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Towards human-centred intelligent envelopes: A framework for capturing the holistic effect of smart façades on occupant comfort and satisfaction

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ABSTRACT

Intelligent buildings have the potential to simultaneously revolutionise the way humans live and reduce energy demand in buildings. In particular, the so-called, smart / dynamic / adaptive building envelope can selectively modulate the energy transfer between the building and its environment in response to transient outdoor conditions and indoor requirements, thereby providing a low-carbon means of achieving occupant satisfaction and well-being. However, the effect of smart facades on holistic occupant comfort and satisfaction with the environment is yet to be fully captured and quantified. This information is essential for evidence-based design and control of smart building envelopes. In this paper, the smart façade characteristics that underpin satisfactory environmental conditions are identified and metrics for their transient and holistic assessment are discussed. A methodology to capture the effect of smart façades on the holistic occupant comfort and satisfaction is then proposed together with its implementation into an early stage design tool. Finally, a ranking system is suggested to assess and compare alternative smart façade technologies according to their overall effect on user satisfaction and productivity for a UK climate.

KEYWORDS

occupant comfort, user satisfaction, intelligent, dynamic façades, human factors

INTRODUCTION

Although human-centred design in architecture is not a new concept, occupants are often dissatisfied with their environment (Frontczak and Wargocki 2011), regardless of the large amount of energy consumed to condition them (IEA, 2017). Novel façade technologies are often able to minimise energy consumption but they are also often the strongest drivers of occupant discomfort or dissatisfaction (Huizenga et al., 2006). Façades are the multi-sensorial skin of buildings, a boundary between indoors and outdoors, which is responsible for filtering light, heat, air and water vapour to maximise the health, well-being and productivity of occupants. Hence, façades have the potential to holistically affect occupants on different sensorial and psychological levels, such as aesthetic or personal control satisfaction, and, thus, actual occupant satisfaction requires a unified balance between all environmental comfort features. For instance, a strong dissatisfaction or "dissonance" (Clements-Croome, 2013) in any of these single comfort features would imply overall discomfort, even if greater satisfaction levels are achieved in the remaining features (Humphreys, 2005). Among all the multi-objective requirements of façades (Favoino et al., 2014), façades primary objective should be to sustain healthy and satisfactory environmental condition for occupants. A human-centred façades should be able to provide and regulate daylight and heat transfer, protecting occupants from overheating and preventing large heat losses, maintaining healthy levels of air quality. Potentially, human-centred façades should be "dynamic", able to change their performance and characteristics according to the changing indoor and outdoor demands. Beyond this, a human-centred façade should have an "artificial intelligence" (Clements-

Croome, 2013) to allow them to be adaptive, able to capture real-time actual occupant demands and learn from past experiences to adapt and sustain optimal environmental conditions. The combination of current façade technologies with accurate control strategies and artificial intelligence provides unprecedented opportunities to create optimal human-centred façades. However, there is a need for new simulative, experimental and theoretical methodologies to capture actual occupant demand and response, and trigger responsive behaviours of intelligent façades that maximise occupant satisfaction. A fundamental distinction is made in this paper between two forms of environmental comfort: satisfaction and preference. In this research, environmental satisfaction is considered as the condition of mind where occupants express satisfaction with overall environment (Figure 1), including satisfaction with view and personal control or interaction strategies. Satisfaction is considered as the condition whereby the occupant might not be in a neutral condition, but expresses the willingness of remaining in the same condition. Environmental preference is instead defined as the desired environmental condition thriven by the occupant. This paper adopts the unified framework of personal comfort model, as defined by Kim et al. (2018), where the individual comfort response is predicted or assessed instead of the average response of a large population, and applies it to the assessment and control of dynamic façade technologies.

This paper attempts to provide initial methodological results of ongoing research at the University of Cambridge on novel methods for capturing the transient and holistic effect of intelligent façades on occupant satisfaction. A framework to capture the transient and holistic effect on personal occupant satisfaction is proposed and its future implementation in early design stage tools or ranking is discussed.

THEORETICAL BACKGROUND AND PROPOSED FRAMEWORK

The proposed framework endeavours to capture the overall holistic occupant response to and preferences for façade environmental effects. The façade effect on occupant holistic environmental satisfaction has been framed conceptually as shown in the diagram in **Error! Reference source not found.**. Holistic satisfaction or preference considers the overall satisfaction with the visual, thermal, aesthetic, view, air quality, acoustic and interactive environment and their mutual interrelationships or conflicts (shown in Figure 1 as linking lines between each single comfort feature). In the diagram, the façade is considered as an interface that modulates the energy and mass flows (so called “primary inputs”) from outdoors and transfers them to indoors. Hence, alternative façades technologies have the potential to filter and modulate these flows in a different manner and according to their physical components or characteristics (such as type of glass, glass thickness, type of cavity, shading devices, coating characteristics, etc.), labelled in the framework as “Façade physical characteristics”. Consequently, the effect of a façade on occupants depends on the joint value in time of all façade properties, such as surface temperature or light transmitted, that directly affect the environment as result of the energy and mass flow across the façade. For the purposes of this framework, these façade properties will be named as “Façade comfort variables” and are considered to be the main drivers of the façade effect on occupant comfort. The façade comfort variables are directly related to “Façade physical characteristics”. However, alternative façade characteristics can result in the same comfort façade variables. For instance, different types for shading devices can produce the same value of light transmittance and different U-values could result in similar values of mean surface temperature. A literature review was conducted to identify the main façade comfort variables that affect occupant environmental satisfaction and the results are summarised in Table 1. The local environmental conditions in the vicinity of the occupant is affected by the transient value of the façade comfort properties and the non-façade input effect of environmental services or other contextual conditions, such as space layout or furniture, that are identified in this framework as "Not-façade inputs". The local environmental characteristics that affect occupant environmental satisfaction are labelled "Local comfort variables". The final output of this process is the holistic response of the occupant to the local environmental conditions, and the façade comfort properties (which includes also the interaction strategies). This final output depends on the "human filter", which is the ensemble of all individual and collective psychological features that affect human perception of the environment. Figure 2 illustrates the overall conceptual model described above. The variables and parameters of this framework are then grouped as follows: External conditions, Façade physical component, Façade comfort variables, Local comfort variables, Contextual variables, Human filter variables and Occupant response. The framework identifies all groups of variables involved in the problem of capturing the façade effect on occupant satisfaction. The research project endeavours to find a correlation between the façade comfort variables and occupant response through direct or indirect collection of occupant feedback. The correlations that will be investigated in the course of this research project are highlighted in green. As above mentioned, all these variables are time and location dependent. In order to identify a correlation between façade comfort variables and physical properties with occupant response (in terms of preferences or satisfaction) it is essential to monitor them locally and transiently, with particular attention to their rate, velocity and frequency of change and, simultaneously, gather high frequency feedback from occupants.

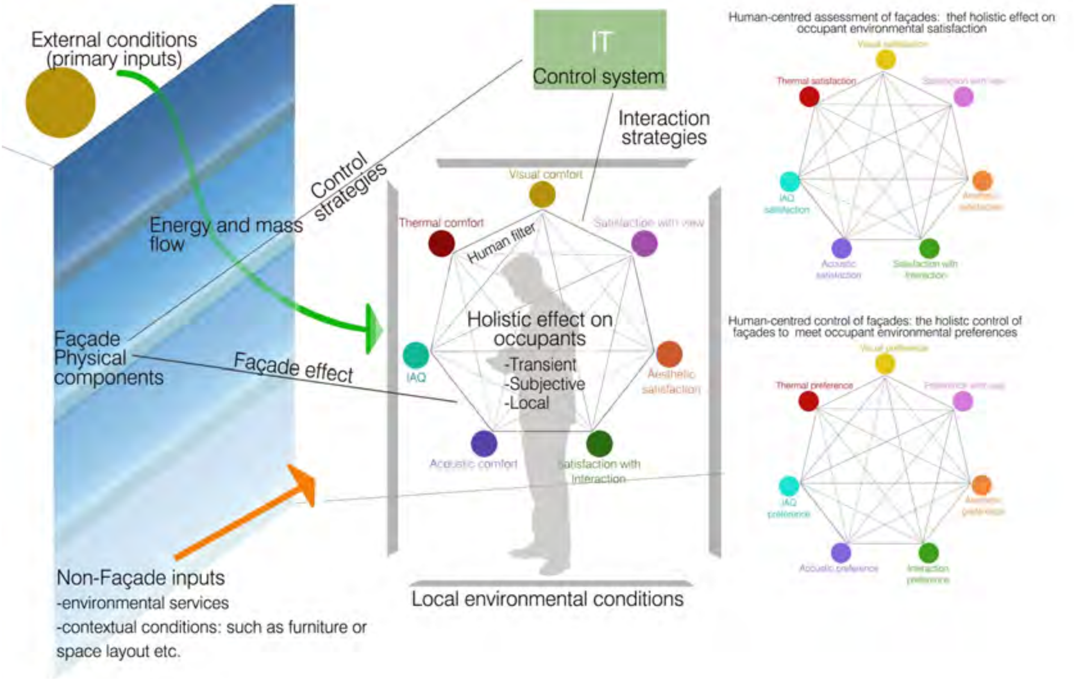

Figure 1 Diagram of the façade effect on occupants

DISCUSSION, EXPECTED RESULTS AND FUTURE WORK

The proposed framework offers a methodology to gather valuable information on occupant levels of dissatisfaction or satisfaction with alternative façades technologies or controls. This could be useful for two purposes (Figure 3): 1) Assessing the façade quality and performance in terms of personal occupant environmental satisfaction and its effect; 2) Informing intelligent façades control strategies on actual personal occupant preferences and on the correlation between façade physical properties and comfort variable with occupant. The post-process of the data through machine learning techniques could also help to predict occupant preferences and create personalized comfort models to be used for controlling jointly intelligent façades and BMS.

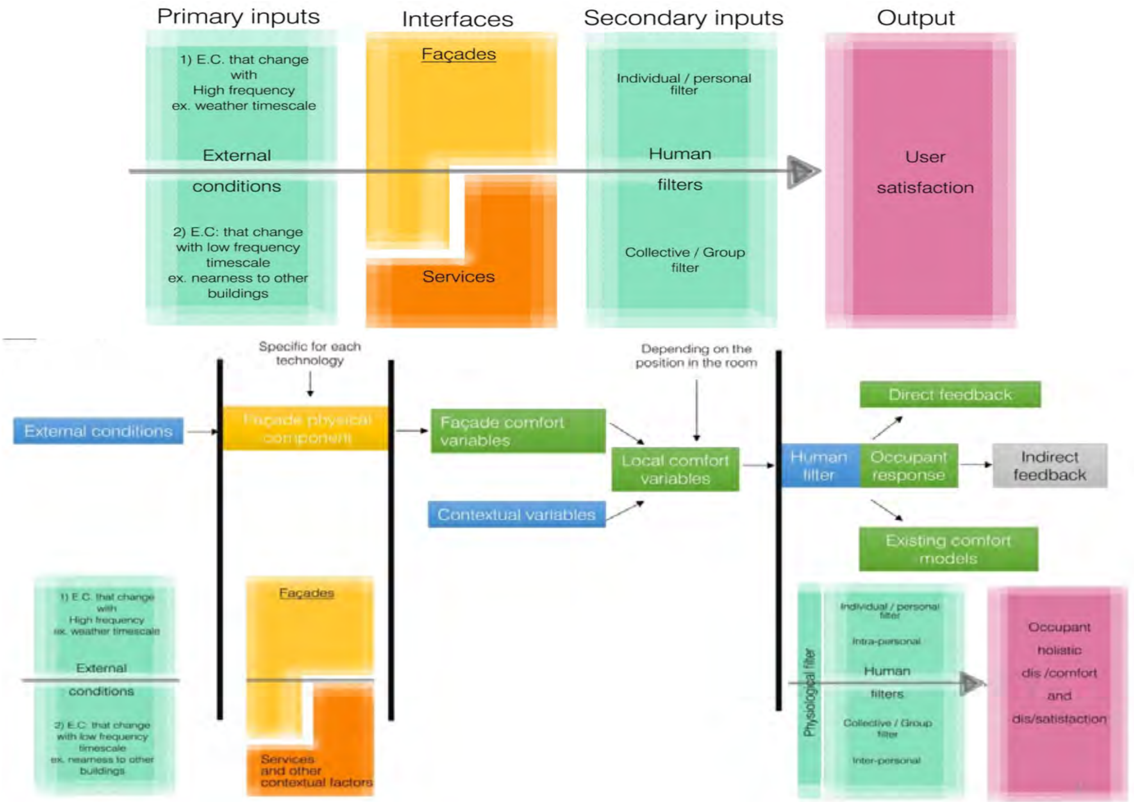

Figure 2 Concept map of the research problem: how to capture the façade effect on occupants

Table 1 Results from a literature review on the main façade comfort properties

Façade comfort variable	Unit of measure	Key reference
Surface temperature	°C	(Huizenga, 2006)
Draft: air velocity, air temperature, humidity	m/s, °C, gr/m^3	(Huizenga, 2006)
Solar radiation transmitted (Irradiance and direction)	W / m^2; degree	(Huizenga, 2006)
Luminance	Cd/m^2	(Wienold & Christoffersen, 2006)
Light transmitted (intensity, direction, colour)	Lux; degree, K	(Nabil & Mardaljevic, 2006);
View extension		(Carmody et al., 2004)
View clarity		(Ko & Schiavon, 2017) (Konstantzos et al., 2015)
Sound absorbed and transmitted	dB	(Carmody et al., 2004)
User friendliness OR Ease of use	-	To be defined by follow-up research

The comfort and satisfaction assessment of façades, particularly intelligent façades, is challenging since there is a lack of holistic and transient metrics to identify occupant response. This is even more challenging considering the strong influence of occupant location on the perceptible effect of façades and the differences in the type of sensorial perception affected with distances from the façade. The data gathered from this framework could be used to identify the main triggers of occupant satisfaction with façades and, potentially, the thresholds of occupant dissatisfaction and discomfort. More importantly, the data from façade comfort properties and occupant response would allow to assess the human-centred performance of alternative intelligent façade technologies. This would also provide the platform to compared façades and understand which façade and control strategy is more appropriate in different contexts, space layouts and building typology.

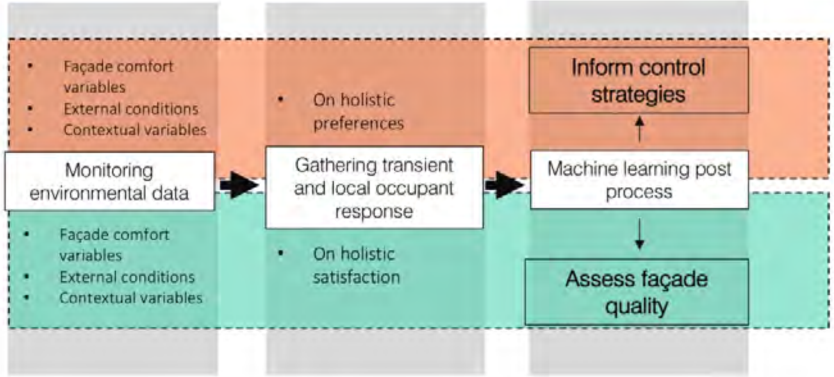

Figure 2 Diagram of the potential applications of the framework

Implementation of the new metrics in early design stage tools

A potential façade comfort scale is then proposed in Figure 3 to assess and measure the level of environmental personal comfort or, conversely, discomfort that a façade and its control strategy is associated with. Since façades need to be assessed transiently and locally, the scale in Figure 3 provides a holistic, local and transient assessment of occupant response for each category of holistic occupant satisfaction. Firstly, each category is assessed holistically considering the potential conflicts and inter-effects with other satisfaction categories, since occupants response is gathered experimentally and exposing them to the overall holistic effect of façades. Secondly, the scale indicates a value of occupant satisfaction regarding three different occupant positions with respect to the façades (1, 3 and 5 metres from the facade) in order to show the different effect of façades with distance on non-uniformity tendency. Lastly, façades are assessed according to 5 classes of occupant response and satisfaction. Each category is an indication of the percentage of time in a year when an occupant is satisfied with the dynamic performances of façades or, in other words, the proportion of time in which a façade has successfully interpreted occupant preferences and personal satisfaction criteria and has adapted with an appropriate frequency and velocity. This comfort assessment tool could average occupant response in time or weight a group of occupant responses according to specific design criteria or motivations (such as importance of task to be performed or health sensitivity). This draft comfort scale tool is highly dependent of the type of building, space layout and all the variables that affect environmental occupant responses, such as cultural and geographic context. Eventually, the scale has the potential to be implemented in an early-design stage tool to rank alternative façade technologies and inform early-design decision on façade physical components and control strategies.

CONCLUSIONS

This paper was conceived to frame the transient changes in façade properties, including frequency, level and velocity of change, to occupant holistic levels of comfort and satisfaction. The short-term experimental work will aim to validate the framework and provide quantitative data to inform the draft comfort scale and gain a better understanding of how to implement the transient and holistic effect of façades in early-design stage tools.

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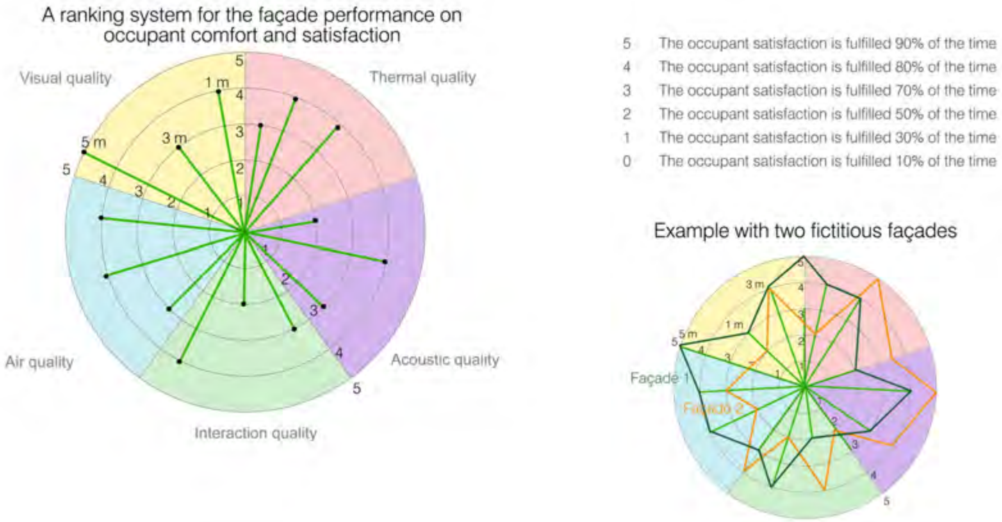

Figure 3 Draft structure of the comfort model tool

REFERENCES

Carmody, J., Selkowitz, S., Lee, E., Arasteh, D., & Willmert, T. (2004). *Window systems for high performance buildings* (First). New York: Norton.

Clements-Croome, D. (2013). *Intelligent buildings: An introduction*. *Intelligent Buildings: An Introduction* (Vol. 9780203737). http://doi.org/10.4324/9780203737712

Favoino, F., Jin, Q., & Overend, M. (2014). Towards an ideal adaptive glazed façade for office buildings. In *Energy Procedia* (Vol. 62, pp. 289–298). http://doi.org/10.1016/j.egypro.2014.12.390

Frontczak, M., & Wargocki, P. (2011). Literature survey on how different factors influence human comfort in indoor environments. *Building and Environment*, *46*(4), 922–937. http://doi.org/10.1016/j.buildenv.2010.10.021

Huizenga, C., Zhang, H., Mattelaer, P., Yu, T., Arens, E., & Lyons, P. (2006). *Window Performance for Human Thermal Comfort. Final report to the National Fenestration Rating Council*.

Humphreys, M. A. (2005). Quantifying occupant comfort: Are combined indices of the indoor environment practicable? *Building Research and Information*, *33*(4), 317–325. http://doi.org/10.1080/09613210500161950

IEA. (2017). World Energy Outlook 2017. *International Energy Agency*. http://doi.org/10.1016/0301-4215(73)90024-4

Ko, W. H., & Schiavon, S. (2017). Balancing Thermal and Luminous Autonomy in the Assessment of Building Performance. In *Proceedings of Building Simulation Conference 2017*.

Konstantzos, I., Chan, Y.-C., Seibold, J. C., Tzempelikos, A., Proctor, R. W., & Protzman, J. B. (2015). View clarity index: A new metric to evaluate clarity of view through window shades. *Building and Environment*, *90*, 206–214. http://doi.org/10.1016/j.buildenv.2015.04.005

Nabil, A., & Mardaljevic, J. (2006). Useful daylight illuminances: A replacement for daylight factors. *Energy and Buildings*, *38*(7), 905–913. http://doi.org/10.1016/j.enbuild.2006.03.013

Wienold, J., & Christoffersen, J. (2006). Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras. *Energy and Buildings*, *38*(7), 743–757. http://doi.org/10.1016/j.enbuild.2006.03.017