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THE CONCEPT OF THE SOLAR ECO HOUSE

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Abstract

Buildings as a shelter are the necessary condition for humans' existence, but the use of resources for construction and buildings' operation becomes a serious environmental problem. Buildings consume ~40% of the European primary energy for their operation; lots of energy is used for production of construction materials. Awareness of the environmental problems created conditions for the development of the concepts of the green house's, passive building's, zero energy buildings', zero carbon buildings' and others, and also for political decisions, such us Directive 2010/31/Eu on the energy performance of buildings enactment. The usage of the solar architecture principles is one of the tools in order to reduce energy needs for buildings and save resources. *Ecococon* concept was developed with the purpose to minimize embodied and operational energy of the house. Made from straw bale panels, designed using solar architecture principles, *ecococons* are healthy and warm surrounding for living, recreation or other purposes. This paper presents the concept and temperature monitoring of the experimental *ecococon* built near Kaunas (Lithuania).

1. Introduction

From ancient there were lots of various concepts for houses: starting from *Vastu Shastra* (Hindu science of construction) and continuing with Chinese *Feng Shui* art, going through various architectural stiles and expression forms and coming to confusing, but also challenging times of these days, requiring switch in thinking and decisions making principles.

The ancient view according the house's functions for an owner – to help staying in harmony with himself, nature and society – changed dramatically to domination: in lots of cases a house become fortress, part of image or other expressions of human ego, over consuming resources – both: overall society's and personal (financial, health, time). Whereas the number of people increased significantly and the Earth resources remained the same, wasting and consuming philosophy's implementation in construction sector became unsafe due to exhaustion of resources and negative impacts to environment. As for Woollard and Ostry: "Somewhere along the road to our present crisis we lost the idea of *enough*" (Woollard and Ostry, 2000). Roodman and Lenssen calculated that one-sixth of the world's freshwater withdrawals, one-quarter of its wood harvest, and two-fifths of its material and energy flow is used for buildings (Roodman and Lenssen, 1995). Construction sector affect environment also because of wastes and emissions, which significantly influence global climate, and locally – indoor environment, making it unhealthy for occupants in third of cases of newly built buildings (EQAR, 2010, ECTP, 2004). And, as revealed in the research study "Climate Change, the Indoor Environment, and Health", poor indoor environmental quality, that result from gas stoves or indoor emission sources, such as building materials, radon, etc., creates health problems and weakens the ability of occupants to work and learn (Institute of Medicine, 2011). This study also mentions, that it is not recommended to increase health risks prioritizing energy efficiency measures (for example, lowering ventilation rates).

Inner factors of every person remain very important for the "greening of a house" process. "Perceptual and behavioral barriers (for example, lack of understanding) affect cognition of circumstances related to sustainability and interfere with action-taking" (Woollard and Ostry, 2000).

Looking back to oil crisis of 20th century and noticing nature destruction – the shortage, the "lack of", became one of the factors, which accelerated awakening process. Construction sector, as one of the important parts of the human activity, got paid attention; and the harmony with nature, resources saving, ethics and health concerns returned to a house concepts (see *Gaja House*, the *Natural House* concept (Pearson, 1995), *Sustainable Building*, *Green Building* (Public Technology Inc., 1996); and *Low Energy Buildings*, *Passive Buildings* – as cases which highlight energy efficiency (Steinmüller, 2008).

Understanding of current crisis created the space for *Energy Efficient* or even *Independent House* ideas, which proved themselves as livable after volunteer experiments in ecovillages, alone examples or demonstration ones.

Earthships could be one of example of such conception realization. Arch. M. Reynolds proposed the idea, that a house should be self-contained, a power plant and a battery, and a green house providing owners with food. The materials to build a house should be easily found, like in earlier times − rock, earth, reeds, etc. "Now there are mountains of by-products of our civilization that are already made and delivered to all areas. These are the natural products of the twenty-first century" (Reynolds, 1990). The needs of owners are adapted to reality of the planet; *Earthships* are made from renewable and local materials, they use little or no fossil fuels to provide for modern amenities, and they come with no utility bills, because all what is needed is produced on site, using already available technologies.

Another example of *Energy-Independent House* could be *S-House* built in Böheimkirchen, Austria which serves as an office and demonstration building at the Center for Appropriate Technology (Wimmer at al, 2005). *S-House* represents combination of the high energy standard of passive solar house technology (less than 15 kWh m^{-2} a) with the use of renewable local resources for construction materials (straw bales, timber) and energy for operation (solar energy and biomass). *S-House* meets also the *Factor 10* concept (Schmidt-Bleek, 1999) – the material, energy and construction area consumption is reduced 10 times comparing with conventional buildings (Wimmer at al, 2005).

Now the similar idea is being realized with political will: from 2019 newly constructed buildings should be nearly zero energy buildings (buildings that have a very high energy performance: the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby) in the EU; and the USA Department of Energy Buildings Technologies Program set a goal to reach net zero energy buildings by 2025 (European Parliament 2010; Pratsch 2006).

Solar architecture principles application is one of a very important measure in construction sector. They are known from ancient times, highlighted in *Gaja*, *Natural*, *Green House*, *Earthship, Sustainable Building*, *Green Building*, *Low Energy Building*, *Passive Building* and other conceptions, and seem as will be necessary implementing requirements for nearly zero energy buildings, but these principles still are not widely understandable for the society.

Modern solar architecture counts its history from 1940s when pioneering solar houses were built in Chicago, USA (42-43°N); and after it was continued with famous Trombe-Michel experiment in France and following experiments in lower latitudes (Porteous and MacGregor, 2005). Porteous and MacGregor with their work seek to fill the gap in lack of information on solar energy applications for places in northern (high) latitudes and cool climates. Hypothesis '*North is better*' was raised and proved with numerous examples from different northern and southern countries. As there was shown by Porteous and MacGregor, the fact, that northern latitudes have grater solar contribution is connected with grater, longer and flatter profile for heating demand in the places of high latitudes. There was revealed differences in solar contribution: in Lerwick (Shetland Isles, 60°N) location solar contribution was 4 times greater than in Messina (Sicily, 38°N) and 60% grater than in London (51°N).

Notwithstanding the tests and experiments, already accomplished in various places around the globe, direct use of solar energy should be made more visible and clear for the society, especially in those cool climate countries, which has no practice of passive solar energy applications for buildings.

The **main goal of this research** was to test eco solar house concept in real conditions of a cool climate.

2. The Concept

The concept of the solar eco house, named *ecococon*, was developed in order to meet environmental (embodied, operational energy reduction and resources saving, care about indoor environment quality) and financial (affordable price of a building, reduced heating costs) efficiency.

These tasks were met searching for optimal combinations of the quantitative and qualitative parameters; special attention was given to the form of the building and materials, which should serve well for energy saving purpose and healthy microclimate.

The house was designed of the form, which provides good insolation possibilities and reduces building's north facade (see Fig. 1–4), at the same time also ensuring proper thermal insulation and using natural building materials (pressed straw and local clay for plaster, which works as a thermal mass inside the building).

Fig. 1: The *ecococon's* form

Fig. 2: 2 story *ecococons'* village

Fig. 3: The *s*outh facade in summer at noon

Fig.4: The south facade in winter at noon. A. Krucius designs made with Google SketchUp software

There were some motives for choosing straw and clay for the construction of *ecococons*:

1. both are local and natural building materials, so they provide a house with a safe indoor microclimate and significantly reduce environmental impact of construction, as indicated in previous research, such materials' use instead of bricks and mineral wool could save 90 kg CO_2 for 1 m^2 of a wall or 1287 MJ m^{-2} of embodied energy (Milutiene, 2010);
2. suitability for solar architecture: pressed straw has good thermo insulating properties (some review on properties and construction methods see in (Jones, 2005, Minke and Mahlke, 2005, Milutiene at al, 2008, Milutiene at al, 2007) and for the construction purposes it should be used together with a natural plaster (mainly made from clayey earth), which than serves as a thermo mass (instead of concrete and other non sustainable materials) besides other important functions;
3. these materials are accessible in big quantities and they are cheap;
4. wide possibilities for creativity and novel construction methods: in the case of *ecococons*, weaknesses of straw bale construction – dependence on harvest time, obligatory protection of straw from the rain, risk do not find clayey earth on a building site – were bypassed inventing original method to prefabricate pressed straw panels and producing several kinds of original clay plasters (dry mixes) using upgraded folk recipes and modern practices.

Several designs of a building were prepared for the implementation in practice. Designs are provided with the possibility to choose the size (36, 80 or 120 m^2); and for smaller houses to be extended during their operation (one story 36 m^2 building could be extended till 80 m^2 or 120 m^2 size, 80 – till 120 m^2 from the glazed side of the house). The idea of such function of a building was to create possibility for the house to "grow" depending on the increase of a number of family members, avoiding very radical changes and much demolition works.

3. The Experiment

The object of this research was *ecococon*, built near Kaunas, Lithuania in 2009. The building's (see Fig. 5, 6) parameters are shown in the Table No. 1.

Fig. 5: The view of the built house. Photo by JSK *Ecococon*

Fig. 6: Interior of the house. Photo by JSK *Ecococon*

The main tasks of this research were to monitor inside temperature of the building and assess influence of global solar radiation and outside temperature to house's thermal behavior in order to make decisions for further improvements of the concept and design.

Tab. 1: Parameters of the tested *ecococon*

Parameter	Value/remarks
South glazing	1.5 m^2
South west glazing (30º from south)	8 m^2
West glazing (60º west from south)	1.5 m^2
Coordinates of the building	55º00'N 23º49'E
Building's area	36 m^2 of living area and 6 m^2 – cubbyhole from the north side
Building's volume	100 m^3
Thermal resistance of walls and roof (according thermo vision picture)	8.6 m^2 K W^{-1}
Thermal resistance of windows	1.1 m^2 K W^{-1}
Glazing/ floor area	~1/3
Thermal mass	10 cm thick clay plaster – walls and ceiling painted white or left in clay color; oak floors and furniture

The period of the research covers 2010 02 17 – 2010 03 14. During this period the building was not occupied, but was visited several times. The days when people were inside the building were not used for analysis.

Measurements of interior temperature (intervals – 5 min.) were performed using thermometer KIMO Kistock KT-100 S/No. 07126031.

Outside temperature and global solar radiation and also diffuse solar radiation on horizontal surface data were collected at the Lithuanian Hydrometeorological station in Kaunas.

Global solar radiation reaching horizontal surface was measured with the help of the pyranometer CM6B No. 994125, and it was situated 85.1 m above see level. Diffuse solar radiation reaching horizontal surface was measured with the help of the pyranometer CM6B No. 994112 at the same height. Average hourly values were used for calculations.

In order to understand dependencies of the house interior temperature with outside temperature and global solar radiation, also determine time lag of heat waves which are connected with outdoor factors affecting the building, correlation coefficients between interior and outside temperatures and global solar radiation were determined. Correlation coefficient values coming to +1 or -1 show increasing or decreasing linear relationship, values about 0 shows, that variables are independent.

4. The Results

The *ecococon* is the first solar building in Lithuania, which is being monitored.

Monitoring results showed that solar radiation provided the house with the significant amount of the heat and during the monitoring period the building did not froze.

In winter time, at February, during cloudy days with the weather temperature -5°C, when all the solar energy was diffuse, it (solar energy) was enough to keep positive interior temperature values (1–5°C). The interior temperature increased only by 2–5°C (see Fig. 7). The effect of solar heating became stronger in sunny days, when global solar radiation exceeded the value of 250 Wm^{-2}. When global solar radiation reached 400 Wm^{-2}, its influence was significant – interior temperature increased by 16°C – from 7 to 23°C (see Fig. 7, data of February 22nd).

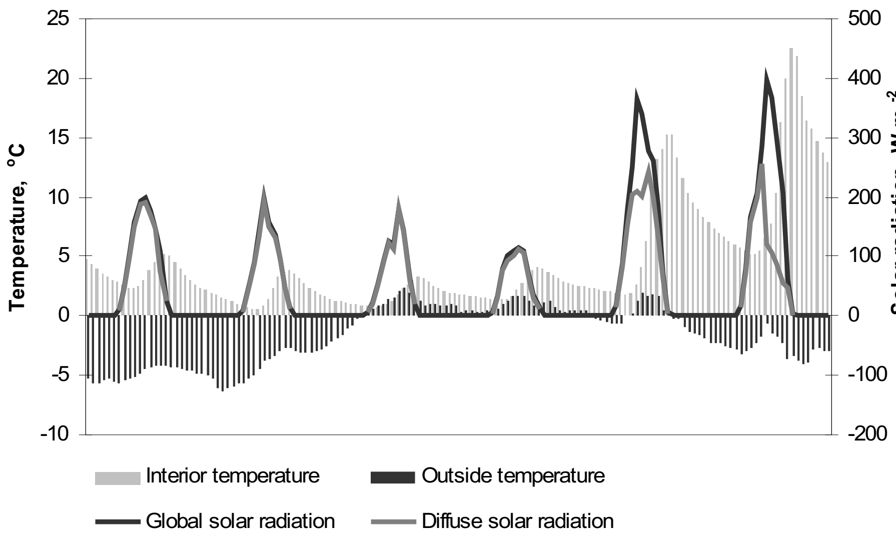

Fig. 7: Dependence of building's interior temperature on solar radiation on horizontal plane and outside temperature on 17th–20th of February, 2010.

In spring, in cloudy days of March, the interior temperatures rose till 10–15°C, and during clear days till 22–31°C, so in some days comfort temperature maximum was surpassed for several hours in the evening time (see Fig. 8). That was because of no overhang installed (according to the project, there should be sun blinds used depending on the need to protect rooms from the extra heat).

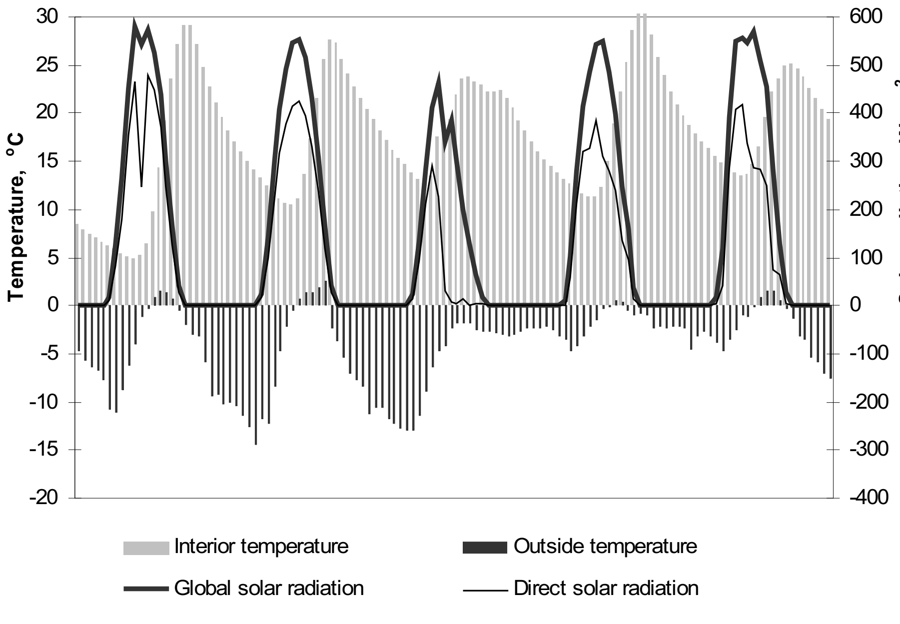

Fig. 8: Dependence of building's interior temperature on solar radiation on horizontal plane and outside temperature on 10th–14th of March, 2010.

It was revealed linear connection (dependence) of the interior temperature and the outside temperature (from days, when global solar radiation exceeded 250 W m^{-2}), and also to global solar radiation on horizontal plane (see Table 2).

Tab. 2: Correlation coefficients between interior temperature and the weather temperature also global solar radiation on horizontal surface.

Correlation between interior and the weather temperatures	Correlation between interior temperature and global solar radiation on horizontal surface	Time lag
February		
-0.18	-0.07	-
-0.01	0.80	-; 5 hours
March		
0.25	-0.46	-
0.66	0.84	4 and 7 hours respectively

Several conditions were important for mentioned correlations: weather temperatures correlation with global solar radiation (after it exceeded 250 W m^{-2}), switch of the main glazing of the house from the south direction by 30° to the west, thermo accumulation mass of a building, solar altitude and azimuth changes.

5. Conclusions

The building of the *ecococon* from the originally constructed pressed straw panels showed several possibilities how to improve prefabricated constructions and use resources more efficiently and also to reduce building's price.

Temperature monitoring of the built house showed, that clay plaster and other interior materials (oak flooring and furniture, etc.) provided the house with accumulation capabilities: daily time lag of the heat waves was 5–7 hours, and time lag increased depending on solar radiation increase.

There was noticed increase of the interior temperature in 10–16°C in sunny days of February and in 18–20°C in sunny days of March. During cloudy weather, when all the solar radiation was diffuse, the impact to interior temperature was less – increase of 2–5°C in February and March.

It was noticed that due to increase of global solar radiation (from 250 W m^{-2}), outside temperature starts correlate with it with the time lag 4 hours and this makes additional impact to interior temperatures, while in the winter time in sunny days weather temperature could drop significantly (till -15°C or less).

During the monitoring period, the building was not fit out with sun blinds, so there were several days when interior temperature exceeded comfort temperature maximum (27°C).

The minimum comfort temperature (18°C) was kept during night time only on several sunny days in March. Interior temperatures dropped till 10–13°C in the morning times (because of time lag) during nights with the temperatures -15, -13°C in sunny periods, and till 1–5°C during cloudy periods with weather temperatures around -5°C.

Monitoring results showed that solar energy gains made significant impact to interior temperatures, but it is important to look for possibilities to improve the building in order not to loose the heat during night times. It was decided to accomplish wind resistance test and to fix sun blinds and to prolong monitoring and research further.

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