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TWIN ROOMS – EXPERIMENTAL FACILITY FOR RESEARCH ON ADVANCED FACADES

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Abstract

New or advanced materials, improved structures in construction, and environmental technological principles are being concurrently and constantly implemented across various individual scientific and engineering disciplines. The field of facade engineering is also enriched with these elements, which are combined into larger units and thus create developed modules. These advanced facade modules need to be researched and tested from several perspectives. The testing and evaluation of building envelopes occur in either static boundary conditions (a laboratory) or dynamic conditions (climatic) in real time. The choice of testing method depends on the specific purpose or the phenomenon investigated that is related to the construction of the building envelope.

In 2023, the newly developed Twin Rooms experimental facility was finished and put into operation. The Twin Rooms facility is based on a test cells principle intended for experimental verification, which means it is designed for experimental research on advanced facade elements in dynamic boundary conditions and is focused on the thermal engineering and energy efficiency of buildings. The test cells comprise two identical laboratory rooms and a compensation space inside of a container; as with research on pavilions, they all maintain the same indoor climate. Only the facade elements of the modules tested are exposed to the outdoor climate; such an arrangement makes it possible to determine an exchange of energy between the testing room and the outside environment only through the facade element. This article provides an overview of the experimental equipment, outlines the basic technical parameters of its technological circuits, and details the methodology employed in the experimental measurements.

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Key words

- Twin rooms,
- Experimental facility,
- Pavilion research,
- Test cells,
- Advanced facade elements,
- Real outdoor climate.

1 INTRODUCTION

Humanity faces a critical challenge: balancing energy needs with environmental preservation. Our planet's ecological footprint surpasses its capacity by 30%, thereby creating an ecological debt. Transitioning to a sustainable society necessitates investments in renewable energy, eco-friendly materials, and low-impact technologies. This involves creating a harmonious balance between humans, nature, and technology to ensure the well-being of current and future generations, while protecting biodiversity and ecosystem functions. Buildings are the second-largest energy consumers, primarily due to their need for heating, cooling, and lighting. To address this issue, we can either reduce energy consumption or increase the production of renewable energy. Renewable energy is transforming buildings into energy generators and consumers that are integrated into energy grids. This concept is leading to the development of "Net Zero" energy buildings.

Facade structures, which are essential and multifunctional components of building envelopes, play critical roles beyond their physical and mechanical attributes (insulation, air permeability, resistance to wind). They also provide natural daylight, ventilation, and aesthetic values. With the technological evolution towards a sustainable society, transparent structures have gained prominence as elements of passive solar systems in buildings. To regulate energy flows through these transparent constructions amidst dynamically changing external climatic conditions, modern elements like adjustable ventilation louvers, flaps, or units are integrated. These components, which are linked to electronic sensors monitoring internal or external climate parameters, dynamically respond to climate changes, thereby optimizing energy flows for comfort, while minimizing demands on building environmental technology, such as energy. Additionally, integrating solar panels directly into these facades can generate energy and reduce reliance on traditional heating and cooling systems. Modern, adaptive facades promise significant energy savings. However, their performance must be rigorously tested under various climate conditions to verify their efficiency in reducing heating and cooling loads, while maximizing the generation of renewable energy.

Modular double-skin transparent facades represent a significant advancement in contemporary architecture by offering a sustainable, energy-efficient, and aesthetically pleasing solution for buildings. By incorporating innovative design principles and advanced technologies, these facades contribute to both environmental sustainability and the well-being of building occupants (Gratia and De Herde, 2007), (Roig at al., 2023). These facades offer superior thermal insulation and minimize heat losses and gains through advanced glazing technologies and optimized cavity design. Integrated shading devices or electrochromic glass dynamically adjust solar heat gains, optimize indoor comfort, and reduce cooling loads. Strategically placed openings and ventilation systems enhance natural ventilation, improve indoor air quality, and reduce reliance on mechanical ventilation. High-performance glazing and cavity design reduce noise pollution and create quieter and more productive indoor environments. Optimized daylighting strategies, such as light shelves and light pipes, improve visual comfort and reduce the need for artificial lighting. Integrated air filtration systems and natural ventilation further enhance indoor air quality. Modular design and a wide range of glazing and shading options enable customization and unique architectural expressions. By incorporating media facades or responsive shading systems, dynamic facades enhance visual appeal and energy performance.

Future research and development will focus on integrating sensors, actuators, and control systems into smart facade systems to optimize performance based on real-time environmental conditions. Additionally, developing innovative materials with enhanced thermal, acoustic, and optical properties will further improve the performance and durability of these facades. Conducting comprehensive life cycle assessments will help identify opportunities to reduce the environmental impact of these facades, i.e., from material extraction to disposal. Furthermore, integrating photovoltaic cells, known as building integrated photovoltaics (BIPV) into a facade, can generate renewable energy, thereby reducing a building's reliance on traditional energy sources. By continuing to explore these areas, researchers and designers can further optimize the performance and sustainability of modular double-skin transparent facades and contribute to a more sustainable and resilient built environment (Gratia and De Herde, 2007), (Roig at al., 2023).

Our research explores the modularity of double-skin facades, which allows for highly customizable building envelopes. In this context, modularity refers to the variability of the facade as a whole. The building facade is composed of individual, dimensionally identical modules, which do not necessarily have the same function. This means that we can arrange dimensionally identical modules with different functions on a single facade according to the building's needs (for example, one module may have an integrated heat recovery unit; another module may have an integrated solar system; a third module may have integrated ejector cooling; and another module may have a combination of the previous functions).

2 TEST CELLS - TWIN ROOMS

Experimental measurements offer a means not only to validate numerical models but also to extract critical parameters, such as the temperature and airflow distribution, which are crucial for assessing the thermal performance of a double transparent facade. This research domain was initiated in 1985 through controlled test cell experiments to establish confidence in the application of energy-efficient and passive solar building components, as well as to refine the methodologies for determining their effective thermal properties. The initiation of the Passive Solar Components and Systems Testing (PASSYS) project represented a pivotal advancement in the field of passive solar building research. By establishing test cell equipment as a primary methodology for evaluating passive solar component performance, the project significantly contributed to the advancement of building design and simulation tools. A key advantage of test cells is their ability to provide a meticulously controlled, occupant-free environment that closely approximates real-world conditions (Baker and Van Dijk, 2008), (Van Dijk and Van Der Linden, 1993).

PASSYS established standardized test procedures for passive solar components and systems to ensure consistent and reliable performance evaluations. These procedures facilitated the development and deployment of innovative passive solar technologies. By rigorously validating simulation models, PASSYS improved their accuracy in predicting the performance of passive solar buildings and enabled designers to make more informed decisions and optimize building designs for energy efficiency. Additionally, PASSYS played a crucial role in disseminating knowledge and best practices related to passive solar design through conferences, workshops, and publications to raise awareness and encourage the adoption of sustainable building strategies. While the original PASSYS project may have concluded, its impact continues to shape the future of sustainable building design. The knowledge and tools developed through this pioneering initiative have been widely adopted by researchers, designers, and policymakers around the world.

A substantial number of experimental facilities, which are commonly referred to as “test boxes” or “test cells”, are located across Europe. Notable examples include the Vliet test building (KU Leuven University in Belgium), (Dirk, Roles and Hens, 2004); the Test Box (Technische Hochschule Rosenheim in Germany), (Technische Hochschule Rosenheim, 2024); the Minibat Test Cell (Lyon, France), (Janssens, Roels and Vandaele, 2011); the ZEB Test Cell Laboratory (Trondheim, Norway), (ZEB and Goia et al., 2017), and The Cube (Aalborg, Denmark), (Liu et al., 2014, and Kalyanova et. al., 2008). A similar infrastructure exists in Slovakia and the Czech Republic. However, it must be acknowledged that none of these facilities currently enables the accurate quantification of the energy flows in the samples examined.

"Twin Room" test cells (see Figure 1) are designed to quantify the thermal performance of advanced facade elements under diverse climatic conditions. Specific parameters determined include the following thermal properties: the U-value, thermal resistance, surface temperatures, temperature fields, and energy fluxes through advanced facade elements. A "Twin Rooms" experimental facility is configured to establish and maintain precise, uniform, and reproducible indoor temperature conditions within the test rooms and compensation space. This controlled environment facilitates the concurrent measurement of heat balances, total and localized heat fluxes, and surface temperatures across two test specimens installed in the aperture walls while they are subjected to dynamic outdoor climatic conditions. A Twin Rooms (test cells) experimental facility is situated in the Central Laboratories of the Faculty of Civil Engineering at Trnávka in Bratislava, Slovakia.

Fig. 1 *Twin Rooms - new experimental facility (south view)*

2.1 Construction of Twin Rooms

The experimental test cells are enclosed within an office-type mobile container, with dimensions of 6.058 m × 2.99 × 4.2 m, which is mounted on a concrete foundation (Figure 2). The container's structural frame is a welded steel space lattice constructed from hollow sections. The envelope consists of lightweight sandwich panels with a galvanized steel exterior, mineral wool insulation core, and chipboard interior lining. Access is provided by a 1 m × 2 m insulated and galvanized steel door located on the 6.058 m × 4.2 m rear wall.

Fig. 2 *Process of placing the Twin Rooms container on pre-built concrete foundations*

The southern facade of the container incorporates two openings, each measuring 2.4 m × 3.4 m, and is designed to accommodate building envelope components for testing. A lightweight wooden partition is installed directly behind these openings; it divides the space into two thermally isolated test cells or "twin rooms," with dimensions of 2.4 m × 2.0 mm × 3.4 m each (see Figures 3 and 4).

Fig. 3 *Process of building two rooms inside the container*

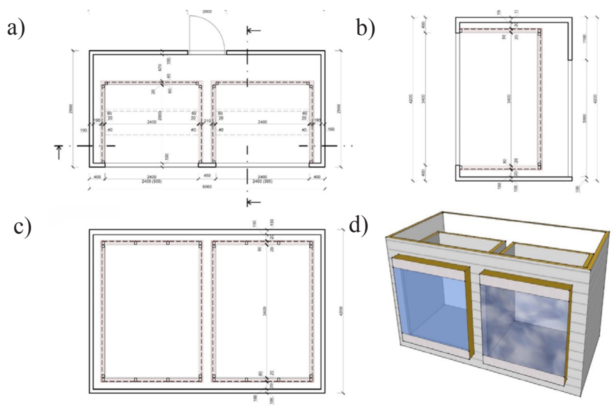

Fig. 4 *Construction schemes of the Twin Rooms (a – Floor plan, b – Cross section, c – Longitudinal section, d – 3D model)*

2.2 Technological equipment

The test cell system comprises interconnected components forming a unified functional unit. Figure 5 (a – Floor plan, b – Cross section) shows the technological equipment scheme. A controlled indoor climate, which is maintained at a constant temperature θai (°C) within both test rooms and the compensation space, is achieved through environmental control technology. This condition eliminates any heat transfer through the partition separating the test rooms from the container's interior and directs all the energy flows exclusively through the building envelope components installed. To sustain the prescribed temperature θai (°C) in the test rooms, an energy input (heating or cooling) is required. This energy input is equivalent to the energy emitted by the facade element tested. By quantifying the energy delivered to each room, the energy transferred through the facade component can be determined. Consequently, energy fluxes through the facade elements can be measured under dynamic outdoor climatic conditions.

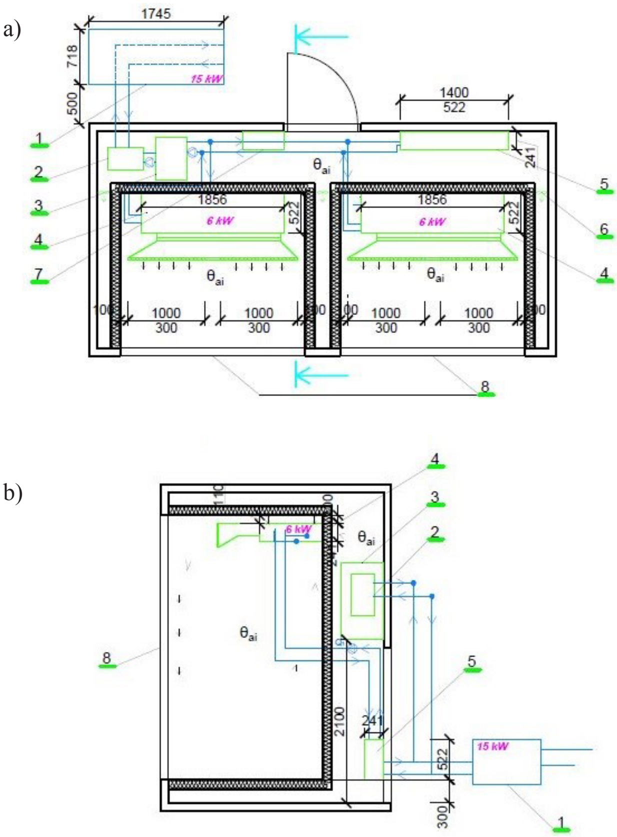

Fig. 5 *Construction scheme of the technological equipment in the Twin Rooms: 1 – Cooling source, Qc = 16,4 kW, MEX EA 117 Z C, 2 – Plate heat exchanger, 3 – Water tank - Galmet 140 l storage tank, 4 – Pipe fancoil - NXKT3-V1000, 5 – Sill fancoil - NXKH3-V600, 6 – Circulating fans - homogeneous thermal field, 7 – Electrical switchgear, 8 – Two openings for mounting new facade samples*

The compensation room's climate control system incorporates an outdoor air conditioning unit and a heating element. This configuration maintains a stable temperature within the compensatory space and prevents the exchange of thermal energy with the test rooms. A concurrent air circulation facilitated by fans within the compensation room ensures a uniform air distribution, thereby mitigating any localized temperature variations in the vicinity of the test rooms.

The air conditioning system for Testing rooms 1 and 2 is composed of an air conditioning unit identical to that used in the container, a shared air-to-water heat exchanger, and a heater. This configuration is designed to establish and maintain precise, homogeneous temperature conditions within the test environments. To facilitate a comprehensive energy performance analysis and system optimization, the system includes instrumentation for continuous monitoring of the key parameters. These parameters encompass the water flow rates, the inlet and the outlet water temperatures, and electrical power consumption of the heater and circulation fans. This data collection is essential for evaluating the system's efficiency, identifying potential energy savings, and ensuring optimal operation of the testing rooms. The concurrent measurements in rooms 1 and 2 are essential for quantifying the total heat fluxes through the test structures. These measurements are focused on two parts:

- Performance of the heat exchanger: Energy transfer through the heat exchanger is determined by measuring the inlet and outlet water temperatures and flow rates.
- Consumption of electrical energy: Power usage by the radiator and circulating fans is measured to assess their energy contribution.

The guaranteed parameters for the compensatory space and both test rooms are documented in Tab. 1.

Tab. 1 *Guaranteed parameters for the indoor spaces*

Parameter	Compensatory space	Test room 1	Test room 2
Cooling Circuit Power (kW)	3	6	6
Heat Circuit Power (kW)	2	2	2
Adjustable Temperature Range (Summer)	+19°C to +40°C	+19°C to +40°C	+19°C to +40°C
Homogeneity (Summer)	±1.5°C	±1.5°C in front of measured sample (up to 2.0 kW output)	±1.5°C in front of measured sample (up to 2.0 kW output)
Adjustable Temperature Range (Winter)	+10°C to +25°C	+10°C to +25°C	+10°C to +25°C
Homogeneity (Winter)	±1.5°C	±1.5°C in front of measured sample (up to 2.0 kW output)	±1.5°C in front of measured sample (up to 2.0 kW output)
Air Velocity Range (m/s)	0.10 to 1.50	0.10 to 1.00	0.10 to 1.00

All the relevant physical parameters are continuously acquired and processed by the local control unit. The system offers remote, real-time access to both the measured and derived data and enables comprehensive monitoring of the system. Additionally, remote control functionalities provide flexibility in the system's operation and management.

2.3 Measuring equipment

To accurately assess the total heat balance of the test structures under dynamic outdoor climatic conditions, a comprehensive meteorological dataset is indispensable. A meteorological station, which is positioned on the container roof (Figure 6), continuously records the ambient air temperature and humidity, wind velocity and direction, solar irradiance on both the horizontal and vertical planes, and precipitation. This meteorological data serves as a critical input for precise modelling and analysis of the thermal performance of the test structures.

Fig. 6 *Position of the meteorological station in relation to the experimental facility*

A comprehensive overview of all the parameters measured, including the corresponding instrumentation and specific sensor types, is presented in Tab. 2.

To comprehensively characterize the local thermal performance of the test structures, a suite of measurements is required (see Figs. 7, 8, 9, 10 and 11 for the sensor placements). These include the determination of the local heat flux through the application of heat plates, the surface temperature mapping using Pt100 sensors on both the external and internal surfaces, the airflow velocity profiles adjacent to the structures, the differential pressure measurements across the structure, and the intensity of the solar radiation on the vertical surface of the perimeter wall.

a) b) c)

Fig. 7 *Placement of measuring equipment: a – in narrow cavity, b – on windows (inside), c – control panel*

The measuring devices can be divided into two groups: The first group consists of devices located within the cells and the compensation room. The test cells have these devices equally distributed and temperature sensors at three height levels, i. e., above the floor, in the middle of the height of the room, and under the ceiling.

Tab.2 *Summary table of the measured parameters and measuring devices (Kaniková, 2022)*

	Measured quantity	Equipment	Specified type
PT	Air temperature in the narrow cavity	Pt 100	CRZ-2005-100-A-1-Ni
PT	Element surface temperature	Pt 100	CRZ-2005-100-A-1-NI
PT	Temperature in the heat recovery unit	Pt 100	CRZ-2005-100-A-1-NI
GT	Radiant air temperature in the cell	Globe thermometer	Testo - 0602 0743
TD	Flow velocities along the measured structures	Heat flux sensor	FQA017C FQA020C FQA017CSI
AN	Air flow rate	Anemometer	EE671
AN	Air flow rate	Anemometer	EE576
PYR	Intensity of solar radiation	Pyranometer	Kipp&Zonen CMP 6
-	Heat recovery unit	-	Lunos Nexxt
-	Temperature and humidity of the outside air, speed and direction of wind, intensity of solar radiation on the vertical and	Meteorological station	AMS 111

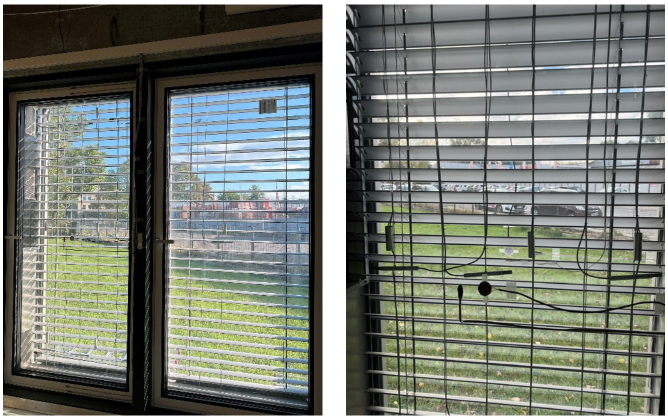

Fig. 8 *Placement of measuring equipment on the facade element (view from the inside)*

These Pt100 sensors are used to measure the temperature in the interspace (PT1, PT2, PT10-PT18, PT25) and are protected by a silver shield from direct solar radiation. Each cell has a spherical thermometer placed within the space. The spherical thermometer, i.e., Testo - 0602 0743, is used to measure the apparent temperature of the air. It utilizes a Class 1, Type K thermocouple, with a measurement range of 0 to 120 °C (Kaniková, 2024).

The compensation room is similarly equipped with temperature and humidity sensors. In addition to these devices, the experimental setup is equipped with flow meters on the technical equipment used to maintain the set environment in all the interior spaces. The second group consists of measuring devices used for the examination of the facade modules. The exact locations of the measuring devices for the facades are shown in Figures 9-11.

Figures 9 and 10 illustrate the arrangement of the measuring devices in the double transparent facade. Figure 9 (right) illustrates the arrangement of the heat flux sensors on the facades, which are used to measure the local heat fluxes throughout the construction. The heat flux sensors labeled TD 1-3 are of the FQA020C type, with a circular diameter of 33 mm and a thickness of 1.5 mm; they are designed to measure heat fluxes in the range of -40 to 80 °C with a calibration value of less than 150 W/m² ≈ mV. The heat flux sensors labeled TD 4, 5, are of the FQA017C type, with a plate size of 100 × 30 mm and a thickness of 1.5 mm; they are designed to measure heat fluxes in the range of -40 to 80 °C with a calibration value of less than 50 W/m² ≈ mV.

When monitoring the aerodynamics of the cavity, it is necessary to measure the air flow velocity and temperature throughout the entire height of the facade module. Figure 9 (left) shows the arrangement of EE576 anemometers (AN3-AN14) in the cavity, which are optimized for low-velocity airflow. These hot-wire anemometers measure air speed with an accuracy of ± 0.05 m/s + 2% at 0.2-1 m/s and ± 0.08 m/s + 4% at 0.2-2 m/s. Additionally, EE671 anemometers (AN1 and AN2) are installed in the duct leading to and from the heat recovery unit. These hot-wire anemometers measure air speed with an accuracy of ± 0.2 m/s + 3% at 0.5-5 m/s, ± 0.3 m/s + 4% at 1-10 m/s, ± 0.35 m/s + 5% at 1-15 m/s, and ± 0.4 m/s + 6% at 1-20 m/s. The anemometers are positioned in the middle of the cavity's width and are distributed across four height levels. They are located at the glazing level on three levels: above the supply openings, in the middle, and at the sill. The fourth height level is located at the highest point of the element's parapet section (Kaniková, 2024).

Figure 10 illustrates the arrangement of the Pt100 sensors (PT) on the double transparent facade. Resistance temperature detector (RTD) sensors for measuring the temperature on the surface of elements (glazing, sill, sash, frame, mullion, and louver) are protected by a sealant (Kaniková, 2024).

Figure 10 shows the placement of a Kipp & Zonen CMP6 pyranometer (PYR1), which is mounted on a steel cable 0.9

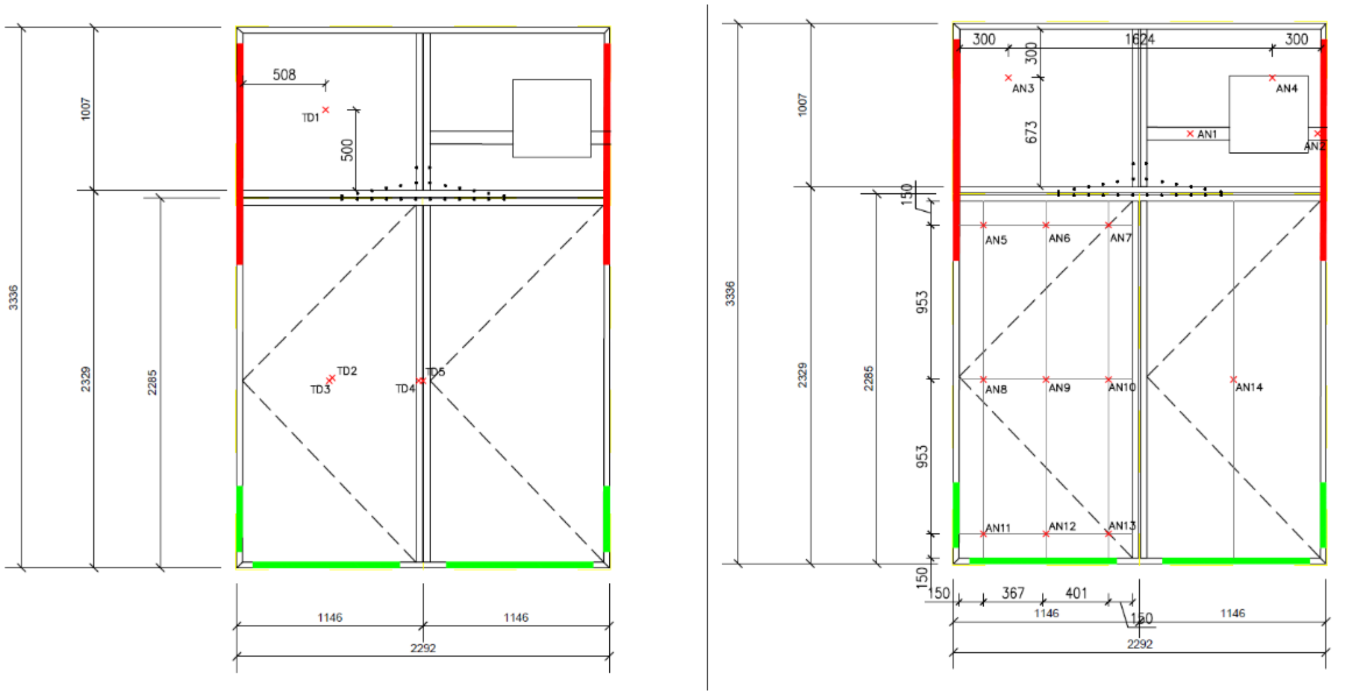

Fig. 9 *Placement of heat flow sensors/plates and anemometers on a double skin transparent facade. The green lines present inlets, and the red lines present outlets.*

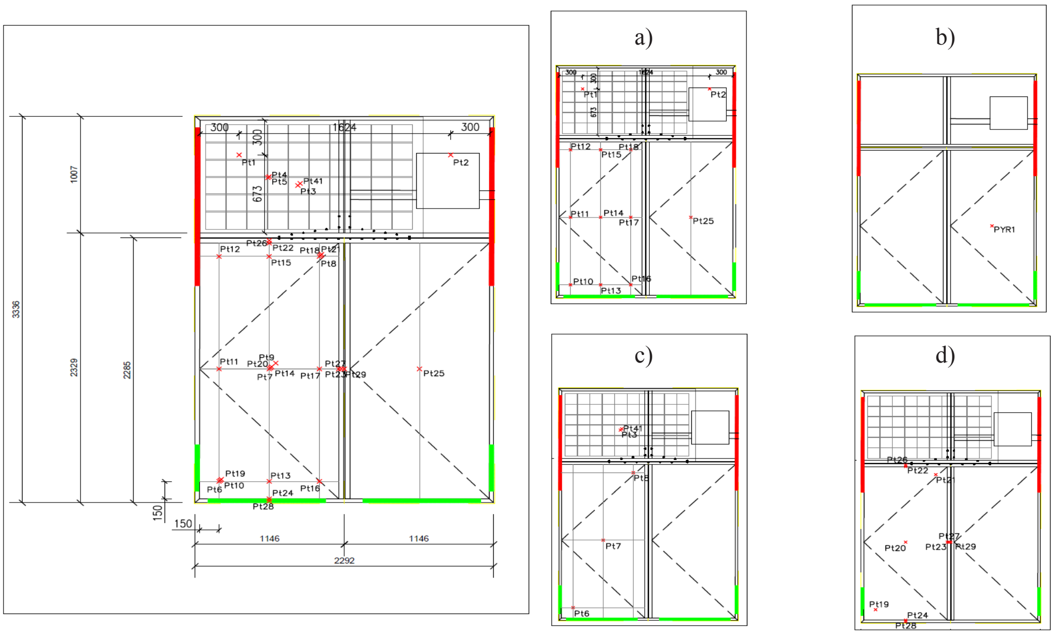

Fig. 10 *Placement of Pt100 and pyranometers on a double skin transparent facade; positions of: a) Pt100 sensors in the cavity, b) pyranometer in the cavity, c) Pt100 sensors on the inner surface of the external glazing/frame, d) Pt100 sensors on the inner surface of the inner glazing/frame. The green lines present inlets, and the red lines present outlets.*

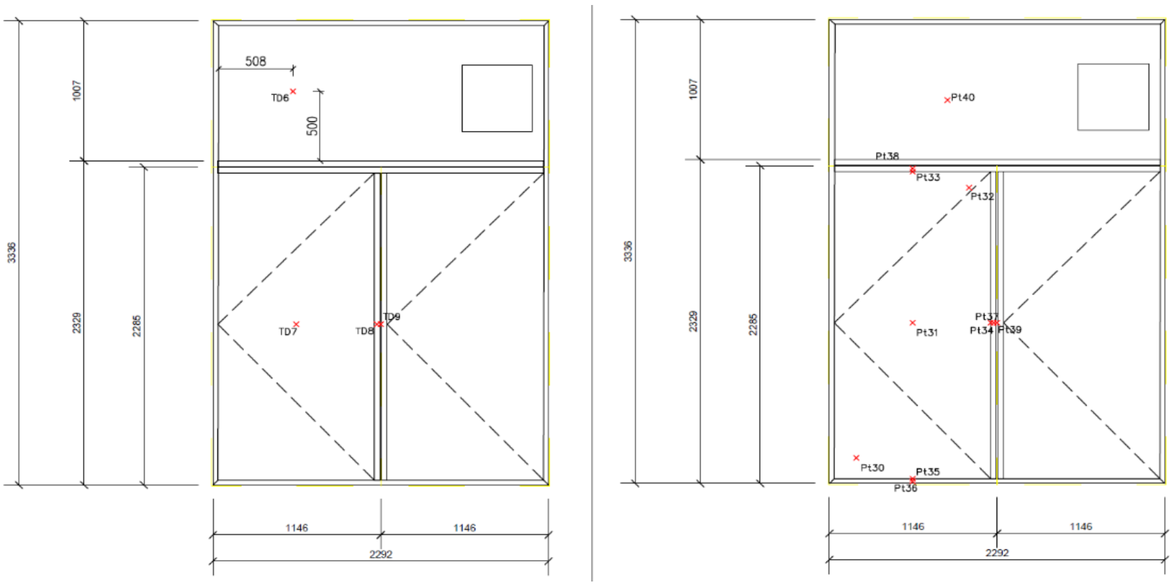

Fig. 11 *Placement of heat flow sensors/plates and Pt100 on a classic, simple transparent facade (identical to the inner layer of the double-skin facade)*

meters above the floor within the cavity. Another CMP6 pyranometer (PYR2) is positioned in a room alongside a spherical thermometer at the same height. With a sensitivity range of 5-20 µV/W/m² and a maximum solar radiation intensity of 2000 W/m², the CMP6 pyranometer measures solar radiation within a spectral range of 270-3000 nm. It offers a high degree of accuracy, with a deviation of less than 10 W/m² at 200 W/m², less than 4 W/m² for a 5 K/h temperature change, and less than 10 W/m² at zero, when operating within a temperature range of 0 to 80 °C (Kaniková, 2024).

Figure 11 illustrates the arrangement of the measuring devices on the single-skin facade. The configuration of the single-skin facade's measurement device is identical to the inner layer of the double-skin facade. Figure 11 illustrates the placement of heat flux sensors on the left and Pt 100 sensors on the right.

All the physical quantities detailed above are continuously captured and recorded using a dedicated data acquisition system. The meteorological station employs a two-minute sampling interval, while the test cells and compensation chamber utilize a five-minute sampling rate. Data is concurrently archived on a local computer and is accessible remotely via the internet. This infrastructure facilitates real-time monitoring, comprehensive data analysis, and the efficient dissemination of knowledge.

3 PROTOTYPES OF FACADE ELEMENTS

Our research focuses on the development of modular double-skin transparent facades. Two prototypical facade elements were produced in collaboration with Ingsteel s.r.o. Bratislava within the framework of the APVV-21-0144 and VEGA 1/0113/19 projects.

The resulting double facade design incorporates several innovative features:

1. A prefabricated modular design enables rapid and flexible assembly.
2. Thermal and acoustic performance are enhanced through optimized component selection and assembly techniques.
3. The cavity configuration is designed to mitigate solar heat gain and reduce heat loss.
4. An integrated ventilation system incorporates heat recovery for improved energy efficiency.
5. On-site renewable energy is generated through integrated photovoltaic technology.
6. A dynamic control system optimizes facade performance based on real-time environmental conditions.

For research purposes, an experimental Twin Rooms facility was needed. The new experimental facility tests new advanced facade elements. Two different facade elements – a double-skin transparent facade element and a classic simple transparent facade element – were installed in the Twin Rooms. These are going to be compared, and the results will be used to create a new advanced facade.

Following the successful installation and commissioning of the Twin Rooms test facility in October 2021, and subsequent successful test operations, the experimental verification of the prototype of a new modular double-skin transparent facade with a narrow slot cavity (Figure 12) was initiated that focuses on a multi-stage utilization of solar radiation:

- 1st stage: transformation of shortwave into longwave solar radiation in the cavity of the double-skin facade and its removal to an outdoor climate in the summer to reduce the need for cooling,
- 2nd stage: use of preheated air in the cavity of the facade for the ventilation recuperation unit in the winter to artificially increase its efficiency and reduce the heat demand,
- 3rd stage: the photoelectric conversion of solar radiation into electrical energy through photovoltaic cells is situated on the overhanging wall of the double-skin facade in its parapet section.

A comparative analysis of the energy performance between an innovative double-skin facade system and a conventional single-skin facade configuration is underway. Both facade prototypes are equipped with identical ventilation heat recovery units and have photovoltaic systems integrated into their parapet sections. To facilitate a comprehensive evaluation, long-term testing is being carried out within the controlled environment of the Twin Rooms test facility. This experimental campaign aims to quantify the energy performance advantages including its ability to mitigate heat gains in summer, re-duce heat losses in winter, and generate renewable electricity through photovoltaic integration.

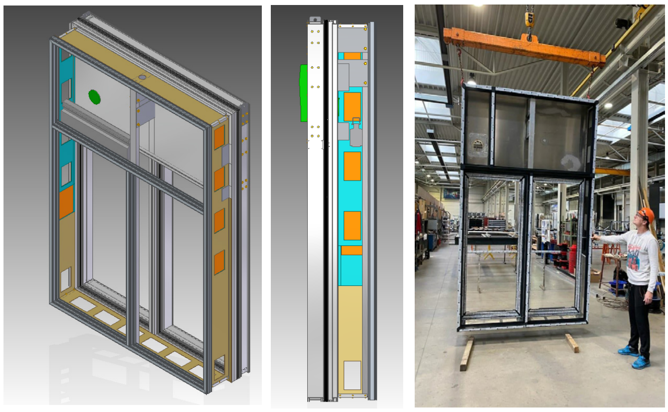

Fig. 12 *3D model of a double-skin transparent facade used for simulations and for manufacturing a prototype for measurements (Prototypical facade element ready for shipment – picture on the right)*

4 COMMISSIONING PROCESS AND SUBSEQUENT MEASUREMENT

In late 2021, two prototype façade systems were installed in the Twin Rooms facility. Subsequently, months were dedicated to completing the finishing works, including the installation of photovoltaic panels, positioning of the measurement devices, and making interior modifications. The Twin Rooms facility underwent a technological integration phase in 2022 to establish a foundational infrastructure for subsequent experimental investigations. In early 2023, a comprehensive measurement system was installed and calibrated within the enclosed test chambers. This system, which was designed to capture detailed data on thermal performance and energy consumption, included a range of sensors and instruments such as temperature and humidity sensors, heat flux sensors, anemometers, and pyranometers.

To ensure optimal experimental conditions, the facility underwent a rigorous validation process, including meticulous debugging and fine-tuning of its operational parameters. This meticulous preparation culminated in the initiation of primary data collection during the summer of 2023.

In March 2023, the facility underwent a comprehensive testing phase that encompassed the calibration of the measurement equipment, the development of the data acquisition and control software, and the establishment of baseline operational conditions.

4.1 Results acquired during commissioning process

Upon the commissioning of the Twin Rooms test facility in March 2022, comprehensive instrumentation was deployed to initiate data acquisition. Preliminary results were obtained that confirmed the functionality of the measurement systems. Two faulty PT100 sensors were replaced with new ones. The issue with the meteorological station (data logging) was resolved, and the entire facility's environmental control system was calibrated. Various flow rates were tested in the pipes and equipment; room temperatures were adjusted; the system's time response was monitored; and the performance of the overall system against the required parameters was evaluated.

Post-commissioning key insights can be segmented into the following categories:

1. Temperature Variations:
   - Day-Night Cycle: Figure 13 shows the temperature fluctuations within the cavity, which are influenced by external conditions like solar radiation and ambient temperature. During the day, the cavity temperature increases due to the solar heat gain, while it decreases at night due to radiative cooling.
   - Seasonal Influence: April, being a transitional month, exhibits moderate temperature variations compared to the more extreme seasons.

2. Airflow Patterns:
   - Stack Effect: Figure 14 depicts the airflow patterns driven by the differences in temperature between the inner and outer skins. Warmer air tends to rise, creating an upward airflow, while cooler air sinks and leads to a downward flow.
   - Wind-Induced Ventilation: The differences in wind pressure across a facade can also induce airflow and influence the ventilation rate within the cavity.

3. Solar Radiation:
   - Seasonal Variation: Figure 15 shows the intensity of solar radiation reaching the facade during April. The angle of its incidence and the duration of sunlight vary throughout the month, which affects the amount of solar heat gain.
   - Shading Effects: Any shading devices or obstructions cn significantly reduce solar radiation and, consequently, the heat gain.

Potential Implications:

1. Thermal Performance:
   - The temperature variations and airflow patterns within the cavity directly impact the thermal performance of the double-skin facade.
   - Effective insulation and ventilation strategies can help maintain comfortable indoor conditions and reduce energy consumption.
2. Energy Efficiency:
   - The amount of solar heat gain can contribute to the building's heating and cooling loads.
   - Optimizing the design of the double-skin facade, including factors like the cavity width, insulation materials, and ventilation openings, can enhance energy efficiency.
3. Indoor Environmental Quality:
   - The air quality within the cavity can influence the indoor environment of the building.
   - Proper ventilation can help remove pollutants and maintain adequate air exchange.
4. Durability and Maintenance:
   - Excessive temperature fluctuations and moisture buildup can affect the durability of the facade materials.
   - Regular monitoring and maintenance are essential to ensure the long-term performance of the system.

These initial findings underscore the importance of continuous monitoring for understanding the dynamic behaviour of a double-skin facade. By understanding the dynamic behaviour of the double-skin facade, it is possible to optimize its design and operation for improved energy efficiency, thermal comfort, and durability. Our ongoing data analysis is generating a series of graphic representations. Figure 13 presents temperature variations within the double-skin facade cavity for the month of April. Complementarily to this, Figure 14 illustrates the airflow patterns within the cavity during the same period. The intensity of the solar radiation reaching the facade is visualized in Figure 15.

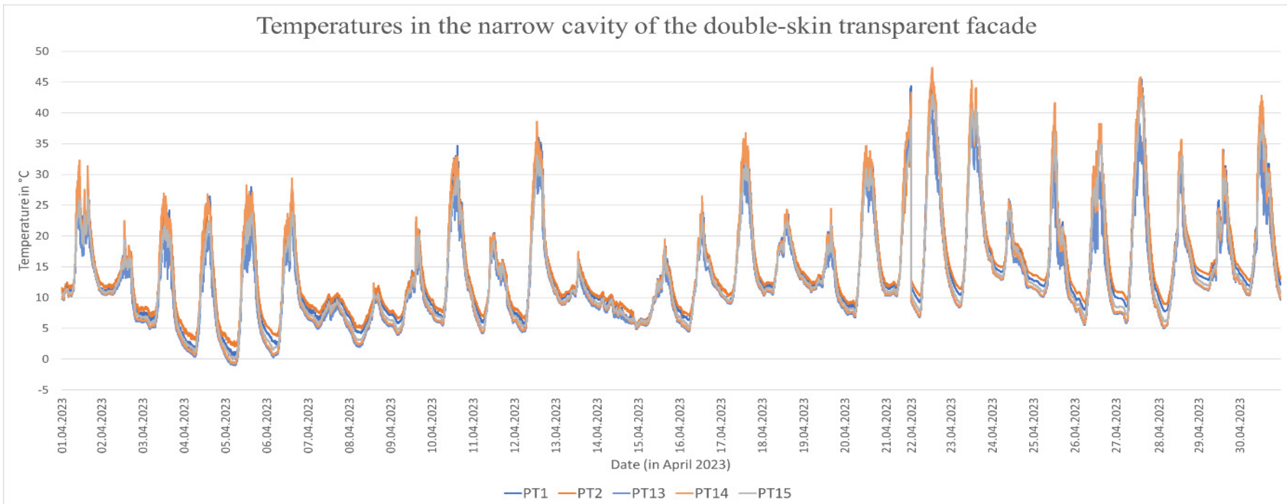

Fig. 13 *Change of temperatures in the narrow cavity of a double-skin transparent facade. PT1 is a temperature sensor located in the left part of the window sill; PT2 is located in the right part of the window sill; PT13 is located in the cavity above the supply openings in the middle of the window's width (1/4 of the module); PT14 is located in the cavity above PT13 in the middle of the window's height; and PT15 is located in the cavity above PT14 on the lintel*

Figure 13 indicates that the temperature throughout the cavity responds to changes in the external climate conditions, with temperatures ranging from -5 to 50°C. This corresponds to the variable climatic conditions in April, including windy days, changing cloud cover, and increasing outdoor temperatures. A clear daily cycle is evident in the graph. The differences between the individual results are attributed to the varying heights of the measurement devices (see Figure 10 for the exact locations). The air velocity within the cavity was measured at various heights using anemometers. Figure 14 shows that air movement was detected throughout the entire cavity, with velocities consistently exceeding 0.01 m/s. The maximum recorded air velocity reached 1.6 m/s. The specific locations of the anemometers are depicted in Figure 9.

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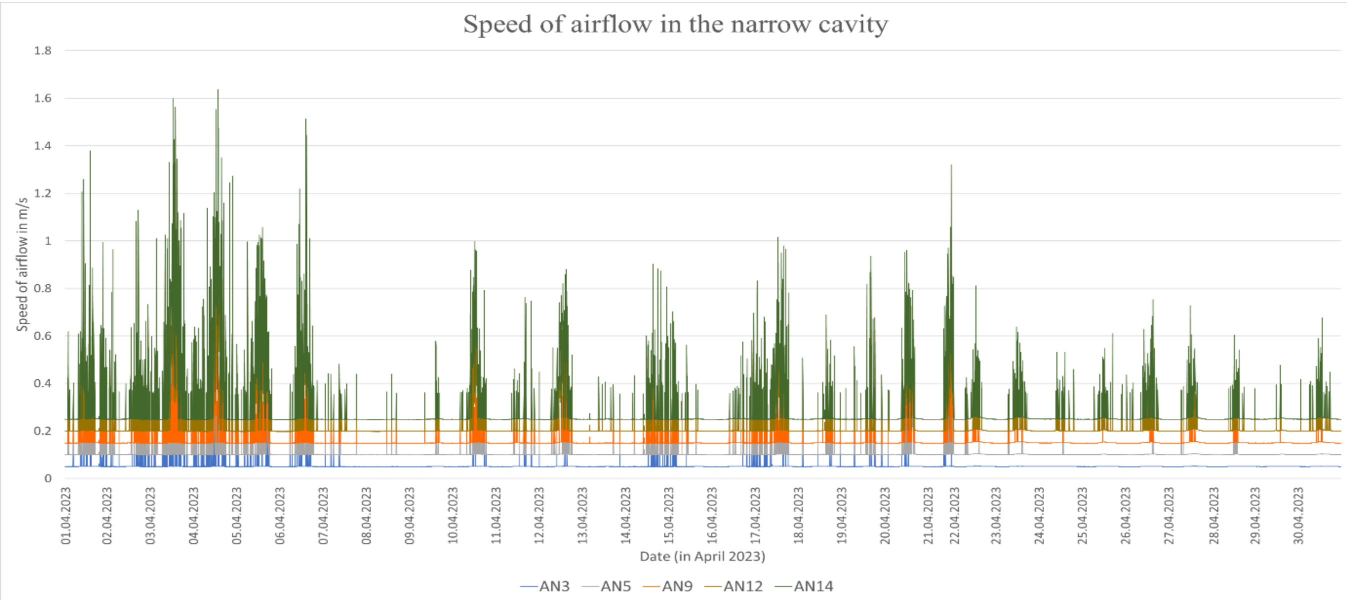

Fig. 14 *Speed of airflow in the narrow cavity. AN3 is an anemometer located on the left side of the window sill; AN5 is located in the cavity on the lintel (near the exhaust openings); and AN9 is located in the cavity above AN12 in the middle of the window's height; AN12 is located in the cavity above the supply openings in the middle of the window's width (1/4 of the module); and AN14 is located in the cavity on the right side of the facade's module in the middle of the window's height.*

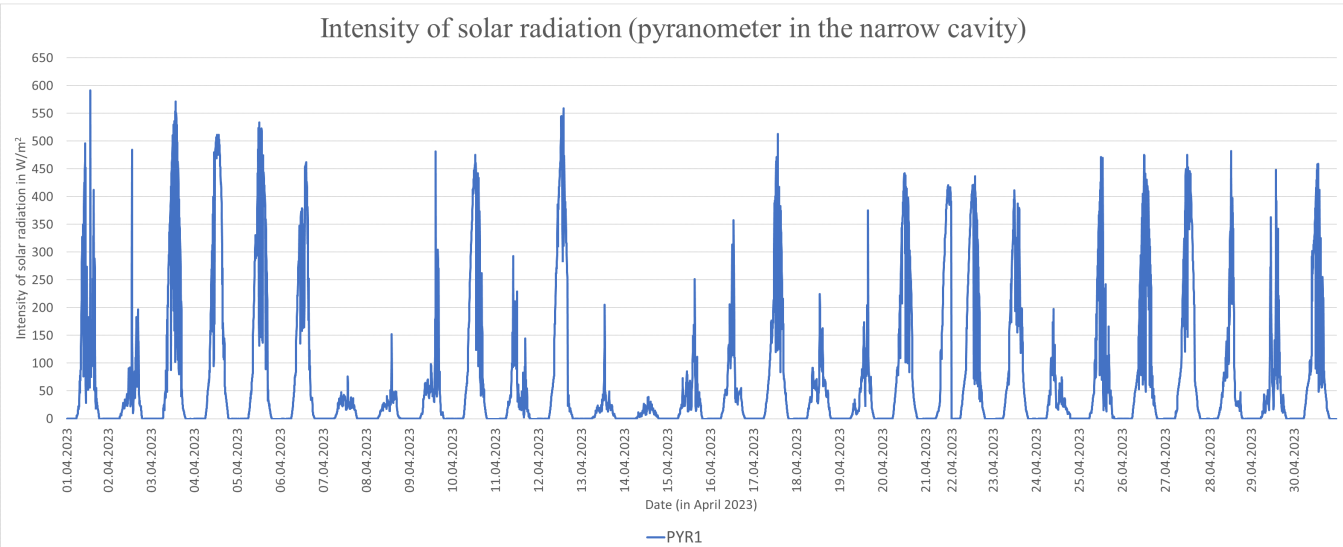

Fig. 15 *Intensity of solar radiation in the narrow cavity – vertically positioned PYR1*

A pyranometer, which is positioned vertically in the right part of the facade module within the cavity, continuously measures the intensity of the solar radiation. Figure 15 clearly shows the daily cycle and indicates that the intensity of the maximum solar radiation in April reaches 600 W/m²

4.2 Subsequent measurements

Following the successful commissioning of the equipment, experimental investigations commenced on the double transparent facades. A comprehensive summer experiment (July-August 2023) was conducted to evaluate the aerodynamic performance, energy transfer characteristics, and solar system efficiency of the cavity. The results indicated a predominant natural convective airflow within the cavity driven by buoyancy forces, thereby validating the facade's design principles. A detailed comparative analysis between the experimental and computational data is forthcoming. Seasonal measurements will be conducted to assess the heating energy consumption of both conventional and innovative double facade configurations. This research aims to provide empirical evidence for the enhancement of the performance potential of the proposed facade system.

5 CONCLUSION

The construction of the Twin Rooms experimental test facility has established a platform for investigating advanced facade systems under real-world climatic conditions. This research infrastructure enables comprehensive studies on the integration of renewable energy sources, particularly solar radiation, into facade designs. By combining passive and active strategies, the facility facilitates the development and optimization of innovative transparent facade structures, contributing to the advancement of building envelope technology and performance

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