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Multi-disciplinary Energy Auditing of Educational Buildings in Azerbaijan: Case Study at a University Campus

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Abstract: One of the ways to contribute of improving international stability is the optimization of energy consumption and saving of the natural resources. Buildings are the largest consumers of energy in Azerbaijan. There is an opportunity for implementing optimal energy conservation measures in the buildings through detailed multi-disciplinary energy auditing. These audits have a critical role in increasing resource and energy efficiency, and environmental stability. This article describes the workflow of building auditing, the main steps and methodology for the optimal estimation of engineering systems and the thermal comfort, the protocol used to answer questions regarding energy efficiency and indoor air quality. The case study was done on the campus of Azerbaijan University of Architecture and Construction. During the audit, a special software was used to calculate the financial cost and effectiveness of proposed energy saving measures. The environmental benefits and reduction in CO_2 emissions were estimated.

Keywords: detailed energy auditing; energy budget; energy consumption; energy efficient measure; thermal insulation

1. INTRODUCTION

A consistent development strategy focused on the improvement of international stability demonstrates close correlation with energy efficiency. The conservation of power resources and thermal energy will be a global scale priority not only today but also in the foreseeable future. These savings have benefits in various areas of human activity. One such sphere is the human life-support environment, as its proper functioning requires considerable energy costs relating to the operation of buildings and their infrastructure. Globally, about one-third of energy is consumed in buildings.

In Azerbaijan the main energy consumers are buildings, industrial enterprises and vehicles (Fig.1). Today Azerbaijan fully meets its domestic energy demands through its own resources. However, the utilization efficiency of primary sources and transformed types of energy within the country is extremely low.

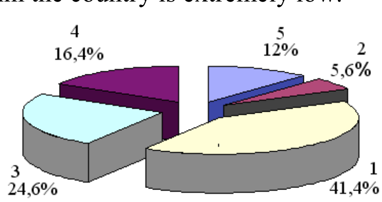

Fig. 1. Scheme of the final energy consumption by sectors in Azerbaijan, %: 1- household; 2- commercial and public buildings; 3-transport; 4- industry, 5-others

According to the State Statistical Committee of the Republic of Azerbaijan, more than 47% of final energy consumption is used for all encompassing energy needs of the buildings. The largest amount of overall energy is spent on heating (Energy balance of Azerbaijan, 2017). The study reveals that the heating system consumes approximately 277 kWh/m^2 of thermal energy for the conditioned area. Throughout different stages of the building life cycle (construction, operation, demolition) they will require additional energy for various needs. A tremendous amount of energy is wasted during operation stage. Examples of energy loss causes include: insufficient insulation of building enclosures, inefficient use of building energy installations, heating, ventilation, air conditioning, domestic hot water system equipment, incorrect management strategies, etc. The waste of energy at this stage can be minimized by the implementation of energy efficient measures (EEMs) in line with building energy auditing standards. (Xiaofeng L., 2016).

Educational buildings are of particular concern when it comes to the indoor environmental quality (IEQ) because students spend up to 25% of their time in the facilities. Hence, it's very important to create a comfortable micro-climate. This example implies huge potential for enhancing of energy efficiency (Porhinčák, M., 2013). Thus, the new holistic energy system approach is required. Advanced control for energy saving in the buildings is required to carry out the audit.

Multi-disciplinary energy auditing is becoming a trend because it can help save energy and natural resources as well as establish an environmentally friendly footprint in the building sector (Mammadov N., Akbarova S., 2017). The main objective of the multi-disciplinary energy

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auditing is to obtain information on the current state of the building (i.e. its envelope), such as indoor climate quality, communication engineering systems and installations. This information is critical to implement the energy efficient measures (EEMs) to the building (Tchervilov L., 2014). Total investment and profitability are key factors in selecting the most energy efficient measures.

This paper focuses on the results of the detailed multi-disciplinary energy auditing of an educational building of Azerbaijan University of Architecture and Construction (AzUAC) and technical recommendations on elimination of energy waste. Considerations not only included the application of low cost energy efficient measures but the control aspects of the building life cycle regarding design, production of materials and their recycling, operating, maintenance, and retrofitting of buildings (Shimon Y. Nof, 2009).

2. METHODOLOGICAL APPROACH

The following directives and norms are often used in Azerbaijan as a normative base for building energy auditing:

– EN 15217: Energy performance of buildings - Methods for expressing energy performance and energy certification of buildings, 2005;

– Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the Energy Performance of Buildings (recast). Official Journal of the European Union L153/13, 18.6.2010:

– SNIP 23-02-2003 "Thermal performance of the buildings", Moscow, 2012;

– EN ISO 13790: Energy performance of buildings – Calculation of energy used heating and cooling the space;

– EN 16247:2014 European Standard Energy audits - Part 2: Buildings. European Committee for Standardization, etc.

According to EN 16247:2014: Energy audit is a systematic inspection and analysis of energy use and energy consumption of a building with the objective of identifying energy flows and the potential for energy efficiency improvements and their reporting. The stages of the multi-disciplinary building energy auditing offered by the experts of AzUAC is shown in Fig.2.

The energy auditing model has been designed by the means of a special software for calculating energy budget and profitability of EEMs. The software considers several parameters. These parameters include building envelope characteristics, climate conditions (including the influence of solar radiation, relative humidity, wind speed, atmospheric precipitations) as well as the influence of condition and type of the automatic control systems, thermostatic control set point and generation efficiencies. Professional assessments have a thermographic scan, blower door tests, etc.

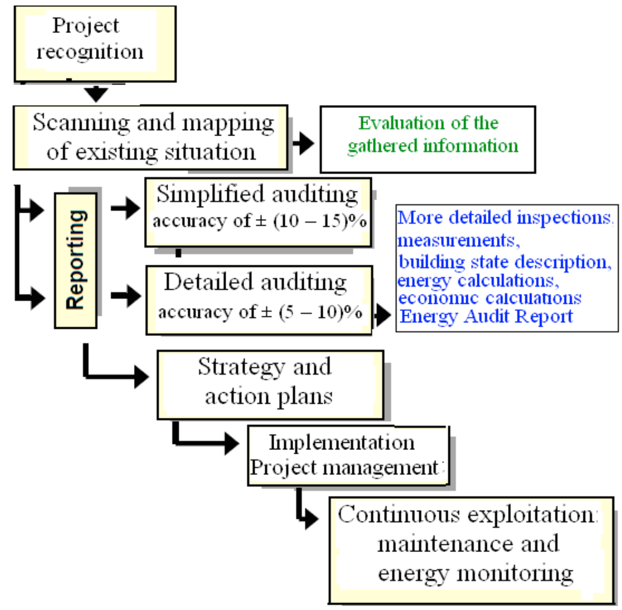

Fig. 2. Stages of energy auditing

3. DESCRIPTION OF THE CASE STUDY

3.1. Brief information about the current situation

The building on which the multi-disciplinary energy auditing was illustrated is the second educational building of the AzUAC (Fig.3) that was built in 1986. Since its construction, the building has not undergone any capital renovation.

Fig.3. Photographs of second educational building of AzUAC

The campus is a 12-story building with a total heated area of 9408 m^2 with a flat roof, unheated attic floor and unheated basement. The walls are made of local limestone with stone lining. The condition the walls are in leads us to conclude that the average heat transfer coefficient is about 1.2 W/(m$^{2}\cdot{}^{0}$C), which allows for large heat losses through the enclosing structures. The indicated heat transfer coefficient is almost 3 times higher than the existing standard requirement for wall thermal protection for European Union countries with similar climates to Azerbaijan. Low thermal protection of the walls leads to the appearance of condensation on the internal surfaces of the outside walls, which contributes to the loss of their enclosing properties and causes the formation of mold. The windows in the building are mostly old wooden windows with double glazing. After almost 30 years of operation, the condition of the frames has deteriorated. It should be noted that in recent years 180 m^2 of windows from 1310 m^2 have been gradually replaced with the plastic double glazing windows.

The existing heating system of the building consists of a single-pipe with an upper wiring. The heating devices are the old type convectors. Thermoregulation of the heating system is absent. The distribution pipelines are metal and do not have thermal insulation. The heating supply in the building is sourced from a local boiler house which runs on natural gas. The boiler house supplies heat to 5 of the university buildings. The temperature diagram of the boiler house is often not properly maintained. Due to low thermal protection of the building and an unbalanced heating system, winter temperatures inside of the premises are about +16^{0}C, which is significantly lower than the minimum acceptable temperature standards. Due to the inadequate room temperature in the winter season, additional electric heating appliances are used to raise indoor air temperature.

There is no hot domestic water supply in the building, although it must be provided in accordance with the construction norms. There are only two individual electric boilers: on the first floor for the student canteen and on the fourth floor for the laboratory

There is unheated building basement with floor area 784 m^2 and height is 3.0m, Height of the floor surface above outside ground level is 1m, depth of basement floor below ground level 2m, the average heat transfer coefficient is about 0.4 W/(m^2·^{0}C). In current building codes the warmest climate zones do not require basement wall insulation, for Baku, average outdoor air temperature for heating is +3.8^{0}C. These areas are dominated by cooling loads, not heating loads.

3.2 Brief information about the proposed activities

The following package of energy efficient measures was proposed by the local energy auditors.

1. Thermal insulation of main pipelines in the basement

It is proposed to insulate the main pipelines in the basement with the mineral-wool with a thickness of 5 cm and coefficient of thermal conductivity about λ<0.04 W/(m·^{0}C). Diameter of the pipelines is 89x4.5мм and length is 115x2 = 230м.

2. Installation of the solar panels

To provide the whole building with hot water, the solar panels should be installed on the building roof. The number of installed solar panels- water heaters will be 20 pieces. The efficient area of each panel is 2.34 m^2. The total area of solar panels should be 47m^2. The installation of them requires a roof area should of approximately 60 m^2. Based on the climate condition in Baku, this device will allow for the generation of 41 000 kWh of energy per year. A figure that covers about 60% of the total DHW load.

The hybrid system of central and solar water heating will be more efficient and optimal because in Baku the average annual amount of sun hours is about 2210 (Meteorology and climate baseline report, 2017).

3. Facade thermal insulation

The thermal insulation of the outside walls from outer side with Rockwool mineral wool of thickness 7 cm is suggested. Due to this change, the coefficient of heat transfer of the outside wall will be reduced approximately 2.5 times. It is about 0.48 W/(m^2·K). The area of the thermal insulated walls is 5224 m^2.

As shown on Fig. 4 the proposed wall construction has four constructive layers:

1- internal plaster is cement-sand mortar with density about ρ=1700 kg/m³, thickness is d_1= 0.02 m, coefficient of thermal conductivity is about λ_1=0.7 W/(m·^{0}C);

2 - basic masonry is limestone, ρ=1600 kg/m³, d_2=0.4 m, λ_2= 0.73 W/(m·^{0}C);

3- thermal insulation with the mineral wool Rockwool Batts, ρ=105 kg/m³; d_3= 0.07 m; λ_3=0.042 W/(m·^{0}C);

4 - facing stone is local lime stone, ρ=1800 kg/m³, d_4=0.04 m; λ_4=0.93 W/(m·^{0}C).

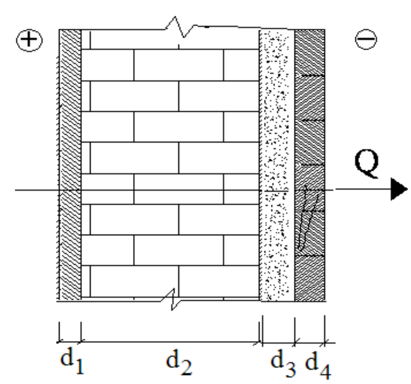

Fig.4. Proposed wall construction

4. Roof thermal insulation

The roof area is 784 m^2. It is proposed that an additional thermal insulating layer is applied by Rockwool Batts with a thickness of 7 cm and λ=0.042 W/(m·^{0}C) from inside. The attic floor should be insulated with clay tile. This would reduce the coefficient of heat transfer from 1.1 W/(m²·^{0}C) to 0.46 W/(m²·^{0}C).

5. New windows

Old windows should be replaced (total area is 1130 m²) with double-glazed windows and metal-plastic frames, with additional energy efficient layer. New windows will have an overall heat transfer coefficient 2.0 W/(m²·^{0}C) instead of 2.9 W/(m²·^{0}C).

6. Renovation of heating system and hydraulic balancing of the thermostatic valves

It is proposed to replace the single-pipe heating system with the upper wiring with a two-pipe system with a lower wiring. The old steel pipes should be replaced with plastic pipes. The total length of pipelines is 1915 m. The heating convectors should be replaced with the sectional aluminum radiators. Total number of the radiator sections after the introduction of energy-efficient measures will decrease from 2 810 to 1 450. All devices will be equipped with the thermostatic valves- 204 pieces.

4.DISCUSSION OF RESULTS

Since there are no heat meters in the building and there is no data on the actual consumption of electricity, the total energy consumption by the building before the implementation of the energy efficient measures is carried out by estimated calculations.

Because the building is not heated enough in winter, and there is no domestic hot water (DHW) supply, it is necessary to calculate the basic energy consumption and considering the minimum standards for indoor air temperature in the premises. Energy consumption before and after EEMs is summarized in the Table1. The energy budget and profitability are computed by special software. Here the DHW consumption is taken close to 0, since two individual electric water heaters are insufficient in the total energy balance of the building.

Table 1. Energy budget

Budget Item	Before EE Calculated	Before EE Baseline	After EE and renovation
	kWh/m²year	kWh/m²year	kWh/m²year
Heating	1 176 760	1 274 818	495 041
Ventilation (heating)	0	0	0
DHW	0*	65 897	25 700
Fans/ Pumps	0	0	0
Lighting	25 797	25 797	25 797
Various	92 868	92 868	92 868
Cooling	9 405	9 405	9 405
Total	1 304 829	1 468 784	648 810

In addition, the internal temperature at the premises will be normalized and the situation with domestic hot water supply will be improved. Taking into account the current state of the building, the actual savings will be 20% lower. The building energy auditing identifies an energy efficient potential and renovation measures. Total energy savings from implementation of the EEMs are calculated on the base of baseline energy consumption. It amounted to 819 974 kWh/year and it corresponds to 56% of savings, including:

• thermal energy saving 779 777 kWh / year;

• savings for electricity of 40 197 kWh / year (installation of the solar panels).

The results are shown in the Table 2. Here all calculated EEPs are listed and ranked according to their profitability, e.g. the most profitable procedure is thermal insulation of the main pipelines in the basement because NPVQ=1.75. Calculations show that the recommendation for new windows is unprofitable (NPVQ = -0.28), but it is necessary to ensure indoor air quality conditions on the premises. Installation of the thermostatic valves as part of modernization of heating system is not cost-effective (NPVQ = -0.54) as well. This is caused by high costs required for the thermostatic valves and partly for the reconstruction cost of the heating system. However, if we assume that a reconstruction will be carried out in any case as part of general building renovation, then the investment for installation of the thermostatic valves will be considered profitable. Table 2 shows that the most energy efficient procedures are facade thermal insulation and installation of the new windows, energy savings are 330 643 kWh/yr and 325 421 kWh/yr respectively.

Thus, the proposed activities will not only improve the internal microclimate in the building, but also help reduce the university's energy account costs. Also, EEMs will reduce CO_2 emissions by 195 tons per year due to reduction of gas consumption at the local boiler house and save up to 10^5 m^3 of natural gas.

Table 2. Energy efficiency potential

EEP	Invest-ment AZN	Net savings [kWh/yr]	Net savings [AZN/yr]	Pay-back [year]	NPVQ *
1	2 600	40 299	1 048	2,5	1.75
2	15 000	40 197	2 412	6,2	0,77
3	82 000	330 643	8 597	9,5	0.16
4	9 500	33 111	861	11	0.0
5	130 000	325 421	8 461	15,4	-0,28
6	25 000	50 303	1 308	19,1	-0.54
Total	264100	819 974	22 687	11.6	0,08

Here the coefficient of Net Present Value Quotient is about 7.6% of the real discount rate, AZN -local currency.

5. CONCLUSION

Building energy auditing in Azerbaijan is becoming more urgent as it directly contributes to the actual saving of energy and natural resources. Hence, reducing the environmental impact of the buildings. This explains why this task is on the agenda of many owners of the modern buildings. In Azerbaijan the trend of building energy auditing is relatively new and process of implementing of such auditing is still slow. The following problems in this area are observed: lack of certified experts in this field; lack of adequate technical standards which slows implementation. The availability of significant reserves of natural resources removed incentives to have significant capital expenditures to make buildings across the country more energy efficient and environmentally friendly. Inadequate measures of assistance and encouragement by the state and insufficient awareness of building owners all hamper the development of the auditing system. Despite all of these setbacks, it is important that local experts continue to develop and implement building auditing methodology based on the national norms and standards combined with theoretical investigations accompanied with appropriate practical experience.

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