Title	A detailed investigation of the impact of an innovative dynamic façade system on indoor environmental quality in offices
Author(s)	Hajdukiewicz, Magdalena; Loomans, Marcel G.L.C.
Publication Date	2023-10-04
Publication Information	Hajdukiewicz, Magdalena, & Loomans, Marcel G.L.C. (2023). A detailed investigation of the impact of an innovative dynamic façade system on indoor environmental quality in offices. Paper presented at the 43rd AIVC Conference: Ventilation, IEQ and health in sustainable buildings, Aalborg University, Copenhagen, Denmark, 04-05 October.
Publisher	University of Galway
Link to publisher's version	https://doi.org/10.13025/z1sp-4481
Item record	http://hdl.handle.net/10379/18070
DOI	http://dx.doi.org/10.13025/z1sp-4481

A detailed investigation of the impact of an innovative dynamic façade system on indoor environmental quality in offices

Magdalena Hajdukiewicz [*1,2], Marcel G.L.C. Loomans[1]

[1] *Department of the Built Environment*
Eindhoven University of Technology
The Netherlands
**Corresponding author: m.hajdukiewicz@tue.nl*

[2] *Construct Innovate*
University of Galway
Ireland

ABSTRACT

In recent years, naturally ventilated glass façades have become a common feature in the design and retrofit of large-scale non-residential buildings, integrating architectural aesthetics and energy efficiency. These façade systems are complex and multifaceted. Thus, introducing them in buildings poses many challenges from economic, engineering, health and behavioural perspectives that can reduce optimal building performance. Building occupant behaviour and preferences are important contributors to the gap between the predicted and actual building energy performance. With people spending on average 90% of their lives indoors, the impact of indoor environmental quality (IEQ) on health, comfort, wellbeing and productivity of building occupants is vital. The use of engineering simulation, validated with data collected from operating buildings, can enable engineers, architects and facility managers to ensure optimal building design, efficient operation and improved IEQ.

This paper presents the results of a detailed investigation of the impact of an innovative adaptive façade system on IEQ in an office case study. This includes the impact of façade operation on the health, comfort and wellbeing of building occupants. The study focuses on the measurement campaign carried out in an operating office environment in the Atlas building at Eindhoven University of Technology (TU/e). This measurement campaign included physical measurements of thermal comfort and indoor air quality parameters and occupant surveys. The surveys aimed to capture the occupants' perception of the indoor environment and the effects of the dynamic façade operation on their comfort and wellbeing. The paper presents the research objectives, measurement protocol and results of the physical measurements and occupant surveys. In general, there was a good alignment between the surveyed and measured data. Furthermore, a high-resolution measurement network allowed for identification of locations where occupants' comfort may be compromised, such as beside the window where higher air temperatures occurred.

KEYWORDS

Indoor environmental quality; Thermal comfort; Air quality; Dynamic façade; Measurements; Surveys

1 INTRODUCTION

1.1 Overview

Airflow and heat transfer through naturally ventilated glass façades have a significant impact on the comfort of building occupants (La Ferla et al., 2020), which must be considered when designing and operating these systems. Optimisation and control of the façade systems is a complex problem with a multidisciplinary perspective (Bianco et al., 2018). Current approaches to designing and constructing façade systems focus on satisfying the requirements of building codes and standards in terms of structural integrity, energy efficiency and occupant-centric criteria; however, the design rarely results in optimal solutions in practice (Moghtadernejad et al., 2020). Occupant behaviour and preferences are usually not considered during the design and post-occupancy optimisation phases but are important contributors to building energy performance. It has been shown previously (Tabadkani et al., 2021) that manual controls for adaptive building systems can compromise their energy consumption, but lack of individual control could decrease the level of user satisfaction.

Please cite as:
Hajdukiewicz, M., Loomans, M.G.L.C. 2023. 'A detailed investigation of the impact of an innovative dynamic façade system on indoor environmental quality in offices.' *43rd AIVC Conference: Ventilation, IEQ and health in sustainable buildings.* 4-5 October 2023. Copenhagen, Denmark.

Adaptive building façades are façades that can interact with the environment, by reacting to its external parameters (weather and indoor environment) and building occupant behaviour, which includes ventilating for indoor air quality and comfort, insulating when required, or generating energy (Luible, 2018). As part of the previous research, Loonen et al. (2015) provided an overview of concepts and classification strategies for adaptive façades, such as dynamic exterior shading facades, glazing with phase change materials and BIPV double-skin facades. Alkhatib et al. (2021) reviewed four key aspects of current and emerging adaptive façade technologies, such as mechanisms and technologies for heat/mass transfer flows, daylight, electricity and heat generation; façade effectiveness and responsiveness; control algorithms and required sensor information. Furthermore, Attia et al. (2020) focused on future trends for adaptive façades, where occupant comfort and well-being emerged as the most important structural trend in adaptive façade technologies and solutions. This showed market demand for human-centric façade designs, which focus on healthy and comfortable working and living environments.

1.2 Research objectives

Previous research by the authors investigated the topics of indoor environmental quality (IEQ), e.g. (Boegheim et al., 2022; Zuhaib et al., 2018); the need for long-term performance monitoring, e.g. (Hajdukiewicz et al., 2015; Loomans et al., 2020); impact of IEQ on building occupants, e.g. (Brink et al., 2022); and the role of indoor climate control devices, e.g. (Boerstra, 2016). Following that expertise, this research focuses on a short-term, detailed investigation of a dynamic façade's operation and its impact on IEQ in offices and occupants' perception on the indoor environment.

The research presented here is part of the FaceINQ project (European Commission, 2023), which aims to develop new operational strategies and designs for innovative building façade systems that ensure IEQ appropriate to users, limit building related health risks and reduce energy consumption, by merging on-site measurements, qualitative user-feedback and pervasive simulation of indoor environments.

2 METHODOLOGY

2.1 Overview

The paper presents a detailed investigation of an office environment in the Atlas building at Eindhoven University of Technology (TU/e). The investigation included physical measurements of thermal comfort and indoor air quality (IAQ) parameters, and occupant surveys. The surveys aimed to capture the occupants' perception of the indoor environment and the effects of the dynamic façade operation on their comfort and wellbeing.

2.2 Atlas Living Laboratory

The research is demonstrated in the BREEAM certified (BRE, 2023) Atlas building at TU/e campus (Figure 1a). Atlas is a 'living laboratory' designed to allow new, project-specific applications to collect environmental data for academic research leading to industry innovation and reduced energy use. The 2019 retrofit of the building resulted in an 80% reduction in CO_2 emissions and transformed Atlas into the most sustainable educational building in the world (TU/e, 2019). An important aspect of the retrofit was an innovative adaptive glass façade system with parallel openable windows (Figure 1b). The façade was designed to insulate the building from excessive heat gains during the day, naturally ventilate indoor spaces at night with full horizontal opening and use natural ventilation for personal thermal or air quality purposes during daytime. However, while the building met energy efficiency targets, a further investigation of the impact of the façade operation on IEQ is needed, in order to verify and optimise future designs of novel adaptive façades (Hajdukiewicz & van Mierlo, 2023).

Please cite as:
Hajdukiewicz, M., Loomans, M.G.L.C. 2023. 'A detailed investigation of the impact of an innovative dynamic façade system on indoor environmental quality in offices.' *43rd AIVC Conference: Ventilation, IEQ and health in sustainable buildings.* 4-5 October 2023. Copenhagen, Denmark.

Thus, the objectives of the measurement campaign in the Atlas office room were to:

- Investigate IEQ parameters, including indoor thermal comfort and air quality (using CO_2 concentration as a proxy), and air temperature and velocity at window opening/ air supply in an office room throughout the day and night.
- Investigate the effect of window's operation on IEQ.
- Investigate the occupants' perception on the IEQ.
- Investigate the occupants' perception on window operation.
- Align the thermal comfort and air quality measurements with occupant surveys.

This paper focuses on the IEQ investigation in an East-facing office (plan dimensions of 5 m x 6.5 m, 2.6 m height) on the 9th floor of the building, occupied by two people between 14 – 21 April 2023. During the investigation, the occupants were asked to carry out their typical work, in this case mainly computer-based work. The office operated with a mixed mode ventilation, including a mechanical constant air volume (CAV=135 m^3/h) supply and natural ventilation through a parallel openable window (1 m x 2.5 m, horizontal opening gap of 125 mm).

Figure 1: a) Atlas building at TU/e, photo by Bart van Overbeeke, (TU/e, 2019).
b) Atlas façade design with parallel openable windows (Arch Daily, 2019).

2.3 Measurement protocol

Several physical sensors measured IEQ in the office between 14 – 21 April 2023, including four thermal comfort poles, five air quality poles, and air velocity/ temperature at window and air supply. All physical measurements were synchronised in time and taken at a minimum of 1-minute time step over a full week. Figure 2a shows the measurement setup in the office.

The thermal comfort poles (Figure 3a) measured (i) dry-bulb air temperature (NTC U-type thermistor) at 0.1 m, 1.1 m and 1.7 m height, (ii) globe temperature (black sphere with NTC U) at 0.9 m height, (iii) relative humidity (RH, Serie EE08) and air temperature (NTC U) at 0.9 m height, (iv) air velocity (SensoAnemo 51XX NSF transducer) at 0.1 m and 1.1 m height. The poles were distributed in the room in the proximity of the desks (Figure 2b) to capture the conditions affecting room occupants. Pole PMV D was located beside the seat of occupant 1 and pole PMV C – beside the seat of occupant 2.

The air quality poles (Figure 3b) measured air temperature, RH and CO_2 concentration (Vaisala HMP1 and GMP252) at 1.1 m and 1.7 m height and were regularly distributed around the perimeter of the room (Figure 2b) to capture changes in the IAQ throughout the measurement period. Six NTC thermistors and six ultrasonic anemometers (Gill WindSonic) were regularly distributed around the window opening to capture parameters of the airflow through the window gap (Figure 3c). One NTC thermistor and one air velocity (SS20.250) sensor were installed at the mechanical air supply (Figure 3d). The accuracy of sensors is shown in Table 2.1. Outdoor

Please cite as:
Hajdukiewicz, M., Loomans, M.G.L.C. 2023. 'A detailed investigation of the impact of an innovative dynamic façade system on indoor environmental quality in offices.' *43rd AIVC Conference: Ventilation, IEQ and health in sustainable buildings.* 4-5 October 2023. Copenhagen, Denmark.

weather conditions, measured by the weather station located on the roof of the Atlas building, included air temperature, wind speed and direction and solar irradiance.

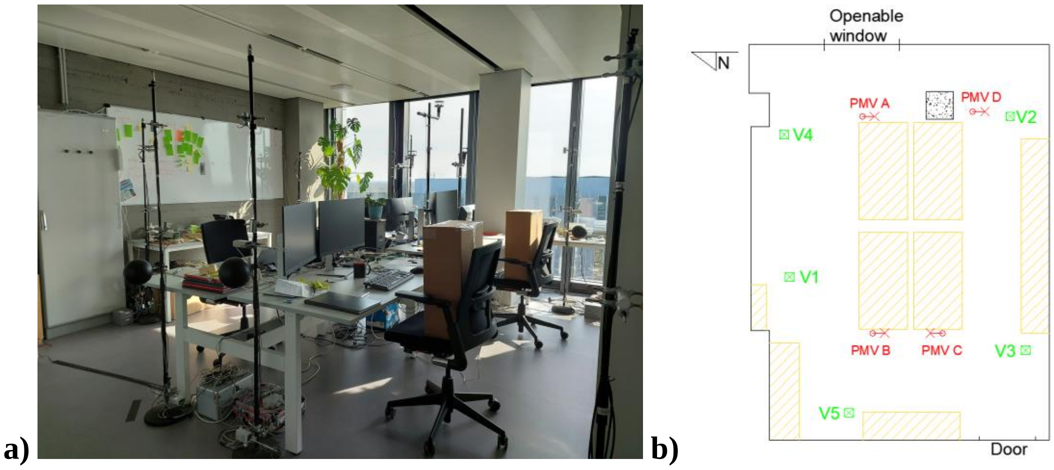

Figure 2: a) The investigated office room with the measurement equipment.
b) Location of thermal comfort (PMV, red) and air quality (V, green) poles.

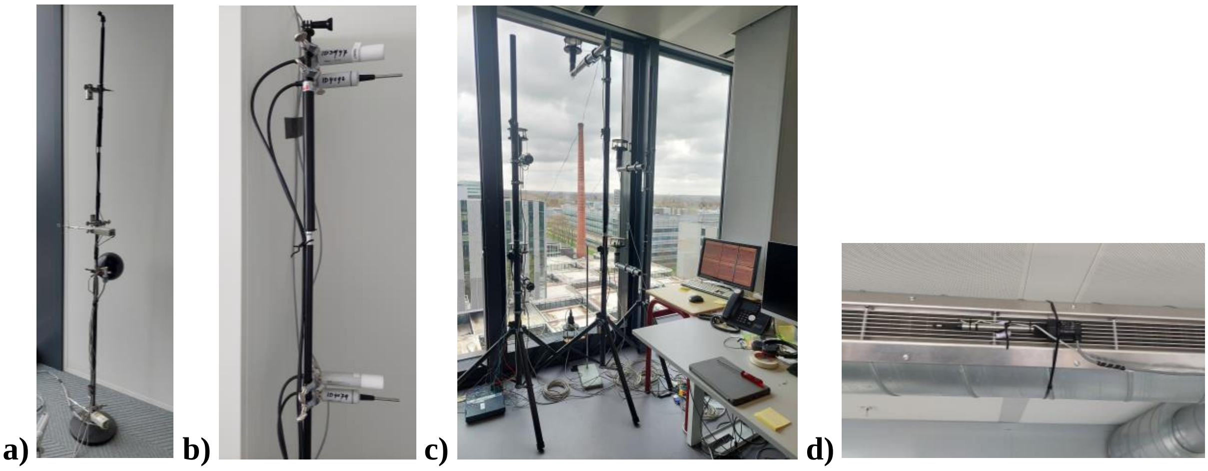

Figure 3: Measurement equipment: a) thermal comfort pole, b) air quality pole, c) window sensors and d) air supply sensors.

Table 2.1: Type and accuracy of sensors used for indoor measurements.

Sensor	Accuracy
NTC U-type thermistor	±0.05 °C (0-50 °C)
Serie EE08	±2.0 %RH (0-90%, at 23 °C)
SensoAnemo 51XX NSF transducer	0.02 m/s ± 1.5% of readings (in range 0.05 - 5 m/s)
Vaisala HMP1	±0.2 °C (at 23 °C)
	±1.0 %RH (0-90%, at 23 °C)
Vaisala GMP252	±40 ppmCO2 (at 25 °C and 1013 hPa)
Gill WindSonic	±2% (measured at 12 m/s, range 0-60 m/s, resolution 0.01 m/s)
SS20.250	± 5% of measured value + (0.4 % of final value; min. range 0.02 m/s)

2.4 Occupant surveys

The online occupant surveys were completed by two office occupants twice daily (morning at ~11am and afternoon at ~ 3pm) over six days (between 14 – 21 April 2023). The surveys included questions on occupants’ perceived comfort, IAQ and health symptoms. The goal was

Please cite as:
Hajdukiewicz, M., Loomans, M.G.L.C. 2023. ‘A detailed investigation of the impact of an innovative dynamic façade system on indoor environmental quality in offices.’ *43rd AIVC Conference: Ventilation, IEQ and health in sustainable buildings.* 4-5 October 2023. Copenhagen, Denmark.

to understand how (local) IEQ conditions are perceived when changes occur (e.g. due to window opening) and quantify those conditions through measurements.

3 RESULTS

3.1 Physical measurements

In order to analyse the indoor environmental conditions during a typical working day (occupants controlling window opening), this section presents results of the measurements taken during the working hours (9am – 6pm) of 21st April 2023. The mean outdoor air temperature during the period monitored was 13.3°C. The air supplied to the room via a mechanical system (CAV) was at a mean temperature of 21°C and velocity of 1.2 m/s (measured at the air supply grill). The building management system (BMS) setpoint for air temperature was 22°C.

Figure 4 shows the distribution of indoor air temperatures measured by the thermal comfort poles (PMV). The data clearly shows the highest variability in air temperatures measured by the pole PMV A, located closest to the window opening; followed by pole PMV D, also beside the window (Table 3.1). Those two poles indicated the highest globe temperatures in the morning, as influenced by the solar irradiance (window facing East). Air temperatures measured by the poles closer to the door (PMV B & C) showed a very similar and less variable (than PMV A & D) pattern. The maximum vertical temperature difference between head and ankles at locations of PMV B, C & D over the period monitored was 1.1°C, 0.7°C and 1.7°C, respectively; thus, less than 2°C, which was not the cause for local discomfort (ISO, 2005). At location PMV A, at 10% of the time (between 9-6pm), the vertical temperature difference between head and ankle level was between 2°C and 3.3°C. Those higher temperature differences occurred when the window was open and were caused by the cool outside air entering the warm room at the floor level. This might have caused local discomfort if an occupant was located near the open window.

According to (ISSO, 2014), the normal level of thermal comfort expectation (class B – max 10% predicted percentage of dissatisfied (PPD)) during intermediary seasons requires indoor operative temperature between 20.0°C - 24.0°C (based on calculated running mean outdoor temperature of 9.8°C, as per weather data). The operative temperature in the room during the period monitored (mean at all PMV poles locations, calculated according to (ISO, 1998)) was 23.0°C, which aligns with the thermal comfort expectation outlined in ISSO, the Dutch Building Services Research Institute (ISSO, 2014).

The mean RH measured by the thermal comfort and air quality poles was 37% and 32%, respectively. The mean CO_2 concentration measured in the room was 448 ppm.

Table 3.2 shows the mean air velocities measured at the ankle and sitting person's head level and their associated turbulence intensities ($Tu = u_n'/u_n * 100\%$) and draught rates (DR). As expected, the highest air velocities (Tu and DR) were recorded beside the open window (PMV A), where also the data had the largest spread. According to (ISO, 2005), the turbulence intensity may vary between 30 - 60 % in spaces with mixed-flow air distribution, which is seen from the periods of open window. When the window was closed, the turbulence intensities were lower, except the first period (9-10.35am) at PMV B & C, which may correspond to occupants activity in the centre of the room. At locations of PMV B, C & D, the majority of draught rates were below 10%, which is equivalent to 6% PPD. AT PMV A, the draught rates were significantly higher, particularly at the ankle level when the window was open (DR of 24% in the morning and 50% in the afternoon), which might have caused discomfort if an occupant was located there.

Figure 4: Indoor air temperatures measured by the thermal comfort poles (PMV); shaded orange area indicates the time of the window being open.

Table 3.1: Mean and standard deviation of indoor air temperatures (in °C) measured between 9am-6pm on 21 April 2023.

		Tair_0.1m	**Tair_0.9m**	**Tglobe_0.9m**	**Tair_1.1m**	**Tair_1.7m**
PMV A	**MEAN**	22.23	23.15	23.60	23.21	23.28
	ST DEV	1.59	1.09	1.38	1.11	0.92
PMV B	**MEAN**	22.18	22.50	22.58	22.68	22.79
	ST DEV	0.74	0.61	0.54	0.63	0.56
PMV C	**MEAN**	22.30	22.93	22.67	22.59	22.73
	ST DEV	0.59	0.59	0.52	0.60	0.54
PMV D	**MEAN**	22.79	23.44	23.89	23.25	23.26
	ST DEV	0.72	0.77	1.41	0.89	0.83

Table 3.2: Mean indoor air velocities (in m/s) measured between 9am - 6pm on 21 April 2023 and associated turbulence intensities (Tu in %) and draught rates (DR in %).

		PMV A		**PMV B**		**PMV C**		**PMV D**	
		V_0.1m	**V_1.1m**	**V_0.1m**	**V_1.1m**	**V_0.1m**	**V_1.1m**	**V_0.1m**	**V_1.1m**
Window closed (9:00-10:35)	MEAN	0.07	0.15	0.08	0.08	0.09	0.08	0.08	0.08
	Tu	16	34	56	38	60	37	28	23
	DR	3	13	6	6	8	6	5	4
Window open (10:36-12:00)	MEAN	0.17	0.16	0.09	0.09	0.08	0.08	0.11	0.10
	Tu	74	41	56	36	32	27	31	28
	DR	24	15	8	7	5	5	9	7
Window closed (12:01-1:19)	MEAN	0.10	0.10	0.06	0.09	0.08	0.07	0.10	0.08
	Tu	21	40	18	22	24	21	23	26
	DR	7	8	3	6	5	4	7	4
Window open (1:20-6:00)	MEAN	0.30	0.20	0.14	0.09	0.08	0.08	0.09	0.09
	Tu	64	34	59	29	32	43	33	28
	DR	50	19	16	6	5	6	6	6

**the measurement range was 0.05-5 m/s, thus values <0.05 m/s were assumed as =0.05 m/s*

Please cite as:
Hajdukiewicz, M., Loomans, M.G.L.C. 2023. 'A detailed investigation of the impact of an innovative dynamic façade system on indoor environmental quality in offices.' *43rd AIVC Conference: Ventilation, IEQ and health in sustainable buildings.* 4-5 October 2023. Copenhagen, Denmark.

3.2 Occupant surveys

The physical measurements were broadly represented by the survey responses of two office occupants. Both surveys were taken while the window was open (Figure 4). In general, the occupants felt comfortable throughout the day and stated that they preferred the window being open. The occupants reported they did not feel any local discomfort, including thermal or draught sensation. However, as reported in the morning, the occupant 1 (located beside PMV D) felt slightly warm. This might have been due to the high air temperatures recorded at this location (mean value measured at ankle and head level of 24.6^{o}C), including high radiant temperature (28.5^{o}C), and relatively low air velocities of 0.1 m/s (mean at ankle and head level). In the afternoon, with decreased air temperatures (mean air temperature measured at ankle and head level of 22.2^{o}C, and radiant temperature of 23.1^{o}C), the occupant 1 felt neutral. Occupant 1 felt 'neither sleepy nor alert' in the morning and very alert in the afternoon.

Occupant 2 (located beside PMV C) also felt slightly warm in the morning (mean measured air temperature of 23.2^{o}C and air velocity of 0.05 m/s at ankle and head level) and neutral in the afternoon (mean measured air temperature of 22.2^{o}C and air velocity of 0.05 m/s at ankle and head level). After feeling alert in the morning, occupant 2 had some signs of sleepiness in the afternoon. Occupant 2 was satisfied with the quality of indoor air, and reported fresh air, well-ventilated room, with pleasant smell throughout the day. While occupant 1, in the morning 'slightly agreed' and in the afternoon 'agreed' that the indoor air was fresh, not stale and the room was properly ventilated.

Table 3.3 compares the surveyed and measured (and calculated based on (ISO, 2005)) predicted mean vote (PMV) values for both occupants. The authors acknowledge that the PMV is an index that predicts the mean value of the votes of a large group of persons and in such complex environments using PMV as an assessment may not be useful. However, here it is only used as an example in this specific case of an office. Table 3.3 shows a good alignment between the surveyed and measured/calculated data in the afternoon for both occupants and for occupant 1 in the morning. However, there is a small discrepancy in the data for occupant 2 in the morning, where surveyed response was 'slightly warm' environment and measured – rather neutral. This discrepancy might have been due to the activity of the occupant prior to taking the survey, which might have increased the occupant's metabolic rate. Furthermore, for those investigated conditions when the window was open the measured/calculated PMV values were underestimated (on the cooler side) when compared to the surveyed values. This may result in less optimal thermal comfort conditions in reality, but still appreciated by the occupants.

The survey data for days when occupants did not have control over opening and closing the window (17 – 20 April 2023) showed that only on two occasions (2 out of 8 survey responses) the occupants felt neutral. Only half of the time the occupants felt comfortable (2 survey responses when the window was open and 2 responses when closed), with other perceptions reported as slightly uncomfortable (2 responses when the window was closed and 1 when it was open) and uncomfortable (1 response when the window was open). Further analysis is required to analyse the measured data for those dates and to understand how (local) IEQ conditions are perceived when changes occur. However, this is not the scope of this paper.

Table 3.3: Surveyed and measured PMV values.

	Occupant 1		**Occupant 2**	
	Survey	**Measured** (ISO, 2005)	**Survey**	**Measured** (ISO, 2005)
Morning survey	1	0.7	1	-0.1
Afternoon survey	0	-0.3	0	-0.4

Please cite as:
Hajdukiewicz, M., Loomans, M.G.L.C. 2023. 'A detailed investigation of the impact of an innovative dynamic façade system on indoor environmental quality in offices.' *43rd AIVC Conference: Ventilation, IEQ and health in sustainable buildings.* 4-5 October 2023. Copenhagen, Denmark.

4 CONCLUSIONS

This paper presents the research objectives, measurement protocol and the initial results of the IEQ investigation in an office room. This case study, focusing on one day results, will be replicated to analyse more extreme conditions in IEQ when the occupants are not controlling the window opening. This will allow for a point-in-time characterisation of Atlas adaptive façade operation and its impact on the occupants' perception and their comfort and wellbeing.

Furthermore, the measured parameters will provide boundary conditions and validation data to develop reliable computational fluid dynamics (CFD) models that capture the airflow and heat transfer through this novel façade system. This will be done to investigate whether the indoor environmental conditions support thermal comfort and air quality for building occupants, and to optimise future designs of novel adaptive façade systems. Previous studies utilised measurements and CFD simulations to investigate the performance of the Atlas' façade system (Hetebrij, 2021; Verbruggen, 2019). Thus, the FaceINQ project builds on those research findings.

5 ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support of the European Commission Horizon MSCA 2021 FaceINQ project (101066362). The authors would like to thank the technical staff in the Department of the Built Environment at Eindhoven University of Technology for their support in carrying out the experiments, as well as the occupants of the Atlas Living Lab for their participation in this research.

6 REFERENCES

Alkhatib, H., Lemarchand, P., Norton, B., & O'Sullivan, D. T. J. (2021). Deployment and control of adaptive building facades for energy generation, thermal insulation, ventilation and daylighting: A review. *Applied Thermal Engineering*, *185*, 116331. https://doi.org/10.1016/j.applthermaleng.2020.116331

Arch Daily. (2019). *Atlas - Eindhoven University of Technology / Team V Architecture*. https://www.archdaily.com/914644/Atlas-Eindhoven-University-of-Technology-the-Netherlands-Team-v-Architecture?Ad_medium=gallery.

Attia, S., Lioure, R., & Declaude, Q. (2020). Future trends and main concepts of adaptive facade systems. *Energy Science & Engineering*, *8*(9), 3255–3272. https://doi.org/10.1002/ese3.725

Bianco, L., Cascone, Y., Avesani, S., Vullo, P., Bejat, T., Koenders, S., Loonen, R. C., Goia, F., Serra, V., & Favoino, F. (2018). Towards New Metrics for the Characterisation of the Dynamic Performance of Adaptive Façade Systems. *Journal of Facade Design and Engineering*, *6*(3), 175–196.

Boegheim, B., Appel-Meulenbroek, R., Yang, D., & Loomans, M. (2022). Indoor environmental quality (IEQ) in the home workplace in relation to mental well-being. *Facilities*, *40*(15/16), 125–140. https://doi.org/10.1108/F-05-2022-0070

Boerstra, A. C. (2016). *Personal control over indoor climate in offices: impact on comfort, health and productivity.* [PhD]. Eindhoven University of Technology (TU/e).

BRE. (2023). *BREEAM*. https://www.breeam.com/ .

Brink, H. W., Loomans, M. G. L. C., Mobach, M. P., & Kort, H. S. M. (2022). A systematic approach to quantify the influence of indoor environmental parameters on students' perceptions, responses, and short-term academic performance. *Indoor Air*, *32*(10). https://doi.org/10.1111/ina.13116

European Commission. (2023). *Innovative dynamic Façade systems for INdoor environmental Quality*. https://cordis.europa.eu/Project/Id/101066362.

Hajdukiewicz, M., Byrne, D., Keane, M. M., & Goggins, J. (2015). Real-time monitoring framework to investigate the environmental and structural building performance. *Building and Environment*, *86*, 1–16. https://doi.org/10.1016/j.buildenv.2014.12.012

Hajdukiewicz, M., & van Mierlo, P. (2023). Discussion on the design of the façade system in the Atlas building. In *Private conversation*.

Hetebrij, R. F. (2021). *CFD analysis of the night cooling capabilities of parallel openable windows including assessment of CFD modeling methodology: case study TU/e building “Atlas”* [Master]. Eindhoven University of Technology (TU/e).

ISO. (1998). *Ergonomics of the thermal environment — Instruments for measuring physical quantities* (ISO 7726:1998).

ISO. (2005). *Ergonomics of the thermal environment — Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria* (ISO 7730:2005).

ISSO. (2014). *ISSO publicatie 74. Thermische behaaglijkheid [ISSO Publication 74. Thermal Comfort]*.

La Ferla, G., Acha Román, C. A., & Roset Calzada, J. (2020). Radiant glass façade technology: Thermal and comfort performance based on experimental monitoring of outdoor test cells. *Building and Environment*, *182*, 107075. https://doi.org/10.1016/j.buildenv.2020.107075

Loomans, M. G. L. C., Mishra, A. K., & Kooi, L. (2020). Long-term monitoring for indoor climate assessment – The association between objective and subjective data. *Building and Environment*, *179*, 106978. https://doi.org/10.1016/j.buildenv.2020.106978

Loonen, R. C. G. M., Rico-Martinez, J. M., Favoino, F., Brzezicki, M., Menezo, C., La Ferla, G., & Aelenei, L. (2015). Design for façade adaptability: Towards a unified and systematic characterization. *10th Conference on Advanced Building Skins*, 1284–1294.

Luible, A. (2018). Editorial. Special Issue FAÇADE 2018 – Adaptive! *Journal of Facade Design and Engineering*, *6*(3).

Moghtadernejad, S., Chouinard, L. E., & Mirza, M. S. (2020). Design strategies using multi-criteria decision-making tools to enhance the performance of building façades. *Journal of Building Engineering*, *30*, 101274. https://doi.org/10.1016/j.jobe.2020.101274

Tabadkani, A., Roetzel, A., Li, H. X., & Tsangrassoulis, A. (2021). A review of occupant-centric control strategies for adaptive facades. *Automation in Construction*, *122*, 103464. https://doi.org/10.1016/j.autcon.2020.103464

TU/e. (2019, April 16). *BREEAM hails Atlas the world’s most sustainable education building*. https://www.tue.nl/En/News/News-Overview/15-04-2019-Breeam-Hails-Atlas-the-Worlds-Most-Sustainable-Education-Building.

Verbruggen, M. (2019). *Design of a smart ventilation control strategy for Atlas* [EngD]. Eindhoven University of Technology (TU/e).

Zuhaib, S., Manton, R., Griffin, C., Hajdukiewicz, M., Keane, M. M., & Goggins, J. (2018). An Indoor Environmental Quality (IEQ) assessment of a partially-retrofitted university building. *Building and Environment*, *139*. https://doi.org/10.1016/j.buildenv.2018.05.001

Please cite as:
Hajdukiewicz, M., Loomans, M.G.L.C. 2023. ‘A detailed investigation of the impact of an innovative dynamic façade system on indoor environmental quality in offices.’ *43rd AIVC Conference: Ventilation, IEQ and health in sustainable buildings.* 4-5 October 2023. Copenhagen, Denmark.