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TWIN ROOMS – NEW EXPERIMENTAL TEST CELLS FOR TESTING ADVANCED FACADE ELEMENTS

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Abstract. Nowadays the global trend is the integration of new materials, constructions and technological principles, which are simultaneously implemented in individual scientific and engineering disciplines. Reducing the energy intensity of buildings will increasingly resonate in individual political and professional circles. As a result, new fragments of building envelopes in the field of facade engineering are being developed and tested. Testing of building envelope is carried out either in static (laboratory) boundary conditions or in dynamic (climatic, real) conditions. The determination of the test method is conditioned by the specific intention or the investigated phenomenon within the construction of the building envelope. Currently, we finished the development and realization of the new experimental facility Twin Rooms for testing advanced elements of building envelopes in dynamic boundary conditions (in the real climate of Central Europe – Bratislava) in terms of building thermal engineering and energy efficiency of buildings. It is based on the concept of pavilion measurement. The essence of the research is that the outdoor climate is modelled by the conditions of the real outdoor climate. Test cells consists of a solar laboratory – two-room for a comparative study of the effect of solar radiation and heat transfer on energy consumption and indoor climate. The space of two identical laboratory rooms is situated inside a container – a pavilion, whose climate is a compensating space. Only the tested facade element walls are exposed to the outdoor climate. The exchange of energy with the environment is possible only through this measured facade wall. The article brings a detailed description of this experimental equipment, basic technical parameters of its technological circuits and methodology of experimental measurements.

Keywords: Experimental pavilion test cells, advanced facade elements, real outdoor climate.

1. Introduction

In the current period, humanity is solving one of the most difficult technical and economic problems of ensuring sufficient energy for continual development of society without negative impact on ecology, production and environmental protection. Approximately in the 1980s, the economic system expressing human activities exceeded the reproductive value of the Earth's biocapacity (3 to 3.5 billion tons of emissions of greenhouse gases) and the man began to produce the ecological debt on the planet. The world, at the present time, produces environmental burden that exceeds its biocapacity by about 30 %. Humanity must find a solution for the repayment of the ecological debt. For a successful solution to this problem, mankind has to reconsider its priorities in investments, which represent the transformation to a sustainable society by transforming the energy sector towards environmentally clean renewable energy sources and their conversion, transformation of material sector towards ecologically clean materials and their production and transformation of the whole economy towards low-energy and low-emission technologies and environmentally friendly products. Sustainability is synonymous with the image of a future world whose aim is to place man, nature and technology in permanently stable equilibrium. This means such a development which allows both current and future generations to meet their basic living needs, preserves the diversity of nature and functions of the ecosystems.

From the internal structure of the overall energy balance of non-productive sphere, the human settlements are the second largest consumer of energy. The majority of this energy consumption falls on the operation of buildings (heating, cooling, ventilation, hot water and lighting), coupled with hygienic and ecological comfort in them. There are two major approaches to sustainable development of society in the interaction Energy – Human Settlements: energy saving by its rational use and focus on environmentally clean renewable energy sources.

Renewable energy sources, as the dominant production technology value of nature, with its simultaneous renewal of ecosystems are becoming determining factors for changes in fundamental concept of energy quantification of buildings. Building is becoming a place for the collection and on-site conversion of renewable energy as part of the transformation of organization of the energy market. It is becoming part of the energy distribution networks and it is just in the interaction to these distribution networks that the new quantification of physical-energy demand of the building is being conceived, expressed by the term Net Zero Energy Building or nearly Net Zero Energy Buildings or Net Plus Energy Buildings.

Facade structures are indispensable and, by their functions, extremely important parts of the building envelopes. Besides their physical (thermal, sound and water insulation and air impermeability) and mechanical features (static and dynamic wind resistance) they also have additional specific indispensable functions (natural daylight, natural ventilation, visual contact with the surroundings, fire escape route, architectural expression). With the development of technology in the architecture towards a sustainable society, the function of transparent structures is highlighted as an element of passive solar systems of buildings. Given the need to regulate energy flows through transparent constructions within dynamically changing conditions of the external climate, new elements are being integrated to modern transparent building constructions (adjustable ventilation louvers, flaps or units, mobile screening devices...), connected to electronic sensors of physical or chemical parameters of internal or external climate that dynamically respond to climate changes and optimize the energy flows through transparent constructions in order to ensure a comfortable indoor climate while minimizing demands on building environmental technology (i.e. energy). With development of active solar systems based on photo thermal or photoelectric conversion, these elements are then integrated directly into transparent facade structures. These transparent structures then partially take over the function of building environmental technology.

With the development of modern climate-adaptive transparent facades capable of dynamically responding to the climatic parameters of the external climate and thus optimizing the energy flows through their construction in order to significantly reduce the heat load in the summer period, the heat losses in the winter period and to maximize the available renewable energy sources, the need to verify their parameters and energy efficiency depending on the conditions of the external climate comes to the fore.

2. Overview of experimental equipment for research of advanced facade elements

Research in the test cell began in 1985 as an effort to increase faith in the application of energy-conscious and passive solar building products and evaluation techniques used to provide practical thermal properties of the products. The PASSYS (Passive Solar Components and Systems Testing) project focused on test cell equipment as a means of determining the performance of passive solar building components and providing additional information on building design and simulation tools. The advantage of test cells is that they provide a well-controlled, realistic room (cell) environment without occupancy [1]. The PASSYS test cell consists of a well-insulated construction $8 \times 2.7 \times 2.7$ m with two rooms. One room measuring $5 \times 2.7 \times 2.7$ m is a south-facing test cell and an adjacent north-facing area is a service room that contains an air conditioning unit. It is possible to test various building elements on the south facade of the test room. For this purpose, manuals for instruments, operations, calibrations and test procedures have been developed. The cells are able to test vertical and horizontal building elements. The PASSYS test cells are located in European countries: Belgium, Denmark, France, Germany, Italy, the Netherlands, Scotland, Greece, Portugal and Spain [2].

Similar test cells in the rest of Europe are Vliet test building at KU Leuven University in Belgium [3, 4], Test Box at Technische Hochschule Rosenheim in Germany [5], Minibat Test Cell in Lyon, France [6], FACT in CEA-INES, Le Bourget du Lac in France [7], ZEB Test Cell Laboratory in Trondheim, Norway [8, 9] and The Cube in Aalborg, Denmark [10–12]. The Vliet test building research facility is one of the Full-scale test cells. The research is solved at the component level and focuses on the combined transfer of heat, air and moisture through walls, roofs and floor systems and their impact on sustainability. The methodology includes modelling, accelerated aging tests, hot-box measurements and "in situ" studies [3, 4]. The Test Box was provided to the Technical University of Rosenheim, Germany, from the facade construction company Josef Gartner, for which it acquired all the rights to research, development and training. In addition to evaluating comfort and energy efficiency, they also evaluate the effect of shading, angle of blinds to obtain the most daylight with the least possible glare. Therefore, the test cell is rotatable about a vertical axis. Thus, it can be adapted to the requirements of the respective test program. Of particular interest are comparative studies on energy efficiency, comfort and visual comfort in real conditions [5]. The MINIBAT Test Cell in Lyon, France, consists of two adjacent cells connected by a door located in a compensating container. One side of the first cell opens into a climatic chamber that models the outdoor climate. The walls and interior rooms are equipped with many sensors and both cells can be ventilated, heated, cooled, etc. The aim of this test device is to gain information about heat and air transfers within one room of a building, between two rooms and between a cell and the outdoor climate simulated by a weather generator. The device allows to collect detailed data for validation of numerical models. Typical studies include air distribution (indoor air quality, analysis of airflow from inlet openings and their mixing with indoor air), heating, cooling (energy efficiency, humidity and heat comfort for different ventilation systems and heating / cooling elements) and facade systems (facade elements, double skin facades, phase change materials, etc.) [6]. FACT (FACade Tool) is a test facility at CEA-INES, Le Bourget du Lac, in south-eastern France. It is an experimental facility consisting of a two-storey building with 10 rooms for testing the perimeter cladding of buildings with different widths and heights of facades, with different geometries of the internal environment. The size of the test cells can be modified so that measurements can be performed in one room or in open space [7]. The ZEB Test Cell Laboratory in Trondheim, Norway, is used to test low-energy integrated building systems with real operating conditions. The test cell can be divided into two smaller chambers, in which different technologies can be used to compare results. In the laboratory, various elements of building materials, building envelopes, energy installations and control systems are jointly developed and optimized in real climate conditions [8, 9]. The University of Aalborg uses a test cell, namely The Cube, which is one of the Full-scale test facilities, for research double skin facades. It is a test cell situated in a compensation space with one side facing south, into which the test sample is inserted. The cell is designed to be able to adapt to operating modes, natural or mechanical flow conditions, various shading techniques and similar. The thermal conditions in the cell can be perfectly controlled, as well as in the room next to it. The test facility is equipped to allow the measurement of any power supplied to the experimental zone in order to maintain the required temperature conditions [10–12].

There are currently several testing facilities at Slovak and Czech universities in Košice [13], Žilina [14], Brno [15–17] and Prague [18]. The laboratories in Košice include 3 outdoor experimental cells, which are designed for monitoring, research of physical properties and characteristics of facade structures – thermal-technical and humidity problems in real conditions of use of buildings and real outdoor climatic conditions [13]. Pavilion research has been built in the UNIZA Research Centre in Žilina, the main part of which consists of two differently oriented (east and south) experimental walls. Stable indoor environment parameters are ensured in the test cells. Temperature and relative humidity sensors are located in the experimental walls. In the middle of the test cells there are sensors for measuring temperature and humidity. Outdoor climate conditions are obtained from a meteorological station located on the roof of the building [14]. In the research centre Centrum AdMaS (Advanced Materials, Structures and Techniques) in Brno, four small test cells were built in 2014 to research the thermal stability of buildings. The exterior walls of the cells have different material bases (brick, aerated concrete and wooden construction). Sensors are placed in the cells to measure surface temperature, air temperature, to quantify the amount of solar radiation in the planes on the surface of the glazing. The outdoor climate is recorded by their meteorological station's prototype. The research centre also includes a mobile experimental full-scale test set of solar-activated facades and their concepts [15–17]. The University Centre for Energy Efficient Buildings UCEEB at the Czech Technical University in Prague has a climate facade with a controlled indoor environment and 6 monitored fields with samples exposed to the weather [18]. However, it must be stated that none of the above-described test facilities in the territory of Slovakia and the Czech Republic makes it possible to accurately quantify the energy flows of the examined sample.

3. "Twin rooms" construction

The "Twin Rooms" test cells are used to determine the thermal properties (U-value, thermal resistance, surface temperatures, temperature fields) and energy flows through advanced facade elements in the range of outdoor climatic conditions. The technological equipment for the "Twin Rooms" must ensure controllable, stable, homogeneous and reproducible indoor temperature conditions in the two measuring cells and in the compensation room. This will make it possible to perform measurements of heat balances, total and local heat flows as well as surface temperatures simultaneously on two tested structures installed in measuring openings under the influence of non-stationary outdoor climatic conditions.

The experimental test cells consist of an office-type mobile container with external dimensions of $6058 \times 2990 \times 4200$ mm, which is placed on pre-built concrete foundations. The supporting structure of the container itself consists of a space frame welded from steel hollow rolled profiles. The envelope consists of lightweight sandwich panels, with an external galvanized shaped sheet, a filling high-efficiency thermal insulation based on mineral wool and an internal lining made of chipboard. The entrance to the container is situated on the rear longer side of the container (6058×4200 mm) and is made by a door opening with dimensions of 1000×2000 mm with galvanized doors with infill thermal insulation – Figure 1.

The south-facing front side of the 6058×4200 mm container has two holes cut out with 2400×3400 mm, within which the test element of the building envelope will be fitted. Directly behind the openings, a dividing structure of a light wooden partition creates two rooms (twin rooms) with dimensions of $2400 \times 2000 \times 3400$ mm thermally insulated from the interior space of the container – Figure 1.

4. "Twin rooms" technology

The technology of the test cells "Twin Rooms" consists of several parts, which form one functional unit. Using environmental technology, the same constant indoor climate θ_{ai} [°C] will be maintained in both cells and the compensating space of the container, which will ensure zero heat flow through the dividing structures separating the two cells from the inner space

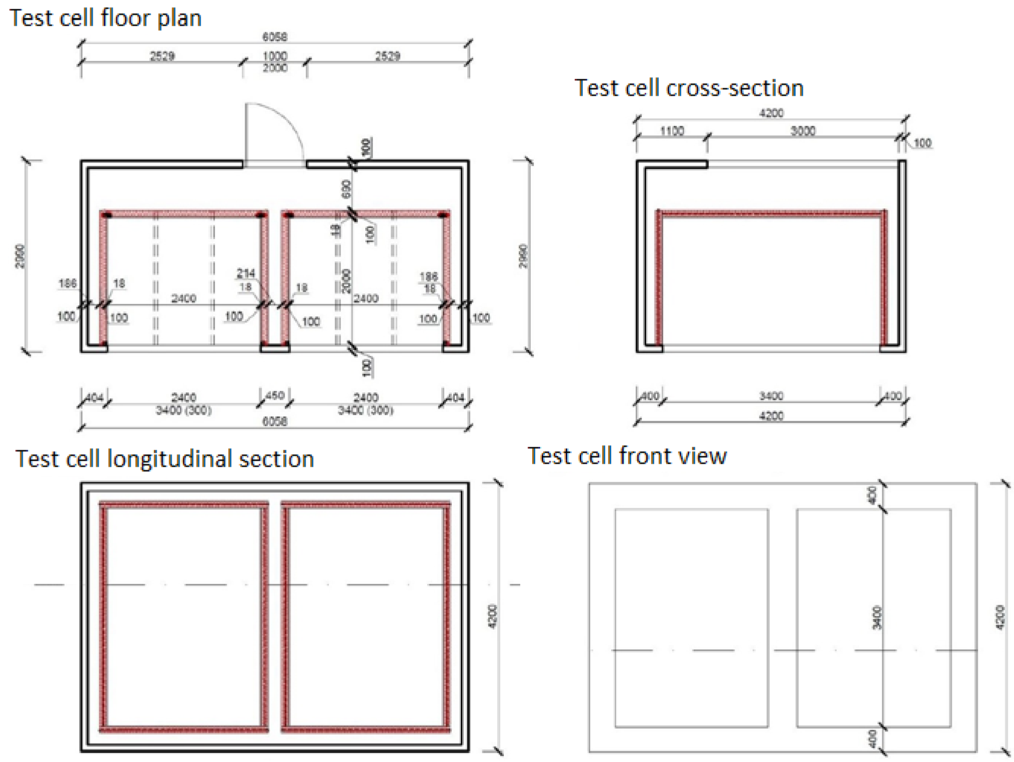

Figure 1. Construction schemes of an experimental test cells Twin Rooms for testing advanced facade elements in real conditions of outdoor climate.

of the container. By ensuring this, all energy flows will be only through the tested facade elements of the building envelopes fitted in the measuring openings of the container. In order to maintain a constant temperature θ_{ai} [°C] in the two measuring cells, we must supply energy (heat or cold) to those cells. The amount of this supplied energy is identical to the energy that was released by the measured facade element. We can measure the energy delivered to individual cells (rooms) and thus we can also measure the energy that was released by through the facade element. In this way we can measure all energy flows through facade elements in conditions of dynamically changing outdoor climate over time.

The technological equipment for air conditioning of the compensation room (container) consists of an outdoor air conditioning unit exterior air – room air for the room "container" with a volume of about 25 m^3 with an output of about 3 kW and a heating element with an output of 2 kW – Figure 2. This ensures a stable temperature in the compensation room to prevent the exchange of thermal energy between the measuring cells and the compensation room. At the same time, it is necessary to ensure even air circulation through the circulating fans in the compensation room, in order to avoid local temperature inhomogeneities of the air surrounding the measuring cells.

Technological equipment for air conditioning of testing cells (rooms) 1 and 2 consists of air conditioning unit (identical as for container) air exterior – water exchanger for space of cells 1 and 2 with a volume of about 15 m^3 with an output of 6 kW and a heater with an output of 2 kW – Figure 2. This ensures a stable and homogeneous temperature in the cells. In this case, it is necessary to continuously measure the power supplied to the air-conditioned space of cell, so on the air-conditioned side there is a water exchanger measuring water flow and its inlet and outlet temperature as well as an electricity meter to measure the electrical power of the heater and circulating fans.

To evaluate the total heat fluxes by the measured structures, it is necessary to measure parallel in "cell 1" and in "cell 2":

- the amount of energy supplied or taken by the heat exchanger (inlet and outlet water temperature – media flowing through the exchanger, the volume of water flowed through the exchanger),
- the amount of electrical energy supplied by the radiator and circulating fans.

Guaranteed parameters for container space:

- cooling circuit power 3 kW,
- heat circuit power 2 kW,
- adjustable temperature range:
  - ▷ for summer period + 19 °C to + 40 °C, homogeneity in space and time ± 1.5 °C,
  - ▷ for winter period + 10 °C to + 25 °C, homogeneity in space and time ± 1.5 °C,
- air velocity range: 0.10 m/s to 1.50 m/s.

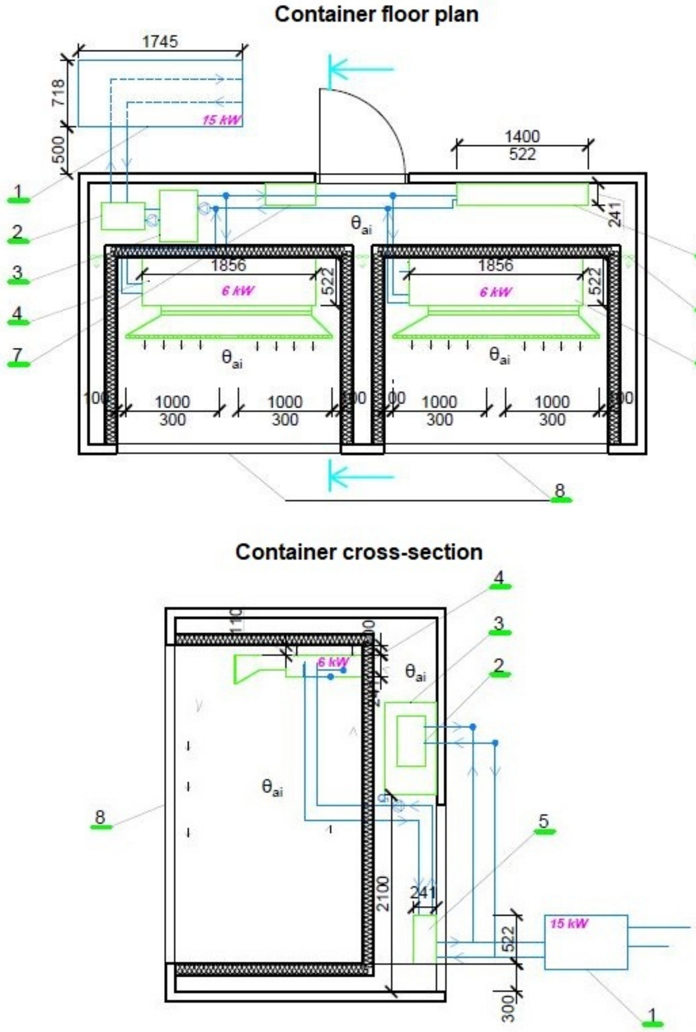

FIGURE 2. Construction scheme of technological equipment of an experimental test cells Twin Rooms. 1 – Cooling source, $Q_c = 16.4\,\mathrm{kW}$, MEX EA 117 Z C, 2 – Plate heat exchanger – part of the supply of the cooling source, 3 – Water tank – storage tank Galmet 140 l, 4 – Pipe fancoil NXKT3-V1000, 5 – Sill fancoil NXKH3-V600, 6 – Circulating fans – homogeneous thermal field, 7 – Electrical switchgear, 8 – Opening for mounting a new facade sample.

Guaranteed parameters for cell space 1 and cell space 2:

- cooling circuit power 6 kW,
- heat circuit power 2 kW,
- adjustable temperature range:
  - ▹ for summer period + 19 °C to + 40 °C, homogeneity in the space in front of the measured sample ± 1.5 °C (at the output of the cold and heat circuit up to 2.0 kW),
  - ▹ for winter period + 10 °C to + 25 °C, homogeneity in the space in front of the measured sample ± 1.5 °C (at the output of the cold and heat circuit up to 2.0 kW),
- air velocity range: 0.10 m/s to 1.00 m/s.

All sensed physical quantities will be continuously recorded and evaluated by the local control unit. The system enables remote access in real time to all sensed and evaluated quantities as well as remote control of the entire control and regulation system.

5. "Twin rooms" measuring equipment

In order to be able to evaluate the total heat balance of the measured structures under the influence of non-stationary outdoor climatic conditions, it is necessary to measure these conditions with the help of a meteorological station. The weather station will be located on the roof of the container with measuring cells. The temperature and humidity of the outside air, the speed and direction of the wind, the intensity of sunlight on the vertical and horizontal planes and the amount of precipitation will be measured continuously.

To evaluate the local thermal parameters of the measured structures, it is necessary to measure:

- local heat fluxes using heat plates,
- surface temperatures on the outside and inside of the structure by Pt100 sensors,
- flow velocities along the measured structures,
- air pressure differences on the outside and inside of

the structure,

- intensity of solar radiation on the vertical surface of the perimeter wall.

All the above-mentioned physical quantities are continuously measured and stored by means of a measuring control panel. At the same time, they are archived by means of a PC and are remotely accessible at any place via the Internet.

6. Initial measurements on the new experimental test cells Twin Rooms

After the successful delivery of technology to the new Twin Rooms test cells for research of advanced facade elements in real climate conditions (October 2021) and after its successful test operation, we plan to start experimental verification of a prototype of a new modular double skin transparent facade with a narrow slot cavity with a usage of multi-stage renewable energy of solar radiation, which was developed within the scientific projects APVV-16-0126 and VEGA 1/0113/19 in cooperation with Ingsteel s.r.o. Bratislava. The resulting design of the double facade is characterized by:

- progressive construction of the completed spatial part – an element mounted from the exterior to the elements of the supporting system of the building, characterized by fast assembly technology and the removal of seasonality,
- high thermal-technical quantification without thermal bridges of frame profiles based on aluminium and anchoring systems and high acoustic quantification of the facade,
- application of the design solution of a double skin transparent facade with a narrow slot cavity and the height of the section identical to the height of one floor, which significantly eliminates the load from solar radiation in summer and at the same time reduces heat losses during the heating period – winter,
- application of the ventilation heat recovery unit in the parapet part of the element, which in winter uses preheated air from the physical cavity of the double skin facade with a positive impact on a significant reduction of heat losses of the building from ventilation,
- application of photovoltaics for direct conversion of solar radiation into electrical energy in the parapet part of the outer transparent wall of the double skin facade for direct use in the building,
- application of an automated control system of individual structural elements of the element (closing of inlet and outlet openings, movement of shading devices, control of heat recovery unit, etc.) based on measuring outdoor climate parameters and indoor climate requirements.

The resulting energy flows of the new double skin transparent facade will be compared with the classic simple transparent facade of similar physical quantification as the inner wall of the double facade, also with the application of the same ventilation heat recovery unit and photovoltaics in its parapet part. We will test both samples of facades by long-term research in the experimental Twin Rooms test cells during the period of 1 year.

7. Conclusion

After the construction of the experimental test cells Twin Rooms for pavilion research of advanced facade elements in conditions of real outdoor climate, the facility will enable research in the field of modern facade technology of buildings using available renewable energy sources (especially solar radiation) with integrated passive and active systems and also implementation of development and optimization of structural creation of modern transparent facade structures for realization sphere.

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