

Indoor air in autonomous building

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Abstract. The paper describes the use of renewable energy sources in an autonomous home in the aspect of sustainable development. The work contains an analysis of the results of the quality parameters of the internal microclimate (carbon dioxide concentration and relative humidity), mycological cleanliness of the enclosed spaces in the study was taken into account, the immediate proximity of the pond as a biological treatment plant, which is also an integral part of the ecosystem with a closed cycle of organic matter and influences independence energy of the tested object. Parameters of the microclimate were taken from the BMS (Building Management System) installed in the facility, while mycological purity tests were carried out using the sedimentation and collision method. Based on the conducted analyses, conclusions have been drawn that can be used in the design of autonomous objects.

1 Introduction

At the end of the 1990s, the idea of sustainable development was created, including in its range a system of ecological building certification, such as BREEAM, American LEED and German DGNB. The autonomous building construction system maximizes the ratings in each of these classification systems. Due to the fact that the main impact of buildings on the external environment is their energy demand during their use, this was reflected in the European Parliament and Council Directive 2012/27 / EU of 25 October 2012 on energy efficiency, changing Directive 2009/125 / EC and 2010/30 / EU and repeals Directives 2004/8 / EC and 2006/32 / EC, which indicates that buildings in EU countries after 2020 should have zero demand for energy. Therefore, the Autonomous Home is an object integrated with the garden as an ecosystem with a closed cycle of organic matter circulation and energy independence. The construction technology of autonomous building also has a social matter because autonomy is the basis for sustainable development and functioning in harmony with the natural environment [9]. In the psychological point of view it is to ensure physical and economic safety by eliminating the threat of energy systems failures and minimizing the level of operating costs [8,10–12].

The basic functions of an autonomous building are: its functioning independently from external infrastructure, neutral impact on the environment due to the used building

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materials and construction technologies. The location of such facilities is dictated by climatic conditions and field factors.

All building assumptions in autonomous building technology have been met during design and construction in the case of Autonomous House in Podzamcze near Chęciny, especially in the field of building construction, exterior walls, roof and gable walls, central heating installations, hot water, wastewater treatment and ventilation.

The indoor air quality problem in buildings took a great importance with increasing the users' awareness of premises and changes in construction technology. As it is well known, people spend about 80–90% of their time in closed spaces. This fact was the reason that moved the burden of interests on the indoor air quality, till now sick building syndrome (SBS) was mainly associated with dust and chemical contaminations, biological allergens presence in the air and incorrect thermo-humid parameters in rooms. There were diseases associated with buildings defined (BRI - Building Related Illness), the most common are carbon monoxide poisoning and asthma, pneumonia, bronchitis, legionnaires disease, and cancer (caused for example by mycotoxins). Biological factors mainly spores of fungi affect the indoor air quality [7,14–15].

In connection with its intended use, the autonomous building provides residents with an adequate microclimate all year round, resulting from the perceived thermal comfort and optimal ventilation due to the constant supply of fresh air[1,10–11,16–17].

2 Materials and methods

The project included testing of indoor air quality in the premises of an aerodynamic facility constructed in 2014 in Podzamcze Chęcińskie near Kielce. Testing was conducted in the summer, for a period of three months.

2.1 Research facility

It is a single-family building with an attic, with a usable area of 142 m² occupied by a family of four (2 + 2). The building was constructed on a single reinforced concrete foundation slab made of waterproof concrete W8, thermally insulated from the deep reservoir. Horizontal and vertical thermal insulation of the foundation slab – 'styrodur' thickness from 20.0÷35.0 cm. The external walls were made of large size prefabricated polygon reinforced concrete elements. The maximum width of the prefabricated element is 2.4 m. The structural wall elements, 15 cm thick, have been insulated with 'styrofoam' 25 cm thick, which allowed obtaining a partition thermal resistance of the $RT \leq 10 \text{ m}^2\text{K/W}$. The external walls were covered with silicate plaster. The longitudinal walls of the attic were made in the technology of polystyrene stay-in-place formwork. The gable walls and the roof were constructed in frame technology with a heat transfer coefficient $U \leq 0,1 \text{ W}/(\text{m}^2\text{K})$. The internal walls were made in the G-K slab construction technology on a metal skeleton filled with mineral wool with improved acoustic properties. The ceiling over the ground floor is a suspended beam and block floor in the JS system covered with gypsum plaster on the underside. The main slab of the building was covered with a pitched roof. Hybrid PVT cells were installed on the southern side of the roof. The northern side of the roof was planted with extensive vegetation. The roof structure was made of wooden elements. The roof insulation is made of mineral wool with a thickness of 30 cm. The building has wooden windows and balcony doors ($a \leq 0,3$). Technical installations installed in the tested facility include: Central heating and hot water installations (home heating is provided by a fireplace with a closed system, ground heat storage tank, solar installation). A wind turbine with a vertical rotation axis of nominal electric power 2 kW and a height of 10 m from ground level. The building was equipped with mechanical

supply-exhaust ventilation with recuperation with a set of maximum air stream of 330 m³/h. It is responsible for the quality of indoor air as an important health parameter in an autonomous home. Mechanical ventilation has been designed as a constant and variable flow system, where fresh air is supplied to the recuperation unit in which its filtration takes place. Heat recovery from the air removed from the rooms takes place on the cross-flow heat exchanger. The control panel cooperates with an active summer throttle, which allows for directing the exhaust air from the rooms directly to the launcher, bypassing the heat exchanger, with the exhaust fan turned off. An active summer throttle allows the achievement of energy savings in the summer.

An important element indicating the creation of a comprehensive ecosystem is the integration of the house, garden and pond as well as the individual reed sewage treatment plant. A dual sewage system was used; gray sewage coming from the washing machine, shower and washbasins is used to flush the toilets. Gray sewage is collected by gravity in a 0.2m³ tank located near the entrance to the garage. Black waste water discharged from the toilets, bidets, bathtub, sink and dishwasher are gravitationally discharged into the septic tank of the household wastewater treatment plant. The sedimentation tank is the first and basic element of a household sewage treatment plant. In the septic tank there is a 60% reduction of impurities. At the next stage, the wastewater is directed to biological wastewater treatment equipment with the pumping system and a pipe system usage. In these devices wastewater flows through a filling layer of a material on which a biological membrane consisting of microorganisms using impurities contained in wastewater as nutrients develops. In the layer of this deposit there are aerated zones and oxygen deficient zones, where various types of microorganisms that break down organic pollutants can develop. Finally, sewage is treated on the filter bed by sand filters which work on physico-chemical and biological treatment of wastewater. They are followed by significant removal of the slime, organic matter but also nitrogen and phosphorus compounds. In this case, they provide effective wastewater treatment. The treated sewage is discharged into an open reservoir in the form of a pond with aquatic vegetation.



Fig. 1. Photographs of an autonomous home (author Robert Piekoszewski).

Due to the presence of a biological wastewater treatment plant, research and analysis of indoor air quality in an autonomous facility was undertaken.

2.2 Research methodology

The study of basic microclimate parameters (temperature (T) [°C], relative humidity (WWP) [%], the carbon dioxide concentration (CO₂) [ppm]) was conducted for a one year period, using the measure of indoor air quality. Instruments used: indoor air quality parameters were tested using the *Indoor Air Quality Monitor PS32* with a CO₂ concentration sensor, using the attenuation dependence of a specifically defined infrared radiation band according to the carbon dioxide concentration. The applied measurement

method guarantees long-term stability and good dynamics of measurements. The device uses two-beam sensors in a voltage system. A compact semiconductor sensor, typical for ventilation and air-conditioning applications, was used to measure temperature and relative humidity. Parallel to that, mycological studies were carried out defining mold species composition and the number of units that can form colonies CFU/m³. The molds spores have been taken from the air of living premises by collision method (flow of 500 l/min and the collision speed of particles on a substrate surface was 20 m/sec). Results of counted colonies are presented according to the Feller's table of statistical revisions. The samples were incubated in microbiological incubators at 26°C for 7 days, pure (axenic) cultures were isolated from the original mixed cultures by passaging on the Soubouard's substrate. In further bred molds strains identification phase they were subjected to identification tests to assess their taxonomic affiliation, based on macroscopic and microscopic observation as well as on morphological and physiological features [2–6,13].

3 Results and discussion

The studies of the premises' indoor air quality of the autonomous facility included the microclimate parameters, the work presents a summary of CO₂ concentration (Fig. 2) as well as a summary of relative air humidity measurements (Fig. 3).

Table 1 presents the average results of the examined parameters of the internal microclimate from the research period. The attachment contains full data recorded and presented in tabular form.

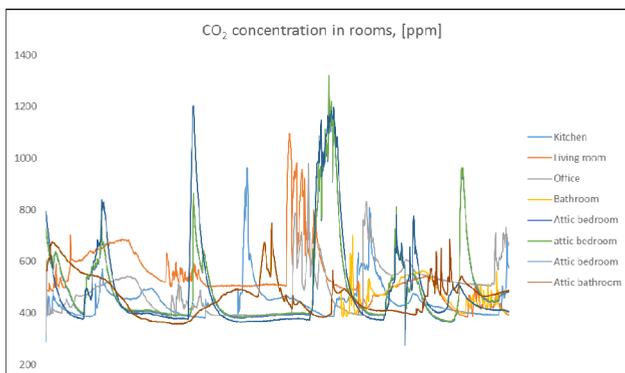


Fig. 2. Summary list for measurements of carbon dioxide concentration in individual rooms.

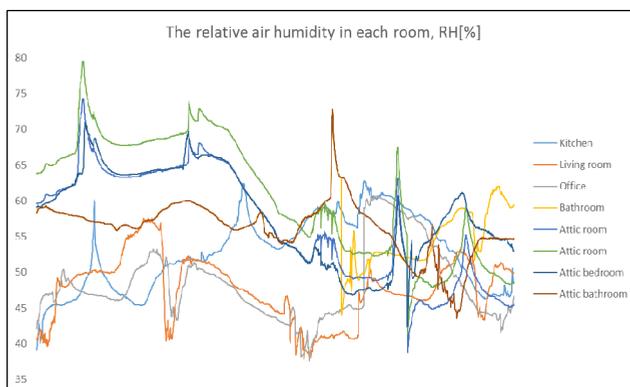


Fig. 3. Summary list of air relative humidity measurements in individual rooms.

Table 1. Average values of microclimate parameters.

Rooms	Average temperatures [°C]	Average humidity [%]	The average concentration of CO ₂ [ppm]	Average atmospheric pressure [hPa]
Kitchen	20.71	52.78	447.24	988.63
Living room	27.26	46.97	517.82	982.86
Office	24.47	53.17	574.46	974.59
Bathroom	24.95	55.54	460.59	994.70
Attic, bedroom	20.54	56.24	475.06	986.92
Attic, bedroom	22.0	60	508	1007
Attic, bedroom	22.15	56.17	490.50	991.08
Attic, bathroom	24.75	56.08	466.46	995.12

Table 2. The qualitative composition of microorganisms present on building partition in the tested facility.

Rooms	Molds	The remaining microflora
Garage	<i>Penicillium spp.</i> <i>Rhizopus spp.</i> <i>Aspergillus spp.</i> <i>Mucor spp.</i> <i>Geotrichum spp.</i>	yeast-like fungi
Office	<i>Penicillium spp.</i> <i>Scopulariopsis brevicaulis</i> <i>Geotrichum spp.</i> <i>Aspergillus spp.</i> <i>Mucor spp.</i>	Actinomycetes yeast-like fungi
Staircase	<i>Penicillium spp.</i> <i>Aspergillus spp.</i> <i>Mucor spp.</i> <i>Trichoderma spp.</i>	yeast-like fungi Actinomycetes
Living room	<i>Penicillium spp.</i> <i>Aspergillus spp.</i> <i>Mucor spp.</i>	yeast-like fungi
Kitchen	<i>Penicillium spp.</i> <i>Aspergillus spp.</i> <i>Geotrichum spp.</i>	yeast-like fungi
Bathroom	<i>Penicillium spp.</i> <i>Aspergillus spp.</i>	yeast-like fungi
Attic, bedroom	<i>Penicillium spp.</i> <i>Aspergillus spp.</i> <i>Mucor spp.</i>	yeast-like fungi
Attic, bedroom	<i>Penicillium spp.</i> <i>Aspergillus spp.</i> <i>Mucor spp.</i> <i>Geotrichum spp.</i>	yeast-like fungi
Attic, bedroom	<i>Penicillium spp.</i> <i>Mucor spp.</i> <i>Geotrichum spp.</i>	yeast-like fungi Actinomycetes
Attic, bathroom	<i>Penicillium spp.</i> <i>Mucor spp.</i>	yeast-like fungi Actinomycetes

Photographic sets showing cultivated mold fungi and remaining micro flora isolated from the surface of building partitions using the imprint method.



Fig. 4. Photographs of mold fungi isolated from building envelope adjacent to a biological wastewater treatment plant (author Dorota Koruba).

Analysis of microclimate parameters during the research period in the building in residential areas, i.e. in the area in which users can stay in continuously and in which it is necessary to maintain a certain comfort, has shown that CO₂ concentration does not show deviations from WHO and ASHRAE recommendations (they recommend up to 1000 ppm in enclosed premises, in which people are staying).

According to the PN-EN 15251 standard, the internal air quality classification criterion may be the concentration of carbon dioxide in rooms. Based on the tests, we can initially determine the category of rooms: IDA 3, (Outside air with a high concentration of particulate contaminants and gases (greater than 1.5 - times the WHO standards)) this is only a preliminary assessment, due to short-term tests of gas concentration in the air, as well as disturbed microclimate conditions, the presence of a large number of people (13÷15) in rooms during analyzed period. It should be remembered that mechanical ventilation has been designed for rooms in which 2 adults and two children are staying. In connection with the above, it can be assumed that the category of rooms can be much higher than the predefined, while maintaining the intended use of the rooms in accordance with the design. In connection with the above, mycological research was carried out throughout the facility, paying special attention to the rooms which are in very close contact with the biological wastewater treatment plant (table 2, fig.4).

After the tests and analysis of the results, it was found that the presence of mold fungi as well as the remaining examined microflora is caused by the close presence of the biological stage and septic tank that serves as a sewage treatment plant.

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