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Advanced transparent facades: market available products and associated challenges in building performance simulation

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Abstract

The starting point of this study is to provide a non-exhaustive overview of relevant transparent advanced facade technologies available on the market and suited to Nordic climates. A corresponding literature review is carried out to assess the existing modelling capabilities in building performance simulation for each type of product, highlighting the main challenges associated with its modelling. Overall, most of the difficulties identified are linked to the inherent dynamicity of advanced facades, the interdependent physical domains they cover, the limitations of the software, and the skills necessary to recognize and implement the best-suited model among the multitude of options available.

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Keywords: Translucent advanced facades; Translucent advanced facades; Building Performance Simulation; Review;

1. Introduction

Current research [1] suggests that building envelopes hold a key stake in meeting sustainability and carbon reduction emissions targets set by legislation across countries. In particular, advanced facades are, according to the International Energy Agency (IEA), the most promising component in building design with the highest impact on building performance [2]. Advanced facades, in this study, refer to a wide range of systems and technologies that allow for dynamic response of the building shell. They are particularly attractive since they have the ability to actively and / or selectively manage the energy flow and heat transfer between the building and its external environment leading to potentially significant reduction in heating and cooling loads. Unlike traditional energy saving strategies, which

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rely on passive measures, such as increasing insulation thickness or optimizing window area, they can provide higher levels of indoor comfort [3,4] without significant additional energy consumption from other building systems like HVAC or lighting [5,6]. This is especially important since, as users, we are concerned with designing indoor spaces where our fluctuating comfort needs are met, while maintaining low energy requirements. Constant innovations in material science have led to the development of a myriad of systems and technologies for advanced facades. However, because of the fast pace of product innovation, a knowledge gap has been created between the progress of technologies and the tools available to building designers to model them sufficiently accurately in relation to the whole building's performance. The resulting situation is a bottom-up approach where modelling possibilities in building performance simulation (BPS) follow instead of drive innovation [3]. The lack of adequate modelling approaches additionally leads to difficulties in predicting the performance of the systems in use and thereby at times limiting their real-world uptake or optimization in the design process. Loonen et al [7] describe four main physical domains that advanced building envelopes influence and that must be taken into account when predicting the behavior of such facades. These domains are Thermal (T), Optical (O), Airflow (A) and Electrical (E). This study provides a general overview of the most relevant transparent advanced facade technologies available on the market; then proceeds to carry out a preliminary assessment of the types of challenges associated with the modelling of these technologies in given available BPS software alternatives. The aim of the study is therefore to give insight into which types of existing technologies can be simulated and which aspects may challenge the level of accuracy in the models.

2. Methods

The first part of the study involved the task of mapping existing technologies of transparent advanced facades [8]. This was carried out through an extensive review of webpages, catalogues and product description brochures of well-known manufacturers as well as documentation provided at exhibitions on the topic. In order to complete this search, an additional terminology based search for relevant products and systems was run through online search engines using the key words: *advanced facades; adaptive facades; dynamic facades; smart facades; intelligent facades; innovative facades; multifunctional facades; solar facades*. Due to the limited scope of this study, the work encompassed only the relevant and market-ready transparent/translucent advanced facade components. The choice to exclude opaque components was made on the basis that transparent facades are intrinsically more complicated and present broader challenges in modelling [9]. Based on the results, a classification of the different technologies is suggested alongside examples of products from manufacturers and a description of the most relevant characteristics. The findings from this initial research work were coupled to a scholarly literature review with the goal of identifying and analyzing existing modelling options in building simulation tools. This work builds upon existing reviews of building simulation tools capabilities [10] and was carried out by reviewing journal articles on the topic of modelling and using keywords related to the specific technologies identified in the first part of the study.

3. Results

3.1. State of the art – innovative technologies and systems classifications

The findings from the technology mapping are shown in Table 1. The technologies are sorted according to a proposed two-tiered categorization system. The main product categories are based on the nature of the component and the technology implemented. Each one is described with an outline of its main characteristics with an explanation of the acronyms below table 1. The specific sub-categories of products are listed in the table along with examples of products available on the market.

Table 1 Description of examples of recent innovative translucent and transparent facade products available on the market.

Product category	Sub product category	Example of manufacturer and product
ATFS	External, transparent insulation system	Sto - Therm Solar [11]
	Double/triple glazing with translucent cavity insulation	Okalux - OKALUX® and KAPILUX® [12]
	Dual glazing with aerogel cavity insulation	Okalux - Okagel [12]
	Dual glazing with translucent cavity insulation	Wacotech - TIMax® GL System [13]
HDSF	Hybrid double skin window	Schüco - AWS 120 CC.SI ; Wicona - Wicline 215/ Wicline 125; Finstral - Twin-line Nova [14–16]
	Translucent PCM window	Glass X - Crystal/ Comfort/ Store [17]
SG	Electrochromic windows	Saint-Gobain- Sage glass [18]
	Thermochromic windows	Prelco - Prel-Shade; Raven Window [19,20]
	Thermotropic windows	Tilse – Solardim ® Eco [21]
	Polymer dispersed liquid crystals	Merck - Smart Liquid Crystal Windows [22]
ASSDS	Facade integrated screen, blades or louvres	Nordan - Nordan screens ; Markilux - 620 Tracfix; Renson-Panovista®/ Fixscreen® ; Reynaers- Reynascreen; Gibus-Tolo GA; Schüco- CTB product family; Okalux-Okasolar [12,14,21,23–26]
	Folding shutters	Renson - Cilium® ; Colt – Elisse [24,27]
	Motorized, window cavity integrated venetian blind	Schüco – CCB [14]
	Sunshade blades or passive louvre with integrated PV	Wicona - Wicsolaire; Kawneer- 1600 Powershade ™; Schüco- Brise Soleil ALB 650 PP [14,15]
BIEC	Window integrated solar thermal collector (BIST)	NorDan – Solar [21]
	Window integrated PV (BIPV)	Schüco- FWS 60 [14]

3.1.1. Advanced translucent fenestration systems (ATFS)

Advanced translucent fenestration systems [28] transmit high amounts of diffuse daylight and solar heat while maintaining good "nighttime" insulation properties. Seemingly, the use of aerogel in windowpanes is the most promising solution because of its high insulation properties. However, in spite of being a thermally promising material, aerogel has not made a substantial market impact yet due to its high material cost and poor structural properties [29]. Other types of ATFS include fenestration systems with capillary inlays between the panes. These insets allow for a better diffusion of light in rooms, while reducing convection and heat radiation.

3.1.2. Hybrid double skin façades (HDSF)

Hybrid double skin façades [30] demonstrate considerable advantages in comparison to regular building façades. The extra air layer in the cavity provides improved acoustic isolation, solar control, and additional insulation in cold climates. The cavity can be ventilated naturally or mechanically, and e.g. be coupled to ventilation systems. The double skin facade can also make use of several other technologies such as PV-cells or phase change materials (PCM). Phase change materials (PCM) reduce thermal fluctuations by storing and releasing energy at specific temperatures acting like additional thermal mass in buildings. The most common type of material used is paraffin based (dispersed or powdered wax mixture) but it is also possible to use salt hydrates and bio-based PCMs.

3.1.3. Switchable glazing (SG)

Switchable glazing systems [31] use glass planes that can change their light and heat transmission properties in response to voltage, light or temperature. The glass color can cover a large range of translucence and typically have multiple intermediate states. The main technologies currently manufactured in glazing components include electrochromic, thermochromic, thermotropic and polymer dispersed liquid crystal glazing systems. Although these technologies rely on different mechanisms, they all experience similar drawbacks due to material and installation costs, as well as uncertainty regarding their durability.

3.1.4. Advanced solar shading and daylighting systems (ASSDS)

Advanced solar shading and daylighting systems [32] are developing towards facade integrated and window cavity integrated shading systems. This is because integrated systems are more discreet and offer improved architectural aesthetics. Additionally, when the system is integrated in a fenestration cavity, it will be less vulnerable to degradations due to wind and weathering.

3.1.5. Building integrated energy conversion (BIEC)

BIEC, in this review, are technologies integrated in glazing components that enable the building to harvest or convert energy from renewable source such as solar irradiation [33]. The energy can be converted to thermal energy or electricity and be directly or indirectly connected to other building systems.

3.2. Simulation tool overview - modelling possibilities and challenges

There exists a myriad of simulation tools used for building performance on different levels. The International Building Performance Simulation Association (IBPSA), states that more than 140 competing building simulation tools with overlapping functionalities are available on the market today [34]; causing non-simulation experts to struggle in identifying the best-suited method [35]. Furthermore, independent developer communities continuously extend the capabilities of software tools and the models they implement. Because of this plurality and redundancy, it was chosen to limit the scope of the review to the most commonly used whole building simulation tools [3]: *EnergyPlus* [36]*;* *ESP-r* [37]*;* *IDA ice* [38]*;* *IES VE* [39]; and *TRNSYS* [40]. Table 2 presents an overview of possibilities for modelling in software simulation related to the products listed in Table 1 alongside the related physical domains that must be accounted for in simulations. Columns marked with an "x" indicate that it is possible to model the technology in the software while the indexation above the "x" refers to the type of challenge associated with the modelling approach.

Table 2 Review of modelling possibilities for the chosen building performance simulation tools

Category	Description	Physical domains*	Simulation tool				
			EnergyPlus	ESP-r	IDA ICE	IES VE	TRNSYS
ATFS	Insulated glazing units with aerogel as cavity insulation	O,T	x	$x^{(1)}$	x	x	$x^{(1)}$
HDSF	Hybrid double skin window	O,T,A	x	$x^{(1)}$	x	x	$x^{(1)}$
	Double skin with translucent PCM	O,T,A			x		
	DSF w/ PV natural ventilation	O,T,A,E	$x^{(2)}$	$x^{(1,2)}$	$x^{(2)}$	$x^{(1,2)}$	$x^{(1,2)}$
	DSF w/ integrated shading systems	O,T,A,E	$x^{(3,4)}$	$X^{(3)}$	$x^{(3)}$	$X^{(3)}$	$x^{(3)}$
	DSF w/ natural ventilation	O,T,A	$x^{(2)}$	$x^{(1,2,4)}$	$x^{(2)}$	$x^{(1,2,4)}$	$x^{(1,2,4)}$
SG	Electrochromic windows	O,T, E	$x^{(3)}$	$x^{(3)}$	$x^{(3)}$	$x^{(3)}$	$x^{(3)}$
	Liquid crystals	O,T	$x^{(3)}$	$x^{(3)}$	$x^{(3)}$	$x^{(3)}$	$x^{(3)}$
	Thermochromic windows	O,T	$x^{(3)}$	$x^{(3)}$	$x^{(3)}$		$x^{(3)}$
ASSDS	Facade integrated shading system	O,T	$x^{(3)}$	$x^{(3)}$	$x^{(3)}$	$x^{(3)}$	$x^{(3)}$
	Foldable exterior shading	O,T	$x^{(3)}$	$x^{(3,4)}$	x	x	x
BIEP	Integrated solar thermal collectors	O,T		$x^{(4)}$			$x^{(4)}$
	Integrated photovoltaics	O,T, E	x	x	x	x	x

* Thermal (T), Optical (O), Airflow (A) and Electrical (E). (1) There is a need for advanced coupling strategies between physical domains via another software [41,42], (2) Need for accurate and high temporal resolution weather data, (3) An advanced control of operation may need to be implemented, (4) General limitations in the model [43–46]

4. Discussion and concluding remarks

Traditional characterization methods for building envelope components are based on static parameters such as thermal transmittance U-values (W/m^{2}K) or solar heat gain coefficients (g-values). Since these values vary according to transient boundary conditions and user requirements for advanced facades, conventional performance simulation methods are not reliable. Instead, successful modelling requires a complex combination of compatible methodologies involving mathematical equations, coupling between physical domains, simulation time-steps, control logics and detailed local climatic data. As shown in table 2, the HDSF class is the most complex product category where in some cases, all four physical domains must be accounted for and solved simultaneously. This complexity is particularly challenging for naturally ventilated HDSFs, as software based on nodal models and fundamental heat balance principles have limited accuracy when modelling complex airflows [46,47,48], this is because the models rely on empirical values for heat transfer coefficients, wind pressure coefficients, loss factors and friction factors and those may not necessarily represent the real airflow. To resolve this issue, one may choose to characterize the behavior of the system by calculating case specific parameters using more detailed tools based computational fluid dynamics (CFD). However, this approach requires high computational power, and is not suited to annual simulations or as a standalone approach. Alternatively, tools like EnergyPlus or IDA ice, which use airflow network methods, can provide an intermediate solution to modelling the problem in a more successful manner [48]. Products in the ATFS category can be simulated in all five-selected software, though some of them require a prior simulation (ESP-r, TRNSYS) [41] to determine the optical parameters of the system. SG and ASSDS systems require advanced control logics in operation, which can be difficult to implement. Attempts to solve this complexity have unfortunately led to many models becoming over engineered [10] or reliance on different tweaks or workarounds to be able to characterize advanced facades [50]. However, possible promising strategies in BPS include the development of tools like Modelica (https://www.modelica.org/) or SOEP (https://energy.gov/eere/buildings/downloads/spawn-energyplus-soep), which are based on product libraries that can be developed by individual manufacturing companies and integrate engines for air and other energy balance equations. Co-simulation [51], which allows the coupling of complementary simulation tools during the simulation run-time is also a promising solution although there is still further progress to be made in the field.

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