Building of Research Centre as the experimental laboratory for civil engineering

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Abstract. The intelligent building of Research center was built during 2014 and 2015. Fragments of its envelope meet the requirements for passive buildings. This building is a part of the University of Zilina campus, located in Zilina, Slovakia. It consists of a high-rise part with five story and a low-rise part with laboratories. Several laboratories of departments are also in the high building. What makes the building unique are several things such as three different heating systems, use of renewable sources, soil heat accumulator, various photovoltaic panels on the roof, vacuum collectors etc. All these technologies can be compared to each other and their efficiency and suitability for different purposes can be evaluated. In this paper, a unique façade monitoring system with 36 façade meteorological stations is described. Each of these stations measures outdoor air temperature near the façade, solar radiation, wind velocity and direction in a short time interval. Recorded values can be used for a more precise simulation of energy consumption, natural air ventilation, HAM simulation, wind-driven rain calculation and also compared to other simulations.

1. Introduction

The University of Zilina has a new part since 2013, which is separated from all faculties. The idea was to create a separated workplace specialized for research and for trade of the results from research to the production only. So the story of Research Centre began. With support of the ITMS project no. 26220220183 “Research centre of the University of Zilina” funded from the Structural funds from the operational program Research and Development. The aim of the project was to create the background, which will enable the possibility to conduct state-of art research with the laboratories, equipment and material basis.

Several faculties and departments from the University: faculty of Civil Engineering, Mechanical Engineering, Electrical Engineering and faculty of Management Science & Informatics participated in the Research center project. These faculties and their departments helped with the early development stage (building design, floor plan and laboratories), technologies and the laboratory equipment.

The architectural and structural drawings were realized in cooperation with the Department of Building Engineering and Urban Planning. Ventilation, heating sources and air conditioning was designed by the other Departments. The construction was finished in November 2016 (Figure 1 and 2).

Aim of the project was not only to create the building for the staff and the laboratories, but was created the laboratory from the building itself. The indoor environment with its heating and air conditioning, technical and technological solutions, several heat sources, use of renewable energy
sources etc. were aimed to create the building, which use and maintenance will be research laboratory itself. With support of the operational programe also two buildings of University Science Park (USP) were built. These buildings are very similar with its shape with the difference in the aim of the buildings: USP building meets the ultra low energy standards and the Research centre (RC) building is an intelligent building in passive standard. Therefore another planned outcome is the direct comparison of energy performance and effectivness of the nearly zero energy building and ultra-low energy building based on the real energy consumption.

In this paper, the technological part of the building and the unique outdoor environment monitoring system which is mounted on the façade of the building is described.

![Figure 1. Western view at the building of Research centre.](image1)

![Figure 2. South-east view at the building.](image2)

2. Building structures design

The building (Figure 1 and 2) has five story, one basement floor and the building can be divided into two parts, the high one (main) with office and light laboratories, and the lower one with heavy laboratories including the climate chamber.

Simplified dimensions of the main building are 22.53 x 26.11 m with its height of 18.86 above the terrain. Ground level is 395.45 a.s.l.

As passive standard requires, the building envelope with all fragments need to meet the requirements of the Slovak standard [1]. The values for individual fragments are stated in the Table 1 with comparison of the Standard values and the calculated values for the building of RC and USP (low energy).

|                      | Wall | Roof | Ground floor | Floor over the basement | Window |
|----------------------|------|------|--------------|-------------------------|--------|
| STN 73 0540:2012    | 0.22 | 0.15 | R > 2.5      | 0.85 – 0.30              | 1.00   |
| valid since 1.1.2016 |      |      |              |                         |        |
| ultra-low energy    |      |      |              |                         |        |
| STN 73 0540:2012    | 0.15 | 0.10 | R > 2.5      | 0.6 – 0.15               | 0.60   |
| valid from 1.1.2021 |      |      |              |                         |        |
| nearly zero energy  |      |      |              |                         |        |
| University Science Park | 0.16 | 0.1  | 0.20         | 0.66                    | 0.88   |
| Research centre     | 0.14 | 0.1  | 0.20         | 0.30                    | 0.88   |
Load bearing construction system is made of reinforced steel concrete. Walls are masonry from the aerated concrete bricks with th. 380 mm. These walls are insulated either with ETICS or with the aerated façade cladding. In both cases, the insulation layer is based on the mineral wool with th. 200 mm.

Roof is flat, non-walkable, covered with mPVC waterproof membrane. It is insulated with the mineral wool with total thickness of 420 mm. On the roof is made separate walkable platform from the metal mesh grating used for the maintenance of the multiple used different devices (Figure 3).

Windows are made of the 6-chambered plastic frames with a triple glazing. All windows are equipped with exterior shading blinds, which are operated automatically and with the building management system are supposed to maintain the set up indoor environment. Nonetheless, they can be operated manually in every office.

The mullion walls, which cover the staircases, lobby near the elevator are made from the aluminum and have triple glazing as well. The staircase glazing has lowered solar gains to avoid overheating of the space because of the southern orientation [3]. Entrance door are automated, with a thermal glazing and with air the layer to avoid thermal losses.

3. Heating, ventilation and air conditioning

Most areas of the building are equipped by the floor heating and ceiling cooling. The system of the floor heating could provide during the summer also the cooling. Combination with blinds are very effective.

Cool demand is satisfied with the two heat pump and one gas heat pump (Figure 5, 6). Primary source of cool are the wells. There are 11 wells with the average deep 150 metres. The wells are connected to the buildings distributions network in the basement machine room (Figure 4).

The cooling ceilings are located mainly in the office spaces, which have transparent opening in the envelope and are heated by the direct solar radiation. The ceilings are realized as the suspended grid ceilings combined of active (cooling parts) and common gypsum board (Figure 7, 8).

The floor heating has temperature difference 45/35 °C and the heat source is condensing gas boiler, two electricity and one gas heat pumps. Also solar system is utilized. The heating distribution network could be divided to six roots according to the actual situation or purpose.

Hot water in the storage water heater is mainly heated with the solar system, which consists of 27 vacuum tube solar collectors located on the roof (Figure 3). These collectors are managed by the solar station with regulation.

The machine room also consist of various system for automated and intelligence system for building management such as fire protection system, electricity distribution, lightning system and other energy sources such as photovoltaic panels on the roof (Figure 3) and the wells outside of the building, which are used by the heat pumps.

Another computer management system is intended to monitor the room occupancy to avoid energy losses of any kind (lighting, heating, cooling, etc.). For example, if the room is empty the lights will be
automatically turned off. The governing mechanism of this is due lack of the space not incorporated in this article.

**Figure 5.** Machine room with the two heat pumps [4].

**Figure 6.** Gas heat pump located outside of the building [4].

**Figure 7.** Office with the combination of active and non-active parts of the ceilings.

**Figure 8.** Floor corridor before suspended ceiling was made. Visible cooling pipes from the divider [4].

4. Heat demand and thermal evaluation of the building

As mentioned above (Table 1), all building envelope fragments have lower $U$ value as was required in the time of the building designing. Therefore also the heat demand is lower than required for this type of building. The calculated heat demand with monthly method based on the STN EN ISO 13 790 [5] (valid during the designing phase) for RC and USP are summarised in the Table 2. The calculated area is only the main building without the heavy laboratories.

The total floor area is 1244.3 m$^2$, building volume gross 4656.7 m$^3$, shape factor 0.41 1/m. For this shape factor according to the STN 73 0540:2012, the energy need for heating has to be lower than 28.9 kWh/(m$^2$.a) (since 2016) and 14.5 kWh/(m$^2$.a) (from 2021).

In the calculation was taken into account that the intelligence building of research centre will have lower heat gains from the lights and equipment caused by the better utilizing of sources and use of devices with lower power consumption, which also means lower waste heat [3].

There was elaborated also a basic simulation in EnergyPlus during the designing phase of building, which results were for the specific energy need for heating 13.5 (with closing the windows blinds if the solar radiation will be higher than 100 W/m$^2$) or 12.5 (closed blinds if solar radiation $> 200$ W/m$^2$).
Table 2. Calculated energy need for heating according to the STN EN 13 790 [5].

| Building   | Average thermal transmittance coefficient [W/(m².K)] | Heat loss coefficient [W/K] | Ventilation heat loss coefficient [W/K] | Solar gains [kWh] | Utilization factor for the gains | Specific energy need for heating [kWh/(m².a)] |
|------------|----------------------------------------------------------|-----------------------------|----------------------------------------|-------------------|---------------------------------|-----------------------------------------------|
| USP Ultra-low | 0.34 | 1266 | 614 | 40919 | 0.66 - 0.97 | 39.3                          |
| RC Nearly zero | 0.33 | 920 | 146 | 40919 | 0.5 - 1.0 | 13.2                          |

5. General description of conducted research activities within the building

The building itself with its monitoring system enables the possibility to conduct research based on the power or energy consumption of many types, of use of energy sources (heat pump, wells, solar, photovoltaic, etc.). It can also analyse better the behaviours of the users = researches. Results of selected areas belongings to the HVAC, electricity or other science areas will be published. In this paper, the unique façade monitoring system is described.

6. Façade meteorological stations

Façade monitoring system consists of façade meteorological stations (FAMS). This system consists of 36 small devices, which are constantly monitoring the outdoor climate around the building and the influence of the building can be examined.

First FAMS (Figure 9) was fixed on the façade in August 2016. Since the end of November 2016, all 36 stations are working with some minor malfunctions and sensors change during the test period. The FAMS itself consists of metal frame, which is fixed on the façade bellow window and is powered by a cable. On the frame, the sensors measuring temperature, relative air humidity and atmospheric pressure, are fixed. The next one is the pyrgeometer for measuring of the long-wave solar radiation, pyranometer for monitoring of the global solar radiation and an ultrasonic anemometer for wind velocity and wind direction measurement. The anemometer is offset from façade 270 mm on short arm to monitor the air flow. During the autumn 2017 were on each façade changed one anemometer to the 3D ultrasonic, to monitor better the airflow.

The data collection is wireless. Each façade has its own access point located on the roof. Measured data, with a one-minute write interval, are collected and stored on a remote server. The location scheme of the stations is shown in Figure 10. There are three FAMS placed on the south façade, fourth façade, 15 on the east and 15 on the west.

Figure 9. Detailed look at façade meteorological station, equipped with following measuring sensors: air temperature, relative humidity, barometric pressure, long and short wave radiation, wind velocity and wind direction. Several FAMS are equipped with 3D anemometer, this one is with 2D.
Figure 10. Scheme of the building with marked numbered façade meteorological stations (FAMS).

7. Results and Discussion
A hot sunny day (21 June) was selected to analyse summer period. Measured results are divided into the climate parameters: air temperature, global solar radiation (short wave) (Figure 11) and long wave (Figure 12) on the vertical surface. Later there is more detailed comparison on the west façade between the solar radiation, temperature and the shape of the building which blocked direct radiation on the part of façade during specific time period (Figure 13). Times stated in the graphs and in the text are in UTC, which means - 2 hours to the local summer time.

The measured air temperatures near the façade in Figure 11 are influenced by the direct solar radiation on the façade near to the FAMS position and are logically following the sun movement on the sky. During the night the temperatures are a bit lower than the air temperature measured by the weather station located on the roof of nearby building [6]. This is caused by the night sky radiation during the cloudless nights, which is cooling the surfaces. In the morning, there is for the short time direct solar radiation on the north façade (the façade is not perfectly aligned to the north). Also the east façade are receiving the solar radiation. This caused very fast heating of the façade and the air around this façade from the starting temperature 12.6 °C.

As the sun moves, the north façade came to the shade and the temperature dropped down, returning to the outdoor air temperature before 9:00 AM, which was 25.2 °C. Maximum temperature on the north façade was 29.7 °C at 7:15 AM. East façade has maximum temperature 37.7 °C at 9:35 (11:35 local time). At that time the most sunshine became the south façade which has the longest sunshine duration. The highest temperature was as expected measured in front of the west façade, exactly 39.1 °C with air temperature on the open ground 28.1 °C. After the sunset the temperature slowly returned to the air temperature. The global solar radiation graph in upper part of Figure 11 showed the south side amount lower than the east and west and as much as twice lower than the measured values by the weather station on the horizontal plane. This is caused by the vertical mounting position of the pyranometers, where the inclination of the solar beams on the surface of pyranometers is crucial. During the winter time period, the courses are opposite - radiation on the horizontal plane is lower than on the vertical plane.
Figure 11. Courses for the 21 June 2017, global solar radiation and the air temperature.

In Figure 12 are shown daily courses for long wave radiation measured by the pyrgeometers, one value for each side. Unfortunately, during that day the pyrgeometer on the weather station did not work so the comparison was not possible. The courses are also following the sun movement on the sky, firstly the north and east FAMS’ temperatures rises, later the south and lastly the west one, which had also the highest amount. Specially, the pyrgeometers should be influenced by the reflectance of the ground, the analysis of FAMS with different heights could be interesting.

The shape of the façade has small overhang on the right side (visible in Figure 10), which caused that the third row (from left) of FAMS are shaded as the sun moves from the south. This is represented as the jump (Figure 14 - FAMS no. 24) when the FAMS is no longer in the shade. Also the temperature rises quickly after that and in this specific case became the highest (Figure 13).
8. Conclusion
In this paper was briefly summarized the idea and the realization of the Research centre building, which serve as the basis for the research conducted not only in the laboratories but in-situ, in the building with the researches in it. More articles about the indoor environment and results of use of renewable energy sources will be published by the other departments.
In this paper was described not only the building but also the façade monitoring system. System was described and summer day courses were analysed.
Future plan is to use the results in natural ventilation simulation (different outdoor air temperature around the façade through the day), impact on the energy consumption, analysis of the air flow around the building etc.

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