Facade 2018 -

adaptive!

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Contents

Strategies for Design

Passive Adaptive Façades – Examples from COST TU1403 Working Group 1

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Buildings often adopt strategies based on the integration of solutions and technologies in façades capable of changing their behaviour in time to improve energy efficiency and comfort. Considering that the envelope is the main parameter that influences the energy performance of buildings, façade elements with adaptive features can provide the buildings the necessary flexibility needed in terms of energy flow and thermal comfort in the context of nZEB, where the buildings must be interactive in the zero energy and smart city context. Several different types of adaptive façade concepts have already been developed, and an increase in emerging, innovative solutions is expected in the near future. However, when referring to adaptive technologies, two main categories can be distinguished. Adaptive technologies, which rely on passive design to improve building energy efficiency and comfort, and active technologies which include renewable harvesting. The aim of this paper is to provide several examples of passive adaptive technologies and their performance features from COST TU1403 Working Group 1 database.

Keywords: adaptive façades technologies, energy efficient design concepts, examples

1 Introduction

The buildings energy demand as well as its environmental impact can be reduced and modified by employing passive and active measures. In this context energy-efficient adaptive façades emerge which are designed to adequately react to daily and seasonal changing external conditions. Moreover, depending on the climate where the building is located, the requirements on the façade can be completely opposite during summer and winter, as well as during night and day. For example, in winter solar energy gain may be allowed into the building during the day while together with a high level of thermal insulation in order to allow the energy to be stored. During summer, however, excessive solar gain should be avoided to prevent overheating in most cases. According to literature, adaptive façades consist of multifunctional highly adaptive systems, where the building envelope is able to change its functions, features or behaviour over time in response to transient performance requirements and boundary conditions, with the aim of improving the overall building performance (Loonen et al. 2015). Façade elements with adaptive features can provide the buildings the necessary flexibility needed in terms of energy flow and thermal comfort in the context of nearly zero energy buildings (nZEB) (Garde et al., 2017) or energy-efficient interactive buildings, both of which are essential parts of any smart city initiative. Several different types of adaptive façade concepts have already been developed, and an increase in emerging, innovative solutions is expected in the near future. However, when referring to adaptive technologies, two main categories can be distinguished. Adaptive technologies, which rely on passive design to improve building energy efficiency and comfort, and active technologies which include renewable harvesting. The aim of this paper is to provide several examples of passive adaptive technologies and their performance features from COST TU1403 Working Group 1 database.

2 Passive Adaptive Façades

We can refer to passive adaptive facades as the facades provided with technological systems which do not require power, controls and require little or no maintenance. Some of these facades are designed with moving parts to allow the increase of the energy performance and indoor comfort of the new or existing buildings where they are integrated. The passive façades falling into this category are: double skin façades; wood based responsive building skins; glass surface with silk-screened patterns of ceramic-based paints; brise-soleil and fixed or pivot-mounted louvres; light-directing systems and Trombe wall. The passive facade mostly designed to react to changes from external factors should be able to:

- Maximize direct solar gains as it is fitted with extensive glass surfaces with high thermal insulation and should be equipped with shielding systems to control the glare effects and provide protection from solar radiation in summer;
- Accumulate solar energy even when it does not directly penetrate the room, using technologies such as Trombe walls, or air- and water-based solar collectors;
- Provide buffer zones between the transparent and opaque closure systems in order to increase the protection against the cold and exploit solar energy in winter;
- Reduce indoor overheating during the summer months through the presence of artificial and/or natural solar screens;
- Increase natural lighting by creating transparent openings of suitable sizes;
- Encourage natural ventilation by reducing energy consumption for summer air conditioning;
- Integrate solutions for the adoption of passive cooling systems that ensure a temperature reduction inside the building in the summer months by night free-cooling.

Passive envelopes are usually integrated in residential buildings, with low energy demand, where the users assume the management responsibility for the regulation of the moving parts which enable the envelope to perform in a number of different ways according to daily or seasonal changes. These envelope solutions, however, can have some drawbacks as they could:

- Restrict the aesthetic/architectural design due to adoption of standard technological solutions;
- Be closely linked to the user's management and behaviour, if not connected to building management systems that can be set up to assume the various "bioclimatic" configurations autonomously;
- Require a specific regulation to change their performance in relation to the changing outdoor weather conditions (and these interventions are not always simple);
- Not make efficient use of solar energy due to both the reduced uptake ability of the passive building components and the absence of effective systems for heat accumulation and distribution.

3 Passive Adaptive Technologies and Performance Features

As mentioned above, among the most common examples of passive adaptive façades there are: double skin façades; wood based responsive building skins; glass surface with silk-screened patterns of ceramic-based paints; brise-soleil and fixed or pivot-mounted louvres; light-directing systems and Trombe wall.

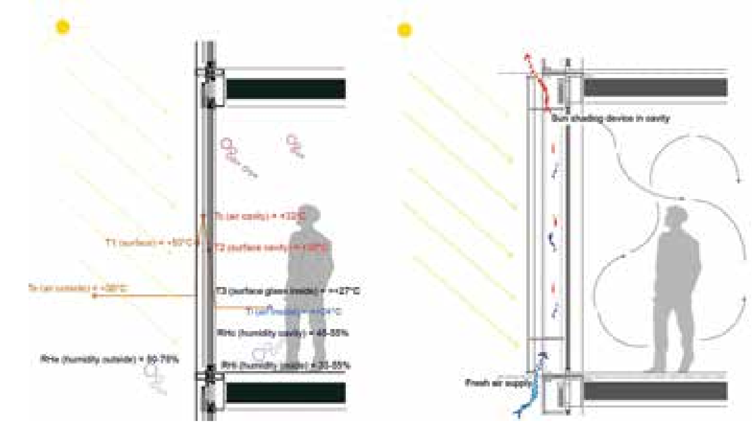

Fig. 1 Closed and opened cavity. The autoreactive façade system adapts its U-value to changing exterior climate conditions and allows natural ventilation of the cavity to avoid overheating due to stack effect (Molter and al. 2017).

Double skin façades consist of three functional layers. Typically, the exterior façade layer is made of single glazing. It is separated from the interior glazing, which is the really "indoor" envelope and usually consists of a double glazing. The distance between interior and exterior façade layer can vary as it depends on the specific design. In order to utilise the effect of a thermal buffer in the space between the two façades, ventilation openings are installed in either one of the exterior and interior façade or in both. The air in the gap between the façades heats up due to solar radiation and in this way, it works as a buffer toward the interior space (Knaack et al. 2007). Due to the thermal difference, the warm air can be used, for example, as a generator of natural ventilation of the indoor room. However, overheating of the cavity in double skin façades could be an important issue. Due to absorption of the solar radiation of sun shading devices, often installed in the cavity, a so-called stack effect can raise the temperature in the cavity itself. These indirect solar gains have a major impact on the indoor comfort, as the raising temperatures of the cavity are transferred into the adjacent internal spaces creating additional cooling loads to the building (Molter et al. 2017).

In this regard an interesting application has been studied by Molter and al. 2017: within a unitized double skin façade system, four thermal cylinders are warmed up by the raising temperature in the cavity and expand at a temperature of 23°C. By a telescopic movement, the outer skin of the façade is pushed outwards (see Fig. 1). This allows external air ventilation of the cavity and, at the same time, an evacuation of the absorbed heat. In case of a fall of temperature, the thermal cylinders redress and close the cavity, which creates a buffer zone and improve the U-value of the glazed façade unit. The temperature range of the triggered components can be adapted to specific contextual requirements as climate zones, façade orientation and user preferences. This process can be repeated several times within one hour since the paraffin has a relatively short reaction time. In this regard, the kinetic components have been used as ventilation elements in greenhouses for decades and show an almost maintenance free and unpowered solution (Molter and al. 2017).

Other applications based on wood responsive building skins have been investigated by Bridgens et al. 2017 and Mazzucchelli and Doniacovo 2017. These components can be used as cladding panels, sunscreen, passive layer (see Fig. 2) for photovoltaic systems (Mazzucchelli and Doniacovo 2017), etc. It should be considered that usually, depending on species and natural durability, timber cladding is often treated with fungicide and/or waterproofing oils. This is not possible in adaptive use, because any surface treatment would prevent the wood from responding to changes in ambient moisture, for example. The exact requirements for each property varies depending on the specific application. For instance, hygromorphs with high responsiveness (i.e. producing large curvature changes at small changes in relative moisture content) may be required for indoor applications, where the materials need to react to relatively small changes in ambient humidity, but for these applications the requirements for strength and durability are not onerous. In contrast, the focus of the material design criteria for outdoor applications shifts towards increased durability and structural resistance, where a comparatively lower responsiveness may be sufficient considering larger fluctuations in external humidity and exposure to precipitation. Similarly, hygromorphs with a rapid response that is completed within minutes allows adaptation to abrupt sporadic changes in the ambient moisture conditions (i.e. a rain shower) whereas a much slower response is needed for periodic daily and seasonal weather patterns (Bridgens et al. 2017).

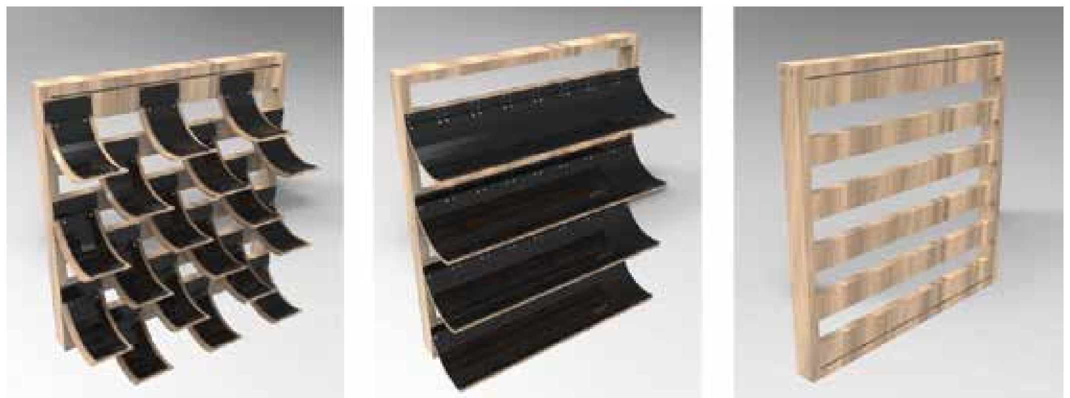

Fig. 2 Render of the 15x10 cm lamellae panel (on the left) and 15x60 cm flakes panel (on the center). Wooden panel substructure (on the right). The wood layer is used to optimize the photovoltaic layer curvature in relation to the external environmental conditions. In this case passive and active technologies are combined together.

Among the technologies to optimize the use of solar energy by the building envelope technologies, thermochromic materials, of which optical properties vary at a characteristic temperature value, assume a relevant position. These materials can adapt to the variations of temperature by the effect of solar radiation during the day and throughout the different seasons of the year. Thermochromic glass have been widely studied. Specifically, for the opaque envelope, materials with high solar absorptance (low reflectance) for low temperatures and low absorptance (high reflectance) for high temperatures are of interest (Gavira et al. 2017). There are different technological approaches to optimize the use of solar energy in building elements, with the aim of improving the energy efficiency and to reduce the effect of solar absorption in buildings on the warming of urban areas. Such use depends directly on the optical properties of the exterior surface of the facade, which include not only its color but also its reflectance and absorbance over the entire wavelength range of solar radiation. This effect has been studied (Gavira et al. 2017) with the goal to determine the temperature for which it is favorable to change from the grey cement properties in the facade to those of the belitic cement, as a first approximation for a critical temperature of a thermochromic mortar. The study showed that the northern orientation, with almost coincident surface temperatures with the outdoor temperature, is considered the optimal to take advantage of thermochromic coatings. The surface temperature of the exterior coating is adequate in this case as the trigger parameter for the change in optical properties of the coating material.

The energy demand of a building can be further optimized by a façade system that can change its permeability to solar energy, using sunscreens. Fixed sun protection provides a good opportunity for shading. Horizontal elements mounted at ceiling level that protrude far out of the façade are known as brise-soleil. Another solution is fixed, or pivot-mounted louvres mounted onto the façade. However, they do not achieve the same protection values as those that can be adjusted by angling. In any case, the maintenance and cleaning of the glass panes needs to be considered at an early stage. Using plants or trees is another method of providing fixed shading. In this regard,

deciduous plants are the best choice as they lose their leaves in winter, increasing the possibility of solar radiation to enter the building during the heating period (see Fig. 3). However, it should be considered that plants must be trimmed regularly and that an irrigation system should be planned too.

Fig. 3 Example of seasonal green sunshield.

A further simple method of sun protection is to imprint the glass surface with silk-screened patterns of ceramic-based paints that consist primarily of pigmented glass particles, called frit, that only affects the glass pane itself. Graphic elements of any pattern or grid can be applied to the glass to reduce the incident sunlight. This method offers a wide range of possible variations and in this way the sun protection can be adapted to the requirements of the specific usage (Knaack et al. 2007).

Quite often, natural lighting is insufficient for very deep rooms, especially if work places are located on the far side of the façade. In these cases, systems that direct the light into those areas can be used. Light-directing systems work in different ways: some are horizontal elements that direct the light by reflection, some are vertically inserted into the sun protection system or the glass layer. These elements do not reflect the light but re-direct it at a different angle. Many solutions are available, all based on this principle: holographic foils, fine prismatic surfaces and reflective louvres arranged in specific geometries, etc.

Among the passive systems, the Trombe wall is probably the most simple and well-known collector wall. It uses the greenhouse effect (Konstantinou et al. 2018): short-wave sunlight penetrates the glass panes on a sun-facing wall and hits on a dark absorbent layer, where it is absorbed and transformed into long-wave heat radiation. The heat in the gap between the façade layers is transmitted through the wall into the room behind it.

Depending on the structure of the wall and its storage capacity, the heat gained can be discharged quickly or over a long period of time, well into the evening hours. If there are openings at the top and the bottom of the wall, then the thermal difference within the gap causes the room air to circulate. If additional openings are installed in the exterior glass layer, the air circulation within the gap feeds warmed fresh air into the room. The same principle applies to leading exhaust air out of the exterior façade.

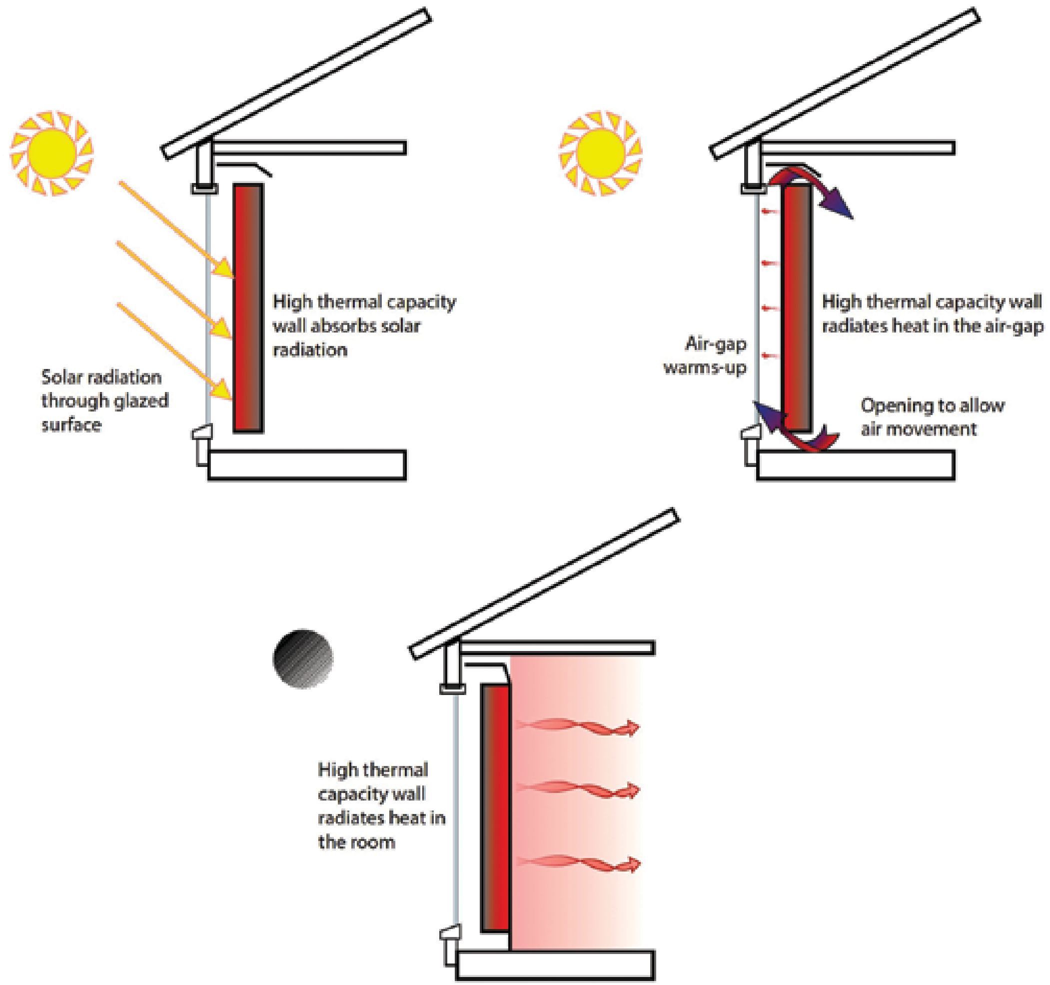

Fig. 4 Principle of Trombe wall and attached sunspaces (Konstantinou et al. 2018).

One can mention in the same context the Transparent heat insulation (THI). THI elements are usually installed in front of the absorbing wall (for example a Trombe wall). In this way the solar radiation penetrates the THI elements and heats the absorbing wall while the THI elements minimize heat loss toward the exterior. However, in order to prevent overheating in summer, sun protection has to be installed in front of the THI itself.

THI elements can also be used alone without a collector wall to light the room with diffused light and to improve heat insulation at the same time. Transparent heat insulation can be based on different operating principles whereby the geometric arrangement of the THI layer varies. All THI elements increase heat insulation and let diffuse light enter the room, depending on the method of construction. In order to protect the materials used, they are all installed between two layers of glass (Knaack et al. 2007).

Another example is a triple glass component, where prismatic panels reflect the solar radiation during summer and instead allow the heating of a thermal storage module (PCM in a polycarbonate box) in the winter season (Fig. 5). An outer insulated glazing unit (IGU) has a suspended prismatic filter between the panes of glass that reflects higher-angle sunlight back out while transmitting low-angle sunlight. This offers a passive solar-control mechanism for south-facing glass to keep out most of the high summer sun, while benefiting from the lower-angle winter sun.

Sunlight that makes it through this outer IGU passes into an inner IGU that is filled with sealed polycarbonate channels into which a translucent salt-hydrate PCM is encapsulated. PCMs store heat as they change phase from solid to liquid (melt) over a narrow temperature range, then they release that heat as they cool off.

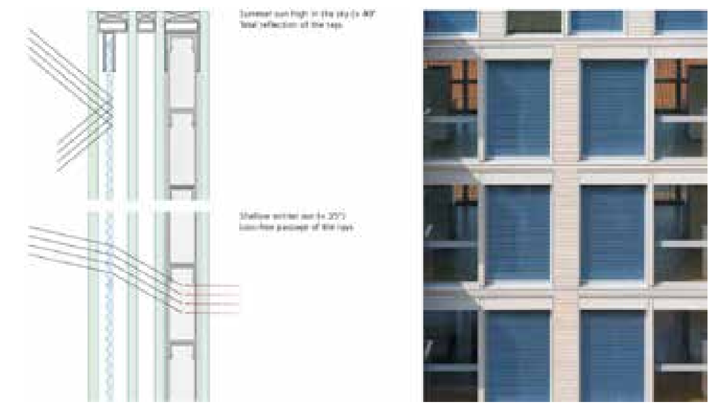

Fig. 5 Example of triple glass component. The prismatic panel reflects the radiation during summer and instead allows the heating of the thermal storage module (PCM in a polycarbonate box) in the winter season. The whole system, which looks like a translucent window, has a thickness of 80 mm, a thermal transmittance of 0.48 W/m2K and a light transmission coefficient that can reach up to 45% (GlassX AG technical documentation - www.glassx.ch).

4 Examples of Passive Adaptive Technologies from COST TU1403 Working Group 1 Database

In this section some case studies of passive adaptive façades from COST ACTION TU1403 WG1 database are selected based on the typologies presented in the section 3 above.

A first example is the ENERGYbase building (Architekten ZT KG, Vienna, 2008). ENERGYbase design is based on the following adaptive passive façade approach. A stepped façade acts as solar generator and sunshield together with a solar cooling plant and plants filtering the air indoors for top quality. The passive thermal gain goes to the south-facing rooms directly and to the north-facing rooms indirectly, via the ventilation system. With its special form, the stepped façade delivers these gains only in winter; in summer sunlight cannot enter the rooms directly, as each step in the façade in overshadowed by the step above. Just behind the stepped façade perforated anti-dazzle slats are located, with the air exhaust for the entire storey above them. This arrangement means that warmed air behind the façade is exhausted directly, not drawn into the centre of the room. On sunny winter days this air passes through a heat exchanger, so its heat content is transferred to fresh air and thus reaches the north-facing rooms, too.

a) b)

Fig. 6 a) ENERGYbase building (Architekten ZT KG, Vienna, Austria). b) Detail of the South façade.

Another example is the GSW Headquarters (Sauerbruch Hutton, Berlin, 1999) with its double skin colored panels on the west façade which creates a cavity that helps to manage solar heat gain and natural lighting. An integrated system of closures, construction technique of low energy consumption inside the wall, allows natural cross ventilation, facilitating the passage of air from front East to West through the interior spaces and through specially designed openings in the corridors. The louver system on the west facade has an important role in reducing the use of artificial heating and cooling. The western facade has a second glass skin that ventilates and cools the building, dispelling hot and stale air. In addition, the double façade serves as a second buffer for thermal and acoustic variations. Convection in the double west façade of the building creates a negative pressure that can pull cool air through the building. When the two facades windows open, fresh air flows flowing from East to West. Because of control fins on the top and bottom of the solar chimney this air flow is independent of the external conditions and allows the air change to be comparable to the mechanical systems.

Fig. 7 Façade example, GSW Headquarters (Sauerbruch Hutton) in Berlin (Germany).

A third example is provided by Solar Building XXI (Architects Pedro Cabrita and Isabel Diniz), built in 2006 at LNEG (National Energy and Geology Laboratory) Campus in Lisbon. Solar XXI is an example of a low energy building using passive systems both for heating and cooling (ground cooling) towards a Net Zero-Energy Building (NZEB) (Aelenei and Gonçalves, 2014). From the NZEB goal perspective, the building, whose design is based on a combination of passive design techniques with renewable energy technologies (PV, solar collectors) may be currently considered, a nearly Zero Energy Building.

Fig. 8 Solar Building XXI in Lisbon (Portugal).

One of the strategies adopted in the design of solar XXI building in order to reduce the thermal loads and provide a good thermal comfort conditions consisted in optimization of building envelope. The set of ventilation strategies (day and night) provide a high comfort level in the summer, especially when applicable during night period minimizing the thermal loads accumulated during daytime within the building and its temperature. The location and dimension of central skylight as a main light distributor in the central hall is fundamental, as also the translucent vents in the doors, which communicate from south and north spaces to corridor and the glazing areas distributed all over the building envelope. These important features adopted in the building design led to a reduction of the electric light building consumption. The building shows how in modern construction passive active adaptive technologies are combined together in order to achieve the Zero Energy goal.

5 Conclusions

When referring to adaptive technologies, two main categories can be distinguished. Adaptive technologies, which rely on passive design to improve building energy efficiency and comfort, and active technologies which include renewable harvesting. This paper provides several examples of passive adaptive technologies and their performance features from COST TU1403 Working Group 1 database. Current typologies based on passive adaptive technologies found in the international projects include double skin façades, wood based responsive building skins, glass surface with silk-screened patterns of ceramic-based paints, brise-soleil and fixed or pivot-mounted louvres, light-directing systems and Trombe wall. However, because façade elements with adaptive features can provide the buildings the necessary flexibility needed to deal with all the challenges buildings face in terms nearly zero energy buildings (nZEB) and energy-efficient interactive buildings, an increase of new innovative passive adaptive solutions is expected in the near future.

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Practitioners’ View on the Implementation Potential of Adaptive Façades with focus on The Netherlands

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The adaptivity of façades is increasingly recognized as an important functional feature to be integrated with the state-of–the-art building technology. The aim is thereby to control its reversible system states in real-time to adapt to current indoor and outdoor conditions. Concepts reported elsewhere integrate two or more functions related to structural integrity, ventilation, heating and cooling, solar protection, as well as energy generation and storage. Although advantages are perceived obvious, the number of realized case studies remains limited. Triggered by this observation, the authors of this contribution report research findings from a literature study and interviews with stakeholders in the field, including contractors, building consultants and architects. The three key-findings suggest that (1) the functions daylighting and energy generation/storage are most commonly integrated into façades or façade components characterized as being adaptive, (2) interviewees are divided on the implementation potential of most of the designs/concepts and (3) the aesthetics of the design, (investment) costs, durability and required maintenance are critical for a widespread market uptake. Herewith, this paper contributes new knowledge to the discussion related to finding the right level of system integration in building technology.

Keywords: adaptive façades, practitioners view, building integration, market uptake, façade functions

1 Introduction

Whilst conventional, static façades do not have the ability to respond to varying meteorological conditions and comfort wishes, climate adaptive façades can utilize this variability to reduce the energy demand and improve indoor air quality and comfort (Loonen, Trčka, Cóstola, & Hensen, 2013). The climate adaptive façade concept may take a wide variety of physical forms (Loonen, Hensen, Trčka, & Cóstola, 2010; Loonen et al., 2013), with each adaptive façade or component thereof having its own characteristics. Concepts reported elsewhere (Loonen et al., 2010) integrate two or more functions related to structural integrity, ventilation, heating and cooling, solar protection, as well as energy generation and storage. These functions correspond with the six ideal functions of an adaptive façade as identified by Struck et al. (2015).

Despite the diversity in the manifestation of adaptive façades and the many available options, it has been noted that the concept has yet to mature (Loonen et al., 2010); thus far, the number of realized case studies remains limited (e.g. Prieto, Klein, Knaack, & Auer, 2017). In the literature, a number of barriers have been identified that underlie this observation. Haase, Andresen, & Dokka (2009) mention issues with integration into the building, such as aesthetics, functionality, economy and flexibility. Prieto et al. (2017) also mention physical integration as an issue, but found that the