Post-Occupancy Evaluation for Adaptive Façades

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Abstract

Post-occupancy evaluation is a valuable method of generating information on the performance of adaptive building façades in relation to users. This evaluation technique involves both procedural methods, such as soft-landing, and empirical measuring, such as environmental monitoring or self-reporting techniques including surveys. Several studies have been carried out in recent decades to identify the most appropriate methods for occupant comfort, well-being, productivity, satisfaction, and health assessments in workplaces. Post-occupancy evaluation of adaptive façades can, however, be a challenging task and information on this topic is still scarce and fragmented. The main contribution of this paper is to bring together and classify the post-occupancy evaluation methods for adaptive façades and suggest a framework for their holistic evaluation. Specific recommendations for improving current standards and guidelines are outlined here to enhance occupant satisfaction and environmental conditions in workplaces for future design projects. Finally, we discuss various ongoing trends and research requirements in this field.

Keywords

advanced façades, user interaction, measurement, surveys, criteria, framework, indoor comfort

DOI 10.7480/jfde.2018.3.2464

1 INTRODUCTION

As we continue to innovate and build energy efficient and advanced façades that are automated, we are looking forward towards the optimisation of the overall work, living, and learning experience indoors. Traditionally, Post-Occupancy Evaluation (POE) was used to assess the users' experience in relation to outdoor and indoor environments. However, POE for Adaptive Façades (AF) (Loonen, Trčka, Cóstola, & Hensen, 2013)due to a growing demand to satisfy more ambitious environmental, societal and economical performance requirements. The application of climate adaptive building shells (CABS requires a specific approach of obtaining feedback about users' experience and building performance in use. POE for AF includes investigating occupants' interactions with the envelope and the overall building performance regarding energy efficiency, indoor environmental quality (IEQ), and occupants' satisfaction, well-being, and productivity. This paper is part of the COST Action TU 1403 on AF and aims to provide an overview of existing and expected POE assessment methods. As part of Work Group 3, previous work has introduced adaptive façades systems assessment (Attia Favoino, Loonen, Petrovski, & Monge-Barrio, 2015; Attia et al., 2019) and reviewed case studies (Attia & Bashandy 2016; Attia, 2017; Bilir & Attia, 2018) of adaptive façades in which POEs were performed. However, there is a lack of comprehensive POE for AF that provides both qualitative and quantitative assessment and more importantly, involves users, designers, and building operators. The nature of adaptive façades that are able to adapt to changing climatic conditions on a daily, seasonal, or yearly basis requires different assessment and evaluation methods. The transient and dynamic behaviour of those façades make them a particular building technology that is novel and without precedent in terms of systematic assessment frameworks and approaches. Therefore, in this paper we present a short introduction to AF and POE. Then, we present a brief literature analysis of three POE projects for AF, assessed to show the challenges and requirements of AF assessment. This includes summarising and comparing key POE assessment. In Section 4, we propose an initial assessment framework and a discussion on the direction for future POE in Section 5.

2 BACKGROUND OF ADAPTIVE FAÇADES AND POST-OCCUPANCY EVALUATION

A major challenge in respect to AFs is the evaluation of their responsiveness to climate and occupants needs. The defining characteristics of AF systems is their dynamic adaptability and multi-usability of their components. Some of them take over certain tasks to change the thermal, visual, or hygienic comfort situation. The influence of, for example, dynamic measures for thermal comfort on the user's perception requires target criteria other than standardised comfort models (EN ISO 7730:2005) (ASHRAE, 2013). The topic "thermal sensation and perception of humans", including the phenomenon alliesthesia (de Dear, 2014) – a physiological approach on how pleasant or unpleasant stimuli can influence the thermal comfort perception of humans – needs to be introduced. This could lead to a "'responsive' standard that acknowledges the richness of human-environmental interaction and the potential for less energy-intensive design" (de Dear, 2011).

The dynamic behaviour of adaptive façades requires the continuous or high frequency data gathering from occupants to capture their response to transient changes in the properties of adaptive façades. Adaptive façades can have different effects on occupants depending on the initial and final state of their adaptive process, as well as on the velocity and frequency of change. For instance, occupant response to automatic shading controls significantly changes if the system is lowering or raising the shading devices (Reinhart & Voss, 2003). Bakker, Hoes-van Oeffelen, Loonen, and

Hensen (2014) also showed that less frequent, discrete transitions in façade configuration are more acceptable to users than smooth transitions at a higher frequency. Traditional POE methods do not allow real-time data gathering or transient assessment of adaptive buildings, and occupants are usually asked to "remember" their comfort state in surveys or interviews (Buratti & Ricciardi, 2009) or to record their comfort state in diaries, thereby undoubtedly losing important information on dynamic environmental changes and their effect on users. Occupant satisfaction with personal control of, and interaction with, adaptive façades is also a time-dependent feature. Examples of this are the changing levels of user acceptance for automatic strategies and expectations for personal control with time. In this sense, Ball and Callaghan (2012) presented an "adjustable autonomy system", in which levels of control were gradually increased as the user gained confidence in using the interactive system.

Another challenge of AF assessment is related to the time of assessment. POE comes at a late stage of the façade's delivery process. POE starts with the operation stage, at the end of commissioning of newly or renovated buildings. As shown in Fig.1, the life cycle of AF is long and does not require an on-off POE, but rather a continuing POE, at least for the time required to assess the range of the façade´s adaptability. The nature of AF requires that POE are adapted to become transient and frequent to match the control strategies, trace occupants response actions and the AF response or action. The automatic control of AF and users' response is, in many cases, conflicting (Bilir & Attia). From one side, building operators control building systems to ensure good IEQ and achieve energy efficiency, and on the other hand, building occupants are seeking localised control of their specific working, living, or learning environment. The conflict between the local and global spatial IEQ and manual versus automated control of AF makes the POE difficult. As learned from several case studies of AF (Bilir & Attia, 2018) there is a lack of comprehensive POE to cater for AF and empower users while assuring control by building operators during the AF's life cycle. This conflict requires continuous feedback and flexible building management systems and control software. Historically, operators are responsible for the control of building systems. However, the awareness about well-being and occupant's feedback, and the proliferation of low-cost sensors and interactions devices, requires a modern approach to manage this complex problem. The operation of AF requires that users are central and that a building management system (BMS) does not only respond to the operators. There is a need to create a balance between running the façades actuators and responding to user's needs.

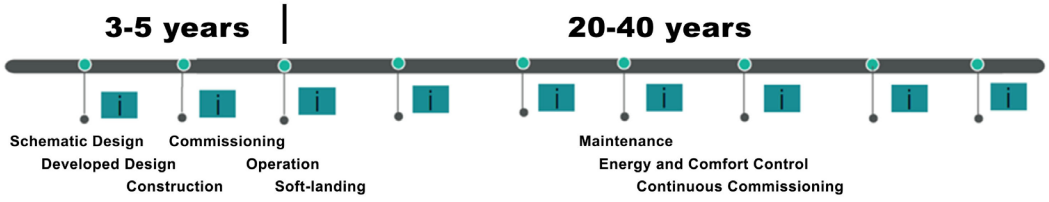

FIG. 1 Adaptive Façade life cycle

3 CURRENT POE METHODS

There are several extensive literature reviews that investigated POE (Preiser, 1995, 2005; Leaman & Bordass, 2001; Bordass & Leaman, 2005; Meir, Garb, Jiao, & Cicelsky, 2009; Pati & Pato, 2013; Kim, de Dear, Candido, Zhang, Arens, 2013; Galatioto, Leone, Milone, Pitruzzella, & Franzitta, 2013; Li, Froese, & Brager, 2018). Preiser (1995) classified three levels of POE: 1) indicative, 2) investigative, and 3) diagnostic. This classification focused on grouping POE methods based on their purpose. However, the most common classification of POE methods is based on grouping them as follows (Li et al., 2018):

- Subjective or Qualitative Methods: 1) Occupants Surveys, 2) Interviews, and 3) Walkthroughs.
- Physical Quantitative Methods: 1) IEQ in situ measurements and 2) energy and water audits and monitoring

Based on our literature review, we identified POE methods that follow a systematic methodology to examine the overall performance of the building. Table 1 provides a brief comparison of the three existing POE methods that were strongly present in the practice.

POE METHOD	YEAR	COUNTRY	ASPECTS EVALUATED
1 Post-Occupancy Review of Building Engineering (PROBE) Building Use Studies (BUS)	1995	UK	BUS occupant survey, benchmarking against an existing database of case studies (Leaman & Bordass, 2001)
2 Center of Built Environment (CBE) Building Performance Evaluation (BPE) toolkit	2003	US	Occupant IEQ satisfaction survey with a score card report generation tool. CBE Thermal Comfort tool to calculate thermal comfort according to ASHRAE Standard 55 (Zagreus, Huizenga, Arens, & Lehrer, 2004)
3 Performance Measurement Protocol	2010	US	Energy and water use and IEQ. Comprises three levels of evaluation. Three levels—Basic (indicative), Intermediate (diagnostic), and Advanced (investigative) (ASHRAE, 2010).
4 ASHRAE 55 Comfort Survey	2001	US	Comfort conditions are measured based on a survey (ASHRAE, 2013).

TABLE 1 Comparison of current POE methods used frequently in practice

Based on our review of POE methods and their suitability for AF evaluation in relation to user satisfaction, we identified emerging limitations inherent in the current POE methods. These limitations, related to POE for AF, can be summarised under the following points:

- Current POE methods do not allow real-time data gathering and transient assessment, which are fundamental to capturing and verifying the dynamic performance and degree of responsiveness of adaptive façades.

- Current methods focus on comfort in relation to the occupant's response and control. They are unable to assess the interaction between the user and the AF in transient terms.

- Current POE methods do not identify the moment of dissatisfaction. Rather, they provide an overall assessment based on a seasonal or annual evaluation and do not allow for the capturing of the effects of AF change at a specific time.

— Researchers and building experts cannot associate or distinguish occupants' interaction and behaviour from the overall environmental impact of AF, likewise in relation to BMS.

— Most of the time, POE outcomes are not fed back to inform the operator. The feedback loop is linear and not circular. Simultaneously, there is a lack of continuous feedback that would allow occupants to respond to energy efficiency or comfort improvement measures during hours of operation. Closing the information loop is also fundamental to allowing a dynamic POE, which is crucial to train and adjust AF control strategies in order to meet or predict actual occupant demands.

— Researchers and building experts don't have a benchmark for AF to compare with the traditional POE of buildings database. The majority of POEs are heavily customised to better assess the building behaviour, but this essential in AF, since they are generally innovative envelopes designed with a specific purpose.

From our current review, we can state that there is, at present, a knowledge gap and a challenge in assessing AF using POE methods. There is a serious need for POE methods that can assess the engagement and overall well-being and productivity of occupants. There is a need to redesign POE methods that focus on the interplay between technology, the user in the physical space, and building operator. At last, since AF are generally new systems and materials, POE (following previous assessment and validation of the adaptive system itself) will provide a further support for their implementation in the building sector.

4 FUTURE POST OCCUPANT EVALUATION METHOD FOR ADAPTIVE FAÇADES ASSESSMENT

In this section, we present a framework for future POE for AF and suggest a User Interface (UI) for a dynamic online use. Furthermore, we suggest some key recommendations for future POE for AF.

We identified the main components that future POE of AF should incorporate, based on our literature review and experience with POE, which was performed for three AF case studies (Attia & Bashandy, 2016; Attia, 2017; Bilir & Attia, 2018). Additionally, as part of TU 1403 COST Action, in Work Group 3 we developed a façade assessment framework for dynamic post-occupancy evaluation. As shown in Fig. 2, the proposed framework allows multiple users, mainly occupants and operators, to share the management and control of the indoor environment and the adaptive façades technology. In this sense, the framework allows instantaneous feedback involving the users and operators in a dynamic and integrated way. Our framework suggests transforming POE into a dynamic and interactive process. The developed framework focuses on energy savings, maintenance savings, control strategies, and productivity and user experience. The framework depends mainly on a central control point that connects users and operators through BMS. Future POE should be based on a platform that receives direct and continuous feedback from the indoor environment, and likewise from the façade system. With the help of BMS, it is expected that a predictive model control with overriding control by the users can better assess the situation as frequently as the adaptability of the façade suggests, and perform a continuous automated POE assessment. It must always be kept in mind that the active interaction of the user is only accepted as and when necessary, since users prefer to be comfortable and feel productive without being aware of the controls, only interacting occasionally (Buckman, Mayfield, & B.M. Beck, 2014).

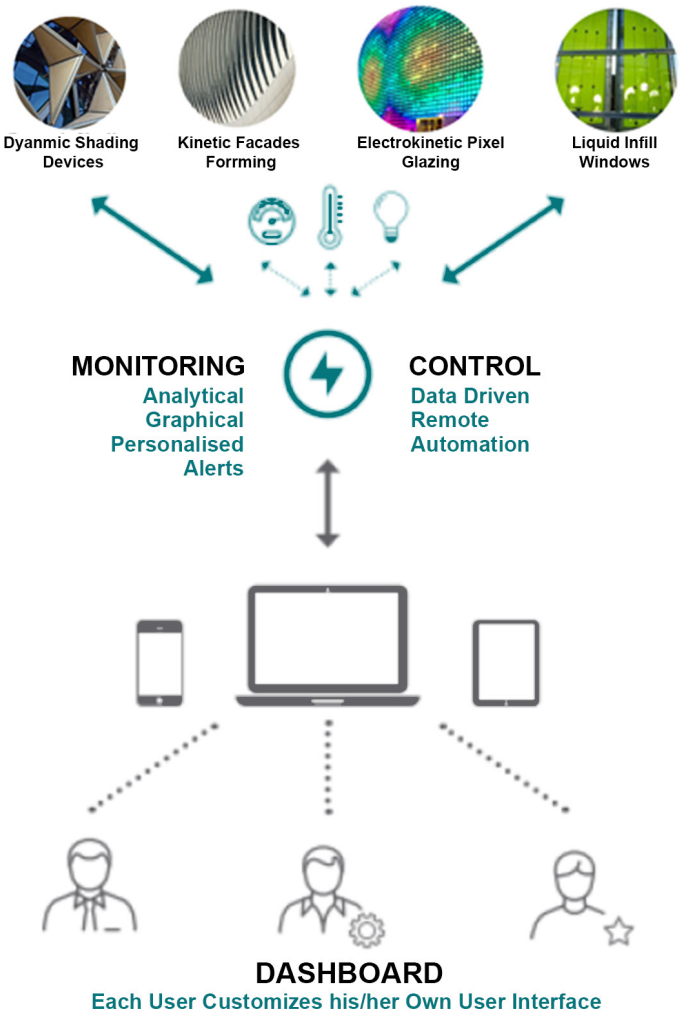

FIG. 2 Adaptive Façade framework for dynamic post-occupancy evaluation

Next, we developed a scheme in the form of a dashboard with a UI that can be used by smart devices or personal computers. The idea of this dashboard scheme is to encourage future studies and research in the area of POE to embrace instant feedback. Historically, the loop of cause and effect was distant in time. However, the advances in IT and sensor technology requires a revolutionary approach for POE. As shown in Fig. 3, the UI provides real time feedback for comfort and energy performance (right). At the same time, the UI allows for the interaction between users and the building operator (left) through alarm messages or modification requests. The satisfaction of users in relation to the façade performance can be directly reported to facility managers. In this sense, users maintain better control on their indoor environment and their façade's adaptive technology. We expect that such a UI is the front end of a complex BMS and platform that integrates advanced control, intelligent algorithms, and actuators that allow the active management of the façade response, thereby providing value to occupants, building operators, and building owners.

Lastly, based in our experience of the COST Action TU1403, we would like to recommend a series of new questions to be added to future POE surveys as they relate to a building with AF (Attia, Bilir & Safy, 2018). As Li et al. (2018) conclude in their review, occupant satisfaction is the most common focus and occupant surveys the most frequently used method in POEs. The following recommendations should be included in surveys:

- Are you aware of the adaptability of your façade?
- Are you comfortable with the adaptability?
- Are you satisfied with your ability to control your façade?
- How often would you like your façade to change?
- Do you think that your façade contributes to the improvement of the thermal characteristics of your workplace/space?
- Do you think that your façade contributes to the improvement of the luminous characteristics of your workplace/space?
- Do you think that your façade contributes to the improvement of air quality in your workplace/space?
- Do you think that your façade contributes to ensuring a satisfactory acoustic environment in your workplace/space?

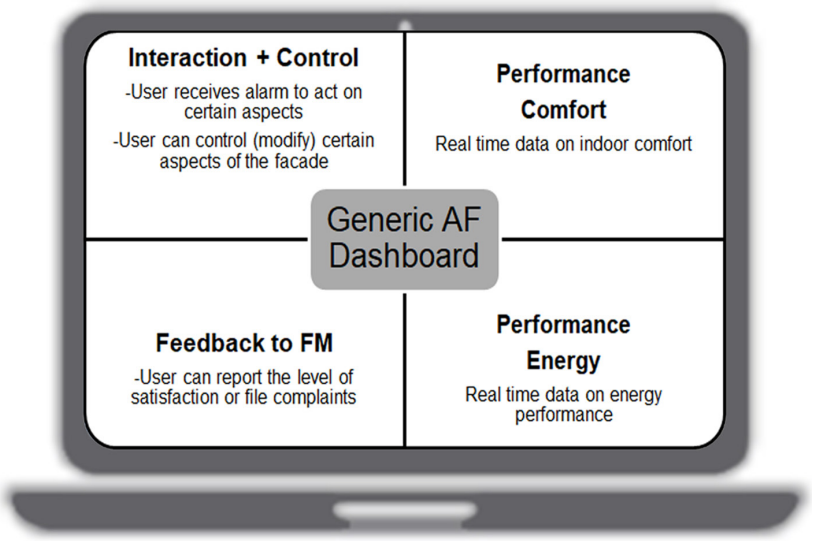

FIG. 3 Adaptive Façade control and feedback dashboard

5 DISCUSSION AND CONCLUSION

There is a market trend for health and well-being within our Architectural, Engineering, and Construction (AEC) industry (Attia, 2019). As we continue to humanise the experience of our working, living and learning places, AFs are advanced and dynamic systems that have the potential to support life quality and people's well-being and productivity in a resource-efficient manner. In this paper, we reviewed the current literature and identified the need for continuous monitoring and interactive control to benchmark the effectiveness of AF. We found that several challenges and implications that have been previously reported in literature hinder the use of POE for AF. Most importantly, there is a very little uptake of POE from the façade industry and an imbalanced focus on the aesthetic aspects of AF.

AF requires a closed loop of dynamic and instantaneous feedback to address the complexity of IEQ, HVAC systems performance, and occupant satisfaction. POE should be able to assess the availability of a range of user or operator control choices and their effectiveness in relation to HVAC and AF system characteristics. Different control objectives in buildings with AF can also work in opposition

to each other. Building operators and owners require tools and user interfaces that can locate and report upon occupants experience behind facades. There is a need for tools that empower users and help to solve those potential conflicts in AF operation and interaction between occupants, façade systems, and other HVAC components.

Therefore, there is a serious need to use test facilities and simulation-based approaches that can help building operators to test, compare, and improve POE methods and, consequently, optimise AF supervisory control strategies based on a variety of metrics. Novel and effective POE methods for AF are also fundamental to allowing optimal façade responsiveness in time and, potentially, providing a means for enabling the modelling of predictive control strategies. Lastly, the future of POE of AF should be based on user experience. User experience is a key factor in the success of POE methods and a fundamental step towards the successful uptake of AF in the construction industry. Future research, therefore, should focus on developing novel metrics to capture user experience of AF.

Our findings can be useful for researchers in identifying new and industry-relevant research areas and for practitioners to learn from empirically investigated challenges in POE, and base their improvement efforts on such knowledge. Identifying and investigating the overlaps underline the importance of these challenges, and can also help in finding other research areas, not only for enhancing POE for AF, but also for BMS and control software quality in general. It also makes it easier for practitioners to spot, better understand, as well as find mitigation strategies for POE for AF, through learning from past experiences and developments in the area of user experience and feedback quality.

Acknowledgements

The authors appreciate the survey respondents' valuable comments and feedback. The author would like to gratefully acknowledge COST Action TU1403 "Adaptive Façades Network" for providing excellent research networking. The authors would like to acknowledge the support of Work Group 3 members.

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