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ASPECTS AND IMPLEMENTATION OF LOW-ENERGY BUILDINGS DESIGN

Підвищення енергетичної ефективності та екологічної безпеки будівель вважають питанням першорядної важливості у всьому світі. З цієї причини енергоощадні технології все частіше реалізуються у всіх секторах. Наведено огляд інтегрованого процесу проектування будівлі, що має вирішальне значення для кращого інтегрування операцій, необхідних для проектування будівель з низьким рівнем енергоспоживання. Проектування енергоефективних будівель потребує поширення інформації про принципи проектування енергоефективних будівель, вибору матеріалів та монтажу, застосування автоматизації будівель, аналізу фізики та комфорту в приміщенні будівлі.

Показано важливість комплексного проектування енергоефективних будівель у світлі нових вимог, які мають виконувати архітектори й інженери, що спеціалізуються в цій галузі. Вона також представляє різницю в проектуванні енергоефективних будівель за різними технологіями, аналізуючи два однородинні будинки. В обох випадках попередня архітектурна концепція дає змогу розрахувати енергоефективність будівлі, поряд з докладним аналізом різних потреб в енергії, тепловому комфорті і перегріву. Цей результат на етапі концептуального проектування дає змогу використовувати економічніші матеріали і системи вентиляції та кондиціонування повітря, підтримувати визначену витрату енергії і конкретних потреб споживача.

Ключові слова: будівля з низьким енергоспоживанням, інтегрована конструкція, потреба в енергії, тепловий комфорт.

Energy saving is a high-priority for civil engineering in developed countries. The improvement of energy efficiency and environmental performance of buildings is considered a matter of high priority worldwide. For this reason, energy-efficient technologies are being increasingly implemented in all sectors. This article provides an overview of integrated building design process that is crucial in order to better integrate the activities required to accomplish the design of low-energy buildings. Design of energy efficient buildings is a process that requires a wide knowledge of the principles of energy efficient building design, material selection and installation, the application of building automation, analysis of the building physics and analysis of indoor comfort.

This article shows the importance of an integrated design of energy-efficient buildings in light of the new requirements that will need to be met by the architects and engineers specializing in this area. It also presents the difference in designing energy efficient buildings in different technologies, by performing various analysis on two examples of a single family house. In both cases preliminary architectural concept enables the calculation of the energy efficiency of the building, along with a detailed analysis of the different energy demands, thermal comfort and overheating. This results at the stage of conceptual design allow the use of more economical materials and HVAC systems solutions, maintaining established energy.

Key words: low-energy buildings, integrated design, energy demand, thermal comfort.

Introduction. The world economy is based on the natural resources, which are limited. The problem of depletion of non-renewable fuels and other natural resources has been recognized in the 70's, when the report of the General Secretary of the United Nations, entitled “Problems of the human environment” was first presented [1]. This report laid the groundwork for the numerous activities undertaken by the European countries, aimed at reducing the use of non-renewable resources and to replacing themwith renewable energy sources. All these efforts are consistent with the idea of Sustainable Development. This is especially important in the areas of economy responsible for the major indicators of energy consumption, such as transport and construction.

Construction sector plays a central role in world energy consumption with an estimated value of 40 %, and the significance of this costs stimulates the development of the Sustainable Building idea, which consists of implementing measures that reduce energy consumption of buildings, taking into account environmental aspects such as minimization of the pollution and an increasing use of energy from renewable sources.

Design and implementation of low energy buildings for the European countries is a new and difficult process, however, it is necessary. Lack of experience, formal regulations and the difficulty of designing energy efficient buildings are the main problems with the implementation of Suistainable Buildings idea in some European countries. New incoming national requirements for energy efficiency of buildings (eg. in Poland) create new challenges for designers. One of these challenges is the process of integrated design.

National and European trends in design and the formal requirements for the energy efficient buildings. The idea of Sustainable Development (Sustainable Buildings) is derived from the quotation in the introduction to a UN report, presented in 1969 [1]. This document for the first time modern history presented data about the destruction of the environment and its consequences, calling all countries to a rational use of the Earth's resources and taking effort to protect the ecosystem. The report, confirmed by statistics data, state for the first time in the history of humanity the range of the global crisis caused by the destruction of the environment.The report of the UN Secretary U Thant shocked the public opinion and led to the strengthening of environmental movement.

The construction sector, which accounts for 40 % of global energy consumption is an excellent example of the possibilities of implementing the principles of Sustainable Development in Construction, often called "Sustainable Buildings". Since the 70's,there were many international meetings, Earth Summits andSummits on Sustainable Development which determined the actions necessary to be taken in energy demanding sectors such as construction. During the Earth Summit in Rio de Janeiro, governments adopted one of the most important documents related to the reduction of energy consumption – Agenda 21. During the Earth Summit in Johannesburg in 2002, representatives of the Member States summed up the global changes that have taken place since 1992. Since that time, the energy consumption worldwide has increased significantly. It is estimated that by 2020 this demand will increase by 2 % annually. This analysis was the key to the identification of five most important areas related to energy efficiency.

During the Earth Summit in Rio de Janeiro in 2012, the State declared the need to ensure broad access to modern sources of energy, including renewables, as well as the efficient use of existing resources. The turning point in the quest to improve energy efficiency was the adoption of the Directive on the Energy Performance of Buildings 2002/91 / EC [2] and its revised version - Recast Directive 31/2010 / EC [3].

Both documents require from European countries (notably EU member states) a number of commitments, including the introduction of nearly zero-energy buildings idea. The “nearly zero-energy building” means a building with a very high energy performance. The nearly zero or very low amount of energy required, should be covered by the energy from renewable sources, including renewable energy produced on-site or nearby. As it is a long and difficult process to introduce the provisions of these directives into national legislation, however, firstly a lot of regulations and new standards have to be created in each country.

Under the terms of the Directive, each European country establishes its own level of minimum requirements for NZEB (nearly zero-energy buildings). The Directive requires Member Countries to implement the terms of NZEB [3]:

a) until 31 December 2020 . all new buildings are nearly zero-energy ; and

b) after 31 December 2018 . new buildings occupied by public authorities and owned by them are nearly zero energy.

Regulations introduced in 2013 in Poland, [4] [5] impose an obligation to build buildings that meet the strict requirements of thermal protection. These provisions have 3 step process of tightening parameters of buildings. In 2021, the requirements will define the Polish definition of NZEB. Thermal protection requirements for new buildings planned in Poland, are presented in Tables 1 and 2.

Requirement 1- value of primary energy EP index [kWh/(m2year)] should not be greater than:

Table 1

No.	Type of building	Partial maximum values of EP_{H+W} for heating, ventilation and DHW [kWh/(m^{2}rok)]		
		from 1.01.2014	from 1.01.2017	from 1.01.2020*
1	Residential building:			
	a) single-family	120	95	70
	b) multi-family	105	85	65
2	Collective residential building	95	85	75
3	Public building:			
	a) healthcare	390	290	190
	b) others	65	60	45
4	Industrial building	110	90	70
*) From 1.01.2019 – in case of buildings occupied by public authorities and owned by them				

Requirement 2 –partitions and the technical equipment of the building must comply with the requirements of thermal insulation specified by the U-value, at:

Table 2

Type of partition and temperature inside room	Heat transfer coefficient $U_{C(max)}$ [W/(m^2·K)]		
	from 1.01.2014	from 1.01.2017	from 1.01.2021
External walls:			
with $t_i \geq 16$ °C	0,25	0,23	0,20
Roofs and floors:			
with $t_i \geq 16$ °C	0,20	0,18	0,15
Floor on the ground:			
with $t_i \geq 16$ °C	0,30		
Windows:			
with $t_i \geq 16$ °C	1,3	1,1	0,9
Doors in external walls	1,7	1,5	1,3

Integrated design of low-energy buildings. Design of energy efficient buildings is a process that requires a wide knowledge of the principles of energy efficient building design, material selection and installation, the application of building automation, analysis of the building physics and analysis of indoor comfort.

The process of designing energy efficient buildings must be guided from the beginning by a cooperating team of skilled designers - sector specialists.

Integrated Design of low-energy buildings is different from the standard design, where the architect presents his idea to the investor, and then orders various separate projects such as HVAC, construction etc. (Fig. 1).

In integrated design all sector specialists from the beginning create a concept based on energy efficiency simulations, and need to work together on the right architectural design and construction (Fig. 2).

The first step in integrated design is agreeing with investor what level of energy efficiency is expected. Typically, the level of energy efficiency of the building is determined by investment opportunities. The definition of energy-efficient building is not parameterized. Under function name – “style” of building that define a standard of the building but not the specific value (for example, the amount of energy that the building will consume during the operation) such as energy-efficient buildings, low-energy, green, sustainable. Buildings that have defined parameters are passive buildings, nearly zero-energy or certified (eg. Certified LEED, BREAM, MCBE [6]).

After determining investor expectations, design team analyzes the location of the building, the environment and the climatic conditions (such as availability of local renewable energy sources) and other assumptions for the concept of the building. The architect then performs a preliminary conceptual design of the building.

The next step is a simulation of the energy demand that will optimize the assumptions, so that the building ensures energy efficiency and comfort for users.

Computer simulations should be carried out in the programs that allow optimization of costs, but also associated with the energy demand and thethermal comfort of the users (eg. Energy Plus, Design Builder, Eco Design).

At this stage, an expert performing simulations should be in constant contact with the sector specialists determining the best solutions, geometry, materials, construction and HVAC systems.

Computer simulations should provide the investor information with an insight how the optimization solutions affect the final cost of the investment.

Initial analysis and design documentation are key steps of the design project which fulfills the conditions of energy-efficient, low-energy or passive (Fig. 2) building, while providing optimum thermal comfort for users, and above all, is a conscious choice of the investor.

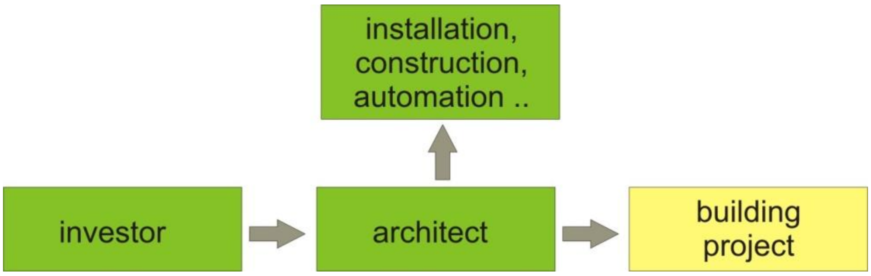

Fig. 1. Design process of traditional building

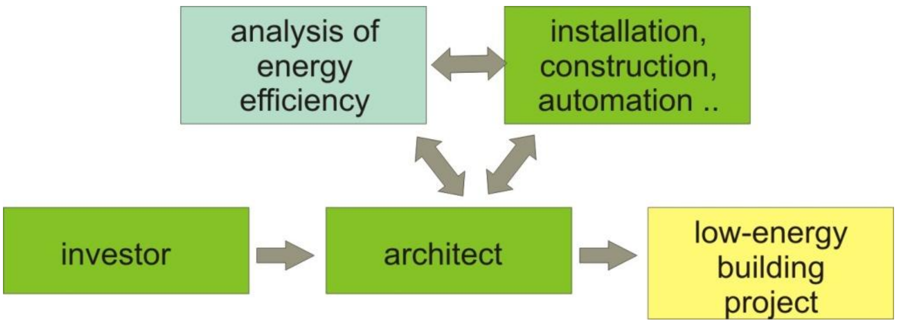

Fig. 2. Design process of low-energy building

Low-energy buildings integrated design examples. This part of the article will focus on integrated design of two different projects of low-energy houses. All architectural concepts were created in an innovative way, according to the principles of integrated design with cooperation of the representatives of all branches of design under the strict supervision of energy efficiency specialists.

Energy analysis of a single-family house in wooden technology

The idea behind the design of this building was to use natural, organic building materials such as wood, to build energy-efficient, single-family house. Expected primary energy consumption of the building is below 70 kWh / year. The building was designed as conventional wooden frame structure with 38 cm of mineral wool as a thermal insulation on the external walls. The heat transfer coefficient for external walls is 0.097 W/m^{2}K. In agreement with the HVAC system specialist, the most optimal solutionfor the heating system is a heat pump and for ventilation is a mechanical ventilation system with heat recovery.

Fig. 3. Architectural concept of the house

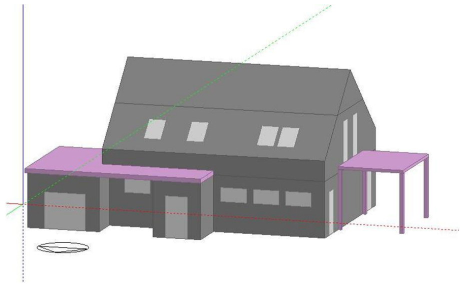

Fig. 4. Energy model in Design Builder

Preliminary architectural concept enabled the calculation of the energy efficiency of the building, along with a detailed analysis of the different energy demands for a variety of tasks in the building (Table 3) and simulation of heat loss through building partitions (Fig. 5). Analysis and simulations were performed in the Design Builder software.

Table 3

	Heating	DHW	Auxiliary energy (pumps, fans etc.)	Total
Usable energy kWh/(m^{2}year)	20,69	10,14	3,53	34,36
Final energy kWh/(m^{2}year)	22,99	11,16	3,53	37,68
Primary energy kWh/(m^{2}year)	25,29	12,28	10,62	48,19

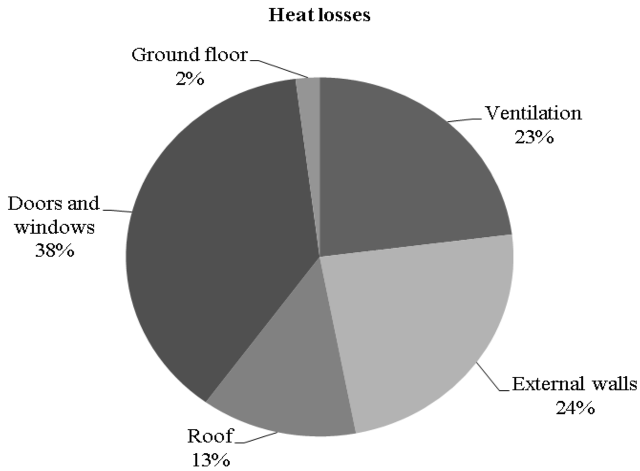

Fig. 5. Percentage of heat loss distribution in the building

The analysis of heat loss and energy consumption revealed that the house at the stage of architectural conception already meets the design assumptions. Due to much a lower consumption of primary energy than expected, re-analysis was conducted, taking into account the different types of energy to see if it is possible to use more economical solutions for house, keeping the design assumptions. Second anylysis focuses on the impact of reducing the thickness of the insulation on usable energy demand (Fig. 6), and changing a source of energy for heating, in order to check the consumption of primary energy by building (Fig. 7).

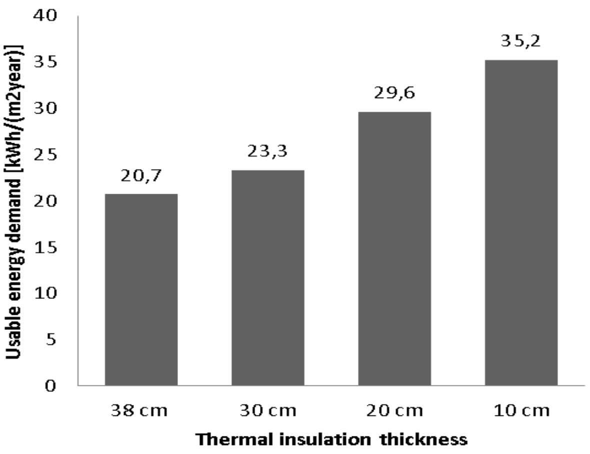

Fig. 6. Impact of the thickness of mineral wool on usable energy demand

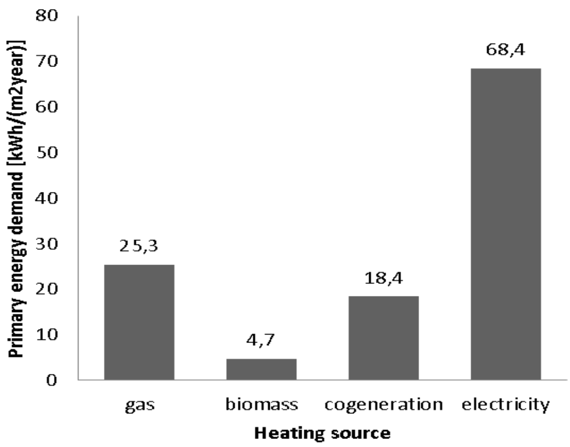

Fig. 7 Impact of the heating source on primary energy demand

The above analysis at the stage of conceptual design allowed the use of more economical material solutions and HVAC systems, while maintaining established energy consumption in the building. This conceptual design can be easily adapted to individual needs and financial capabilities of the investor.

Thermal comfort and overheating analysis of a single-family house in traditional technology

The structure made in traditional technology is simply a building made of bricks, usually with multilayer walls. It is the most popular and cheapest technology for small buildings.

Fig. 8. Architectural concept of the building

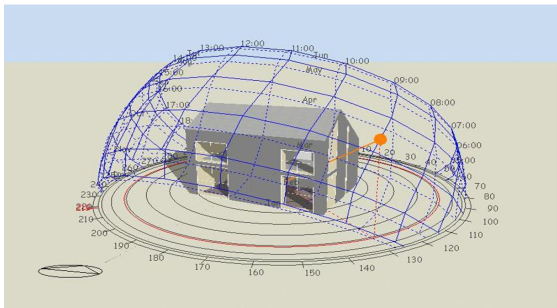

Fig. 9. Comfort and overheating model

In the analyzed house, similar to the one in wooden technology - design began from taking key decisions regarding the conceptual design – i.e., materials, technologies, size, HVAC systems and assumptions on energy demand. After the initial analysis of the energy consumption, similar to the first house example, thermal comfort and overheating analysis was performed.

Thermal comfort analysis is very important in energy-efficient buildings, characterized by high tightness, a thick layer of insulation and a large area of glazing. In the analyzed building the south side of facade is dominated by the glazing , which in winter allows for additional heating of the building, reducing heating costs. On the other hand, in the summer it can lead to overheating of the building, which generates additional costs associated with the air conditioning or ventilation. To check the thermal comfort within the house, the annual simulation of temperature, humidity and thermal comfort index PMV was performed in different rooms of the building in order to determine the degree of overheating and to recommend some possible changes. The most important results in this case are from the rooms exposed to the south, such as living room.

PMV (Predicted Mean Vote) - an indicator used in the description of indoors comfort. Describes the experience of thermal comfort, expressed in a 7-point scale of thermal sensations as: hot (+3), warm (+2), slightly warm (+1), neutral (0), slightly cool (-1), cold (- 2) very cold (-3). It is recommended (for comfort conditions) that PMV index is in the range: -0.5 <PMV <0.5 [7].

The analysis performed in the Design Builder software, shows that in the living room during the summer, the value of PMV reaches 1.91. To avoid the effect of overheating, a further analysis, this time with the use of internal and external blinds is required (Table 4).

Table 4

Thermal comfort monthly simulation on July for different case studies

	Without blinds	Internal blinds	External blinds
Temperature [C]	30,79	28,6	26,61
PMV	1,91	1,33	0,81

The analysis shows that the use of external blinds increased significantly the comfort of users in the living room during the summer, but this solution is problematic due to the blackout of windows and lack of sunlight, which increase energy costs by artificial lightning. In this case, it is highly recommended to look for other solutions to improve thermal comfort, through and increased ventilation airflow or the use of air condition.

Conclusion. The results of the performed analyses show the importance of an efficient colllaboration between various specialists focusing on differnet aspects of the design of an energy efficient building. The obtained results present an optimal approach to the optimization of the design process while keeping in line with the predefined goal of the design. By performing the energy efficiency analysis for the architectural design of the building we are able to modify the projects according to the specific preferences of the investor.

1. Janina Zbierska GENEZA IDEI I EDUKACJA NA RZECZ ZRÓWNOWAŻONEGO FRAGMENTA AGRONOMICA 2007 (XXIV) NR 4(96) ROZWOJU. 2. http://eur-lex.europa.eu/legal-content/ EN/TXT/?uri=CELEX %3A32002L0091. 3. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do? uri=OJ:L:2010:153:0013:0035:EN:PDF. 4. ROZPORZĄDZENIE MINISTRA INFRASTRUKTURY1) z dnia 12 kwietnia 2002 r. w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie. 5. OBWIESZCZENIE MINISTRA INFRASTRUKTURY I RO ZWOJU1) z dnia 17 lipca 2015 r. w sprawie ogłoszenia jednolitego tekstu rozporządzenia Ministra Infrastruktury w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie. 6. http://www.mcbe.pl/oferta-malopolski-certyfikat-budownictwa-energooszczednego.html 7. Fanger, P Ole (1970). Thermal Comfort: Analysis and applications in environmental engineering.