Facade Leasing Demonstrator Project. Technical Delivery Report
Annex 4.2.6. FLD D2

Azcarate Aguerre, Juan; Klein, Tillmann; den Heijer, Alexandra

Publication date
2019

Document Version
Final published version

Citation (APA)
Azcarate Aguerre, J., Klein, T., & den Heijer, A. (2019). *Facade Leasing Demonstrator Project. Technical Delivery Report: Annex 4.2.6. FLD D2*. Delft University of Technology.

Climate-KIC is supported by the EIT, a body of the European Union

Facade Leasing Demonstrator Project

4.2.6.FLD D2. Technical Delivery Report

Arch.Ir. Juan F. Azcárate-Aguerre | Prof.Dr.-Ing. Tillmann Klein
Department of Architectural Engineering + Technology

Prof.Dr.Ir. Alexandra den Heijer
Department of Management in the Built Environment

Faculty of Architecture and the Built Environment |

Facade Leasing Demonstrator Project Technical Delivery Report

Annex 4.2.6. FLD D2

December, 2018

Authors:
Arch.Ir. Juan F. Azcárate-Aguerre
TU Delft Faculty of Architecture and the Built Environment
Department of Architectural Engineering + Technology
Julianalaan 134, 2628BL Delft, Netherlands
j.f.azcarateaguerre@tudelft.nl

Prof.Dr.-Ing. Tillmann Klein
Department of Architectural Engineering + Technology
Chair Building Products Innovation
t.klein@tudelft.nl

Prof.Dr.Ir. Alexandra den Heijer
Department of Management in the Built Environment
Chair Public Real Estate
a.c.denheijer@tudelft.nl

Project partners:

Co-funder:

Climate-KIC

Climate-KIC is supported by the EIT, a body of the European Union

Scientific partners:

TU Delft

TUM

University of Exeter | Business School

ibr instituut voor bouwrecht

Industry partners:

Alkondor Hengelo

ABN·AMRO Lease

Het Opdrachtgevers Forum in de Bouw

VMRG Vereniging Metalen Ramen en Gevelbranche

officevitae

0. Executive Summary

Accelerating deep building energy retrofits within the Circular Economy transition.

This technical report is an annex to the Facade Leasing Demonstrator Project 2018 performance report (4.2.6.FLD.D1). For general information on the Facade Leasing research project, its process, and objectives please refer to the aforementioned document.

This technical delivery report focuses on the design, engineering, construction, and monitoring process towards the energy retrofit of the East facade of the building of the Civil Engineering and Geo-sciences faculty at TU Delft (CiTG in Dutch). After building an initial prototype in November 2018, on one of the building's typical office spaces, plans are to continue with the full retrofit of the East facade of the building throughout 2019.

The CiTG case is representative of a massive volume of buildings across Europe - over 50% according to some estimates - which have been built during the post-second world war period, and which are currently reaching the end of their original service life. Such buildings need urgent technical intervention in order to improve their energy, safety, and indoor comfort performance. Such interventions, however, must be realized in line with Circular Economy principles, as they demand the strategic investment of immense amount of resources: material, financial, and human. Resources which we cannot afford to keep using under a linear mentality of take - make - dispose.


Civil Engineering and Geoscienc
Building
23
Civil Engineering and Geosciences
AIN ENTR

The building of the faculty of Civil Engineering and Geo-sciences (CiTG in Dutch) at the TU Delft campus. Delft, The Netherlands.

Photo: Juan Azcarate-Aguerre, 2018

The building of the faculty of Civil Engineering and Geo-sciences (CiTG on Dutch) at the campus of the Delft University of Technology was selected in late 2017 as the possible target of the Facade Leasing Demonstrator Project (FLDP). Built in the late 1960's by the famous Dutch architecture firm Broek Bakema, the building is representative of the brutalist period, which large portions of the building's envelope and exposed structure consisting of massive concrete elements.

In accordance with the technical practices of its time (before the 1970's energy crisis) the building's facade consists of uninsulated steel frames with single glazing and manually operable windows. Solar shading is only present internally, and only in certain areas. This combination results in a poor thermal performance of the building - which becomes too hot in the summer (over 30 overheating days per year) and requires considerable energy investment to keep heated during the winter - and a corresponding negative effect on the indoor comfort and user satisfaction of the faculty's employees.

In 2017 the decision was made by TU Delft's Campus Real Estate (TUD CRE) group and the University's board of director's (CvB in Dutch) to continue the operation of the CiTG building for another 10 years. This mid-term strategic horizon meant that some technical intervention would have to be done on the facade to avoid it's further deterioration, such as repainting of the steel framing and minor repair of window sealing. However, no major technical retrofit could be planned, as such an investment would require an exploitation period beyond 10 years in order to be justifiable.

These circumstances represented an ideal scenario for the development of a "Facade Leasing" retrofitting alternative. The research team and project consortium proposed to analyze the case before starting work on the East facade (as the West facade maintenance work was already in process). The project team would compare the expected cost and value offered by a full state-of-the-art technical retrofit, contracted through a long-term service-inclusive agreement, against that of the planned minor maintenance.

Beyond the simple initial investment cost of a new facade versus a minimum maintenance operation, the analysis had to include long-term operation costs for each alternative, including (missed) energy savings and deferred maintenance costs which would have to be born at some point in the future. It also had to the take into account the value of an improved indoor comfort for over 300 employees working behind the approximately 2.600m^2 of facade targeted by the intervention decision.

The following pages show the engineering and planning process for a cost-effective facade renovation package. One that would improve the technical quality of the building and lead to considerable energy savings without requiring the use of highly specialized (and high-cost) systems. The engineering process took into account an energy performance and indoor comfort analysis, a technical retrofitting process study leading to an initial prototype, and a financial and business case study (further described in annex *4.2.6 FLD D3. Business delivery report*).

2. Energy and indoor climate engineering

The first step towards proposing a deep energy renovation solution for the CiTG building was to understand its current performance through the use of climatic simulation software. The chair of Building Technology and Climate Responsive Design at TU Munich's Faculty of Architecture was responsible for creating this simulation model and experimenting with a number of technical variables such as energy performance of base facade elements (framing and glazing), presence and operation of solar shading, and presence and operation of night-cooling ventilation.

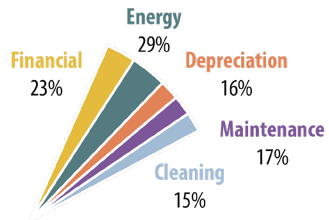
Corresponding to data gathered from user interviews, the model showed over 300 over Kelvin hours per year in the existing situation. Since most of these occur during office hours this translates into more than 30 days per year during which the building's temperature is above that which would be allowed by current indoor comfort regulations.

Improvement of the thermal performance of the base facade elements and use of internal solar shading would normally be a standard response to a building's thermal performance problems. Insulation of the building envelope does indeed reduce energy consumption by vastly reducing the demand for active heating during the winter. However, as shown by variants 1 through 3, over Kelvin hours in scenarios where only glazing and framing are improved actually worsen compared to the benchmark, with indoor shading doing little to solve the problem. The reason for this is that the current facade, after 50 years of operation, has considerable air leakage due to natural deterioration of the facade elements. While this would normally be undesirable, in this case it contributes to lowering the temperature of the building during the summer by providing an uncontrolled form of night-cooling.

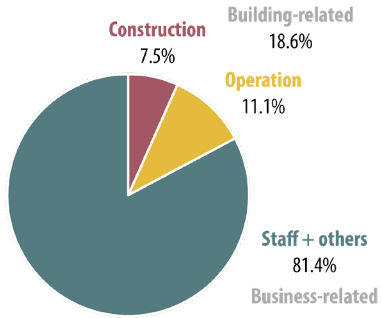
Variables 4 and 5 show the impact of applying either external solar shading or centrally controlled night ventilation, with neither one of these solutions fully solving the over-heating problem. Variant 6 applies both solutions in combination, and achieves the elimination of over-heating hours.

This study shows the importance of taking into account not only energy savings (as variants 1 through 3 provided a reduction of almost 80% in primary energy use) but also indoor comfort and occupant satisfaction. While it is hard to scientifically measure the drop in staff productivity resultant from an inadequate indoor comfort, the high relative cost of staff to a business or organization points towards a much higher monetary value for improving staff comfort and productivity than from simple and direct energy savings (figures on the right).

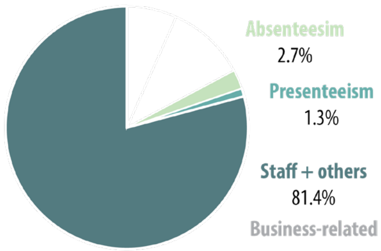
The building envelope's performance is therefore expected to decrease from a current benchmark of 214,3 kWh/m^2 to a post-renovation consumption of 45,6 kWh/m^2. The effects of this from a greenhouse gas emissions and global warming potential mitigation perspective is broken down in section 4 of this report.



Typical building operating cost breakdown over 30 years (as below).



Typical building-related costs in relation to overall business expenses over 30-years (de Jong, P. and M. Arkesteijn (2014). "Life cycle costs of Dutch school buildings." Journal of Corporate Real Estate 16(3): 220-234).

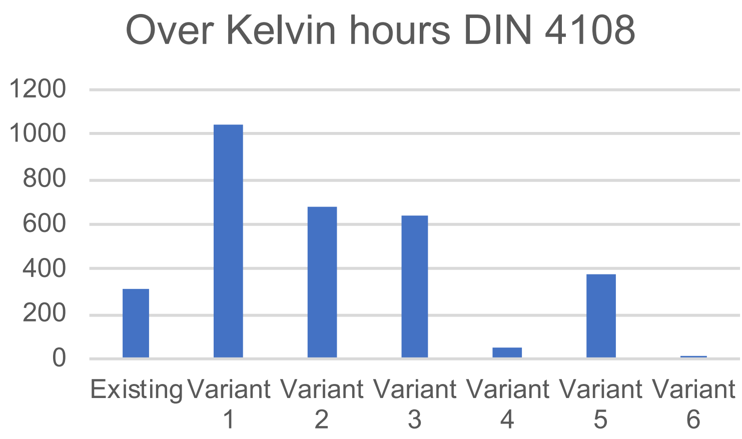


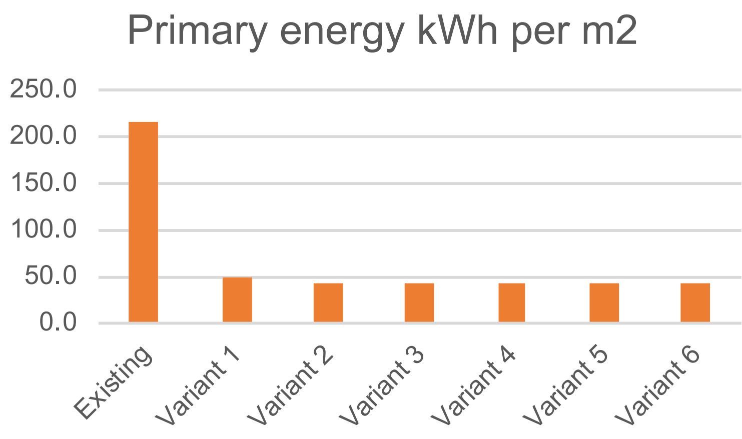
Suggested impact of poor indoor comfort on staff health and productivity (Terrapin Bright Green (2012). "The economics of Biophilia." Why designing with nature in mind makes financial sense. New York (NY): Terrapin Bright Green).

Comparative breakdown of current situation and six technical variables. While all retrofitting variables offer a significant and similar improvement in terms of primary energy consumption (with almost 80% energy savings against the benchmark) only variant 6 virtually eliminates over-heating hours during the summer.

Base case model:
East orientation
3.6 m x 5 m x 4.2 m (L x W x H)
0.75 m overhang
Window: 3.4 m x 2.46 m
2 users – DIN EN 13779
2 laptop
2 x Lighting
Ideal heating
Set point 23°C
Max power 500 W
Natural ventilation
Top > 23°C air change rate 1,5
Top > 25°C air change rate 3
Top > 27°C air change rate 6
No air conditioning

Scenarios:
Existing. Single glazing, steel frames
Variant 1. Double glass
Variant 2. Triple glass
Variant 3. Triple glass, internal blinds
Variant 4. Triple glass, external sun-shades
Variant 5. Triple glass, night ventilation
Variant 6. Triple glass, external sun-shades, night ventilation





	Infiltration 1/h	Window	Sun protection	Night cooling	Over Kelvin hours DIN 4108	Over Kelvin hours DIN 15251	Primary energy kWh per m²
Base case model	0.35	Single-U ID 122 U=5.4 g-value = 0.81	None	Deactivated	313	10	**214.3**
Variant 1	0.15	**Double-U** ID 3212 U=1.23 g-value = 0.74	None	Deactivated	1039	98	**48.7**
Variant 2	0.15	**Triple-U** ID 11304 U=0.76 g-value = 0.62	None	Deactivated	673	46	**42.6**
Variant 3	0.15	**Triple-U** ID 11304 U=0.76 g-value = 0.62	**Internal fc = 0.7**	Deactivated	634	43	**42.2**
Variant 4	0.15	**Triple-U** ID 11304 U=0.76 g-value = 0.62	**External fc = 0.13**	Deactivated	9	0	**45.8**
Variant 5	0.15	**Triple-U** ID 11304 U=0.76 g-value = 0.62	None	**Activated**	373	19	**42.5**
Variant 6	0.15	**Triple-U** ID 11304 U=0.76 g-value = 0.62	**External fc = 0.13**	**Activated**	0	**0**	**45.6**

Rendering of new CiTG Facade Leasing renovation solution, which includes high performance framing and glazing, centrally operable windows including an upper window for night-cooling airflow, and external solar shading with high-wind velocity resistance. The panels have also been designed in consultation with the original building architect to ensure its close resemblance to the original architectural appearance of the building.

TUDelft Delft University of Technology

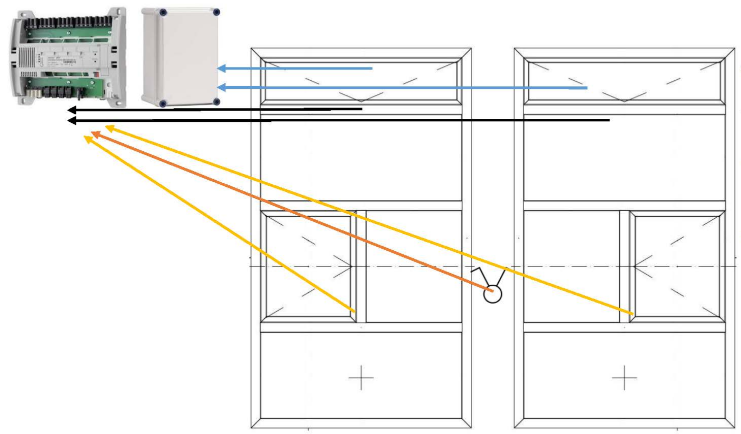
Facade components are operated and monitored by a centralized KNX-based facility management system. This allows for both centralized (facility manager) and decentralized (building user) control of components. It also allows the facade service provider Alkondor to keep track of the correct operation of engines and actuators, so they may be timely replaced before their expected end-of-service, contributing to the reliabilkity of the system and the fulfillment of Key Performance Indictaors. Some functions facilitated by this KNX system are:

- *Sun-shades and night cooling.*
- *Sun and wind detection.*
- *Individual control per room.*
- *Overrule function by TU Delft CRE.*
- *Measuring activity and performance (number of cycles and indoor climate).*
- *Service and maintenance by one informed and coordinated party.*

Based on the outcome of the climate and energy design study previosuly presented TU Delft AE+T and Alkondor Hengelo collaborated on the design and engineering of the facade solution. The proposed facade is based on a high-performance Schüco AWS 75 BS HI aluminium block-frame system, with insulated triple-glazing. The system achieves a U-value (or thermal transmitance coefficient) of aproxiumately 0,8 W/m^{2}K, an 85% improvement from the current facade which has been calculated to have a U-value of 5,4 W/m^{2}K. A block-frame alternative has been selected as it results in more slender framing elements, closer in appearance to the current and original facade system used in the building.

External solar shading is installed within the overhang of the upper floor, reducing the visual presence of the system while not in operation. An automated window at the top of each facade panel is connected to a centralized control system, allowing for simultaneous opening of all windows in order to passively ventilate the office spaces during cool summer nights. Also automated operable windows at user-height can be both decentrally and centrally operated to permit user flexibility while also providing central management capacity to control all windows for indoor climate or building security reasons.

Also connected to a central building management system are the engines powering solar shading systems and actuators powering operable windows. As part of the performance service delivered by the service provider is the maintenance and replacement of such systems. In the current way of working preventive maintenance is rarely enforced, automated systems are operated until an engine or actuator failure, at which point the building manager will request a facade fabricator or system supplier to replace the failing component. The cost of this is needlessly high, as individual service request are issued for each system failure and a service team must visit the building and setup maintenance infrastructure such as elevators or cranes to access the failing system. Under a performance service contract the service provider has the incentive to monitor the operation of these systems, controlling the number of operation cycles through which engines and actuators have gone. As these components reach the end of their expected statistical service life the service provider iwll then plan and execute a single replacement project, removing and replacing hundreds of components in one go with considerable economy of scale savings. The same economy of scale also allows for a circular reprocessing of bulk quantities of components, which can be remanufactured for further use in the same building or another similar service contract.



4. Global warming mitigation potential

Global warming mitigation potential calculations have been done for the specific CiTG case study, as well as for a standard renovation scenario representative of future upscaling activities. These calculations are described below. Mitigation related to the building facade can be divided into two main groups: 1. Mitigation linked to circular reprocessing of embodied materials, and 2. Mitigation linked to the improved energy performance of the facade and target buildings. Both types of mitigation are addressed by the Facade Leasing systemic innovation proposal, and contribute to a lower total carbon footprint of deep energy renovation projects and new constructions.

The standard Facade Leasing case

The standard case is based on the extrapolation of data from cross-European references. First, embodied energy of materials related to the production and sourcing costs associated to the construction of the façade is estimated at an average of 211 $kgCO_2eq/m^2$ of façade (Hildebrand, 2014). The success of a circular procurement model, in which the fabricator is contractually obligated, and economically incentivized, to remanufacture components could in principle lead to a no-waste end-of-service scenario. Based on a mean operational period of 50 years ongoing distributed embodied energy savings would amount to 5 $kgCO_2eq/m^2$ of façade per year.

Second, operational energy savings are calculated based on an average energy consumption in the European non-residential building sector of 280kWh/m^2 of ground floor area (BPIE, 2011) , this can be translated to approximately 155 kWh/m^2 of façade, based on an average 55% façade-to-floor ratio for this building typology (Ebbert, 2010) . Buildings from the target time period (1960's to 1970's) majorly contribute to the lower performance end of this average. Operational energy savings of 60% can be expected as a conservative figure for deep energy renovations like the ones facilitated by the Façade Leasing contracting model. This would mean on average 92,4kWh/m2 of façade per year, translated into 51,3 kgCO2eq/m2 of façade per year.

The CiTG case

While an embodied energy analysis of the specific CiTG case has not yet been elaborated, and will be the target of further work in 2019, global warming potential mitigation tied to primary energy savings is expected to be beyond the average scenario previously described. As described in section 2 of this report, energy savings on the CiTG east facade are expected to amount to a 78,5% yearly reduction, or 168,7 kWh/m^2 from a baseline of 214,3 kWh/m^2. These savings translate into 93,6 $kgCO_2eq/m^2$ of facade, and 243.370 $kgCO_2eq$ for the entire 2.600m^2 surface area. Over the projected fifteen years of operation this would amount to 3.650.560 $kgCO_2eq$, with further savings to be gained if the CiTG building is maintained as part of the TU Delft building portfolio and the facade remains in place and adequately maintained for its 50- to 70-year service life.

Hildebrand, L. (2014). Strategic investment of embodied energy during the architectural planning process. (Doctoral dissertation, Delft University of Technology), TU Delft.

BPIE (2011). Europe's buildings under the microscope. Brussels, Belgium, Building Performance Institute Europe.

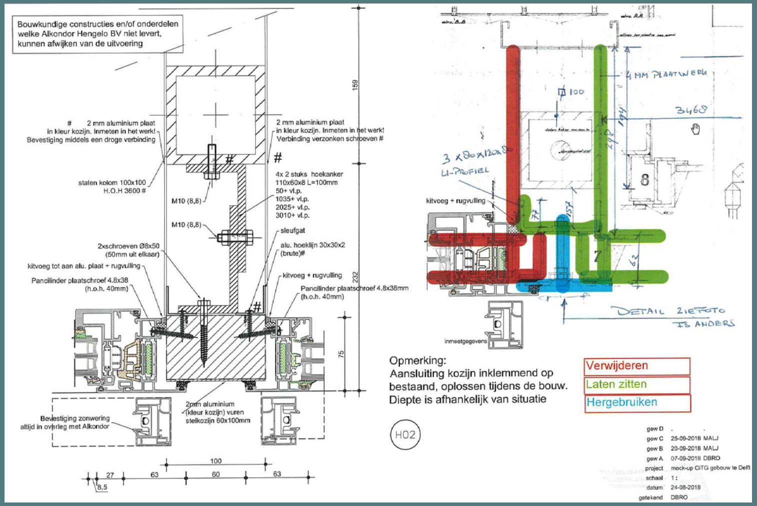
Ebbert, T. (2010). Re-face; refurbishment strategies for the technical improvement of office façades. (Doctoral dissertation, Delft University of Technology), TU Delft.

Machining process of a building envelope components. The facade fabricator is traditionally an assembler of components delivered at their factory floor by sub-suppliers such as aluminium systems, insulated glazing units (IGU's), solar shading systems, et. While the process is highly automated and supported by Computer Aided Machining (CAM) techniques, final assembly is still done on a project-by-project basis and relies on specialized manual labour.

Dimensioning and evaluation process for the existing CiTG east facade. Beyond the regular technical complexities poresented by a building renovation, such as dimensioning and interfacing of remaining and new components, the CiTG building facade also presents the challenge of asbestos presence on a number of sealing and closing elements. The removal and recycling of materialstherefore requires a particularly careful planning process.

In August 2018 the TU Delft board of directors approved an additional investment to build a mockup / prototype of the proposed facade. A standard industry procedure, technical mockups provide first hand expertise on the engineering and construction challenges that will be faced once the large-scale renovation process begins. Through a mockup the facade fabricator can verify the dimensioning of elements, and secure an effective interface between existing and new components to guarantee technical and indoor climate goals are achieved which resemble as closely as possible the results of the initial climatic and energy efficiency simulations.

In the case of the CiTG facade this process also allowed the TU Delft asbestos management team to analyse the presence of toxic substances in the construction and elaborate a protocol to safely remove them. An innovative contribution at this stage has been the involvement of a new company, "Purifed Metal Company" (PMC), which has developed the technological process to remove asbestos from existing steel elements in order to extract clean and reusable recycled steel. Purified Metal, which is in the process of building their new facilities in The Netherlands expected to start operations in 2020, will take over responsibility for the proper reprocessing of the asbestos, a task which is normally the responsibility of TU Delft CRE. By stockpiling industrial input such as the old CiTG facade in the months prior to the opening of their facilities PMC aims to secure the necessary volume of materials to feed their industrial process. This new supply-chain actor is instrumental for the implementation of retroactive circularity on legacy systems which - due to changing regultions regarding performance and health safety - have limited reuse or remanufacturing prospects.



Technical drawing of the new CiTG facade, with diagram showing interface between new (red), existing (green), and reused (blue) components.

Image by: Alkondor Hengelo BV

The new facade system is designed for easy disassembly and removal. Aluminium framing and automated components such as solar shading and window actuators can be reocever and remanufactured, adapting them to new buildings with different facade dimensions, or ideally being used in the design process of new buildings which can then take into account the grid of hundreds of panels which would become available if they are removed from the CiTG. Economic and governance interests are expected to shift the way in which buildings are designed and commissioned, demanding an increasing rate of reused or reclaimed components as policy instrument to enforce Circular Economy principles in practice.

6. User comfort monitoring

Indoor climate and user comfort monitoring has been initiated in August 2018 for 50 office rooms randomly selected between floors 2 and 5, on both east and west sides of the building. This monitoring, which will continue for 18 months until the end of the project phase in December 2019, will provide a reliable scientific comparison of the improvement in building performance before and after renovation.

OfficeVitae, a startup supported by EIT Climate-KIC, monitors indoor performance based on four key parameters:

CO_2 content - A metric of ventilation rate within an enclosed space. At high levels CO_2 concentration can pose a health risk, from causing headaches and drowsiness to oxygen deprivation in extreme cases. At moderate levels it is a good indication of user comfort, as low ventilation rates are often associated with perception of poor air quality, concentration of body odors or other bad smells, among other discomforts. 350-1.000 particles per million (ppm) is a generally good indication of a properly ventilated space. However, a good air exchange rate could be caused (as is the case in the CiTG building) by a poorly performing facade with high infiltration rates, as opposed to a well-performing system in which air-exchange rates are purposefully managed. Air leakage is directly related to poor energy performance, as it leads to unwanted thermal losses or gains. It also means rainwater or air drafts could infiltrate the facade, adding to user discomfort.

Humidity - Humidity levels should be kept between 30% and 70%, with optimum values between 40% and 60%. Extremely low or high humidity rates can cause discomfort, increase chances of illness, and lead to the creation of condensation or mold, which further affect user comfort and health, as well as technical integrity of building components.

Light - Sufficient lighting in office spaces is crucial to the comfort and productivity of users. Poor lighting conditions can lead to headache or eye-strain. Recommended lighting levels should be between 300 and 500 lux. Quality of lighting is also important, with glare, high or low contrast, unwanted shadows, or other poor light distribution effects affecting the health and productivity of users.

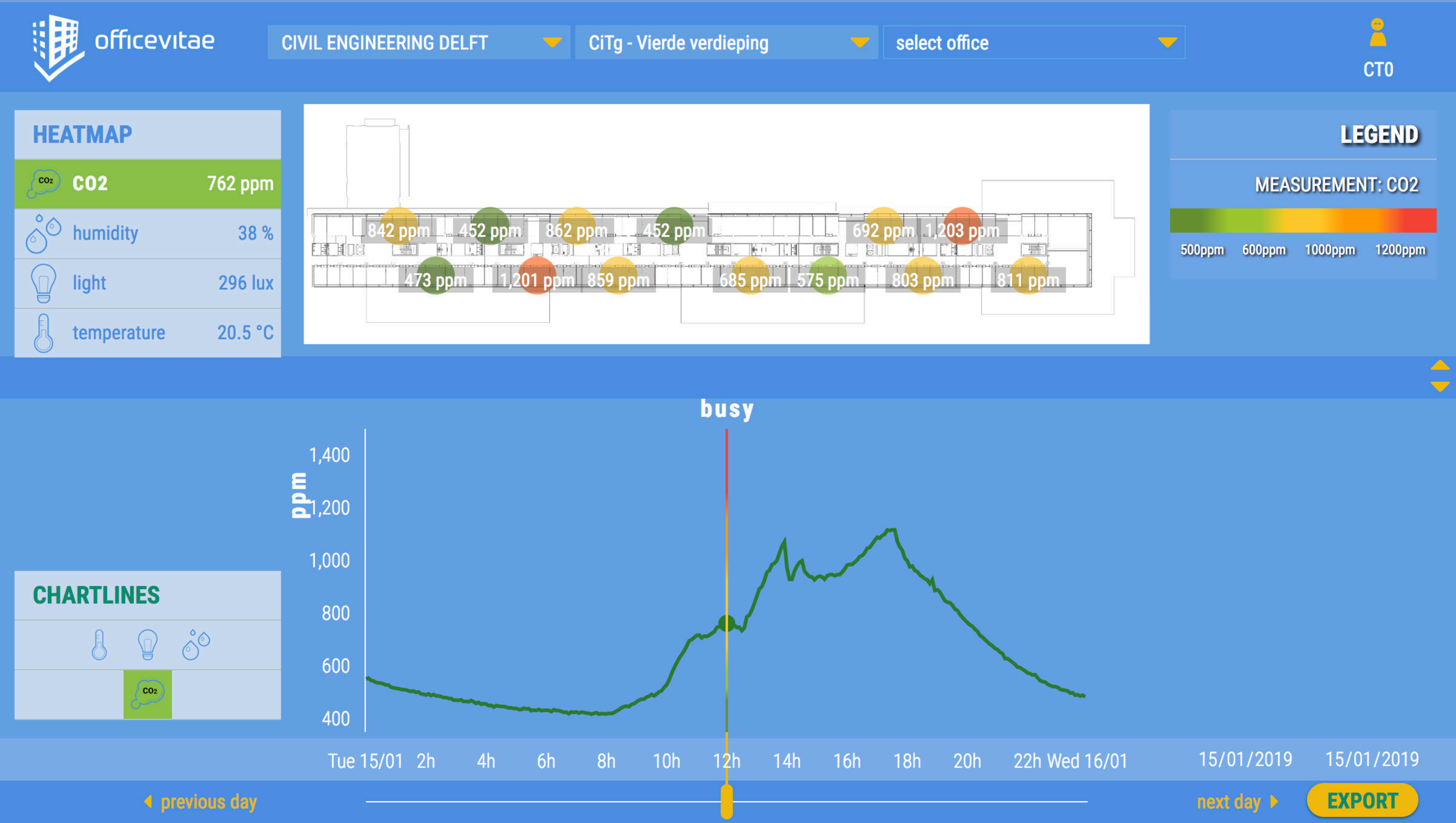
Temperature - Probably the predominant user comfort parameter in office spaces, temperature needs to be kept within a small margin for users to feel comfortable. High or low temperatures are associated with diverse health problems, drop ion productivity and absenteeism. Ideal temperature is generally considered between 21°C and 23°C, but this can vary based on external conditions (eg. summer or winter), and even more between different user preferences.

At the moment of writing, winter-time monitoring shows above-optimal concentrations of CO_2 in certain spaces, with a general air dryness caused by over-use of active heating.

Top: OfficeVitae integrated room sensor.

Right: Online dashboard for the OfficeVitae monitoring application showing user presence and indoor comfort values for selected rooms throughout the day.

TU Delft Delft University of Technology


officevitae
CIVIL ENGINEERING DELFT
CiTg - Vierde verdieping
select office
CTO
HEATMAP
CO2 762 ppm
humidity 38 %
light 296 lux
temperature 20.5 °C
842 ppm
452 ppm
862 ppm
452 ppm
692 ppm
1,203 ppm
473 ppm
1,201 ppm
859 ppm
685 ppm
575 ppm
803 ppm
811 ppm
LEGEND
MEASUREMENT: CO2
500ppm 600ppm 1000ppm 1200ppm
busy
ppm
1,400
1,200
1,000
800
600
400
CHARTLINES
Tue 15/01 2h 4h 6h 8h 10h 12h 14h 16h 18h 20h 22h Wed 16/01
15/01/2019 15/01/2019
previous day
next day
EXPORT

7. Service delivery Key Performance Indicators (KPI's)

The shift from product to service delivery proposed by this innovation project for the facade industry requires the creation of contracts and other collaboration models establishing performance indicators as the key value proposition in the commercial transaction. While these key performance indicators are still been developed and agreed upon for the case of the CiTG facade, such KPI's are not new to the sector. VMRG, the branch organization for the Dutch metal facade industry, establishes quality criteria which must be followed by all member companies when delivering a project. Manufacturing standards, industry standards, local and European building regulations are other types of norms which must be followed by all parties engaged in a building project.

The main difference is the long-term adherence to such norms in a product-based economy versus a service-based one. In the former, the manufacturer is only responsible for delivering such quality, and is committed to the product for a certain number of years due to contractual guarantees. Such guarantees, however, are often too short to properly protect the client, or result in long litigation processes in which sub-contractors debate the sub-optimal performance of each others' work scope. Such a system provides no incentives, other than penalties, for manufacturers to be interested in the long-term performance of their systems.

A transition towards long-term, measurable performance indicators under a service contract makes the service-provider directly responsible for the operation of its systems over the entire period of the contract. Time-frames of 15 to 25 years are much more likely to cover the degradation of products over time than guarantees held over 2 to 5 years after construction. Furthermore, long-term servicing provides incentives for manufacturing and assembling companies to invest resources into engineering of equipment of higher quality, with lower maintenance requirements. Since the client pays a fixed fee for the facade service, and maintenance is responsibility of the service provider, any difference between the calculated service fee and the actual management and maintenance expenses will determine the final profit made by the service provider.

The examples KPI's shown on the opposite table provide an impression of the service provider's responsibility over the facade components over the planned 15 year contract period. Quality and performance metrics are determined by industry standards, and response times are established and agreed upon by both parties. Such agreements form the core of the Facade Leasing contract.

Performance	Urgency*	Established	Measurability
Wind and waterproof	**Fault on hold**	Per event	Water leakage. Air permeability greater than VMRG requirements.
Sun-shading. - Up and down movement	**Urgent fault**	Per use	Operability of sun-shading.
Operability of windows (open & tilt)	**Fault on hold**	Per event	Window / door does not open or does not close or has difficulty doing so. Window / door produces noise when opening or closing.
Automated / centrally controlled operation of top windows for (night cooling.	**Fault on hold**	Per event	Window / door does not open or does not close or has difficulty doing so. Window / door produces noise when opening or closing. Central control system does not respond.
Glass surface transparency **	-	half-yearly	100% see-through / transparency according to VMRG façade cleaning standards.
Aluminum surface cleaning / aesthetic quality **	-	half-yearly	Color quality and maximum glossiness according to VMRG standards.

**Aesthetic performance is coupled to the service intervals. Cleaning may create a certain degradation of the standard over time, expressed in color and gloss decrease.

8. Contributors

Facade Leasing meeting at the office of ABN AMRO Lease in summer 2018. Present are representatives from TU Delft (research), TU Delft CRE, Alkondor Hengelo, VMRG, Houthoff and ABN AMRO Lease.

Photo: Juan Azcarate-Aguerre, 2018

TU Delft Consortium Partners:

Tillmann Klein	BK Building Product Innovation and Circularity
Juan Azcarate -Aguerre	BK BPI and Facade Economics
Alexandra den Heijer	BK Public Real Estate and Campus Management
Zeno Winkels	Valorisation Centre TUDelft / Climate-KIC
Marleen Hermans	BK Public Commissioning
Hendrik Ploeger	BK Geo-information and Land Development
Monika Chao-Duivis	BK Building Law
Stijn van Boxmeer	CiTG Faculty Manager
Paul Althuis	Valorisation Centre TUDelft
Hubert Linssen	The Green Villlage
Sacha Silvester	IO Sustainable Design and User Interaction
David Keyson	IO Social Contextual Interaction Design
Marcel Reinders	EWI Pattern Recognition Laboratory
Kelvin Berghorst	CRE Strategic Campus Management
Rob Weststrate	CRE Manager Maintenance
Johan Hogervorst	CRE Maintenance
Jan van der Pol	CRE Asbestos management
Arjen Keuning	CRE Project manager
Danny van der Ende	CRE Project manager
Koert Riemslag	TUD Project Manager Procurement
Floor Berger-Smeets	TUD Legal
Ronald van der Bosch	TUD Treasury
Robert Bierman	TUD Treasury

External Consortium Partners:

Martijn Veerman	Alkondor Hengelo. Façade Builder
Jan Bergman	Alkondor Hengelo. Façade Builder
Stingo Huurdeman	VMRG Branch Association for the Dutch Metal Façade Industry
Hanneke Veldhuis	OGF Het Opdrachtgeversforum in de Bouw IBR Institut voor Bouwrecht
Thomas Auer	TUM Building Technology and Climate Responsive Design
Tobias Wagner	TUM Building Technology and Climate Responsive Design
Peter Hopkinson	University of Exeter Business School
Robert Peterson	ABN AMRO Lease
Pim van Lexmond	ABN AMRO Lease
Tako Werts	OfficeVitae
David Keyson	OfficeVitae
Marnix Aarts	Houthoff
Jeroen van den Bos	Houthoff
Dolf de Jong	Houthoff

eit Climate-KIC

TU Delft Delft University of Technology