

The built environment is heterogeneous by nature. Many of the first-generation solar envelope systems, however, are either black or dark blue, and therefore face opposition from an architectural perspective. During workshops and interviews about innovative solar envelope components, architects have expressed a clear wish for more versatility in shapes, colors, textures and sizes [22]. There is also a perceived lack of suitable, ready-to-use components available on the market [22]. Standardization of solar building elements in the form of scalable components is much needed, but there should also be attention for providing options to customize the design, thereby promoting variety in the development of architectural products for building integration.

Solar building skins tend to be more complex than conventional alternatives. This leads to issues during procurement and tendering, because there is often insufficient knowledge to develop a project brief with clear targets and requirements [23]. More complexity also means that there are more uncertainties, more options to choose from, more specifications, more technical details to be resolved, and hence more decisions to be made. All these processes require time. For optimal integration in the building, it is important that the design of the solar building envelope is considered as early as possible, ideally before e.g. façade orientation, general building shape, materialization and floor plan layouts are determined. Unfortunately, there is only very limited information in this early phase of the design process. The challenges appear to be numerous, and things that need to be sorted out may be perceived as overwhelming. There is a need for tools and methods to ease this process, because if solar envelope systems are not considered from an early phase, they will likely not be considered at all.

Architectural barriers are further discussed at the case of windows with switchable transmittance as example for a solar envelope system. Adaptive glazings are an example of technologically promising, fast developing, growing market but still architecturally challenged technologies. Electronically switchable windows intelligently control the transmission of natural light thereby reducing the heating and cooling load of a building between 20% and 30%, and provide indoor lighting comfort[2]. The awareness about dynamic solar factor architectural products is recognized as being necessary to reach the more and more stringent energy performances that modern buildings are commanding. However, as of today, the combination of average performance, poor aesthetics and high perceived prices have been responsible for a slow market penetration of dynamic windows. The slow market penetration of dynamic windows can be explained by several factors among which are the aesthetical and performance barriers.

Aesthetics barriers: Electrochromic materials have been studied for the past 30 years and even though they have had a good success in the transport industry (electrochromic mirrors), their penetration into the building market has been extremely slow. For most of electrochromic windows the clear state is distinguished by a yellow hue and blue color in the dark state. Recent developments provide windows with a choice of green or neutral grey in the opaque state[2,3]. Using a set of materials that are extremely neutral in the dark state provide a very high

[2] AGC (2017). Discover Halio: AGC Glass Europe's new interactive windows and walls. Available from http://www.agc-glass.eu/en/news/press-release/discover-halio-agc-glass-europes-new-interactive-windows-and-walls [Accessed 27/06/2017].
[3] Sage Glass (2017). Optimize Design with SageGlass. Available from https://www.sageglass.com/en/products [Accessed 27/06/2017].

color rendering index (CRI) for the light coming through (CRI >90 for light transmission as low as 15%)[4]. In addition, a very clear state with no obvious color is achieved, making it hardly distinguishable from a regular glass when in its clearest state.

Performance barriers: While the dynamic range of the solar factor has been a factor of success for dynamic windows, the technology has been slowed down by limited visible transmission (T_v) range and long switching time. Extended T_v range is important to maximize daylighting and provide glare relief. Typically having light transmittance above 65% is desirable to closely match daylighting specifications while very low transmittances are needed to avoid glare by direct irradiance [24,25]. Table 1 compares the performance of standard products from industry leaders. The developments aim at short transition times, a large range of transmittances at competitive costs.

Table 1 Basic specifications for a selected reference of electrochromic windows

• Brand	• Transition time (min)	• T_v range Clear/Dark (%)	• Solar Factor range Clear/Dark (%)
Sage Glass[5]	• 15-30	• 60/1	• 40/5
EControls[6]	• 20	• 57/15	• 43/13
Halio[7]	• 3	• 66/3	• 45/5
Halio Black	• 3	• 57/0.1	• 35/4

Integration barriers: For new buildings, the physical integration of wired dynamic windows does not add complexity when it has been considered appropriately at the design stage. However retrofitted buildings are the most challenging as, similarly to the retrofitting of any new product, technical barriers are most often encountered to achieve the desired minimum disturbance, aesthetic, working condition and ease-of-use. When cables or pipes have to pass through cavities (walls, floor or ceiling), access and understanding of the current cabling or piping situation are the main issues. Typically, surfaces have to be ripped apart and rebuilt which disproportionally add cost and time to the installation of the new system. Further on, when a system needs be connected to an existing cabling or pipe network, information on that network is most often unavailable. As mapping down such network is not always such easy task, adding time and cost, the installation project of the new system may well be discarded right at its start. To counteract these wiring issues, technologies are progressively moving towards self-powered systems. For dynamic windows, research and developments aim to achieve self-powered devices, for example, by integrating photovoltaic and battery technologies[8].

As technologies are increasingly provided with Internet of Things (IoT) components with cloud-based services, smart-devices connected to building management systems or your wireless home network can be holistically controlled with a network of other connected systems to instantaneously and predictively optimize building occupants comfort, minimize energy consumption, maximize renewable energy production and storage.

The integration of dynamic windows as well as any other technologically advanced products commercially available is rather more a skill challenge than a technical challenge thereby slowing down the widespread use of such technology. As these systems are more complex, requiring set of competences ranging from building design, glass expertise, electrical installation and system integration. It is mandatory that companies who want to commercialize successfully this technology take into account all these elements by making sure that none of these steps are neglected and are properly executed by skilled professionals. For professionals to carry on their work, the right tools need to be made available. At the design stage, current models are somehow limited in

[4] Halio (2017). Halio at Work. Available from https://haliolife.com/commercial-2/ [Accessed 08/09/2017].
[5] Sage Glass (2017). SageGlass Product Guide. Available from https://www.sageglass.com/sites/default/files/productguide_mkt_48.pdf#page=4 [Accessed 08/09/2017].
[6] EControl (2017). Control Switchable Solar Control Glazing. Available from https://www.econtrol-glas.de/fileadmin/econtrol-glas/dateien/technische_dokumente/Broschuere_E_K.pdf [Accessed 08/09/17].
[7] Halio (2017). Halio is no ordinary glass. Available from https://haliolife.com/why-halio/ [Accessed 08/09/2017].
[8] Self-powered switchable window (2017). Self-powered system makes smart windows smarter. Available from https://www.princeton.edu/news/2017/06/30/self-powered-system-makes-smart-windows-smarter [Accessed 08/09/2107]

taking into account dynamic products. Complex calculations using multi-dimensional models considering the building location, its orientation, usage, weather conditions and its interaction with other building components need to be simplified and fast to use. Reliable dynamic simulations tools that will enable such calculations need to be developed to educate and train building professionals. Integrating these tools under a BIM platform could provide widely spread knowledge primarily to architects, developers, consultants, building owners and operators on the appropriate use of the technology during the design process, quality assess the performances during the operation and alert for required maintenance.

Economic barriers can result from the perceived value and the complexity of the value chain to design and build a building. Indeed, the premium cost for dynamic windows is significantly higher of dynamic windows compared to standard solar control coated glass. However, as illustrated in Table 2 the function brought by dynamic windows is much more advanced than a solar control products.

Table 2 Comparison of key attributes between electrochromic (EC) windows and external solar shadings

	 **Neutral Grey EC window[9]**	 **Colour EC window[10]**	 **External shading[11]**
Thermal comfort	=	=	=
Visual contact to the exterior	++	+	o
Aesthetic	Slick	Slick	Textural
Color rendering	+	-	+
Fast and uniform switching	++	+	o

Therefore, the question becomes what solution would be required without dynamic windows? To achieve the same level of yearly average performances as dynamic windows, outside and inside solar shadings are used to limit the amount of light and energy coming into the building. Those solutions are reaching somehow the desired function but have main drawbacks: i) they are creating visual barriers between inside and outside and ii) they can hardly be applied when there is much wind. In case of interior venetian blinds, the technical building plant becomes more expensive due to the increased cooling demand. By contrast, dynamic windows will lower the initial investments on HVAC investments (for instance) but they will represent significant savings over the life cycle of the windows by reducing the operating cost for the building management and the owner with their low maintenance cost. A calculation of total cost of ownership is therefore one of the best way to approach such systems. However, the current value chain structure can be a barrier: An electrochromic system can have three main components: a glass façade element, an electronic intelligence and a set of services that allow the system to evolve in time to adapt and adjust to the environment and the building usage. The perceived value may be well understood by the owner and/or the investors but from the façade maker or the general contractor perspective, it represents a challenge. The system will have an impact on three separate budgets: the façade of the building, the electrical system and the control of the building. All the traditional players do not benefit at first from savings on operating cost that represents such system. In addition, dynamic windows become a direct competition to the external shading system that façade makers or profile makers can propose.

Figure 2 presents the results of one question of a survey regarding barriers and needs conducted by IEA SHC Task 41 “Solar Energy and Architecture” [26]. For this question, 439 architectures and other practitioners answered. The answers show that many different issues may prevent solar envelope systems. Several of these

[9] © Halio
[10] https://www.flickr.com/photos/scott_shell/5439476950/
[11] https://www.flickr.com/photos/coltgroup/5208942297/in/photostream/

issues are related to knowledge, because a perceived “lack of suitable products” can sometimes be a lack of knowing the suitable products.

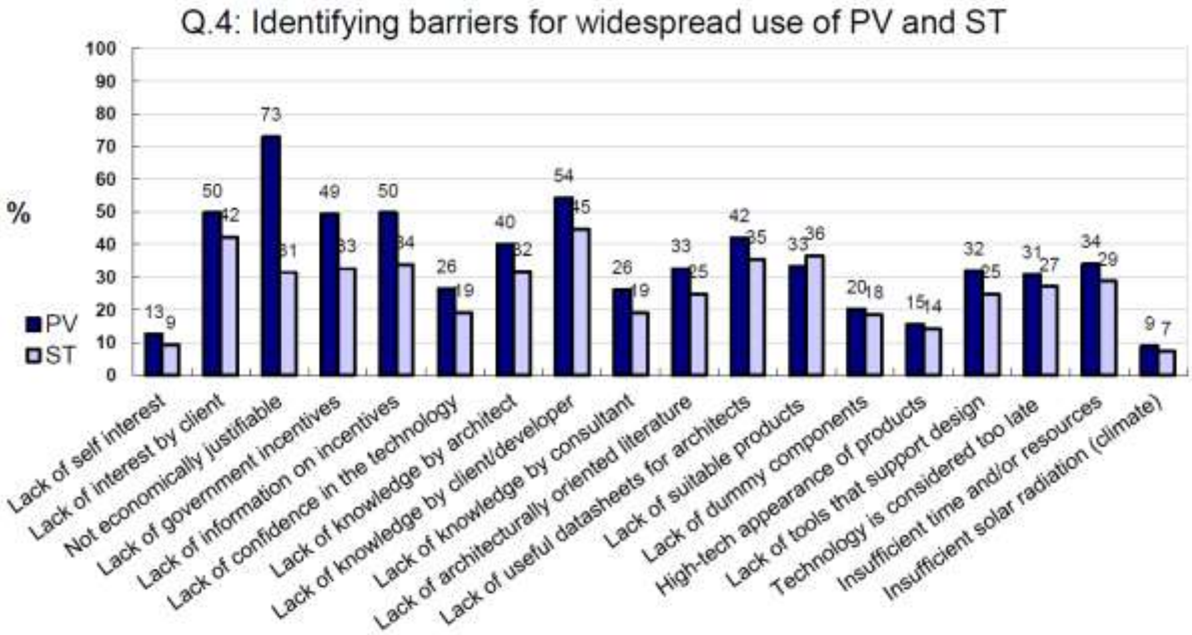

Figure 2 Barriers for widespread integration of PV and solar thermal in architecture [26]

In the survey for [1], it was surprising that people without experience considered the on-site interaction of different trades as a major barrier for building-integrated solar thermal systems, while the practitioners with experience of such building processes did not. The conclusion of [1] points out economic issues as the number one barrier for building integrated solar thermal solutions. However, [27] presented a detailed cost analysis of three building with building-integrated solar thermal systems built between 2002 and 2009. Two of them had investment costs 40% below the investment costs of not integrated conventional solar thermal flat-plate collectors. Therefore, it needs to be carefully analyzed whether a perceived cost issue may be a lack of knowledge about cost savings.

Architects and engineers must be educated on the advantages and aesthetics of building-integrated solar. Of course, it is essential that solar designs do not compromise other aspects of a building such as durability, appearance, fire codes or lead to increased maintenance.

6 Economic barriers

The initial investment of innovative building projects is typically higher than for projects with conventional solutions.

Economic barriers for solar envelopes systems are not only due to the components being more expensive, but also in some cases to the mismatch between the design budget and the construction budget. Intrachooto et al [28] highlight five circumstances from which financial obstacles emerge:

(1) Component interdependency: advanced facades are innovative components that can affect multiple building systems and significantly increase the overall investment cost or the timescale of the return on investment.

(2) Speculative financial return: The return on investment is based on assumptions of performance and predictability and there is an uncertainty whether this return on invest will be reached.

(3) Focus on low investment costs: innovative technology commands higher investment than the widely used standard solutions. Their price in themselves can be a barrier in budget related aspects of building planning, although the improvements in technologies are making advanced facades more competitive in terms of price and return on investment.

(4) Neglected innovative effort: the budget may lack financial compensation for devising and developing innovative solutions.

(5) Financial misallocation: there can be a mismatch between the design and construction budgets with a focus on building costs, while restricting expenditure on the basic design process that is necessary for implementing innovative solutions.

Furthermore, additional financial barriers can arise when the clients are not the direct beneficiary of the return on investment. This occurs in so-called landlord-tenant relationship situations for example, when the investor is not the one directly benefitting from the improvements in a building's energy use or comfort.

The price differences between energy costs for fossil fuels and renewable alternatives are not large enough to promote the emergence of competitive solar driven alternatives on a large scale [12]. The costs of emitting greenhouse gases into the atmosphere should be internalized into the cost of fossil fuels so that the economies become sustainable. However, solar envelope systems also offer several other advantages that cannot be captured by price comparisons only. Traditional economic metrics, such as payback time or levelized cost of electricity (LCoE) are therefore not favorable for supporting the adoption of solar envelope systems.

In the construction industry, more emphasis appears to be given to limiting the capital investment cost. Since integrated building envelope systems tend to require higher investments compared to add-on solar systems, this can form an additional barrier in the decision-making process. As a consequence, there is a need for new appraisal mechanisms that take the value of solar envelope systems into account in a more holistic way [30,31]. An example of such an evaluation approach for BIPV systems has recently been presented by [32] including aspects such as: design, flexibility, ecology/sustainability, production, economy, and building physics/construction.

The points raised above reinforce the need for valuing solar facades on the basis of life-cycle costs (LCC) or total cost of ownership (TCO) instead of e.g. capital costs or LCoE. Such a change in mind-set will be necessary to truly integrate all aspects that make it possible to have a fair evaluation of the performance of solar envelopes over the entire building life cycle [29].

Investments in energy harvesting façades can be affected by the split incentive principle. Those responsible for paying the energy bill (e.g. tenants) are often not involved in making decisions about capital investments. Landlords or building owners may not be inclined to choose for solar envelope systems, because the monetary benefits over the building life cycle may not come to their benefit [33].

Innovative façade technologies often lack a proven track record. Apart from questions about expected performance, this also leads to uncertainties about maintenance costs, failure risks, insurance and liability, and guarantees. Decision makers might be reluctant to take such risks.

There is also a need for detailed solutions' cost breakdowns to obtain comparable cost data that can be used to properly inform stakeholders about the associated costs in comparison to other systems. More case study analyses of installed systems need to be published in order to develop a good overview of realistic figures for installed prices and indications where price reductions are most likely [13].

A good business plan is most important to convince the building owner. The purpose of the business plan must be targeted to the specific building owner, but generally speaking, most of the owners require a confirmation that the planned investment will not increase during the construction phase and that the return of the investment will reach at least the same performance of the reference solution (and additional value over the lifetime).

Increased use of new collaboration strategies and business models, in which financial risks and rewards are in better balance, could accelerate the market adoption of solar envelopes. For example, the design-build-finance-maintain-operate (DBFMO) scheme could stimulate more investments in design solutions with high value over the whole building life-cycle [34]. Solar envelope systems can also benefit from the market trend towards energy performance contracts (EPC). In this financing mechanism, a building owner and an energy services company (ESCO) will typically agree to implement selected energy efficiency upgrades, which will result in energy cost savings. In return, the building owner makes periodic repayments over the course of a fixed term, to compensate for the ESCO's costs. The ESCO typically guarantees that the energy savings realized will cover the cost of the project. Another development worth mentioning is the idea of façade leasing (Azcarate et al., 2016). The idea behind this innovative business model is to replace the current, linear contracting method based on the selling of technological products, with a circular model based on the long-term delivery of performance services. By spreading risks and removing investment barriers, such a financing mechanism opens the door for adoption of innovative building systems such as solar envelopes. However, compared with other contracting concepts, building integrated solar technologies cannot be easily removed and sold at a good price. Therefore, innovative concepts are needed how to deal with terminating a contract, selling the property etc. at low costs.

<u>The example on the guaranteed performance, Kildeskovshallen</u>

Kildeskovshallen is a swimming bath built in 1966. In 1999 the whole swimming bath became protected by the national heritage agency, which means that there have been extra demands to the placement and the overall architectural look of the photovoltaics and the installations that are connected to the photovoltaics. The project has been done in close dialog with the National heritage agency.

Figure 3 presents a photo of the final PV installation.

Figure 3 Photo of the PV installation on the cultural heritage site in Kildeskovshallen.

In the tender for the photovoltaic plant there is a chapter dedicated to the guaranteed kWh performance where there is an explanation on how to correct the monitored kWh production, so it is possible to compare it with the theoretical, which the tender was won. The chapter is short and clear and has the following equation that is used for the correction of the guaranteed performance (kWh production).

$$\text{Corrected yearly production} = \text{Measured yearly production [kWh/year]} * \frac{\text{Predicted insolation [kWh/m2 per year]}}{\text{Measured insolation [kWh/m2 per year]}}$$

If the performance does not fulfill the guarantee, the compensation is calculated with the following equation

$$\text{Compensation [euro]} = \text{Total price for the plant [euro]} * (1 - \frac{\text{Corrected yearly production [kWh per year]}}{\text{Guaranteed yearly production [kWh per year]}}$$

In the example Kildeskovshallen, the guaranteed performance was not fulfilled. Due to the lower kWh performance there was raised a compensation of (320.979 euro * (1-(234.590 kWh/year)/(260.837 kWh/year)) =) 32.299 euro.

These experiences from PV sector can be helpful for large building-integrated solar thermal installations, in the sense that the owner does not need to take care of the solar thermal system actual performance. However, solar thermal systems accurate performance measurement is more expensive than PV solutions. This means that for small building-integrated solar thermal systems, it may not be economic to offer a guaranteed performance based on accurate performance measurements.

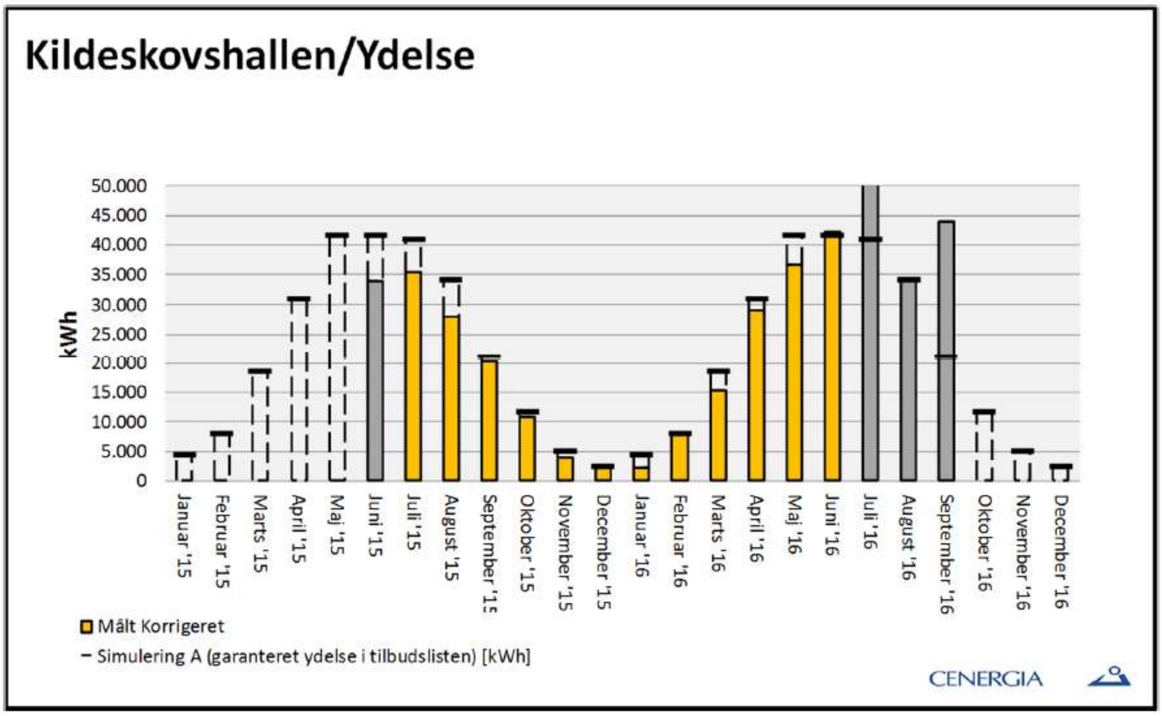

Figure 4 Comparison of the predicted PV performance on Kildeskovshallen (indicated by black horizontal lines) with the monitoring results (yellow). The grey columns indicate that there are some mistakes in the received monitoring data.

7 Social barriers

Social barriers are formed by underlying beliefs, perceptions and expectations regarding the innovative/sustainable façade components or building products, and are often created by the culture of the community. These elements are typical when describing the process of technical diffusion, as first outlined in the psychological model from E.M. Rogers in 1962 and revised in 2004 by the same author [35]. Rogers explains that the decision to adopt innovative technologies and thereby take a risk and lead to a shift in how a population will see a challenge, depends on the actions of a small group of individuals who are "early adopters". Once this group starts to promote a technology or design approach, more cautious individuals will slowly follow on the same path. This model is illustrated by an S curve where the "laggards" group of the population are the last ones to adopt the concept and the "innovators" the first ones

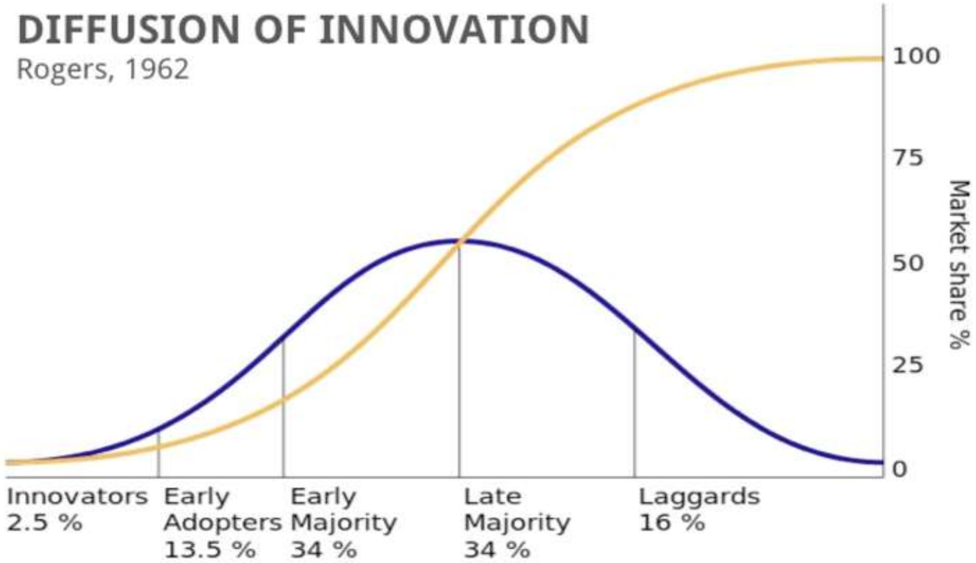

Figure 5 Schematic drawing of the relative increase of the market share of an innovation over time. The users are grouped depending on how early they use the innovation. [36]

The analogy between the Rogers model and energy efficient innovative buildings is detailed by Shove [37]. Shove points out that in the context of buildings, if "star" members of a community adopt the technologies, for example renowned architects or developers, the technology transfer is more likely to happen faster. However, the barriers can also be anchored in misconceptions about cost or performance of innovative technologies. Additionally, other social barriers described as social acceptance of, for example, renewable energy create a schism between the general support of the public for lower carbon emissions along with the continued reluctance to actually implement the associated measures that are necessary [38].

Additionally there might be issues regarding information sharing between the various parties involved in the construction process, which could inhibit the success of innovative/sustainable façade components or building products. Lacks of practical or understandable information about the technologies, about the process of integration, or general absence of "know-how" in the construction or operation phase are all elements that can lead to challenges for advanced facades. If the systems are not properly implemented, they will not perform as expected and this might lead to financial issues later in the operation phase of the building. However, these barriers concern both tangible and intangible aspects and can affect building planners as well as building users [39]. This is because if the users are not informed about the properties of the building or do not know how to use the technical systems, the building will not only underperform, but the users will reject the building all together.

One important social barrier is the fear of using innovative technologies. People are at the core of all decisions along the value chain trust in technologies that have been used for years and that seem to promise low maintenance because low maintenance was experienced directly or by others. Even if a new technology has been tested for its durability, there can be irrational fears of failing with the new technology. Maybe failing with a conventional technology in a conventional way is socially better accepted than failing with an innovative technology. Of course, the long service life of buildings and the low margins make it more difficult for innovations than for example the short service life and high margins of electronic consumer industry. There should also be attention for risk quantification, to mitigate uncertainties based on unfamiliar techniques, the lack of previous experience, additional testing and inspection in construction, and a lack of manufacturer and supplier support (Hakkinen and Belloni, 2011). Guarantees as presented in section 6 could help to overcome this barrier.

Large-scale adoption of solar building skins will require new skills from professionals in all levels of the workforce [2,40]. To fill the gaps of missing competences, there is a need for a human capital agenda that outlines strategic education plans. In any case, technical training programs should be jointly developed by the building and solar energy industries for architects, engineers, façade installers and manufacturers, to streamline the market uptake of solar envelope systems.

In a recently conducted international questionnaire study regarding the adoption of green building technologies in the construction industry, it was found that the lack of information about lifecycle benefits is one of the principal barriers that hinder the decision to opt for solar envelope systems [41]. Finding effective communication means to express the prospective benefits is not only necessary for built environment professionals, but especially also to make the general public aware of the existence of the technologies and their associated benefits [42].

Installation of solar envelope systems can also have unintended consequences for the urban surroundings. There is, for example, a risk of exterior glare due to excessive uncontrolled reflection of sunlight from BIPV systems [43]. Despite the fact this that this is a widely known issue, there are currently no universal guidelines or performance metrics for assessing external glare impacts on typical urban environments [43,44]. It is unknown how much glare is “acceptable” and unclear how to understand results if there is no generally accepted definition of what is “typical” glare in a city. Hence it is difficult to communicate with clients and building authorities.

Commissioning is the process that ensures that a system is installed according to the design requirements, and that all systems are interacting properly to achieve performance as intended. For HVAC systems, the field of commissioning is quite mature with well-established standardized procedures for quality assurance. For building envelope components, however, there is hardly any guidance on how this process should be coordinated and what the responsibilities of the stakeholders are (Attia et al., 2015). Refraining from proper commissioning after installation leads to increased probability for malfunctioning and sub-optimal performance. There is also a shortage of performance monitoring and fault detection & diagnosis frameworks that can give a building operator continuous insights into the operational performance of the solar envelope system. This makes it difficult to verify whether a system performs according to its potential, and to detect if maintenance is required.

Another challenge can be the information of the users. In general the decision for solar envelope system is not made by the occupants, who have to deal with the system in their daily routine. So the considerations that finally led to the choice of a specific system are not clear to the occupants. But within their work process a new system can especially at the beginning lead to some inconveniences like noise during the installation or uncomfortable conditions during the calibration.

When installed the occupants have to deal with a changed situation. For example PV on the façade might reduce the transparent part of the façade and therewith the connection to the outside world, the installation of thermal insulation glazing reduces the daylight inside and a modern light management system switches off the electric light when there is enough daylight on the working plane regardless whether the user wants more light.

Furthermore the usage of new systems is often not clear to the occupants. For example modern sun shading allows different positions and orientations of the lamellas (completely closed, cut-off,…). By using this variability during the most time of the day rooms can be illuminated only by daylight. But in reality the sun shading is often completely closed and the electric light is switched on.

Additionally there is usually no introductory session that informs sufficiently about the advantages, like energy benefit from PV or modern thermal insulation glazing.

Taken together a stronger involvement of the occupants during the planning process of the solar envelope system, the explanation of the energetic background and an introduction into the usage of new systems could help to enhance the occupant’s acceptance and support of the system.

Finally, solar envelope systems may be blamed for errors of the conventional building services e.g. by late changes. In an innovation building project where Cenergia was hired in for a third opinion, the air tightness and insulation of the building envelope was decreased at a very late stage of the building process without informing the other stakeholders. Therefore, the recommended heat pump was not able to cover the heating demand. First a malfunction of the heat pump was assumed until the true reason was found. Such mistakes can be a barrier for manufacturers of components of innovative buildings.

8 Conclusions

This report has presented the barriers for solar building envelope as the experts of Task 56 perceive them. Although there are a large number of challenges, most of these challenges can be addressed appropriately when the stakeholders are aware of them. Several companies that are successful with their solar envelope systems technologies for several decades prove that it is possible to deal with these barriers in a productive way.

A deep understanding of the difficulties can be beneficial to many different stakeholders such as engineers, decision makers, programmers, architects, managers and salesmen. With this understanding, the barriers should be reduced in the upcoming years by joint efforts, because this could boost the market for low-energy buildings. Each difficulty also offers a chance for those who find a smart way to solve it.

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