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Adaptive Façade: concept, applications, research questions

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Abstract

Adaptive building envelopes can provide improvements in the building energy efficiency and economics, through their capability to change their behaviour in real time according to indoor-outdoor parameters, by means of materials, components and systems. Therefore, adaptive façades can make a significant and viable contribution to meeting the EU´s 2020 targets. Several different types of adaptive façade concepts have already been developed, and an increase in emerging, innovative solutions is expected for the near future. The objective of this paper is to contribute to these developments by presenting the findings of an analysis of the existing concepts and case studies and by proposing a new approach for characterization of these elements.

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Keywords: Adaptive Façade, Building Envelope, Classification.

1. Introduction

Recent studies show that in developed countries people spend on average 90% of their time indoor [1]. This trend reflects the large number of requirements of the indoor environment, where buildings assume a key role in ensuring the welfare of people. Statistics are also showing that, in terms of primary energy consumption, buildings represent around 40% in most IEA countries [2]. In this context, it is of fundamental importance to devise strategies for the building stock to achieve the objectives in terms of energy efficiency and climate change set by different countries [3].

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In Europe, one of the most important legislative instruments aiming at improving the energy efficiency of European buildings is the directive 2010/31/EU [4]. A key element of this Directive is its requirements regarding Nearly Zero Energy Buildings (nZEBs). Similar policies were also promoted in other developed countries outside Europe (e.g. USA, and Canada) [5,6]. Taking into account that the façade is the main parameter that influences the energy performance of buildings, façade elements need to be designed to provide the buildings the necessary flexibility needed in terms of energy flow and thermal comfort.

Current standards require building envelopes to behave as energy efficient mechanical systems, able to react to non-continuous, changing external conditions. In practice this means that, to reach the prescribed levels of efficiency and functionality, the façade needs to change or adapt. Therefore, the adoption of adaptive façades provides opportunities for significant reductions in building energy use and CO_2 emissions, while preserving the thermal and visual comfort of occupants. Several different types of adaptive façade concepts (materials, components and systems) have already been developed, and an increase in emerging, innovative solutions is expected in the near future. The goal of this paper is to contribute to these developments aiming at providing a classification of the adaptive façade materials, components and systems according to indoor and outdoor parameters. This analysis is supported by a case studies database [7] and is developed within EU COST Action TU1403 – Adaptive Façade Network [8].

2. Adaptive façades

According to recent research [9], the term adaptive in the context of building façades is often associated in the literature with a long list of similar terms, as shown in Fig. 1. While the meaning of some of these terms in the context of building façades is not entirely clear, the definition of adaptive façade in this study uses as common basis the description according to which adaptive façades consists of multifunctional highly adaptive systems, where the physical separator between the interior and exterior environment (i.e. 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 [10].

Fig. 1. Adaptive concept in the literature [9].

According with the above semantic frame, adaptive facades should provide adequate response to changes in internal and external environment to ensure or improve the functional requirements of the envelopes in terms of heat, air and water vapour flow, rain penetration, solar radiation, noise, fire, strength and stability and aesthetics. Therefore, multi-functional adaptive façades should be able to respond repeatedly and reversibly over time to changes in performance requirements and changing boundary conditions. In other words, adaptive façades would be able to provide controllable insulation and thermal mass, radiant heat exchange, ventilation, energy harvesting, daylighting, solar shading or humidity control. Moreover, in the context of nZEB, where the buildings must be interactive in the zero energy and smart city context to provide the operational flexibility needed to avoid or reduce the mismatching, such façades can play an important role.

Given the complexity of the topic and multiple variables affecting the performance of these systems, the collaborative COST Action TU1403 [8] was organized in four Working Groups:

- WG1: Adaptive technologies and products;
- WG2: Component performance and characterization methods;
- WG3: Whole building integration and whole-life evaluation methods of adaptive façades;
- WG4: Dissemination and future research.

The present study is part of the work developed within WG1 - Adaptive technologies and products - of which major objectives is the development of novel adaptive façade technologies, materials and systems.

3. Characterization methods and research questions

Ever since there has been an interest in design and development of adaptive building materials and dynamic façade systems, there have also been efforts to classify the different concepts into sub-groups with shared characteristics. Several comprehensive review papers have recently been published on different categories of adaptive façade concepts, such as adaptive glazing [10], phase change materials [11], solar façades [12] and daylighting systems [13]. While these publications mostly serve as overview or database of solutions [7], the function of a classification scheme/approach is deeper, as it tries to identify relationships among different concepts, and thereby aims at increasing the understanding of this multi-disciplinary field. The intuition behind this approach is to recognize patterns and identify unexplored concepts and therefore help pave the way for the development of high-potential, innovative adaptive façade components.

3.1. Characterization parameters

According to the scientific plan of COST TU1403, before moving towards evaluating and testing the performance of adaptive façades, it is fundamental to characterize them in terms of technologies and purpose. These two parameters are summarised together with other key parameters in Fig. 2 [10]. As can be seen from Fig. 2, the first column represents the purpose of façade/components with adaptive capacity, which can be related with thermal comfort, energy performance, indoor air quality (IAQ) and visual and acoustic performance, among other requirements. The reasons behind the adoption of adaptive façades are considered one of the most important problems in this survey, reason for which the analysis of the buildings available in the database will be focused on this first parameter.

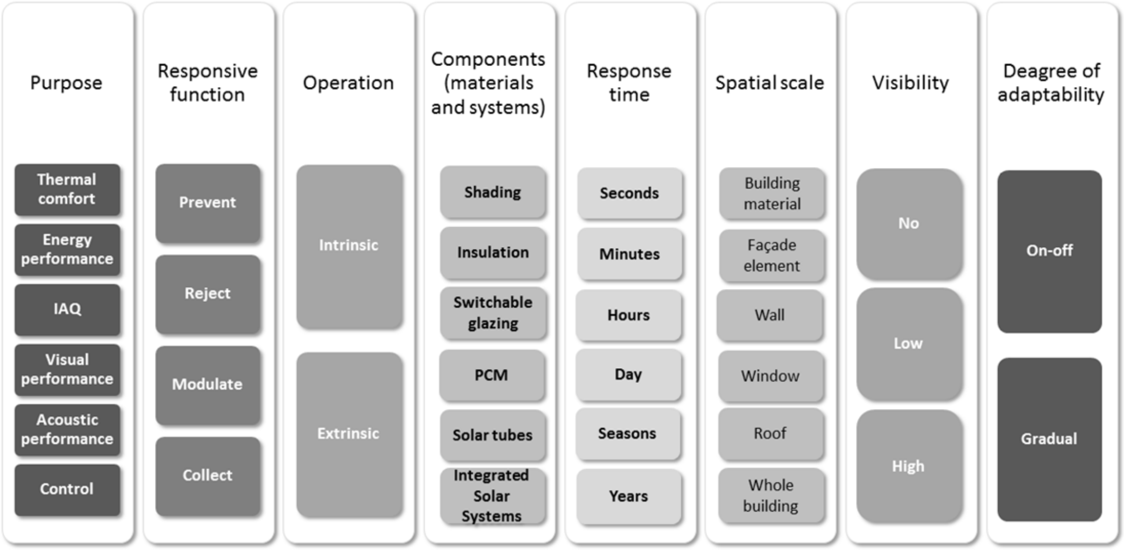

Fig. 2. Overview of characterization concepts for envelope adaptivity. Adapted from [10]

3.2. External factors

Understanding the need for adaptability in the context of each building is a complex task. Because of this and because the façade needs to respond to changes from both internal and external factors, in the case of this study we focus primarily on the analysis of the need for adaptability driven by external factors. To accomplish this task, a representative sample of 130 buildings [14] was analysed, most of which are located in the temperate climate, 63 in warm temperate climate and 29 in maritime temperate climate, according to Köppen Climate Classification.

The external factors considered for the analysis were solar radiation, outdoor temperature, wind, humidity, precipitation and noise. As can be seen from Fig. 3, the adaptive façade acts in response to external factors to provide an acceptable internal environment which can be described in terms of thermal comfort, energy performance, IAQ, acoustic performance, visual performance and durability.

As one can imagine at this point external factors may influence the human comfort categories in multiple ways. as described briefly in the following.

- Solar radiation: The amount of sunlight needs to be balanced continuously between adequately addressing the thermal comfort and visual comfort needs.
- Outdoor temperature and Humidity: These parameters vary throughout the day and throughout the year and are one of the most important factors in passive heating and cooling design. The fluctuations of outdoor temperature and humidity are related to heat and moisture transfer at the level of the envelope.
- Wind and Precipitation: These outdoor environment characteristics are also likely to affect the human comfort and need to be considered in façade design. In this respect, it is known that wind can provide natural ventilation and passively increase occupant comfort, in addition of assisting the precipitation in migrating through the building envelope (wind driven precipitation).
- Noise: Buildings are often subjected to outdoor noise (environmental noise) caused mostly by traffic, which is characterized by strong temporal variability. Sound design and noise control implementation at the level of façades can play a fundamental role in obtaining the adequate acoustic comfort inside the rooms.

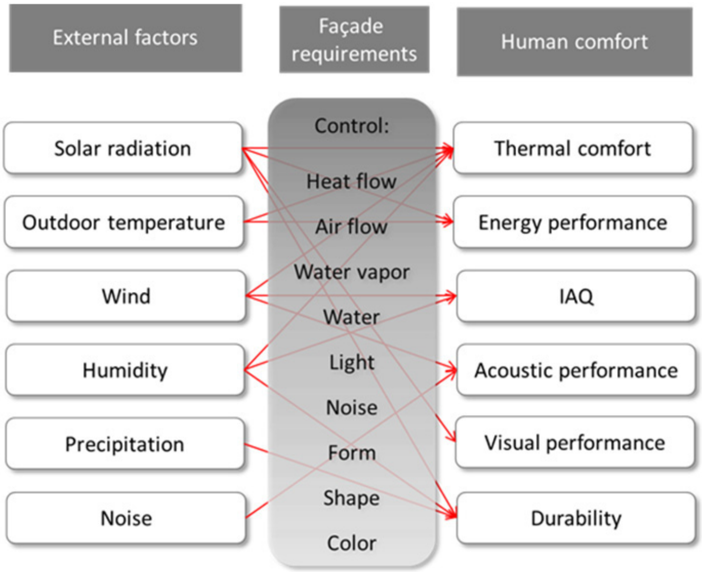

Fig. 3. Schematic role of adaptive façade.

4. Characterization methods and research questions

Two different kinds of analyses were conducted on the 130 buildings. The first analysis was conducted with the objective to find the distribution of the external factors on all buildings regardless of type or climate. As shown in Fig. 4, the reasons for adopting adaptive façades or façade elements are mostly related with solar radiation and outdoor temperature. Then, wind and precipitation are found in approximately equal proportions, followed by humidity with 13%. Noise appears in the last place in the distribution with presence in 6% of the cases.

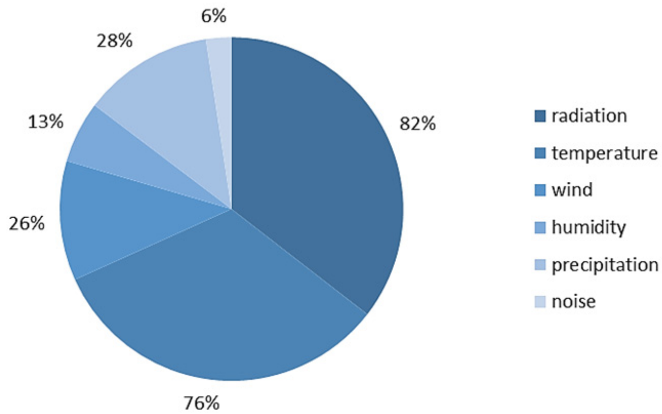

Fig. 4. Global distribution of external factors.

The second type of analysis was conducted with the aim to find if the distribution of the external factors appears with different weights when the buildings are organized by type or by climate. To this aim the buildings were classified in two categories, residential (51%) and non-residential (49%) and the distribution was recalculated. As shown in Fig. 5, the comparison of the distribution of the external factors reveals a higher number of adaptive features related with solar radiation in residential buildings. External factors as humidity and precipitation also appear in higher percentage in the case of residential buildings. This, however, was somehow expected given the large amount of opaque area of envelope present in the case of residential buildings, which is normally affected by precipitation and moisture condensation.

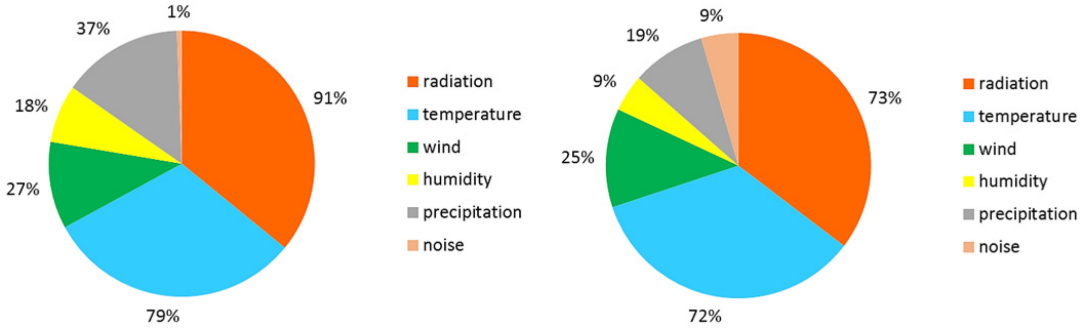

Fig. 5. Distribution according to building type (left) residential; (right) non-residential.

The distribution based on climatic features with the buildings grouped according to Köppen Climate Classification did not revealed significant differences between buildings. However, taking into account that the adaptive technologies and products in the case of glazing are different than those applied in the case of opaque wall, an additional comparative analysis was conducted on this basis (Fig. 6). As expected, this approach reveals that all adaptive solutions applied to windows have solar radiation present, fact which confirms the known influence exerted by solar radiation on windows. Further analysis of this figure indicates that wind is less associated with windows than with walls and that humidity and noise are not at all present in the case of windows. The lack of adaptive features at the level of windows with the objective of controlling air flow and noise is a surprising observation.

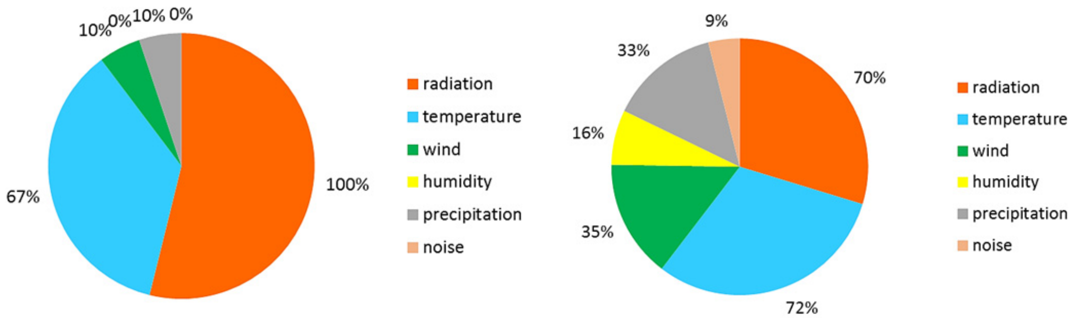

Fig. 6. Distribution according to type of surface (left) windows; (right) walls.

5. Conclusions

A simple data-analysis study was designed to assess the external factors associated with the need of adaptive façades. The study, conducted on a representative sample of 130 buildings available in a database, has revealed interesting features regarding the need for adaptability in the context of building façades. It was found that solar radiation together with outdoor temperature are the most common external factors associated with adaptive façades. Because these factors are known to have a direct influence on thermal and visual comfort and on energy performance of buildings it is reasonable to conclude that the existing adaptive façades projects have as primary objective the improvement of human's comfort. Although the studies of adaptive façades under EU COST Action

TU1403 – Adaptive Façade Network are still in an early stage, it is believed that this paper will provide useful insights for the development of high-potential, innovative adaptive façade components.

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