

Document Version

Final published version

Citation (APA)

Luna-Navarro, A., Welti, A., de la Barra, P., Martinez-Alcaraz, P., & Porta, M. (2025). Impact of Dynamic Façades on Smart Readiness Indicator and User Satisfaction. In U. Berardi (Ed.), *Multiphysics and Multiscale Building Physics : Proceedings of the 9th International Building Physics Conference IBPC 2024, Building Systems and HVAC Technologies* (pp. 471-478). (Lecture Notes in Civil Engineering; Vol. 554 LNCE). Springer. https://doi.org/10.1007/978-981-97-8313-7_65

Important note

To cite this publication, please use the final published version (if applicable).
Please check the document version above.

Copyright

In case the licence states "Dutch Copyright Act (Article 25fa)", this publication was made available Green Open Access via the TU Delft Institutional Repository pursuant to Dutch Copyright Act (Article 25fa, the Taverne amendment). This provision does not affect copyright ownership.
Unless copyright is transferred by contract or statute, it remains with the copyright holder.

Sharing and reuse

Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

Takedown policy

Please contact us and provide details if you believe this document breaches copyrights.
We will remove access to the work immediately and investigate your claim.

Green Open Access added to TU Delft Institutional Repository

'You share, we take care!' - Taverne project

<https://www.openaccess.nl/en/you-share-we-take-care>

Otherwise as indicated in the copyright section: the publisher is the copyright holder of this work and the author uses the Dutch legislation to make this work public.



Impact of Dynamic Façades on Smart Readiness Indicator and User Satisfaction

Alessandra Luna-Navarro¹ , Andrea Welti² , Pedro de la Barra¹ ,
Pablo Martinez-Alcaraz¹  , and Matteo Porta² 

¹ Architectural Engineering and Technology, Faculty of Architecture and the Built Environment, Delft University of Technology, Delft, The Netherlands
{a.lunanavarro,p.martinezalcaraz}@tudelft.nl
² RINA Consulting S.p.A., Genova, Italy

Abstract. The Smart Readiness Indicator (SRI), introduced by the European Union in 2018, assesses a building's capacity to accommodate smart-ready services. This evaluation focuses on optimizing energy efficiency, aligning operations with occupant needs, and responding to signals from the grid. Previous studies have evaluated SRI feasibility in various locations and retrofit scenarios, estimating the costs associated with implementing smart technologies in existing European buildings. However, the specific impact of digitizing distinct building services on SRI scores remains unexplored. Particularly, adaptive façade technologies show potential in enhancing overall building performance, being worthy to understand how these services influence the smart readiness rating of buildings. This study investigates the impact of adaptive façade technologies on SRI scores and user satisfaction. A case study of an office building in Delft (The Netherlands) was selected to assess the impact of smart technologies on energy efficiency and comfort. This paper shows preliminary results from the pre-intervention phase, where the SRI was calculated for both the baseline condition and a scenario with the highest possible level of smart services for the building envelope. The results from the SRI methodology showed an increase of approximately 4% in energy efficiency and 15% in terms of energy flexibility. In addition, the SRI predicts similar improvements in user convenience, information, health & well-being, but only 4% in user comfort. This was confirmed by the assessments on user perception and preferences. Users reported to be "slightly satisfied" with several comfort domains. Additionally, several users considered better control of external shadings very important, which was currently reported as very disruptive by users. This preliminary finding shows potential for smart services applied at the façade level to improve user satisfaction if aspects of interaction and convenience are adequately addressed. Post-intervention phase data is now required to confirm these preliminary findings.

Keywords: Smart Building · Smart Readiness Indicator · Adaptive Façade · Smart Façade · Occupant reference

1 Introduction

Smart building technologies, such as smart control of windows, lights or heating, can enable significant energy efficiency gains and reduce carbon emissions for approximately 350 Mt CO₂ by 2050 [1]. In addition, smart buildings can also drive and foster more energy-efficient occupant behavioural changes [1], which in turn can also leverage a reduction of almost 250 Mt CO₂ in 2030 [2]. This can be achieved for instance by adjusting cooling or heating indoor setpoints or reducing artificial lighting and hot water consumption. These potential benefits have been recently recognised by the European Union Directive with the establishment of the “Smart Readiness Indicator” [3]. The Smart Readiness Indicator (SRI) is a metric developed by the European Union to assess the capability of buildings to: (i) adapt to occupants’ needs, (ii) optimize energy efficiency, and (iii) integrate with smart energy grids. These three domains are assessed by considering the score of each one of the following seven impact criteria: (1) energy efficiency; (2) energy flexibility and storage; (3) user comfort; (4) user convenience; (5) health, well-being and accessibility; (6) maintenance and fault prediction; (7) information to occupants. Smart services are considered on the following nine areas, namely: heating, cooling, domestic hot water, ventilation, lighting, dynamic building envelope, electricity, electric vehicle charging, monitoring and control. It is currently not clear to what extent implementing smart services at the building envelope is crucial to achieve high scores in the smart readiness indicator and, more importantly, higher energy efficiency, user comfort and energy flexibility. The dynamic and automated control of smart facade technologies, such as glazing or shading in the building envelope, can leverage important energy savings. However, it has often been found to be disruptive to users [4, 5]. User acceptance of smart building technologies is often a barrier to widespread adoption of these systems [4]. Factors that drive this disruption are trust and privacy [5, 6], the mismatch between user requirements and automated control actions [7], lack of information and understanding of building control rationales [8] or poor interaction and interface design [9]; for instance, disruptive frequency and mode of actuation of the smart components [10], or insufficient perception of personal control of the environment. With the recent advent of artificial intelligence and cost-effective and pervasive sensing technologies, buildings will become increasingly smarter, but it is essential that the technological progress is mirrored by advances in human-building interaction [11]. Changes in façade behaviour (shading position or blind angle, glazing state or vent position) are very noticeable, and users tend to place significant importance on the personal control of the façade (e.g. windows, shadings, etc.) [4]. Smart shading devices are often disruptive because of the noise they generate in operation, while overall the speed, frequency and direction of movement can also have a detrimental impact on user acceptance or satisfaction [4]. For instance, Bakker et al. [10] showed that less frequent but discrete transitions in facade configurations produced higher user acceptance and satisfaction than smooth transitions at a higher frequency. This paper explores the impact of smart services implemented at the level of the building envelope on the impact score as calculated by the Smart Readiness Indicator and on user preferences and satisfaction by means of workshops, interviews and questionnaires.

2 Method

2.1 Case Study

The building of the TU Delft Faculty of Architecture was used as a case study for this study (as shown in Fig. 1). The building was built in 1918, and it is listed as a monument building. Therefore, no deep renovation of the building envelope is possible. The building is currently in energy class F. The case study relates to six open-space office environments located at the first and second floor on the south-east façade. The façade has a window to wall ratio of approximately 60% and external automated black roller blinds. The blinds are currently programmed to be lowered to reduce solar gains and glare when the sun is in the field of view. Users always have access to override by means of wall-mounted switches. The opening of the vents is only manually controlled, while there is mechanical ventilation to maintain healthy indoor air quality levels. The lighting systems is also automated by movement sensors and users can manually override the system by means of wall-mounted switches. Every user has also access to task lighting. The smart readiness of the building with the current existing smart services is approximately 22% by using the detailed calculation method “B” as for the Smart Readiness Methodology [12]. A higher smart readiness level reflects a “smarter” implementation of the service, which generally should increase the benefits for users, energy efficiency and grid. In the proposed method, the smart readiness score of a building or building unit is expressed as a percentage which represents the ratio between the smart readiness of the building compared to the maximum smart readiness that it could reach. In the context of the “Smarteestory” EU-funded research project, this building will be integrated with additional smart services that will tackle all the nine domains of the SRI. After these interventions, the SRI value is projected to be approximately 78%.



Fig. 1. Images from the case study: a. Interior view of the office; b. external view of the building façade; c. overview of the building site.

2.2 Smart Readiness Indicator Assessment

For this study, the smart readiness of the building was assessed by using the pre-calculated spreadsheet based on the multi-criteria assessment method defined in Commission Delegated Regulation (EU) 2020/2155 [12]. This spreadsheet provides weights to evaluate the influence of smart services on the seven different impact criteria considered by the SRI. The weights vary depending on the building typology, year of construction and climate.

For this study, the average weights provided in the spreadsheet were used. For the baseline scenario, the current level of smart services were considered. Then, to evaluate the impact of smart services associated to the building envelope, the following smart services related to the integrated control of lights, blinds and vents were considered, here reported with the corresponding code from the SRI methodology: (a) control for indoor lighting based on occupancy (L1); (b) control of artificial lighting power based on daylight levels (L2), (c) window solar shading control (DE-1); (d) window open/closed control combined with HVAC system (DE-2); (e) reporting information regarding performance of dynamic building envelope system (DE-4); (f) detecting faults of technical building systems and providing support to the diagnosis of these faults in relation to the building envelope control (MC-4); (g) occupancy detection: connected services (MC-9); (h) central reporting of TBS performance and energy use (MC-13); (i) reporting of information regarding demand side management performance and operation (MC-28); (l) override of DMS control (MC-29); (m) single platform that allows automated control & coordination between TBS + optimization of energy flow based on occupancy, weather, and grid signals (MC-30).

2.3 User Assessment

A workshop with end-users and facility managers was organized on the 16th of October in Delft. Follow-up interviews were also held consequently to the workshop to engage with the participants that were not present during the workshop. The participants of the workshops were all the users of the intervention area. Their participation in the workshops was requested by e-mail or face-to-face on both demo-sites. A total of 22 participated in the interview and workshop in Delft. All participants received an information consent sheet, where information about the project, workshop description and data privacy concerns were reported (attached in Appendix). Each participant was explicitly asked for consent to attend the workshop. In addition to the workshop and the interviews, users were also asked to fill in a questionnaire on their level of satisfaction with the indoor environmental quality, the building control and interaction strategies.

3 Results and Discussion

3.1 Influence on Smart Readiness Indicator

As shown in Fig. 2, by only adding to this case study only smart services related to the building envelope and the integrated control of lights, the SRI methodology predicts increases in impact scores in the range of 4–20%. No impact is considered on energy efficiency, while a small impact is calculated for energy flexibility (increasing of 13%). Similarly, only 4% increase in user comfort is predicted, while the largest impact on the users seems to be on related to convenience (15%), health & well-being (17%), and information (19%). The maintenance and fault prediction is the domain with largest improvement (20%).

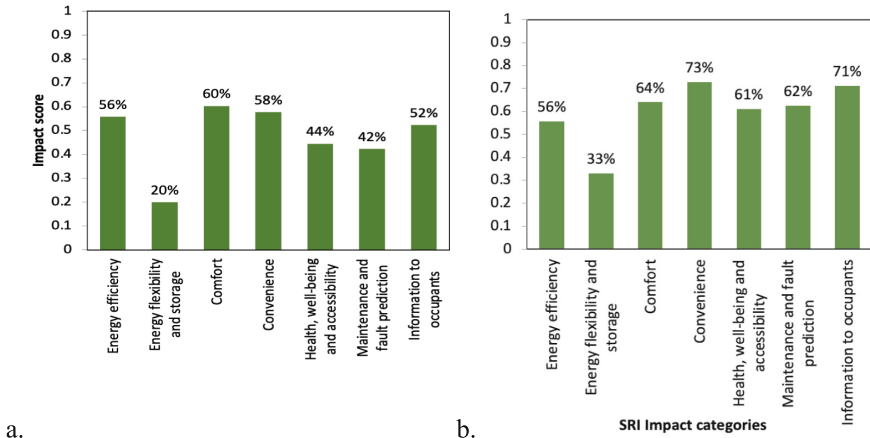


Fig. 2. Impact scores on the smart readiness indicator for: a) the baseline condition in Delft, b) condition with highest level of smart services applied at façade level.

3.2 User Satisfaction and Requirements with Adaptive Facades

As shown in Fig. 3, the users from the case study attributed large importance to the several indoor environmental aspects that are closely related to the building envelope. In particular, the importance of satisfaction with glare mitigation, satisfaction with daylight access, satisfaction with lights, satisfaction with personal control of shades, satisfaction with personal control of light and window vents. Privacy through the window was considered less important, while access to outdoor view was also considered important for users. This indicates that improvements in the control of the building envelope can noticeably affect users. Overall, in Fig. 4, it can be seen that users were slightly satisfied with the indoor environmental quality in the office space. The satisfaction with outdoor view access was the highest, while several users indicated that there is space for improving several aspects related to the building envelope, namely: daylight access, view clarity, glare mitigation and temperature. This figure shows that better controls of the building envelope could potentially also improve several aspects of users satisfaction with indoor environmental quality. During the workshop, several users reported being strongly dissatisfied with the current control of the blind system. The automated control of the blinds was perceived disruptive and not logical, since users could not understand the reasons behind the control strategy. This was claimed when users did not see a consistent behaviour between the control of the blinds and the observed weather conditions. In terms of view clarity, users reported the current blinds to be excessively dark, thereby considering the space to be either excessively bright when blinds were raised or excessively dark when blinds were lowered. The fact that lights could not be dimmed depending on the daylight levels indoor was also considered as a negative aspect. In addition, users were asked to rate several smart services in terms of their perceived level of necessity for the smart service and their perceived level of importance. As shown in Fig. 5, smart window vents were not considered either important or necessary by the

users, while smart lights were considered moderately important and necessary. Smart blinds were considered very important and necessary.

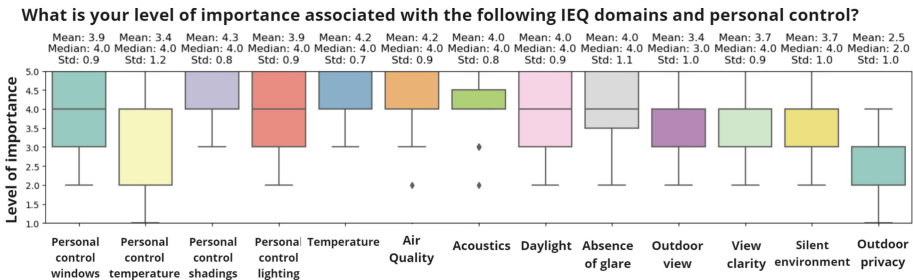


Fig. 3. Level of importance associated with the satisfaction with domains of indoor environmental quality and personal control, while being at the office space.

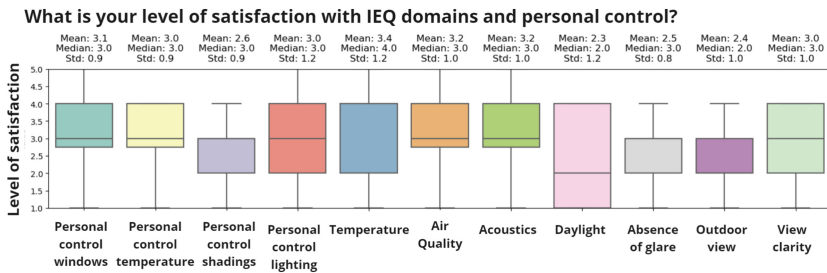


Fig. 4. Current level of user satisfaction with several domain of indoor environmental quality. The question was phrased as: “To what extent do you agree to this statement: “I feel satisfied with...”. The users could then express from 1 to 5 their level of agreement, as 1- strongly disagree, 2 – slightly disagree, 3 – neither agree or disagree; 4 – slightly agree and 5 - strongly agree.

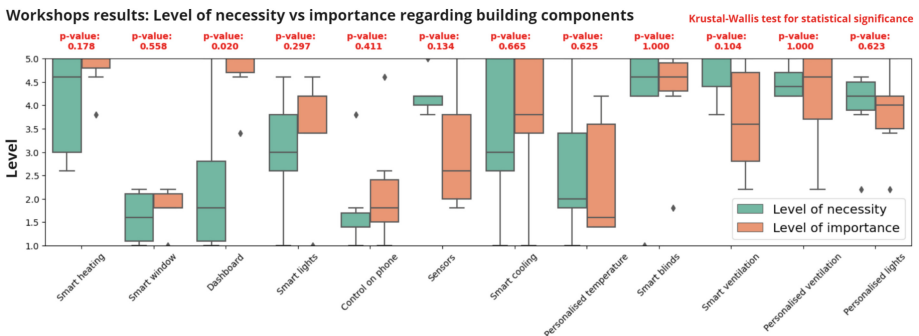


Fig. 5. Distribution of necessity and level of importance for each of smart building items asked for during the workshop activity in Delft demonstrator site.

4 Conclusion

This paper shows preliminary results on the impact of smart controls and technologies (here referred to as smart services) on energy efficiency and user satisfaction in an office building in The Netherlands. The aim of the work was to gain preliminary knowledge on the potential impact of smart services related to the building envelope on energy efficiency and user satisfaction according to the EU Smart Readiness Methodology. In addition, qualitative and quantitative user assessments were performed to investigate user perspectives on smart building envelopes. Applying smart controls in an integrated manner to building envelope and lighting seems promising especially for user satisfaction and energy flexibility according to the SRI methodology. However, this is highly dependent on the weights that are assigned to each smart service during the calculation of the SRI. Future work will be focusing on monitoring energy performance and user satisfaction after the implementation of the smart services to validate these preliminary findings.

Acknowledgments. This study has received funding from the European Union under the Horizon Europe Research & Innovation Programme (Grant Agreement no. 101103956 SMARTeeSTORY).

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

References

1. IEA: World Energy Outlook 2021, IEA (2021). <https://www.Iea.Org/Reports/World-Energy-Outlook-2021>
2. He, M.: Investigation on typical occupant behavior in air-conditioned office buildings for South China's Pearl River Delta. *Architectural Intell.* **1** (2022)
3. European Commission, Commission Implementing Regulation (EU) 2020/2156 of 14 October 2020 detailing the technical modalities for the effective implementation of an optional common Union scheme for rating the smart readiness of buildings
4. Luna-Navarro, A., Loonen, R., Juaristi, M., Monge-Barrio, A., Attia, S., Overend, M.: Occupant-facade interaction: a review and classification scheme. *Build. Environ.* **177**, 106880 (2020)
5. Tak, A.N., Becerik-Gerber, B., Soibelman, L., Lucas, G.: A framework for investigating the acceptance of smart home technologies: findings for residential smart HVAC systems. *Build. Environ.* **245**, 110935 (2023)
6. Balta-Ozkan, N., Davidson, R., Bicket, M., Whitmarsh, L.: Social barriers to the adoption of smart homes. *Energy Policy* (2013)
7. Nguyen, T.A., Aiello, M.: Energy intelligent buildings based on user activity: a survey. *Energy Build* (2013)
8. Meerbeek, B.W., de Bakker, C., de Kort, Y.A.W., van Loenen, E.J., Bergman, T.: Automated blinds with light feedback to increase occupant satisfaction and energy saving. *Build. Environ.* **103**, 70–85 (2016)
9. Day, J.K., et al.: A review of select human-building interfaces and their relationship to human behavior, energy use and occupant comfort. *Build. Environ.* **178**, 106920 (2020)

10. Bakker, L.G., Hoes-van Oeffelen, E.C.M., Loonen, R.C.G.M., Hensen, J.L.M.: User satisfaction and interaction with automated dynamic facades: a pilot study. *Build Environ.* **78**, 44–52 (2014)
11. Becerik-Gerber, B., et al.: The field of human building interaction for convergent research and innovation for intelligent built environments. *Sci. Rep.* (2022)
12. Commission Delegated Regulation (EU) 2020/2155 of 14 October 2020 supplementing Directive (EU) 2010/31/EU of the European Parliament and of the Council by establishing an optional common European Union scheme for rating the smart readiness of buildings C/2020/6930. <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32020R2155>