Building and Environment 157 (2019) 268–276

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Development and validation of a survey for well-being and interaction assessment by occupants in office buildings with adaptive facades

S. Attia[a,*], S. Garat[a,b], M. Cools[c,d,e]

[a] Sustainable Buildings Design Lab, Dept. UEE, Applied Sciences, Université de Liège, Belgium
[b] EPF Graduate School of Engineering, Sceaux, France
[c] Local Environment Management & Analysis (LEMA), Dept. UEE, Applied Sciences, Université de Liège, Belgium
[d] KULeuven Campus Brussels, Department of Informatics, Simulation and Modeling, Warmoesberg 26, BE-1000 Brussels, Belgium
[e] Hasselt University, Faculty of Business Economics, Agoralaan Gebouw D, BE-3590 Diepenbeek, Belgium

Keywords:
Dynamic facades
User interaction
Questionnaire
Occupant satisfaction
Thermal comfort
Acoustic comfort

A B S T R A C T

Assessing well-being and occupants satisfaction is a growing concern in façade design practice, as increasing recognition of the value of well-being of occupants in office buildings. The objective of this study was to develop a validated survey for evaluating the indoor environmental quality in office buildings with adaptive facades to provide feedback to designers and operators and inform the building community at alarge. A total of 70 employees completed an initial survey containing 14 questions grouped into six domains (OCAFAS-14). Factor analysis of the responses was performed resulting into a final survey grouped into three domains and containing 15 questions (general feeling, thermal comfort and acoustic comfort) (OCAFAS-15). Statistical analysis indicated that the OCAFAS-15 had good validity, reliability, and internal consistency. The survey succeeded to benchmark well-being, satisfaction and interaction changes of employees in an open-space office with dynamic louvers. The results indicates that the OCAFAS-15 provides a basis for dialogue between occupants and façade engineers regarding the user interaction, façade control adaptation and in particular in tracking of changes of indoor environmental quality, evaluating response of facades to occupants' requirements, and guiding the operation of adaptive facades. A validated well-being and occupant interaction survey could be particularly useful in benchmarking building with adaptive facades and recognizing and managing occupants' dissatisfaction in buildings with dynamic facades.

1. Introduction

Occupants' well-being and occupants' interaction assessments are considered to be the most important design goals in facades engineering [1,2] and are now common place in building with adaptive facades [3]. An adaptive façade is a facade which can change his transports properties for all kinds of energies (radiative, thermal …) either as a passive reaction to changing environment conditions or as an active switch controlled by a building control assistant. The purpose of adaptive facades is creating maximum comfort for occupant with minimum energy consumption. However, there are very few pre and post-occupancy survey tools that can help façade designer and operator to understand occupants' experiences, perceptions and levels of satisfaction, in buildings with adaptive facades. There is often a gap between the automated/responsive behavior of these facades and the requirements of occupants', which creates discomfort, both visually and thermally [4]. Only in the past five years has occupant-centered adaptive façades assessment been extensively studied and measured as part of the scope of EU COST Action TU1403 “adaptive facades network”, under whose auspices the present study was carried out [5]. The initiated COST Action TU1403 “adaptive facades network” aims to pool together the knowledge, technologies and research from across European countries and beyond [6]. One of the main objectives of this Action is assess and evaluate different adaptive facades technologies from an occupant-centered approach and create good-quality survey tools to benchmark and compare the indoor environment in office buildings with adaptive facades.

Historically, most well-being and satisfaction surveys have been

Abbreviations: AC, Acoustic Comfort; CFA, confirmatory factor analysis; DBO, Design Build and Operate; EFA, exploratory factor analysis; G, General; IEQ, indoor environmental quality; ICC, intra-class correlation; OCAFAS, occupant-centered adaptive façades assessment survey; POE, post-occupancy evaluations; TC, thermal comfort

* Corresponding author.
E-mail address: shady.attia@uliege.be (S. Attia).

https://doi.org/10.1016/j.buildenv.2019.04.054
Received 20 February 2019; Received in revised form 22 April 2019; Accepted 27 April 2019
Available online 04 May 2019
0360-1323/

developed with a focus on the indoor environment [2]. Because thermal comfort, visual comfort, acoustic comfort and air quality are the strongest discriminators of well-being and satisfaction of occupants in buildings [7,8]. For example, the UK BUS occupant survey allows benchmarking office buildings against an existing database of case studies [11]. Other standard-setting bodies such as the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) developed a Performance Measurement Protocols for Commercial Buildings [9]. The Center of Built Environment (CBE) developed a Building Performance Evaluation (BPE) toolkit with an occupant satisfaction survey with a score card report generation tool [29]. This was emphasized by emergence of post-occupancy evaluations (POE) in 1990s as an approach to address the sick building syndrome and occupants' complaints in working environment [11]. A literature review published by Attia et al. (2018) [1], indicates that the evolution of post-occupancy evaluation resulted in creating two procedural approaches or methodologies namely: (1) Subjective or Qualitative Methods: a) Occupants Surveys, b) Interviews, and c) Walkthroughs and (2) Physical Quantitative Methods: a) IEQ in situ measurements and b) energy and water audits and monitoring [10–18]. However, most of these surveys are developed by researchers and are not validated or are developed by third-party survey providers which make them not accessible for design teams, owners and buildings managers and more importantly they do cater for buildings with static facades.

Although POE methodologies in buildings with static facades can be used in building with adaptive facades, the creation of novel occupant-based behavioral and opinion survey that cater for adaptive facades and address the interaction of users is becoming a growing concern [3,19]. There is a consensus that occupants' well-being and occupants' interaction in buildings with adaptive facades should be more intensively investigated [1]. Next to IEQ parameters, these can include needs satisfaction, facade control, façade feedback, control adaptation, user appropriation and the learning ability of the façade control system [4]. Using this inclusive definition of occupant-centered well-being makes it harder to measure occupant interaction and engagement in buildings with static facades. The usual method for constructing a valid occupant-centered adaptive façades assessment survey (OCAFAS) is to identify different domains that independently contribute to well-being and occupants interaction assessment for individuals in open-office spaces with adaptive facades [1]. The domain concept allows the topic of well-being and occupants interaction in building with adaptive facades to be separated into different parts that mirror its multifactorial nature. Then survey designers can group various assessment items, which are intrinsic to the topic of well-being and occupants interaction within each domain [27].

In architectural and engineering firms, well-being and occupants satisfaction is a growing concern as increased awareness of employees owns health and well-being is becoming a global trend [20–22]. In response to increasing recognition of the value of the assessment of well-being and occupants interaction in buildings with adaptive facades in practice, previous efforts have been made to develop assessment studies of well-being and occupants interaction in building with adaptive facades. One of the earliest studies is the study of Vine [23] who investigated interaction between occupants and a dynamic venetian blind in an experimental setting. Clear et al. [24] investigate the responses of 38 subjects to electrochromic windows in an experimental setting. Similarly, did Lee et al. [25] assess an electrochromic window control system in a fully monitored test-bed. The measurements took place during 328 meetings in 6-months without indicating the nature of questions that were used. Among the previous studied we consider the work of Bakker et al. (2014) the most significant. In their study, they assessed the user satisfaction and interaction with automated dynamic facades in an experimental facility with 26 test subjects [3]. Also, the work of Karlsen et al. (2015) is relevant because they assessed the occupant satisfaction with two blind control strategies in an experimental facility with 40 test subjects [19]. Exceptionally, the study of Stevens (2001) is the only found study that investigated the correlation between occupant satisfaction and their ability to overrule automated façade control in real buildings [26]. However, most those studies were mostly performed in experimental settings and did not focus on creating generic surveys or POE methodologies catering for occupants in building with adaptive facades [1]. They focused on the technical trial assessments of specific adaptive façade technologies in relation to occupant's satisfaction and interaction. Previous studies did not enable occupants and operators in real buildings with adaptive facades to track changes in well-being, evaluate response to façade control and guide the operation decisions.

Thus, in order to bridge this gap and improve the quality of evaluation of interactions between occupants and their working environments in buildings with adaptive facade, we need to know the requirements and troubles of the occupants. This is why we propose an occupant-based behavioral and opinion survey, the analysis of the answers to which will allow us to identify the main problems in order to attenuate or eliminate them. The aim is the creation of a validated survey that could be used in POE and also would enable facades designers (architects and engineers) and operators (facility managers) to design and manage adaptive facades.

The purpose of this study was to create and evaluate the validity of an occupant-centered, multi domain occupant well-being related survey appropriate for baseline benchmarking and ongoing evaluation of occupants' satisfaction in experimental and real building settings. By including physical and non-physical assessment domains, the survey was designed to accurately reflect the occupants' well-being and interaction in buildings with adaptive facades.

2. Materials and methods

For this study we developed a study conceptual framework that summarizes and visualizes our research methodology. Similar to the work of Lavan (2013) [27], Lesley Wiseman Orr et al. (2004) [28] and Zagreus et al. (2004) [29], our research methodology combines mixed methods of research involving quantitative (e.g., case studies) and qualitative (statistical factor analysis) and quantitative (extensive usability testing) research. As shown in Fig. 1, our conceptual study framework is based on three axes that will be described in the following sections.

From an epistemological point of view our study is not experimental and not empirical. By experimental we mean measuring user's interaction and satisfaction in laboratory or test cell conditions. By empirical we mean measuring the influence of the adaptive façade operation and design on user satisfaction, interaction or indoor environmental quality. However, our study is a modelling study. We are not here focused on the nature of reality (satisfaction, interaction and indoor environmental quality), rather we are focused on how we can know it. Also due to the sensitivity of the building owner to release any negative information that can be used by occupants in any future struggle, we hardly succeeded to convince the owner to allow us to benefit from the building occupants to create the survey and not assess the building. In order to manage to do this study, we had three previous failing case studies were the owner allowed us to do such study. Therefore, we found it more important to build and create a valid and open-access survey first, as a start, before using it on a large scale in different case studies with the same adaptive façade technology.

2.1. Survey development and testing

2.1.1. Domain identification

The domain identification for the survey was based on a literature review and framework for adaptive facades evaluation developed by the first author to assess the well-being and interaction in buildings with adaptive facades [1,2]. Based on a novel object-based façade characterization and classification framework we identified six domains

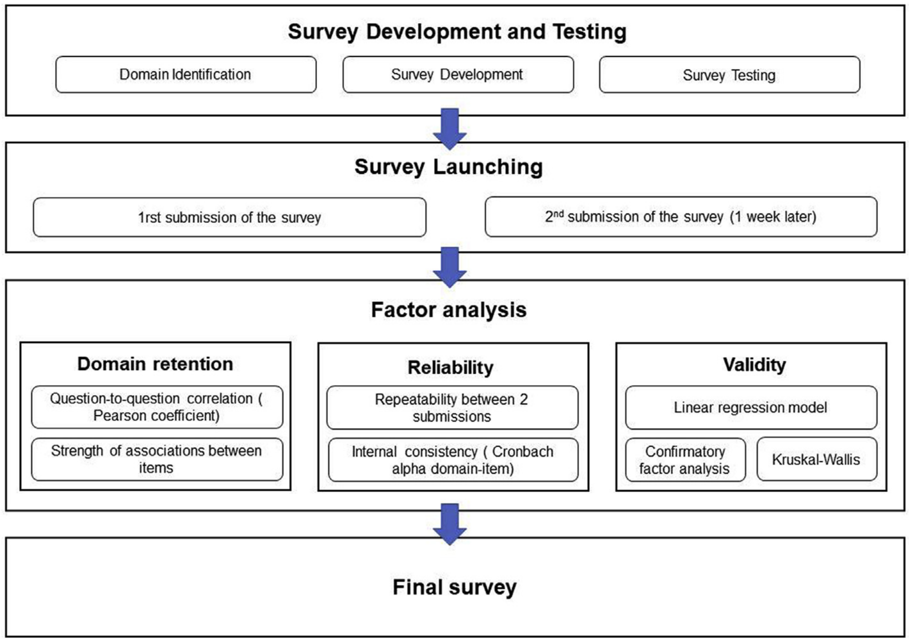

Fig. 1. Study conceptual framework.

Table 1
Domains and assessment items in the occupant-centered adaptive façades assessment survey (OCAFAS-17).

Domain of adaptive façades assessment	Item number and description
Personal Data	Gender, Age, Working Years, Closeness to window, Closeness to wall, Orientation, Floor, Location, Control Options, Computer/Paper work
General Feeling	(1) General satisfaction
	(2) Source of Disturbance
View	(3) Satisfaction with view
	(4) View importance
Visual Comfort	(5) Glare disturbance
	(6) Illuminance level I
	(7) Illuminance level II
Thermal Comfort	(8) Thermal preference
	(9) Temperature perception
	(10) Thermal comfort satisfaction
Adaptation Control	(11) Learning ability of control system (intelligence)
	(12) Control adaptation
	(13) Control disturbance
User Interaction	(14) Control importance
	(15) Satisfaction with feedback
	(16) Satisfaction with control and interaction
Acoustic Comfort	(17) Noise disturbance I (Movable shading)

as shown in Table 1. The survey was developed based on questionnaire responses by occupants. Their input was used to validate the six domains empirically thought to be related to an adaptive facades performance with external movable shading, namely, views, thermal comfort, visual comfort, acoustic comfort, façade control adaptation and user interaction.

2.1.2. Survey development

The alpha and beta version of the OCAFAS-14 was developed by the author to assess the satisfaction and interaction of occupants with adaptive facades in office working environments. The identification of the survey domains resulted in creating a survey with six domains empirically thought to be related to occupants' well-being in office buildings with adaptive facades. Each domain contained some related items that were scored on a 5-level Likert scale. Two general questions were added (personal data and general satisfaction, followed by an occupant-centered adaptive façades assessment. The general feeling was scored on a 5-point numeric rating scale from very poor to excellent. Based on informal responses during the survey testing (see next Section), the survey domains and items were considered suitable for inclusion in an initial, 14-item occupant-centered adaptive façades assessment survey (OCAFAS) (OCAFAS-17; Appendix A) after minor modifications. Since employees occupants who reviewed the survey prior to testing considered the question on 'general feeling' to be valuable, it was held in the final survey. Based on the rule-of-thumb used in factor analysis that at least five times as many respondents should be used as the number of items in the questionnaire the target sample size was estimated [30,31]. The target minimum sample size for survey was calculated to be 70 to cover the 14 questions.

Occupants who were employees in an office building with an adaptive façade were asked to participate in the survey. The building is a nearly zero energy building located in Louvain-La-Neuve, Belgium (Lat: 50.6770°N, Long: 4.6233° E), with unique glass façade, comprising thermal isolated glass sunshades printed with white silk screen. The external façade is fully covered with double glazing system in combination with movable sunshades printed with white silk screen. An external louvers system respond dynamically and automatically to the angle of the sun which improves the control over energy consumption, solar radiation and glare with the ability to admit natural light into the building while affording a view over the surrounding countryside [32]. The main characteristics of the buildings are reported in the work of Samyn and De Coninck (2014) [33]. The criteria for the selection of the case study building required it to have an adaptive façade with multiple and identical working settings regarding, South orientation, occupant's number, function and furniture. The building is built in 2014 and is equipped with HVAC system and was designed to have fixed, non-operable windows. The external louvers are automated centrally for shading and occupant have access to internal roller blinds. As shown in Fig. 2, employees working in the South-East Section of Floor 1 and 2 (above ground) were selected. Fig. 3 provides an overview of the façade with the automated louvers opened.

Respondents were requested to provide data for their workstation's position, gender, age, and floor location. The A4 double-page paper survey was structured into domains and their associated items (see Appendix A). The paper format allowed the responders to go review or change their responses. 11 days after completing the initial survey,

Fig. 2. Floor plans of the study location and AGC Glass Building, Louvain-La-Neuve, Belgium [33].

responders were invited to complete the survey a second time. The two responses were analyzed to test and retest reliability between surveys. Responses of the OCAFAS-14 were analyzed to determine which survey components were relevant and should be reserved or adapted.

2.1.2.1. Survey testing. A pilot study was carried out thanks to the feedback of the building manager. This allowed us to properly define the main lines of evaluation for questionnaires. The main result of this pilot study is the expansion of the initial three main axes (Comfort perception, Adaptation control and User interaction) into six new axes: View, Thermal comfort, Visual comfort, Adaptation control, User interaction and Acoustic Comfort. After these multiple steps, the following initial survey (see Appendix A) was printed in paper version.

2.2. Survey launching

The survey was carried out twice at two-week intervals: on the 23/11/2018 and 04/12/2018. Participants were who participated in the study were kept anonymous. The survey was conducted in accordance with the ethical standards in the Declaration of Helsinki and the European Union General Data Protection Regulation (GDPR). The study took place on the first and second floor of a two open-space offices located in the South-East of the AGC Glass Building. The questionnaires were distributed twice in the autumn of 2018 at 14:00. Respondents required 12 min in average to fill in the survey. Recorded temperatures were conventional for the season. The climatic conditions in Louvain-La-Neuve over these 2 days were essentially the same: clear sky with solar radiation and ambient temperature around 5 °C. This 2-week interval was considered short enough for subjects to make an assessment under identical conditions and long enough for them not to remember exactly their answers. Thanks to two-week intervals, it was possible to compare the answers of test-retest reliability. Indeed, since surveys might be subjective and can be influenced by factors such as mood, we repeated the survey twice. By distributing the survey twice, the risk of dependence on these factors is reduced. In total, 70 employees responded to both survey rounds.

2.3. Factor analysis

Factorial statistical analysis was done using SPSS AMOS software, to identify links, redundancies, similarities between questions and between questions and their categories [34]. Once the answers were collected, an Excel table was created including all the answers. In order to be able to do a better factor analysis, it was necessary to transform all questions into Likert-type questions (scale evaluating a parameter on a scale of 1–5). Indeed, the comparison of Likert questions is much stronger in terms of meaning than the comparison of several binary answers having no defined link between them. In order for SPSS AMOS program to work properly, we removed the surveys that were not answered twice from the answers database. A question with more than 5% missing answers indicates that it is not comprehensible enough and must be changed or deleted. Then, we investigated three major indicators namely the item retention within domains, validity and reliability.

2.3.1. Domains identification

To identify the different domains inherent in the questionnaires, two procedures were followed. First, from a theoretical point of view, the different subdomains that were found in literature and proposed in the framework of Attia et al. (2018) were tested using confirmatory

Figure 3. (Left), overview of the façade with the automated louvers opened; Fig. 3 (right) Exterior – Windows Double-skin façade combining glass louvres made of extra-clear glass (outside skin) with super-insulating glazing and white spandrel double glazing (inside skin); Architect: Philippe SAMYN and PARTNERS sprl, architects and engineers – BEAI sa, Photographer: Jean-Michel Byl, Courtesy Notice: AGC Glass Building - © Project: Philippe SAMYN and PARTNERS sprl, architects and engineers – BEAI sa [33].

Table 2
Demographics of survey responders that provided information.

Gender (n = 70)		Location		Age		Working place[a]				
Male	Female	Within 4 m from facade	Within 8 m from facade	Average	in survey location	1[a]	2[a]	3[a]	4[a]	5[a]
44 (63%)	26 (37%)	26 (38%)	44 (62%)	43 years	4 years	11	21	0	15	23
						15%	30%	0%	21%	33%

[a] (see Appendix A).

factor analysis (CFA) [2]. The correlation between two questions of the same domain was analyzed using the confirmatory factor analysis (CFA) and the exploratory factor analysis (EFA). The CFA was used to test whether our domain classification presented in initial survey version in Appendix A is consistent with the occupants' understanding of the nature of well-being and interaction in buildings with adaptive facades. The objective of confirmatory factor analysis is to test whether the data fit our seven hypothesized classification framework. This hypothesized framework is based on theory and/or previous analytic research [2].

Secondly, an exploratory factor analysis was carried out to reveal the different domains and their relevance. The EFA is a statistical method used to uncover the underlying structure of a relatively large set of variables. EFA is a technique within factor analysis whose overarching goal is to identify the underlying relationships between measured variables. It is commonly used by researchers when developing a domain (a domain is a collection of questions used to measure a particular research item) and serves to identify a set of latent constructs underlying a series of measured variables. The domain relevance was calculated by an Eigenvalue > 1.0. The Eigenvalue feature prominently in the analysis of linear transformations [35]. To help determine which questions should be retained to enhance the domain structure, the quality and strength of relationship among questions was used.

2.3.2. Item retention within domains

Standardized regression weights, were calculated to define the correlations of the different items to each of the different domains. To proof a correlation the standardized regression weight should be at least 0.5 and higher to be moderator or significant between an item and a domain.

Then, the correlation between two questions of the same domain was analyzed using the Pearson correlation coefficient. The percentage of the correlation variation was used as a guide to reinforce the importance of the selected domains. Questions were assembled into specific domains based on factor loadings ≥0.4. Correlations between an item and another item of 0.3–0.8 were considered adequate to assemble questions within a domain [36]. A correlation of less than 0.3 means that the questions are not similar enough to be grouped in the same domain, a correlation of more than 0.8 means that the questions are too similar and should be merged into a single question. This analysis led us to delete several questions, which were not sufficiently correlated with the other questions in the field. A pattern of extreme low or high scoring would indicate the questions might not be sensitive enough to detect nuances in the well-being and interaction of occupants in buildings with adaptive facades. The pattern was used to test for discriminant (known-groups) validity.

2.3.3. Validity

The OCAFAS-14 items and domains were analyzed for discriminant validity through correlating to the well-being and interaction of occupants items (Appendix A). The discriminant validity tests whether domains that are not supposed to be related are actually unrelated. A correlation of 0.4–0.7 indicated good divergent validity. Discriminant validity was assessed by comparing the correlation among the domains, in comparison to the individual items correlations.

2.3.4. Reliability

Internal consistency was examined to degree to which OCAFAS-14 questions, within each domain, measured the domains concept. A Cronbach-alpha score > 0.6 indicated good internal consistency of the questions measuring a domain concept. The reliability was calculated by comparing the test and retest answers. The 11 days period was considered long enough that a responder would remember his or her first response. In the same, the 11 days period was short enough so that changes in the occupants' indoor environment status occurred.

3. Results

3.1. Survey responses

A total of 70 individuals completed both surveys for the test and retest analysis. Surveys with missing responses were excluded. A total of 140 valid survey responses were received and provided complete personal data during the survey personal data for the respondents in the study is presented in Table 2.

In asking questions about the overall well-being and satisfaction with the adaptive façade and their working environment, a majority of responders indicated their dissatisfaction with the façade (Question 11) as shown in Fig. 4. Fig. 5 provides an insight regarding this unexpected dissatisfaction. 82% of responders reported glare as the main reason for

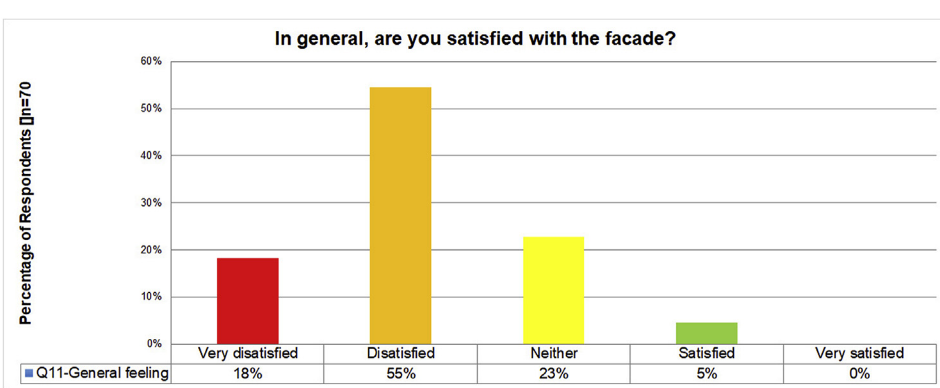

Fig. 4. The breakdown of responses regarding the general satisfaction of occupants.

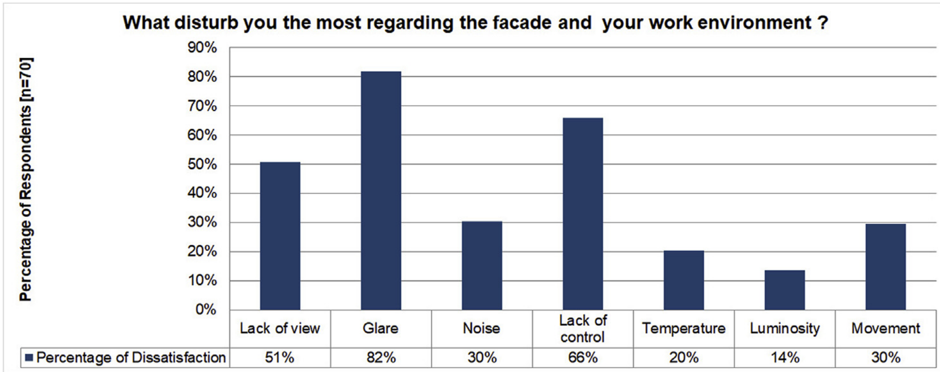

Fig. 5. The most disturbing factors behind the dissatisfaction of the survey respondents.

dissatisfaction followed by the lack of control (66%) and lack of view (51%). During the testing period of the survey, we amended Question 11 with a multiple choice question and an open question to make sure our survey will cover all well-being and satisfaction domains. Fig. 5 provides a valuable insight to measure the reasons of dissatisfaction and their order of magnitude.

3.2. Domains identification

To identify the different domains inherent in the questionnaires, two procedures were followed. First, from a theoretical point of view, the different subdomains that were found in literature and proposed in the framework of Attia et al. (2018) were tested using confirmatory factor analysis (CFA) [2]. The results of this CFA showed that the seven domains identified in Table 1, based on the literature review and framework developed by Attia et al. (2018) could not be discriminated based on the results presented in Table 3 [2].

Secondly, an exploratory factor analysis was carried out to reveal the different domains that could be discriminated. Based on the principal component analysis only three domains out of seven domains have been retained using the Eigenvalue criterion. Table 3 displays the Eigenvalues from this principal component analysis underlining the 3-factor solution. Note that this three factor solution explains 64% of the variation present in the different items that were measured. Only the Thermal Comfort (TC) and Acoustic Comfort (AC) were discriminated under two groups. The other items belong to a General (G) domain. See Appendix A.

3.3. Item retention within domains

The standardized regression weights results indicate that most of items show a strong relationship between the individual items and the latent dimension factors or domain (see Table 4). This confirms the validity of the new domains structure (G, TC and AC) and the strong correlation between each domain and the investigated items. See Appendix A.

Table 3
Eigenvalues of the correlation matrix: Total = 14 average = 1.

	Eigenvalue	Difference	Proportion	Cumulative
Q1	5.830	3.708	0.416	0.416
Q2	2.122	1.106	0.151	0.568
Q3	1.015	0.145	0.072	0.640
Q4	0.869	0.131	0.062	0.702
Q5	0.738	0.071	'0.052	0.755
Q6	0.667	0.110	0.047	0.803
Q7	**0.556**	**0.105**	**0.039**	**0.842**
Q8	**0.451**	**0.062**	**0.032**	**0.875**
Q9	**0.389**	**0.046**	**0.027**	**0.902**
Q10	0.342	0.052	0.024	0.927
Q11	0.289	0.012	0.020	0.948
Q12	0.276	0.026	0.019	0.967
Q13	0.250	0.050	0.017	0.985
Q14	**0.199**		**0.014**	**1.000**

Table 4
Standardized Regression Weights: (Group number 1 - Default model).

Items		Domains	Correlation with Domain
Q9	←	TC	,716
Q8	←	TC	,832
Q7	←	TC	,637
Q1	←	G	,724
Q3	←	G	,597
Q2	←	G	,721
Q4	←	G	,828
Q5	←	G	,761
Q6	←	G	,754
Q12	←	G	,788
Q13	←	G	,560
Q10	←	G	,584
Q11	←	G	,660
Q14	n/a	AC	–

The correlation between the ten items (questions) of the General (G) domain was analyzed using the Pearson correlation coefficient. As presented in Table 5, all items had a factor loadings ≥0.3. Item-to-item correlations of 0.3–0.8 were considered sufficient to group the ten items indicated in Table 5 within the General domain (G). This proofs correlations sufficient to group items according to the domain. See Appendix A.

The correlation between the three items (questions) of the Thermal Comfort (TC) domain was analyzed using the Pearson correlation coefficient. As presented in Table 6, all items had a factor loadings ≥0.45. Item-to-item correlations of 0.3–0.8 were considered sufficient to group the three items indicated in Table 6 within the Thermal Comfort (TC) domain. This proofs correlations sufficient to group items according to the domain. See Appendix A.

3.4. Validity

Discriminant validity was assessed by comparing the correlation among the latent dimensions (see Table 7), in comparison to the individual correlations (correlations Tables 5–6). From this table one could see that the correlation between the different dimensions are weak (correlation between TC, and AC, and TC and G), and only moderate between G and AC. See Appendix A.

3.5. Reliability

For reliability and internal consistency we calculated the Cronbach alpha's of the three domains. A high Cronbach alpha is indicating a

Table 5
Pearson correlation coefficients of general domain questions.

Pearson Correlation Coefficients, General Domain, N = 140, Prob > |r| under H0: Rho = 0

	Q1	Q3	Q2	Q4	Q5	Q6	Q10	Q11	Q12	Q13
Q1	1.000	0.493	0.679	0.6320	0.504	0.553	0.406	0.445	0.517	0.369
Q3		1.000	0.498	0.527	0.411	0.530	0.408	0.317	0.362	0.287
Q2			1.000	0.600	0.520	0.585	0.441	0.365	0.510	0.396
Q4				1.000	0.585	0.571	0.555	0.611	0.641	0.453
Q5					1.000	0.652	0.396	0.489	0.665	0.425
Q6						1.000	0.324	0.405	0.577	0.452
Q10							1.000	0.430	0.416	0.386
Q11								1.000	0.644	0.288
Q12									1.000	0.505
Q13										1.000

Table 6
Pearson correlation coefficients of thermal comfort domain questions.

Pearson Correlation Coefficients, Thermal Comfort N = 140
Prob > |r| under H0: Rho = 0

	Q18	Q19	Q20
Q18	1.000	0.523	0.459
Q19		1.000	0.599
Q20			1.000

Table 7
correlations between thermal comfort and acoustic perception and thermal comfort and general domain.

Domain Correlations			Estimate
TC	↔	AC	,346
TC	↔	G	,123
G	↔	AC	,547

large shared variance, indicating good internal consistency. The Cronbach-alpha score for Thermal Comfort (TC) domain was 0.770, indicating a good repeatability of survey scores submitted for the same occupant. Also, the Cronbach-alpha score for the General (G) domain was 0.904, indicating a very good repeatability of survey scores submitted for the same occupant. See Appendix A.

3.6. Final survey OCAFAS-15

Based on factor analysis the original OCAFAS-14 (Appendix A) items were consolidated into 15 items organized into three domains, namely, general feeling (10 items), thermal comfort (3 items) and acoustic comfort (2 items) [37]. The final OCAFAS-15 (Appendix B) retained all question related to the interaction with the façade and it's and control adaptation. Item-to-domain correlation for OCAFAS-15 demonstrated significant correlation of all items within their respective domains. Factor analysis of the three-domain survey demonstrated the created survey is valid and can assess the well-being and interaction of occupants in buildings with adaptive facades.

4. Discussion

4.1. Summary of main findings

Guided by the factorial analysis, the original six domains, OCAFAS-17 survey was reduced to a smaller three-domain, 15 item survey, OCAFAS-15. The analysis showed that: (1) the structure of the different domains (General Feeling, View, Visual Comfort, Adaptation Control and User Interaction) was perceived by the respondents as one domain. (2) Thermal Comfort was perceived as a distinguished domain. (3) Acoustic Perception Comfort was perceived as a distinguished domain. (4) The Acoustic Comfort domain needed to be amended to include at least two items (questions). (5) Study results indicate that the OCAFAS-15 has good validity, reliability, high internal consistency to assess the well-being and interaction of occupants in buildings with adaptive facades. The correlations are sufficient to group the 15 items under three major domains. See final survey in Appendix B.

4.2. Strength and limitations

We created a new survey and validated it with a sample of N-140 responses in a real office building with an adaptive facade. No previous study, explored this terrain and until this moment there is no single survey for adaptive facades that is open-access and validated through N = 140 responses. Our work is part of the activities of COST Action TU1403, European Solar Shading Organization and ISO Committee 52022-5 activities. Experts in those organizations explicitly identified the need to create surveys that are validated and that can be used to assess users' satisfaction and interaction in buildings with adaptive facades [1,2]. The findings of the past Annex 66, and ongoing Annex 79 efforts confirm that in automated buildings, occupants remain one of the greatest influences of building energy use [38,39]. For instance, Hong and Lin (2013) showed that occupant behavior at the office scale could increase energy use by 80% or reduce it by 50% from standard assumptions [40]. There is an increasing global expectation for comfort and user satisfaction, which necessitated a new look at how occupants are incorporated into building design and operation. In this context, our paper presents one of the rare case studies where researchers get access to a building with an adaptive façade and inquire about users' interaction and satisfaction. For this research, we consulted a statistics scientist and linguistic expert to create a new survey that we consider as a good start. We know that our survey is not perfect but it should be seen as novel contribution that future researcher should build upon and turn it from a generic survey to more technology and context specific survey.

The proposed approach has been implemented among participants of an office building with an external dynamic shading system made of movable louvres. In order to use the questionnaire, all occupants of a building had an equal chance of participating in the survey for our select (random) sample. Thus, in the context of this research, we focused on occupants of office buildings with an adaptive façade in French Speaking Belgium, that do paper and computer office work. 31% of the participants were females and 69% were males with a total average age of 43 years. The 140 response of occupants working in office spaces with automated and movable shading, suggest that OCAFAS-15 is useful for post-occupancy evaluations. We believe that the new survey could be particularly useful for occupants to encourage discussion of occupant satisfaction and productivity in relation to user interaction, façade adaptation control and comfort perception [1–3]. The OCAFAS-15 is a short survey with an average response time of 12 min that can assess the well-being and interaction of occupants in buildings with adaptive facades. The survey benefits from its brevity and ease of completion. The OCAFAS-15 survey includes multiple domains and emphasizes the relation with external facades parameters for the well-being and interaction of occupants. In this respect, it differs from surveys that focus on mainly on indoor environmental parameters such as thermal and visual comfort [11,26and41]. It should be noted that parameters directly discernible by the real building occupants have been reported to be more likely to have greater reliability compared to experimental test-based studies [3].

The ultimate goal of well-being and occupants interaction assessment is to focus on well-being as the first consideration in designing adaptive facades [2]. In this respect, a well-being and occupants interaction survey has a potential role in influencing design decisions and assessing control strategies for automated movable shading particularly when the goals is to inform designers during design or operators during operation. Other benefits of a well-being and occupants interaction questionnaire are to raise awareness among adaptive façades designers and operators of factors that influence well-being of occupants, monitor change in satisfaction over time, improve compliance, increase the occupant's sense of interaction in the facades' operation, and improve the practice's relationship with solar shading designers, contractors and operators. To illustrate, 82% (115/140) of occupants investigated in this study stated that they dissatisfied with the interaction with the movable shading system and that the survey made them feel more involved in articulating their concerns.

Ensuring a good quality survey with different domain and scales is not an easy task. It requires a way of asking and wording the questions and many years of experience to make a survey mature. When surveys include multiple domains, it gets more complicated because each domain and its correlations with other items need to be validated. We recognize that there is an entire field in social sciences and even third-party survey providers that is devoted to survey and scale development-psychometrics [42]. We recognize that the 140 responses from two tests provided by 70 respondents are little. In the same time, it might be difficult for façade engineers to understand the reasons of satisfaction or dissatisfaction in the presented case study. However, in this study we did not seek to assess this specific case study. We aimed to create a tool that can be used to enable a dialogue between occupants and façade engineers. Adaptive facades with automated movable shading are a niche type of buildings and we believe are the first study to investigate users in such buildings with a sample of 70 respondents [3].Also, we believe this work will allow to benchmark working environments with adaptive facades and to be able in the future to create a database of case studies [32,43and44]. In the recent years, several certified green buildings were designed following an integrative design process where Design, Build and Operate (DBO) contracts are performance driven. Thus, our survey can be used as a tool for post-occupancy evaluation and it can provide feedback to integrative design teams. Our aim in this study is not to establish that dialogue between building designers and operators. This is not our responsibility. However, our aim is to provide a tool that can be used to enable this dialogue within green certified and DOB contracted project including the case of our case study [45].

Needless to say, we only chose one time interval during the autumn on the 23rd of November and 4th of December from 14:00 to 15:00. We should ideally have tested our survey three times daily by selecting representative days at least in four seasons of the year. However, we could not have a full access to repeat our survey. We hardly got access to this building after several trials with building owners of adaptive facades. We did our best to push the limits and get a good representative sample of occupants who can help us to shape a generic survey that can be developed in the future. But we had the advantage to have all respondents in the same building in a space with the same orientation and interior setting. Another limitation is that we focused mainly on surveys responses and did not include any measurement in the study. In fact, we did not want to provide an assessment of the current building, we rather wanted to create a new survey that can be used easily by professionals and researchers in buildings with automated dynamic facades. Also, the for the Acoustic Comfort domain we included in the running survey only one single question. However, the occupants indicated the importance to include at least two questions related to noise disturbance.

4.3. Future work

In summary, this study presents a novel survey with good validity to be used to assess occupants' well-being and interaction in buildings with automated dynamic facades. Future research should test our survey in a wider context with a larger sample of respondents with respect to different orientations, climates, view types and time of the year. More work is also needed to test the three suggested domains and in particular the General Feeling domain. We expected that visual comfort would lead to the creation of an independent domain, however, the factor analysis proofed we were wrong. Surprisingly, acoustic comfort emerged as an important domain that was undermined in our initial classification. Future research should, extend the Acoustic Comfort domain and add more items and measure their validity and relevance. We believe that the same questionnaire can be adopted for other type of commercial buildings with similar functional uses and similar dynamic shading technology. Further research and adoption of the same framework would be excellent avenues for further research for further validating and generalizability of the proposed survey for chromogenic, solar active and insulative facades.

It is clear that occupants' well-being and interaction surveys in buildings with automated dynamic facades can take various forms and still be useful instruments. However, we have currently very few of them. Therefore, researcher should create more surveys for the evaluation of experience and self-reported health and well-being of building occupants. We believe that a statistically, valid and reliable instrument for evaluating the satisfaction and well-being of occupants in building with automated and dynamic facades provided an excellent opportunity for considering what is most important to the occupant and to convey to facade designers and façade operators that the occupant well-being and satisfaction is their primary consideration. Finally, we encourage researcher to develop more specific surveys that cover the different technologies of adaptive facades from an occupant-centered approach. Future surveys should address electrochromic facades and solar active facades and not only automated dynamic facades.

5. Conclusion

Study results indicate that the OCAFAS-15 has good validity in assessing well-being and interaction of occupants in buildings with adaptive facades. The OCAFAS-15 is a reliable and consistent survey that is brief and easy to complete (generally, 12 min or less). A statistically valid and reliable survey for evaluating occupants' satisfaction provides façade designers and operators with a useful tool for considering what is most important to the occupant. The survey can guide facades design decisions, and convey to the operators and building owners that the occupants' well-being and interaction in buildings with adaptive facades is the facades community' primary consideration.

Acknowledgements

The authors express their thanks to all survey respondents. This research was partially funded by the European Cooperation in Science and Technology Action TU 1403. The authors would like to gratefully acknowledge COST Action TU1403 “Adaptive Facades Network” for providing excellent research networking. The authors would like to acknowledge the support of Working Group 3 members. Also, we would like to acknowledge the Sustainable Building Design Lab for the survey development and the valuable support during the experiments and the analysis of data.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.buildenv.2019.04.054.

References

[1] S. Attia, A. Luna Navarro, M. Juaristi, A. Monge-Barrio, S. Gosztonyi, Z. Al-Doughmi, Post-occupancy evaluation for adaptive façades, J. Facade Des. Eng. 6 (3) (2018) 1–9, https://doi.org/10.7480/jfde.2018.3.2464 sep. 2018. ISSN 2213–3038.

[2] S. Attia, S. Bilir, T. Safy, C. Struck, R. Loonen, F. Goia, Current trends and future challenges in the performance assessment of adaptive façade systems, Energy Build. 179 (2018) 165–182 15 November 2018, ISSN 0378–7788 https://doi.org/10.1016/j.enbuild.2018.09.017.

[3] L.G. Bakker, E.C.M. Hoes-van Oeffelen, R.C.G.M. Loonen, J.L.M. Hensen, User satisfaction and interaction with automated dynamic facades: a pilot study, Build. Environ. 78 (2014) 44–52.

[4] S. Attia, S. Bilir, T. Safy, S. Garat, Adaptive Facades Performance Assessment: Interviews with Façade Experts, 9782930909097SBD Lab, Liege University, Belgium, 2019 Retrieved from https://orbi.ulg.ac.be/handle/2268/213736.

[5] COST Action TU 1403, available from: http://tu1403.eu/?page_id=1816 , Accessed date: 14 February 2019.

[6] A. Luible, COST Action TU1403 – adaptive facades network, Advanced Building Skins Economic Forum, 2015, pp. 1226–1233.

[7] S. Altomonte, S. Schiavon, M.G. Kent, G. Brager, Indoor environmental quality and occupant satisfaction in green-certified buildings, Build. Res. Inf. 47 (3) (2019) 255–274.

[8] L. Pastore, M. Andersen, Building energy certification versus user satisfaction with the indoor environment: findings from a multi-site post-occupancy evaluation (POE) in Switzerland, Build. Environ. 150 (2019) 60–74.

[9] ASHRAE, Performance Measurement Protocols for Commercial Buildings, American Society of Heating Refrigeration and Air Conditioning Engineers. Inc., Atlanta, 2010.

[10] W. Preiser, Building performance assessment—from POE to BPE, a personal perspective, Architect. Sci. Rev. 48 (2005) 201–204, https://doi.org/10.3763/asre.2005.4826.

[11] A. Leaman, B. Bordass, Assessing building performance in use 4: the Probe occupant surveys and their implications, Build. Res. Inf. 29 (2001) 129–143, https://doi.org/10.1080/09613210010008045.

[12] B. Bordass, A. Leaman, Making feedback and post-occupancy evaluation routine 1: a portfolio of feedback techniques, Build. Res. Inf. 33 (4) (2005) 347–352.

[13] I.A. Meir, Y. Garb, D. Jiao, A. Cicelsky, Post-occupancy evaluation: an inevitable step toward sustainability, Adv. Build. Energy Res. 3 (1) (2009) 189–219.

[14] D. Pati, S. Pati, Methodological issues in conducting post-occupancy evaluations to support design decisions, Health Environ. Res. Des. J. 6 (2013) 157–163, https://doi.org/10.1177/193758671300600312.

[15] W. Preiser, Post-occupancy evaluation: how to make buildings work better, Facilities 13 (1995) 19–28.

[16] J. Kim, R. de Dear, C. Candido, H. Zhang, E. Arens, Gender differences in office occupant perception of indoor environmental quality (IEQ), Build. Environ. 70 (2013) 245–256, https://doi.org/10.1016/j.buildenv.2013.08.022.

[17] A. Galatioto, L. Leone, D. Milone, S. Pitruzzella, V. Franzitta, Indoor environmental quality survey: a brief comparison between different post occupancy evaluation methods, Adv. Mater. Res. 864–867 (2013) 1148–1152 https://doi.org/10.4028/www.scientific.net/AMR.864-867.1148 , Accessed date: 14 February 2018.

[18] P. Li, T.M. Froese, G. Brager, Post-occupancy evaluation: state-of-the-art analysis and state-of-the-practice review, Build. Environ. 133 (2018) 187–202.

[19] L. Karlsen, P. Heiselberg, I. Bryn, Occupant satisfaction with two blind control strategies: slats closed and slats in cut-off position, Sol. Energy 115 (2015) 166–179.

[20] S. Attia, Net Zero Energy Buildings (NZEB): Concepts, Frameworks and Roadmap for Project Analysis and Implementation, Elsevier, 2018, https://doi.org/10.1016/c2016-0-03166-2 ISBN: 978–0128124611.

[21] IWBI, WELL: the WELL Building Standard V2, Delos Living LCC, New York, 2019.

[22] ESSO, Solar Shading for Low Energy and Healthy Buildings, European Solar-Shading Organization, Zaventem, Belgium, 2017 available from: http://www.es-so.com/images/downloads/Downloads%20publications/ES-SO_Technical_GuideBook_BD_Final.pdf , Accessed date: 14 February 2018.

[23] E. Vine, E.S. Lee, R. Clear, D. DiBartolomeo, S. Selkowitz, Office worker response toan automated Venetian blind and electric lighting system: a pilot study, Energy Build. 28 (1998) 205e18.

[24] R.D. Clear, V. Inkarojrit, E.S. Lee, Subject responses to electrochromic windows Energy, Build 38 (2006) 758e79.

[25] E.S. Lee, E.S. Claybaugh, M. LaFrance, End user impacts of automated electrochromic windows in a pilot retrofit application, Energy Build. 47 (2012) 267e 84.

[26] S. Stevens, Intelligent facades: occupant control and satisfaction, Int. J. Sustain. Energy 21 (2001) 147e60.

[27] R.P. Lavan, Development and validation of a survey for quality of life assessment by owners of healthy dogs, Vet. J. 197 (3) (2013) 578–582.

[28] M.L. Wiseman-Orr, A.M. Nolan, J. Reid, E.M. Scott, Development of a questionnaire to measure the effects of chronic pain on health-related quality of life in dogs, Am. J. Vet. Res. 65 (8) (2004) 1077–1084.

[29] L. Zagreus, C. Huizenga, E. Arens, A Web-Based POE Tool for Measuring Indoor Environmental Quality, (2004).

[30] R.L. Gorsuch, Factor Analysis, second ed., Lawrence Erlbaum Associates, Hillsdale, NJ, USA, 1983, p. 332.

[31] L. Hatcher, A Step-by-step Approach to Using the SAS System for Factor Analysis and Structural Equation Modeling, SAS Institute, Inc., Cary, NC, USA, 1994, p. 73.

[32] S. Attia, H. Bashandy, Evaluation of Adaptive Facades: the Case Study of AGC Headquarter in Belgium. Challenging Glass 5 – Conference on Architectural and Structural Applications of Glass, Belis, Bos & Louter, Ghent University, Belgium, 2016ISBN 978–90-825–2680-6.

[33] Samyn, De Coninck, AGC Glass Building, Lannoo Publisher, Tielt, Belgium, 2014 ISBN 978–2-87386–884-0.

[34] I.S. Amos, IBM SPSS Amos, IBM Software Business Analytics, 2012, pp. 1–8 YTD03114-U.

[35] Marvin Marcus, Henryk Minc, Introduction to Linear Algebra, Courier Corporation, 1988.

[36] P.M. Fayers, D. Machin, Quality of Life, second ed., John Wiley and Sons, West Sussex, England, 2007, p. 118.

[37] S. Attia, Occupant-Centered Adaptive Façades Assessment Survey (OCAFAS-15), Liege University, Belgium, 2019 available at: https://orbi.uliege.be/handle/2268/232980 , Accessed date: 15 February 2019accessed.

[38] D. Yan, T. Hong, B. Dong, A. Mahdavi, S. D'Oca, I. Gaetani, X. Feng, IEA EBC Annex 66: definition and simulation of occupant behavior in buildings, Energy Build. 156 (2017) 258–270.

[39] A. Wagner, L. Obrien, Occupant Behaviour-Centric Building Design and Operation EBD Annex 79, Proposal, International Energy Agency, 2018.

[40] T. Hong, H.-W. Lin, Occupant Behavior: Impact on Energy Use of Private Offices, Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, CA (US), 2013.

[41] ASHRAE, Thermal environmental conditions for human occupancy, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2017 (Atlanta, USA).

[42] A. Loder, Why should I use a third-party survey provider for my WELL project? Available from: https://www.wellcertified.com/en/articles/why-should-i-use-third-party-survey-provider-my-well-project, (2019) , Accessed date: 18 February 2019accessed.

[43] S. Bilir, S. Attia, Performance Evaluation of Adaptive Facades: a case study with electrochromic glazing, in: A. Luible, S. Gosztonyi (Eds.), Adaptive Facades, Lucerne University of Applied Sciences and Arts, Luzern, Switzerland, 2018, pp. 315–324.

[44] S. Attia, Evaluation of Adaptive Facades: the Case Study of Al Bahr Towers in the UAE,Shaping Qatar's Sustainable Built Environment vol. 2, Hamad Bin Khalifa University Press, 2017 Issue 6, P1-13.

[45] E. Lee, L. Fernandes, B. Coffey, A. McNeil, R. Clear, T. Webster, F. Bauman, D. Dickerhoff, D. Heinzerling, T. Hoyt, A Post-Occupancy Monitored Evaluation of the Dimmable Lighting, Automated Shading, and Underfloor Air Distribution System in the New York Times Building, (2013).