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ENERGY AND ENVIRONMENTAL PROFILE OF LOW-ENERGY HOUSE - CASE STUDY

Integrated building design should take into account environmental, social and economic dimensions of sustainability. Building design from energy performance ranges from architectural design to the application of technologies for energy conservation. Many applications are focused on insulation of facades, roofs and floors to those that are used systems for renewable energy sources. The aim of the innovations is not only energy saving but also reduces costs and preserves natural resources. One key element of low-energy building design is using the basic form and enclosure of a building to save energy while enhancing occupant comfort. Besides energy need for building operation the significant part of the total energy is energy used in the extraction, processing and transportation of materials used in buildings. This study is aimed to analyze the building materials and structures in terms of embodied environmental impacts and monitoring of physical factors of indoor environment. The paper deals with evaluation of environmental and energy indicators in selected low-energy family house and its optimization in order to reduction of environmental impacts.

Keywords: **building, low-energy house, embodied energy, emissions, environmental impacts**

INTRODUCTION

Building energy consumption can be reduced through the use of better design backed up by more stringent national and state energy standards and codes. Truly low-energy buildings are achievable by using passive energy strategies that take into account the orientation and mass of the building to maximize daylighting and minimize heat gain except when needed. Coupled with the best emerging technologies, significant reductions in building energy use can be realized [1]. In the study [2] a low-energy family house in Northern Italy is selected by Regione Piemonte as an outstanding example of resource efficient building. A detailed LCA of this house has highlighted that, when addressing energy-saving and sustainability performances of low-energy buildings, the role and significance of all life cycle phases and subsystems must be carefully considered. Moreover, the lower operation energy, the more important is the adoption of a life cycle approach. The study confirmed that in comparison to a standard house, while the winter heat requirement was reduced from 109 to 10 kWh/m^2 (10:1 ratio), the life cycle energy was only reduced by 2.1:1 and the carbon footprint by 2.2:1. According to study [3] the impact of the variation of building parameters on embodied energy varies from very small to negligible. The reasons for this are two-fold: embodied energy compared with operational energy is much smaller even when the life of a building of 30 years is considered (in reality, building life would be much longer), a large part of the embodied energy in buildings is in the substructures, frame, roof, floor, internal wall, external wall, etc. so that a variation in one component (e.g. insulation) does not have a significant impact on embodied energy. LCA approach based on the input-output hybrid analysis demonstrates that the embodied energy can be as significant as the operational energy over the lifespan of the building. On average, the embodied energy represented 77, 60 and 43% of the life cycle operational energy for the passive house, low-energy house and normal construction, respectively [4]. Correct evaluation should adopt to a life cycle perspective [5, 6] considering not only the impact of material production stage (raw material supply, transport, manufacturing of products and all upstream processes from cradle to gate), but also its contribution in the building construction process (transport to the building site and building installation/construction), use phase (energy losses, maintenance, repair and replacement, refurbishment), and finally end-of-life stage (recycling and disposal, including transport). Study [7] deals with values on embodied energy, energy needed for operation and the recycling potential of the most energy-efficient apartment housing in Sweden (45 kWh/m^2). The embodied energy accounted for a considerable part, 40% of the total energy use in low energy buildings during an assumed lifetime of 50 years. About 37÷42% of the embodied energy can be recovered through recycling. The recycling potential was about 15% of the total energy use during an assumed lifetime of 50 years.

1. METHODS OF INVESTIGATION

1.1. Method of energy analysis

Since December 2012 there are started test measurements of temperature in the sub-foundation of the vertical height of the foundation on the edge and center of the building. Concurrently, data of indoor parameters (temperature and humidity) are recorded. During the construction of the house there are installed temperature sensors Dallas DS1820 in the foundation (Fig. 1) [8]. This is a digital sensor (with an accuracy of ±0.5°C), which communicates via collector "1-wire". Each sensor has serial number that is recognized by the system. System of 1-wire has so far been applied mainly in automation control of some elements of the household [9]. Theoretically, 1-wire system is discussed in studies [10, 11].

Due to the limited deployment of sensors in structures defined by the investor of the house at own discretion (especially his interest about course of temperatures in the lower structure of building) the sensors were placed vertically along the perimeter of the base and the center of the house as shown in Figures 2 and 3.

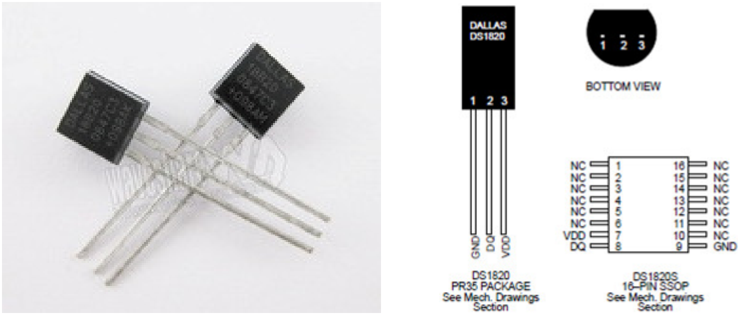

Fig. 1. Temperature sensors Dallas DS1820 [8, 9]

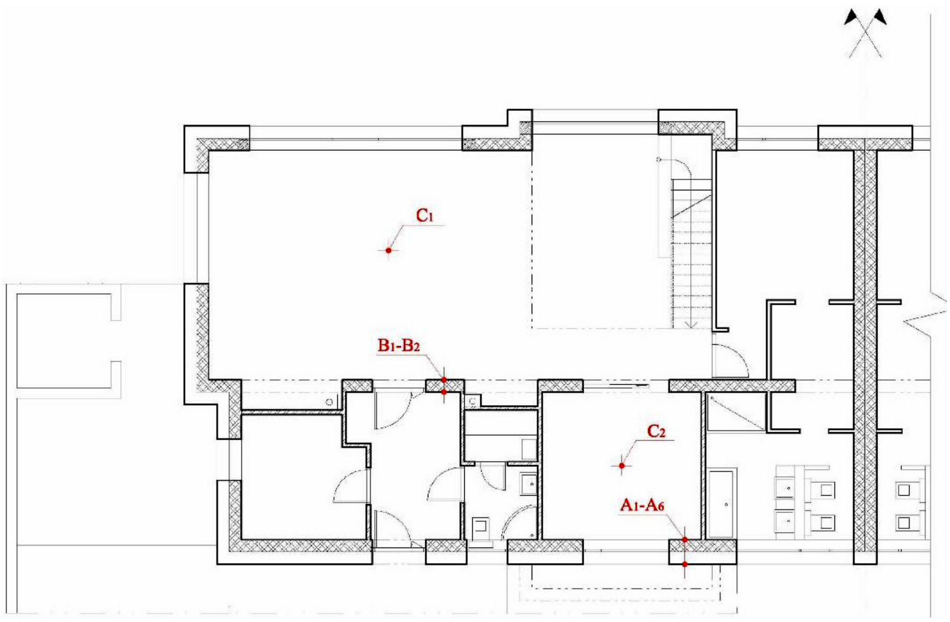

Fig. 2. Schematic illustration of sensors deployment in floor plan of the first overhead floor of the house in the village Lorinčík

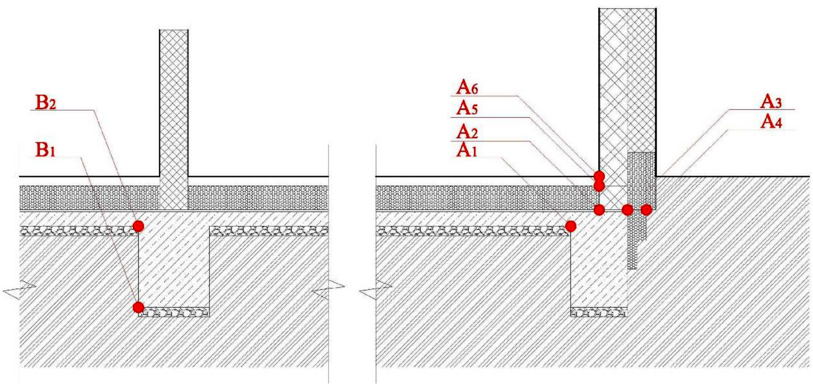

Fig. 3. Schematic illustration of sensors deployment in foundations of the house

1.2. Method of environmental analysis

Environmental analysis of this case study is based on Life Cycle Assessment (LCA). LCA is a well-known tool for analyzing environmental impacts on a wide extent throughout the life cycle of the building (cradle-to-grave). It involves the assessment of specific elements of product system to determine its environmental impacts. However, it has some limitations in practical building design by reason of highly data-demanding and work-intensive [12, 13]. This case study evaluates material selection of structures by using LCA within system boundary: "cradle to gate" and LCA provides better decision support when optimising environmentally suitable solutions. The input data are especially extracted from IBO database [14]. The material compositions are compared with calculated environmental indicators such as embodied energy from non-renewable resources (EE, global impact), embodied CO_2eq. emissions (ECO_2, global warming potential, global impact) and embodied SO_2eq. emissions (ESO_2, acidification potential, regional impact). This study takes into account impact of locked carbon in plant materials on total balance of ECO_2. Environmental and energy analysis is an integral component of sustainable building practice. Assessing amount of different criteria can help to make better decision which solution is the most optimal for a given building design in a given context.

2. DESCRIPTION OF EVALUATED LOW ENERGY HOUSE

The family house is situated in the village of Lorinčík, district of Košice in the Košice Region. A family house with a rectangular ground plan is located on flat terrain. It is a two floor house with a flat roof. The house is symmetric coupled through expansion joints. Entry to the building is from the north side. It is a brick house with massive envelope structures. The building is based on the foundation strips and base plate. Envelope walls are made of ceramic bricks of 300 mm thickness with contact insulation system of polystyrene with thickness of 300 mm. Horizontal supporting structures consist of reinforced concrete ceiling beams. The roof structure is designed as a flat roof "DUO" with composition: thick reinforced concrete ceiling with thickness of 200 mm, EPS polystyrene with thickness of 150÷250 mm. Waterproofing, polystyrene XPS with thickness of 200 mm, separating layer, and gravel with thickness of 50 mm. Staircase linking the floors is designed as a self-supporting timber. Windows are aluminum with brake thermal bridge. Glazing system is designed as a triple glazing. The ground floor is insulated with a layer of polystyrene with thickness of 250 mm on the base plate.

Source of heat is gas boiler. In a house is installed hot air heating and heating by the system Duplex RK2 (ATREA). It is a dual-zone heating and circulation of hot air at the same time for comfort ventilation with heat recovery. Heating is designed as underfloor heating. The whole HVAC system is properly regulated. The evaluated low-energy house is situated in Košice - Pereš (Slovakia) (Fig. 4).

Fig. 4. Views of the building - family house

Foundations: gravel, concrete strip, reinforced concrete plate (150 mm), waterproofing
Bearing walls: Porotherm brick (300 mm), thermal insulation from polystyrene (300 mm), textile net, plaster (3 mm)
Partitions: Porotherm brick (100 mm), textile net, plaster (200 mm)
Ceiling: gypsum board
Roof: reinforced concrete ceiling (200 mm), EPS polystyrene of 150÷250 mm, waterproofing, polystyrene XPS of 200 mm, separating layer, gravel of 50 mm
Floor: wood floor/ceramic tiles, concrete screed, separate foil, EPS (250 mm)
Windows: aluminum, triple glass insulation

3. RESULTS

3.1. Results of energy aspects

The measurements of temperatures in the sub-foundation carried out from 12th January 2013 to the end of April 2013, whereby any missing data were caused by PC disruptions (reboot, install update). In the Table 1 is presented a statistical summary of the measurements for period from 12th January to 13th March 2013.

Table 1. **Statistical summary of temperature recorded by sensors**

Sensor	Median [°C]	Minimum [°C]	Maximum [°C]
A1	11.19	9.62	11.94
A2	14.69	13.5	16.69
A3	10.62	10.31	11.44
A4	1.19	–3.75	6.81
A5	17.75	16.06	18.37
A6	22.12	20.19	22.87
B1	13.31	12.69	13.87
B2	13.81	13.19	14.56
Exterior	0.62	–9.31	11.5

Due to the length of the period in which the above-mentioned measured temperatures and humidity of the areas may be stated that the temperature in the sensor B1 and B2 the held relatively constant temperature (13.19÷14.56°C). On the contrary side of a building at the sensor A1, the temperature ranged from 9.62 to 11.94°C. In the sensor A2 is shown a larger temperature fluctuation in temperature and ranged from 13.5 to 16.69°C. Indoor air temperature in the sensor C1 in the period from 6^{th} December 2012 to 21^{th} January 2013 ranged from 20 to 27.5°C. The relative humidity during this period ranged from 16.3 to 53.8%.

The above parameters - temperature and humidity have quite a significant impact from the function and use of space. Due to the open space and patency of the living room and kitchen there is a significant impact of using the kitchen to the course of temperature and humidity. Temperature also rises to 27°C in some places, which is caused by higher gains from sunlight. A significant variation in values of relative humidity is caused by ventilation and operation of the exhauster of vapor in the kitchen.

A little more stable seem to be the spaces of nursery where is the sensor C2 (used mostly during the day when children are playing). The course of the temperature during the reporting interval ranged from 21 to 25.4°C and relative humidity ranged from 13 to 47% with a mean of 32%. This value is lower than recommended limit (40÷60%).

The course of monthly average from program “Slab” for outside environment *epw - Košice and indoor environment “Tinside” is shown in Figure 5.

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! ====================================================================
! The following was created by the Slab preprocessor program.
! Check the convergence message at the end of this file.
! Weather File Location=KOSICE - SVK IWEC Data
!
!  Monthly Slab Outside Face Temperatures, C and Heat Fluxes(loss), W/(m^2)
!  Perimeter Area: 10.95
!  Core Area:      114.49
!
!       Month   TAverage   TPerimeter    TCore      TInside AverageFlux PerimeterFlux CoreFlux
!         1      18.65      18.90        18.63      20.00      4.595        3.719      4.661
!         2      18.60      18.93        18.58      20.00      4.733        3.613      4.818
!         3      18.70      19.10        18.67      20.00      4.407        3.058      4.509
!         4      18.82      19.26        18.79      20.00      4.006        2.524      4.118
!         5      20.53      21.31        20.47      22.00      4.984        2.331      5.185
!         6      22.46      23.29        22.39      24.00      5.236        2.424      5.448
!         7      24.34      25.24        24.27      26.00      5.633        2.576      5.864
!         8      24.64      25.28        24.59      26.00      4.607        2.448      4.770
!         9      23.09      23.38        23.06      24.00      3.100        2.120      3.174
!        10      21.23      21.38        21.21      22.00      2.628        2.105      2.668
!        11      19.26      19.22        19.27      20.00      2.499        2.637      2.489
!        12      18.80      18.98        18.79      20.00      4.067        3.456      4.113
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Fig. 5. Monthly courses of temperature in contact of floor with soil generated from “Slab” – E+

The courses of temperature is great uncertainty modeling. In calculation in the program “Slab” was considered the vertically thermal insulation from extruded polystyrene with total thickness of 0.3 and 0.9 m in the foundation. The floor was considered with thermal insulation from extruded polystyrene with thickness of 0.25 m. The course of temperatures from program is despite the use of database reference year *epw in the area of Kosice higher than the actual measured temperatures early in the period 2013. Vertical thermal insulation in the foundation influences the course of temperatures greatly. From the measured data for the monitored period the course the temperatures is appeared to be in fairly good agreement with the default temperature of 14°C as is determined by the DesignBuilder software. This applies to heating season, summer and transition period in time cannot be compared. Referred to above uncertainty in the thermal boundary condition is the result of the parametric study of the house, at which was considered the range of temperatures for the monthly averages ranging from 14 to 20°C for each month. Results of the energy consumption for heating, depending on the boundary conditions can be seen in Figure 6.

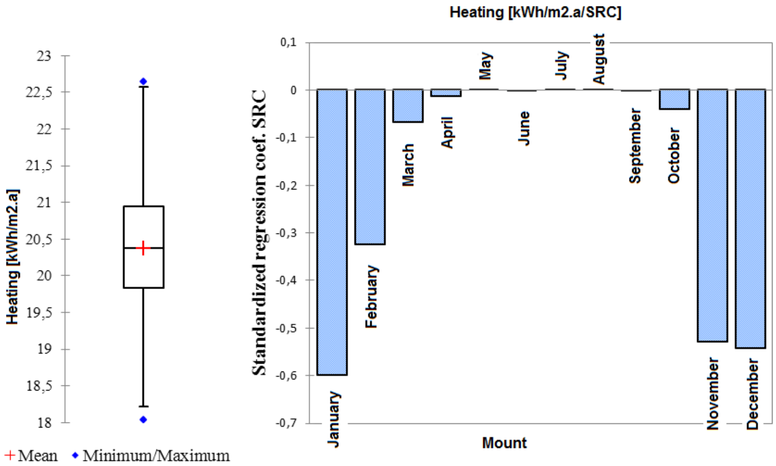

Fig. 6. Impact of temperatute under base plate on energy consumption for heating

Impact of orientation and *epw scenarios of future weather on energy consumption for heating and average operative temperature of the house is shown in Figure 7 (note: 0° - orientation to the North).

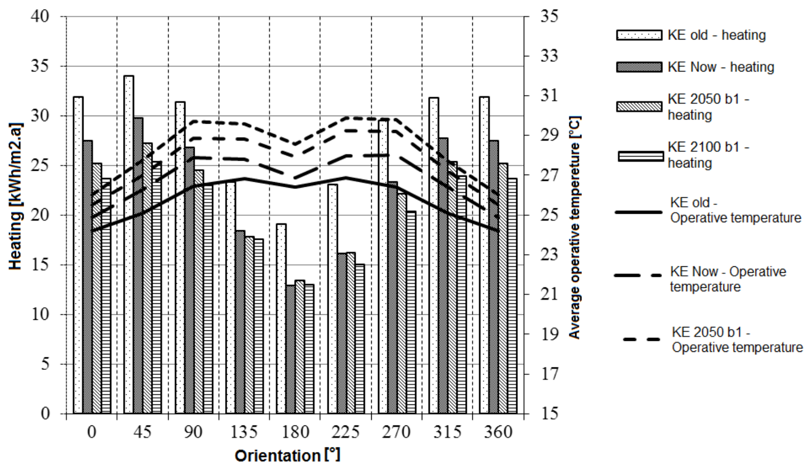

Fig. 7. Influence of orientation and *epw on energy consumption for heating and operative temperature in summer

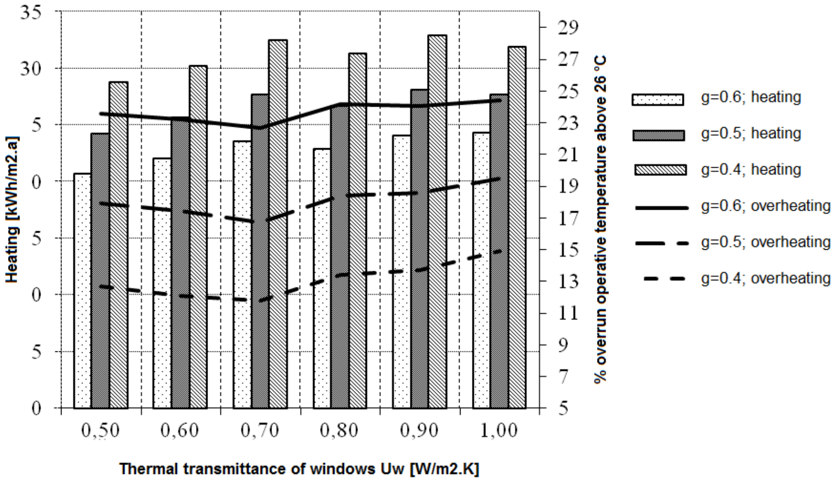

Fig. 8. Influence of glazing properties on energy consumption and thermal comfort

Influence of optical properties of glazing and air change intensity on the frequency of overheating in the summer from 1th April to 31th September is shown in Figure 9.

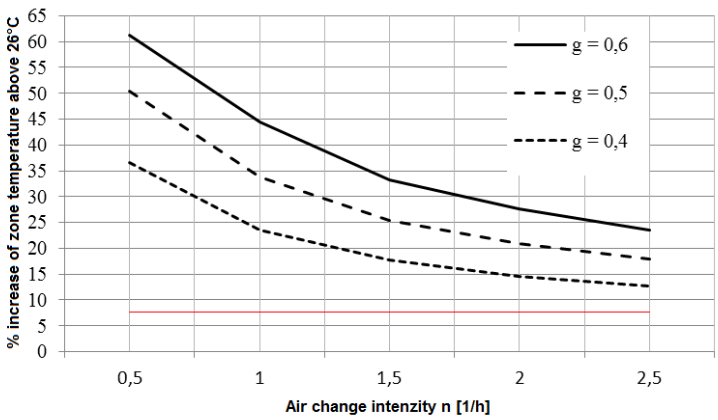

Fig. 9. Influence of air change intensity and glass property on thermal comfort in summer

3.2. Results of environmental aspects

The aim of this case study is to determine values of environmental indicators for selected low-energy house. The results of environmental assessment are presented in Table 2.

The percentage share of structures on total embodied energy and embodied emissions are presented in Figure 10.

Table 2. **The results of assessments of environmental indicators**

	EE [MJ]	ECO_2 [kg CO_2eq.]	ESO_2 [kg SO_2eq.]
Foundations	199601	20383	68.6
Bearing walls	384454	24548	91.9
Partitions	11195	791	2.5
Ceiling	127091	11389	38.7
Roof	399627	24227	116.4
Floor	189141	4920	51.8
Opening structures	28682	1634	6.2
Total	1339791	87892	376

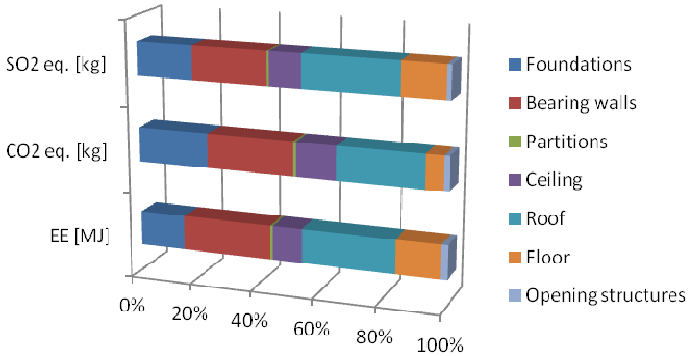

Fig. 10. Embodied energy and embodied emissions of CO_2eq. and SO_2eq.

Total results of environmental analysis for this family house are following: 4.5 GJ/m^2 for floor area, 295 kg CO_2eq./m^2 for floor area and 1.3 kg SO_2eq./m^2 for floor area. In comparison with results of other case studies, this family house requires higher reduction of embodied energy and embodied emissions with optimalized material compositions of structures for the purpose of possible way towards sustainable future.

CONCLUSION

Life cycle assessment (LCA) belongs to broadly used methodology which helps to make decisions in sustainable building design. The relative contribution of embodied impacts of building materials has been recognized as being significant, especially for high energy-effective residential buildings. The overall environmental and energy performance of building structures is important in achieving more sustainable solution. This case study implements life cycle assessment within “cradle to gate” (especially low-energy houses). The aim is to assess environmental indicators such as embodied energy from non-renewable resources, embodied emissions of CO_2eq. and SO_2eq.

Although operational energy constitutes the highest proportion in total energy consumption over entire life cycle of building, it is important to take into account embodied energy. Values of embodied energy and associated emissions grow by improving energy quality of building envelope by using extra components and insulation materials.

Improvement energy performance of building envelope in order to reduction of operational energy consumption in buildings may result in rise proportion of embodied impacts of building materials on total life cycle environmental impacts. Influence of thermal boundary conditions at the point of contact of the ground floor with soil to the energy consumption for heating is presented in figure above, where the energy consumption is in the range from 18 to 22.7 kWh/($m^2 \cdot a$). In terms of impact orientation and scenarios of future weather it can be stated that object orientation is properly fitted. Furthermore, it can be stated that possible overheating (expressed through the mean operative temperature) is of forecasts about future weather (*epw scenarios) affect the orientation of the average operational temperature zones is marked, from which one can infer a significant impact on climate change outside the frequency of overheating. In terms of impact and optical properties of glazing on energy consumption and thermal comfort of the house should pay more attention to excessive heat gain in summer.

Acknowledgements

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ENERGETYCZNY I ŚRODOWISKOWY PROFIL BUDYNKU O NISKIM ZAPOTRZEBOWANIU NA ENERGIĘ - STUDIUM PRZYPADKU

Zintegrowany projekt budowlany powinien uwzględniać środowiskowe, społeczne i ekonomiczne aspekty zrównoważonego rozwoju. Projektowanie budynków w zakresie efektywności energetycznej obejmuje różne aspekty, począwszy od projektu architektonicznego aż po wykorzystanie technologii związanych z oszczędzaniem energii. Wiele uwagi przywiązuje się do prawidłowej izolacji ścian, dachów i podłóg aż po zastosowanie systemów wykorzystujących odnawialne źródła energii. Celem innowacji jest nie tylko oszczędzanie energii, ale również obniżenie kosztów i ochrona zasobów naturalnych. Niniejsze opracowanie koncentruje się na analizie materiałów budowlanych i konstrukcji w odniesieniu ich do oddziaływania na środowisko oraz na monitorowaniu fizycznych parametrów środowiska wewnętrznego. W pracy przedstawiono ocenę wskaźników energetycznych i środowiskowych w wybranym budynku o niskim zapotrzebowaniu na energię i ich optymalizację w celu zmniejszenia oddziaływania na środowisko.

Słowa kluczowe: **budynki o niskim zapotrzebowaniu na energię, emisja, oddziaływanie na środowisko**