Adaptive facade network – Europe

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EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

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This book is based upon work from COST Action TU 1403 adaptive facade network, supported by COST (European Cooperation in Science and Technology).

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It allows researchers, engineers and scholars to jointly develop their own ideas and take new initiatives across all fields of science and technology, while promoting multi- and interdisciplinary approaches. COST aims at fostering a better integration of less research intensive countries to the knowledge hubs of the European Research Area. The COST Association, an International not-forprofit Association under Belgian Law, integrates all management, governing and administrative functions necessary for the operation of the framework. The COST Association has currently 36 Member Countries.

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Andreas Luible, Mauro Overend, Laura Aelenei, Ulrich Knaack, Marco Perino, Frank Wellershoff
TU Delft for the COST Action 1403 adaptive facade network

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Journals

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Housing complex Oklahoma / Amsterdam

General introduction

Energy efficient buildings significantly contribute to meeting the EU climate and energy sustainability targets for 2020 as approximately one third of all end-user energy in Europe today is consumed by space heating / cooling, ventilation and lighting of buildings. In this context, the energy performance of future building envelopes will play a key role.

Today's facades are mostly passive systems and are largely exhausted from an energetic point of view. They can neither adapt to changing environmental conditions related to daily and annual cycles nor to changing user requirements.

Multifunctional, adaptive and dynamic facades can be considered the next big milestone in facade technology. Adaptive building envelopes are able to interact with the environment and the user by reacting to external influences and adapting their behaviour and functionality accordingly: the building envelope insulates only when necessary, it produces energy when possible, it shades or ventilates when the indoor comfort so demands.

In spite of numerous already realised projects the development and realisation of adaptive building envelopes is still in the initial stage. In addition to new technologies that enable adaptive behaviour, simulation tools and suitable testing methods must be developed; existing norms and regulations must be adapted and holistic concepts to integrate such facades in the overall building system must be developed.

Currently, European research in the field of adaptive building envelopes is coined by numerous nationally funded projects and a lack of knowledge transfer between the individual research institutes amongst each other and the industry. To counteract this situation, COST Action TU1403 - *Adaptive Facades Network* (www.tu1403.eu) was initiated by several research institutes in 2014. The COST framework is financed by the H2020 program and supports trans-national cooperation between researchers and the industry through science and technology networks.

The main aim of COST Action TU1403 with 120 participants from 26 European countries is to harmonise, share and disseminate technological knowledge on adaptive facades on a European level and to generate ideas for new innovative technologies and solutions. This shall lead to:

1. Increased knowledge sharing between the various European research centres and between these centres and the industry;
2. The development of novel concepts and technologies and/or new combinations of existing technologies for adaptive facades;
3. The development of new knowledge such as effective evaluation tools / methods for adaptive facades;
4. The start of new collaborations and research projects in the area of adaptive facade technologies.

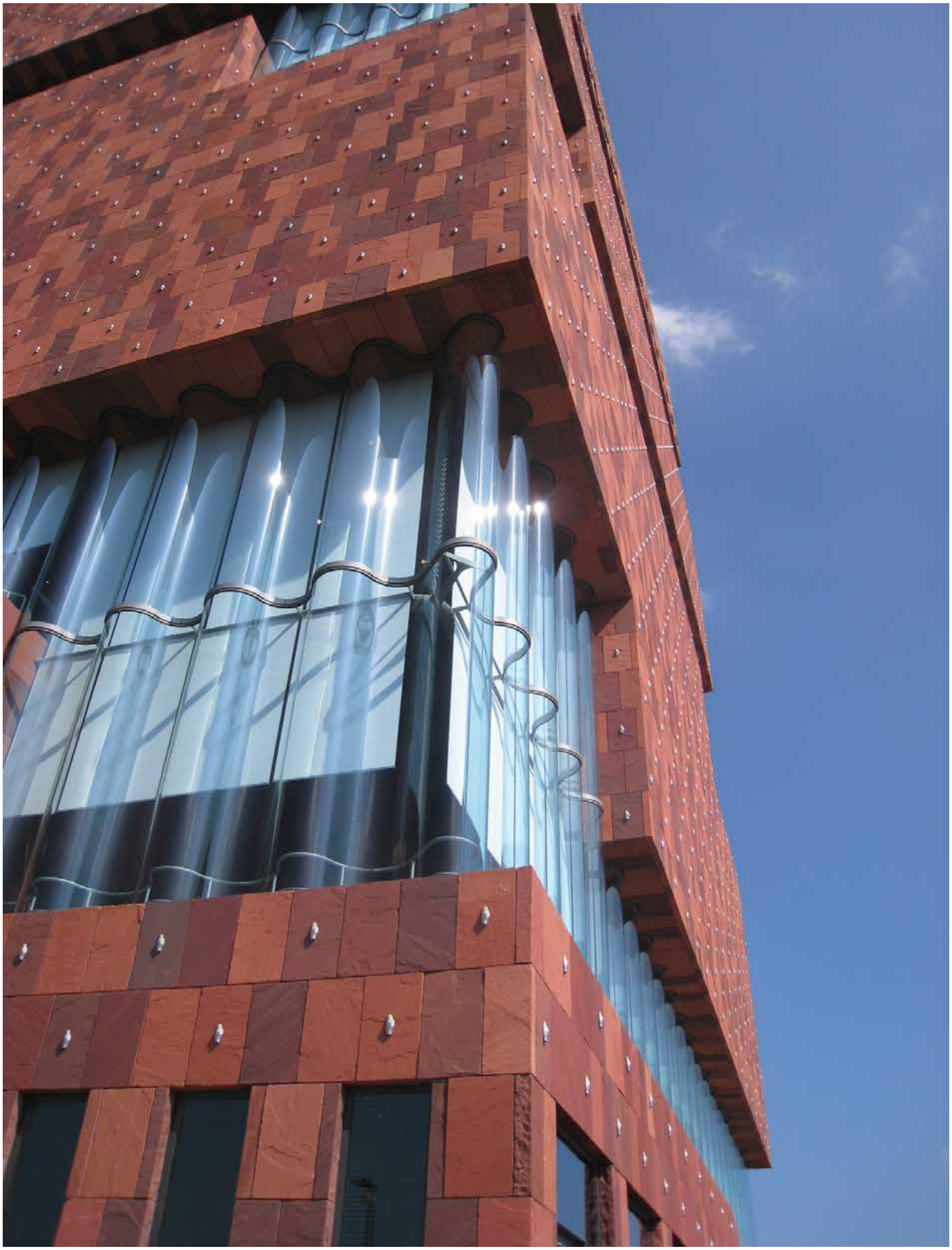
COST Action TU1403 started in January 2015; planned to run for a period of four years. The Action is organized in four working groups, three scientific and one with the objective to disseminate results:

- **WG1.** Adaptive technologies and products
- **WG2.** Component performance and characterization methods
- **WG3.** Whole building integration and whole-life evaluation methods of adaptive facades
- **WG4.** Dissemination and future research

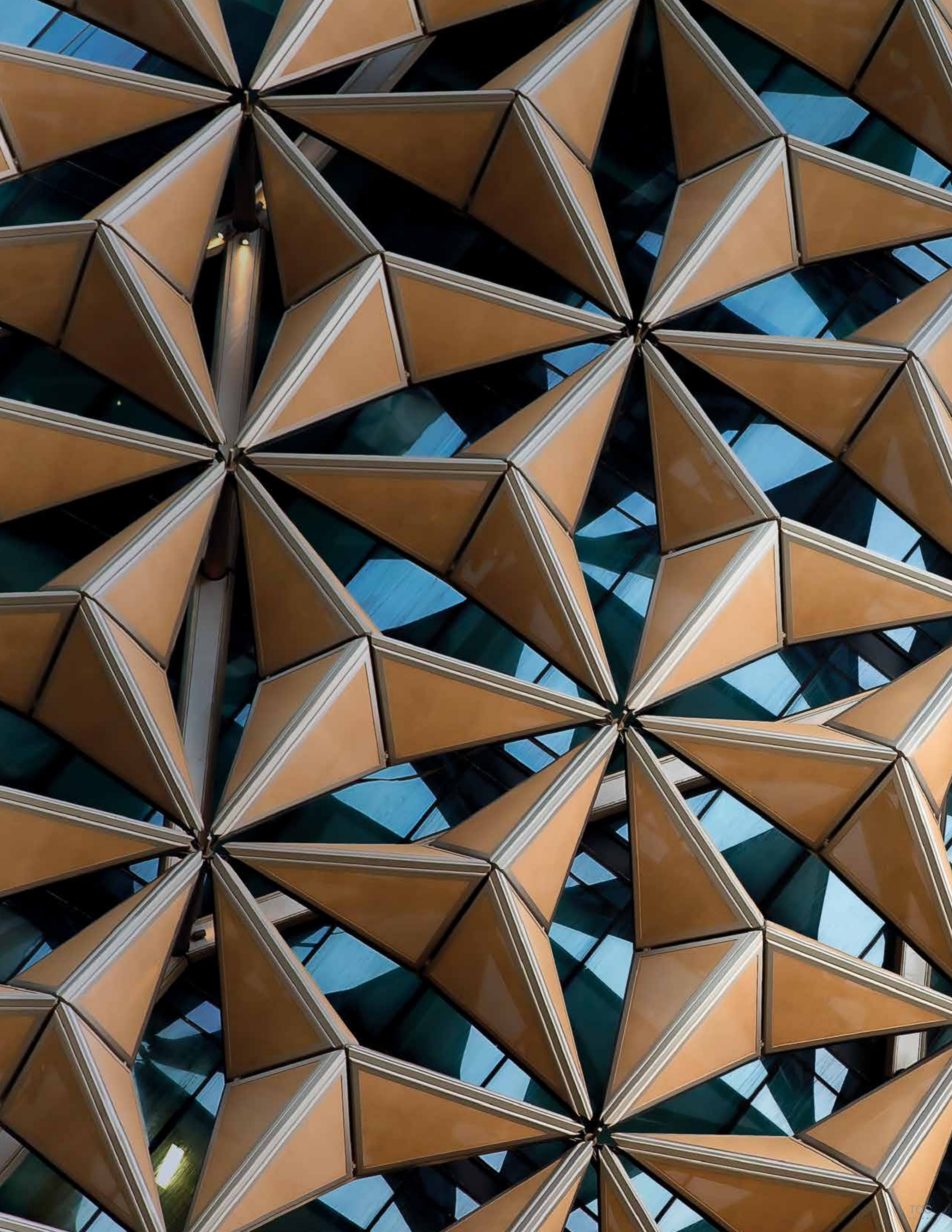
This publication with a collection of posters is a first state of the art database with the objective to gather information about ongoing projects and research activities, which are carried out by the Action participants and their research institutions.

This publication is based upon work from COST Action TU1403 “Adaptive Facades Network” supported by COST (European Cooperation in Science and Technology).

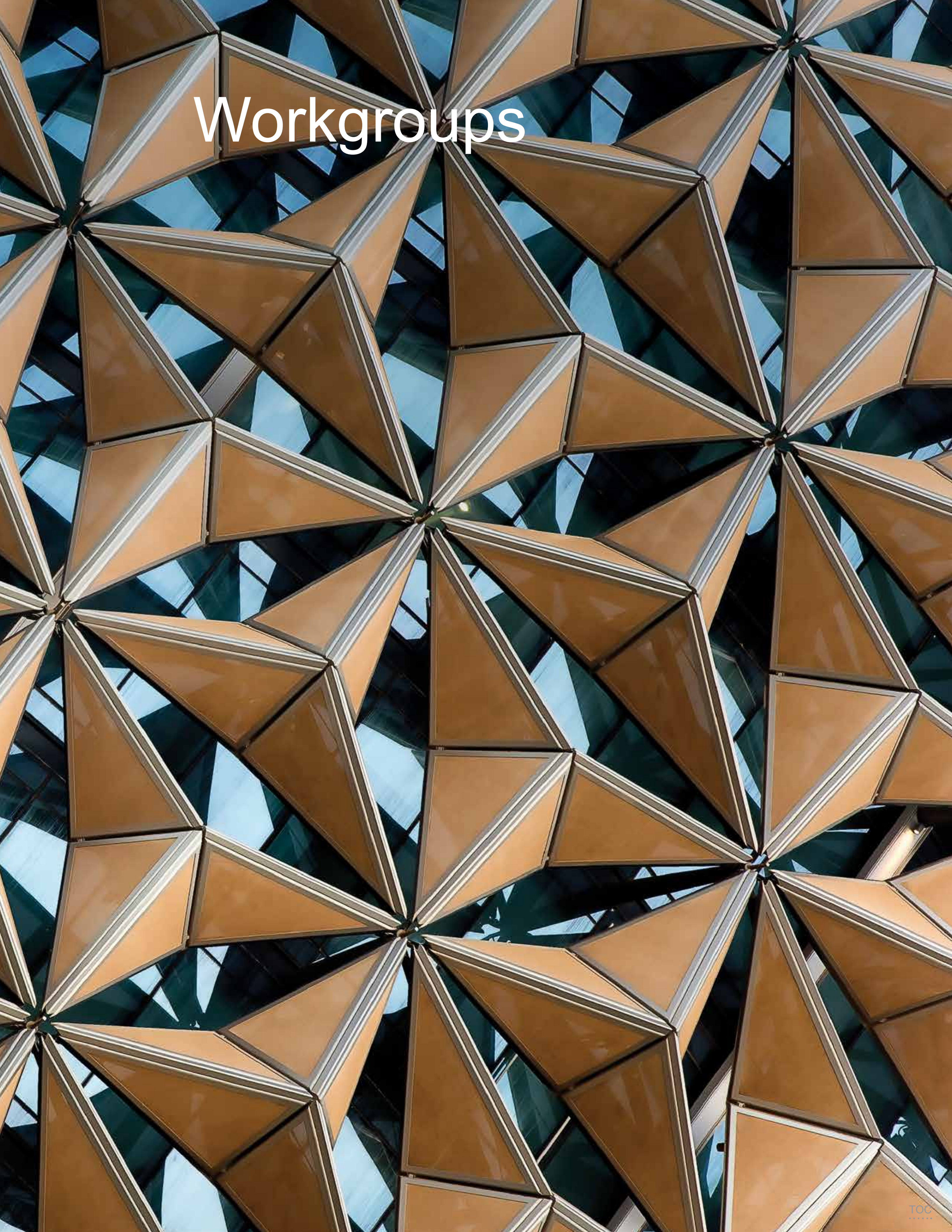
Andreas Luible
Chair of COST Action TU1403



MAS Museum Antwerp



Workgroups



Housing complex Silodam / Amsterdam

WG1
Adaptive technologies and products

New building challenges arise from moving toward a paradigm of decentralized energy generation and highly interconnected urban infrastructures, where buildings become interactive nodes of larger networks. Further increase of buildings' energy efficiency and enabling coordinated interaction of energy with the grids while providing a comfortable healthy indoor environment for the users are the main challenges and tasks for the development of a new generation of intelligent adaptive buildings through design and components.

Facing these challenges, the building façade as the main building component has to be designed not only as a static boundary between the conditioned interior of the building and the outdoors but also has to integrate active functions which can provide step-change improvement of the building's energy efficiency, comfort for the occupants, and flexibility of energy production (collect, convert, store, distribute) from renewable integrated systems.

In spite of the existing research on responsive/adaptive/interactive building envelopes, and in consideration of this paradigm, there is a need to:

- Articulate a conceptual paradigm, working vocabulary for the development of high-performance active building façades, pooling together the knowledge, technologies and research from across European countries and beyond;
- Identify the adaptive façade operation modes and response functions, structure and components (materials properties, systems, control, changing parameters) toward a systematic characterization of the adaptive façade;
- Identify the differences between the traditional, static high performance façade and adaptive ones in terms of construction, durability, structural behaviour, energy savings, cost, energy management, indoor quality.

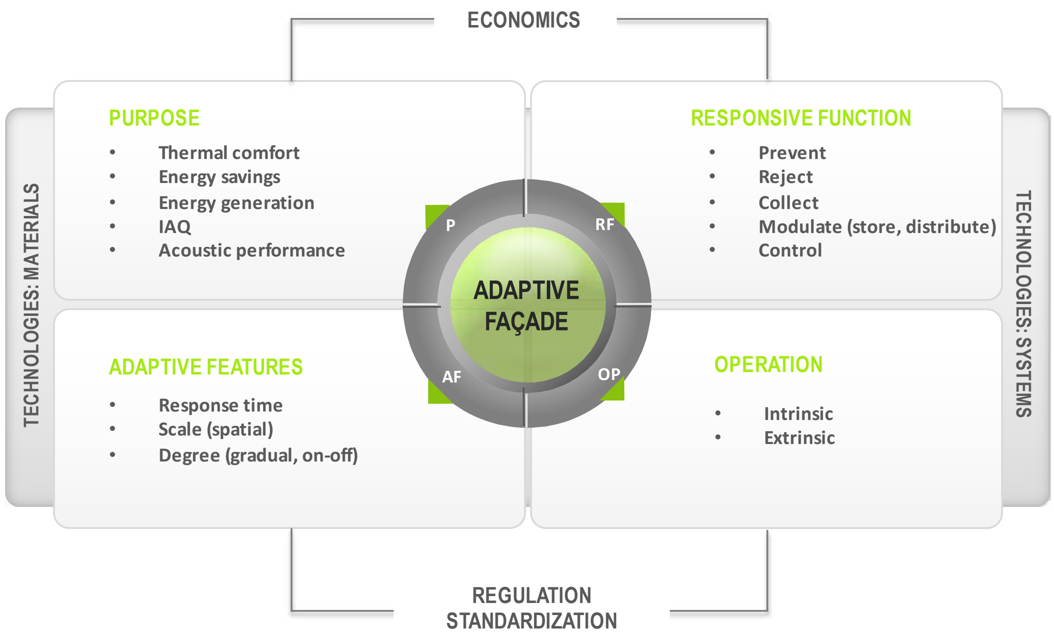
Therefore the main aims of Working Group 1 are:

1. Developing an extensive database of different technological solutions and applications of adaptive facades, characterized by a matrix of influencing parameters;
2. Developing a literature review of new market technologies and possible developments and research projects of adaptive facades;
3. Based on 1 and 2, providing a systematic characterization of the adaptive façade for future trends of adaptive facades design, development of novel adaptive technologies.

And the WG1 specific objectives:

- to map out the different technologies (available either on the market, or as prototypes or concepts) allowing a façade to be adaptive and responsive, in terms of materials and systems (including control systems);
- to provide an overview of the performance of each technology compared to the state-of-the-art high performance facades;
- to identify and pursue new concepts and new products for adaptive façades;
- to provide a selection of applications of technologies already adopted in existing projects identifying the strongest and weakest points.

The main output of the WG1 work will be an adaptive façade characterization matrix, based on: state of the art, database of different applications, projects developed in this area which could be a useful tool for developing new adaptive façade design and technologies.



Adaptive façade characterization matrix

WG2
Component performance and characterization methods

Modern building envelopes are high-tech components that must meet several requirements and constraints with regards to architecture/planning, structural performance, energy efficiency, indoor environmental quality, easiness of construction and ultimately, value.

To tackle this challenge an emerging technology has recently appeared on the market: the so-called adaptive facades. This next generation of facades consists of multifunctional and highly flexible/ responsive systems, whereby the physical separator between the interior and exterior environment (i.e. the building envelope) is able to change its functions, features or behaviour over time in response to transient performance requirements and boundary conditions with the aim of improving the overall building performance.

Highly adaptive facades offer unprecedented opportunities to reduce the energy demand of buildings, to improve the indoor environmental quality and to facilitate the exploitation of RES at the building site. Therefore, they can become a key technology to satisfy the 2020 Net Zero Energy Building target and beyond.

In spite of these potentialities, they are, however, particularly complex as they often involve the use of novel materials, interact dynamically with the external environment, the installations and, last but not least, with the occupants.

This highly non steady state behaviour, and the fact that the properties/features of the façade change over time, pose huge challenges to manufacturers, designers and certification bodies.

In fact, the parameters usually adopted to label the performances of the façade, in terms of energy behaviour (like e.g. the U-value), indoor thermal comfort, durability, structural behaviour etc., are seldom useful and their assessment becomes tricky or impossible. Moreover, the experimental and numerical analysis tools used so far to design and investigate the “static” building envelope components, appear to be rather limited and unsuitable to design adaptive façades.

At present there is a lack of standardized procedures to study and test the performance of adaptive building envelope components; forming a barrier against widespread adoption.

Such problems will be addressed by the research activity carried out within the working group WG2 of the “COST Action TU1403: Adaptive Facades Network”.

Specifically, the most critical issues that have been identified and that need to be solved are:

- the lack of parameters and synthetic metrics to assess adaptive facades performance;
- the lack of experimental techniques to analyse component behaviour in the lab and on site;
- the lack of holistic methods and simulation tools able to account for the interaction of the adaptive façade with the building and users.

Therefore, the objectives of WG2 are:

- to identify for each aspect of façade performance (energy efficiency, structural, safety, fire, weather protection, durability, aesthetics) where the adaptive technologies would be most beneficial;
- to establish and standardise numerical and experimental methods for characterizing the performance (with an emphasis on energy efficiency);
- to evaluate the suitability of conventional performance parameters to fully address the behaviour of adaptive facades;
- to develop new metrics that are able to capture the transient and multi-parameter performance of adaptive façades;
- to develop new numerical tools for evaluating the most promising adaptive technologies.

In order to reach these ambitious goals, the overall activity of WG2 will be articulated in five specific tasks.

Facility for advanced facades characterization: Climate simulator at SINTEF Byggforsk (Photo: Remy Eik)

WG3

Whole building integration and whole-life evaluation methods of adaptive facades

The main aim of WG3 is to evaluate the integration and interaction of an adaptive façade with the building (aesthetics, structure, etc.), the building services, the building users and the environment, thereby providing an account of the whole-life performance of an adaptive façade. The quality of future energy efficient buildings depends on the performance of each component (established in WG2) but also on the interaction between these components in the entire façade system and how the façade interacts with the internal / external environment and users.

The objective of WG3 is thus the evaluation of the pros/cons of adaptive façades when these technologies are analysed with a wider perspective, i.e. the impact of the adaptive façade when:

1. Integrated into a building;
2. Under realistic boundary conditions and users' interaction;
3. In a multidisciplinary, holistic perspective.

Another objective of this WG is to initiate and harmonise European and national research projects in order to further develop these methods and create a basis for future European standards, design rules and testing procedures.

WG3 has built task groups to establish a structured workflow to compile the state of the art of adaptive facades systems and existing design methods, and to evaluate the pros/cons of them. As the complexity of the overall design of adaptive facades requires a close collaboration of different professionals and stakeholders, the task groups are not composed based on professional backgrounds, but on typical design and assessment phases. These phases where defined as:

Task Group 1 / Phase 1

Definition of design targets for the façade interaction with the building services

- Desired capacity to adapt to changing external conditions (weather) and internal conditions (use of the room);
- Desired comfort criteria for defined potential user;
- Definition of required design process methods.

Task Group 2 / Phase 2

Schematic and conceptual Design

- Aesthetic design and system engineering including functional integration of structural and service systems components;
- Numerical analysis of building performance and occupant comfort;

Task Group 3 / Phase 3

Design assist and pre-construction validation

- Feedback and optional fine tuning from potential suppliers to phase 2;
- Visual mock up;
- Performance mock up (water tightness test, blower door test).

Task Group 4 / Phase 4

Design of occupant operating options

- User flexibility;
- User education and communication.

Task Group 5 / Phase 5

Post-occupancy evaluation and optimization

- Performance assessment methods.

WG4
Dissemination and future research

Objectives

Responsibilities of WG4 is to organise and manage the Action website, the workshops and meetings, the Short Term Scientific Missions (STSM), training schools and symposium (each early stage researcher will present his/her work published as papers in a booklet). Also, the coordination of international conferences, publication of journal papers and guidelines, and finally coordination of the application for future research projects are positioned here. Next to the defined topics the workgroup is developing formats to link the COST action to stakeholders in the industry with industry workshops, other COST actions and related academic environments.

This concludes the following primary tasks

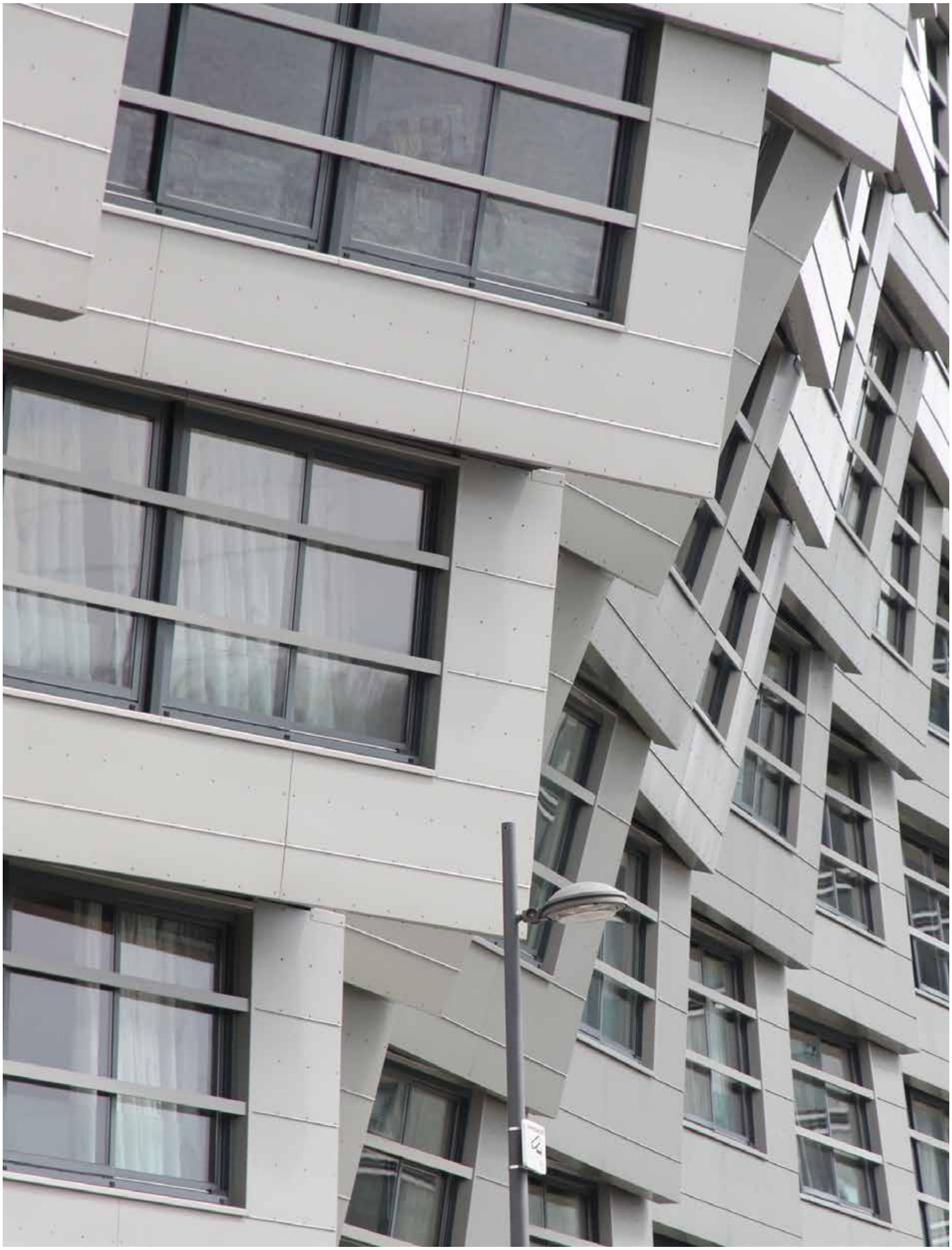
- Organisation and coordination of Action events (MC/WG meetings, stakeholder/industry meetings; Mid-term and final conferences);
- Educational package and training school;
- Coordination of Short Term Scientific Missions;
- Database of research projects and experimental facilities in the domain of the Action;
- Creation and management of Action website;
- Dissemination through journal, conferences, trade publications and website;

As a consequence Working Group 4 is responsible for the following deliverables

- Creation and maintenance of the Action specific website;
- Organisation of all meetings and related minutes reports;
- Educational package content definitions and development;
- Organisation of 3 Training Schools (1 per year except the first year) and related material published;
- Completion of STSMs;
- Organisation of Cost Action Mid-term Conference (beginning of 3rd year);
- Organisation of Cost Action Conference (end of the 4th year) and production of proceedings;
- Coordination of peer reviewed scientific journal papers and conference publications.

Posters

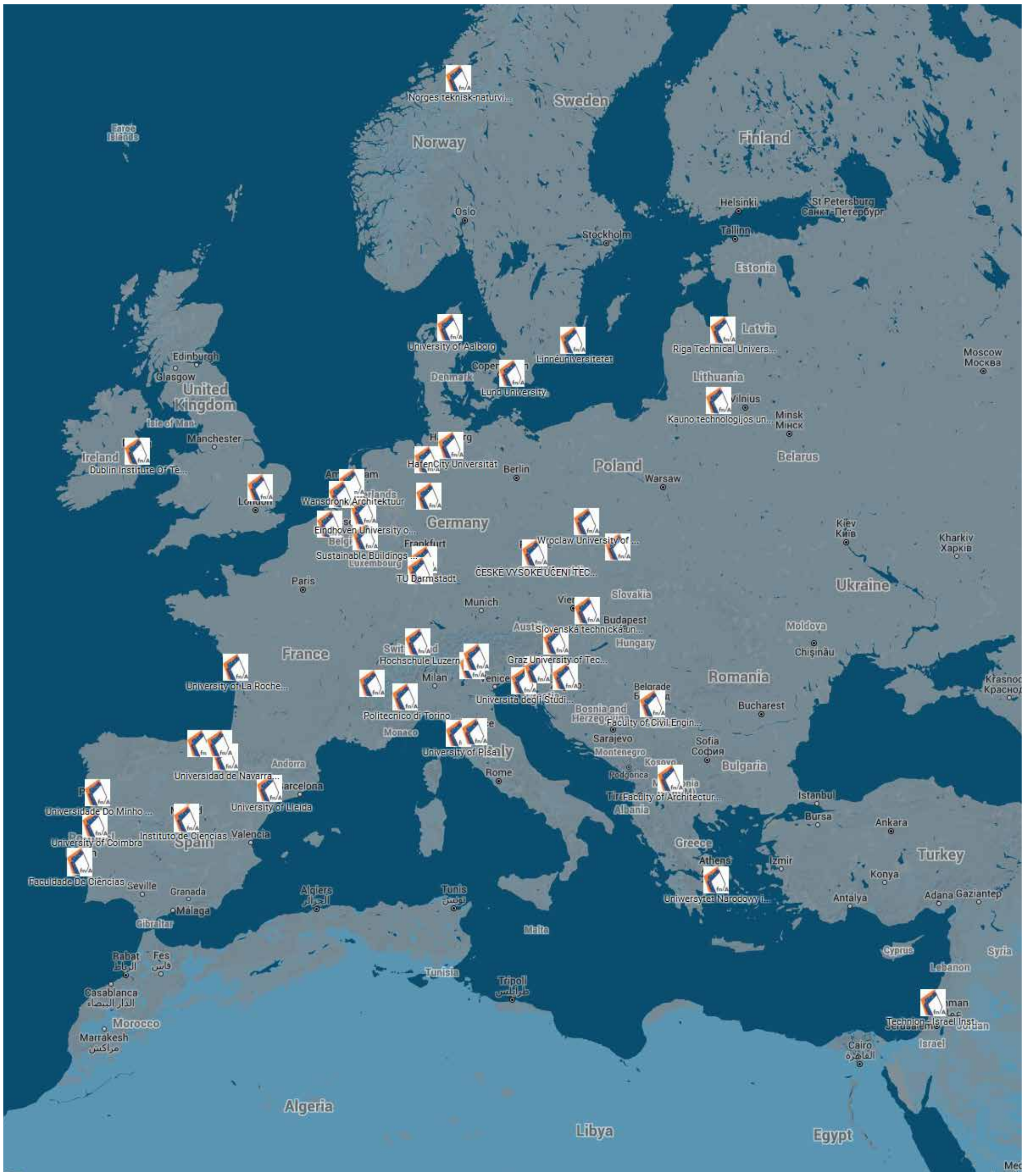
TOC



Block 16 / Almere

Database of AFN ongoing projects and research activities

As the participants of COST TU 1403 Action come from different institutions and have different back-grounds it was a WG 4's initiative to encourage AFN researchers to prepare posters providing the basic information about the research area and subject of the individual COST TU 1403 action contributions.



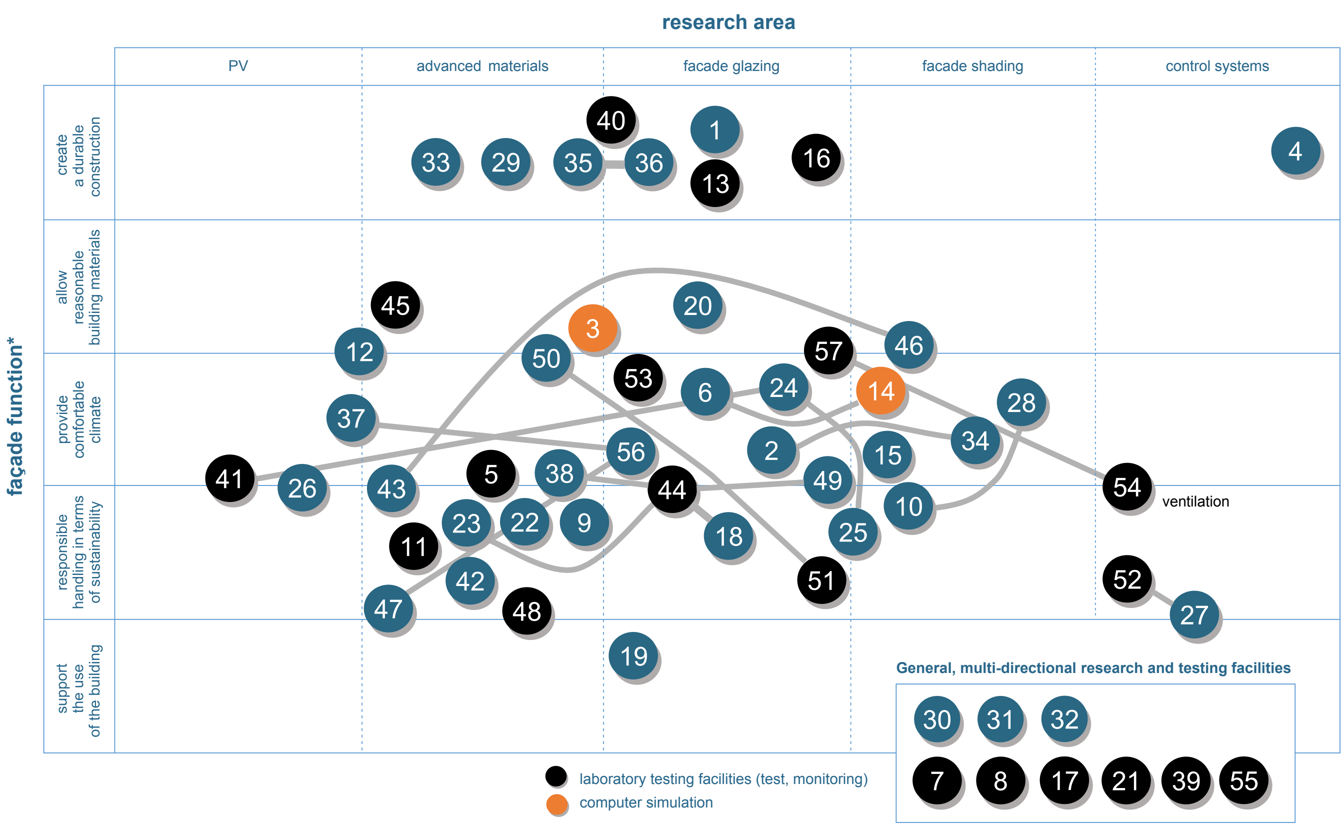
COST Action TU1403 – 120 participants from 26 European countries

Poster map

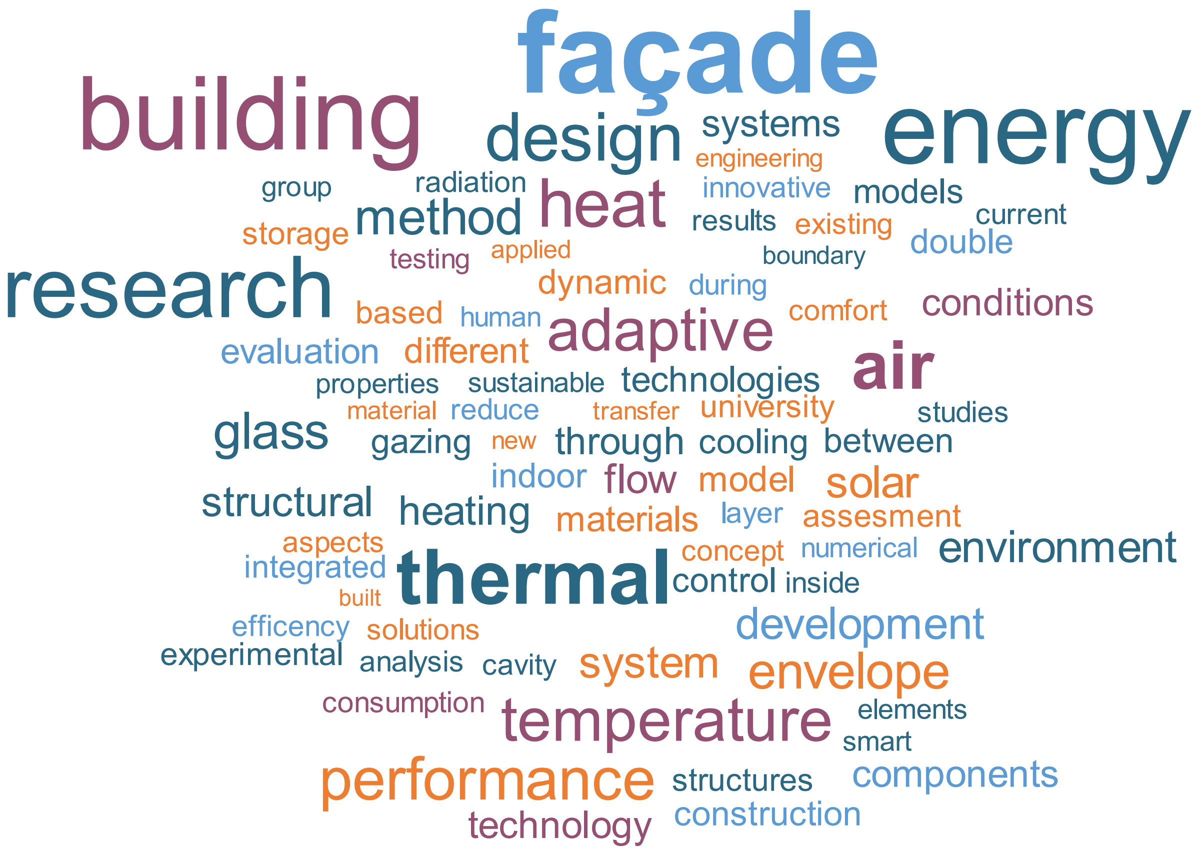
A poster map is a visual presentation of gathered information in the form of a diagram (a coordinate system type of diagram). Main AFN research areas are presented on the X axis including: PV (photo voltaic), advanced materials, façade glazing, façade shading and control systems. On the Y axis the main façade functions are presented based on T. Klein's book Integral Façade Construction (2013) including: creating a durable construction, allowance of reasonable building materials, provision of a comfortable climate, responsible handling in terms of sustainability, support the use of the building.

The numbers representing the posters are placed on the map according to the poster content and the keywords, e.g. research in the area of micro-climate conditions resulting from the use of double façade is placed in the area of "façade glazing" on the X axis, and at the "provide a comfortable climate" function on the Y axis. If more research areas are present, the assignment is done based on the predominant area featured in the poster. In general, a separate category was created for multi-disciplinary research (applies mainly to institutions and laboratories). Selected numbers representing posters are linked with grey lines to visualize the research done in different areas but connected by other aspects (e.g. by climatic zone, interests in bionics, NZEB). Black dots represent participants (or participating institutions) with access to test facilities.

The purpose of the map is to visualize research areas that COST TU 1403 action participants actively participate in, while illustrating research areas that offer potential for further development.



New poster map – façade function vs. research area
Map prepared based on the contents of the posters, COST TU 1403, WG 4



Poster keyword map
Keyword frequency map prepared based on the contents of the posters, COST TU 1403, WG 4

1 Advanced analysis of glued connections for facades systems Innovative solution for exterior elements connections of adaptive facades

Klára Machalická, Martina Eliášová

Research information

Main goals of research

Adaptive facades are the future in the field of energy saving in buildings. The behaviour of external elements of the glass facade can continuously affect the flow of energy and light according to the current outside environmental conditions, and can thus significantly reduce energy consumption for heating/cooling and lighting. Facing elements connections with other facade parts are advantageously designed as a glued connection due to the important benefits that adhesive connections provide. But there is a lack of information about semi-rigid or rigid adhesive connections in facades, which is a very specific application for glued joints due to the requirements on durability, strict geometrical imperfections and connections of unconventional materials often used in facade design. The main goals of the project is the inclusion of all of these requirements for experimental analysis of the chosen adhesives, selection of suitable testing methods, including ageing effect, and development of numerical models.

- Development of innovative solution for the connection of outside facing elements of adaptive façades
- Suitable methods for testing adhesive connections, incl. the ageing effect (comparison of several laboratory ageing methods with natural ageing)
- Numerical models of adhesive connection

Fig. 1: Amager Bakke - New Energy Plant in Copenhagen unitised facade, external cladding, fire-rated constructions, atypical constructions, completion: 2016, BIG Architects

Research activities related to adaptive facades

Our CTU team has cooperated for a long time with the main Czech contractor in the engineering, project management, manufacturing and installation of architectural glazed building envelopes [1].

Previous research of adhesive connections

Reliability of the bond is influenced by many factors, starting with the appropriate selection of adhesive for a specific joint. Five types of glue were selected for the experimental analysis. The adhesives in the joints were applied in different thicknesses to determine the effect on the mechanical properties of the joint. Shear loaded joint tests were performed for connections glass-glass or glass-steel, stainless steel, aluminium and wood. Particular attention was paid to the influence of environmental factors, all types of joints were subjected to conditions of accelerated ageing, and were then tested to compare load-carrying capacity and failure mode with the results of joints unexposed to laboratory ageing, [2]. The last part of the experimental analysis deals with testing glued glass beams loaded by four-point bending. UV-adhesive was applied to the beam to verify the behaviour of the adhesive in the long joint.
Numerical analysis is done for the experimental part of the thesis and deals with the creation of the accurate models for all selected adhesives. Unique numerical model were created that respond with change in the thickness of the joint for semi-rigid acrylate adhesive and UV-adhesive. These two models of adhesives were applied to create numerical models of two types of beams – a glued glass beam with UV-adhesive and a hybrid glass-steel beam with semi-rigid acrylate adhesive and U-shape connection.

Fig. 2: Structural elements with essential usage of adhesive joint, developed at CTU (hybrid steel-glass beam - Netušil & Eliášová; glass column – Kalamar & Eliášová; glass beam – Machalická & Eliášová)

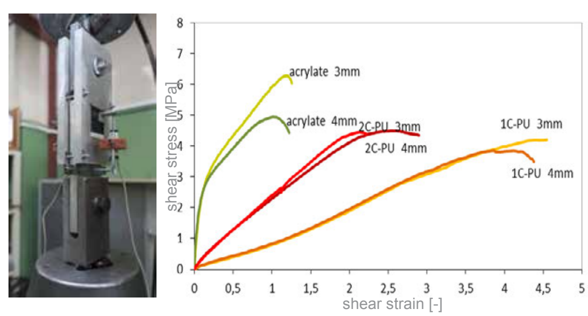


Fig. 3: Testing of adhesive connection; influence of adhesive layer on mechanical behaviour of joint

Involved persons: Klára Machalická
Martina Eliášová

Time span: 2014 - 2018

Contact data: klara.machalicka@fsv.cvut.cz
eliasova@fsv.cvut.cz

Associated Publications:

1. SIPRAL (2015). *Sipral projects*. [Online] Available from: http://www.sipral.cz/en/projects. [Accessed: 12th June 2015]
2. MACHALICKÁ K. & ELIÁŠOVÁ M. (2012), *Influence of Various Factors on Mechanical Properties of Adhesive Joint in Glass Structures*, Proceedings of Challenging Glass 3 – Conference on Architectural and Structural Applications of Glass, Amsterdam: IOS Press

2 Industrialized Sunspace Prototype with Solar Heat Storage. Assessment of Post-Occupational Behaviour in Adaptive Facades.

SAVIArquitectura Research group. University of Navarra (Spain)

Information of SAVIArquitectura Research Group

Main Research Topics

- Eco-design of industrialized and sustainable components for building envelopes
- Energy and sustainable rehabilitation of buildings
- Performance-based design for buildings envelope rehabilitation
- Materials and Waste Management
- Lifecycle analysis, LCA
- Environmental Building Certification
- Simulation and monitoring of buildings
- Adaptive Facades

:

Team

Ana Sánchez-Ostiz (Director), Purificación Gonzalez-Martinez, Juan B. Echeverría Trueba, Aurora Monge-Barrio, Germán Ramos Ruiz, Joaquín Torres Ramo, Carlos Fernández Bandera, Silvia Domingo-Irigoyen

Synergies

- School of Architecture. University of Navarra (Spain) (http://www.unav.edu/en/web/escuela-tecnica-superior-de-arquitectura)
- MDGAE. Master Degree in Environmental Management and Building Design. University of Navarra (http://www.unav.edu/en/web/master-en-diseno-y-gestion-ambiental-de-edificios/home)
- PHD Programme on Environmental and Technological Design in Architecture. University of Navarra

Industrialized sunspace prototype with solar heat storage

The thermal performance of two passive solar components has been investigated. An attached sunspace with horizontal heat storage and another one with vertical thermal storage were designed in order to optimize the use of solar gains and its storage and distribution in an industrialized component.
These sunspaces have been tested under real conditions, comparing their thermal performance with two commonly used components in residential buildings in Spain: a window and a double window making up an attached sunspace. Different series of experimental measurements were conducted in two test-cells exposed to outdoor conditions in Pamplona (Northern Spain). As a result, nine scenarios during winter 2011 and six during summer 2012 have been carried out, comparing all of the prototypes two by two with different use modes.
Results show that a sunspace with heat storage takes advantage of the solar energy and improves the indoor thermal performance of the adjacent room during winter in a better way than a window or a simple sunspace, and that it also offers better performance in summer. The best results in winter and summer were obtained when an appropriate use of the component was performed, in concordance with outdoor conditions. Several thermal control keys for the use of these components are suggested.

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Assessment of post-occupational behaviour in adaptive facades

Research in adaptive facades located in Spain and in Southern Mediterranean areas, looking for truly efficient energy and thermal performance, and for occupants evaluation (through comfort and use surveys), to validate the design and optimization of adaptive facades.
Collaborators: María Martinez Ruidiaz, Miren Juaristi

Involved person in COST Action: Prof. Dr. Aurora Monge-Barrio

Time span: 2007 - 2012, 2015 - 2016
Contact data: amongeb@unav.es

Associated Publications:

1. A. Sanchez-Ostiz, A. Monge-Barrio, S. Domingo-Irigoyen, P. Gonzalez-Martinez, Design and experimental study of an industrialized sunspace with solar heat storage, Energy and buildings 80 (2014) 231–246.
2. A. Monge Barrio, A. Sánchez-Ostiz, S. Domingo Irigoyen, P. Gonzalez Martinez, Sun-space: industrialized element for energy saving, Conference Proceedings of the Energy Forum. Solar building skins, Bressanone, EF Economic Forum, 2012.

Fig. 1: P4 Prototype. Sunspace with vertical solar heat storage. Images of University Campus in Pamplona (Spain).

Fig. 2: P1 Prototype. Sunspace with horizontal solar heat storage. Images of University Campus in Pamplona (Spain).

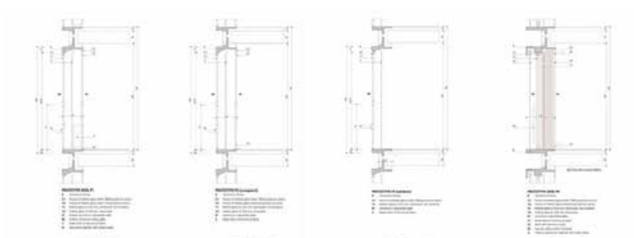


Fig. 3: Vertical sections of the prototypes monitored, including a window and a double façade to be compared with P1 and P4 prototypes.

Fig. 4: Barcelona Growth Centre in Barcelona (Spain), previously named MediaTIC. Case study in Post-Occupational Behaviour Research in Adaptive Facades.

3 Modeling and simulation of adaptive facades
Opportunities to advance the development of innovative concepts

Roel Loonen, Jan Hensen. Eindhoven University of Technology

Research information

The potential of adaptive facades

Adaptive facades provide buildings with the flexibility to respond to variable weather conditions and occupant preferences (Fig. 1 and Fig. 2). They are recognized as a promising design concept for achieving high levels of indoor environmental quality (IEQ), while offering potential for low-energy building operation. The interest in adaptive facades is therefore growing steadily.

Decision-support tools in design and product development

Prescription-based design methods, rules-of-thumb and simplified calculations have only limited value in supporting decision-making in the complex design process of buildings with adaptive facades. Dynamic simulations on the other hand are able to provide insights into whole-building performance aspects of adaptive facades throughout various stages of the building design process. Simulation-based support can also be a helpful tool in the product development process of innovative facade concepts.
A major obstacle is that most of the currently used building performance simulation (BPS) programs have limited options for modelling the time-varying behaviour of dynamic building envelopes. More research is needed to develop effective strategies for performance prediction of adaptive facades.

Simulation support for research and development (R&D)

The objective of our research is to investigate how computational modelling, simulation and optimization techniques can be used to support, stimulate and accelerate the transition towards next-generation adaptive façade systems. We do this by developing and applying computational methodologies to facilitate design analysis and performance-based design space exploration of innovative adaptable building envelope components and concepts.
BPS adds many favourable opportunities to design and product development processes, because it:

- allows for testing multiple what-if scenarios in a virtual, and thus relatively inexpensive way;
- can be a useful resource for managing risk and uncertainty in product development, and thus increases chances that promising concepts successfully make the transition from lab to market;
- is able to detect the relationships between relevant whole-building performance indicators, going beyond component-level metrics such as U-value or g-value;
- generates useful inputs for many types of subsequent analyses, such as life cycle assessment, business models and marketing strategies.

Research examples

Many of our present research projects are carried out in collaboration with academic and industrial partners. Examples include:

- Energy harvesting smart window systems for enhanced daylight control and thermal comfort (i.c.w. www.peerplus.nl).
- Building-integrated transparent concentrating photovoltaic solar shading (Fig. 3) (i.c.w. http://www.solarswingenergy.com).
- Windows with switchable reflection properties in the near infra-red part of the solar spectrum.
- Opaque building elements with adaptable thermal insulation.

Involved persons: Roel Loonen, Jan Hensen

Time span: 2014 - 2017 (EU COST Action TU1403)

Contact data: r.c.g.m.loonen@tue.nl

Associated Publications:

1. Loonen, R.C.G.M., Trčka, M., Cóstola, D., & Hensen, J.L.M. (2013). Climate adaptive building shells: State-of-the-art and future challenges. *Renewable and Sustainable Energy Reviews*, 25, 483-493.
2. Loonen, R.C.G.M., Singaravel, S., Trčka, M., Cóstola, D., & Hensen, J.L.M. (2014). Simulation-based support for product development of innovative building envelope components. Automation in Construction, 45, 86-95.
3. Hensen, J.L.M., Loonen, R.C.G.M., Archontiki, M. & Kanellis, M. (2015). Using building simulation for moving innovations across the "Valley of Death". REHVA Journal, 52(3), 58-62.

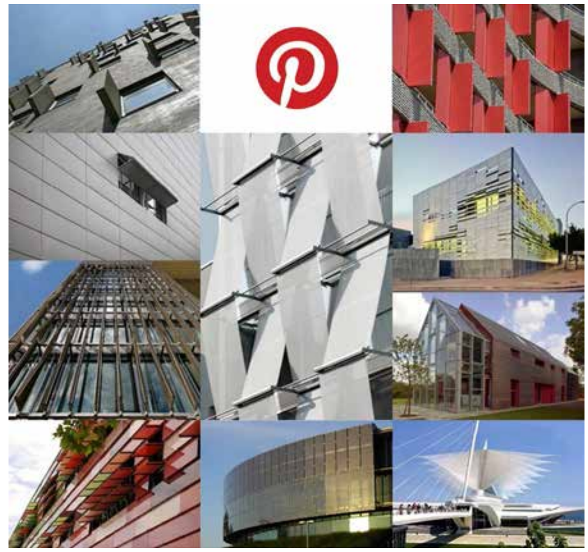


Fig. 1: Adaptive façade systems are available in many different shapes and colours. On www.pinterest.com/CABSoverview, we keep an overview with currently more than 400 adaptive façade concepts.

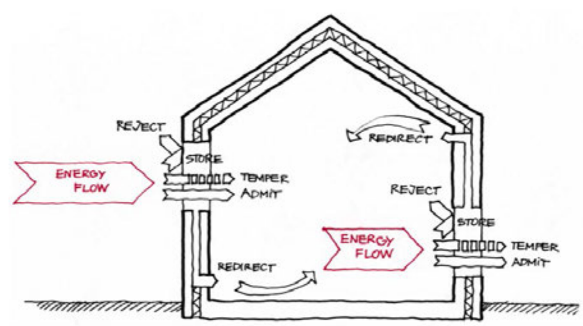


Fig. 2: Illustration of the dynamic energy flows and interactions in buildings with adaptive facades (from: IEA EBC Annex44, adapted by Fernández Solla (2014)).

Fig. 3: SolarSwing Energy® in the roof of a glazed sunspace

4 Passive and active control systems for adaptive glazing facades and envelopes

▶ Chiara Bedon, Filipe Santos, Claudio Amadio, Corneliu Cismasiu

▶ Research information

Introduction

Glass curtain walls and glazing systems are used in modern buildings as envelopes and enclosures for wide surfaces and large spaces, due to a multitude of aspects (Fig.1). In them, tensile brittle panels are connected - through mechanical or adhesive joints - with steel frameworks or aluminium bracing systems. Due to the interaction of several structural components the behaviour of the so assembled system is rather complex to predict, especially under exceptional loading conditions such as explosive events [1].

Passive control devices for glazing systems during explosive events

Passive, semi-active or active control systems have been broadly applied in buildings and infrastructures over the past decades, as additional sources of structural damping, stiffness or strength – especially for vibration control applications and mitigation of wind or earthquake effects. In order to avoid severe damage of the glass panels, the supporting framework or cable-net and the structural background, hence possible injures, several typologies of dissipative devices are investigated and proposed to be introduced at the support points of each modular glazing unit. In the case of cable-supported façades, these devices can consist of elasto-plastic (EP) dampers at the cables ends, as well as viscous solid dampers (VE) applied at the points of support of the single glass panes (Fig. 2, [2,3,4]). The application of the same design concept to stick or unitized glazed curtain walls can take the form of VE dampers or elasto-plastic devices (e.g. ADAS devices) replacing the traditional rigid brackets [5]. In both façade typologies, VE dampers are typically able to provide additional flexibility at the façade restraints and significant damping capacities to the assembled glazing systems. EP devices, due to yielding of special steel components, can also ensure appropriate energy dissipation. A recent application of active control systems to cable-net façades is proposed in [6].

Adaptive glass panels using smart materials

Innovative and markedly efficient active control systems can find application in cable-net glazing systems under blast as well as in large glass panels under ordinary dynamic loads (Fig.3). The main structural concept, in this latter case, is to control the deformation of single glass panels due to wind loads, taking advantage of shape-memory alloy actuators, working through thermal activation by Joule heating. A strain based PID control approach is used to effectively adjust the shape of the glazing system, according to the daily variations in main speed (Fig.3).

▶ Involved persons: Dr. Chiara Bedon (UniTS, IT)
Dr. Filipe Santos (UNL, PT)
Prof. Claudio Amadio (UniTS, IT)
Prof. Corneliu Cismasiu (UNL, PT)

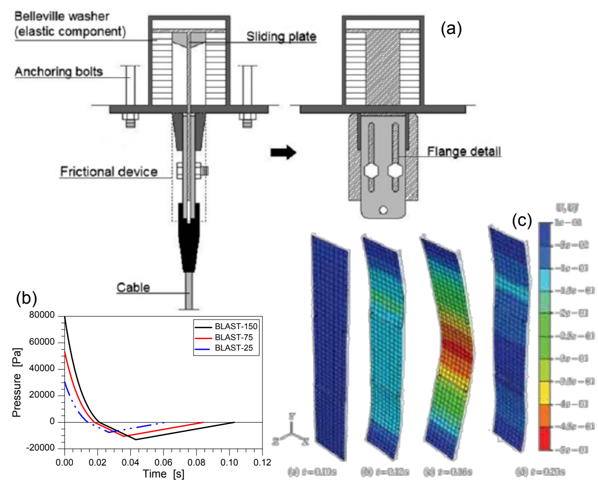
▶ Time span: 2011 - ongoing

▶ Contact data: bedon@dicar.units.it (UniTS); fpas@fct.unl.pt (UNL)

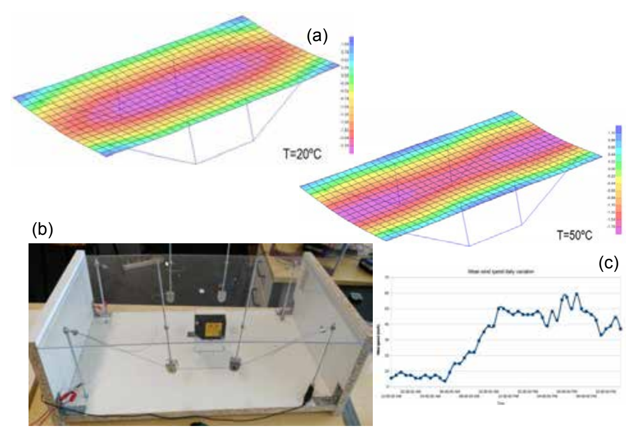
▶ Associated Publications:

1. STOLZ, A., BEDON, C., VAN DOORMAAL, A., HABERACKER, C., GŐTZ, H., LARCHER, M., SAARENHEIMO, A., SOLOMOS, G., THAMIE, L. (2015) *Numerical simulations for classification of blast loaded laminated glass: possibilities, limitations and recommendations.* European Union Publications Office, Report EUR 27137 EN, doi:10.2788/083832, ISBN 978-92-79-46172-9
2. BEDON, C., AMADIO, C. (2014) *Exploratory numerical analysis of two-way straight cable-net façades subjected to air blast loads*. Engineering Structures, 79(11): 276-289.
3. AMADIO, C., BEDON, C. (2012) *Viscoelastic spider connectors for the mitigation of cable-supported façades subjected to air blast loading.*, Engineering Structures, 42(9): 190-200.
4. AMADIO, C., BEDON, C. (2012). *Elastoplastic dissipative devices for the mitigation of blast resisting cable-supported glazing façades.* Engineering Structures, 39(6): 103-115.
5. AMADIO, C., BEDON, C. (2012) *Blast analysis of laminated glass curtain walls equipped by viscoelastic dissipative devices.* Buildings, 2(3): 359-383. MDPI-Open Access Publishing (Basel, Switzerland) DOI: 10.3390/buildings2030359. http://www.mdpi.com/2075-5309/2/3/359
6. SANTOS, F., CISMASIU, C., BEDON, C. (2015) *Smart glazed cable façade subjected to a blast loading.* Structures & Buildings, *accepted for publication*

▶ **Fig. 1:** Example of a cable-net façade (Markthal in Rotterdam, The Netherlands). http://www.royalhaskoningdhv.com



▶ **Fig. 2:** Example of elasto-plastic passive device for cable-net façades [4]. (a) Schematic view; (b) air blast time-pressure wave; (c) dynamic response of a cable-net modular unit (University of Trieste, Italy).



▶ **Fig. 3:** Adaptive glass panel, with smart cable system. (a) Finite element simulations; (b) smart panel prototype and (c) wind pressure daily variation (Universidade Nova de Lisboa, PT)

5 Saxion University of Applied Sciences (NL)
Research Centre for Urban & Environmental Development

▶ Christian Struck, Jan de Wit, Richard van Leeuwen, Annemarie Weersink

▶ Saxion Hogeschool (NL)

Saxion University of Applied Sciences with more than 26,000 students, at three locations in Enschede, Deventer and Apeldoorn, is one of the largest institutions for higher education in the Netherlands. Saxion has a rich history, with roots tracing back to 1875, see Fig. 1.

Saxion consists of eleven schools among which the school of Creative Technology, Business, Building and Technology as well as Life Science, Engineering and Design. Over the last years Saxion has become a recognized centre of expertise for 'Living Technology' on a regional, national and international level.

The focus on 'Living Technology' overarches the school's activities and defines technology as an integral part of the human environment. It thereby links educational programs and research activities dedicated to e.g. healthcare, building and system design, education and IT services.

▶ Research group: Sustainable Energy Systems

The research group Sustainable Energy Systems (SES) lead by Prof. Jan de Wit is one of seven groups organized in the Research Centre for Urban & Environmental Development, part of the School Life Science, Engineering and Design.

The group SES focuses its research and development activities on the efficient generation, distribution and utilization of energy from sustainable sources. The multidisciplinary team of experts, see Fig. 2, consisting of mechanical, chemical, process and building services engineers as well as building physicists works on projects clustered around four research topics:

1. Generation of bio-energy and bio-based economy,
2. Comfort and energy use in smart buildings,
3. Development of energy-neutral areas and districts,
4. Energy efficiency in industry and processes.

Research topic 2: "Comfort and energy use in smart buildings"

The research theme "comfort and energy use in smart buildings" focuses on the provision of a comfortable indoor environment for its occupants whilst minimizing the energy use of the required mechanical equipment. The group makes use of extensive workshop and laboratory facilities for the dynamic performance characterization and monitoring of components for energy generation, distribution and storage, see Fig. 3. The dynamic performance evaluation of mechanical components goes beyond the steady-state approach under design conditions and enables the performance characterization under close-to-real conditions.

▶ Research projects, selected

1. SOTAC 9/2015-12/2016

SOTAC targets the performance evaluation and market analysis of a solar-driven chiller for the built environment. The deliverables are: (1) the characterization of a solar-driven thermo-acoustic cooler under laboratory conditions, (2) the development of a dynamic simulation model for building integrated performance evolution and (3) stakeholder specific design requirement for a successful market introduction.

2. Sustainable Intelligent Buildings (DIG) 1/2013-12/2015

DIG focuses on increasing the longevity of the existing building stock by increasing the adaptability of its building services. The hypothesis is that an adaptive building services system topology is capable of compensating demand peaks and is thereby able to provide improved indoor air quality. Focusing on classrooms, a school's hybrid ventilation system is monitored and airflows are re-directed to predictively control the indoor environment based on the number of pupils and outdoor environmental conditions.

2. ECOVAT 1/2015-1/2016

ECOVAT is dedicated to the development, testing and monitoring of an underground water tank for seasonal thermal energy storage. SES provides support for the development of a grid balancing system governing the conversion of electric to thermal energy being stored in the unit.

▶ **Fig. 1:** City campus Saxion, Enschede

▶ **Fig. 2:** Sustainable Energy Systems Group – Team

▶ **Fig. 3:** SES laboratory facilities: a) prototypical pyrolysis plant, b) climate chamber, c) IAQ measurement equipment

▶ Publications, selected

Struck, C., D. Markov, P. Stankow, G. Ilic, M. Serafimov, A. Seerig, and D. Bionda, 2014b, Towards compensating the HVAC system degradation phenomena with adaptable building elements: 13th International Conference on Sustainable Energy Technologies.

Struck, C., A. Seerig, D. Jurt, D. Ehrbar, and V. Wouters, 2014c, Beurteilung des Einflusses des Klimawandels auf den Heiz- und Kühlenergiebedarf von Schweizer Bürobauten: BauSIM 204 "Gebäude für Menschen".

van Leeuwen, R., J. Fink, J. de Wit, and G. Smit, 2015, Upscaling a district heating system based on biogas cogeneration and heat pumps: Energy, Sustainability and Society, v. 5, p. 16.

van Leeuwen, R. P., J. B. de Wit, J. Fink, and G. J. M. Smit, 2014, Thermal storage in a heat pump heated living room floor for urban district power balancing - effects on thermal comfort, energy loss and costs for residents: SMARTGREENS 2014 - 3rd International Conference on Smart Grids and Green IT Systems, p. 43-50.

Wit, J. B. d., 2014, Back to the future: simpele oplossingen van vroeger vragen om hoogwaardige technologie van nu: Enschede, Saxion Hogeschool, 71 p.

6 Spectrally selective glazing systems Circadian characteristics

Prof. Ing. Jozef Hraška, doc. Dr. Ing. arch. Roman Rabenseifer., Ing. Hanuliak Peter, PhD., Ing. Peter Hartman, Ing. Arch. Paulína Šujanová

Research information

Introduction

The significance of the biological effect of light on human behaviour, also known as circadian efficiency of light became a frequently discussed issue during last decade. Biological stimulation demands more complex requirements than visual perception. In fact, biological stimulation is invoked mostly by light, which penetrates into the retina; thus in the case of a sitting person, the vertical plane at eye height should be evaluated in terms of light design. The parameters that have the most powerful effect on human biological response are: illuminance level, spectral composition, distribution, timing and duration of light exposure [1]. Since the action spectrum of biological entrainment differs from the visual stimulation (fig. 1), the spectral composition of the light has received higher attention.

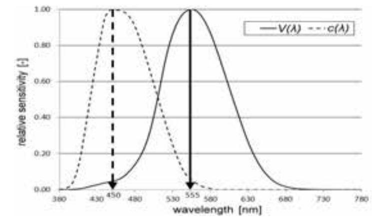


Fig. 1: Curves of action spectrums of biological system - c(λ) and visual system - V(λ) with peak sensitivities.

Glazing systems

For a large part, modern architecture relies on glazing products. Glazing systems in the building's envelope are irreplaceable but since the market offers unlimited possibilities in terms of glazing properties we have to be informed about all the consequences. Glazing systems act as an initial filter of the daylight that penetrates into the building and has the ability to change its spectral properties.

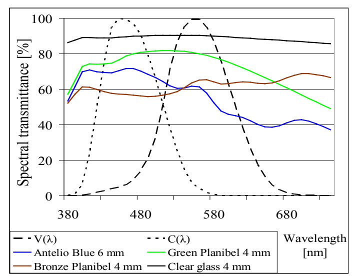


Fig. 2: Spectral transmittances of the tested glazing plotted over the sensitivity curves of circadian and visual systems. Types: Planibel Bronze 4 mm; Planibel Green 4 mm; Antelio Blue 6 mm and clear glass 4 mm were used.

Testing and evaluation

Three models of a typical office were tested with selected special glazing types and one, a reference model was equipped with clear glazing in a natural daylight scenario. Spectral transmittance of the glazing samples show differences in the course of wavelengths (fig. 2).

The Konica Minolta CL–500A device installed inside the models was used for the investigation into modified indoor daylight SPD levels at all specified positions. The outputs of SPD were used as the primary input for our calculation program based on Rea`s computational model method [2] – the Circadian Light (CLA) and Circadian stimulus (CS) were evaluated.

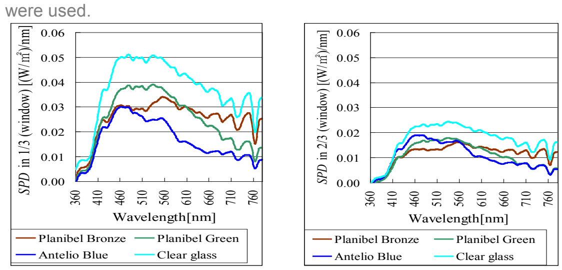


Fig. 3: SPD levels recorded in 1/3 and 2/3 of the model room's length – sensor oriented toward window

Results

The results from illuminance levels and CLA in the experiment confirmed the fact that high illuminance levels are able to cover a deficiency in spectral composition. Despite the important blue band filtrating glazing – Planibel Bronze, the CS levels were appropriate for rhythms entrainment and there were minor differences in comparison to clear glass. The results of CS were approximately 0.60 for clear glass and 0.49 for Planibel Bronze glazing. When we used a shading obstacle, imitating the surrounding buildings (α_{ev} = 30°), the CS for particular positions became more different in rooms equipped with tinted glazing as compared to the reference room. These outputs indicate that despite of very high illuminance levels with clear blue sky, the glazing caused a noticeable negative impact on both visual and non-visual human response especially when in combination with external dark coloured shading obstacles. When the illuminance level reached less than 400 lx, the CS levels were less than 0.5. It can be expected that especially during winter, in association with low external illuminance levels, the negative influence of an inappropriate selection of glazing will be much more obvious.

The circadian photometry is still under investigation. The establishment of strict requirements for non-visual indoor daylight evaluation is a long–lasting issue. Continual progress in the scientific field states the importance of this research. Continuation of this research may help to design healthier buildings and thus reduce the SAD and circadian disruption occurrence especially in industrialized countries at higher latitudes.

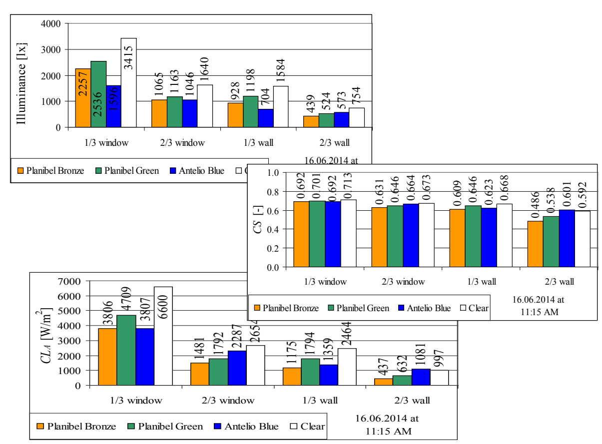


Fig. 4: Photopic illuminance levels recorded at all positions in all models - CLA levels estimated with Rea`s equation for all positions in all of the models - Computed CS levels acquired from Rea`s model in all positions in all of the models

Involved persons: Prof. Ing. Jozef Hraška, PhD.
Time span: 2012 - 2016
Contact data: jozef.hraska@stuba.sk

Associated Publications:

1. BELLIA, L.SERACENI, M.: A proposal for a simplified model to evaluate the circadian effects of light sources. Lighting Research and Technology, 46(5), (2013), 493-505. doi: 10.1177/1477153513490715.
2. REA M. S, FIGUEIRO M. G, BULLOUGH J. D, BIERMAN A. 2005. A model of phototransduction by the human circadian system. Brain Research Reviews 2005, 50/2, 213-228.

7 Sustainable building construction technology for better living conditions

C. Alonso (COST action contact), M. Olaya, I. Oteiza, J. Salas, B. Frutos, B. Arranz, JM. Chillon, J. Galvan, F. Martín-Consuegra

Research information

Research on living conditions and sustainable building construction technology

Knowledge and technology on comfort and functionality in buildings from the end user perspective. Analysis and proposals for:

- Energy rehabilitation in buildings and especially in the housing sector.
- Thermal performance of the building enclosure, energy monitoring and simulation.
- Analysis of system and components in building facilities.
- Indoor air pollution, mechanisms of natural and forced ventilation.
- Remedial actions against radon gas entry in living spaces.
- Vibroacoustic in building systems.
- Industrialization and rationalization of housing construction systems.
- Construction materials and system technology for housing in developing nations.
- Sustainability assessment in buildings, proposals for improving life cycle performance.
- Improving the use of living spaces for people with disabilities or other limitations.

Recent research projects

1. Social housing in large Spanish cities. Façade energy refurbishment with innovative DIT and DITE systems (REFAVIV) funded by the Spanish Ministry of Economy and Competitiveness (2013-2015)
2. Energy retrofitting of social housing, using innovative window products satisfying CE marking requirements. (REVen) (2015-2018)
3. Optimization of mitigation solutions against indoor radon and development of a design method for protective strategies. (Zero-Radon) funded by the Spanish Ministry of Economy and Competitiveness 2014-2017)

LABS. Experimental facilities:

- Acoustic performance of materials and building elements.
- Thermal performance of building components.
- Energy monitoring and comfort analysis of buildings.
- Indoor air quality. Contamination by radon.

Proposals for participation in this cost action:

Harmonisation in the concept of facade passivity values.

Involved persons: Arch. PhD student Carmen Alonso
Dr. Manuel Olaya, department director
Dr. Ignacio Oteiza, group director
Dr. Julian Salas
Dr. Borja Frutos
Dr. Beatriz Arranz
Eng. José María Chillón
Eng. PhD student Jorge Galvan
Arch. PhD student Fernando Martín-Consuegra

Time span: 2011 - 2017

Contact data: c.alonso@ietcc.csic.es i.oteiza@ietcc.csic.es

Associated Publications:

1. OTEIZA, I. ALONSO, C. MARTIN-CONSUEGRA, F. MONJO, J. GONZÁLEZ-MOYA, M. (2015) Energy Retrofitting for Social Housing by Improving the Building Envelope: Madrid, 1939-1979. *The Sustainable Renovation of Buildings and Neighbourhoods*. Betham Science Publishers.
2. ALONSO, C. GONZÁLEZ, M. OTEIZA, I. MONJO, J. Hacia una rehabilitación de la vivienda social. Transmitancia e inercia térmica de la envolvente vertical de edificios singulares en madrid 1939-1979. 2014 Rehabend congress.
3. MARTÍN-CONSUEGRA et al. (2014) Analysis and proposal for energy efficiency measures for the main building of the Eduardo Torroja Institute – CSIC. *Informes de la construcción* 66
4. SALAS, J. LUCAS, P. (2012) The validity of Previ, Lima, Peru. *Open House International* 37
5. FRUTOS et al. Experimental study of effectiveness of four radon mitigation solutions, based on underground depressurization, tested in prototype housing built in a high radon area in Spain. *Journal of Environmental Radioactivity* 102
6. ALONSO, C. OTEIZA, I. GARCÍA-NAVARRO, J. (2011) Environmental analysis of residential building facades through energy consumption, GHG emissions and costs. 2011 Helsinki World Sustainable Building Conference.

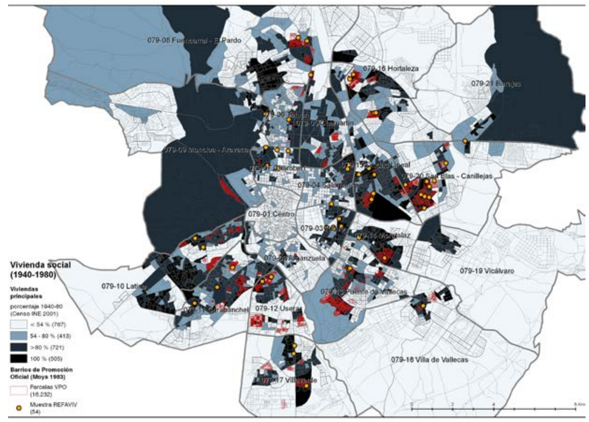


Fig. 1: Madrid sample for social housing façade energy refurbishment (REFAVIV project)

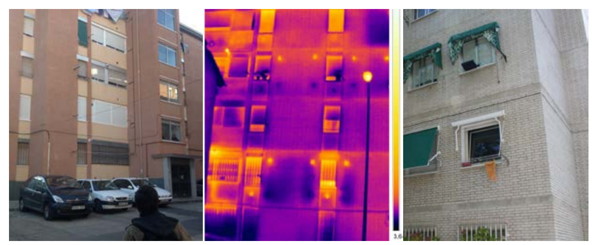


Fig. 2: Monitored buildings for façade energy refurbishment (REFAVIV project)

Fig. 3: Tested systems for facade refurbishment (REFAVIV project)

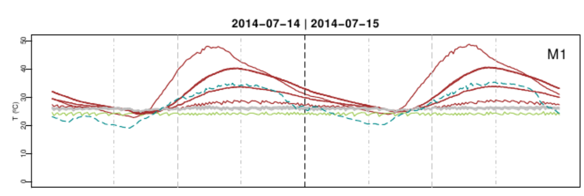


Fig. 4: Monitored data in experimental facilities (REFAVIV project)

GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD
CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

Eduardo Torroja Institut for Construction Science. CSIC. Spanish National Research Council.

8 University of Minho (UMinho)
School of Engineering, Department of Civil Engineering

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Universidade do Minho
Escola de Engenharia
Departamento de Engenharia Civil

The University of Minho

The University of Minho is a research university, engaged in the valorisation of the chain of knowledge - Research, Development and Innovation - as is evidenced by a series of indicators. The ratio between PhD students and PhD teaching staff is more than 1; the share of postgraduate students in the total student population exceeds 20%; 80% of the teaching staff hold a PhD; the ratio between research projects and PhDs is higher than 0.5; around 150 PhD theses are awarded every year; the average yearly production of refereed papers published in international magazines is 2/full time equivalent/year; and 250 R&D contracts are signed every year with external companies. Amongst the 30 University Research Units reckoned by The FCT (Portuguese Science Foundation), 18 were considered in 2009 to be Very Good or Excellent by International Evaluation Panels, placing the UMinho on the top of the Portuguese Universities ranking. The Times Higher Education 100 under 50 University Ranking 2014 ranked UMinho on the 64^{th} position worldwide. The CWTS Leiden Ranking 2015 placed UMinho as the 2^{nd} Portuguese university "PP top 1%" and "PP top 10%"; 1^{st} Portuguese university "PP top 50%"; 2^{nd} Portuguese university "PP top 50%" in "Physical sciences and engineering".

The Research Team

The group active in the project is the Building Physics and Construction Technology Group (http://lftc.civil.uminho.pt) that is a part of the Department of Civil Engineering and the CTAC - Territory, Environment and Construction Research Center (Sustainable Construction Group). The group has expertise in building technology with a special focus on product development, building thermal performance, ventilation and indoor air quality, natural lighting in buildings, renewable energy, building acoustics, sustainable development and building renovation with a special focus on nZEB, cost optimisation and building performance simulation. The group has excellent lab facilities and is well equipped in these fields. Its main objectives are the promotion and implementation of solutions that result from the scientific research made by its researchers, as well as to serve the community by undertaking specialised projects and consultancies.

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Associated Projects:

1. IEA EBC Annex 56 project – Energy and Carbon Emissions Optimization in Building Renovation (Coordinated by Manuela Almeida)
2. IEA ECBCS Annex 50 – Prefabricated Systems for Low Energy Renovation of Residential Buildings
3. H2020 MORE-CONNECT – Development and advanced prefabrication of innovative, multifunctional building envelope elements for MOdular REtrofitting and CONNECTion
4. H2020 BAMB - Developing Buildings as Material Banks (BAMB), eliminating waste and establishing symbiosis in supply industries.
5. INPATH-TES - PhD on Innovation Pathways for TES (thermal energy storage technologies)
6. FP7 IEE project - SouthZEB - nZEB training in the Southern EU countries – Maintaining building traditions
7. COST Action TU1205 - BISTS - Building Integration of Solar Thermal Systems
8. COST Action TU0802 - Next generation cost effective phase change materials for increased energy efficiency in renewable energy systems in buildings

Fig. 1: Real scale test cells

Fig. 2: Thermal and acoustic chamber and outdoor test cell

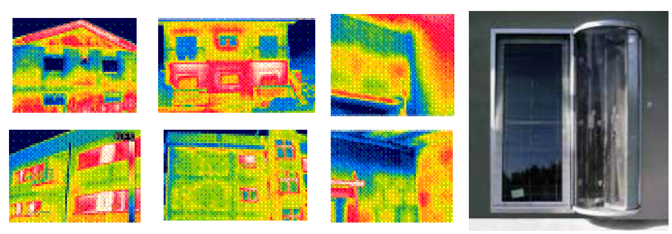


Fig. 3: IR assessment of buildings and smart window

Associated Publications:

1. C. Lamnatou, D. Chemisana, R. Mateus, M. G. Almeida and S. Monteiro Silva (2015), *Review and perspectives on Life Cycle Analysis of solar technologies with emphasis on Building-Integrated solar thermal systems*. Renewable Energy Journal, Volume 75, March 2015, Pages 833–846. (http://dx.doi.org/10.10.16/j.renene.2014.09.057)
2. M. Ferreira, M. Almeida, A. Rodrigues and S. Monteiro Silva (2014), *Comparing cost optimal and net-zero energy targets in building renovation* in Building Research & Information Journal. (http://dx.doi.org/10.1080/09613218.2014.975412)
3. M. Ferreira, Manuela Almeida, A. Rodrigues (2014), *Cost Optimality and Net-Zero Energy in the Renovation of Portuguese Residential Building Stock - Rainha Dona Leonor Neighborhood Case Study* in International Journal of Sustainable Building Technology and Urban Development. (http://dx.doi.org/10.1080/2093761X.2014.979268)
4. M. Almeida, M. Ferreira, A. Rodrigues and A. Coelho (2014), *Deep energy retrofit of vernacular housing*. REHVA Journal. Volume 6, "Innovative HVAC system solutions in high performing buildings, (http://www.airtradecentre.com/downloads/AA/Rehva/rehva-newsletter-6-2014.pdf)
5. S. Monteiro Silva, P. P. Silva, M. Almeida and L. Bragança (2013), *Operative Conditions Evaluation for Efficient Building Retrofit – Case Study*. Indoor and Built Environment Journal (doi:10.1177/1420326X12456542).

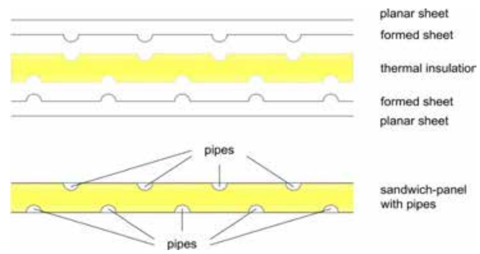
9 Research topics at the Institute of Building Construction TU Graz UNAB; KAWO

▶ Prof. Dr. Englhardt Oliver; Em. Prof. Dr. Gamerith Horst; Dr. Zellinger Manfred; Mr. Schober Helmut; Mr. Schabernak Uwe

▶ Research information

UNAB - Sustainable Design Process and Integrated Building Envelopes

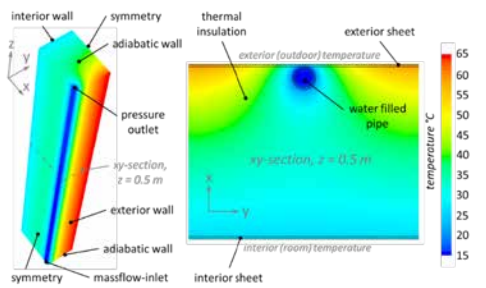
In the course of the research project “Sustainable Design Process and Integrated Building Envelopes“ (UNAB) the potential of solar activated sandwich panels, which simultaneously enable thermal conditioning (heating and cooling) of the interior rooms is being analysed. These features are achieved by conforming the shape of the inner and outer steel sheets of the sandwich panel to pipes filled with a heat transfer fluid. A parameter study was performed in order to find a suitable construction, using three-dimensional CFD and FEM models. In a first step the results regarding the fluid outlet temperature, the heat transfer efficiency and the thermal protection were compared. In a second step the positive static influence of the pipes, especially on normal stress within steel sheets and elastic deformation of the whole sandwich panel was evaluated.



▶ **Fig. 1:** Solar activated sandwich panel (cross section).

In the course of an initial thermal evaluation a number of different geometrical and operational scenarios of the thermally activated sandwich panel were conceived. The computed temperature contours of these scenarios are shown in Figure 3. The variations are as follows:

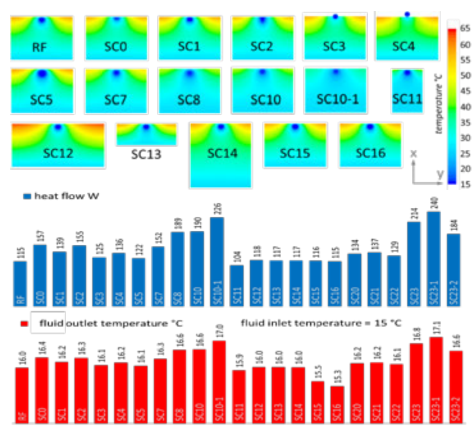
- ✓ Shape of the fluid pipes, whereby all pipes had the same sectional area
- ✓ Position of the fluid pipes
- ✓ Size (radius) of the fluid pipes
- ✓ Sheet thickness and wall thickness of the pipes
- ✓ Materials for pipes and sheets
- ✓ Distance (y-length) between the pipes
- ✓ Thickness (x-length) of the thermal insulation
- ✓ Volume flow rate of the fluid inside the pipes



▶ **Fig. 2:** Three-dimensional thermal reference CFD model (RF) and a section through the xy-surface with temperature contours at the middle of the panel´s height (z-length = 0.5 m) for summer conditions.

After the preliminary evaluation of a variety of scenarios a wave profile was chosen for further investigation on the thermal behaviour and heat flow. For this investigation a sandwich panel with the wave profile was modelled over one as well as two stories with a storey height of 3.5m.

In further investigations a network of pipe channels and an integrated glass cover will be examined to improve the thermal performance of the sandwich panel. Moreover, the thermal insulation is glued shear-fixed to the sheets in conventional sandwich panels. A following step is to realize the shear-fixed joint without glue, only by means of mechanical connections.



▶ **Fig. 3:** Comparison of the temperature contours & of the non-area-weighted heat flow of a single pipe and the fluid outlet temperature between the RF scenario and the scenarios SC0 - SC16.

▶ Involved persons: Prof. Dr. Englhardt Oliver
Dr. Zellinger Manfred
Dr. Mach Thomas
Mr. Schober Helmut
Mr. Schabernak Uwe
Mr. Brandl Daniel

▶ Time span: 2014 - 2016

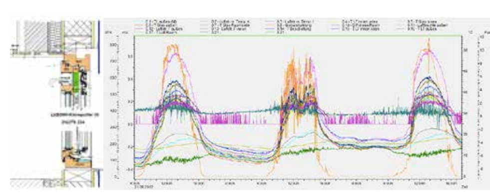
▶ Contact data: englhardt@tugraz.at
schabernak@tugraz.at

▶ Associated Publications:

1. SCHOBER, H.; BRANDL, D.; et al (2015) *Hybrid Element Façade - Thermal Engineering and Related Structural Evaluation of a Solar Activated Integral Panel*. Technical University of Graz Publishing

KAWO

In the Kawo system a multifunctional window element assumes the function of preheating the fresh air and acts as a supply air element for the room beyond. Together with a highly efficient, demand-controlled ventilation system and an absorption heat pump in the attic, the entire hot water supply of the prototype building section is realized with this innovative window element in addition to the ventilation. The project was the first plus energy refurbishment of a residential building in Austria and was awarded as Europe's trend-setting "House of the Future“ – demonstration object by an international jury.
For the façade the main ideas of the Kawo system form the basis for current research at the Institute of Building Construction on a bigger scale.



▶ **Fig. 4:** Simulation data & cross section of the Kawo system

▶ Involved persons: Prof. Dr. Englhardt Oliver
Em. Prof. Dr. Horst Gamerith
Mr. Ferk Heinz

▶ Contact data: englhardt@tugraz.at
ferk@tugraz.at

10 Improving building sustainability by optimizing facade shape and solar insulation use

Aleksandar Petrovski

Research information

Introduction

A method is introduced that optimizes the environmental and the economic aspects of different design proposals. The optimization methodology is tested on an ongoing public procurement project where the south facade is optimized.

It is argued that redesigning and optimizing the facade shape and glazing percentage can substantially contribute to a positive environmental influence as well as economic and social benefits.

Research methods

A new optimization methodology is proposed utilizing parametric optimization tools coupled with energy performance tools to evaluate several design proposals from environmental and economic aspects regarding the sustainability of the building.

Optimization coupled with energy simulation programs allows the design space to be explored in the search for an optimal or near optimal solution(s) for a predefined problem.

The methodology is tested on three models of an existing building situated in Skopje, R. of Macedonia, positioned between three neighbouring buildings where only the south-east facade is exposed to the sun.

Results

Model 1 represents the building with its current energy performance.

Model 2 represents the existing building with a refurbished facade. The choice of insulation fell on a product by manufacturer Knauf Insulation because of its sustainable characteristics. It is a product of the innovative ECOSE technology based on renewable materials. This technology has a positive environmental impact due to a reduction of embodied energy in the insulation material of up to 70% compared to standard materials using conventional binders.

Model 3 represents the building redesigned with an optimized south-east facade. The optimized surface which has the strongest genes and maximal fittest value is subjected to window perforation.

It can be concluded that Model 3 is most optimal in terms of energy performance due to several factors. The most significant factor is the optimal shape of the facade and its irregularity outperforms the existing facade in terms of optimal solar insulation and possibilities for passive solar heating.

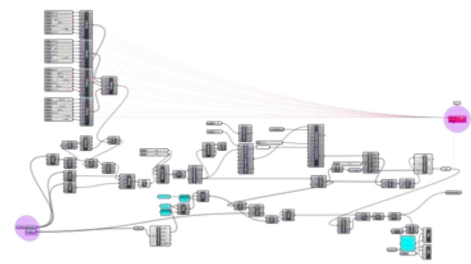


Fig. 1: Optimization algorithm

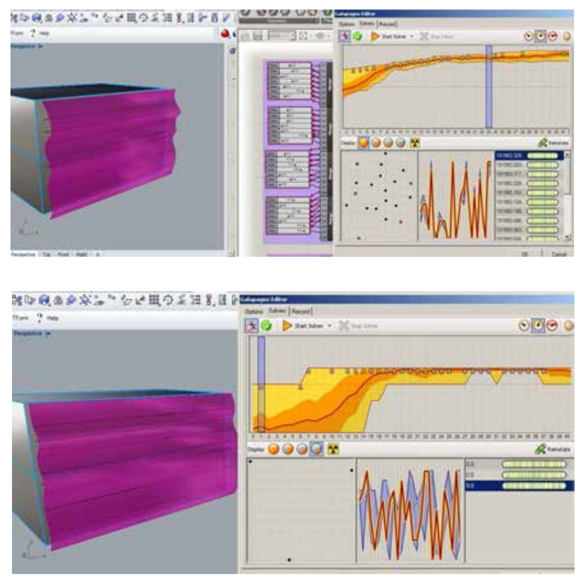


Fig. 2: Optimization of the facade shape regarding insulation

Involved persons: MSc Aleksandar Petrovski

Time span: 2012 - 2016

Contact data: petrovski.aleksandar@arh.ukim.edu.mk

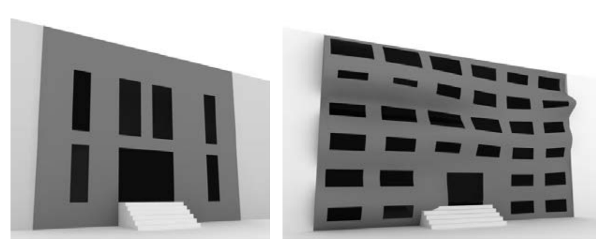


Fig. 3: Models 1 and 2 Model 3 – Optimized facade

Associated Publications:

1. PETROVSKI, A., ZILESKA-PANCOVSKA, V.& Zujo, V (2014) Improving building sustainability by optimizing facade shape and solar insolation use. International Scientific Conference People, Buildings and Environment 2014 (PBE2014), Kromeriz, Czech Republic , p. 374-383.
2. PETROVSKI, A., ZILESKA-PANCOVSKA, V., & KOCHOV, A. (2014) Sustainable improvement of the energy efficiency of an existing building. Mechanical Engineering - Scientific Journal, 23(1).
3. PETROVSKI, A., MARINA, O., DIMKOV, G. & PAPASTEREVSKI D., (201) Sustainable design improvement of healthy built environment. Proceedings of 2nd International Academic Conference on Places and Technologies, Nova Gorica, p.52-58.

11 Development of outdoor test facility cells to evaluate the thermal performances of real-scale envelope components in an oceanic climate

Maxime DOYA, Francis ALLARD

Research information

Introduction

Current building energy simulation (BES) tools calculate envelopes' energy budgets on the basis of thermal and optical characteristics measured with standard climate-controlled tests (Guarded hot-box, hot-plate, Calorimeters, spectrophotometer). However, studies tended to prove the dependence of these parameters to seasonality and components interaction under real climates. Also, efforts are made by designers to develop adaptive technologies capable of addressing evolving energy needs. Thus, the thermal characteristics shall no longer be determined with static methods.

The Paslink / Passys European projects developed procedures in order to determine thermal dynamic properties in outdoor test facilities. Experimental measurements obtained following these procedures can be processed according to several data-fitting techniques in order to assess dynamic properties and their potential cycling variations. Recent test facilities were built with similar purposes (TWINS in Torino, KUBIK in Bilbao, VERU in Hölzkirchen, ZEB in Trondheim, etc.) striving to respond to a growing need of standardization of procedures for robust comparison of results. Tipee platform and La Rochelle University participate in the development of a multiple test-cell facility providing the possibility of testing thermal performance of façade and roof components with their original joints and anchorages to the primary building structure.

Description Of The Test Facility

The construction is on-going and due in June 2016. Five cells are implemented (Fig.1): Two pairs of twin cells (for both façade and roof components) are required in the technical specifications assuming comparison might be needed for scientific evaluation of 2 technologies. The last test bed is built across double height and will be used to test components requiring an application on large volumes (industrial buildings, ventilated façade, etc.) Façade rigs are oriented south and south-west. Cells backsides are included in a controlled thermal guard to guarantee controlled boundary conditions.

Special attention is paid to joint design technology to bond the test component to the cells. The concept is such that the technology should allow an evaluation of thermal performances of most building envelope's technical solutions with or without their original ties. This features means that the studied envelope solutions can be regarded with or without thermal bridges (near 1-D conductive heat transfer). A specific numerical method was designed to evaluate heat fluxes due to thermal bridges and to implement their dynamic contribution within BES (Fig. 2).

Research On Identification Methods

The dynamic thermal characteristics used in a numerical model of an envelope system are usually identified by a fitting method applied to real measurements. Considering the current level of development, heat fluxes and temperature evolutions resulting from preliminary BES are used as experimental measured data to test existing methodology to identify static thermal characteristics (thermal resistance, volumetric heat capacitance) of reference wall components with a deterministic RC-model (Fig. 3).

On-going research consists of evaluating identification methodologies –thermal transfer models, fitting methods and instrumentation (basic set of sensors) – allowing to identify dynamic thermal properties on reference façade components.

Methodologies currently in evaluation are:

- ✓ Numerical inversion of one-dimensional conduction heat transfer model performed through finite differences method.
- ✓ Development of continuous time models matching test cells thermal behaviour and estimation of influencing parameters through statistical approach
- ✓ Numerical inversion of thermal quadrupole models

The current approach focuses on façade components made of single or multiple material layers. Future researches will be targeting adaptive technologies (double skin façade, movable solar shadings, a.o.) with a more complex description of thermal models for data fitting.

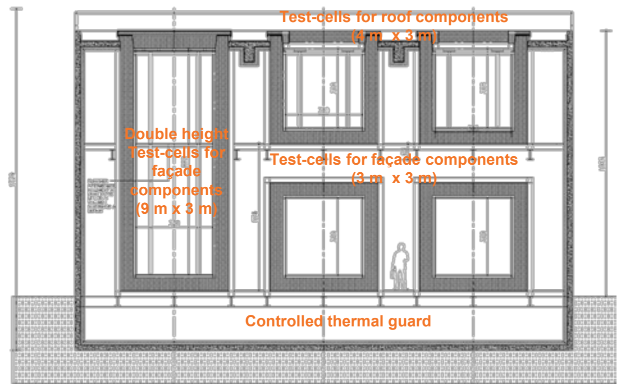
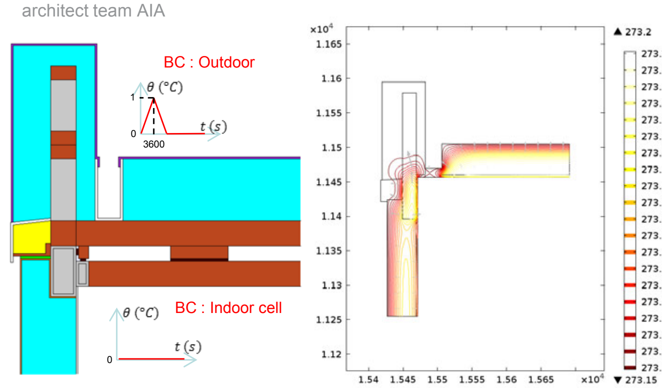


Fig. 1: Front view of design plans for the Tipee's test cell facility drawn by architect team AIA



Cross-view of double-height cell's acroterion and boundary conditions

Isothermal contours of resulting heat transfer displayed after 24 hours

Fig. 2: Evaluation of linear thermal bridge in a time-dependent heat transfer

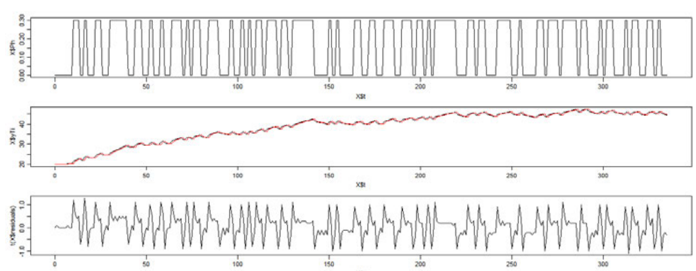


Fig. 3: : Typical heating impulse sequence, indoor air temperature measured (black) and fitted (red), residual function of an identification process (model *TiTeTh*, Bermani's Master Thesis)

Involved persons: Prof. Allard Francis, Dr. Doya Maxime
Time span: 2013 - 2016
Contact data: maxime.doya@univ-lr.fr

Associated Publications:

1. F. Causone, M. Doya, F. Goia, O. K. Larsen, A. Kindinis, V. Serra Experimental facilities for adaptive façades characterization // submitted paper for 10th Advanced Building Skin Conference (03-04 November 2015, Bern, Switzerland).

2. V. Viola ,A. M. Frigerio, supervisor: M. Doya, Master Thesis, Full-scale testing facilities: development of experimental procedures of Tipee test facility, Politecnico Di Torino, 2013

3. E. Bermani, supervisor: M. Doya, Master Thesis, Evaluation of methodologies for the identification of parameters influencing heat dynamics in reference building facade, Politecnico Di Torino, 2015

12 Active Thermoelectric Intelligent Apertures for high efficiency building facades

M. Santamouris, D. Kolokotsa

Research information

Introduction

The quality and energy efficiency of building envelopes are the most important factors that affect the energy consumed for heating and cooling as well as indoor comfort. Analysis of building envelopes is complicated due to the diversity of building materials and climates, as well as practices of building design and construction. There are vast differences in construction practices and optimum envelope technologies between the various EU regions mainly due to the climatic diversions. Moreover although there are technologies able to improve the envelope performance as a passive component there are still issues to be addressed in terms of applicability to particular climatic conditions while more ground-breaking strategies should be pursued. As a result, the building envelope should be understood as a smart and active component able to dynamically respond to occupants' comfort requirements by simultaneously decreasing significantly energy waste and demand.

The adaptive façade concept

The research is focused on the development of a smart high efficiency Active Building Envelope (ABE) facade that integrates effectively and efficiently photovoltaic (PV) panels with innovative nano-thermoelectric systems while contributing to a 65-70% higher primary energy efficiency with respect to the existing conventional heating and cooling approaches. The concept is depicted in Figure 1. A series of smart high efficiency components will be developed to be then combined in a single product ready to be integrated in existing building envelopes. The product will be able to dynamically self-adapt its features to the outdoor climatic conditions, energy requirements and occupants' comfort demands by harmonically regulating and integrating the various units as depicted in Figure 2.

The adaptive façade components

The development of a smart active building facade that makes use of innovative technology integrates the following (see Fig. 1 and Fig. 2):
- Nano thermoelectric (TE) units integrated into a heat exchanger able to convert the electric power directly into cooling and heating.
- Photovoltaic panels to produce the necessary electric power for the TE units.
- The heat sink.
- Internal heating/cooling surface panel that will provide the necessary heating and cooling to the indoor environment through radiation and ventilation heat transfer.
-Smart control unit for the overall system's monitoring and operation.

The overall concept has a wide interdisciplinary approach as it combines the following research areas: nano materials technology for semi-conductors application in TE, energy conversion and energy efficiency technologies for building envelopes, energy production by building integrated PV as well innovative sensing systems to control and optimise the real time performance of the envelope. Moreover, the concept covers the whole cycle starting from the components' design and testing, to its architectural aspects to its installation in case studies (Fig.3).

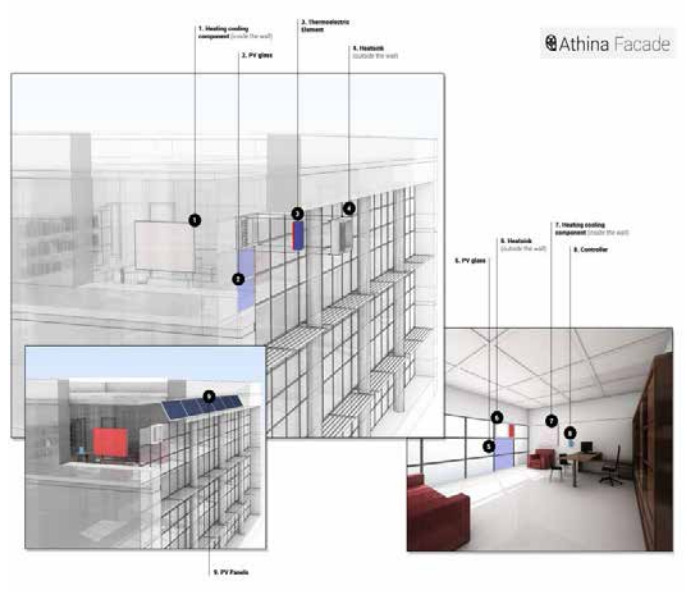


Fig. 1: The ATHINA components: Heating-cooling component, PV glass, thermoelectric element, heat sink

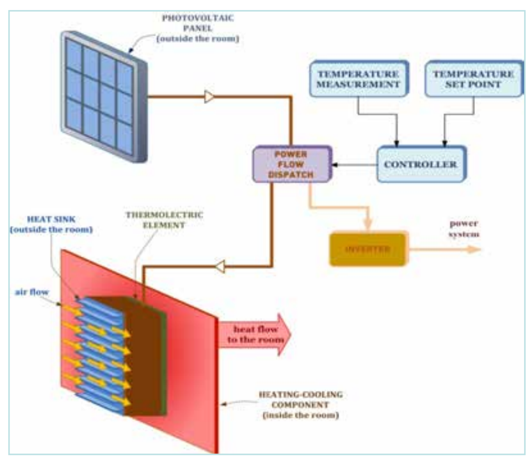


Fig. 2: Interrelation of the facade components

Fig. 3: Installation of ATHINA facade

Involved persons: Prof. Mat Santamouris
Dr. Denia Kolokotsa

Time span: 2014 - ongoing

Contact data: msantam@phys.uoa.gr, dkolokotsa@enveng.tuc.gr

Associated Publications:

1. A. Shakouri, "Recent Developments in Semiconductor Thermoelectric Physics and Materials," *Annual Review of Materials Research*, vol. 41, no. 1, pp. 399–431, Aug. 2011.
2. M. Gillott, L. Jiang, and S. Riffat, "An investigation of thermoelectric cooling devices for small-scale space conditioning applications in buildings," *International Journal of Energy Research*, vol. 34, no. 9, pp. 776–786, Jul. 2009.
3. B. P. Jelle, A. Gustavsen, and R. Baetens, "The path to the high performance thermal building insulation materials and solutions of tomorrow," *Journal of Building Physics*, vol. 34, no. 2, pp. 99–123, 2010.

13 Ongoing research on structural glass Dep. of Civil Engineering University of Coimbra Portugal

Sandra Jordão, Luis Simões da Silva, Aldina Santiago

Research information

Summary

The research on structural glass at the University of Coimbra started in 2010 under the auspices of COST Action TU 0905 (Structural glass |Novel Design Methods and Next Generation Products). In 2011 a research project was funded by the Portuguese Foundation for Research and Technology (S-Glass). It was a joint project with the University of Minho (PI Prof. Paulo Cruz) concerning the behaviour of laminated glass beams with a pre-stress system under monotonic, cyclic and thermal load. A hybrid layout with steel flanges was also considered.

Within this framework, the University of Coimbra performed the full scale tests and the numerical finite element modelling of the referred structural layouts.

Eleven MsC theses have been produced at the University of Coimbra on the topic of researching glass.

Other topics of research: long-term behaviour of structural glass elements, rehabilitation of structural glass and development of a hand-held application for the support of design of structural glass.

Involved persons: Prof. Dr. Sandra Jordão
Prof. Dr. Luís Simões da Silva
Prof. Dr. Aldina Santiago

Time span: 2011 - 2015

Contact data: sjordao@dec.uc.pt

Associated Publications:

1. Jordão, S., Pinho, M., Martins J.P., and Santiago, A., "Behaviour of laminated glass beams reinforced with pre stressed cables", *Steel Construction – Design and Research*, Special issue 3/2014 (2014). DOI: 10.1002/stco.201410027 http://onlinelibrary.wiley.com/doi/10.1002/stco.201410027/abstract

.2. Jordão, S., Pinho, M., Martins J.P., Santiago, A. and P. Cruz "Numerical modeling of laminated glass beams reinforced with pre stressed cables" in Christian Louter, Freek Bos, Jan Belis and Jean-Paul Lebet (Eds.), *Challeging glass 4*, COST Action TU0905 Final Conference, February 6-7, Lausanne, Switzerland, (2014).

3. Jordão, S., Pinho, M., Martins J.P., and Santiago, A., "Behaviour of laminated glass beams reinforced with pre stressed cables" in Landolfo, R. and Faggiano, B. (Eds.), *Eurosteel 2014*, September 10-12, Napoli, Italy, (2014).

4, Firmo, F., Jordão, S., Costa-Neves, L., Gonçalves, A., Pinho, M. and Lopes, C.,"Behaviour of steel-glass hybrid beams" International Conference on recent advances in rehabilitation and sustainability of structures, 1-2 June 2015, Açores, Portugal.

5, Gomes, C.; Jordão, S.,Santiago, A. and Pinho, M., "Laminated glass beams subjected to high temperature" International Conference on recent advances in rehabilitation and sustainability of structures, 1-2 June 2015, Açores, Portugal.

6, Tavares, C.; Jordão, S., Rebelo, C. and Pinho, M., "Laminated glass beams subjected to cyclic load" International Conference on recent advances in rehabilitation and sustainability of structures, 1-2 June 2015, Açores, Portugal.

7. Imre, V.; Jordão, S.; Santiago, A., "Mobile application for structural glass" International Conference on recent advances in rehabilitation and sustainability of structures, 1-2 June 2015, Açores, Portugal.

8. Jordão, S.; Costa Neves, L.; Pinho, M., "Rehabilitation of glass load bearing structures" International Conference on recent advances in rehabilitation and sustainability of structures, 1-2 June 2015, Açores, Portugal.

9, Jordão, S., Pinho, M., Martins, J.P. e Santiago, A., "Modelação numérica de vigas de vidro laminado" in Simões da Silva, L., Silvestre, N. e Santos, F. (eds.), IX Actas do IX Congresso de Construção Metálica e Mista, 24-25 Outubro, cmm Press, Porto, Portugal (2013).

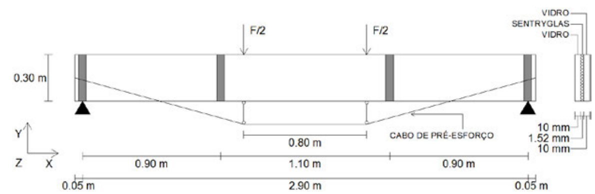


Fig. 1: Layout for the full scale tests as part of the S-Glass project at the University of Coimbra (pre-stressed non-hybrid system)

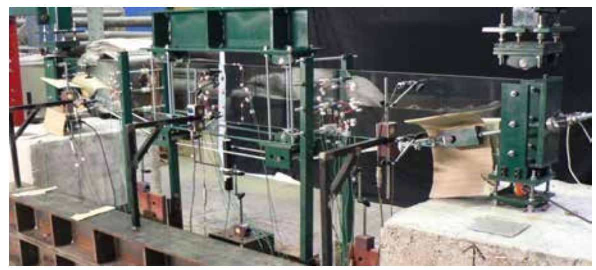


Fig. 2: Experimental setup for the full scale tests as part of the S-Glass project at the University of Coimbra (pre-stressed non-hybrid system)

Fig. 3: Thermal conditioning chamber for glass testing, University of Coimbra

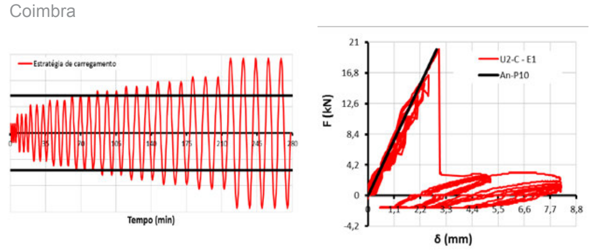


Fig. 3: Cyclic tests: Load strategy and damage in elastic and post fracture regimen.

14 Considerations of the building envelope in terms of energy efficiency and its impact on humans

▶ Aleksandra Krstic-Furundzic Serbia

▶ Research information

Introduction

Office buildings have one of the highest levels of energy consumption and CO_2 emissions compared with energy consumption in other building sectors. Multi-functional and adaptive building envelopes can provide step change improvements in the energy efficiency and economic value of new and refurbished buildings, while improving the well-being of building occupants. These aspects are considered by means of the following four researches conducted at the Faculty of Architecture, University of Belgrade, Serbia:

Designing movable shading systems for adaptive envelopes to reduce energy consumption

This research is focused on the procedure how to design adaptive shading systems to reduce electricity consumption for lighting by considering possibilities of using daylight. Several shading system types that adapt to changeable environmental conditions are analysed regarding their use to control insulation on the building envelope to minimize lighting and cooling loads. The methodological approach is based on conducting lighting and thermal simulations as well as finding optimal solutions according to given criteria (Fig.1).

▶ Involved persons: Prof. Dr. Aleksandra Krstic-Furundzic
Zizic Komnen, PhD student

relationship between certain performances of adaptive facades and the daily human rhythm

The purpose of the research is to investigate the relationships between climatic conditions of artificial environments and changes of physiological functions of the human body concerning circadian clocks or the biological clock (Fig. 2). In this context the impact of the building envelope should be considered. The research method is based on an analysis of correlation between certain performances of adaptive facades, as creator of artificial indoor environment, and the daily rhythm of protective functions of the oral cavity. The idea is to create metrics and tools to evaluate the impact of adaptive facades on humans.

▶ Involved persons: Prof. Dr. Aleksandra Krstic-Furundzic
Furundzic Z. Nikola
Furundzic P. Dijana

Energy and environmental performance of different concepts of office building envelopes

This research concerns energy performances of different scenarios of office building envelope construction. Hypothetical models of the office building in downtown Belgrade are designed. A few scenarios are created for each hypothetical model: basic scenario and scenarios of two shading device types in order to reduce the cooling demand. The office building scenarios are modelled and analysed by using PHPP'2007 software to estimate final energy consumption for heating and cooling, the share of passive solar energy, primary energy consumption and CO_2 emissions (Fig. 3).

▶ Involved persons: Prof. Dr. Aleksandra Krstic-Furundzic
Ass. Tatjana Kosic, PhD student

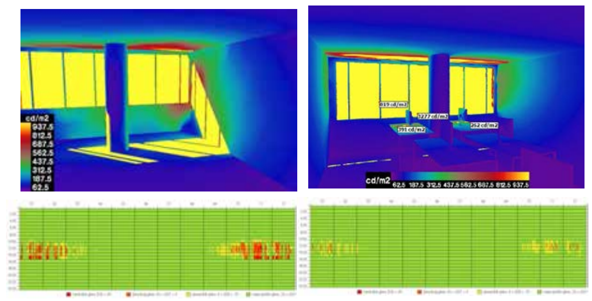
Energy and environmental benefits of application of PV modules

The main concern of the research are different models of energy efficiency improvement of the existing office buildings in Belgrade, Serbia, by integration of PV modules into the facade structure. Different variants of PV modules integration into the suspended facade are proposed as hypothetical models (Fig. 4). The methodological approach includes analyses of electric energy consumption and production, as well as analysis of CO_2 emissions, and comparative analyses of the results obtained.

▶ Involved persons: Prof. Dr. Aleksandra Krstic-Furundzic
Doc. Mr Budimir Sudimac
Ass. Andjela Dubljevic, PhD student

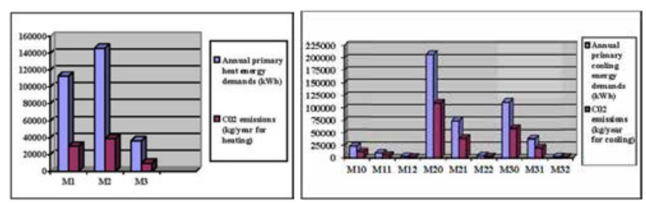
RESEARCH METHODS

Listed studies are characterized by a similar methodological approach which entails the following steps: creation or selection of facade concept, evaluation of energy and environmental performances / influence on humans and comparative analyses and discussions.



▶ **Fig. 1:** Behaviour analysis of shading system of the basic unit of an office building (numerical and graphical daylight simulations)

▶ **Fig. 2:** Circadian rhythms are regulated by circadian clocks or the biological clock (left). The building envelope separates the interior space as the artificial environment from the natural environment (right).



▶ **Fig. 3:** Annual primary energy demands for heating and CO_2 emissions (left) and annual primary energy demands for cooling and CO_2 emissions (right)

▶ **Fig. 4:** Design variants of integration of PV modules into the envelope

▶ Time span: e.g. 2013-2017

▶ Contact data: akrstic@arh.bg.ac.rs

▶ Associated Publications:

1. Krstić-Furundžić, A., Kosić, T. Assessment of energy and environmental performance of office building models: A case study // In: Energy and Buildings, Elsevier, doi:10.1016/j.enbuild.2015.06.050, Available online 22 June 2015 http://dx.doi.org/10.1016/j.enbuild.2015.06.050
2. Furundzic, N., Furundzic, D., Krstic-Furundzic, A. Responsibility to the employees' health is unavoidable in the creative and innovative design of office spaces // In: Proceedings of the 2nd International Academic Conference Places and Technologies 2015 – Keeping up with technologies to make healthy places - ISBN 978-961-6823-68-5, Nova Gorica, Slovenia, 18-19 June 2015, pp. 610-616.
3. Krstic-Furundzic, A., Sudimac B. Improvement of Energy Efficiency of Office Building in Belgrade by Application of PV Modules // In: Proceedings of the 2nd International Conference - Advanced Construction - ISSN 2029-1213, Ed: Z. Rudzionis, Lithuania, Kaunas, 11-12 November, 2010, pp. 248-254.

15 Passive use of solar energy in double skin facades to reduce cooling loads

▶ Anatolijs Borodinecs, Institute of Heat, Gas and Water technology of Riga Technical University

▶ Research information

Introduction

Most known studies on double facades focus on maximal reduction of heat gains in the summer period and use of solar energy for heating during the spring and autumn. These methods usually are used together with passive heating and passive cooling strategies as well as with active heating and cooling methods.

This study focuses on an innovative method to explore how the increase of heat gains can reduce total energy consumption by full air-conditioning systems. The double skin facades can be efficiently used to regulate the building envelope's thermal and solar resistance.

SPECIFICS OF HVAC WORKING REGIMES IN SUMMER TIME

There are four main temperatures that are usually used to evaluate the working parameters of an air-conditioning system:

- ✓ temperature of outside air t_e, °C;
- ✓ temperature of inside air (working zone) t_i, °C;
- ✓ temperature of supply air t_s, °C;
- ✓ temperature of exhaust air t_{ex}, °C.

The temperatures of supply air and exhaust air are the most important for creating optimal indoor air parameters and ensuring HVAC energy efficiency.

In a typical office building heat and moisture production (ΔQ>0, ΔG>0) occurs during the summer time. So the supply air passing through the working zone assimilates the heat and moisture, raising the temperature and moisture content of the exhaust air (Figure 2a).

RESEARCH METHODS

The research method is based on the analysis of interactions between climate, HVAC systems working regimes and thermal properties of the building envelope.

The resistance to solar radiation:

$$R_R = \frac{\Phi_R - \Phi_I}{\Phi_I}, (m^2 \cdot K)/W$$

- whereby: Φ_R is the heat flow from solar radiation coming to the outer side of the building envelope, W; Φ_I is the solar radiation heat flow that enters the building, W.

If there are heat sources in the inside space and the outside air temperature te is lower than the inside air temperature ti, the building envelope heat loss has to be equal to the internal heat gains to ensure constant inside air temperature .

In that case the thermal resistance of the building envelope has to be:

$$R_T = \frac{(t_i - t_e)A}{\Phi}, (m^2 \cdot K/W)$$

- whereby: A is area of building envelope structures, m²; Φ is heat gains, W.

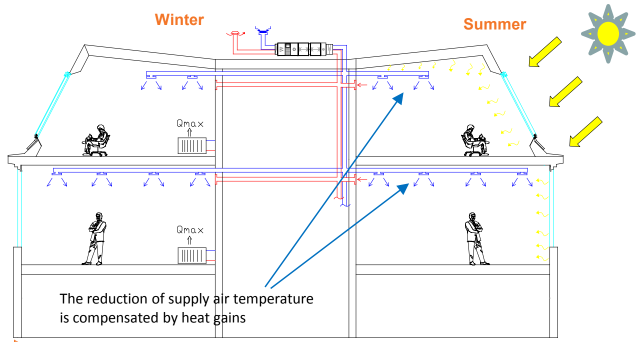
In order to evaluate the potential of passive solar energy to reduce cooling loads that can be absorbed by the external building envelope, the research is based on HVAC working regimes during the year (Figure 2b).

In general the capacity of an air-conditioning system in "dew point regime" could be calculated using the following equation:

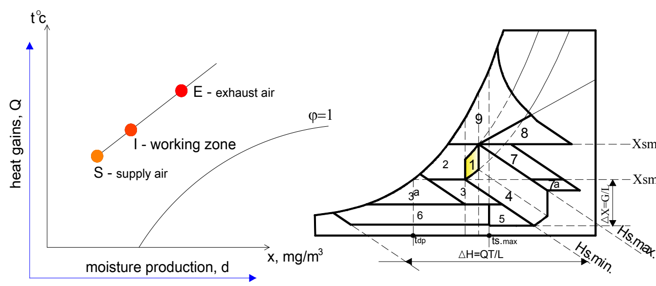
$$Q_{total} = \Delta H_{cooling} + \Delta H_{heating}, kWh$$

- whereby: energy consumption for outdoor air cooling, kWh; energy consumption for supplied air heating, kWh.

Solar energy through the double skin facades can be used to reduce heating loads using solar radiation and heat transfer from outside air to the inside through the building envelope in order to heat up the outdoor air until it reaches the minimal required supplying air temperature. For that purpose it is necessary to reduce the thermal performance of the building envelope and resistance to solar radiation.



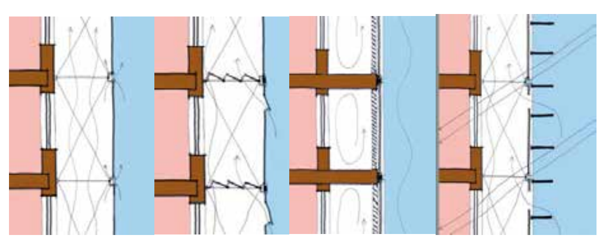
▶ **Fig. 1:** The reduction of supply air temperature is compensated by heat gains



a
Process in room with normal solar radiation and thermal resistance

b
The supply air parameters and main regulation regimes of HVAC on psychometric chart

▶ **Fig. 2:** Typical air-conditioning working regimes



▶ **Fig. 3:** : Regulation of solar resistance using external shading (Bratuskins U., Borodinecs A 2009)

▶ Involved persons: Prof. Dr. sc.ing. Anatolijs Borodinecs
▶ Time span: planned 2012 - 2016
▶ Contact data: anatolijs.borodinecs@rtu.lv

▶ Associated Publications:

1. Borodiņecs A., Zemītis J., Prozuments A. Passive use of solar energy in double skin facades for reduction of cooling loads // Proceedings of World Renewable Energy Forum (WREF) - ISBN 978-1-938547-04-1, USA, Denver, 13 -17 May, 2012. – p. 1.-6.
2. Borodiņecs A., Bratuškins U., Krēsliņš A., Pelīte U. Building Envelopes with Controlled Thermal Resistance // In: Proceedings of the World Conference SB08 - ISBN 978-0-646-50372-1 - World Sustainable Building 2008, Melbourne, Australia
3. Prozuments, A., Borodiņecs, A. The Optimal Operating Range of VAV Supply Units. In: ASHRAE/REHVA/SCANVAC Seventh International Cold Climate HVAC Conference Proceedings: Seventh International Cold Climate HVAC Conference, Canada, Calgary, 12-14 November, 2012. Calgary: 2012, pp.265-270

16 Racking testing of an innovative hybrid load-bearing panel composed of laminated glass inserted in a CLT frame

Vlatka Rajčić & Roko Žarnić

Research information

Introduction

The idea to develop an innovative multipurpose structural element arose following the recent decade of rapid development of laminated glass structural elements as well as the popularity of cross laminated timber elements. CLT frames infilled with load-bearing glass sheets represent an innovative, composite structural element that can serve as a panel with load-bearing capacity in both lateral directions. It can be used as a part of a prefabricated timber house, or as a strengthening structural element in an existing timber building, or as a supporting structural element in historic buildings during or even after their retrofitting an/or restoration. The type of element presented here has been designed to have high ductility and energy dissipating properties. It is suitable for construction of earthquake resistant structures or for increasing the earthquake resistance of existing structures. Glued-in steel rods in the frame joints provide element ductility while specially designed glass-to-wood contact along the frame joists act as energy dissipater. The panel is directly applicable for construction of adaptive facades.

Testing of panel

Full-scale samples were tested under combined constant vertical load and displacement controlled cyclic horizontal load (racking load, Fig. 1). The purpose of the racking test was to obtain data to develop a computational model of the tested type of structural element that can be used to predict the inelastic response of buildings with the glass-infilled CLT frames on seismic action. Samples were tested under combined constant vertical load of 25 kN/m' and cyclic horizontal load (racking load) up to reaching serious joint damages. Three out of twelve samples were repaired and retested. A simple repair method was employed. Along each side of the upper and lower lintel steel a threaded rod (8 mm in diameter) was placed and tightened on both ends with a nut over a 10 mm thick steel plate. By tightening the rod the timber frame was returned to its original geometry.
The test setup enables testing of panels exposed to three different configurations that simulate three different boundary conditions. In our case two boundary conditions were applied on the lower edge of the panel: free translation and rotation (1) and translation and rotation as much as allowed by the ballast; ballast could translate only vertically without rotation (2).

Test results

Table 1 presents an overview of the tested samples showing the characteristics of testing and sample configuration. The diagrams show responses of typical samples in form of hysteresis backbone curves (Fig. 2) and entire hysteric response of one original and repaired sample (Fig.3). The high level of ductility and energy dissipation as well as the effectiveness of repair is demonstrated. Similar behaviour was observed in all other cases. Damages that were concentrated in joints were repairable with a simple and cost-effective method because the laminated glass remained undamaged. The mechanism of behaviour and damage development observed during the racking test was comparable to mechanism observed during testing of a prototype box structure on a shaking table.
The single glazed panels can be applied for bracing and increase of lateral strength of internal parts of frame buildings while double glazed panels can, in addition to load-bearing, serve as the basis of different configurations of adaptive facades. The particular advantage lies in the cost-effective prefabrication and simple mounting in existing or newly constructed frame structure.

Involved persons: Prof. Dr. Vlatka Rajčić, University of Zagreb
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Time span: 2007 - 2015

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Associated Publications:

1. ANTOLINC D., RAJČIĆ V., ŽARNIĆ R. (2014) Analysis of hysteretic response of glass infilled wooden frames. Journal of civil engineering and management, Year 20, No. 4, pp. 600-608.

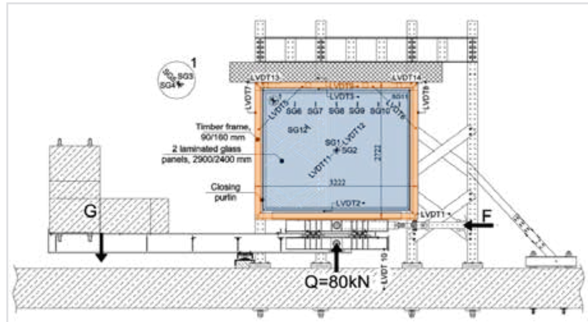

Fig. 1: Racking test set-up and instrumentation of specimen

✔ ✔

Tab. 1: Overview of the racking tested samples

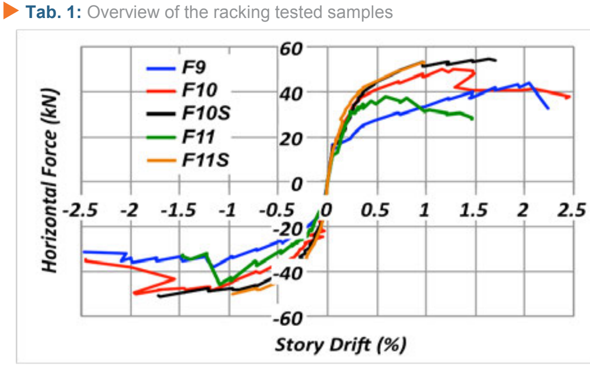

Fig. 2: The hysteresis backbone curves of the selected cases

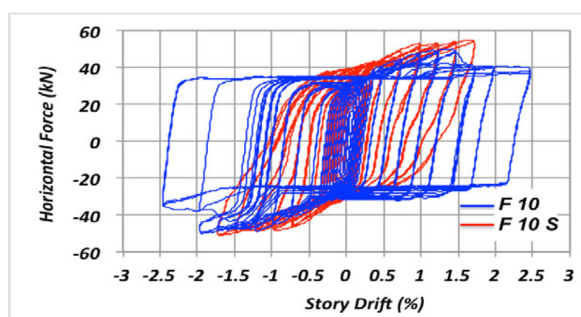

Fig. 3: Response diagrams of original and repaired double-glazed frame with φ14mm rod test setup and instrumentation of sample

17 Glass and façade technology research group University of Cambridge

Dr. Mauro Overend; Fabio Favoino; Jacopo Montali; Antonella Emili; Hanxiao Cui

Research information

gFT research group

The Glass and Façade Technology Research Group aims to provide solutions to real-world challenges in the field of structural glass and façade engineering through fundamental and application-driven research. These range from reducing the energy use in buildings achieving a higher level of environmental comfort, to improving the mechanical performance of glass and façade design / construction processes. The group consists of one senior lecturer (Dr. Mauro Overend) and 9 research students (postgraduate and postdoctoral).

Early stage façade design optimisation tool

An evaluation/optimisation framework and tool (MATLAB based) has been developed in order to evaluate and optimise façade design based on different perspectives (energy use, environmental comfort, productivity of occupants, embodied carbon of construction, economic value and whole life value).

Enabling performance prediction of adaptive façades

Various constraints limit widespread application of adaptive building envelope technologies in the construction industry. One of them being the inability to predict their energy and comfort performance when integrated into the building and the building systems. This research project aims to provide a method/design tool enabling to predict and optimise the energy and comfort performance of building integrated adaptive façade systems and controls. This framework/tool adopts an inverse approach using dynamic optimisation, solving different limitations of Building Performance Simulation tools to evaluate adaptive façade systems. The tool is based on MATLAB/ EnergyPlus, but it can easily be extended to other software.

Adaptive insulation

The ability to reject/admit thermal energy through the building envelope has high energy saving and improved thermal comfort potential. Technologically this can be achieved in different ways at a macro and micro-scale. This project aims at quantifying this potential for different applications (building typologies and climate) and at developing a cost efficient and reliable technology for this purpose.

Assessing user comfort in the perimeter zone

The occupant comfort in the perimeter zone can be stressed due to environmental and control factors. There is a lack of understanding on the interaction/control/comfort perception of building occupants in the façade zone, especially when adaptive façade components are used. This project is aimed at providing a general framework of comfort/control/interaction of building occupants in the perimeter zone of a building and at quantifying this effect in a performance metric.

Optimised façades for manufacture and assembly

Active façades should be seen more like an industrial product, where manufacturing issues, together with performance, are the most relevant drivers of design. In a typical design process, where 20% of the product is specified, 80% of costs are committed, raising the problem of including manufacturing and cost considerations at early design stages. This research project investigates methods to include manufacturing issues in the early design stages, in order to provide the designer with a quick tool for assessing the feasibility of a particular design solution.

Involvement in WGs

WG1, WG2, WG3, WG4 (Teaching and teaching material).

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Eng. Fabio Favoino (ff279@cam.ac.uk)
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Time span: planned 2014 - 2019

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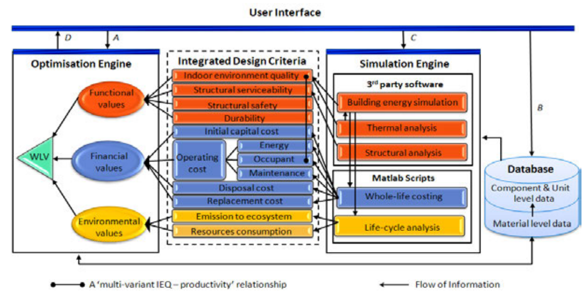


Fig. 1: Multi-objective assessment and optimisation tool for facades developed within the gFT research group. This SW framework is the basis for different ongoing research projects within the research group.

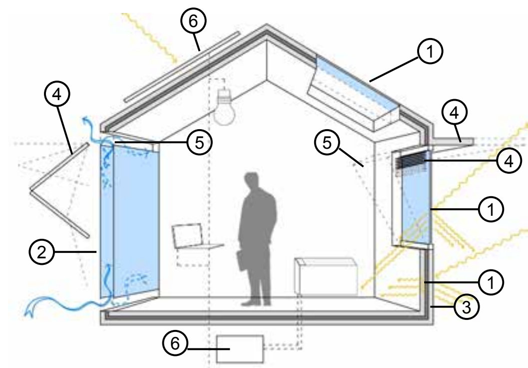


Fig. 2: Adaptive building components energy and comfort simulation capability of the tool/method developed within the gFT: 1. Construction properties; 2. Surface heat transfer; 3. Material surface properties; 4. Schedules; 5. Openings; 6. RES generation and storage.

Fig. 3: Control and optimisation of façade manufacturing process

Associated Publications:

1. Favoino F., Overend M., Jin Q., The optimal thermo-optical properties and energy saving potential of adaptive glazing technologies, Applied Energy, Volume 156, 15 October 2015, Pages 1–15.
2. Favoino F., Overend M., A simulation framework for the evaluation of next generation Responsive Building Envelope technologies, Proceedings of International Building Physics conference 2015, Torino, Italy
3. Favoino F., Fantucci S., Serra V., Perino M., Building Envelope Test CELL: development of an indoor test cell for advanced façade systems thermal performance assessment. Proceedings of Advanced Building Skins, Graz, Austria, April 2015.
4. Favoino F., Jin Q., Overend M., Towards an ideal adaptive glazed façade for office buildings, Proceedings of 6th International Conference on Sustainability in Energy and Buildings 2014, Cardiff, UK, July 2014, Energy Procedia, Volume 62, 2014, Pages 289-298, ISSN 1876-6102
5. Jin Q., Overend M. 'A prototype whole-life value optimization tool for facade design', Journal of Building Performance Simulation, 2013.
6. Jin Q, Overend M, Thompson P. 'Towards productivity indicators for performance-based facade design in commercial buildings'. International Journal of Building and Environment, Volume 57, 271-281, 2012.

18 Emporium Building Concept
Zero-energy buildings with low-exergy storage

▶ **Renee Wansdronk, architect**

▶ Research information

Wansdronk develops the solar energy, zero-emission and material saving building concept Emporium.

Energy system

A warm water storage container and heat collectors provide the space heating and hot water supply, and a cold water storage container and cool collectors deliver the space cooling and cooling source for the refrigerator. The water circulates without pumps; instead it uses thermosiphon, and therefore requires no high-grade energy such as electricity or fuel.

Building construction

A lightweight construction supports the water storage containers. This mass of water also replaces the hot and cold accumulating capacity of the building mass. The building concept is suitable for free-standing, connected, or high-rise residential and utility buildings in all climate zones. The technical feasibility has been proven and confirmed. Economic feasibility is characterized by zero-emission, biodiversity, safety, health, comfort and lifelong durability.

Exergy strategy

The Emporium concept is characterized as a seasonal heat storage with the smallest exergy loss (low-exergy), and without any energy loss. In this case exergy (applicability or quality of energy) stands for the temperatures which are used in the Emporium system, and which are as close as possible to the demand temperatures (20 ˚C indoor and 45 ˚C shower). The heat storage water temperature is above these two demand temperatures and below 100 ˚C, and between 50 and 90 ˚C throughout the year.

European research

European Commission (EC) and Innovation Partnership (EIP) projects

EC EIP SCC Smart Cities and Communities, Market Place
EC EIP SCC Smart Cities and Communities, Stakeholder Platform
EC MESSIB Multi-source Energy Storage System Integrated in Buildings
EC PETUS Practical Evaluation Tools for Urban Sustainability
ECTP QoL European Construction Technology Platform, Quality of Life
EUREC RHC Renewable Heating & Cooling European Technology Platform

European Cooperation in Science and Technology (COST) projects

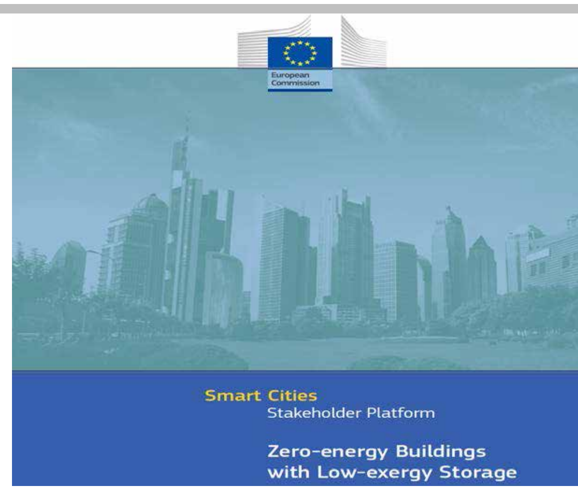
C2 Large Scale Infrastructure and Quality of Urban Shape
C8 Best Practice in Sustainable Urban Infrastructure
x12 Improvement of Building´s Structural Quality
C23 Strategies for a Low Carbon Built Environment (LCUBE)
C24 Innovative Systems for Low-Exergy in the Built Environment
E29 Innovative Timber & Composite Elements for Buildings

TU0802 Next Generation Cost Effective PCM (NeCoE-PCM)
TU1003 The effective Design and Delivery of Megaprojects
TU1104 Smart Energy Regions (SmartER)
TU1205 Building Integration of Solar Thermal Systems (BISTS)
TU1303 Novel Structural Skins through Textile Materials
TU1403 Adaptive Facades Network

▶ Involved persons: Renee Wansdronk, architect
Wansdronk Architektuur
▶ Time span: full time activity
▶ Contact data: rw@wansdronk.com

▶ Associated Publications:

1. NLD ECN 2013-11-01, Smart Cities and Communities, Key to Innovation, Integrated Solution, Zero-energy Buildings with Low-exergy Storage
2. ESP Acciona 2013-01-01, MESSIB Brochure
3. BEL CEPS 2013-06-05, Smart Cities and Communities, Key Innovations and Strategies



▶ **Fig. 1:** Smart Cities and Communities Stakeholder Platform Key to Innovation 'Zero-energy Buildings with Low-exergy Storage' based on the Emporium Building Concept and Emporium Business Interests

▶ **Fig. 2:** MESSIB examines thermal energy storage such as PCM and underground, and electric energy storage such as batteries and flywheels http://www.messib.eu

▶ **Fig. 3:** Smart Cities and Communities, supported by the European Commission (EC) to define Horizon 2020, selected the Emporium concept as Key to Innovation

19 Adaptive Façades Systems: procedures and protocols for performance monitoring & evaluation

Shady Attia[1]*

Research information

Keywords:
Façade engineering, advanced fenestration, monitoring, performance, occupant behaviour, dynamic façade, evaluation, commissioning, audits

Introduction

The assessment of adaptive facades presents a challenge because there is no established evaluation strategy to systematically reach this goal and many of the available building energy standards and codes have limited applicability for such advanced facade systems.

This paper **aims** at providing an overview of recent research and development in this field as well as the assessment of adaptive facades as integrated systems with different subsystems.

The paper reviews current evaluation methods for assessing adaptive facades system through a literature review. The review is used to identify gaps in existing assessment methods and to help develop strategies for the holistic evaluation and assessment of adaptive facade systems as part of high performance buildings.

Results: Key challenges of adaptive façade performance assessment

- Novel and Unique

Very limited number of documented case studies and many different concepts and technologies make generalisations or extrapolations biased.

- Dynamic and Complex

Performance assessments were not developed to address their complexity and dynamism. Moreover, user interaction, overrule options, understanding of the systems and other human factors play a major role in operating adaptive facades.

- Intelligent and Sensitive

It is hard to operate and control adaptive facades because they are highly climate and occupant dependent. Therefore every façade solution is extremely local, reacting to air, radiation and temperature differently.

- Unpredictable and Fragile

In many cases performance gaps between design intent and measured performance are encountered. It is less obvious to understand how they perform.

Conclusion

The assessment of adaptive facades using currently available measuring and evaluation protocols poses a number of challenges and questions, such as benchmark performance and methodology, the complexity and integration of adaptive facades with occupant response, HVAC systems and controls, technology representation and modelling information. So far we could not find a protocol for the assessment of adaptive facades. The reviewed literature is scattered and lacks a focus on adaptive facades. There is no agreement on defining what are adaptive facades (sometimes named intelligent, smart, dynamic). We could define specialized technology monitoring techniques to assess the performance of technologies such as fabric-integrated solutions (e.g. electrochromic glazing, phase-change materials, building-integrated photovoltaics with heat recovery (BIPV/T, shade shutters) and advanced controls.

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Time span: planned 2014-2018

Contact data: shady.attia@ulg.ac.be

Associated Publications:

1. ATTIA, S., Favoino, F., Loonen, R., Petrovski, A., Monge-Barrio, A. (2015) *Adaptive Façades System Assessment: An initial review, Advanced Building Skins, Bern, Switzerland (under review)*.
2. ATTIA, S., REY, E., ANDERSEN, M., (2013) Bioclimatic Facades: Architecture and sustainability: Performance studies. EPFL, Switzerland.

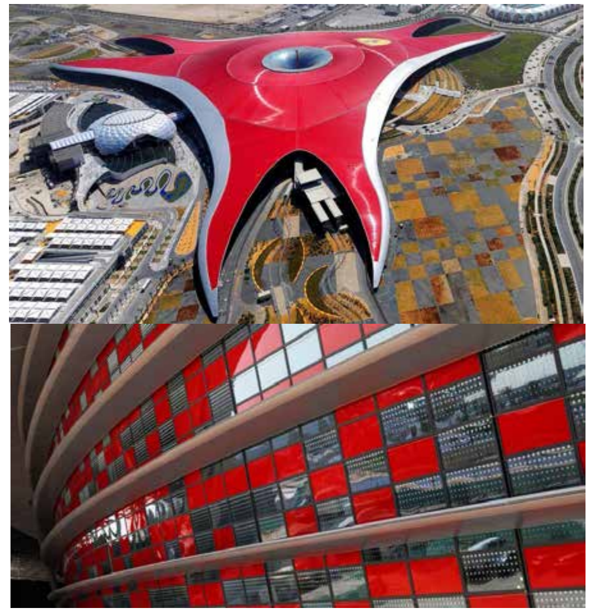


Fig. 1: Ferrari World Abu Dhabi building is aligned on the north-south axis to maximize shading from the tri-form arms on the primary façade. This has the advantage of reducing solar gain and heat loads within the building itself (www.e-architect.co.uk). The façade is furnished with solar control glass and individual screen printing. (interpane.com). (Photo top: Wikipedia.com, bottom: Interpane.com)

Fig. 2: Head office of AGC - Glass Europe. The sunshades of this building adapt automatically to the sun angle. Diffused natural light can still enter the building, because the sunshades are treated and printed with alternative bands of white. (http://www.domusweb.it)

SBD LAB
Sustainable Buildings Design Lab

20 Multiplication of optical phenomena. Façade glare studies. Understanding perception of transparency in architecture

▶ Marcin Brzezicki, Wroclaw University of Technology, Poland

Politechnika Wrocławska

▶ Research information

Multiplication of Optical Phenomena

Optical phenomena developing between the layers of glass sheets of a double façade can fundamentally change the perception of the building's transparency. Overlapping reflections, multiplying virtual images, misleading optical illusions and obstacles are difficult to predict. It is therefore essential for practicing designers to be aware of the wide range of possible perceptible obstacles and – depending on the architect's vision – to prevent them or skilfully exploit them (see. ▶ **Fig. 1a, b**) [1].

Façade Glare Studies

The purpose of this study was to investigate the effects of glare reflection on the surroundings from differently shaped glossy façades. The first stage of the research involved studying various forms of building façades, including rectangular and angular as well as concave and convex shapes (see ▶ **Fig. 2a, b**). For the second stage, concave façades were selected, as they had shown to generate the highest luminance values. This detailed examination of concave façades includes a mathematical analysis of the caustic curve and the formulation of geometrical conditions for its formation with supporting, custom-made software. In conclusion, this study suggests how designers can either avoid caustic curve formation or how to predict its precise position in the building's surroundings [4].

Understanding Perception of Transparency in Architecture

Transparency presents a challenge associated with human perception. The proper and accurate execution of this complex process is conditioned by many factors and determinants. Homogeneous transparency was not common in the real world when the mechanisms of perception evolved (unlike fog and smoke), which is why it currently presents particular problems for vision and the notion of three-dimensional (3D) architectural space. From this perspective, the introduction of large-scale, clear, thin, and uniformly transparent materials was not only a great technological breakthrough accompanying industrial revolution and new methods of manufacturing (e.g. float glass, polycarbonates, and acrylics), but also a new demand for human cognition.

In this research the issues of transparency perception are addressed from an architectural perspective, pointing out previously neglected factors that greatly influence this phenomenon on the scale of a building. The presented simplified perforated model of a transparent surface involves the balance of light reflected versus light transmitted (see ▶ **Fig. 3a**). Under certain conditions, a perforated plate is perceived as a transparent surface because multiplied small apertures, when observed from a distance, are beyond the resolution of the human eye (0.6–1.0 arc min) (see ▶ **Fig. 3b**).

The model's aim is to facilitate an understanding of non-intuitive phenomena related to transparency (e.g. dynamically changing reflectance). A verification of the presented model has been based on the comparison of optical performance of the model with the results of Fresnel's equations for light-transmitting materials.

The presented methodology is intended to be used both in the design and explanatory stages of architectural practice and vision research. Incorporation of architectural issues could enrich the perspective of scientists representing other disciplines [2, 3].

▶ Involved persons: Marcin Brzezicki, PhD

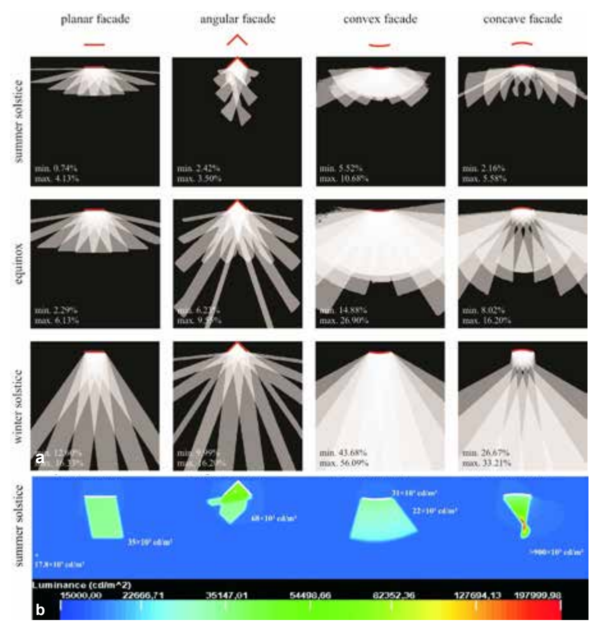
▶ Time span: planned 2010 - 2014

▶ Contact data: marcin.brzezicki@pwr.edu.pl

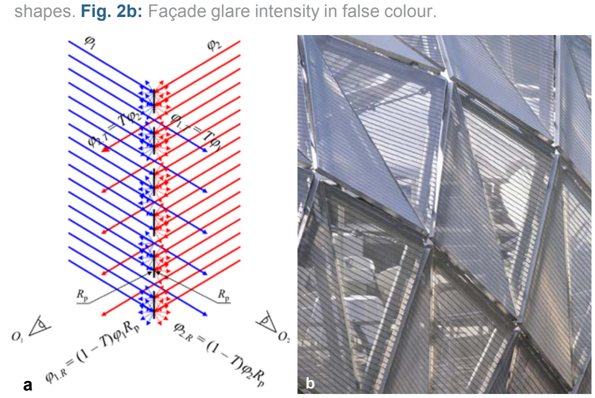
▶ Associated Publications:

1. BRZEZICKI MARCIN (2015) Redundant transparency: the building's light-permeable disguise, *Journal of Architectural and Planning Research*, Locke Science P.C., pp. 297-301
2. MARCIN BRZEZICKI (2014) *The perception of transparency in architecture. Visual and cognitive aspects*. Publishing House of WrUT, 274 pp.
3. BRZEZICKI MARCIN (2013) Understanding transparency perception in architecture: presentation of the simplified perforated model, *Perception*, 2013, vol. 42, no. 1, pp. 60–81.
4. BRZEZICKI MARCIN (2012) The influence of reflected solar glare caused by the glass cladding of a building: application of caustic curve analysis, *Computer-Aided Civil and Infrastructure Engineering*, 2012, vol. 27, no. 5, pp. 347–357.

▶ **Fig. 1a:** The multiplication of refection in double leaf facades. Department store of the Galleries Lafayette in Berlin, (arch. J. Nouvel) **Fig. 1b:** Jakob-Kaiser-Haus w Berlinie (arch. de Architekten Cie, Pi de Bruijn)



▶ **Fig. 2a:** The glare reflected off the smooth façade on the ground for south-facing test façade at different times of the year for different façade shapes. **Fig. 2b:** Façade glare intensity in false colour.



▶ **Fig. 3a:** Section through the perforated plate. Initial luminous fluxes are marked φ_1 and φ_2. O_1 and O_2 are the observers of the scene. **Fig. 3b:** The perforated metal shell is like cellular polycarbonate. The Island on the Mur in Graz, AT (arch. Vito Acconci).

21 Energy performance assessment of adaptive façades through experimental activity - TEBE (Politecnico di Torino)

Marco Perino, Valentina Serra, Alfonso Capozzoli

Research information

The experimental facilities

The energy performance assessment of adaptive envelope components requires advanced test rigs able to perform analyses at different levels: at material scale, component scale and system scale. The experimental facilities available at TEBE POLITO (fig. 1 and fig. 2) are:

- two outdoor test cells (TWINS);
- a double climatic chamber apparatus (BET cell);
- a guarded heat flow meter apparatus (GHFM).

Advanced transparent façades

In the last 10 years a number of monitoring campaigns on advanced transparent façades have been carried out, aimed at identifying methodologies for testing and data post processing and at defining suitable performance metrics. Analyses, focused on both energy and indoor comfort related aspects, so far concerned the following components (fig.3):

- Active façades based on mechanical, natural and hybrid ventilation,
- Thermotropic and thermochromic glazing,
- PCMs filled glazing and PCMs filled shading device

Opaque dynamic ventilated façades

Extensive experimental campaigns on ventilated opaque double skin façades have been carried out (Fig. 4). Summer and winter thermal performance has been investigated on three different façade configurations both through an in-field monitoring campaign and through a series of laboratory tests in a double climatic chamber apparatus (BET cell). The performance of dynamic insulated façades (supply and exhaust air configuration) was assessed in a BET cell, whilst the naturally ventilated façade (outdoor air curtain) configuration was analysed through an extensive in-field monitoring campaign under real operating summer conditions.

Thermal bridge measurement on advanced frame/glazing unit

[Activity in cooperation with gFT Glass and Facade Technology, University of Cambridge]

The quantitative evaluation of the thermal bridge effect in advanced frame/glazing unit was performed by means of the BET cell facility using two different methods. The first method relies on the measurement of the heat flow density and surface temperatures in different points along a line perpendicular to the thermal bridge area, while the second method relies on IR measurements of surface temperatures in the proximity of thermal bridge (Fig. 5).

Involved persons: Prof. Marco Perino
Prof. Valentina Serra
Dr. Alfonso Capozzoli
Lorenza Bianco, Ylenia Cascone, Stefano Fantucci, Alice Lorenzati, Gianluca Serale

Time span: 2010 - 2016

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Associated Publications:

1. Favoino F., Goia F., Perino M., Serra V. (2014) *Experimental assessment of the energy performance of an advanced responsive multifunctional façade module*. ENERGY AND BUILDINGS, vol. 68, Part B, pp. 647-659
2. GOIA F., PERINO M., SERRA V. (2014) *Experimental analysis of the energy performance of a full-scale PCM glazing prototype*. SOLAR ENERGY, vol. 100, pp. 217-233
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4. FANTUCCI, S. SERRA, V. PERINO, M. (2015) *Experimental assessment of the energy performance of an advanced ventilated clay bricks façade,* in: Proceedings of Advanced Building Skin 2015, Graz (A)
5. FAVOINO, F. FANTUCCI, S., SERRA, V. PERINO, M. (2015) *Building Envelope Test CELL: development of an indoor test cell for advanced façade systems thermal performance assessment,* Proceedings of Advanced Building Skin 2015, Graz (A)

Fig. 1: Outdoor test cell units (TWINS), Building envelope test cell (BET cell), Guarded Heat Flow Meter (GHFM)

Fig. 2: Shielded sensors and ventilated thermocouple for energy performance measurements of advanced transparent building components

Fig. 3: Prototypes tested (thermotropic, thermochromic and polycarbonate filled with PCMs).

Fig. 4: a) Ventilation scheme of the supply air configuration, b) Outdoor test in laboratory building of POLITO.

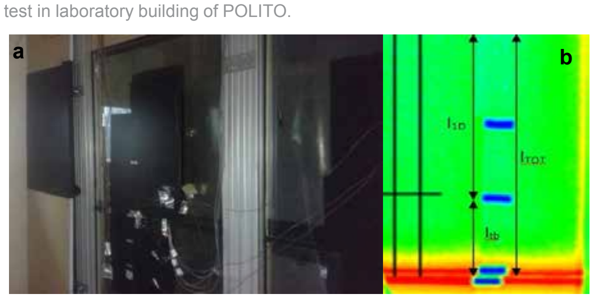

Fig. 5: a) The glazing unit equipped with sensors inside the BET cell apparatus, b) Thermal bridge infrared image.

22 Adaptive facades with energy collection and storage systems enabling zero energy operation of buildings, occupants comfort and health

▶ Philippe Lemarchand

▶ Research information

Introduction

Innovative architecturally integrated systems are required in which solar energy can (i) be offset and regulated by combining passive and active technologies within building claddings to adapt to building users comfort and avoid otherwise overheating a building, (ii) transfer the excess energy to a heat store for use at other times when heating is required, and/or (iii) provide cooling via induced ventilation.

Research Interests and Methods

Our research consists of (i) individually studying and/or developing large-area highly-insulating evacuated glazing, switchable windows, high energy-storage-density phase-change material thermal heat store that can be efficiently charged and discharged via air flow and (ii) studying how to best associate them with sensors, actuators, louvres, fans and controls in the context of the mutual optimisation of an integrated interdependent system.
Laboratory studies, extensive component and system simulations, design studies and long-term field performance characterisation in outdoor test cells are investigated to achieve a full understanding, for differing climates, weather and occupancy, of the optimal mutual interactions between system components and how they are best controlled.

Vacuum glazing

Vacuum windows that include appropriate low emittance coatings are predicted to have an overall heat loss coefficient of about 0.5 W/m2K. This is the only glazing technology predicted to achieve such low levels of heat loss whilst providing high visual and solar transmittance. Questions remain on (i) how to maintain structural stress in the glazing within acceptable limits and (ii) how to develop framing systems to avoid excessive heat loss via conduction at the contiguous edge seal of the vacuum glazing. Key interests therefore reside in techniques for the fabrication of large-area highly insulating vacuum glazing and characterisation of their thermal, optical and structural properties.

Switchable glazing

Switchable glazing components are of specific interest as they allow varying the light absorptivity or reflectivity without any mechanical part. The choice of technology, the window design and factors influencing switching duration and repeatability at elevated temperatures made to achieve required cyclability and longevity are examined both theoretically and experimentally.

PCM storage

Heat-exchange from heated air flow to a heat store using phase change material that can be efficiently charged and discharged allow to both make use of the excess of solar energy and provide a heat source when required while reducing cooling and heating energy demand. A designed PCM heat storage system offers a 600% increase in the thermal energy storage capacity during the heating season compared to sensible heat water based storage units of identical volume. It can thus be more readily fitted into smaller spaces enabling its possible full or partial inclusion in the building fabric. Investigations include materials selection that influences long-term durability such as avoiding corrosion, system design and performances.

System optimization and control

Optimisation of multifunctional facades potentially integrating switchable windows, luminescent solar concentrators, photovoltaic panels, aerogel/vacuum layers, sensors, actuators, louvres, fans, etc. required to achieve a full understanding, for different climates, weather and occupancy of the optimal mutual interactions of integrated parts of a system with interdependent physical properties/characteristics. Modularity, inter-changeability, scalability and ease of integration of assemblies and how to best control the interaction between parts are investigated to achieve near-zero-energy use and satisfy occupants comfort and health demands for both new buildings and refurbishing.

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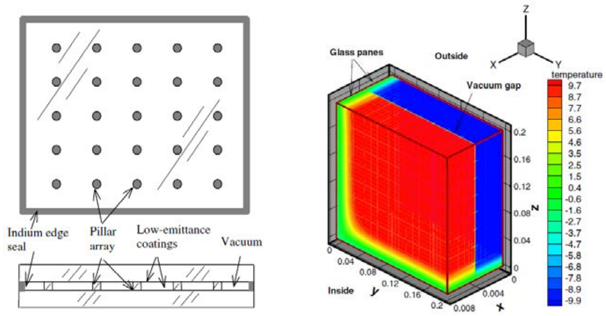
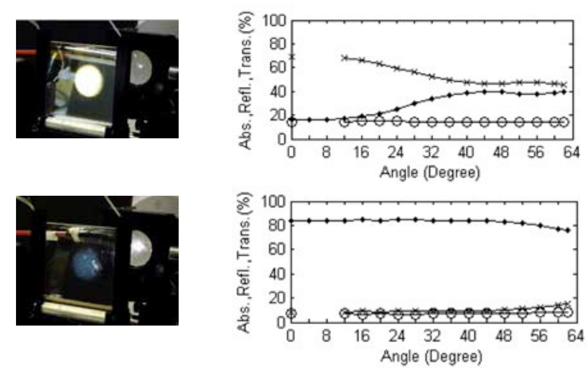


▶ **Fig. 1:** Left: Schematic diagram of a vacuum glazing. Right: Predicted isotherms for a vacuum glazing with coatings of emittance 0.12 and 0.16 on the two glass pane surfaces within the vacuum gap.



▶ **Fig. 2:** Average transmission (dots), reflection (crosses) and absorption (circles) of a chiral liquid crystal switchable mirror in the 380-780nm range with light incidence angle in the reflective state (top) and clear state (bottom).

▶ **Fig. 3:** Left: PCM-TES storage unit prototypes (0.52m tall by 1.45m diameter) developed to TRL7. Right: Three PCM-TES units stacked in a test bed laboratory fired by a CHP unit

▶ **Involved persons:** Mr. Philippe Lemarchand, Prof. Dr. Brian Norton, Dr. Mick Mc Keever

▶ **Time span:** Ongoing

▶ **Associated Publications:**

1. Fang Y., Eames P.C., Norton B., Hyde T.J., Zhao J., Wang J., Huang Y., Low emittance coatings and the thermal performance of vacuum glazing, Solar Energy, Volume 81, Issue 1, January 2007, Pages 8-12, ISSN 0038-092X.
2. Lemarchand P., Doran J., Norton B., Investigation of liquid crystal switchable mirror optical characteristics for solar energy. Proceeding of CISBAT 2013 - September 4-6, 2013 - Lausanne, Switzerland Pages 29-34, ISBN 978-2-8399-1280-8.
3. B. Norton, Thermal Energy Storage; Selection and Sizing in, Handbook of Clean Energy Systems (Jinyue Yan, Editor), John Wiley and Sons, 2015. ISBN: 978-1-118-38858-7

23 The Research Centre on Zero Emission Buildings Norwegian University of Science and Technology (NTNU)

Arild Gustavsen, Francesco Goia

Research information

About the Centre

The vision of The Research Centre on Zero Emission Buildings, ZEB, is to eliminate the greenhouse gas emissions caused by buildings.
The main objective of ZEB is thus to develop competitive products and solutions for existing and new buildings that will lead to market penetration of buildings that have zero emissions of greenhouse gases related to their production, operation and demolition.

ZEB activities

The activities of ZEB are divided in five work packages (WP), described below.

WP-1: Advanced materials technologies

The work package aims at developing new materials and material technologies for application in zero emission buildings. The main emphasis has been on materials for utilization in the building envelope. Examples of research areas include thermal insulation materials, phase change materials, building integrated photovoltaics, window materials and technologies, new lightweight glass materials, various coating materials, as well as the environmental impact of the developed materials technologies.

WP-2: Climate-adapted low-energy envelope technologies

This work package deals with development of climate adapted and verified solutions for roofs, walls and floors that minimize heat loss and reduce the need for cooling to ensure low CO_2 emissions. Concepts and solutions for multifunctional and dynamic facades, window technologies and solar shading are central research areas. Aspects related to integration of active elements in the building envelope are also essential to the work package.

WP-3: Energy supply systems and services

This work package focuses on energy supply, building services, indoor environment and building interaction. To avoid suboptimal solutions, tools are developed to find the best combination of different energy supply sources with regard to emissions and economy. Simulations and experiments together with data collection, measurements and user experiences from the ZEB pilot buildings contribute to improve future solutions, design tools and design guidelines for energy supply, HVAC and indoor environment quality.

WP-4: Energy efficient use and operation

This work package analyses how zero emission buildings perform under real life conditions that are characterized by a high number of non-technical influences. End-users exhibit unexpected behaviours, building operators act on a tight time budget, and economic considerations influence which solutions are selected when the building is built. The research conducted here aims at describing societal, cultural and political patterns that can be used to deliver zero emission buildings that work at least as well as expected when they are used, operated and implemented by real human beings.

WP-5: Concepts and strategies for zero emission buildings

The work package deals with definitions, strategies and concepts for zero emission buildings. The findings from the other work packages provide the basis for the development of general knowledge about what it takes to make a zero emission building. This includes developing transparent guidelines/instructions on how to document zero emission buildings, which in turn can form the basis for future norms and regulations. Pilot buildings are an important part of the work package

Involved persons: Prof. Dr. Arild Gustavesn (Director)
Dr. Anne Gunnarshaug Lien (Centre manager)
Ms. Katrine Peck Sze Lim (Sen. Exec. Officer)

Time span: 2009 - 2017

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Associated Publications:
The full list of publications can be retrieved at:
http://www.zeb.no/index.php/publications

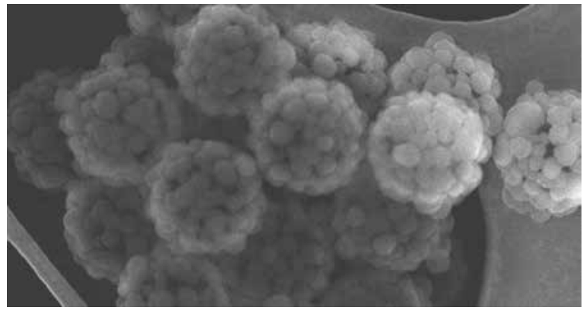

Fig. 1: Microscopy of a Nano Insulation Material (NIM) developed at the Research Centre

Fig. 2: Double skin windows with ventilation features, façade integrated solar thermal collectors and roof integrated PV panel installed on the ZEB Living Laboratory

Fig. 3: New type of a cross flow energy exchanger using membrane technology developed at the Research Centre

Fig. 4: Zero Village Bergen, one of the pilot building projects developed at the Research Centre (Illustration: Snøhetta)

24 Radiant Glass Façade as Energy Efficiency System for Building Envelopes in the Mediterranean Climate

Arch. Giuseppe La Ferla. Technical School of Architecture, Polytechnic University of Madrid – Chapman Taylor

Research information

Introduction

Commercial buildings usually have high internal loads, and short cycles of use because the main activity lasts only 8 hours during the working day. If located in the Mediterranean climate they have a limited heating demand for most of the cold season, also due to high internal heating loads. In integrated façades equipped with Radiant Glass Façade (RGF), the heating exchange area between the environment and the heat source is the whole extension of the glazing, which achieves a low increase between the mean radiant surface temperature and the inside temperature. As the temperature of the glazing is near the comfort range, the low radiant asymmetry temperature ensures better thermal comfort.

Characteristics of the system

1. The research aims to demonstrate that the technology applied to this particular climate area can serve to emit heating radiation to be used in winter as a primary heating system. When maintaining the temperature of a glass surface at near 30ºC, the indoor air temperature can be maintained at a lower level than usual, resulting in energy saving. Also in summer it can reduce heat gain from solar radiation (depending on the orientation), thus decreasing the cooling demand and achieving more energy savings in the annual energy balance of the building.

2. The main component of this technology is the Low-e glass, usually used in common insulating glazing, also known as Transparent Conductive Oxide (TCO), with optical transparency and electrical conductivity properties. If the low-e coat is a conductive layer and it is electrified with anode and cathode bars along the edge of its plane and stimulated by electrodes, it operates as a semiconductor that produces heat radiation due to its resistance.
The technology is composed of low-e double glazing (Argon or krypton filled), with an ITO electrified layer on the inner face (side #3) as radiant system; side #2 is coated with a low-e layer as well, to reduce heat loss to the outside environment by reflecting part of the radiation received from the inner panel.

3. The efficiency of the RGF system is proportional to the electrical heat output which is used to cover the heat losses from the glass and from the heating of the room, and is inversely proportional to the U-value of an unheated glass. Moreover it is practically independent of the inner surface temperature of glass, and it can be expressed by a simple linear equation of U-value (Kurnitski 2004).

Research Methods

The research method is based on three main phases:

- Validation of the theoretical model of thermal performance of windows according to ISO 15099/2003, in real seasonal experimentation with an environmental chamber module in the Mediterranean climate.
  The equations of thermal balance (Moreau 2008) for each of the glass surfaces are:

$$E_{ex}\,\varepsilon_1 - \varepsilon_1 \sigma \theta_1^4 + k_1(\theta_2 - \theta_1) + h_{ex}(T_{ex} - \theta_1) + S_1 = 0$$
$$k_1(\theta_1 - \theta_2) + h_c(\theta_3 - \theta_2) + \sigma[\varepsilon_2 \varepsilon_3 / 1 - (1-\varepsilon_2)(1-\varepsilon_3)](\theta_3^4 - \theta_2^4) + S_2 = 0$$
$$k_2(\theta_4 - \theta_3) + h_c(\theta_2 - \theta_3) + \sigma[\varepsilon_2 \varepsilon_3 / 1 - (1-\varepsilon_2)(1-\varepsilon_3)](\theta_2^4 - \theta_3^4) + S_3 + P = 0$$
$$E_{in}\,\varepsilon_4 - \varepsilon_4 \sigma \theta_4^4 + k_2(\theta_3 - \theta_4) + h_{in}(T_{in} - \theta_4) + S_4 = 0$$

  Whereby P (W/m²) expresses the electrical power injected to the conductive low-e layer (#3).

- Analysis and comparisons of results with a standard double glass façade performance in the Mediterranean climate. Calculation of efficiency of the façade system.

- Evaluation of the annual energy balance of the building. Energy saving and increasing of the thermal comfort for a glazed façade of office buildings.

Radiant Glass Façade can be considered a different approach to the growing interest in using highly-glazed facades in commercial buildings especially in the Mediterranean climate zone, while not neglecting occupant comfort and sustainable design associated with daylighting and energy savings.

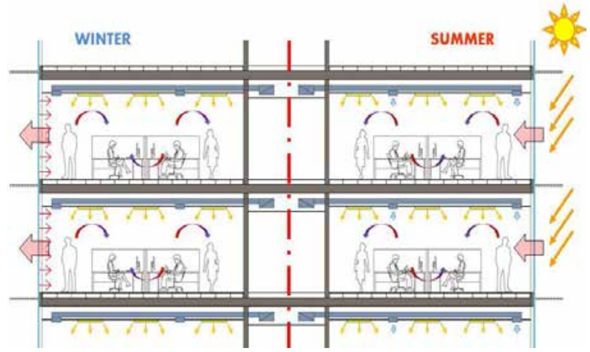

Fig. 1: The heating exchange between the environment and the office building through a glass envelope equipped with Radiant Glass Façade, during summer and winter.

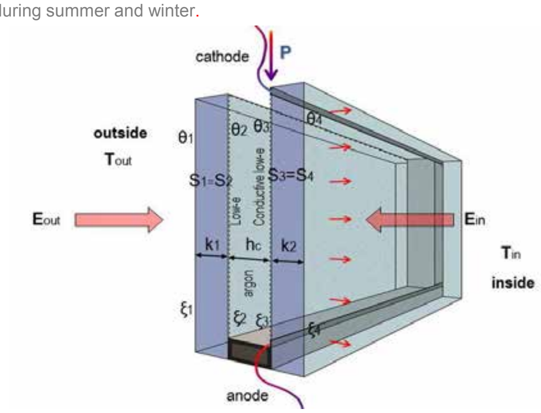

Fig. 2: Diagram of a Radiant Glass Façade, and variables used to determine the thermal balance.

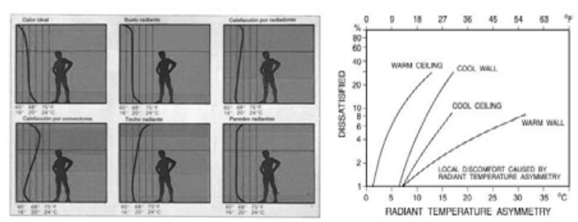

Fig. 3: Gradient of the temperatures for different types of heating systems; and diagram of Predicted Percentage of Dissatisfied (PPD) for radiant temperature asymmetry by different heating systems, according to ASHRAE 2001.

Involved persons: Prof. Dr. Consuelo Acha Román
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Time span: planned 2014 - 2016

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Associated Publications:

1. La Ferla G., Acha C., Roset J. (2014). El vidrio calentado eléctricamente y su eficiencia energética como sistema de calefacción en una envolvente acristalada. *1st International Congress on research in Construction and Architectural Technologies*. ISBN: 978-84-617-0504-7. ETSAM, Madrid, Spain. 11-13 June 2014, pp. 250-254.
2. La Ferla G., Roset J. and Lopez A. (2015). Electrically Heated Glass in Mediterranean Climate. In: *Knowledge, training, skills and supply chains handbook*. Editor P. Jones, and others. The Welsh School of Architecture, Cardiff University. Approved for pubblication on November 2015.

25 Novel façade technologies for the Mediterranean climate. Planning, design, retrofit

Luca Lanini, Benedetta Marradi

Research information

Existing condition, aims and objectives

In the last decades Mediterranean countries have been affected by a significant increase in energy consumption, especially in the summertime, mainly due to the use of air conditioners.
The energy consumption for air conditioning and climate control are tightly linked to the thermal characteristics of the building envelope and the efficiency of systems.
The traditional building techniques of the Mediterranean included passive systems and, in particular, exploited methods such as massiveness of the walls, use of lodges and mobile screens, realization of "green" screens with deciduous plants that provided shade in summertime.
Instead, more recent buildings are characterized by technological solutions that show poor energy performance, as well as a low architectural quality.
If we consider the Italian situation, for instance, a large part of buildings has been realized after 1946 and only 8% was built after 1991, when the first energy law was enacted. The energy consumption of the buildings of the '50s -' 80s is estimated at approximately 200-250 kWh / (m² /year).
The main objective of our research is to determine the potential and the impact of applying novel façade technologies in Mediterranean climate condition.
The study, to be conducted over approximately three years, focuses on adaptive systems, with a special regard on passive properties.
The goals are:

- reduce operating costs,
- increase energy efficiency,
- provide an increased level of quality in architecture,
- improve the level of occupant comfort.

Concept and approach

The present research aims to identify the major methodological issues and the case studies to support the development of adaptive facade design and construction process.
The purpose is to support the architectural designer to consider the issues, to be aware of the available solutions and of the main elements that need to be evaluated in the choice of a façade, especially in the early stages of design.
The study will introduce the aspects of integration, identify some of the key parameters to compare the performance of the envelope and unfold a scenario for a novel approach to environmentally sustainable adaptive systems.
An important aspect of the research will focus on the use of modern façades intended for renovation projects. The "retrofit challenge" is considered a crucial opportunity: the increase of energy performance of existing envelopes with technologies not present at the time of original construction, and therefore "innovative", represents an improved level with respect to maintenance, as it aims to define new quality and new performances and adapt the buildings to current standards.

How the objectives will be achieved

Master thesis, lectures, papers, involving master students and ESRs.

Involved persons: Prof. Dr. Luca Lanini
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Time span: planned 2015 - 2018

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Associated Publications:

1. B. Marradi, "Smart façades design process: interviewing the experts" Architectural Science Association Conference 2014, Genoa, 10-13 Dec 2015
2. B. Marradi, "Glass façades in the design process", Codice ISBN 978-3-639-64020-5, EAI – Edizioni Accademiche Italiane, Saarbrücken, 2014.
3. B. Marradi & M. Overend, "Development of a process mapping for glass façade renovations", Challenging Glass 4 Conference & COST Action TU0905 Final Conference, EPFL - Ecole Polytechnique Fédérale de Lausanne, Losanna, CH, 7-8 Feb 2014.

Fig. 1: D&C steps for facades (Image by the author).

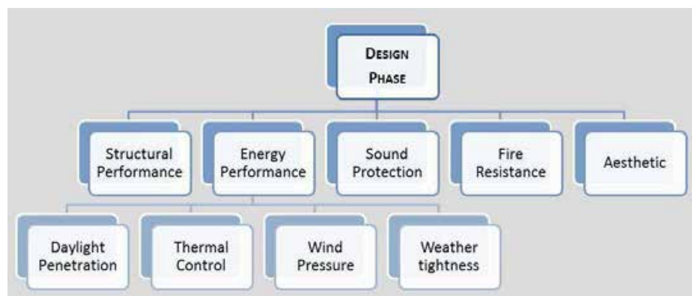

Fig. 2: Façade engineering: main requirements during the design stage (Image by the author).

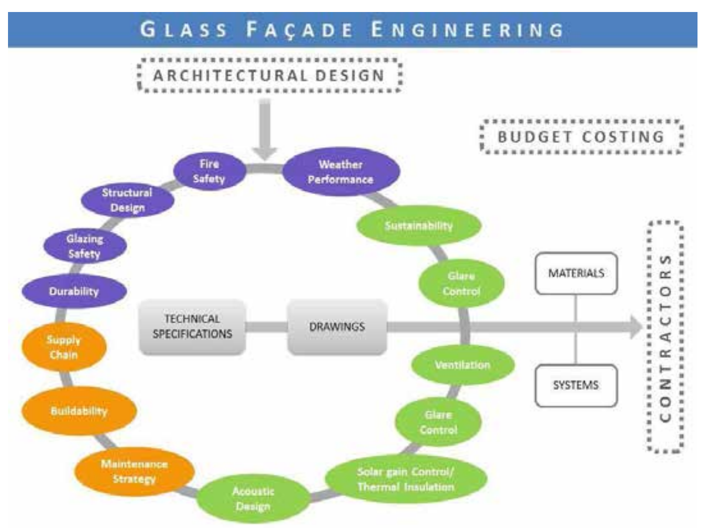

Fig. 3: Design process and deliverables (Image by the author).

26 BIPV/T-PCM Automated System

Laura Aelenei, Ana Rute Ferreira, Ricardo Pereira, José Ventura

Research information

Introduction

One of the issues concerning the research community is the increasing energy consumption, which leads to shrinking resources and rising energy costs. Integration of PV cells in facades per se is insufficient to reduce these problems in buildings, since, as is well known, only approximately 16% of the solar energy incident on PV is converted to electricity, the rest is absorbed and transformed into heat, possibly leading to overheating of the PV cells, which reduces their solar energy conversion efficiency.

BIPV/T-PCM System

The work presented here aimed to develop a BIPV/T-PCM system that was capable to improve indoor thermal comfort, reduce the building's energy demand and improve the efficiency of the photovoltaic system by limiting temperature rise inside the system.

Such objectives were achieved by ventilating the air gap behind the PV cells and successfully recovering the heat released in the conversion process for indoor heating, and using PCM to regularize the indoor-outdoor temperature difference and the stabilization of the PV temperature (Figure 1).

BIPV/T-PCM Components

The system will provide three services: capture, storage and management of energy. Heat, as a form of energy, is the agent to be administered. Figure 1 (b) presents the scheme of the system, the numbers correlate to: **1. exterior gates** (separates outdoor air from the rest of the system); **2. central gates** (separates the air in the cavity from the indoor air); **3. indoor gates** (separates the air of the system from indoor air); **4. photovoltaic module** (transforms incident solar radiation in electric and thermal energy); **5. air cavity** (allows air circulation behind the PV cells, transporting heat to the room, to the outside or to the PCM battery. The width of the air cavity is 10 cm and the air flow is supported by a set of ten fans); **6. PCM battery** (stores heat based on the concept of a thermal battery, a set of PCM plates are placed in parallel within an insulated box (adiabatic)); **7. insulation** (prevents heat exchange between the PCM and the outside in both directions); **8. fans** (two groups of fans: fans of the air cavity and fans of the thermal battery ensure air flow); **9. drawers** (insulate the PCM battery and act as gates).

Figure 2 presents photographs from the inside (a) and outside (b) of the prototype and from the PCM battery (c). As the management of energy is the brain of the system, automatizing it was imperative. The electrical scheme of automation is presented in Figure 3.

BIPV/T-PCM Operation Modes

There are nine operating modes, that will vary the open/closed status of gates and drawers and on/off status of the fans. These operating modes, for now, are aggregated to the seasons; in the future it is intended to have the selection of the operating modes based on real and instant measured indoor temperatures following a code, and based on an intelligent memory system which is based on previous default situations (Figure 4).

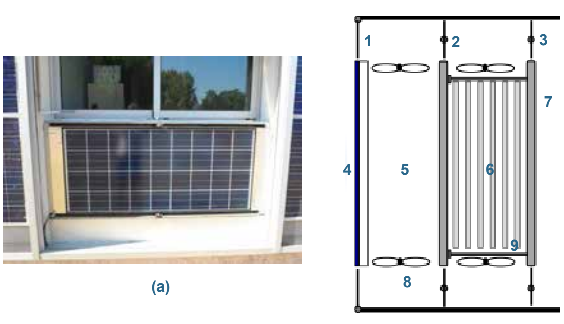

Fig. 1: (a) BIPV/T-PCM system in a south façade of an office in Solar XXI; (b) Scheme of the BIPV/T-PCM system.

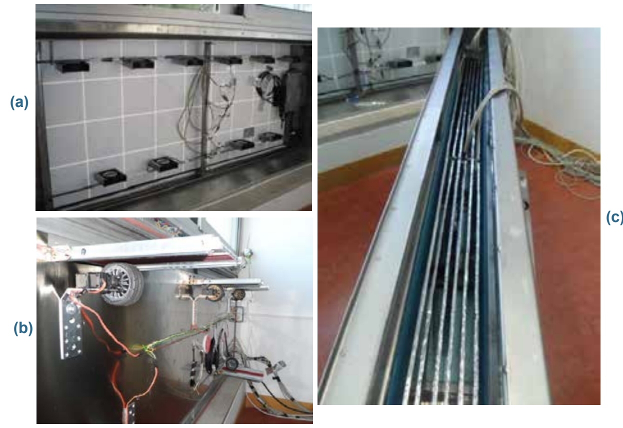

Fig. 2: Photos of the BIPV/T-PCM system prototype.

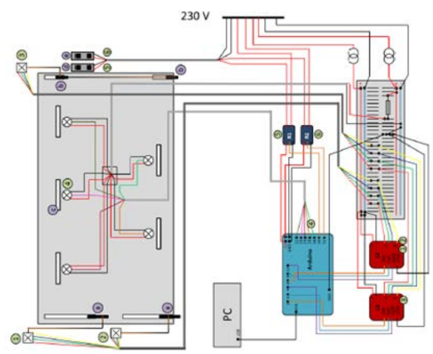

Fig. 3: Electrical scheme of automation.

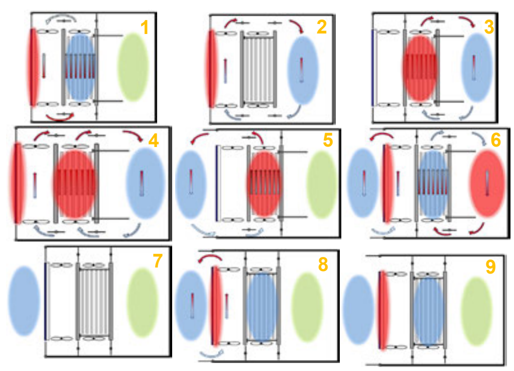

Fig. 4: Different operation modes of BIPV/T-PCM system. Green is the indoor zone, blue is cold air and red hot air. Operations modes from 1 to 4 and 7 are for heating season and 5, 6, 8 and 9 are for cooling season.

Involved persons: Dr. Laura Aelenei, MSc. Ana Rute Ferreira, MSc. Ricardo Pereira, MSc. José Ventura

Time span: 2010 - 2014

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Associated Publications:

1. Aelenei L., Pereira R., Ferreira A, Gonçalves H., Joyce A. Building Integrated Photovoltaic System with Integral Thermal Storage: A Case Study // Energy Procedia Renewable Energy Research Conference, RERC 2014 - doi:10.1016/j.egypro.2014.10.425.

27 The Communicational Relationship between Facade and User: Interface Design

▶ Prof. Dr. Uta Pottgiesser, M. Eng Anan Ashour, MA Jens Boeke / HS OWL, Detmold

Hochschule Ostwestfalen-Lippe
University of Applied Sciences

▶ **Research information**

INTRODUCTION

There is an ongoing debate on who and what is influencing each other in the built environment. Is it the human being reacting to spaces and building elements or are those influencing the human being's behaviour? Regardless what this debate ends up with, research (ConstructionLab) and education (Master International Facade Design and Construction – IFDC and Computational Design and Construction – MCDC) in Detmold are focusing on one concrete thing: behind each great envelope there is a great user. Technological and emotional aspects are necessary to build this relationship.

PRODUCT AND USER RELATIONSHIP: INTERFACE DESIGN

Before the steam engine, craftsmen used to adjust their products to individual needs, each user used to have a unique product and therefore a special relationship with it. This concept evaporated after creating the steam engine, the products became rationally produced in large quantities, at a cheaper price, less individual and less emotional. Nevertheless, now with the new technologies and the open source software development, the possibility to produce individual products with an emotional meaning comes back to life. In contrast to architecture and engineering, product design has crossed a longer way towards interface design since the consumer and industrial products are closely connected with the users and their needs. According to Meyer-Eppler's (1958) communication model (fig. 1) the designer's task has to be to translate a product's function into signs that the receiver can understand.

RESEARCH BY DESIGN APPROACH - HUMAN CENTERED DESIGN

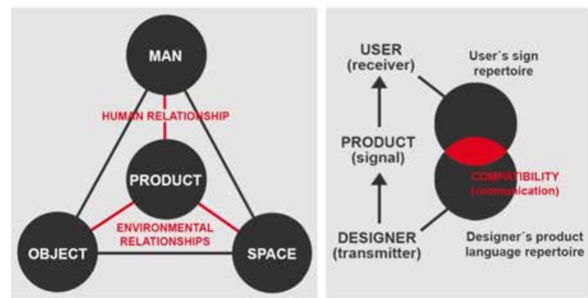
Therefore product design methodologies are used in research and education in Detmold in order to develop facade elements and components, and to create a meaningful relationship between the user and the facade based on communication and emotion. The goal is to produce products that have emotional meaning and at the same time provide functionality. Daniel Pink (2005) argues that once our basic needs are met, we tend to look for meaningful and emotionally satisfying experiences. This design-oriented approach connects user and facade at different levels of adaptivity:

✓adaptivity to movements, presence or changing comfort conditions realized by sensors,
✓adaptivity by individual regulation realized by tools, apps and programmes,
✓adaptivity by multifunctional design by integrating interior, technical aspects into the façade.

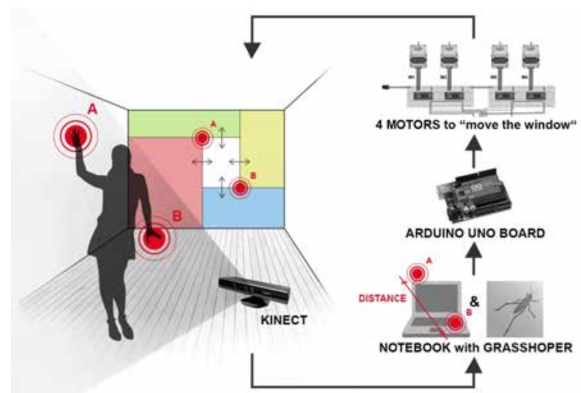
Two examples are shown where the students tried to apply this concept during two of the six workshops organised within the European Facade Network (efn) – called efnMobile.

The Movable Window translates the human body movement into physical movement of facade elements. This will be useful especially for persons with low mobility, who can control the amount of light in the room, privacy, view (functional aspects/ communication) just with the movement of their hands. Each user can create his/her individual gesture to control the window and adapt the position and the size of the window according to their needs (individuality/communication). Controlling the movement of a heavy element from a long distance merely with the movement of the hands is no longer an exclusive ability of superheroes (fun and emotional aspects/communication). Body movement is read by a Kinect Camera which is a Xbox video game tool (technology from another industry) and is translated into the digital model (fig. 2). The Grasshopper Firefly definition (open source software) which is connected to an Arduino UNO board (single-board microcontroller) converts the physical movement of the hands into the physical movement of the window elements by a formula. In an interdisciplinary workshop the students built a very interesting physical prototype (fig. 3 left).

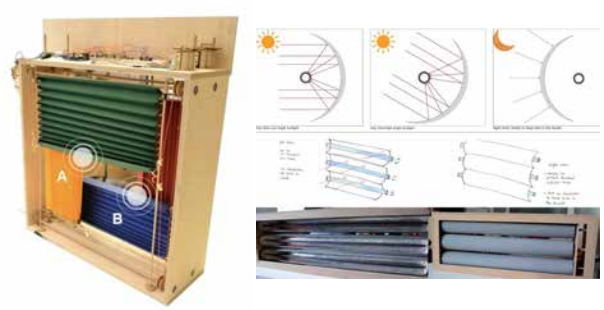
ThinkingSkins describes the exploration of adaptive building envelopes on the basis of negotiated information. This includes the conceptual analysis of current technical developments towards a total construction system. During the workshop prototype facades were made that respond to dynamically changing environmental conditions, displaying individual facade functions which will be studied and then be integrated into a holistic system (fig. 3 right).



▶**Fig. 1:** Left: Product design approach according to Heufler. Right: Designer uses interaction through products according to Meyer-Eppler.



▶ **Fig. 2:** IFDC efnMobile Workshops Lucerne 2014: Movable window using Kinect and Arduino UNO to detect the movement of the hand to control the Movable Window.



▶ **Fig. 3:** (left): IFDC efnMobile Workshops Lucerne 2014_First prototype of the Movable Window and (right): Workshop Delft 2015_Solar flip collector facade

▶ **Involved persons:** Prof. Dr. Uta Pottgiesser, M. Eng. Anan Ashour, MA Jens Boeke

▶ **Time span:** 2008 - 2016

▶ **Contact data:** uta.pottgiesser@hs-owl.de

▶ **Associated Publications:**

1.Pottgiesser U., Strauß H. (2013) Product Development and Architecture: Visions, Methods, Innovations: Birkhäuser, Basel.
2.Ashour A. (2013) meaning: the hidden part of facade innovation (Master thesis IFDC), HS OWL, Detmold.
3.Pottgiesser U., Knaack, U. Boeke, J. (2011) facade2011. Design vs. Development. Proceedings conference facade2011. HS OWL, Detmold.

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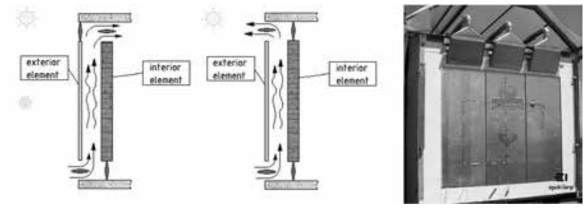
▶ Research information

Ventilated Active Façades – VAF

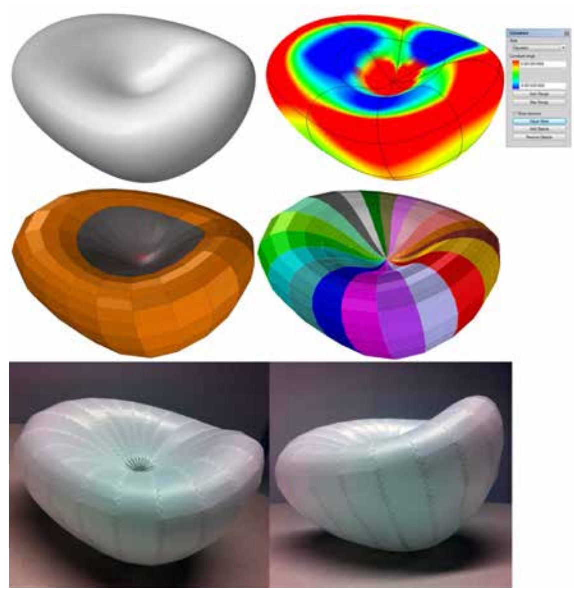
The Ventilated Active Façade - (VAF) is a double skin opaque façade in which the air in the cavity is heated (up to 40ºC) and flows into the building interior reducing the heating demand and supplying fresh air. The first VAF prototype consists of a 2mm galvanized steel panel and a 30mm air cavity. Due to its minimal thickness it demonstrated high energy saving potential (more than 40% in many cases).



▶ **Fig. 1:** Winter and summer operational modes of the VAF. Testing the first prototype in a laboratory of the Basque Government.

Freeform Surfaces Adaptation using Developable Surfaces

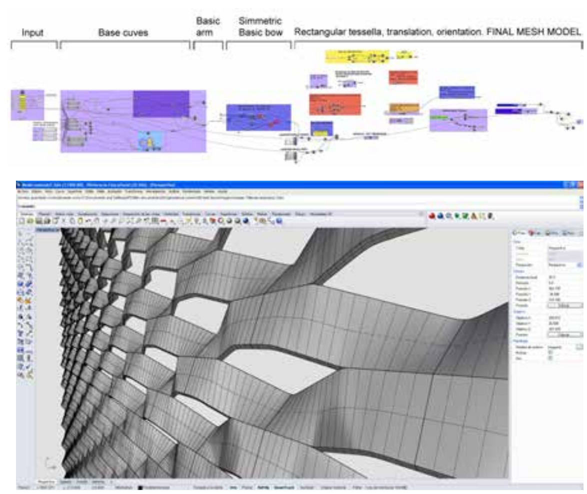
Using two prototypical types of developable surfaces we have formulated an adaptation method of double curvature surfaces by means of developable and planar quadrilateral surfaces.
Exploiting the concept of geometric apparent contours and the systematization of a process inspired by traditional projective geometry, an algorithm is built using outstanding software that allows obtaining single-curvature strips or flat facets strips. In order to be able to address its construction using materials with the possibility of bending in one direction or rigid material with no possibility of bending at all with simple procedures.
These obtained strips are absolutely developable from the geometrical point or view. They are patches extracted from cones or cylinders.



▶ **Fig. 2:** Graphical adaptation using developable strips and construction of physical prototype

Bidirectional Scattering Light Distribution of Façade Systems

Daylight performance of building envelopes is a key issue in sustainable architecture. Our work develops and tests tools and methods for a better assessment of daylight transmittance of industrial products such as expanded metal, a widely used industrial product in façade design that has not been accurately analysed. Many of the industrial products used as solar control layer in facades lack this kind of research to characterize them and to facilitate simulation in a straightforward building design process.
In the process of analysis of expanded metal we also created an automated 3D modeller by means of Grasshopper and Rhinoceros software. This modeller makes it fast and easy to obtain any of the uncountable different types of expanded metal that can be manufactured.



▶ **Fig. 3:** Grasshopper interface for the expanded metal 3D modeller and example of resulting model

▶ Involved persons: Dr. Gonzalez Quintial, Francisco
Dr. Irulegi Garmendia, Mª Olatz
Dr. Rico-Martinez, Jose Miguel

▶ Time span: 2012 - 2016

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▶ Associated Publications:

1. IRULEGI,O., SERRA,A., HERNÁNDEZ,R., RUIZ-PARDO,A. (2011), *Ventilated Active Façades to Reduce the Cooling Demand of Office buildings - the Case of Spain.* The International Journal of Ventilation, Vol 10, N2, pp 101 – 115.

2. RICO-MARTINEZ, J.M., SAIZ BOMBIN, S., LECETA MURGUZUR, A. *Product Development and Architecture. Vision/Methods/Innovations. Measuring light-calculating geometry.* Book chapter. Birkhauser. 2013. ISBN 978-3-0346-0841-1.

3. GONZÁLEZ-QUINTIAL, F, SÁNCHEZ-PARANDIET, A. BARRALLO, J. (2013) Freeform Surfaces Adaptation through Developable Surfaces Using Apparent Contours.Global Design and Local Materialization. Springer 2013. Volume 369 of the series Communications in Computer and Information Science pp 358-367

29 Glass & Transparency Research Group – TU Delft

Prof. ir. Rob Nijsse (Full Professor), Dr. ir. Fred Veer (Associate Professor), Dr. ir. Christian Louter (Assistant Professor)

Research information

Introduction

The Glass & Transparency Research Group at TU Delft in the Netherlands focuses on the development of innovative glass solutions for structures, buildings and facades. The research group is situated at the Chair of Structures at the Faculty of Architecture and the Built Environment and has strong links to the Faculty of Civil Engineering and Geosciences.

Research topics

The topics that are addressed within the research group range from material investigations, via investigations into new connection technologies to the development and assembly of full scale glass structures.

Several topics are currently under investigation, such as:
- Innovative facade constructions by means of cast glass bricks
- Innovative bridge design making use of dry assembled glass bricks
- Production and residual stress investigations for glass bricks
- Strength of structural glass components
- Safety performance of structural glass components
- Reinforcement technologies for optimized safety performance
- Deployable glass structures
- Glass shell structures
- New glass material compositions
- and several other topics

Education

The research group is also actively providing education on the structural use of glass in structures, buildings and facades. As such, the research group offers a BSc course “Bend and Break” to Civil Engineering students. This course includes a series of lectures and hands-on physical testing in the laboratory to raise the understanding of the structural performance of glass. In addition, the research group is involved in the MSc course “Technoledge Structural Design” for Architectural Engineering & Technology students. In this 9 week course the students focus on the design of a glass structure. The course consists of a series of lectures and practical (design) sessions. Finally, the research group guides 10 MSc thesis projects in the field of structural glass every year.

Associated activities

The research group is involved in several structural glass activities, such as:
- Glass Structures & Engineering Journal (Springer Publishers)
- Eurocode Committee on Structural Glass
- European COST Action TU0905 on Structural Glass, 2010-2014
- Challenging Glass Conference

TU Delft Glass & Transparency Research Group

Involved persons: Prof. ir. Rob Nijsse (Full Professor)
Dr. ir. Fred Veer (Associate Professor)
Dr.ir. Christian Louter (Assistant Professor)
ir. Joris Smits (Lecturer)
ir. Ate Snijder (PhD-student)
ir. Phaedra Oikonomopolou (PhD-student)
ir. Peter Eigenraam (PhD-student)
ir. Telesilla Bristogliann (PhD-student)
Clarissa L. Justino de Lima, MSc (PhD-student)

Time span: ongoing

Contact data: www.glass.bk.tudelft.nl

Associated Recent Journal Publication:

1. Oikonomopoulou, F., Veer, F., Nijsse, R., Baardolf, K., (2015) *A completely transparent, adhesively bonded soda-lime glass block masonry system,* Journal of Facade Design and Engineering, vol. 2, no. 3-4, pp. 201-221, 2015
2. Other publications are retrievable via www.glass.bk.tudelft.nl

Fig. 1: Innovative glass brick façade technology

Fig. 2: Rendering of a dry assembled glass brick bridge design (rendering by XKP visual engineers)

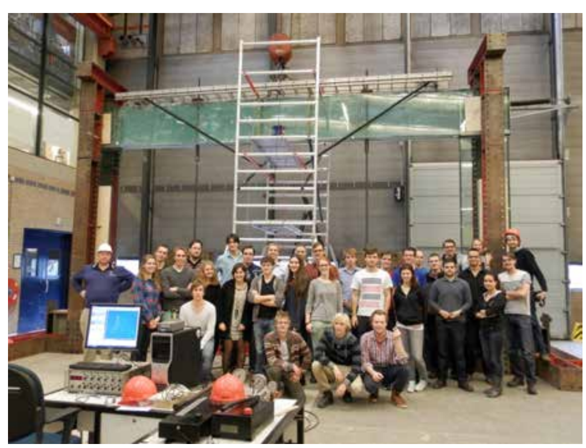


Fig. 3: BSc students testing a 6m glass portal in the laboratory.

30 Facade Research Group

Strategy and development of research in the field of the building envelope

▶ **Facade Research Group TU Delft**

▶ Research information

GOAL

The goal of the Façade Research Group is to improve the performance of the building envelope as part of the entire building and to enhance the possibilities for architectural design by exploring new strategies and design tools as well as construction and production technologies. The group consist of nationally and internationally located PhD students under the leadership of Dr. Tillmann Klein and Prof. Dr. Ulrich Knaack.

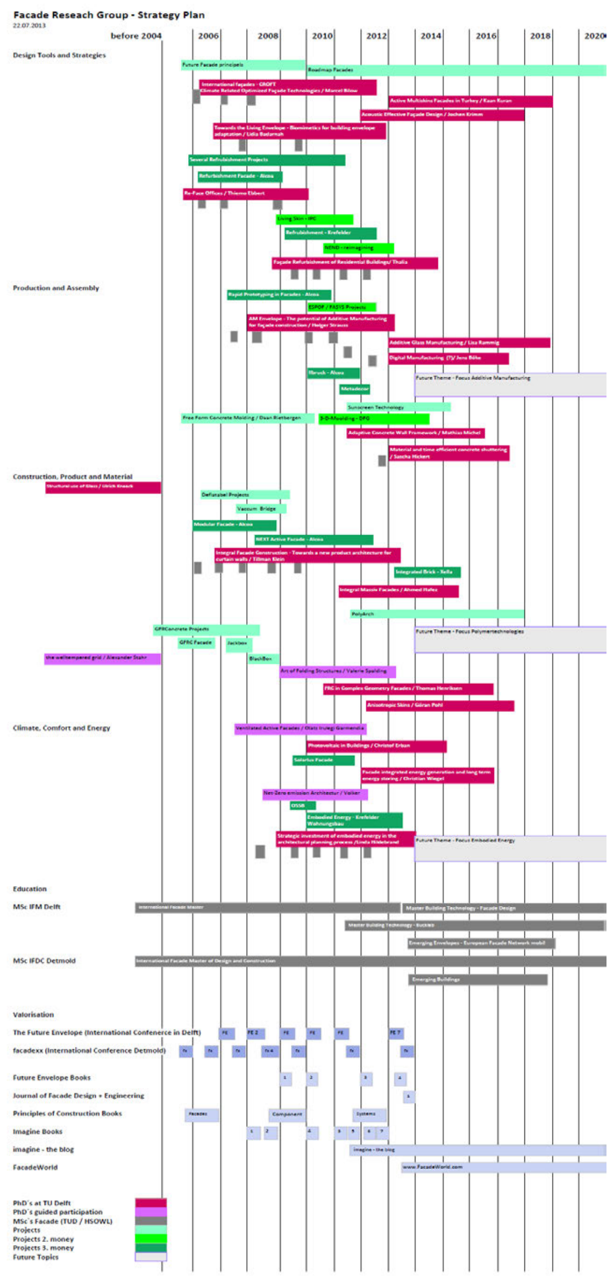
DESCRIPTION

The Façade Research Group organises itself via 4 topics:
Design Tools and Strategies; Production and Assembly, Construction, Product and Material, Climate, Comfort and Energy. Since 2006 6 PhD´s completed their studies within the group, 13 PhD´s are currently active. Peer review sessions are executed twice per year – to meet, interact and secure success of the research. Future research areas are identified and targeted in relation to the 4 topics.

The activities are linked to education via the track International Façade Master in Delft, embedded in the Building Technology Master, and the International Façade Master of Design and Construction in Detmold.

Valorisation is done via the book series “The Future Envelope”, which will merge with the newly established Journal of Façade Design and Construction at IOS Press, the “Principles” series with Birkhäuser publisher and the imagine series with 010/Nai publisher. In addition, the group organises two conference series: “The Future Envelope” – Delft / Bath and “façadesxx” - Detmold / Lucerne.

▶ **Fig. 1:** Façade Research Group



▶ **Fig. 2:** FRG strategy plan

▶ **Involved persons:** Prof. Dr. Ulrich Knaack
Dr. Tillmann Klein

▶ **Time span:** 2006 - ongoing

▶ **Contact data:** T.Klein@tudelft.nl

31 TU DELFT | Façade Research Group Ongoing PhD Projects

Photovoltaics in Buildings | Christof Erban
Photovoltaic panels are conventionally mounted on South oriented roofs and façades to maximize their annual power generation. Since a new EU regulation will possibly demand much more photovoltaic to be used in the building envelope a deeper understanding of non due South oriented photovoltaic is required.

Biomimetic use of thermoregulation for dynamic facades | Susanne Gosztonyi
With respect to the level of energy efficiency of a building, the façade is highly required to achieve maximum efficiency by dynamic adaptability. With the integration of active technologies and materials, the façade shall be able to react autonomously and dynamically to changing thermal conditions.

Integral massive facades | Ahmed Hafez
In recent years the facade industry has witnessed significant developments. New materials were introduced, energy performances were enhanced, and new functions were added. However, the industry still depends on scattered decisions taken by scattered disciplines resulting in a façade composed of different layers performing different functions. Integration can be a successful strategy for the façade industry.

Geometrically complex concrete panels | Thomas Henriksen
Glass fibre reinforced concrete (GFRC) has not yet been researched with a detailed empirical performance characterization of limits of functionality/systematic approach to understand their use in geometrically complex facades. This research looks into options to find design solutions and technical details which enable more flexible design with free-form GFRC.

Material and time efficient concrete shuttering | Sasha Hickert
Concrete forms inspired by biomimicry of mathematical patterns gain increasingly more relevance in architectural design. The production of free-form concrete or free-form concrete surfaces requires great technical and economical effort for the casting process. The technical abilities for efficient form generation exist and are applied in other disciplines such as the automotive and nautical industries.

Acoustically effective façade design | Jochen Krimm
Façades at the threshold to urban spaces add extra noise to the rising average noise levels of today's major cities by reflecting acoustic energy. The measurable, negative effect on people's health caused by the increasing average noise level in major European cities leads to a change in façade designs. The acoustic performance of a façade becomes more important in noisy surroundings.

Adaptive concrete wall formwork | Matthias Michel
The scope of geometry for free-form concrete structures is basically determined by it's formwork. While concrete shells can be produced by a single layer formwork, free-form concrete walls require two sides of formwork that have to withstand a remarkable amount of hydraulic pressure. There is an unquestionable potential for an actuator driven adjustable wall formwork.

Anisotropic skins | Goran Pohl
Building skins are mostly made of added systems that show the same attitude across the entire surface. High requirements concerning energy efficiency and material efficiency will not match this construction type. Fiber reinforced composites naturally and smartly generate homogenous envelopes, and could stand as paradigms for technical composites in architectural hulls.

CoolFacade | Alejandro Prieto
The necessity to lower energy consumption demands us to take action to optimize systems currently under operation, while developing new technologies driven by renewable sources of energy. This research project examines the feasibility of solar cooling integration in façades as a response to the current scenario, while exploring further possibilities for the development of new architectural façade products.

Additive glass manufacturing | Lisa Rammig
During the past two decades Additive Manufacturing (AM) has been enhanced from a prototyping tool used mainly for product development to a fully independent production method. Whilst meanwhile the direct fabrication of materials such as plastics or metals has become a sophisticated technology, the additive fabrication of glass, perhaps one of the most fascinating building materials, is almost unexplored.

Advection based adaptive building envelopes | Jason Vollen
The concept is a ceramic based cladding system optimized to work with local climate conditions, absorbing or reflecting solar radiation by using variable surface morphology, colour and material properties, while vectoring energy via phronetic advection. The ABABE is designed to use this multivalent strategy to absorb, release, and redirect heat or cold to conserve energy by managing entropy production.

Facade integrated energy generation and long term storing | Christian Wiegel
Building envelopes need to be less energy permeable in case of fossil energy or need to generate energy for climate conditioning with respect to environmental energy sources by themselves. Long term or seasonal energy storage is necessary for demand related provisions.

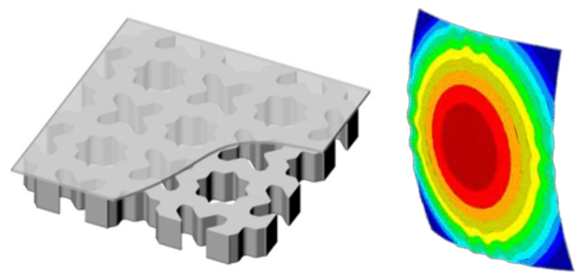


Fig. 1: Details for formwork components / Matthias Michel

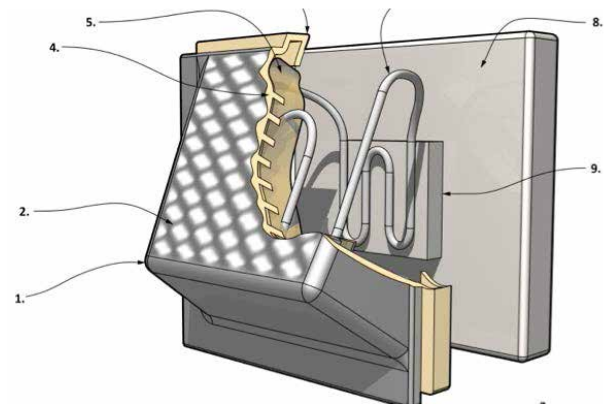


Fig. 2: ABABE prototype scheme / Jason Vollen

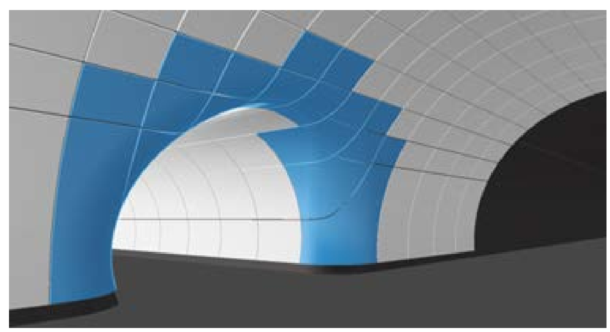


Fig. 3: GFRC use in complex geometry panels / Thomas Henriksen

Fig. 4: Experiments with latex formwork / Sasha Hickert

Involved persons: Façade Research Group
Time span: 2006 - ongoing
Contact data: T.Klein@tudelft.nl

32 TU DELFT | Façade Research Group Completed PhD Projects

Re-Face | Thiemo Ebbert (2010)
Two thirds of all office real estate in Europe is older than 30 years. Practice has shown that at this age the façades and climate installations of a building do no longer fulfil current requirements and are responsible for extraordinarily high energy consumption. This thesis evaluates existing façade types and develops refurbishment strategies that can be applied with minimal intervention.

International Facades (CROFT) | Marcel Bilow (2012)
How can architecture be transferred to regions with entirely different climate conditions? The answer lies in the technological possibilities we have at our disposal today. The main research question of this thesis refers to utilising the local climate. Which methods are necessary to plan a façade while working with, not against the climate?

Integral Façade Construction | Tillmann Klein (2013)
Curtain wall constructions are one of the most applied facade constructions today. With continuously rising requirements in terms of energy savings the constructional principle has reached its limits and strategies for improvement are needed. The dissertation concludes that a greater diversity with a more integral construction is needed to meet the sometimes conflicting future challenges.

AM Envelope | Holger Strauss (2013)
Over the past twenty years additive manufacturing has evolved from a support tool for product development into an independent production method. The term 'AM Envelope' (Additive Manufacturing Envelope) describes the transfer of this technology to the building envelope. This dissertation shows the potential of the additive methods for the development of façade construction: Additive methods change the way we design, build and produce building envelopes.

Strategic investment of embodied energy during the architectural planning process | Linda Hildebrand (2014)
Energy concepts rarely include the energy invested to construct, maintain and demolish a building. This share -the embodied energy- can account for half of the building's overall balance. Materialization and mass of the façade define the extent of environmental impact. The ratio of invested (embodied) energy and the gained functions and qualities bear the basis to judge environmentally sensible decisions.

Façade Refurbishment Toolbox | Thaleia Konstantinou (2014)
The starting point of the research is the need to refurbish the existing residential building stock, in order to reduce its energy demand. The early design phases are particularly important, as decisions taken during this stage can determine the success or failure of the design. However, most existing tools focus on post-design evaluation. The thesis aims at integrating the energy upgrade potential of residential façade refurbishment strategies in the early design phase, in order to support decision-making.

Fig. 1: Dissertation books published in the A+BE series, TU Delft

Involved persons: Façade Research Group
Time span: 2006 - ongoing
Contact data: T.Klein@tudelft.nl

33 ISM+D – Institute of Structural Mechanics + Design

Prof. Dr. Ing. Jens Schneider / Prof. Dr. Ing. Ulrich Knaack

Research information

Profile

The Institute for Structural Mechanics and Design combines research and education in the fields of structural analysis, structural dynamics, materials, facade and structural engineering, in order to achieve consistent, integrative basic knowledge for resource-efficient design and construction. With this vision in mind the Institute promotes fundamental theoretical work on mathematical and design methods, material testing and modelling, numerical simulations, safety theory, construction processes as well as applied research and design of structures from the component down to the material level. At this juncture, energy issues are taken in consideration as well, from an integrated point of view of structural design and materials.

Research

The Institute of Structural Mechanics and Design engages in fundamentals of theory and applied research and development with the research groups Methods, Materials, Technologies, and Energy. Here it cooperates with partners from science and research, industry and administration. Fundamental research, applied research and development are synergistically linked in approximately equal proportions.

Research activities are in line with the comprehensive approach on material and structure distinctive of the Institute, and are not only limited to construction, components and materials, but can rather be found throughout all applications of the field of engineering. In the field of Structural Mechanics and Dynamics they include modelling of structures to record their static and dynamic behaviour, mechanical modelling and simulation of deformation, damage and failure of materials, components and load-bearing structures, the development of new materials and their application in the construction industry under consideration of safety issues, environmental aspects in construction, design-related energy issues, simulation and experiment of shock, explosion and contact accidents, simulation and measurement of the vibration behaviour of structures, structural glass and polymer mechanics.

Research in the field of the building envelope deals with questions of development and evolution, from filigree structures to massive constructions, and their feedback into the overall design and energetic performance. Current topics can be found in the field of integration between smart-home technology and building envelope; evaluation of constructions against the background of grey energy considerations and the consequent redesign of structures and joints, as well as material and design development exemplified through additive manufacturing (AM) technologies.

Thanks to a horizontal connection between scientific fields, the research groups operate across disciplines and react to evolving research questions and connections. Through cooperation with other institutions and private investments, the Institute of Structural Mechanics and Design has access to many experimental facilities and has a wide range of tools to perform tests and measurements on site.

Involved persons: Prof. Dr. Ing. Jens Schneider
Prof. Dr. Ing. Ulrich Knaack

Time span: ongoing

Contact data: Jens Schneider (schneider@ismd.tu-darmstadt.de);
Ulrich Knaack (knaack@ismd.tu-darmstadt.de)

Associated Publications:

1. Jonas Hilcken: Cyclic fatigue of annealed and tempered soda-lime glass; PhD TU Darmstadt; Springer Verlag
2. Sebastian Schula: Characterization of the scratch resistance of glasses in civil engineering; PhD TU Darmstadt, Springer Verlag
3. J. Schneider, Glass Strength in the Borehole Area of Annealed Float Glass and Tempered Float Glass, International Journal of Forming Processes (IJFP), Special Issue on Glass, Vol. 7 (2004), No.4, pp. 523-541 (2004).

J. Schneider, S. Kolling, J. Kuntsche, S. Mönnich, Tensile properties of different polymer interlayers under high strain rates, Engineered transparency: International conference at Glasstec, ISBN 978-3-86780-294-9, pp. 427-437 (2012).

Fig. 1: ETA factory TU Darmstadt – cooperative research into industrialised building to investigate thermal collector systems, thermal storage systems and the interaction with internal thermal loads.

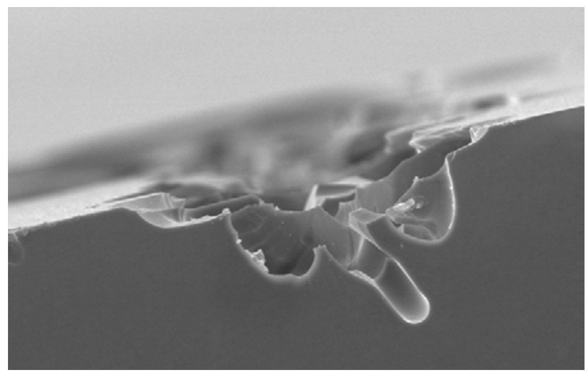


Fig. 2: Material technologies, properties, and construction technology of glass and polymers

Fig. 3: Additive manufacturing technologies for building envelope construction

34 Attached sunspaces in retrofitting design

Daniel Aelenei, Hugo de Azevedo Leal

FACULDADE DE CIÊNCIAS E TECNOLOGIA UNIVERSIDADE NOVA DE LISBOA

Research information

Introduction

Approximately 65% of the residential building stock is built before the implementation of the first building code, most of it displaying poor energy performance. Therefore, the use of attached sunspaces in these buildings is very attractive given the great solar potential of Portugal and the economic advantages the system offers when compared to traditional retrofitting approaches based on the use of thermal insulation.

Attached sunspaces have been used successfully in retrofitting existing buildings with poor energy performance. Overall, the studies show that sunspaces can be effective all year round if properly designed to take full advantage of the local climate and if overheating is addressed by passive means. Although the need for heating is higher than the need for cooling in most of the territory of Portugal, a dynamic building simulation code was used to accurately predict the potential influence of various factors on the thermal performance of a residential building with an attached sunspace in the present study.

CASE STUDY

Four sunspace configurations were studied (Fig. 2):

- Attached a);
- Attached b):
- Integrated/embedded c);
- Partially integrated/embedded d)

The north and south boundaries (external envelope) of the flat are made of a single layer of brick masonry (typical for buildings built before the publication of the first building code) with a thermal transmittance U = 1.3 W/m2. K. Both north and south facing building envelopes have single-glazed operable windows with thermal transmittance U = 5.7 W/m2 K. All other surfaces are considered adiabatic.

RESEARCH METHODS

The thermal performance of the sunspace was evaluated with EnergyPlus to estimate the energy demand for various configurations, locations and design variables (natural ventilation, shading devices, number of glazed surface layers, orientation).

The simulations were performed for a single zone with the sunspace implemented into EnergyPlus as a different thermal zone. All building surfaces were modelled explicitly, including internal partition walls.

The thermal behaviour of the building model with the sunspace attached was simulated for an entire year, assuming set point temperatures of 20 ºC and 25 ºC respectively for the calculation of the energy need for heating and cooling. Throughout all simulations, values of internal heat gains and ventilation rate around the year equal to 4W/m2 and 0.6 h-1, respectively, were considered.

CONCLUSIONS

The potential for energy savings in winter can be very important, ranging from 100% in Faro (energy demand for heating is reduced to zero) to 48% in Bragança. Regarding summertime thermal behaviour, some locations are subjected to the risk of overheating (Fig. 3).

Involved persons: Prof. Daniel Aelenei
Time span: 2014 - ongoing
Contact data: aelenei@fct.unl.pt

Associated Publications:

1. Aelenei D., de Azevedo Leal H., Aelenei L. The Use of Attached-sunspaces in Retrofitting Design: The Case of Residential Buildings in Portugal // Proceedings of the 2nd International Conference on Solar Heating and Cooling for Buildings and Industry (SHC 2013) – Energy Procedia (48) – p. 1436.-1441.

Fig. 1: Example of sunspace in Portugal – Francalumínios Lda.

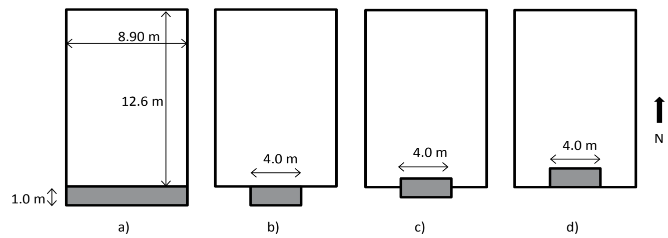


Fig. 2: Building floor dimensions and sunspace configurations

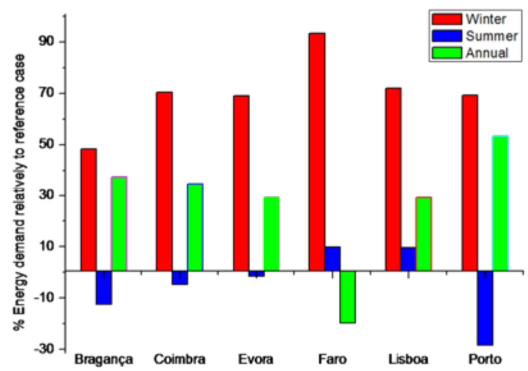


Fig. 3: Energy demand with attached sunspace in configuration a) relative to reference case (no sunspace)

Location	Config. Fig. 1	Glazed surface layers	Opaque wall
Faro	d)	Single	With
Lisboa	d)	Single	Without
Évora	d)	Single	Without
Coimbra	d)	Single	Without
Porto	a) / d)	Double	Without
Bragança	a) / d)	Double	Without

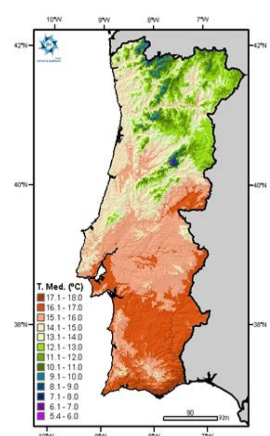


Fig. 4: Qualitative analysis of the design variables which are most appropriate for energy demand reduction

35 Timber Glass Composites

▶ Marcin Kozłowski, Erik Serrano, Michael Dorn

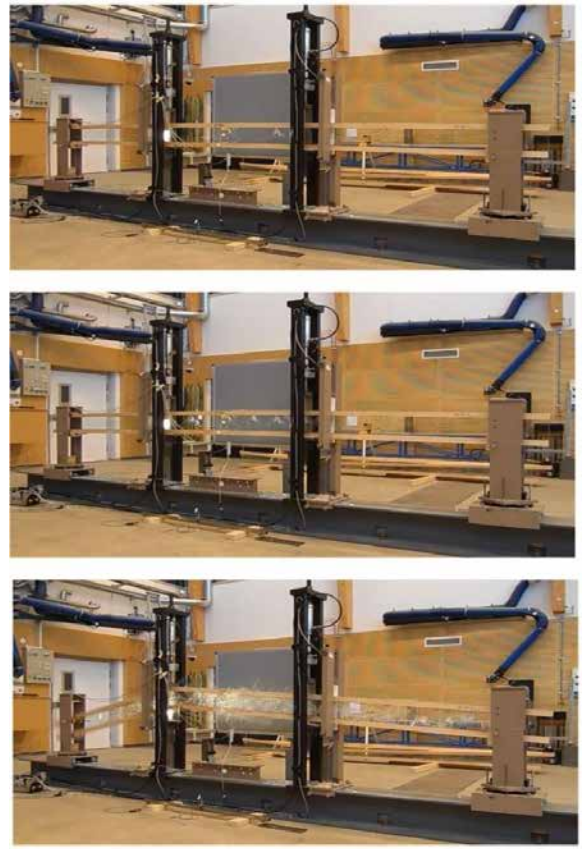
▶ Research information

Innovative structures: It is not the combination of timber and glass that makes the research project innovative - solutions such as glass panes bonded to timber frames have been used for a long time. However, traditional solutions assume that glass only fills the frame and does not contribute to the total load-bearing behaviour, merely transferring wind load to the structural frame. Consequently, the glass pane relies on a secondary structure to resist external loading. The research project is based on a different assumption - namely, that timber and glass work together to carry external loads - glass no longer acts as a filling but actively participates in load transfer and becomes, equivalent to timber, a structural element.

Sustainability: Timber is a natural material, environmentally friendly and perfectly in line with the principles of sustainable development. Its high strength–to–weight ratio in combination with its low thermal conductivity makes timber a strong alternative to other construction materials. In addition, an increased use of timber as a material for structural purposes will allow the European countries to reduce CO_2 emissions, mitigating climate change in accordance with international agreements such as The Kyoto Protocol. It can also contribute to meeting the EU 2020 targets regarding improving existing and future building envelopes. In addition, modern trends in architecture are oriented towards high quality of life and low energy consumption, in which modern glass products fit perfectly. Double glazed façades or large glass walls can allow a significant reduction of energy demand and costs related to air conditioning during summer and heating during winter.

Health and quality of life: It is well known that natural sunlight has a positive impact on health and quality of life of people living or working in buildings. For this reason, the possibility of increasing the translucent surfaces through the use of hybrid timber-glass structural components is desirable.

Glass as a load-bearing material: Glass is one of the most important materials in modern architecture. However, the material glass itself poses many difficulties in structural terms, such as brittleness and susceptibility to stress concentration. A traditional approach to design glass elements takes into account the above issues by the use of tempered glass. Tempered glass has a considerably higher strength than annealed float glass, and by laminating panes together the probability of total glass failure is minimised. However, structural design today is performed using very high safety factors and applying sacrificial sheets to the laminate to protect the load-bearing core. Such extremely conservative design approaches seem to be uneconomical and do not fully take advantage of the material glass. The proposed research project is based on a different concept. It involves panes made of annealed float glass and timber in a synergetic cooperation. This concept provides ductility and prevents brittle failure of the glass. The glass cracks into shards which are held in place by the beam's timber flanges. Therefore it offers a high post-breakage strength after possible glass failure.



▶ **Fig. 1:** Progressive damage of timber-glass beam with annealed float glass

▶ Involved persons: Dr. Marcin Kozłowski
Prof. Erik Serrano
Dr. Michael Dorn

▶ Time span: 2012-2016

▶ Contact data: marcin.kozlowski@polsl.pl

▶ Associated Publications:

1. DORN M. & KOZŁOWSKI M. & SERRANO E.: Development of large-scale load-bearing timber-glass structural elements. World Conference on Timber Engineering, August 10-14, 2014, Quebec City
2. DORN M. & KOZŁOWSKI M., & SERRANO E.: Design approaches for timber-glass beams. Engineered transparency. International Conference at Glasstec, October 21-22, 2014, Düsseldorf
3. KOZŁOWSKI M. & SERRANO E., & ENQUIST B.: Experimental investigation on timber- glass composite I-beams. Challenging Glass 4 and COST Action TU 0905 Final Conference, February 6-7, 2014, Lausanne

36 Glafo – the Glass Research Institute Selected research projects

Jerry Eriksson

Research information

Load-bearing Timber Glass Composites

A European research project to investigate and test load-bearing beams and shear wall elements (Fig. 1), constructed from the materials glass and wood. The different materials glass, wood, and adhesive were characterized for optimal structural performance, with a strong emphasis on the type of adhesive to be used. Small and large scale testing was performed and a prototype was also shown at the Glass Technology Live Area of Glasstec 2014.
Currently a continuation of this project is being planned where shear wall elements constructed of glass and wood will be applied in factory produced housing modules. Question marks surrounding fire resistance, long term behaviour, product certification etc. will also be addressed during this project. The aim is to get the project running during 2016.

Fig. 1: A glass/timber shear wall element being tested at Linnaeus University in Växjö, Sweden.

Limes

A European project to develop thinner and stronger cover glass for solar cell applications. The goal is to reduce the thickness of the cover glass from 3 to 1 mm without compromising strength. At the same time the optical properties and scratch resistance should be improved. The challenge presented by the funding agency is to achieve this without increasing the cost of the cover glass.
To reach the goals the chemical composition of the glass is being studied and optimized for the desired properties. Novel toughening techniques are also investigated to increase strength. If successful, the number of applications outside cover glasses for solar cells are numerous.

Optimization of glass bond line

A research project in collaboration with the automotive industry focussing on optimizing the bond line for windshields. Different plasma treatments are studied to map their capabilities to clean and activate the glass surfaces. The goal is to find an effective way to create a high quality bond line that can be implemented in an industrial process with high output. If successful, such a process could be applied for many other applications as well.

Printed electronics on glass

Printed electronics is an increasingly growing field. To investigate the possibilities with printed electronics in flat glass applications, Glafo has initiated a project in collaboration with the research institute Acreo and the Swedish industry. As an initial test a small printed display was successfully incorporated in a laminated glass (Fig. 2). By adding electronic components and sensors to glass applications with this technology creates numerous possibilities for intelligent system solutions.

Fig. 2: An example of how printed electronics can be integrated in glass. Here, a printed display has been added to a laminated glass light.

Prototypes

Glafo have produced several prototypes in collaboration with industrial partners to demonstrate traditional flat glass applications with added functionality. This is a very productive and informative way of demonstrating new possibilities and getting industrial partners more involved and interested in finding new solutions.

Interactive window

A window with integrated touch functionality that can be used to control different functions (Fig. 3). By using different touch inputs you can start/stop music, change songs, increase/decrease the volume, as well as controlling a lamp and a fan. The prototype was developed in collaboration with Ericsson and displayed at the Mobile World Congress in Barcelona 2013.

Window with integrated antenna

Currently, modern buildings in the Nordic countries are constructed with a very high emphasis on energy efficiency. Highly effective facades and windows offer very good energy performance, but also shield radio waves causing low reception indoors for mobile phones. However, by using the existing coating on the glass Glafo, in collaboration with Ericsson, developed a window with an integrated antenna (Fig. 3). This prototype was also displayed at the Mobile World Congress in Barcelona 2013.

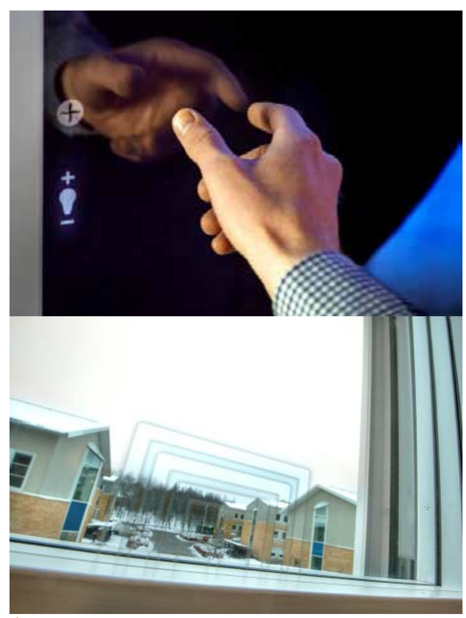


Fig. 3: Examples of prototypes that have been produced by Glafo. Top: interactive window with integrated touch function, bottom: window with integrated antenna.

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Time span: 2012 – 2016

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37 Active, Adaptive and Evolving building envelope components

Research developed by University Savoie Mont-Blanc – INES – FédEsol CNRS 3344

Christophe Ménézo/Stéphanie Giroux, Yvan Rahbé, Gérard Merlin, Julien Ramousse, Amen Agbossou, Gilles Fraisse, Monika Woloszyn

Research information

Research centre and federation

The research is led by the University Savoie Mont-Blanc, LOCIE UMR 5271 Laboratory, and the National Institute of Solar Energy (INES). It also implies other research from the CNRS National Research Federation (FédEsol)/ Solar Building Section. A transdisciplinary research is conducted and involves researchers from building physics, mechanics, biology and philosophy.

Objectives

The building envelope must ensure stability and mechanical strength, the health and safety of occupants (emission of pollutants and fire resistance), a level of acoustic comfort, visual comfort (natural light), and thermal comfort (solar radiation, control of steam flow, heat and air), as well as environmental compliance, a.o.

There are physical mechanisms for damping and heat-wave phase shift, for capturing or releasing amounts of heat to dissipate or convert the surrounding energy, or to protect themselves from passive or low-assisted behaviour. The integration of these processes into adaptive envelope components, i.e. able to change their physical variables over time without compromising the quality of indoor environments, compensates energy producer's variable performance and scalable multiple capabilities and finally, by varying the functions of the system based on their condition and environment

Active and Adaptive Façades

The concepts of active and adaptive BIPV envelope components demonstrate that it is possible to combine highly visible aesthetic and technological innovations. Within the French RESSOURCES project, BIPV double-skin facades with different shapes, colours, opacity level and orientations (façade and roof) have been developed. Such facades are adaptable with respect to the seasons. In winter, a mechanically ventilated cavity (extrinsic and with gradual control) can be used for heat recovery, pre-heating or coupling with a heat pump. In summer, the solar-driven ventilation process serves for natural cooling of the PV wall, as well as ventilation cooling of indoor spaces.

Bio-inspired building envelope

Our approach focusses on the complexity of the phenomena and physical mechanisms that govern the thermal-hygric and aerodynamic behaviour of buildings, the energetic challenges and the associated scientific and technological barriers.

A combined analysis consists of the identification of potential strategies, the phenomena/processes and the biological materials transposable to building technologies and in particular the envelope. Consequently, the biological or biochemical mechanisms utilized in the natural world to sustain life, protect the organism from various biological envelopes, and are thus studied in order to adapt to external stresses. For the building envelop, requiring the incorporation of a selective barrier in terms of interior and exterior conditions and representing an ability to harness a significant amount of energy, without being exhaustive, this could include in particular the mechanisms of respiration or of fluid exchange with the environment, photo-induced responses, the management of water and humidity, the importance of polymers in mechanical properties and the properties of envelopes and the trophic relationships between partners

Fig. 1: Helios Building – Bioclimatic design at National Institute od Solar Energy Institute (INES)/CEA/University of Savoie Mont-Blanc

Fig. 2: Double-skin prototype for detached houses (ETNA Test house – EDF R&D) - Pleated façade prototype for office buildings (HBS-Technal)

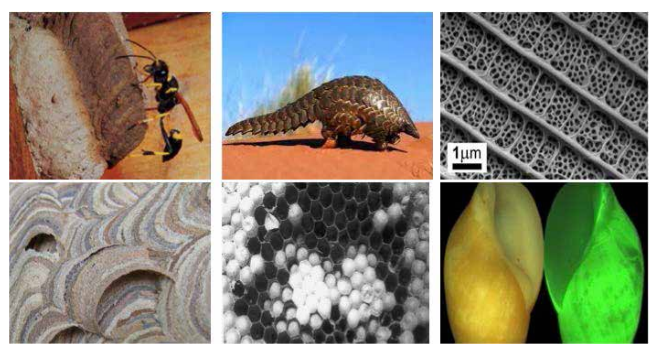

Fig. 3: Bio-inspired approach regarding physical phenomena that allow to dump and phase shift climatic stimuli or to generate heat, cool or even electricity

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Associated Publications:

1. L. Gaillard, S. Giroux-Julien, C. Ménézo, H. Pabiou (2014), Experimental evaluation of a naturally ventilated PV double-skin building envelope in real operating conditions, Sol. Energy. 103 (2014) 223–241.
2. Florian Labourel, Claudia Gutierrez-Silva,, Deniz Yalcin (2015), Rapport d'ouverture thématique: L'énergie solaire dans le monde vivant. HAL Id: hal-01144250
3. R.C.G.M. Loonen, J.M. Rico-Martinez, F. Favoino, M. Brzezicki, C. Ménézo, G. La Ferla, L. Aelenei (2015) Design for façade adaptability – Towards a unified and systematic characterization. 10th Conference on Advanced Building Skins, November 2015, Bern, Switzerland

38 TECNALIA research & innovation research priorities www.tecnalia.com\en

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▶ Partner information:

TECNALIA Research & Innovation is the first privately funded applied research centre in Spain and one of the leading such centres in Europe. A combination of technology, tenacity, efficiency, courage and imagination.
We identify and develop business opportunities through applied research. Inspiring Business is a different, unique vision: we visualize ideas that generate value and provide creative technological solutions to produce real results.

▶ Research priorities:

New active solutions with renewable energy integration in the architectural envelope

The achievement of nearly zero-energy building (NZEB) is a demanding challenge that requires the design of self-sufficient buildings with regard to satisfying the demand for climatisation and indoor comfort according to the intended occupancy.
Therefore, TECNALIA is interested in new ways of integrating renewable solar thermal energy harvesting, and in smart solutions to achieve the aim of an active envelope that can contribute to this objective.
The solutions for which we are developing our research are based on the design of new systems for low intrusive energy retrofitting and envelope industrialization by means of: "Use and management of the harvested thermal energy in the air gap of the ventilated façades"; "Use of the solar thermal energy as support to the HVAC system and performance improvement".
In addition, at TECNALIA we do not forget the relevance of photovoltaic integration (BIPV) in the envelope and new ways to improve the performance of these types of technologies.
The focus of Tecnalia in this field is related to the renewable active technologies that can be used to achieve the objective of NZEB

Smart Envelopes. Environment adaptable solutions for the improvement of user comfort

Due to the relevance of the envelope to improve a building's thermal and energy performance, significant advances have been made to integrate new functionalities and capabilities in the envelope to adapt it to outdoor and indoor environments over the past years. This is being achieved by means of sensors and actuators that allow changing the building's thermal and energy configuration according to real demand.
However, for that to happen it is necessary to offer solutions that are able to manage correctly unbalanced scenarios of energy generation and energy demand in the building.
Thus TECNALIA is interested in the development of these systems that are able to benefit from the energy harvested in the envelope and, at the same time, to improve the performance and efficiency of the building energy installations.
The focus of Tecnalia in this field is related to the development of these sensors, actuators and systems to manage correctly the different scenarios.

High performance envelopes based on materials with adaptive characteristics

The EU Directives regulate the more demanding energy efficiency requirements, for new building and for retrofitting the building stock, leading to new and improved insulation materials.
The traditional insulation materials lack sufficient performance to meet the new requirements on energy efficiency: new technologies and improved characteristics to provide innovative functionalities such as light weight, low thickness and increased insulation values. Moreover, research in new types of materials have demonstrated (under laboratory conditions) the possibility to change their physical characteristics to adapt to the exterior requirements in a passive way (not connected to any system that manages its properties) or in an active way (connecting them to a power supply). Example: more or less insulation depending on the exterior and interior conditions, to provide more or less shading when the light/heat from the sun reaches certain values, etc.
The focus of Tecnalia in this field is related to the development of new materials with active/passive properties (aerogels, nanomaterials, etc.

Solutions for the building envelope with low environmental impact

The relevance of sustainability in construction is totally consolidated and the materials industry is aware of the necessity to offer constructors and specifiers solutions with lower environmental impact yet economically competitive in the marketplace.
At TECNALIA we have recently developed new concepts and validated prototypes of solutions made of bio-based materials with low embodied energy (biomaterials) as well as recycling of sub-products for both the envelope and thermal insulation. Some examples include: "Forest based composites for façades and interior partitions to improve indoor air quality"; "Thermal performance evaluation of an industrialized façade based on biomaterials"; "High durability and fire performance wood-plastic composites (WPC) for ventilated façades".
The focus of Tecnalia in this field is related to the use of new materials with improved characteristics that could help the active envelope to achieve its objectives related to environmental impact.

39 COST Action TU1403 Adaptive Façades Ongoing research at Ghent University, BE

Belis, Bouten, Carbonez, Dispersyn, Janssens, Maroy, Martens, Steeman, Van Den Bossche, Van Goethem, Van Lancker

Research information

Introduction

This poster illustrates some recent and ongoing work at Ghent University, Department of Structural Engineering and Department of Architecture, which may be relevant for COST Action TU1403 on Adaptive Façades.

Kinematic systems

1. Kinematic systems enable translations and rotations of an array of interconnected structural elements. In the transformation phase, controlled movements must be potentiated, but once the mechanism is locked in place, the resulting structure must be rigid and secure in its use. "Adaptivity" in such systems is direct, as location and volume of the structure can be changed, but also indirect, as also the interior building climate can be altered by e.g. controlling shading devices with a kinematic system. The study looks into kinematics, connections, materialisation, force transfer and applications.

Structural glass response to changing loads

2. Structural glass has become increasingly important in façade design. However, as human lives may depend on it, its structural safety needs to be ensured also in accidental cases such as glass breakage, unintended removal of supports, fire, blast, etc. Adaptivity here means that the glass structure or system should be able to adequately redistribute such accidental loads, even if in most cases this will lead to irrevocable damage to the structural glass. This means that during such an event the glass will behave safely, but afterwards it will need to be replaced. LMO at UGent is highly specialised in this topic, and is currently investigating a.o. robustness of reinforced hyperstatic glass members, adhesive point fixings, glass in fire, structural closed cavity façade units, buckling, special laminates, etc.

Thermographic evaluation of the building envelope

3. Infrared thermography (IRT) is a non-destructive technique that can be used to detect thermal bridges, missing insulation and moisture inclusions. The question here is whether IRT could also be used to quantify air tightness of junctions, or thermal performance of walls and glass panels, and which parameters should be considered then. Parameters which should be taken into account when relating surface temperatures to air flow rates include joint width and geometry, configuration of adjoining surfaces, and convective heat transfer coefficient. These make it practically impossible to derive quantitative information on air leakage from IRT measurements.

For glass panels, the U-value calculated with the indoor surface temperature approximated the theoretical value when no solar radiation or clear sky temperatures were influencing the indoor surface temperature (Tsi).

Water and air tightness

4. The co-occurrence of wind and rain during a weather event results in wind-driven rain. Rain is given a horizontal component, causing raindrops to collide obliquely with the building façade. The resistance of wall elements to driving rain can be determined with 4 types of water tightness test methods: static, cyclic, dynamic and wind tunnel testing. Test procedures that are mostly executed in the research facility are static and cyclic test methods. Both protocols use a similar approach: wind and rain are decoupled and treated independently.

During the test, the amount of water that is drained from the test specimen can be measured. By means of these results it is possible to, for example, test the effect of the water deposition rate and the pressure difference on the ingress of water through deficiencies.

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Prof. Dr. ir. Arnold Janssens,
Dr. ir. Nathan Van Den Bossche
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& researchers mentioned below title

Time span: 2010 - 2018

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Associated Publications:

… references can be consulted online through https://biblio.UGent.be

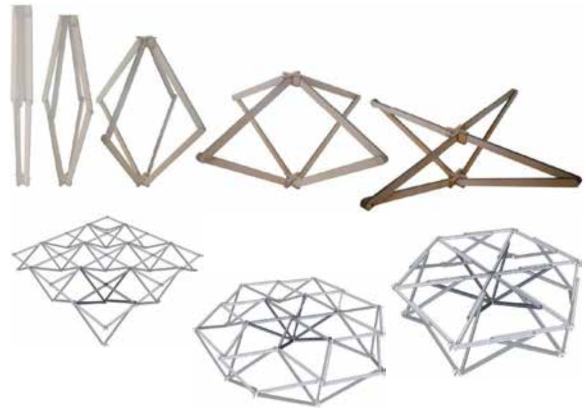

Fig. 1: Kinematic systems: uneven Sarrus chains. Top: basic module; Bottom: i) Flat rectangular joint-to-joint array, ii) Flat hexa-triangular joint-to-joint array, iii) Flat hexa-triangular overlap array

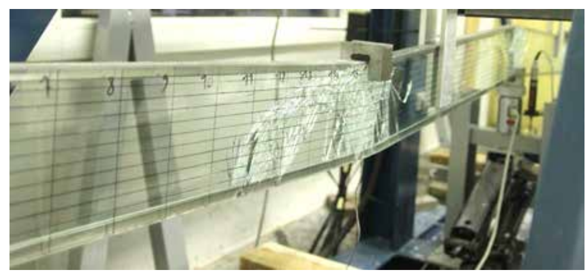

Fig. 2: Structural glass research: robustness of reinforced hyperstatic glass members, including safety after accidental removal of intermediate support.

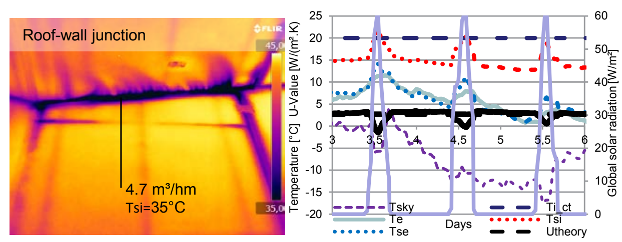

Fig. 3: Left: IRT visualization of air flow rates inside a test house. Right: DGU with argon filling, simulated with reference weather: Comparison of theoretical and simulated U-value. The accuracy of U-value estimation with IRT improves when avoiding solar radiation and a clear sky.

Fig. 4: Water tightness test: both rain and wind are simulated. Wind effects are represented by pressure differences generated by a fan (green). Rain is provided by means of water spraying nozzles in front of the test setup (blue).

40 Folded Reinforced Glass Connection System

Paulo J. S. Cruz, UMinho; Paulo L. Carvalho, UMinho; Frederic A. Veer, TUDelft

University of Minho
School of Architecture

Research information

Introduction

A folded reinforced glass structure has been developed using an innovative connection method. The concept relies on extending the reinforcement outwards from the laminated glass and using it to transfer a significant part of the load. The goal is to accomplish a glass element with high stiffness using a discrete almost invisible and easily assembled/ disassembled mechanism.

Structural analysis

Experimental investigation in a laboratory environment was conducted to scientifically collect and analyse data about the structural behaviour of the different materials and interfaces that compose the connection system. It included the tensile behaviour of thin steel plates, the adhesive behaviour of embedded thin steel plates, the compressive behaviour of intermediate layers in contact with glass and the bending behaviour of the connection. In a later phase of the connection development, in the scope of the full-scale prototype, the experimental investigation included the analysis of the out-of-plan compressive behaviour of a folded structure.

Detail and morphological adaptability

Design of the connection detail - technical requirements and morphological possibilities and applications have been addressed. The design development then focused on the specific folded geometry connection technique, clarifying the boundary conditions and necessary improvements of the lamination technology. Five main versions of the detail evolution are addressed corresponding to the same connection prototypes.

Industrial feasibility

Experimental investigation in an industrial setting was conducted to develop more insight based on contact with the several technologies that intervene in the fabrication process of the connection system. It included analysis execution and evaluation of the several steps within the transformation work of the materials (glass, steel and polymers). In the case of glass transformation, where most of the investigation took place, it was possible to make contact with the whole production sequence from material supply to final delivery.

Prototype

The combination of an empirical hands-on learning-by-doing process developed in the industrial setting with the methodologically scientific investigation supported by laboratorial equipment turned out to be critical in the accomplishment of the integrated approach.

Also important for the integrated design development was the possibility to execute several prototypes during the research, which were found to be a very useful tool to critically evaluate the intermediary design decisions. On the one hand it allowed the anticipation of new problems, clarifying the necessary changes to solve them; on the other hand it allowed controlling and improving the constructional and aesthetic quality of the connection that led to the execution of the full-scale prototype.

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Time span: 2010 - 2014

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Associated Publications:

1. CARVALHO, P.L.L., CRUZ, P.J.S. and VEER, F.A. (2014), Connecting through the reinforcement - design, testing and construction of a folded reinforced glass, Journal of Facade Design and Engineering, 2, pp. 109-122, DOI 10.3233/FDE-140013, IOS Press

2. CRUZ, P.J.S., CARVALHO, P.L.L. and VEER, F.A. (2014), Detailing for (de)materialization - design and fabrication of a folded reinforced glass connection, Engineered Transparency- International Conference at Glasstec, Düsseldorf, 21 and 22 October.

Fig. 1: Final full-scale prototype of the folded reinforced glass facade panel system.

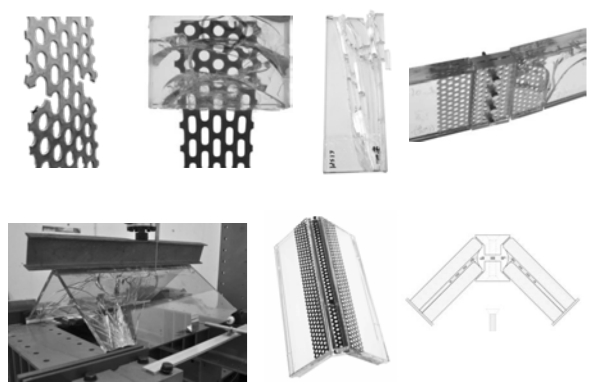

Fig. 2: Different tested specimens used during the experimental investigation.

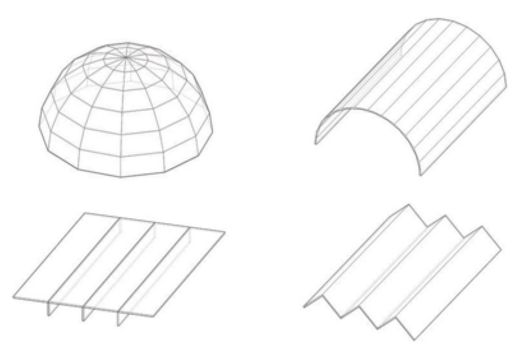

Fig. 3: Different shapes to which the connection system can be adapted.

41 Smart Envelopes for the Mediterranean Area. The new façade system in the ICT Centre in Lucca

Marco Sala and Rosa Romano, Department of Architecture, University of Florence

UNIVERSITÀ DEGLI STUDI FIRENZE
DIDA DIPARTIMENTO DI ARCHITETTURA

Research information

Abstract

The research project Smart Envelope, developed at ABITA Research Centre, analyses the evolution of smart façade systems in the area of design and industrial production, in order to investigate the technological, functional and qualitative standards of dynamic façades and to evaluate energy performances of the building envelope as a dynamic system that is able to interact with indoor and outdoor space. The study is focused, in particular, on the DOMINO facade, a dynamic envelope developed to improve the energy performances and the indoor comfort in office buildings located in Southern Europe.

Technological features

The DOMINO facade is a modular "dry assembled" system made with an aluminium frame, divided in an opaque and a transparent module. The modules consist of fixed and mobile layers: an aluminium-shading device, a glass panel and a metallic mosquito net that can be moved, with automatic or manual controls, from the opaque module in front of the transparent module.

The modularity of the components allows customizing the facade to fulfil the structural, energy-related and aesthetic requirements. In order to change the image and the energy performance of the façade different types of panels (made with PV, metal, glass, terracotta, etc.) can be integrated in the opaque module.

Furthermore the modularity of the frame and the possibility to move the three dynamic layers located in the opaque module, guarantees to change the energy performance of the façade during the year's seasons:

- In winter, the mobile glass panel is placed in front of the transparent module in order to realize a buffer zone and to increase the transmittance value of transparent and opaque panels.
- In summer: the mobile panel with the shading device is placed in front of the transparent module in order to decrease overheating inside of the building. During the night, the mosquito net is located in front of the operable window to increase air change by night cooling.

Energy simulations

We have simulated the energy performance of the facade system using the thermodynamic software TRNSYS. The energy simulations were done based on placing the façade system in a virtual test room with a size of 5,00 x 5,00 x 3,00 m and analysing the energy requirement of primary energy for heating and cooling in three different climatic zones in Italy (Milan, Florence and Palermo) and for four cardinal directions (East, South, West and North).

The simulations have shown that:

- In winter months the smart facade should be oriented toward the south to improve the solar heat gains and decrease the energy consumption for heating by at least 5%.
- In summer months the smart facade should be oriented south or north to reduce the thermal loads and the solar heat gains and decrease the energy consumption for cooling. During the summer day, the possibility to remove the glass panel from the transparent module allows to reduce the energy consumptions by 70 %, compared to a traditional double skin façade.

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Time span: 2007 - 2012

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Associated Publications:

1. ROMANO R., (2011) Smart Skin Envelope. Integrazione architettonica di tecnologie dinamiche e innovative per il risparmio energetico, Florence University Press, Firenze.
2. MARCO SALA, ROSA ROMANO, (2013), Innovative Dynamic Building Component For The Mediterranean Area, in *International Scientific Conference CLEANTECH FOR SUSTAINABLE BUILDINGS FROM NANO TO URBAN SCALE CISBAT 2013,* Lausanne, Switzerland, 4-6 September 2013, pp. 267-272

Fig. 1: The Domino facade was used in the construction of the south and east facades of the New Centre in virtual environments and ICT of Lucca Chamber of Commerce.

Fig. 2: The south façade of the ICT in Lucca. In this case, three PV panels generating an electrical energy production of 0.30 kWP are integrated into the opaque module of the DOMINO façade.

Fig. 3: The smart façade prototype was realized by DAVINI, an Italian Tuscan company. The façade system has a thermal break frame by Schueco and glass panels by Pilkington.

42 Bio-materials for the building envelope – expected performance, life cycle cost & controlled degradation

Anna Sandak, Jakub Sandak

Research information

BIO4ever concept

The Bio4ever project is a multi-disciplinary research dedicated at filling gaps of lacking knowledge on some fundamental properties of novel bio-based building materials. The two driving objectives of the project are:

- to promote the use of bio-materials in modern construction by understanding/modelling its performance as function of time and weather conditions
- to identify most sustainable treatments of bio-material residues at the end of life, improving their environmental impact even further.

Project scope

Investigated bio-materials will be characterized before and during degradation by biotic and a-biotic agents. The experimental data obtained will be used for development of the numerical models simulating the material deterioration in a function of time and exposition. The optimal solution from an environmental point of view for each disposal of investigated bio-materials will be provided. Additionally, life cycle costing will be performed, in parallel to LCA, in order to reflect on economical aspects. This is consistent with a sustainability perspective by using renewable resources, optimizing material structure on different length scales, extending product lifetime and by using green chemistry and minimum energy input.

Project output

Accurate service life time prediction, service life costing and aesthetical performance models of recently available bio-based building materials are foreseen as the most important deliverables. Dedicated algorithms simulating material modifications by taking into account original material characteristics and degrading process parameters will be developed on the micro, mezzo and macro scale. The appropriate numerical tools, able to capture the multi-scale evolution of damage will be tested under realistic conditions with field trials and surveys on structures in service.

A dedicated software simulating bio-materials performance, degradation and end-of-life in severe operating environments will be developed. It will serve as a tool for demonstrating advantages of using bio-based materials when compared to other traditional resources. The tool will be dedicated for investors, architects, construction engineers, professional builders, suppliers and other relevant parties, including the final customer as well.

It is expected that the result of this project will provide not only technical and scientific comprehension and methods, but will also contribute to the public awareness, by demonstrating the environmental benefits to be gained from the knowledgeable use of bio-based materials.

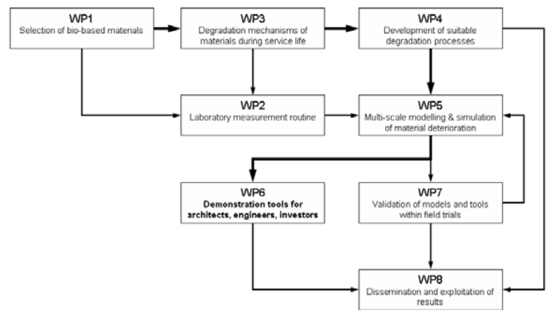

Fig. 1: Bio4ever project concept

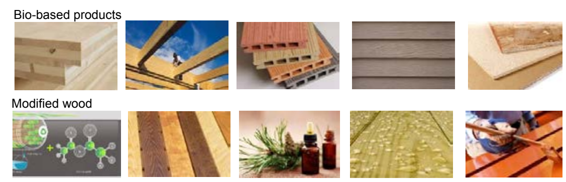

Fig. 2: Example of selected bio-based materials for evaluation tests

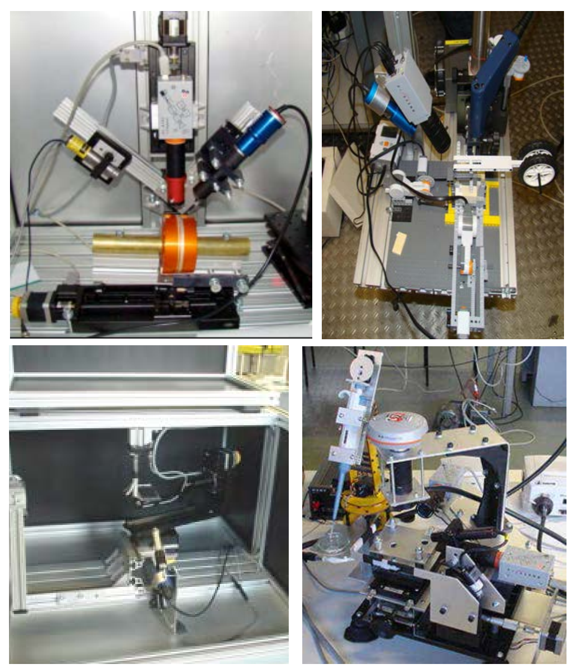

Fig. 3: Experimental set-up for multi-scale characterization of bio-based materials performance

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Time span: 2015 - 2018

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Acknowledgments:

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IVALSA TREES AND TIMBER INSTITUTE   BIO4ever

43 Smart material systems for high performance building envelopes

Guidelines for smart material implementation in the design of climatically responsive building envelopes

TECHNION Israel Institute of Technology

▶ **Arch. Noy Lazarovich, Prof. Guedi Capeluto, Prof. Michael S. Silverstein. Technion - Israel Institute of Technology**

▶ Research information

Motivation

The dynamic nature of the environment has led to the need for adaptive solutions for which the architect must possess a set of tools in order to cope with a wide range of interim changing climatic conditions. New advanced materials with an emphasis on smart materials have a significant potential to impact the design of building façades by achieving high performance envelopes and sustainable design.

SMARTerials classification system

1.One of the major reasons for the limited architectural use of advanced materials is the difficulty involved in creating an information flow between the field of material engineering, and the end users, architects and designers.
2. The proposed classification system for smart materials helps architects identify and 'fit' the best material for their goals from a smart materials library. The web based digital tool is called "SMARTerials" *(www.smarterials.co.il)*.
3. The main design process flow diagram (Figure 1) demonstrates how the proposed classification system is incorporated into the architectural design process at different work stages: using the tool between the conceptual stage and the schematic design is useful for exploring new material possibilities without having a final specification of the system needs; the material gallery of projects existing within the classification tool may provide inspiration for further development; between the schematic and detailed design stage, the usage of the classification tool provides a more specified classification of materials for well defined needs thus enabling the user easy communication with the materials manufacturers.

Case study

The case study deals with a responsive shading element for an existing façade. Materials identified by the program belong to the family of shape memory materials (alloys or polymers). This material was explored and used both as a sensor and actuator, and tests were done on prototype components based on compression SMA springs (Figure 2). The largest impact of these smart materials based shading systems can be achieved by combining a responsive smart material system (passive system) with a control system for intermediates situations. The case study of shading responsive components (Figure 3) presented the basic hypothesis according to which there is a direct connection and correlation between the surrounding temperature or radiation level and the desired building shade level.

Discussions and conclusion

This research presents theoretical and practical platforms for the integration of smart materials into structural systems. A new classification system for families of smart materials is proposed for integration into the architectural design process. An examination of this tool and its application is demonstrated in a case study that examines building facades relevant for specific climatic conditions (such as temperature change or solar radiation). Smart materials and technologies enable architects to animate their architecture by making it more interactive and responsive to the surrounding environment. In this way, smart materials may replace more conventional building materials or mechanical electric based systems – thus creating a new architectural vocabulary.

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▶ **Time span:** 2010-2012

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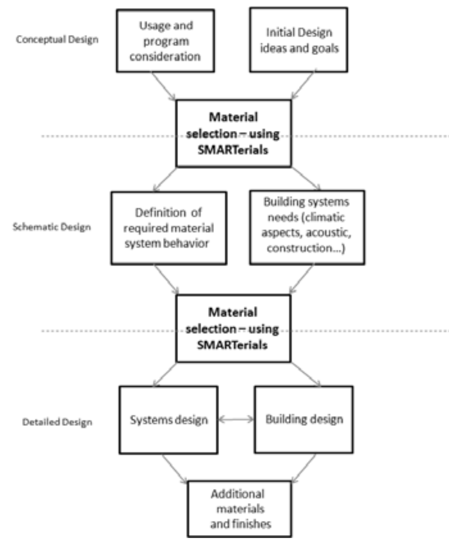
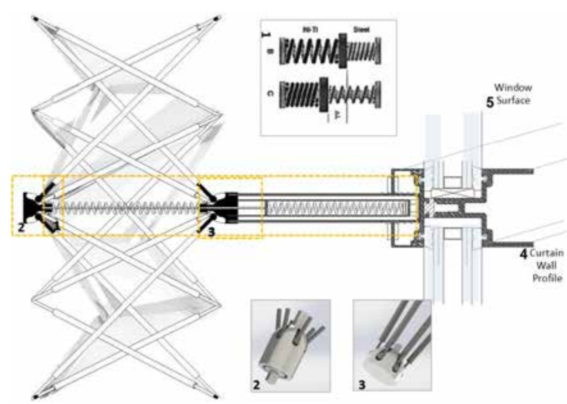
▶ Associated Publications:

1. ***Lazarovich N***., Capeluto I.G. and M.S. Silverstein, 2011 **"SMARTerials for High Performance Buildings"**. VRAP 2011, *Advanced Research in Virtual and Rapid Prototyping,* 5th International Conference, Leiria, Portugal, Bartolo at al.(eds) 2012 Taylor & Francis Group, London. ISBN 978-0-415-68418-7.
2. ***Lazarovich N***., Capeluto I.G. and M.S. Silverstein, 2010 **"SMART ARCHITECTURE – Architectural Aspects of Materials Engineering"**. *Square the Circle* ,Seminar with Professor David Leatherbarrow, Conference, Tel Aviv, Israel.



▶ **Fig. 1:** Flow chart of the design process integrating the SMARTerials tool.



▶ **Fig. 2:** Section of the shading component: 1. SMA smart thermal actuator that works against the bias compression spring to create linear motion. 2. 3D printed spherical joint 3. 3D printed spherical joint with a connector for a metal tube. 4. The connection to the curtain wall profile.

▶ **Fig. 3:** The western façade of Migdalei Tamam with the proposed shading solution, using smart materials for the actuating function, according to climatic and functional requirements.

44 Innovative Façade Concepts Toward NZEB
Façade related activities at EURAC Research

R. Lollini, S. Avesani, A. Passera, L. Baglivo, P. Vullo. Eurac Research / Institute for Renewable Energy

▶ Research information

The Energy Efficient Buildings group of the Institute for Renewable Energy is working on multi-functional façade system concepts design and engineering: solar façades (BIST, BIPV, passive solar walls), green walls, adaptive and responsive façades.

Methodological Approaches to assess Façade Concepts

1. **Building modelling and simulation**
2. **Experimental characterization of building systems and components**
3. **Building performance assessment in-situ**

Test Facilities

INTENT: indoor dynamic or steady-state thermal and energy performance assessment of traditional building components and of innovative building envelope systems also using solar technologies. (Fig. 1)

g-value: experimental arrangement for fenestration and shading concept development aimed at the investigation of solar heat gains in combination with performance characterization through simulations. (Fig.1)

e-lab: "the envelope Lab" (under development)

Outdoor testing laboratories for innovative façade systems and building technologies. The aim of e-lab is undertaking applied research for testing method development and validation and supporting companies in developing innovative products.

e-lab includes two test facilities, the **"Paslink cell**" (absolute calorimeter) and "**Multilab**" for façade system comparison and effect on IEQ. (Fig.3)

Façade Related Projects

- Development of a modular multifunctional climate adaptive façade system (**EU FP7 CommONEnergy,** 2014 - 2018)
- Envelope retrofit kit for office building retrofitting (**EU FP7 Inspire**, 2012 - 2016)
- Integration of energy efficiency technologies in existing public buildings **(EU FP7 Bricker,** 2013 - 2017)
- On-the-fly alterable thin-film solar modules for design driven applications (**EU FP7 Solar Design,** 2013 - 2015)
- Novel façade systems to produce and distribute thermal energy in the façade **(Sunrise** local project, 2014 - 2017)
- Introduction of a user-friendly tool to asses the early design façade concept in public procurements with multi criteria performance indicators **(Façade Performance-based Tender,** local project 2014 - 2015)

Developed technology concepts

- Prefabricated multifunctional façade integrating solar thermal collectors and wall radiant system for heating
- Integrated solar thermal façade using cassette system integrating unglazed solar collector

Events and Involvements

- **Façade working group** in Bolzano (a roundtable involving several parties dealing with façades in South Tyrol)
- **Klimainfisso** (biennial local fair for façades, windows and envelope components)
- **FACE** (training course for engineers, architects, contractors, researchers dealing with façade technology, legislation and management)
- **European Façade Network**

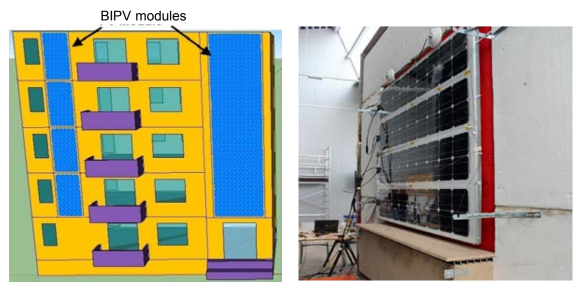
▶ **Involved people:** Roberto Lollini: coordinator of the research group «Energy Efficient Buildings»; Stefano Avesani and Alessio Passera: façade concept, modelling & simulations: Luca Baglivo and Pascal Vullo experimental assessment.

▶ **Contact data:** roberto.lollini@eurac.edu / www.eurac.edu

a. **INTENT** guarded hot-box double chamber, sun simulator, hydraulic circuit

b. **g-value:** continuous-light sun simulator, climatic box, absorber

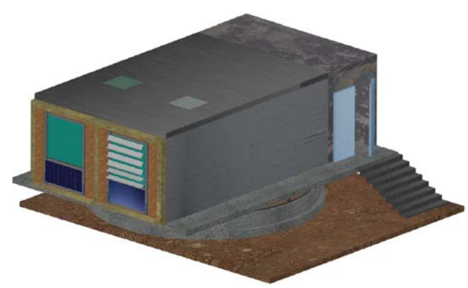
▶ **Fig. 1: Indoor test facilities at EURAC**



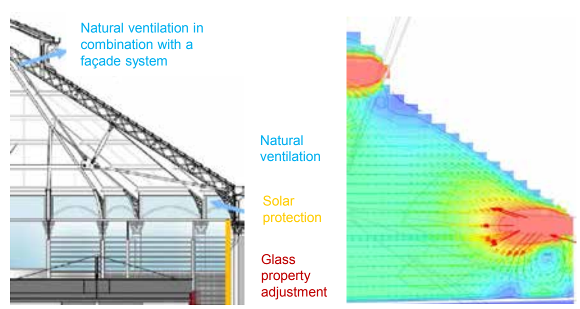
a. Dynamic simulation of building integrated photovoltaics with TRNSYS

b. Experimental validation with the INTENT test facility

▶ **Fig. 2:** Optimization of BIPV systems
Numerical and experimental performance assessment
Optimization of the air gap between BIPV and wall



▶ **Fig. 3:** Outdoor test facility "Multi-lab"



a. Adaptive façade system including a natural ventilation strategy

b. Natural ventilation wind velocity profile, CFD simulation

▶ **Fig. 4: EU FP7 CommONEnergy** (2014-2018)
Developed modular multifunctional climate adaptive façade system as implemented in "Mercado del Val", Valladolid demo-case

45 ISISE-SMCT: Thermal Behaviour and Energy Efficiency R&D Activities Overview

Paulo Santos, L. Simões da Silva, Helena Gervásio, Nelson Soares, Cláudio Martins, Nuno Rosa

Research information

Research Centre

ISISE – Institute for Sustainability and Innovation in Structural Engineering; **SMCT** – Steel and Mixed Construction Technologies Group; Sustainability and Energy Efficiency Cluster. https://www.isise.net

Research Keywords

Thermal Behaviour; Energy Efficiency; Lightweight Steel Framed (LSF); Thermal Bridges; Flanking Heat Losses; Thermal Inertia; Phase Change Materials (PCMs); Numerical simulation; Experimental approach; Guarded Hot Box.

CoolHaven (R&D Project)

The main goal was to develop and implement a new modular and eco-sustainable Lightweight Steel Framing (LSF) construction system for low-rise residential buildings. The focus was on: the characterization of thermal performance of modular LSF walls, with experimental measurements and numerical 3D FEM models; the importance of flanking thermal losses; thermal bridges mitigation strategies; and optimization of the wall module thermal insulation [1-4]. (Fig. 1)

EcoSteel Panel (R&D Project)

EcoSteel Panel R&D project aims to develop a new sustainable LSF solution that could be used as a rain water harvesting wall and improve thermal behaviour and energy efficiency of buildings. (Fig. 2)

PCMs4Buildings (R&D Project)

This recently funded R&D project will start in 2016 and the main goal is to study and optimize systems with Phase Change Materials (PCMs) filled rectangular cavities for the storage of solar thermal energy for buildings. Nelson Soares [5-7] is now concluding his PhD being his research focused on this area. (Fig. 3)

Guarded Hot Box (Experimental Facility)

This guarded hot box test station was designed according to EN ISO 8990 requirements and will be used to measure steady-state thermal transmittance of real-sized construction elements up to 3.6 x 2.7 x 0.4 m. The method is suitable to measure thermal transmittances in the range 0.1 to 15 W/(m^2.K) for testing within a temperature range of 0 to 50°C. This test station is now under calibration tests. (Fig. 4)

- **Contact person:** Prof. Dr. Paulo Santos
- **Time span:** 2010 - 2018
- **Contact data:** pfsantos@dec.uc.pt

Associated Publications:

1. Santos, P., Simões da Silva, L., & Ungureanu, V. (2012). Energy Efficiency of Light-weight Steel-framed Buildings. European Convention for Constructional Steelwork (ECCS), Technical Committee 14 - Sustainability & Eco-Efficiency of Steel Construction, ISBN 978-92-9147-105-8, N. 129, 1st edition. http://www.steelconstruct.com
2. Santos, P., Martins, C., & Simões da Silva, L. (2014). Thermal performance of lightweight steel-framed construction systems. Metallurgical Research & Technology, 111(6), 329–338. http://dx.doi.org/10.1051/metal/2014035
3. Santos, P., Martins, C., Simões da Silva, L., & Bragança, L. (2014). Thermal performance of lightweight steel framed wall: The importance of flanking thermal losses. Journal of Building Physics, 38(1), 81–98. http://dx.doi.org/10.1177/1744259113499212
4. Martins, C., Santos, P., & da Silva, L. S. (2015). Lightweight steel-framed thermal bridges mitigation strategies: A parametric study. Journal of Building Physics. http://dx.doi.org/10.1177/1744259115572130
5. Soares, N., Costa, J.J., Gaspar, A.R. & Santos, P. (2013). Review of passive PCM latent heat thermal energy storage systems towards buildings' energy efficiency. Energy and Buildings, 59, 82–103. http://dx.doi.org/10.1016/j.enbuild.2012.12.042
6. Soares, N., Gaspar, A.R., Santos, P. & Costa, J.J., (2014). Multi-dimensional optimization of the incorporation of PCM-drywalls in lightweight steel framed residential buildings in different climates. Energy and Buildings, 70, 411–421. http://dx.doi.org/10.1016/j.enbuild.2013.11.072
7. Soares, N., Gaspar, A.R., Santos, P. & Costa, J.J. (2015) Experimental study of the heat transfer through a vertical stack of rectangular cavities filled with phase change materials. Energy and Buildings, 142, 192–205. http://dx.doi.org/10.1016/j.apenergy.2014.12.034

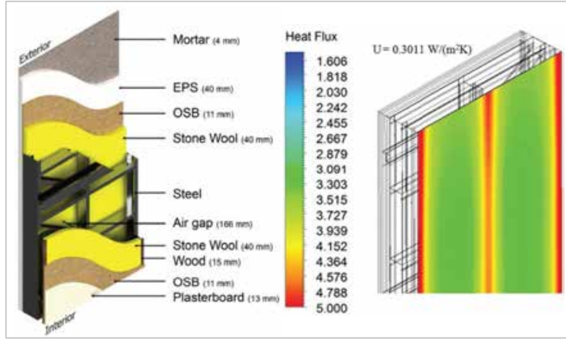


Fig. 1: Thermal performance of a LSF wall: heat flux.

Fig. 2: EcoSteel panel experimental prototype and virtual prototype integrated in a LSF house.

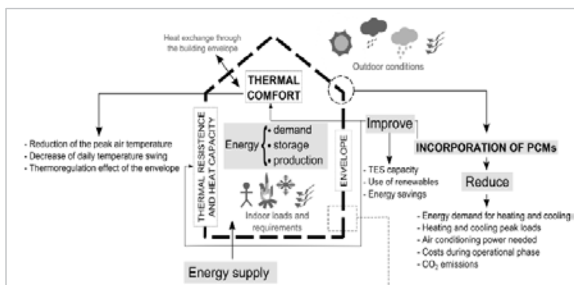


Fig. 3: Sketch of the building as a thermodynamic system and main advantages of incorporating TES systems with PCMs in buildings.

Fig. 4: Guarded Hot Box Test Station developed at University of Coimbra.

46 Pinwheel Origami

Exploring the potentialities of a dynamic shading device by means of Origami geometries

▶ M. Pesenti, F. Fiorito (Ph.D), G. Masera (Ph.D)

▶ Research information

Introduction

The research takes into account the potentialities of a multi-faced Origami shading device actuated by shape memory micro-actuators which enable the façade shape change in direct response to the incoming solar radiation. The importance of natural light as a way to reduce the energy consumption while providing a better level of satisfaction for the users has been evaluated through geometry investigation, material combinations and deployment actuation.

Origami geometries used to optimise movements

As a way to increase the feasibility of Shape Memory Alloys (SMAs) micro-actuators, the research considered Origami folded patterns activated by embedded SMA. The kinematic performed by the folding geometries has been investigated with digital software and tools in order to understand how cuts and folds react when actuated by external forces.

The digital analysis focuses on the rate of deployment derived by geometric manipulation and arrangement of SMAs onto their surface. Hence, the research points out which micro actuator configuration provides better folding percentages and thus can be used as a concept to develop a dynamic shading device that would be effective on a building scale. For each pattern, eight type of wire distribution have been proposed and a fixed contraction of 25% has been set, so as to remain within the range of SMA contraction.

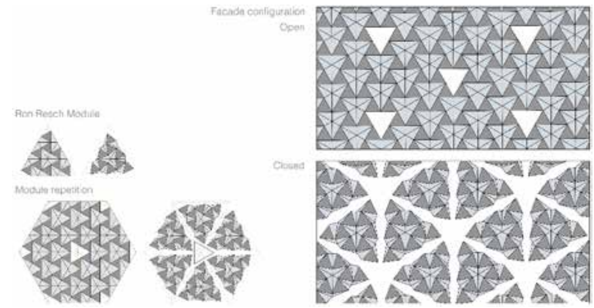
Daylight and thermal simulations

Dynamic simulations have been carried out using 3D parametric tools to reproduce the behaviour of the Origami shadings for a medium size office room throughout the year. The Ron Resch Origami pattern has been chosen because of its dynamic characteristics and the higher values of contraction shown when actuated. Environmental simulations focuses on different percentages of contraction, set to 0, 10 and 25%, and material combinations. To do that, the plug-in Honeybee has been adopted, as it allows the user to connect Grasshopper with EnergyPlus, Radiance and Daysim. The calculation has been developed in two steps, before considering UDI, DA and DGP as parameters to assess the visual comfort conditions, after evaluating the primary energy needed for cooling, heating and lighting.

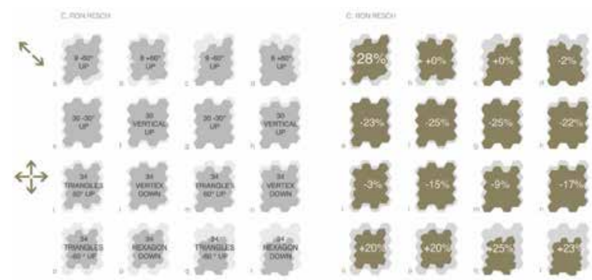
The combinations of different materials to cope with the imposed thresholds highlighted the intrinsic potential to have a dynamic shading device instead of a static one. Mixed combinations show the most promising behaviour, highlighted by their ability to contribute to a reduction of the energy consumption throughout the year, an increment of the daylight autonomy and a more uniform daylight distribution in the office room.

Exploration with physical SMA actuators

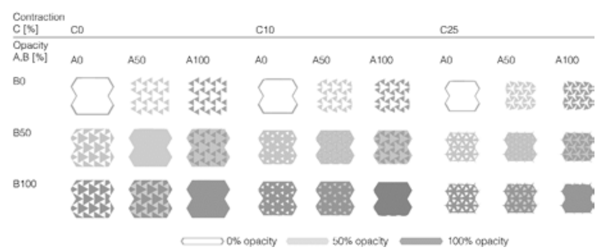
The geometric analyses conducted on both physical and digital models have shown some potentialities in the study of new deployable solar shading devices. The first experiment has been made using 720 mm SMA wires with a 150 μm thickness stimulated by 16 V electricity input and 0.48 A. Test results of this module pattern highlighted how the self-folding properties of Origami can be used to bring the wires to their initial position.



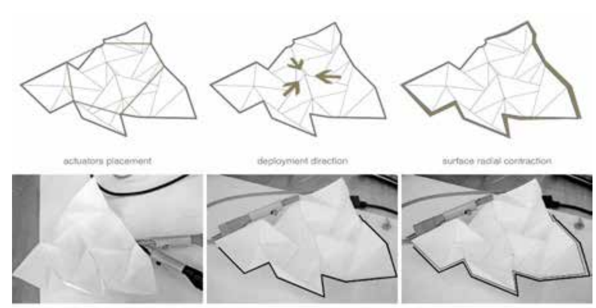
▶ **Fig. 1:** Ron Resch pattern module geometry allows to repeat the pattern on different scales, creating a self-similar pattern. The repetition of hexagonal modules gives an example of facade's integration.



▶ **Fig. 2:** The digital analysis focuses on the deployment optimisation of each folded pattern according to wire distribution, constrained points and self-folding feature.



▶ **Fig. 2:** Twenty-seven configurations of shadings: no shadings (A0; B0), complete shading (A100; B100) and mixed combinations of opacity for the A and B faces, each for a specific rate of contraction.



▶ **Fig. 3:** The actuators placement allows envisioning the deployment direction. To prevent local deformation, the experiment did not take into account connection wires from the boundary vertexes to the central vertex.

▶ Involved persons: Prof. Dr. Francesco Fiorito
Prof. Dr. Gabriele Masera
Mr. Marco Pesenti

▶ Time span: 2012 - 2015

▶ Contact data: francesco.fiorito@sydney.edu.au, f.fiorito@unsw.edu.au

▶ Associated Publications:

1. Pesenti M., Masera G., Fiorito F., Sauchelli M. (2015). Kinetic Solar Skin: A Responsive Folding Technique. *Energy Procedia*, *70*, 661-672.
2. Pesenti M., Masera G., Fiorito F. (2015). Shaping an Origami shading device through visual and thermal simulations. *Energy Procedia*, *IN PRINT*.

47 University of Ljubljana Faculty of Mechanical Engineering

▶ Sašo Medved, Ciril Arkar, Tomaž Šuklje, Boris Vidrih, Suzana Domjan

Research information

Introduction

Laboratory for Sustainable Technologies in Buildings (LOTZ) is focused on the development of technologies for efficient energy use and the exploitation of renewable energy sources in buildings. Educational activities include lectures on RES and Energy & Environment at the Faculty of Mechanical Engineering; Building Physics and Building Services at the Faculty of Architecture and Energy & Environment at the Faculty of Health Care.

Research areas

Main R&D areas of LOTZ can be divided in:

- heat transfer and performance optimization of low-exergy systems for active natural heating and cooling of buildings,
- development and modelling of systems and components for solar energy and energy of the environment utilization for heating and cooling of buildings,
- system performance optimization, as well as evaluation of impact of these technologies on indoor and outdoor (urban) thermal environment.

Associated research topics

In LOTZ, laboratory and *in situ* experimental measurements, as well as numerical studies of heat and mass transfer are carried out in:

- vertical greenery systems (VGS) (Fig. 1), which enable evaporative cooling, shading of the building envelope and CO_2 sink [4],
- green roofs with mineral wool substrate, optimizing water retention and thermal response [3],
- urban areas, evaluating heat island mitigation applying VGS, selective façade coatings, green roofs, water surfaces, urban parks (Fig. 2) [5],
- bionic façades, which enhance the advantages and eliminate disadvantages of VGS (Fig. 3) [1],
- building envelope elements (transparent and opaque), which enable utilization of solar energy and energy of the environment (Fig. 4) [6],
- Active natural heating and free cooling technologies (Fig. 5), incorporating PCM and building's structure as thermal storage material [2],

We also have an experimental and demonstrational "Self-sufficient living cell" (Fig. 5) near the faculty, in the city centre of Ljubljana, which is used for educational and research activities (laboratory with remote access) as well as public awareness of energy efficiency and RES in buildings.

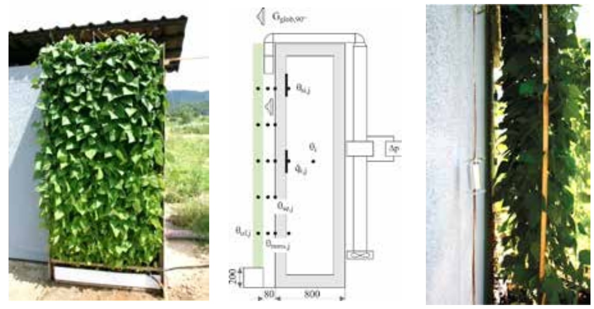
Involved persons: Prof. Dr. Sašo Medved
Assoc. Prof. Dr. Ciril Arkar
Dr. Vidrih Boris
Mr. Tomaž Šuklje
Ms. Suzana Domjan

Time span: ongoing

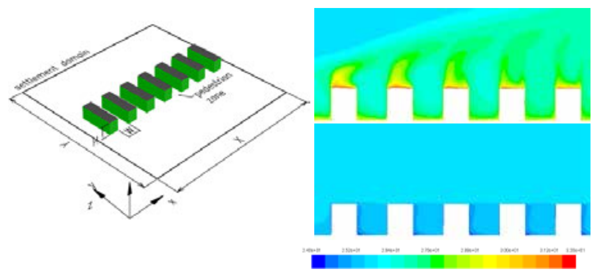
Contact data: ciril.arkar@fs.uni-lj.si www.ee.fs.uni-lj.si

Associated Publications:

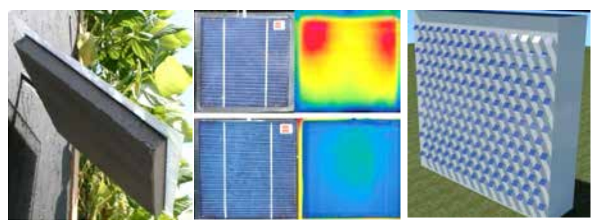
1. ŠUKLJE, T., ARKAR, C. & MEDVED, S. (2015) A Hydro-Thermal Study of the Bionic Leaf - A Basic Structural Element of the Bionic Façade Inspired by Vertical Greenery. *Energy Procedia*.
2. ARKAR, C., MEDVED, S. (2015) Optimization of latent heat storage in solar air heating system with vacuum tube air solar collector. *Solar energy*. 111. p. 10-20.
3. ARKAR, C., DOMJAN, S., MAJKOVIČ, D., ŠUMI, J. & MEDVED, S. (2015) Lightweight green roofs' thermal response under freezing conditions. *Energy Procedia*.
4. ŠUKLJE, T., MEDVED, S. & ARKAR, C. (2013) An Experimental Study on a Microclimatic Layer of a Bionic Façade Inspired by Vertical Greenery. *Journal of Bionic Engineering*. 10 (2). p.177-185.
5. VIDRIH, B & MEDVED, S. (2013) Multiparametric model of urban park cooling island. *Urban Forestry & Urban Greening*. 12 (2). p. 220-229.
6. LESKOVŠEK, U., ARKAR, C., ČERNE, B. & MEDVED, S. (2008) Multiple parametric models of heat transfer in lightweight building elements with ventilated cavities. *Journal of mechanical Engineering*. 830-840



▶ **Fig. 1:** Experimental setup for evaluation of thermal response of vertical greenery systems (VGS).

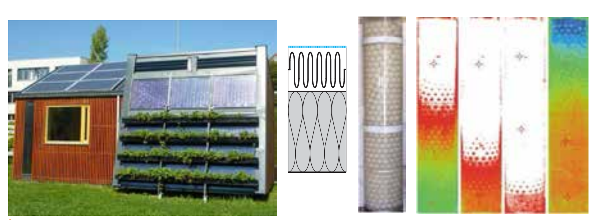


▶ **Fig. 2:** Evaluation of urban heat island mitigation potential using combined TRNSYS – CFD model. Comparison of UHI of the grey urban canyon (right top) and engaging VGS (right bottom).



▶ **Fig. 3:** Bionic leaf (left) enhancing electricity production (centre), evaporative cooling and shading of the building envelope. Bionic leaf is a basic structural element of the bionic façade (right), mimicking VGS.

▶ **Fig. 4:** Outdoor laboratory site (left), where adaptive façade technologies, such as glazed SC absorber (centre) and lightweight panel with VIP and PCM layer (right), are tested.



▶ **Fig. 5:** Self sufficient building (left) with integrated decentralized ventilation unit (centre) and active natural heating system with air vacuum tube SC and PCM storage (right).

48 Kaunas University of Technology Laboratory of Building Physics

▶ Raimondas Bliudzius, Juozas Ramanauskas, Edmundas Monstvilas, Karolis Banionis

▶ Research information

Introduction

The Laboratory of Building Physics is the 2nd level department of Kaunas University of Technology. Activities of the laboratory cover three areas: scientific research, evaluation of performance of building materials and components (accredited and notified laboratory) and scientific and technical support for the building industry and governmental institutions.

Scientific research

The Laboratory has 2 research groups working on: investigation of energy efficiency of buildings and live cycle analysis of finishing materials. The energy efficiency group focuses on investigation of energy performance of low energy houses, use of renewable energy in buildings, search for efficient solution for facade and roof structures. The live cycle analysis of finishing materials research group analyses behaviour of different finishing materials in cold and wet climate conditions, methods for determination of frost resistance and durability of roofs and facade coatings.

Scientific and technical support for the building industry and governmental institutions:

1. Evaluation of energy performance characteristics, air tightness and airborne sound insulation properties of facades.

For the evaluation of the influence of thermal bridges on the thermal performance of ventilated facades we use software for numerical calculation and testing equipment according to the "Hot box" method. To achieve a high energy performance class of building it is necessary to increase the thermal resistance of the facade and change aluminium and steel facade framework elements to stainless steel or composite connectors. In a first stage of investigation we provide 3D calculation, later preparing fragments of facades for testing in the "Hot Box".

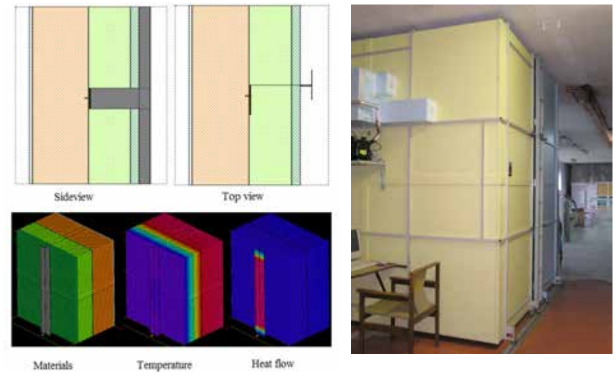
We check new facades solutions for sound insulation and air tightness performance. In the design stage we provide calculations, later testing fragments or in real buildings during construction process.

2. Technical evaluation of new building materials and solutions, energy certification of buildings.

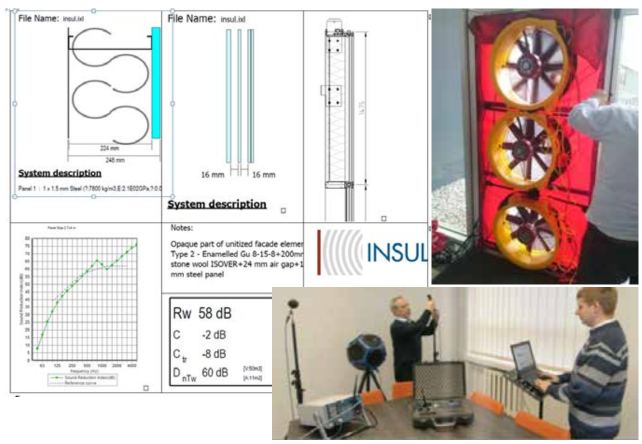
The Laboratory provides cost-optimizing calculations for governmental institutions, prepares scientific and technical programs for introduction of new building materials and elements into the Lithuanian building sector.

The energy certification group manages the energy certification system in Lithuania:.

- Gaining energy certification expertise;
- Preparing methods of calculation and data bases;
- Certify "complicated" buildings.



▶ **Fig. 1:** For the introduction of new elements into the facade network, we provide 3D calculation ant determine the U-value of facade fragments in a "Hot Box"



▶ **Fig. 2:** The influence of new materials and solutions on facade airborne sound insulation is predicted by calculation and checked by testing of large-scale models or in completed buildings. "Blower door" tests also show the performance of new solutions.

▶ **Fig. 3:** Energy certification group manages the energy certification system in Lithuania, gains energy certification expertise, prepares methods of calculation and data bases and certifies "complicated" buildings.

▶ **Involved persons:** Prof. Dr. Raimondas Bliudzius
Dr. Juozas Ramanauskas
Dr. Karolis Banionis.
Dr. Edmundas Monstvilas

▶ **Time span:** 2010 - 2015

▶ **Contact data:** raimondas.bliudzius@ktu.lt

▶ Associated Publications:

1. Šadauskienė, Jolanta; Paukštys, Valdas; Šeduikytė, Lina; Banionis, Karolis. Impact of air tightness on the evaluation of building energy performance in Lithuania. Energies Basel: MDPI, 2014, Vol. 7, Iss. 8 p. 4972-4987. ISSN 1996-1073. DOI: 10.3390/en7084972. [Science Citation Index Expanded (Web of Science)]. [IF: 2,072, AIF: 4,081 (E, 2014)].
2. Miškinis, Kęstutis; Dikavičius, Vidmantas; Bliūdžius, Raimondas; Banionis, Karolis. Comparison of sound insulation of windows with double glass units. Applied Acoustics. Oxford: Elsevier, 2015, Vol. 92 p. 42-46. ISSN 0003-682X. DOI: 10.1016/j.apacoust.2015.01.007. [Science Citation Index Expanded (Web of Science); Science Direct]. [IF: 1,024, AIF: 1,741 (E, 2014)].

49 Research expertise and topics

▶ Dr. Albert Castell, Dr. Marc Medrano, Dr. Ingrid Martorell,
▶ Dr. Cristian Solé, Dr. Lídia Rincón, Sr. Sergi Vall; University of Lleida

Universitat de Lleida

▶ Research capabilities

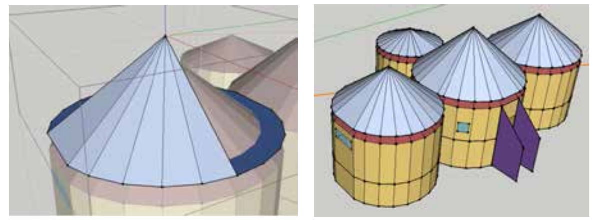
Experimental work

The research team has been involved in many experimental works, gaining thorough expertise in setting up and monitoring systems and components, as well as evaluating data. Some of the experimental work carried out include:

- Thermal evaluation of building envelopes including new insulation materials and thermal inertia
- Evaluation of the energy performance of active building façades for solar collection and cold storage
- Performance evaluation of storage tanks and solar collectors for domestic hot water and industrial applications
- Development and evaluation of improved HVAC systems

Numerical simulation

The research team has expertise in using different simulation tools. For the energy simulation of buildings EnergyPlus is typically used (Fig. 1) to determine the best strategies for demand reduction. On the other hand, Trnsys is used to simulate energy systems, while Comsol Multiphysics allows for detailed heat transfer simulations. Own developed codes (C+ and EES) are also used for specific designs.



▶ **Fig. 1:** Numerical simulation for energy optimization of an experimental construction. Influence of weather conditions, materials, roof shading, window size, glazing, cross-ventilation, etc.

▶ Research topics

Radiative Cooling

A new concept to adopt radiative cooling for active systems integrated in building roofs and façades is under development. The new concept will be able to produce both heat and cold for domestic use.

Thermal Energy Storage

Thermal Energy Storage is an enabling technology for the integration of renewable energies at both grid and local level. The development of such technology is crucial for the correct deployment of renewables.

▶ **Fig. 2:** Research building at the University of Lleida, incorporating several energy technologies. Reduction of energy consumption and waste production to nearly zero on a campus-wide level

Multifunctional Optimization

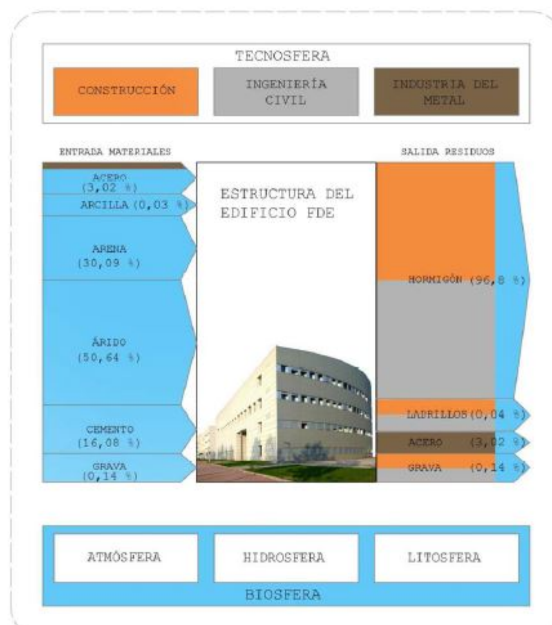
In order to address the development of new technologies from a more holistic approach, multifunctional optimization techniques are used, considering energy performance, environmental issues, cost, etc.

Nearly Zero Energy and Waste Buildings

In recent years the team started working on developing the concept of Nearly Zero Energy and Waste Buildings on a campus level. Using the University Campus as a laboratory, several strategies are proposed (Fig. 2 & 3).

Construction Systems for Developing Countries and Catastrophe Areas

Having also a strong social awareness, the team started working on a cooperative project to develop new construction systems based on the Earthbag concept. Both structural and energy problems are addressed in the process of building a medical centre in Burkina Faso (Fig. 1).



▶ **Fig. 3:** Material Flow Analysis methodology applied to a building of the Cappont Campus at the University of Lleida. The methodology aims at reducing and managing the materials and waste produced at the end of the life span of the building

▶ Involved persons: Dr. Albert Castell, Dr. Marc Medrano, Dr. Ingrid Martorell, Dr. Cristian Solé, Dr. Lídia Rincón, Mr. Sergi Vall

▶ Time span: 2015 - ongoing

▶ Contact data: acastell@diei.udl.cat

▶ Associated Publications:

1. Castell A, Solé C. (2015) An overview on design methodologies for liquid-solid PCM storage systems. Renewable and Sustainable Energy Reviews, 52, 289-307.
2. Castell A, Farid MM. (2014) Experimental validation of a methodology to asses PCM effectiveness in cooling building envelopes passively. Energy and Buildings, 81, 59-71.
3. Rincón L, et al. (2013) Evaluation of the environmental impact of experimental buildings with different constructive systems using Material Flow Analysis and Life Cycle Assessment. Applied Energy, 109, 544-552.
4. Medrano M, et al. (2008) Economics and climate change emissions analysis of a bioclimatic institutional building with trigeneration and solar support. Applied Thermal Engineering, 28, 2227-2235.

50 Adaptive insulation: intelligent control of local energy flow across the building skin

Nikolaus Nestle, Advanced Materials and Systems Research, BASF SE Ludwigshafen

150 years
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Research information

Needs and concepts for switchable insulation

While well-insulated building skins offer clear energetic advantages in reducing unwanted heat losses from heated rooms in winter or air-conditioned rooms in a permanently hot environment, they also suppress beneficial heat flows from overheated rooms to a colder exterior environment. Under such conditions, energy and comfort benefits could be achieved by "switching off" the insulation. Fig. 1 shows the basic concept for a switchable insulation element [1,2]: In the "on" state, convection around the insulation is suppressed and a low U-value typical for an insulation element is achieved. In the "off" state, by contrast, convection around the insulation element is possible and a U-value in the range of 1.5 W/Km^2 is achieved by spontaneous convection. Using forced convection, even higher U-values can be reached. If a translucent insulation element is used, the closed element sketched in Fig. 1 can be used as a wall element with both daylight and thermal energy management functionalities. Unwanted additional solar gains arising from the translucence can be controlled by using solar IR reflective coatings on the glass. The well-known thickness limitations for translucent insulation in closed elements can be overcome by under-pressure housing of the translucent insulation element itself [3].

The principle of switching insulation by convection control can be also applied to opaque insulation. In this case, the air flow in a back-venting gap between the insulation and the wall is switched (see figure 2). Demonstrators for both types of switchable insulation have been built and integrated into the LUMit building on BASF's premises in Ludwigshafen (see figure 3).

Ongoing work and challenges

In order to make best use of the energetic functionality of elements with switchable U-value, novel strategies for building control are needed in which e.g. cooling via switchable U-value is given priority over free cooling or active air-conditioning devices. Validation of such strategies will need both appropriate simulations and a demonstration building in which sufficient parts of the façade are equipped with switchable U-value elements.

On the materials side, the development of foams with optimized translucence and good thermal performance is a priority.

The use of a back-vented gap in the opaque open insulation elements needs careful consideration in the context of fire codes; the requirements for maximal and minimal acceptable gap widths are quite different in the national standards of different EU member states. The closed element, by contrast comes with rather good fire rating due to the use of glass on the external skin of the building.

Combination with solar wall collectors

Wall elements with switchable U-value also open up new options for the use of solar heating energy from simple wall collectors as energy-intensive long-distance transport of low energy density heat carriers is no longer needed to transport the heat from the façade into the building. The main challenge in this case is an appropriate approach to avoid the solar gains from the collectors in conditions with high outside temperatures.

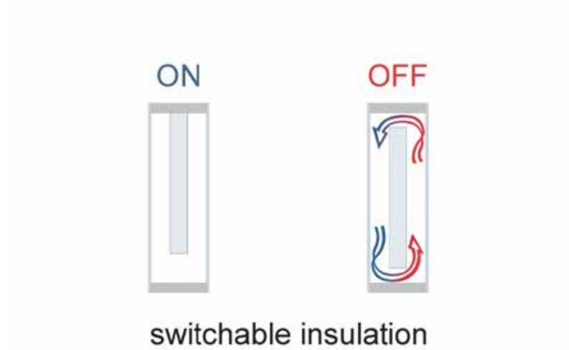


Fig. 1: Basic principle of a closed element with switchable insulation: if convection around the insulation is supressed, the insulation is "on", if it is enabled, the insulation is effectively switched "off". Convection control can also be achieved by other mechanisms than displacing the insulation.

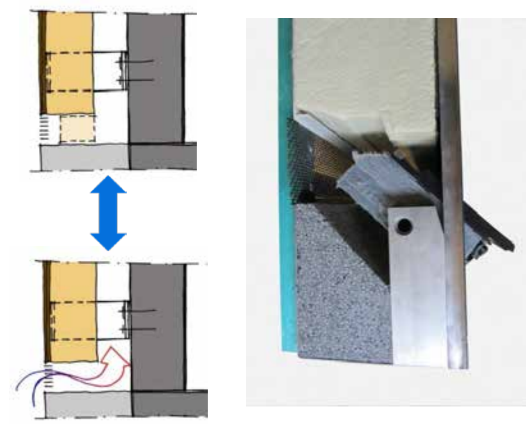


Fig. 2: Basic principle and actual implementation of an opaque switchable insulation with convection control in a back-venting gap. In order to prevent heat bridges at the openings of the gap, the doors are insulated with a high-performance, aerogel based insulation material. The main insulation in the example element is a standard PU foam

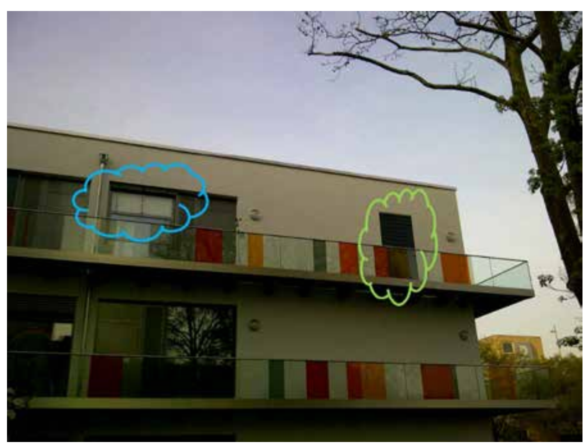


Fig. 3: Building-integrated demonstrators in the façade of BASF's LUMit building: translucent closed element (blue cloud, left) and opaque open element (green cloud, right)

Involved persons: Dr. Nikolaus Nestle

The development was carried out with funding from BMWi's EnOB programme (03ET1032B) and Vinylit (Kassel), Fraunhofer ISE (Freiburg), LuWoGe consult (Ludwigshafen), Okalux (Markt Heidenfeld) and Stockwerk (Mannheim) as partner institutions.

Time span: 2011 - 2014, follow-up project in preparation

Contact data: nikolaus.nestle@basf.com

Associated Publications:

1. NESTLE, N. et al. (2014) *Construction element having a controllable heat transfer coefficient U. he Complete Guide to Referencing and Avoiding Plagiarism*. WO2014114563 (A1).
2. PFLUG T et al. (2014) *Closed translucent facade elements with switchable U-value – a novel option for energy management via the facade* Energy and Buildings, DOI: 10.1016/j.enbuild.2014.09.082
3. NESTLE, N., HAFNER, A. & SCHNEIDER, F. (2015) *Diffusionsdichtes Isolierelement* Priority number15158592.4

51 Experimental study, modelling and control of intelligent glazed façades

▶ Mingzhe Liu, Department of Civil Engineering, Aalborg University; Frederik Vildbrad Winther, Rambøll

▶ Research information

INTRODUCTION

In the European Union, buildings are responsible for 40 % of the total energy consumption and for 36 % of CO_2 emissions. The energy performance of buildings is the key to achieving objectives of both EU and Denmark. To successfully achieve this goal it is necessary to identify and develop innovative building and energy technologies and solutions for medium and long-term periods.

One of the most important parameters influencing the building energy-performance is the facade. Glazed facades are becoming an increasingly dominant choice of facades for office buildings because of the requirement of higher light transmittance and better views by users. However, the glazed façade has significant challenges to overcome in order to remain an attractive envelope solution in future zero-energy-building concepts since it contributes to higher energy demand for heating. cooling, etc.

The objective of this project was to improve performance of glazed façades by investigating intelligent façade solution. The project consists three parts:

1) full-scale experiments were conducted on each technology showing the performance of the technology under varying boundary conditions;
2) simulation method was developed for the intelligent glazed facade with integrated building services in order to accurately evaluate its energy and comfort performance;
3) by applying the method, a holistic control strategy of intelligent façade and building services was developed to minimize energy consumption and optimize the indoor comfort of office buildings.

RESEARCH METHODS

In order to demonstrate the performance of different facade technologies (dynamic U-value, dynamic g-value and PCM in glazing), experiments have been conducted in the test facility, the Cube, at Aalborg University [1 and 2] (Fig. 1 and Fig. 2). The method integrating properties of different facade technologies was verified with the Danish building simulation tool BSim and with measurements to achieve reliable calculations of energy and comfort performance. The model developed is now capable of conducting hourly calculations of one year with acceptable computation time. In addition, control strategies were also tested in the “Cube”.

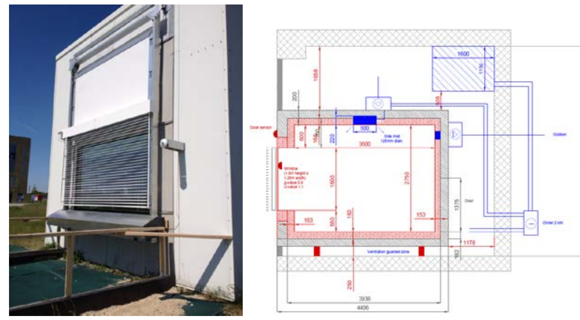
RESULTS

The results from the experiments with the dynamic U-value technology showed a potential to reduce the U-value by 68 % and with special focus on tightening the technology, thus minimizing the air leakage to the surroundings greatly reduces the heat transfer. The experiments of the solar shading technology worked well keeping the room temperature 10 °C lower compared to if the technology was not deployed. The experiments with PCM in glazing show a lowering of the energy demand for cooling, heating and increase of thermal comfort in the near perimeter of the facade.

According to all the comparisons, the correlation between the results of the simulation method and the experiments is relatively high. Therefore it supports the application of the method in simulation and evaluation of the performance of buildings with intelligent glazed facades in Denmark.

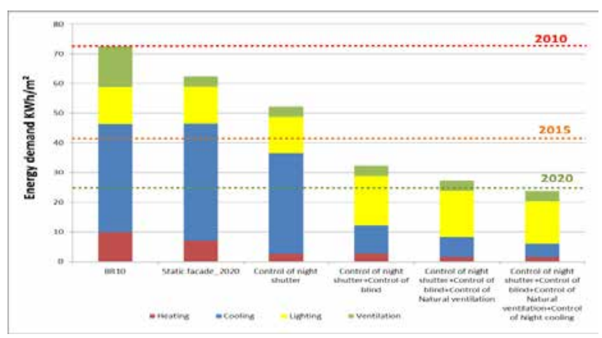
Control strategies for facades and building services were developed for both occupied and unoccupied hours, considering both energy efficiency and indoor comfort. The energy consumption of the given building is reduced by approximately 60 % when using the intelligent glazed facade instead of a static facade in the Danish climate (Fig. 2). Together with the improvement of the entire building quality, the building installed with the intelligent glazed facade can comply with the Danish energy requirements of the Building Class 2020, which cannot be fulfilled by the building with static glazed façade (Fig.3).

The method can also be used in optimizing the glazing ratio of the building envelope.



▶ **Fig. 1:** Full-scale test facility in Aalborg University, the Cube. (Left: test facility, Right: section).

▶ **Fig. 2:** Experimental setup with external insulation shutter and venetian blind (left), experiment of glazing integrated with PCM (right).



▶ **Fig. 3:** Energy demand of the office building under different control strategies.

▶ Involved persons: Mingzhe Liu, Frederik Vildbrad Winther

▶ Time span: 2009-2015

▶ Contact data: ml@civil.aau.dk

▶ Associated Publications:

1. Liu, M; Wittchen, KB; Heiselberg, P. MODELLING AND CONTROL OF INTELLIGENT GLAZED FACADE. PhD thesis 2014. 160 p.
2. Winther, FV. Intelligent Glazed Facades : an experimental study. Aalborg : Department of Civil Engineering, Aalborg University, 2013. 200 p. (DCE Thesis; No. 43).

User interaction and control of adaptive facades

Kim Trangbæk Jønsson; Line Røseth Karlsen

Research information

INTRODUCTION

The façade is a determining factor both for indoor environment and energy consumption of a building. It can be a challenge to design facades, especially in relation to thermal comfort, daylight and heat consumption. Because by improving one area another area can worsen.

The study of users and their interaction is divided into two PhD projects, one which deals with an improved methodology for design of commercial buildings in the Nordic climate where the aim is a balanced approach to fulfil future energy requirements, thermal comfort and daylight quality demands (Line Røseth Karlsen).

The other PhD deals with user interaction with dynamic facades. The aim here is to understand the user with regards to new technologies in residential buildings. By understanding the user it should be possible to lowering the gap between theoretical and practical buildings. This should enable the development of improved communication, feedback and control platforms (Kim Trangbæk Jønsson).

RESEARCH METHODS

Lines' study focuses on verifying if simple illuminance based measures like vertical illuminance at eye level or horizontal illuminance at the desk are correlated with the perceived glare reported by 44 test subjects in a repeated measure design occupant survey and if the reported glare corresponds with the predictions from the simple Daylight Glare Probability (DGPs) model. The measurements where done in the "Cube", which can be seen in Fig. 1.

Kim's study focuses on the potential of utilizing a dynamic facade in residential building flats and what the user needs in order to minimize the gap between theoretical potential and the real potential. Potential related both to the energy demand and the thermal indoor environment. The investigation into the potential of utilizing a dynamic facade was done with the Danish building simulation tool Bsim. Further investigations are going to be done by implementing dynamic facades to real building flats and conduct qualitative and quantitative measurements. The measurements should show how dynamic façade control can be realised in order to satisfy the user as well as improve the building performance.

RESULTS

Large individual variations were seen in the occupants' assessment of glare in the study of daylight. Yet, the results confirm that there is a statistically significant correlation between both vertical eye illuminance and horizontal illuminance at the desk and the occupants' perception of glare in a perimeter zone office environment. This is promising evidence towards utilizing these simple measures for indication of discomfort glare in early building design. Another point of the measurements where that the occupants where more tolerant of low illuminance and more sensitive to high illuminance than the DGPs model.

The calculated potential of dynamic facades are show in Fig. 2 and Fig. 3 for the building stock in Denmark. In order to define the potential different control strategies where developed which are going to be used as a guideline for the experiments. The results show that in order to improve the thermal indoor environment one needs to be careful with regards to choosing a proper control. For the heating demand it seems easier to get a positive effect by using a dynamic façade, but when looking at new buildings we can see that it is harder to achieve a positive effect.

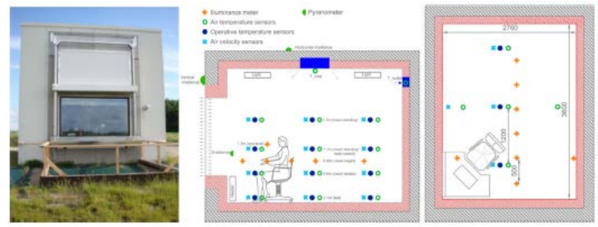


Fig. 1: Full-scale test facility in Aalborg University - Cube. (Left: test facility, Right: section with measurement points).

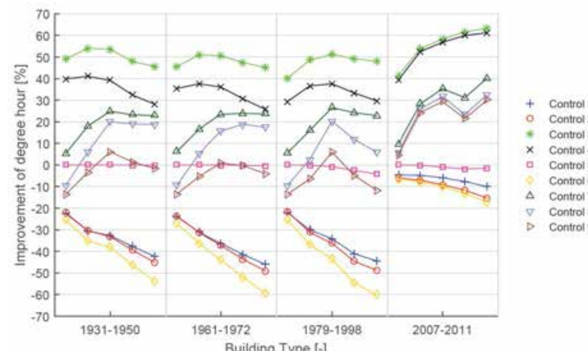


Fig. 2: Potential of using dynamic facades with different control strategies related to the indoor thermal climate.

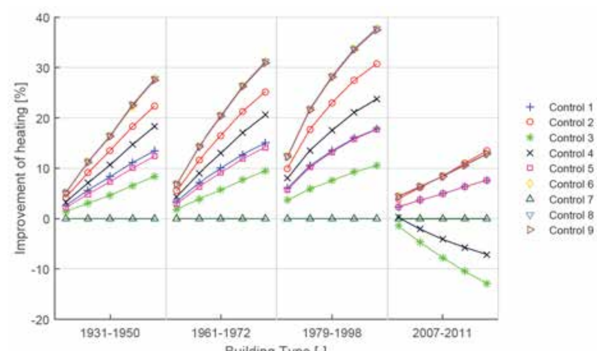


Fig. 3: Potential of using dynamic facades with different control strategies related to the heating energy demand.

Involved persons: Kim Trangbæk Jønsson, Line Røseth Karlsen

Time span: 2011 - 2017

Contact data: ktj@civil.aau.dk

Associated Publications:

1. Karlson, L; Heiselberg, P; Bryn, I; Johra H. Verification of simple illuminance based measures for indication of discomfort glare from windows. Building and Environment 2015. 11 p.

53 Ventilated window and glazed façades

▶ Olena Kalyanova Larsen and Per Heiselberg

▶ Research information

INTRODUCTION

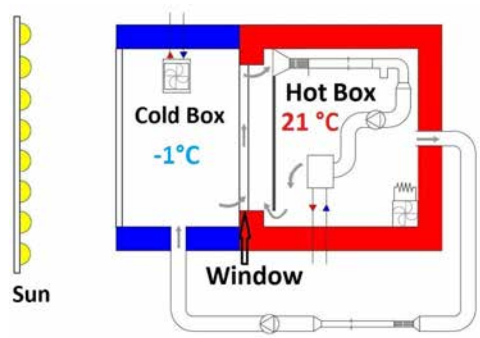
Glazed facades (i.e. double-skin façade) and ventilated windows are an example of highly adaptive systems for the building envelope. Thermal and energy performance of such systems can be difficult to predict, as is illustrated in the framework of IEA SHC Task 34 /ECBCS Annex 43 "Testing and Validation of Building Energy Simulation Tools" [1]. High dynamics of such envelopes, as well as the lack of knowledge of the heat and mass transfer processes in the air gap are the reasons here for.

Aalborg University was involved in several projects dealing with the performance of ventilated facades and windows, in particular:

- In [1], the empirical validation of a building model with the double-skin facade is carried out for several building simulation tools, performed by different research institutions. The experimental data was obtained in the outdoor full-scale test facility, the Cube (Fig. 1). This work was mainly focused on naturally ventilated double-skin facade cavities.
- In [2], the dynamics of ventilated facade systems is documented. Here, the presence of certain phenomena is discussed that influence the convective and mass transfer in the gap. However, the experiments carried out in real outdoor conditions were not conclusive enough to fully confirm the hypothesis.
- CLIMAWIN project [3] aimed at developing a novel high performance window with electronic operation of an auto-regulated natural ventilation system and electronic insulating night blind powered by solar power. The project's focus lay on the renovation sector, for old buildings which do not have energy efficient ventilation systems.

▶ **Fig. 1:** The Cube. Southern façade with double-skin façade system.

▶ **Fig. 2:** Large Hot Box system. Cold zone (left), hot zone (right)



▶ **Fig. 3:** Small Hot Box system with artificial sun (OSRAM Ultra-Vitalux)

EXPERIMENTAL METHODS

The full-scale outdoor test facility, the Cube [4] allows installation, control and testing of different façade systems with all of the benefits inherent to an outdoor test facility. However, the results obtained under outdoor conditions cannot be reproduced, and some boundary conditions can never be reached.

To overcome the limitations of an outdoor facility and to support the experiments performed in the Cube, a large Hot Box suitable for testing wall elements of appr. 3.6 x 3.6 m is introduced (Fig.2). The Hot Box can be equipped with an artificial sun system, SolarConstant 4000, which is able to generate a shortwave heat flux similar to the solar spectrum with even surface distribution.

For testing on a component level, the laboratory is equipped with several smaller Hot Boxes, which also allow measurements with artificial sun, using 56 OSRAM Ultra-Vitalux 300 W light bulbs (Fig.3).

Together all three experimental facilities allow for complete testing of facade systems and their elements both in dynamic and steady-state conditions for overall characterization of the system performance .

▶ **Involved persons:** Olena K. Larsen, Per Heiselberg
▶ **Time span:** 2006 - to present
▶ **Contact data:** ok@civil.aau.dk, ph@civil.aau.dk

▶ Associated Publications:

1. Larsen, OK, Heiselberg, P, Felsmann, C, Poirazis, H, Strachan, P & Wijsman, A 2009, 'An Empirical Validation of Building Simulation Software for Modelling of Double-Skin Facade (DSF)'. in PA Strachan, NJ Kelly & M Kummert (eds), Building Simulation 2009 : University of Stractclyde, Glosgow, 27th-30th July: Proceedings of the 11th International Building Performance Simulation Association Conference. Energy Systems Research Unit : University of Strathclyde.

2. Kalyanova, O 2008, Double-Skin Facade: Modelling and Experimental Investigations of Thermal Performance. Ph.D. thesis, Department of Civil Engineering, Aalborg University, Aalborg. DCE Thesis, no. 17

3. Heiselberg, P (red.), Larsen, OK, Liu, M, Zhang, C, Johra, H, Herold, L, Mendez, J, Cabral, J, Brito, N, Zegowitz, A & Heusler, I 2013, CLIMAWIN: Technical Summary Report. Department of Civil Engineering, Aalborg University, Aalborg. DCE Technical Reports, nr. 160

4. Larsen, OK, Heiselberg, P & Jensen, RL 2014, Experimental data and boundary conditions for a Double-Skin Facade building in external air curtain mode. Department of Civil Engineering, Aalborg University, Aalborg. DCE Technical Memorandum, nr. 38. (vbn.aau.dk)

54 Energy efficient retrofitting of buildings in Brazil

HCU HafenCity Universität Hamburg

▶ Wellershoff, F.; Friedrich, M.; Labaki, L. C.; Fernandes, L.; Lenderoth, Ch.

▶ Joint German and Brazilian Research Project

Research aim and motivation

Depending on the climate region, the local comfort standard, and the efficiency of the existing building services the share of energy for cooling, heating and artificial lightning of buildings is between 30% to 50% of the overall energy consumption of a country. The required energy for cooling of buildings can be significantly reduced by night ventilation. The efficiency of this method depends mainly on the air exchange rate between the outdoor environment and the indoor air volume.

The aim of the Brazilian-German research cooperation is to develop design nomograms for the prediction of the air exchange rate in buildings by natural ventilation. The intended use of these nomograms is to retrofit facades of Brazilian buildings. With natural ventilation the user comfort can be optimized with minimal energy demand. The nomograms will cover different climate conditions like hot and medium air temperatures, different temperature changes from day-time to night-time, and different external wind speeds.

One key factor for the air exchange rate is the discharge coefficient of the window or louvre system. From existing research reports first discharge coefficients of top pivoted window systems are available, but the coefficients of often used facade openings are still unknown.

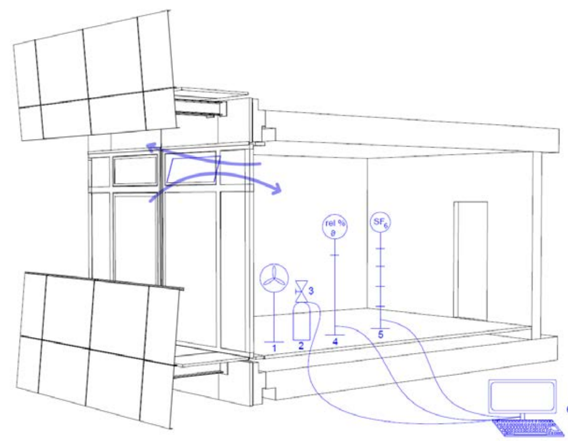
▶ **Fig. 1:** Overview of the UNICAMP wind tunnel

Wind tunnel tests

Measuring of pressure loss factors by air flow rates and pressure differences in the wind tunnel laboratory of the University of Campinas, Brazil (Fig. 1). To determine the discharge coefficients, commonly used window systems (bottom pivoted, side pivoted) will be tested.

Tracer gas measurements

Additional tracer gas measurements with these window systems in double and single skin facades will be carried out at the façade test laboratory of the HafenCity University Hamburg, Germany (Fig. 2).



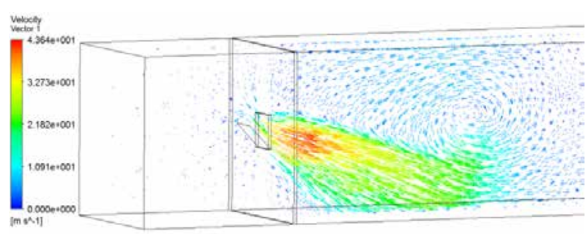
▶ **Fig. 2:** Façade test laboratory with tracer gas equipment

Numerical simulations

Based on these tests computational fluid dynamic models (CFD) can be verified and the field of window systems can be extended by a numerical parameter study. In the next project step the energetic and comfort performance of typical buildings with natural ventilation will be analysed by multi-zone modelling.

Design nomograms for natural ventilated buildings

With the results of the experimental studies the above mentioned design nomograms will be developed. Recommendations for the geometry of the window openings with maximum discharge coefficients can be given based on the successive testing and numerical analysis.



▶ **Fig. 3:** Exemplary numerical simulation of the airflow through a bottom pivoted window

Improvement of national standards

With the knowledge obtained during the project time, the project team will compare the results with valid national standards regulating the design approaches for natural ventilation to be able to make improvements for future projects.

▶ Involved persons: Prof. Dr.-Ing. Frank Wellershoff, HafenCity University
M.Sc. Matthias Friedrich, HafenCity University
Profa. Dra. Lucila Chebel Labaki, UNICAMP
M.Sc. Luciana Fernandes, UNICAMP
Mr. Christophe Lenderoth, Christophe Lenderoth GmbH

▶ Time span: 2015 - 2017

▶ Funding: Deutsch- brasilianisches Forschungskooperationsprogramm
NoPa DAAD – GIZ – CAPES

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55 Lucerne University of Applied Sciences and Arts Department of Engineering and Architecture

▶ Prof. Dr. Andreas Luible, MSc Thomas Wüest, Prof. Dr. Stephen Wittkopf, Dr. Ludger Fischer

Lucerne University of Applied Sciences and Arts
HOCHSCHULE LUZERN
Technik & Architektur

▶ Research Information

Three competence centres at Lucerne University of Applied Science and Arts are currently active in research projects related to building envelopes and adaptive facades.

Competence Center Facade and Metal Engineering (CC FM)

The CC FM is an accredited test lab and Notified Body. Our Façade Test Facility (Fig. 1) allows testing of façades up to 8 by 12 meters according to EN 13830 for Curtain Walling and EN 14351 for Windows and Doors (air permeability, wind load and static / dynamic water).
Along with free-form façade designs, questions about wind loads came up. By means of Computational Fluid Dynamics (CFD) wind loads for any shape of building can be simulated (Fig. 3) and connected with architectural and structural knowledge.
Research at the CC FM focusses on various topics: Actual projects deal with condense water risk evaluation in breathing closed cavity façades or thermal loads on Insulated Glass Units (IGU) due to varying solar radiation and the influence on the structural design.
Green facades are getting more popular, however loads on overgrown steel ropes are mostly unexplored. In collaboration with an industrial partner the forces of wind and climbing plants are studied on a special test rig (Fig. 4)
Another research project is about the application of textiles in building envelopes: textiles as exterior weather protection, as interior thermal retrofitting (Fig. 5) or as a self-supporting pavilion.
Projects on bio-based plastics for the building envelope investigate current and future composite plastics with regard to their potential for further substitutions by renewable ingredients. Our core target is the development of a “Green-Composite-Façade (GCF)” which is solely made from plants and which is both durable and compostable.
Beside our service for the façade industry and research, education (Bachelor and Master degree) is a further main focus of the CC FM. A recently completed Master Thesis addressed the structural use of glass, especially lateral buckling of glass beams with continuous lateral restraint (Fig. 2). The results are buckling curves similar to those being used in structural steelwork.

CC Envelope and Solar Energy (CC EASE)

Research at the CC EASE focuses on the capabilities of the façade to transmit or produce energy by means of daylight redirection or building integrated photovoltaics (BIPV). Measurements of the scattering characteristics (BSDF) of daylight redirection components in the CC EASE goniophotometer lab are combined with the application and development of advanced simulation tools. Applying RADIANCE with Contribution Photon Mapping within a frontend for dynamic annual daylight simulations (EvalDRC) allows quantitative assessments of the façade’s potential for providing increased daylight availability in the interior spaces.
In the BIPV context, a current research topic is the combination of classic PV panels with a layer of printed glass to dispel aesthetic reservations and make PV panels on façades an attractive proposition, by still retaining much (> 80%) of their original performance.

Centre for integral building technology (ZIG)

The ZIG practises research in the field of building integrated technologies. An actual example is an adaptive façade comprising movable wings with integrated latent heat accumulator, which can be used for heating an cooling of a building. The system allows a phase shift between energy production and use which discharges the heating and cooling systems.

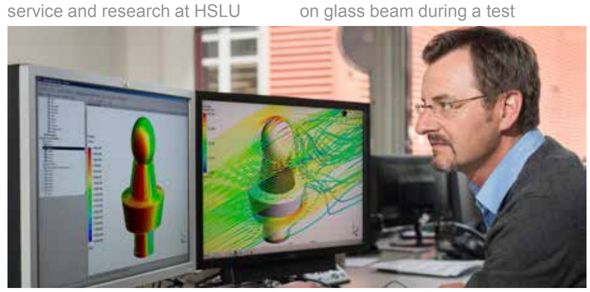
▶ Involved persons: Prof. Dr. Andreas Luible (CCFM)
MSc Thomas Wüest (CCFM)
Prof. Dr. Stephen Wittkopf (CCEASE)
Dr. Ludger Fischer (ZIG, CCTEVT)

▶ Time span: ongoing

▶ Contact data: andreas.luible@hslu.ch

▶ **Fig. 1:** Façade test facility for service and research at HSLU

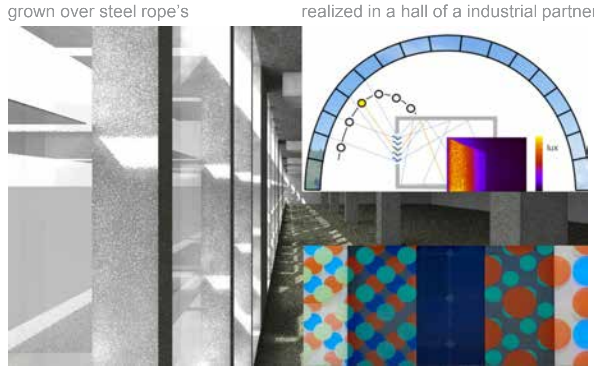
▶ **Fig. 2:** Double waved buckling on glass beam during a test



▶ **Fig. 3:** CFD wind simulation of a radar station on a summit

▶ **Fig. 4:** Long-term observation of grown over steel rope's

▶ **Fig. 5:** Textile retrofitting mock-up realized in a hall of a industrial partner



▶ **Fig. 6:** Photon Map rendering of a light shelve facade. Top right: schematics of contrib. Photon Mapping, bottom right: PV panels with printed glass layers

56 Climate-adaptive and solar facade research @ EBD
Energy and Building Design, LTH, Lund University

▶ **Susanne Gosztonyi, Ricardo Bernardo, Jouri Kanters, Åke Blomsterberg, Maria Wall**

LUND UNIVERSITY

The Division of Energy and Building Design (EBD) focuses on energy-efficient and environmental buildings. With the whole building life cycle as the starting point, the aim is to develop and test environmentally friendly and energy efficient buildings of high thermal and visual quality in interaction with building services technologies and renewable energy systems. The research is complemented with a 2-year master programme in 'Energy-efficient and Environmental Building Design' that has been developed by EBD in collaboration with the Divisions of Building Physics and Building Services.

▶ Research topics focusing on adaptive facades

Research activities for adaptive facades are targeting novel concepts and design tools, as well as integration of sustainable, decentralized supply and energy technologies. The developments consider architectural applicability, thermal and visual qualities, energy performance and design process optimization, as well as the influence of such systems on the well-being of inhabitants. Interdisciplinary methods such as e.g. biomimetics and environmental psychology are used for designing and testing the concepts.

Exploring nature for climate-adaptive facade functions (bionicfacades)
Concepts: "Daylight dissipating 3D fabric", "Smart façade agents", "Thermal regulation principles", ongoing, FFG, LU / www.bionicfacades.net
The biomimetic research targets the exploration of biological phenomena that deal with daylight use, energy flow regulation, as well as with self-adaptive, dynamic processes. This research is rather new and highly interdisciplinary, with experts from architectural engineering, biology, chemistry, material sciences, physics, or production technologies being involved. Current activities are aimied at thermal adaptation processes (Ph.D. work, FRG, TU Delft) and the development of daylight redirecting 3D fabrics, which can be used for new constructions or retrofitting (Fig 2).

▶ Involved: Susanne Gosztonyi

▶ Associated Publications: Gosztonyi, S. et al. (2013) *BioSkin - Research potentials for biologically inspired energy efficient façade components and systems*. Final report: nachhaltig wirtschaften 46/2013, BMVIT (ed.).

Designing a Multi-Active Facade module for refurbishments (MAF)
"Förstudie av prefabricerade multiaktiva fasadelement för energirenovering av flerbostadshus", 2015-2017, SBUF, Swedish Energy Agency
The purpose is to design a cost-effective multi-functional façade concept for refurbishments of Swedish multi-family houses. It is based on a pre-fabricated element that can be added to the existing building structure. It contains integrated ventilation with heat recovery and solar cells for energy supply, as well as well shading and thermal insulation.

▶ Involved: Ricardo Bernardo, Susanne Gosztonyi, Åke Blomsterberg

▶ Associated publications: Gosztonyi, S., et al. (2013): Architectural benefits of virtual and experimental assessments of active components in multifunctional facades. in: Advanced Building Skins, Conference Proceedings of the 8th ENERGY FORUM, EF Economic Forum, Bressanone, ISBN: 978-3-9812053-6-7, p. 29 – 33.

Solar energy facades in architecture and urban planning
IEA SHC Task 51: Solar Energy in Urban Planning, 2013-2017; IEA SHC Task 41: Solar Energy and Architecture, 2009-2012 / www.solarplanning.org
The objective is to provide support to relevant players in the planning processes of solar buildings and solar cities. The aim is to adapt or develop tools for the early design phase that incorporate design criteria as well as the required economic, technical and urban planning information (Fig.1).

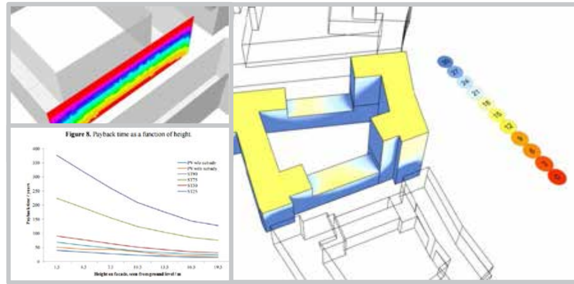
▶ Involved: Jouri Kanters, Maria Wall, Susanne Gosztonyi

▶ Associated Publications: Kanters, J., Wall, M. & Dubois, M.-C., 2014. Development of a Façade Assessment and Design Tool for Solar Energy (FASSADES). *Buildings*, pp. 43-59.

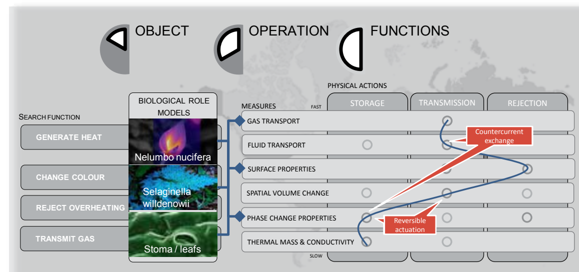
▶ **EBD team:** Maria Wall, Ph.D., Åke Blomsterberg, Ph.D., Jouri Kanters, Ph.D., Marie-Claude Dubois, Ph.D., Niko Gentile, Ph.D. cand., Ricardo Bernardo, Ph.D., Henrik Davidsson, Ph.D., Susanne Gosztonyi, Ph.D. cand. (contact)

▶ **Time span:** ongoing

▶ **Contact data:** susanne.gosztonyi@ebd.lth.se



▶ **Fig. 1:** Assessment of integration profitability of solar systems in the urban built environment: e.g. the solar facade tool FASSADES shows the profitability of solar surfaces vs payback time. (J. Kanters)



▶ **Fig. 2:** Biomimetic investigation into thermal adaptation principles in nature: Biological examples with colour adaptive, heat generating or permeable properties to reject, store, or transmit heat. (S. Gosztonyi)

▶ **Fig. 3:** EBD test facilities for façade systems - outdoor façade laboratory (left and upper right) and solar energy technologies - indoor full-scale solar simulator (lower right)

▶ EBD test facilities

Outdoor Full-Scale Facade Laboratory
– four test rooms for calorimetric and photometric measurements, user comfort monitoring, thermographic imaging of façade components, combined performance-based assessments via virtual and real test environment

Solar Laboratories
– outdoor rooftop test bench for performance tests of solar systems;
– indoor full-scale solar simulator for angle-depending radiation tests

Daylight Laboratory
– daylight measurements in facade lab (photometric measurements, energy efficiency, user perception), indoor & mobile daylight lab

57 Bypass Double Skin Facade

Wellershoff, F.; Friedrich, M., HafenCity University Hamburg

HCU HafenCity Universität Hamburg

Double Facade System with natural ventilation in optional flow path

User Comfort and Double Skin Facades

Due to the lack of sufficient design guidelines for double skin facades the energetic and acoustical aspects are often insufficiently considered and the design is primarily driven by aesthetic perspectives. Complex thermal effects in the facade cavity often lead to losses in energy efficiency and user comfort.

The Bypass Double Skin Facade

The main aim of the bypass double facade is to maintain user comfort and to protect the interior against overheating in summer without active cooling or mechanical air ventilation. Therefore the focus of this facade lies on bypass air channels through which the external air will be directed into the interior without absorbing additional thermal energy in the regular facade cavity. In winter time this absorbed energy in the facade cavity will be used to reduce the demand of heating energy. The energetic conception of the facade and the dimensions of the bypass channels and all louvers is based on four climatic design cases.

Climatic Case I – cloudy winter day

Limitation of the air exchange rate to the hygienic required minimum to minimize heat loss. For an intelligent control of the louvers, the CO_2 level of the room air will be measured. A heat recovery system will be used.

Climatic Case II – sunny winter day

The inlet air is preheated by the heat recovery system. Then the inlet air is directed through the facade cavity to gain additional thermal energy before it reaches the opening to the interior.

Climatic Case III – hot summer day

Limitation of the air exchange rate to the hygienic required minimum to reduce heat gains in summer. The inlet air flow is directed through the bypass channel directly to the interior to avoid additional heating in the cavity.

Climatic Case IV – summer night cooling

Maximize the heat convection from inside to outside. The air exchange rate is limited by air velocities which, if too high, may cause damages during the night or affect user comfort (draught) during the morning.

Dynamic facade control system

Electromotive adjustment of the facade openings based on decision data. A field bus system collects temperature, humidity and CO_2 data for the control system. Additional data such as air velocity, concrete core temperatures, surface temperatures of walls and glass, solar radiation, illuminance and pressure differences will be recorded for verification of transient models that can be used for parameter studies.

Target results of the research project

The objective is to design simple design tools to dimension facades with natural ventilation and advanced dynamic control methods.

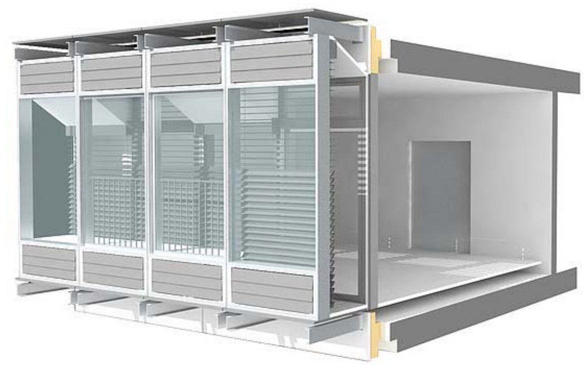


Fig. 1: Rendering of the test room equipped with a bypass double skin facade

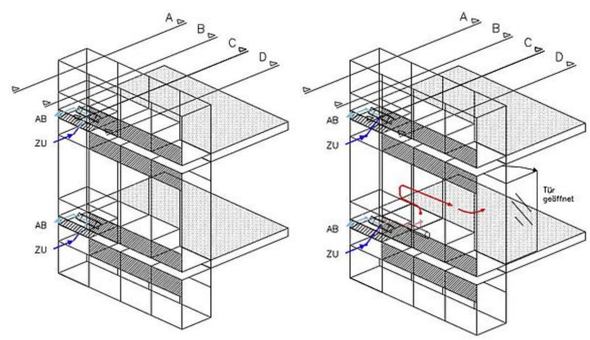


Fig. 2: Variable air flow directions in climatic case I (left) and II (right)

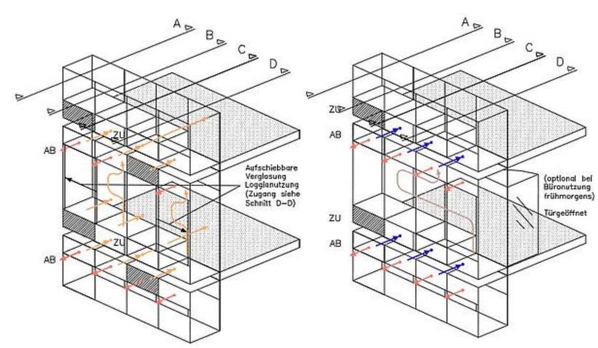


Fig. 3: Variable air flow directions in climatic case III (left) and IV (right)

Involved persons: Prof. Dr.-Ing. Frank Wellershoff, HafenCity University
M.Sc. Matthias Friedrich, HafenCity University
Time span: 2014 - 2017
Funding: BMWi / EnOB: Forschung für Energieoptimiertes Bauen
Contact data: frank.wellershoff@hcu-hamburg.de

Journals

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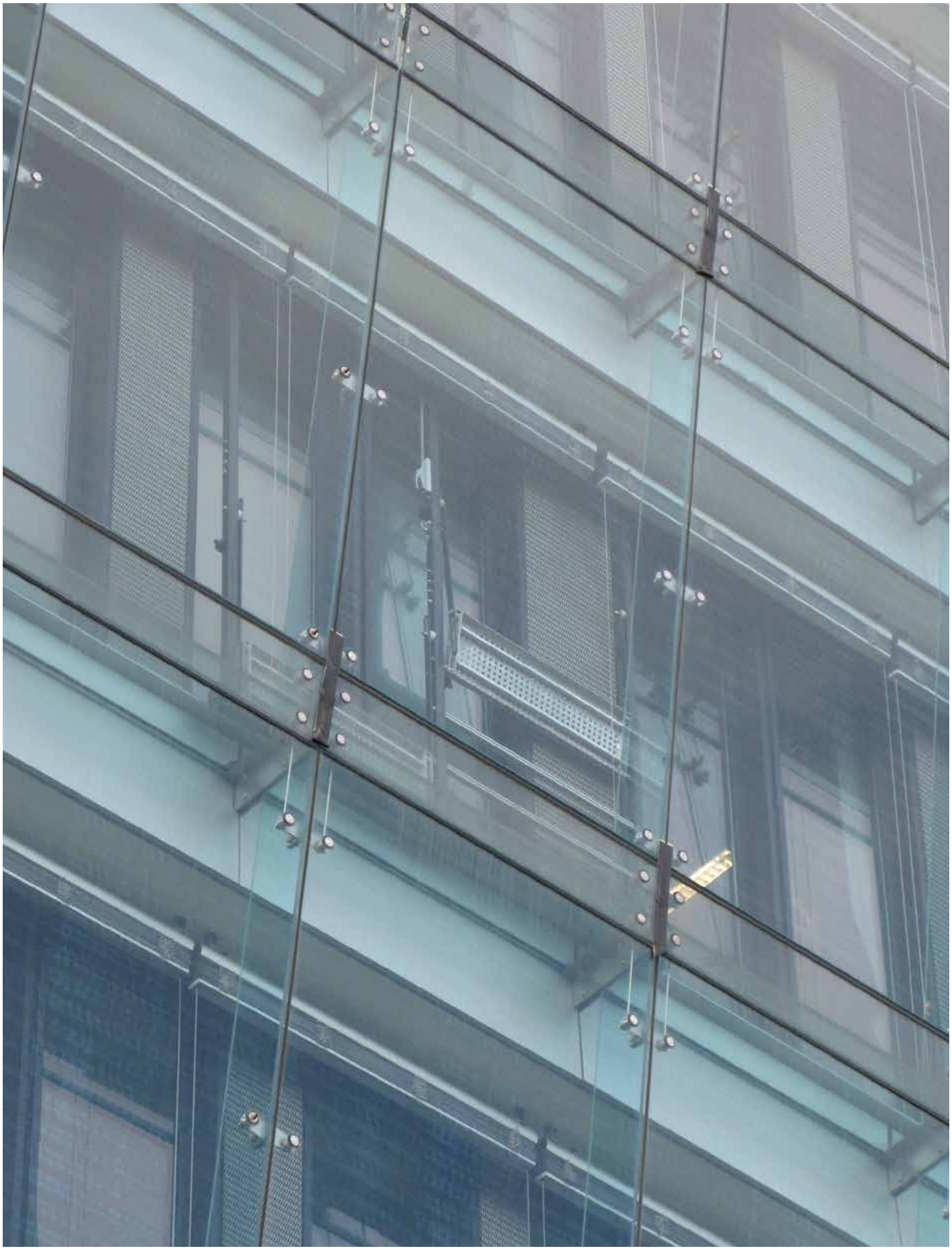

Twin face façade

Glass Structures & Engineering

Glass Structures & Engineering is an international journal on the structural application of glass, situated in the building engineering and civil engineering domain. The journal addresses all aspects of structural glass research and applications, including theoretical and experimental research on elements, assemblies, connections and material. Amongst others, the journal addresses the following topics:

- Structural glass design philosophy & safety
- Loads on glass structures
- Stability of structural glass components
- Glass in façades
- Architectural geometries
- Insulating Glass Units
- Automotive
- Solar glass applications
- Projects & case studies
- Curved glass
- Joints, fixings & adhesives
- Strength & fracture mechanics
- Laminated glass & composites
- Post-fracture performance
- Glass forensics and fractography
- Post processing

Contributions from the scientific community, engineering practice and industry are welcomed. The journal is published by Springer, and the first issue will appear in 2016.

Submission and publication process

To publish in the journal Glass Structures & Engineering, authors are invited to submit their manuscript at any time through www.editorialmanager.com/glas according to the author instructions as provided at www.springer.com/40940. Manuscripts are double-blind reviewed by experts in the field, and the authors will receive the review comments, if any, to be included in a revised version of the manuscript. Once accepted, manuscripts will be published online first within +/- 20 days.

The journal is available as an e-journal and in print format. Authors have the option to publish their manuscript in the traditional way or with open access. All articles published in 2016 and 2017 will be available online for free.

Editorial board

The editors-in-chief of Glass Structures & Engineering are:

- Jan Belis, Ghent University, Belgium/Eindhoven University of Technology, The Netherlands
- Christian Louter, Delft University of Technology, The Netherlands
- Jens Henrik Nielsen, Technical University of Denmark, Denmark
- Mauro Overend, University of Cambridge, United Kingdom
- Jens Schneider, Technical University of Darmstadt, Germany

An international editorial board of experts has been appointed, covering different geographical locations and a variety of disciplines within the domain. The editorial board currently consists of:

- Claudio Amadio, Università di Trieste, Italy
- Paulo Cruz, University of Minho, Portugal
- Martina Eliasova, Czech Technical University in Prague, Czech Republic
- Qian Jin, Tongji University, P.R.China
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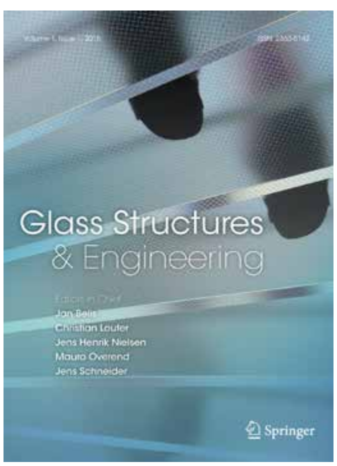
- Frank Wellershoff, HafenCity Universität Hamburg, Germany
- Jian Yang, Shanghai Jiao Tong University, P.R.China

More information

The journal’s website www.springer.com/40940 provides more information on the journal, and the editors-in-chief are available to answer any additional questions you may have.



Glass Structures & Engineering
Vol.1 / Is.1

JFDE – Journal of Façade Design and Engineering

The Journal of Facade Design and Engineering presents new research results and new proven practice in the field of facade design and engineering. The goal is to improve building technologies, as well as process management and architectural design.

The journal is a valuable resource for professionals and academics involved in the design and engineering of building envelopes, including the following disciplines:

- Architecture
- Building engineering
- Structural design
- Climate design
- Building services engineering
- Building physics
- Design management
- Facility management

The journal will – initially - be directed at the scientific community, but it will also feature papers that focus on the dissemination of science into practice and industrial innovation. In this way, readers explore the interaction between scientific developments, technical considerations and management issues.

Editorial board and review process

The editorial team has four members: two editors in chief Ulrich Knaack and Tillmann Klein, editor Thaleia Konstantinou and editorial manager Marjan Vrolijk.

The editorial board is composed of eight representatives of the partner institutions of the European Façade Network EFN. (http://facades.ning.com/). EFN partner institutions are active in both MSc education as well as research in the field of façade design and construction.

We are using a double-blind peer reviewed process. The review of papers is carried out by 24 associate editors and numerous additional reviewers. The list can be found on the website. The reviewers are chosen according to their expertise and unbiased relationship with the author. Guest editors are appointed when needed, in order to guarantee the scientific quality of issues which are dedicated to certain research areas.

Scientific partnerships

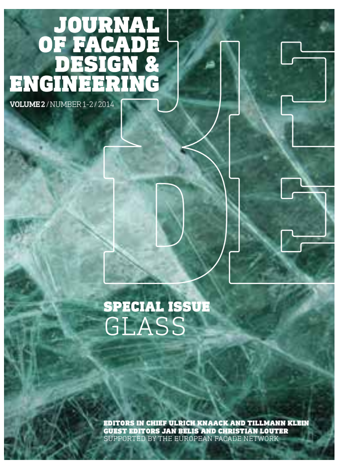
JFDE is scientific partner of the following events:

- The International Congress on Architectural Envelopes ICAE, San Sebastian
- 'The Future Envelope' conference series, Delft University of Technology and University of Bath
- 'Facades' conference series on building envelopes, Detmold University of Applied Sciences and Lucerne University of Applied Sciences
- COST Action 1043 Adaptive Facades Network
- ICBEST 2017 International Conference on Building Envelope Systems and Technologies, Istanbul

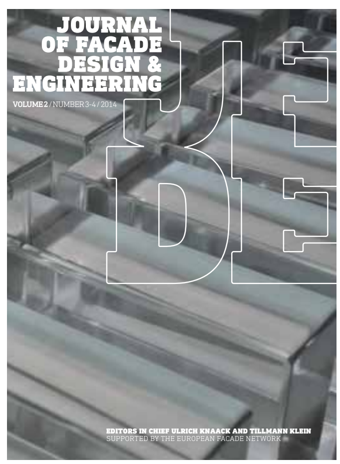
Web visibility and indexation

JFDE papers can be found via http://journals.library.tudelft.nl/index.php/jfde. JFDE is a relatively new journal, which has recently been listed at DOAJ (Directory of Open Access Journals), Scopus, Google Scholar, ISI and Avery Index.

Façade Design and Engineering is a peer reviewed, open access journal, funded by The Netherlands Organisation for Scientific Research NWO (www.nwo.nl).



JFDE Vol.2 / Nr.1-2



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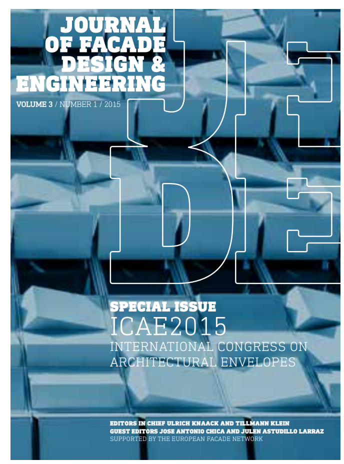
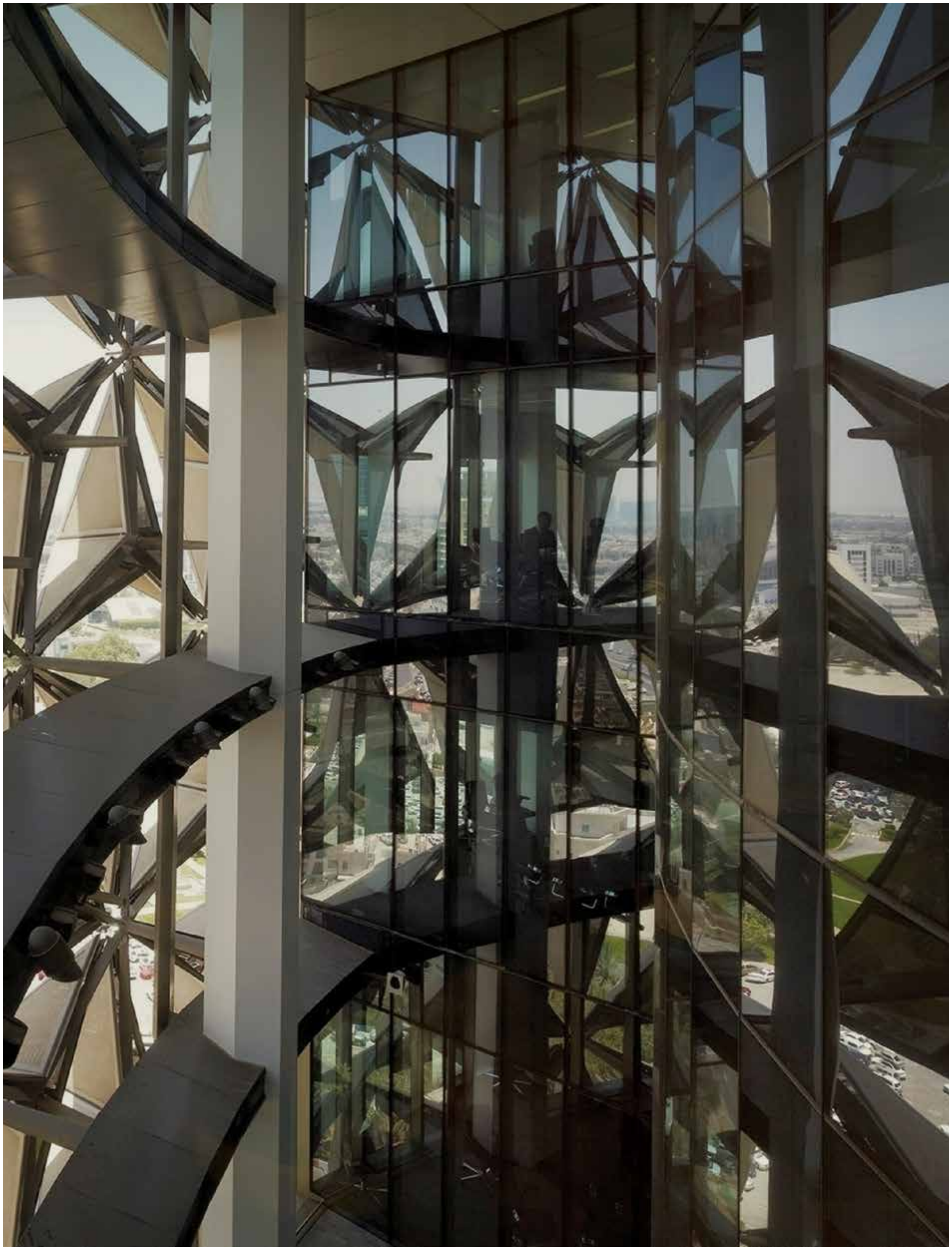
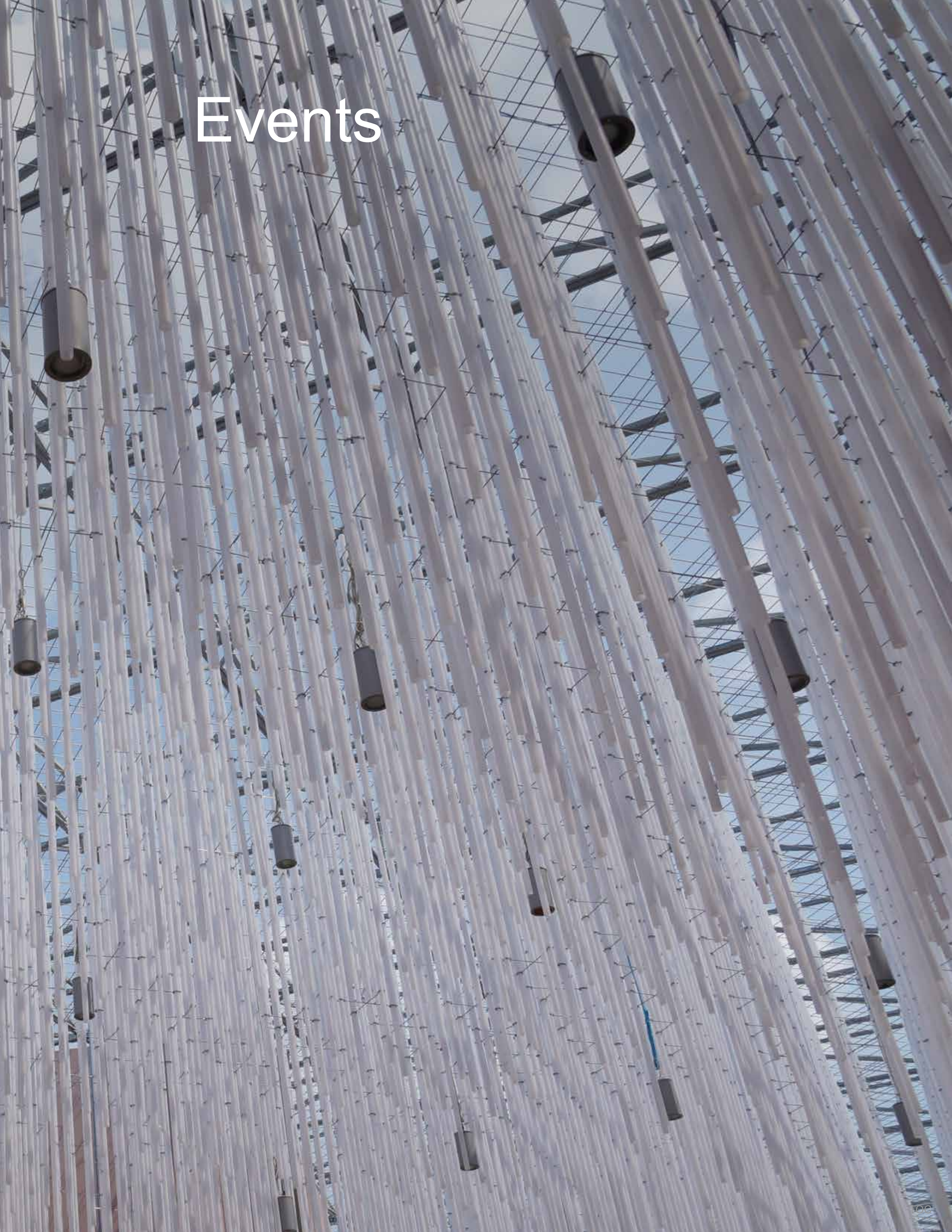


JFDE Vol.3 / Nr.1


Adaptive sunscreen at Al Bahar Tower / Abu Dhabi

Events



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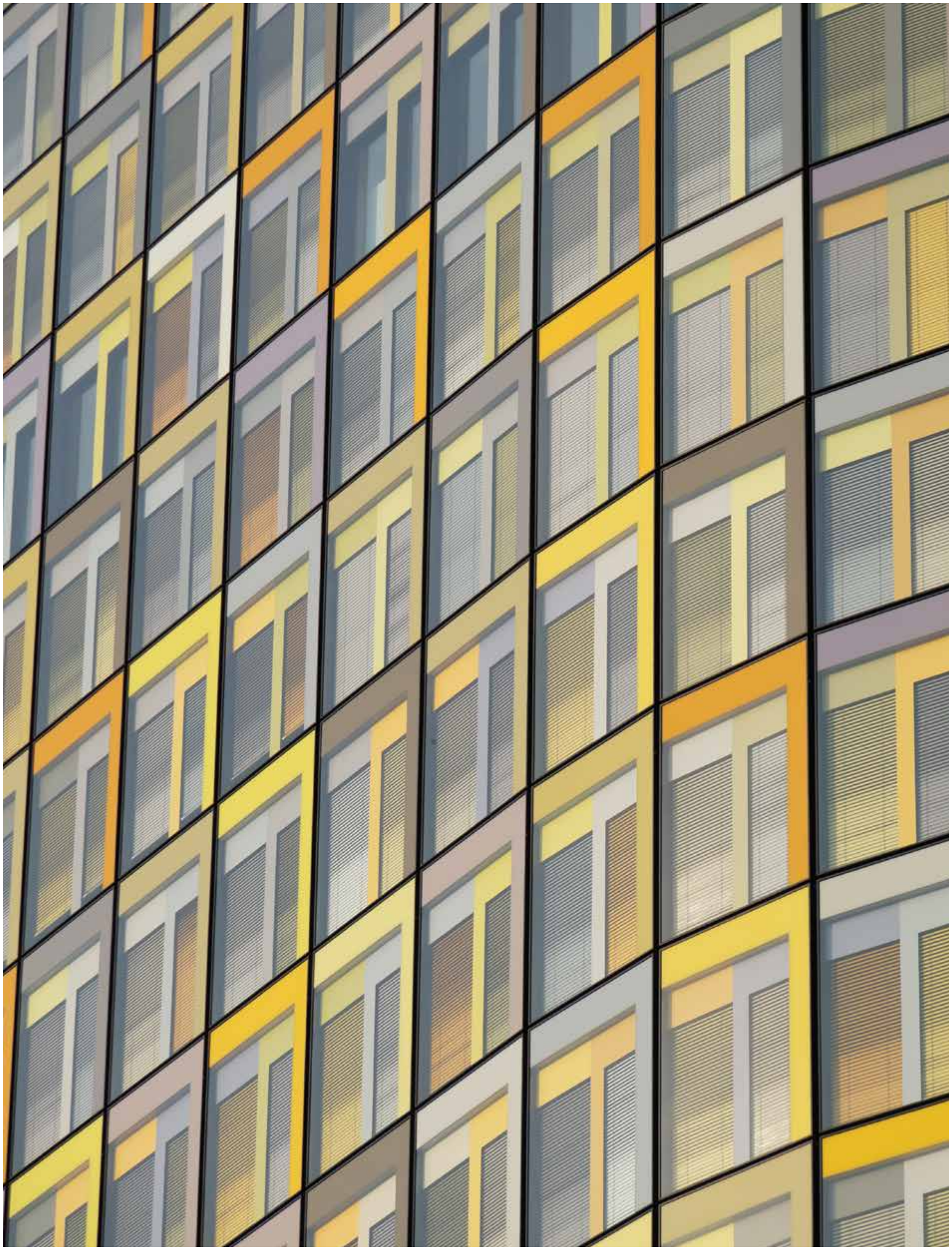

ADAC Office tower Munich

COST Action TU1403 meetings

One of the main objectives of COST Action TU1403 is the exchange of knowledge and research by creating a strong network between research institutes and the industry. Regular meetings are one means of the COST Action to promote this exchange. So far three meetings have taken place:

- First Management Committee Meeting at the COST office in Brussels on 28 October 2014
- Management Committee and first Working Group Meeting at CTU in Prague on 10/11 March 2015
- Management Committee Meeting, Working Group Meeting and Industry Workshop at TU Delft on 16/17 September 2015

Meeting at TU Delft on 16/17 September 2015

First Management Committee Meeting in Brussels

The first management committee meeting was the official start of COST Action TU1403, organized by the COST office in Brussels. The science officer of the COST Action, Mickael Pero, welcomed all 32 participants from 22 participating COST member countries and gave instructions and information about the mechanism, the funding and the reporting of coordination activities within a COST Action.

The chair, vice-chair and the chairs of the working groups were elected by the management committee, and the elected chair, Andreas Luible, summarized the main objectives, the working programme, the organisation and also the planned results and dissemination of COST Action TU1403 according to the Memorandum of Understanding.

Management Committee and first Working Group Meeting at CTU in Prague

The spring meeting in Prague with 43 participants was hosted by the Faculty of Civil Engineering at CTU and organized by Martina Eliášová and Klára Machalická. The four established working groups met for the first time and set the course for the future work in order to achieve the objectives of the COST Action. Focusing on the tasks and the research background of the individual members and affiliated research institutes, smaller subgroups within the working groups were established. The collection of data for the state of the art database on adaptive facades by means of an inventory form was initiated and the concept and schedule of the first industry workshop in Delft established.

Meeting at CTU in Prague on 10/11 March 2015

Management Committee Meeting, Working Group Meeting and Industry Workshop at TU Delft

The autumn meeting with 62 participants was hosted at the Faculty of Architecture and the Built Environment at TU Delft. The objective of the meeting was to involve the industry and the façade associations in the activities of the COST Action in order to build up a strong link between research and industry. Besides some representatives from the industry, which are already participating in the COST Action, four renowned experts were invited to give a lecture about their view on adaptive facades and on future trends in building envelope design.

Meeting at TU Delft on 16/16 September 2015 / from left, Andreas Luible, Bert Lieverse and Rudi Scheuermann

- *Rudi Scheuermann***,** Global Building Envelope Design Leader at ARUP
  About the Range of Responsive Facades

- *Bert Lieverse*, President & Director at VMRG (Facades Netherlands)
  and IPC en R&D&E at FAECF (European Facades)
  Industries Vision RD&I

- *Winfried Heusler*, Head of Corporate Building Excellence and technical ambassador
  for Schüco worldwide at Schüco and Honorary Professor for “Façade Design and Technology”
  at the University of Applied Sciences in Detmold

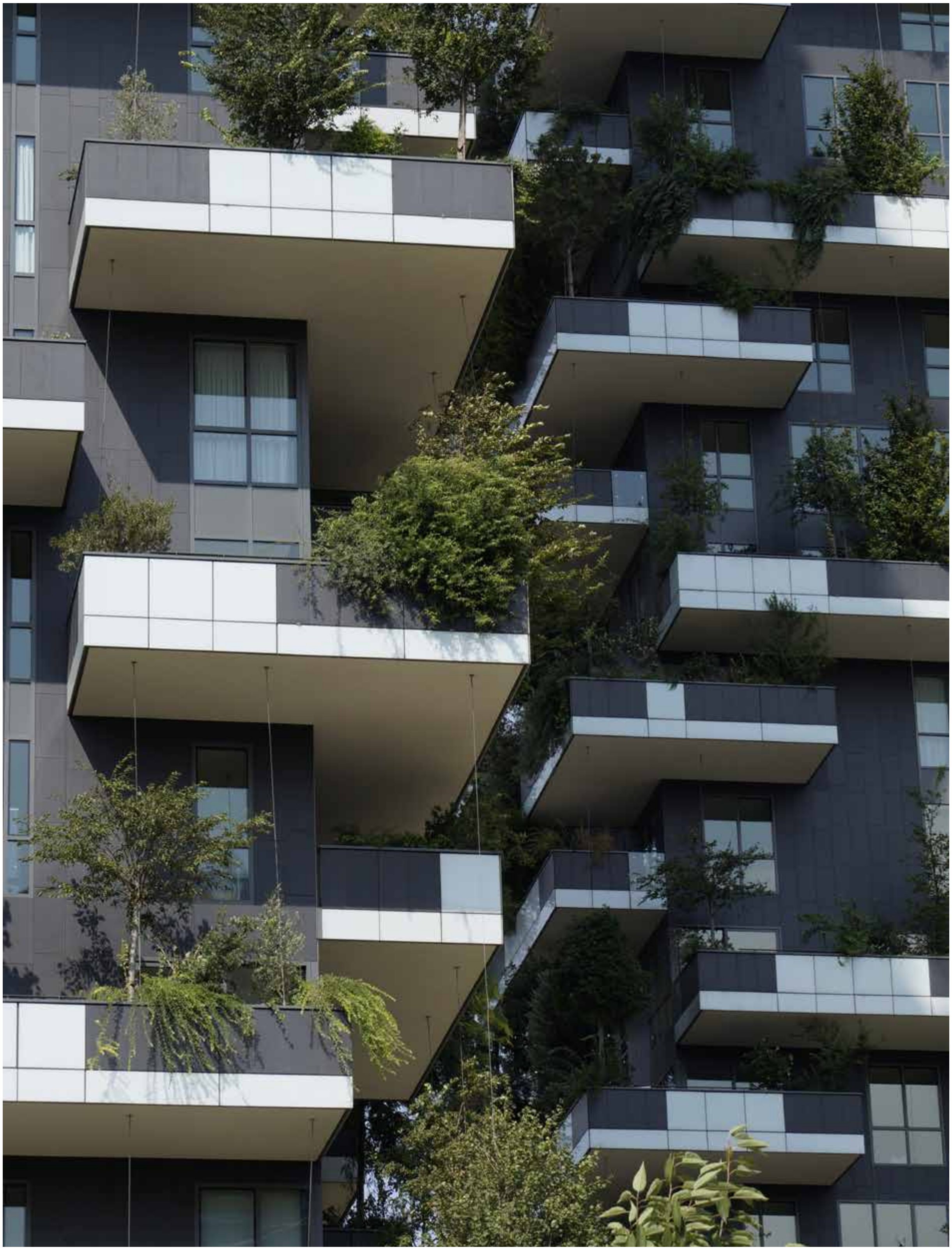
- *Stephen Selkowitz*, Leader, Windows and Building Envelope Materials Group,
  Senior Advisor for Building Science, Building Technology and Urban Systems Division,
  Lawrence Berkeley National Laboratory
  Advancing Façade Performance: Technologies, Systems, Simulation and Field Testing

The presentations can be downloaded from the COST Action webpage (www.tu1403.eu).

The presentations were grouped in two sessions, followed by a discussion. The active discussions demonstrated and highlighted the importance of a strong collaboration and knowledge exchange between all different disciplines and actors.

After the industry workshop the working groups worked individually on their working group tasks and the objectives of the meeting, namely the first stage of the state of the art booklet or database, the concept of the educational package and the training school which will take place in summer 2016.

Meeting at TU Delft on 16/17 September 2015



Housing complex Bosco vertical / Milan