The environmental benefits of the architectural optimization of a building

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The article presents the pro-ecological consequences of the architectural optimization of the building. The author has conducted an environmental analysis taking into consideration accumulated energy and accumulated CO2 emissions of five single-family buildings, whose architectural forms were slightly different. The buildings under analysis were: a reference, simple building without any additional elements and a buildings with sunscreens (canopies, roller blinds and overhang of the building). The environmental impacts of various solutions were compared.

Keywords: sustainable development, life cycle assessment, architectural optimization

Background

The existence of buildings involves large energy costs and, as a consequence, adverse influence on the natural environment [1],[2]. The energy is used mostly during the exploitation phase of a building (heating, domestic hot water, electric household devices). But energy is also necessary to produce building materials, as well as during transportation and the process of construction, repair-works, conservation and, eventually, the demolition of a building [2],[3].

In the case of buildings with lower energy demand for heating (for instance: passive buildings) the share of embodied energy can be more than 60% of energy demand in 50 years of use of the building [4]. Therefore, designing such a building should place strong emphasis on its optimization in terms of LCA (Life Cycle Assessment), on early stages of the designing process. LCA is a technique to assess the potential environmental impacts associated with a product life through the life cycle (from cradle to grave analysis) [5],[6].

Significant importance for designing of low energy buildings and user comfort are external shading devices. This article describes the various cases buildings with different types of sunscreen.

Material and methods

The buildings under analysis are single-family buildings meeting the standard of a low-energy building. The demand for usable energy for heating is from 30.37 kWh/m²a to 38.90 kWh/m²a. Two buildings subjected to comparison were: a reference building of a simple shape – without sun protection – and a buildings with sun-protection in the form of canopies and external roller blinds.

All versions of the building have the same characteristics listed below.

It is a detached house for a family of four. It is a two storey building with a flat roof, it has no cellar. The building has a simple form on a rectangular plan (10.66 m x 7.61 m) (Figure 1, Figure 2):

Net usable floor area is 126.8 m² and heated volume (net) is 319.13 m³. The form factor A/V (area/volume) [7] of the building is 0.87. The building is located in Warsaw, on a plot without trees, exposed to the south on the garden side. The south elevation has large balcony windows with a total area of 40.5 m². The windows have the parameters required by the regulations in Poland – Uw = 1.3 [W/m²K] or better [8]. The windows are equipped with double glazing with coefficient of TST 70% (Total Solar Energy Transmittance – coefficient g) and Ug=1,2 [W/m²K]. The walls were constructed out of calcium-silicate bricks, insulated with mineral wool. Foundation slab was used as substructure. The building is heated by means of a condensing gas boiler. The energy source – natural gas. The building has an high efficiency recovery unit ventilation. It is assumed that the minimum temperature in the building can be 20 degrees Celsius, the maximum 25 degrees Celsius. Above
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this temperature, the air will be cooled by the air conditioner powered electrically.

The analysis covers 20 years life cycle of the building. It takes into account the energy and CO₂ emissions as a result of manufacture of basic materials and building products and the generation of heating, supply of lighting, pumps and fans. The analysis uses the method of LCA. Because there are no adequate databases on the Polish market concerning built-in energy and accumulated CO₂ emissions for building materials, the author has created his own database. Because the process of producing building materials is very similar or nearly identical in other European countries, the author has used available information from the European market, changing the numbers for energy-mix to fit Polish conditions.

The database contains data from the following sources:
- European EPDs (European Product Declaration) from the IBU – Institut Bauen und Umwelt eV [9],
- Polish EPDs mainly from the ITB - Building Research Institute [10],
- ICE database (Inventory of Carbon & Energy V2.0) [11],
- base Oekobau.dat [12],
- base DGNB Navigator [13].

Models of buildings were made using ArchiCAD program. Energy simulations were made using the module EcoDesigner. EcoDesigner is used to simulate the energy and has the advantage that it is integrated with ArchiCAD and that it analyzes the sunlight on the 3D model. The software module used for the dynamic energy simulation complies with ANSI/ASHRAE Standard 140-2007 and the performance rating functionality complies with ASHRAE 90.1-2007 [14].

In these simulations, the actual shading of objects in front of the windows of the building is analyzed. Weather data loaded into the simulation program come from IMiGW (Institute of Meteorology and Water Management) [15]. In the next step the results of calculations (amount of building materials and the demand for energy during operation) were loaded to the application designed by the author [16]. The author has prepared a database of building materials and products. Each record has information about the country of origin, the density of the material and indicators of the embodied energy and emission apply only to phase A1-A3 (product stage) [17]. At this stage of the study construction processes or installations in the building have not been taken into consideration. The present study will use coefficient of cumulative energy [MJ] and GWP (Global Warming Potential) [kgCO₂ eq.].

The involvement of different building materials and processes has been calculated. Next, the total amount of accumulated energy and accumulated CO₂ emission was stated. Moreover, a simulation of energy use during the exploitation phase has been conducted. The same calculations have been carried out for all buildings – the reference building and the modified buildings. The results were compared with the conclusion that the architectural changes do have influence on the environmental impact of the building.

The author has examined the two types of shading elements that protect the building from overheating. The results of simulations and analysis were carried out for the following versions of building:
- v1 – Reference building without any sunscreen (Figure 3),
- v2 – Building with sun protection in the form of canopies in steel and reinforced concrete structure,
- v3a – Building with sun protection in the form of canopies in the wooden structure (in this case, the author used data on the carbon footprint from ICE database),
- v3b – Building with sun protection in the form of peaks in the wooden structure (in this case, the author used data on the carbon footprint by Oekobau.dat),
- v4 – Building with sun protection in the form of external roller blinds.

Building version v1 (Figure 3). The building is devoid of any sun protection. The need for cooling the building appears in the 20th week of the year (mid-May) and lasts continuously for 40 weeks (end of September). The energy demand for space heating (ESH) is 30.37 kWh/m²a, and the energy demand for space cooling (ESC) is 28.20 kWh/m²a.

Building version v2 (Figure 4). For the body of the building v1 added the most optimal canopies. They are

Figure 2. First floor plan.

Figure 3. Building version v1
The environmental benefits of the architectural optimization of a building designed in such a way to minimize sun exposure in the summer months and enable the achievement of the biggest gains in the heating season. Canopy (terrace) allows to exit from the rooms on the first floor. Canopies are designed in mixed construction - in steel and reinforced concrete structure. The energy demand for space heating \( \text{ESH} \) is 30.89 kWh/m²a, and the energy demand for space cooling \( \text{ESC} \) is 21.15 kWh/m²a.

Building version v3a/v3b (Figure 5). Building has the same canopies with spans as in version V2, a similar form, but the wooden structure. Structure are wooden poles with dimensions 140x140 mm and 140x225 mm wood beams. The energy demand for space heating \( \text{ESH} \) and cooling \( \text{ESC} \) is the same as the v2 – \( \text{ESH} = 30.89 \text{ kWh/m²a}, \text{ESC}=21.15 \text{ kWh/m²a} \). The difference between the v2 and v3 is only for the use of other canopy materials.

Building version v4 (Figure 6). This option looks the same as version v1, but every window has its own external roller blinds.

This version takes into account the installation of external blinds consist of slats that can be rolled up into the cartridge above the window. In this way you can adjust the amount of sunlight, and thus affect the reduction of solar gains. The study did not include automatic control, which can automatically close during night in the heating season - which could further improve the thermal performance of windows [18], [19]. Blinds was assumed aluminum profile, an environmental assessment was adopted on the basis of [20]. The energy demand for space heating \( \text{ESH} \) is 38.90 kWh/m²a, and the energy demand for space cooling \( \text{ESC} \) is 8.18 kWh/m²a.

Results

As a result of the simulation and calculation of the following results:

Conclusions

Architectural changes have little, but noticeable effect on the change in carbon dioxide emissions. Even a slight impact of architectural changes on environmental effect is valuable and in a large scale can alleviate the negative impact of buildings on the environment. Advantageous is the
use of protection systems in buildings – they are beneficial not only because of the increased comfort, but also because of the improvement of the energy performance of the building.

Not every solution is beneficial for the environment. Even in long-term use of the building structures based on steel and concrete have a negative environmental balance. In contrast, already under 20 years of use, the benefits of protection made of wood (regardless of the method of counting GWP) or external roller blinds (or jalousies) are showing tangible environmental benefits – in plus. However, the differences are small in the whole object – at the level of 1-2 Mg of CO2 and higher in the case of construction based on steel and concrete. Certainly greater improvement of the environmental effect can be achieved by using alternative building materials. With materials with less impact on the environment should be replaced by reused or recycled materials [22], sourced locally, low-tech materials such as adobe or straw-bale and the wooden structures [23]. Of course, the wood must be harvested in a sustainable way from controlled cultivation.

References


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