Warehouse facility energy efficiency assessment model

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Abstract

The aim of this paper is to investigate the formal structural elements of the energy efficiency assessment system of a warehouse facility as part of a complex distribution system. The problem of work starts from the fact that there is still no single method of assessing the energy efficiency of warehouse facilities that would unequivocally evaluate the planned and taken corrective measures, given the lack of methods related to such intensive construction. In this paper, we determine the final consumption systems of the warehouse facility and the supply systems of the warehouse facilities. The goal of a successful assessment model is to look at the financial and environmental benefits of individual measures, point out the possibilities of reducing costs and the cost-effectiveness of investing in energy efficiency measures of warehouse facilities. A successful assessment model should create the preconditions for determining clear economic criteria when setting priorities for the implementation of energy efficiency measures. The research findings show that it is possible to significantly improve the procedure for assessing the energy efficiency of warehouse facilities.

Keywords: *Warehouse facility, Inspection, Energy efficiency, Consumption reduction*

1 Introduction

Warehouse facilities are fenced or unfenced spaces, covered or uncovered, which are used to store raw materials, semi-finished products, or finished products. The basic task of the warehouse is to preserve the value and quality of stored material or goods and to ensure the uninterrupted and uninterrupted flow of the supply chain. The warehouse facility is an arranged and equipped place for temporary and safe disposal, preparation and release of materials before, during and after their wear and use in the production process. The goal of warehouse facility operators and the necessary commitment of the entire logistics sector as one of the significant consumers of electricity with a noticeable item in the energy balance and infrastructure facilities dispersed in a wide area, is the design, construction and use of various high energy efficiency devices to save electricity consumption (LED lighting, energy efficient mechanical installations, energy efficient ventilation, etc.). Continuous improvement of energy efficiency is one of the most important pillars of modern energy policy and is the key and most cost-effective mechanism for achieving sustainable development goals [1]. In this process, the energy audit of the warehouse facility is a key step in the analysis of energy efficiency. Namely, the energy audit is an unavoidable step on the way to control costs and reduce energy consumption in the logistics system. As a result of the energy audit, there are recommendations for changes in the way of working or behaving, as well as recommendations for the implementation of interventions and the implementation of investments that improve energy efficiency without compromising working conditions in the warehouse facility. When the results of the inspection indicate the existence of significant space for improving energy efficiency, standard methods require that a detailed energy audit be conducted in order to confirm the identified potentials by on-site measurements. After the energy audit, a list of priority energy efficiency measures is created. The key parameters of the analysis of possible measures are the amount of savings in energy, water and money that will be achieved by implementing the proposed measure in the warehouse facility. Identification of measures to improve the energy efficiency of warehouse facilities and equipment is a key and unavoidable step in the analysis of energy and water efficiency, control of consumption and reduction of costs and consumption of energy, energy and water in buildings. By implementing and improving energy efficiency measures in facilities within its competence, the warehouse system operator would set an excellent example of the fact that investing in energy efficiency measures has very positive effects on budgets and the common environment. Improving the efficiency of energy consumption in warehouse facilities reduces costs, thus contributing to the competitiveness of the sector.

2 Elements of warehouse system - structure of energy consumers

Warehouse facilities (systems) are an important but often neglected factor in energy efficiency assessments. Successful and sustainable warehouse design is a necessary condition for the success of the optimization process of the entire logistics chain. Each warehouse is part of a larger chain, and it needs to be viewed with a holistic approach. The specifics of warehouse systems are the need for different devices in the function of storing different goods and materials (Figure 1.). Various warehouses are equipped with complex equipment (electric carts, diesel, gas and electric forklifts, electric cranes, high-rack cranes, bar code readers, radio frequency technology, handheld scanners, magnetic strips, magnetic strips, sensors for the correctness of goods, etc.).

Fig. 1. Warehouse facility and equipment - consumers

On the other hand, we identified five groups in the warehouse facility supply system, and nine components in the warehouse facility final consumption system (Table 1.). Table 2. displays the main consumers of the warehouse facility.

Table 1. Warehouse facility energy consumption systems

	Final consumption systems of warehouse facilities	Warehouse supply systems
1.	KP_1 - Heating of auxiliary rooms	SO_1 - Power system
2.	KP_2 - Warehouse cooling	SO_2 - Heat production system
3.	KP_3 - Warehouse air conditioning	SO_3 - Cooling system
4.	KP_4 - Warehouse ventilation	SO_4 - Plumbing system
5.	KP_5 - Domestic hot water consumption	SO_5 - Fossil fuels (gas, fuel)
6.	KP_6 - Electric motor drives	
7.	KP_7 - Electric lighting	Losses - Q
8.	KP_8 - Diesel and gas drives	
9.	KP_9 - Other devices and equipment	

Table 2. The main consumers of the warehouse facility [2]

	Major consumers	Ancillary consumers
1.	Warehouse facilities (different types)	
2.	Material warehouse facilities	
3.	Material disposal agents	
4.	Means for shaping unit loads and transport	
5.	Auxiliary warehouse equipment	communication and information system
		means for assembling and disassembling unit loads
		means for determining measurements and weights
		means of transport over rails and other unevenness
		transhipment means and packaging equipment
		material capture means
		aids to connect with the environment
6.	Accessories	safety and protection devices
		air conditioning devices heating / cooling
		sanitary and hygienic devices
		cleanliness devices

3 Energy efficiency assessments of the warehouse facility

Energy efficiency in warehouse facilities means consuming less energy for the same amount of stored products or services provided. Clear objectives of energy efficiency assessment and implementation offer many benefits to the operator, depending on the type of intervention (Table 3.).

Table 3. Energy efficiency goals/warehouse facility

1.	Reduction of load in warehouse facilities with increasing energy prices.
2.	Increasing the energy security of the facility.
3.	Increase the necessary investments for the supply of alternative energy.
4.	Reducing air pollution and slowing climate change.
5.	Improving the employment of skilled and unskilled labor.
6.	Reducing the burden on the company's budget.
7.	Increasing economic competitiveness.

In order to assess the energy saving potential of a warehouse facility, the existing energy efficiency of different systems must be defined. In fact, it is necessary to establish what the current energy situation is. It is not possible to estimate the energy saving potential just by looking at the total energy bill (eg 60,000 kWh / year). The question is whether it is a large or small warehouse building, what are the auxiliary warehouse facilities, etc. The specific energy required gives a clearer picture of the energy efficiency of the warehouse facility. There are many other factors such as the type of warehouse building, climatic conditions, technical installations, etc. which affect the overall "energy needs" [3].

The aim of marking potential measures to improve the energy efficiency of warehouse facilities and equipment is to establish an energy management system. Considering the real state of sources and potentials for improving energy efficiency of warehouse facilities and equipment, and energy consumption in system elements, identifying the necessary energy efficiency measures, includes estimating the amount of investment required in the implementation of proposed energy efficiency measures and expected amounts of energy savings. and proposals for financing them. In the analysis, we identified four sectors that are potentially possible in the system of warehouse facilities and which are a priority for low-emission development strategies are shown in Table 4.

Table 4. Improvement sectors

	Sectors
1.	Electricity consumption of warehouse facilities from renewable sources.
2.	Energy efficiency in warehouse facilities.
3.	District heating system for auxiliary warehouse facilities.
4.	Electric warehouse transport

4 Analysis of the energy audit functions of the warehouse facility

Energy audit is the first step in all programs of rational energy management of facilities and equipment. Energy audit e.g. we analyze the thermal and cooling characteristics of the building envelope and the characteristics of technical systems in order to determine the efficiency / inefficiency of energy consumption and draw conclusions and recommendations for increasing efficiency. This procedure determines the manner of energy use and systems and places where large energy losses are present in order to determine measures for rational energy use and increase energy efficiency. Review of energy efficiency of warehouse facilities and equipment includes detailed analysis of technical and energy characteristics and analysis of all technical systems in facilities at the level of warehouse system that consume energy and water in order to determine efficiency / inefficiency of energy and water consumption and make conclusions and recommendations for energy efficiency. and equipment. The two main purposes of the energy audit are shown in Table 5.

Table 5. Purposes of energy audit

1.	Analysis of the state and possibilities of application of measures to improve the energy properties of the warehouse facility and increase energy efficiency.
2.	Determining the class of energy consumption in the energy certification of a warehouse facility.

Data accuracy is the key to a successful energy audit. This is most pronounced in existing buildings. Sometimes it is not possible to get all the necessary data, sometimes it is necessary to perform additional measurements. It is important for the quality of the energy audit that the lack of data or inaccuracy of data is kept to a minimum.

The person conducting the energy audit must be professional and trained to inspect the existing condition, conduct measurements and the necessary calculations, to more accurately establish the existing energy status and make recommendations for improving the energy performance of the warehouse facility.

A key part of the energy audit of the warehouse facility is to identify recommendations for changes in plant and equipment or changes in user behavior and recommendations for the implementation of measures and implementation of measures to improve energy efficiency of facilities without compromising or improving working conditions, service process or service quality. object. The primary goal of the energy audit is to determine the energy properties for new or existing facilities, and to make recommendations for increasing energy efficiency. The energy audit must contain the information required for energy certification.

The primary goal of the energy audit of facilities and equipment is to collect and process detailed data on facilities and all technical systems in the facility and to determine the energy properties of the facility. The standard content of the energy audit of the facility includes eight phases (Table 6.).

Table 6. Stages of energy audit of the warehouse facility

	Phases
1.	Phase of analysis of technical specifications of the construction warehouse facility in terms of thermal protection (analysis of thermal characteristics of the casing).
2.	Phase of analysis of technical specifications of energy properties of ventilation systems.
3.	Phase of analysis of technical specifications of energy properties of domestic hot water systems in the main and auxiliary facilities.
4.	Phase of analysis of technical specifications of energy properties of energy consumption systems of transport and warehouse systems.
5.	Phase of analysis of technical specifications of energy properties of electricity consumption system - system of electrical installations, lighting in the warehouse and other subsystems of electricity consumption.
6.	Phase of analysis of facility technical system management specifications.
7.	Phase of analysis of the possibility of using renewable energy sources and efficient systems.
8.	Phase of introduction of proposals for economically favorable measures to improve the energy performance of the warehouse facility, achievable savings, investment assessment and payback period.

Based on the characteristics of individual warehouse facilities and equipment, it should be noted that certain steps of the energy audit are specific. The energy audit of warehouse facilities and equipment, in addition to identifying the possibility of applying energy efficiency improvement measures, must include all the necessary information for the implementation of the energy certification procedure.

5 Mathematical model for estimating the energy efficiency of a warehouse facility

The mathematical model of energy efficiency of all processes within the warehouse system can be defined as the ratio of utilized energy output (work and usable energy) and input energy consumed in the process (energy loss) (Figure 2).

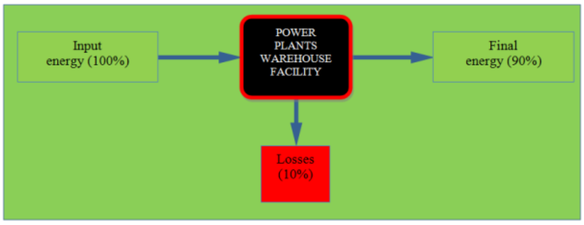

Fig. 2. The concept of energy efficiency of a warehouse facility

The energy efficiency of the warehouse facility system, ie the degree of efficiency (energy efficiency) is formally equal to the ratio of final energy and input energy:

Degree of efficiency of the warehouse facility system

=

Final energy / input energy

Formalized relationship is defined as:

$$SO_1+SO_2+SO_3+SO_4+SO_5 \rightarrow (KP_1+KP_2+KP_3+KP_4+KP_5+KP_6+KP_7+KP_8+KP_9) + Q \quad (1)$$

The main consumers or components of the warehouse system that are subject to energy audit are shown in Table 2.

The research should take into account the degree of efficiency of all warehouse facilities and the type of energy / fuel used.

The balance of energy consumption by main groups of consumers within the defined energy cost centers is prepared on the basis of information on working hours and habits of employees in the warehouse. Information on the operating hours of warehouse devices and equipment used during warehousing is obtained through interviews with on-site logisticians, review of available logs of individual devices (read directly from device memory or work logs) and personal experience related to the type of activity performed within the analyzed warehouse building [4].

6 Proposal of a three-phase model of energy efficiency analysis of warehouse facilities

For the analysis of facilities and equipment of the warehouse facility, we propose a three-phase model of energy audit. The first phase of the model consists of a preliminary review that does not include detailed calculations or measurements and modeling of energy consumption. In the first phase of the model, we perform an energy audit that includes a brief overview of the energy properties of warehouse facilities and equipment, in order to determine the potential for increasing energy efficiency, or determine the need for a detailed energy audit of all elements. The basic steps of the first phase of the energy audit are given in Table 7.

Table 7. Steps of the first phase of the three-phase energy audit model

1.	Preparation phase - collecting data on the characteristics of the warehouse facility and construction equipment, important energy systems and energy costs.
2.	Interview with the responsible person in the warehouse facility.
3.	Tour of the warehouse facility - visual determination of the energy state of the shell and all technical systems, recognition of the basic characteristics of energy consumption and places of large energy losses.

By visual inspection of the energy condition of the warehouse facility and its main characteristics (Table 8.) and all technical warehouse systems and a brief analysis of the collected data, we identify a key problem and compile a set of recommendations to increase energy efficiency.

Table 8. The main characteristics of the system

1.	Construction characteristics of thermal protection.
2.	Energy properties of ventilation, lighting, air conditioning, heating and cooling systems.
3.	Energy properties of warehouse transport.
4.	Representation and energy properties of individual groups of consumers.
5.	Object management structure.
6.	User access to energy issues - the so-called. human factor.

The main goal of the first phase of the energy audit is to determine the potential for rationalization of energy consumption and to make a decision on the need to conduct the second detailed phase of the energy audit.

The second phase of the model consists of a detailed energy audit in which we perform in-depth energy analysis of the warehouse facility and based on measurements we have a starting point to evaluate more complex energy efficiency improvement measures that are recommended for additional analysis.

The third phase of the model introduces an appropriate simulator (eg. Flexsim) to mimic the real state and processes in the warehouse facility (Figure 3.). Namely, in the analysis of the relationship between the activities in the warehouse facility and energy consumption, the human factor must not be neglected. Improvements in the efficiency of the warehouse facility should be sought on the side of technology (machinery and equipment) but also on the side of equipment management (human factor). That is why we use simulation to determine the impact of changes in the parameters of certain behaviors on other elements of the warehouse system.

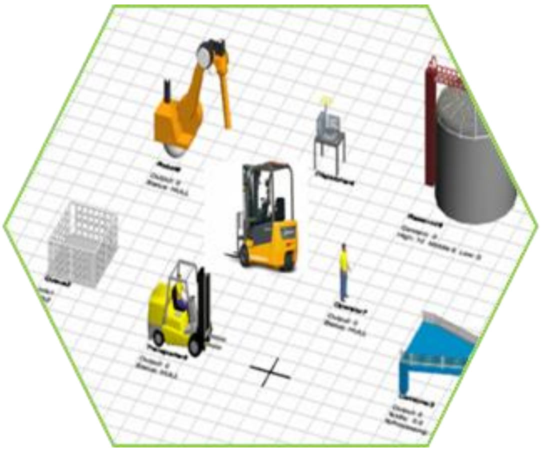

Fig. 3. Elements of consumer simulation in Flexim environment

With the simulation method we try to solve the problem situation of complex warehouse processes that have the following characteristics:

1. Dynamics in energy consumption in the warehouse, which means that the phenomenon in which the problem occurs changes over time;
2. Excessive complexity of the logistics problem, ie the existence of complex interdependencies of consumption in the warehouse and the relationship between the elements of the problem;
3. Stochasticity of some elements of the consumption problem in the system.

The result of the three-phase model is the final document which suggests that the key output of the energy audit model is a list of measures to improve the energy efficiency of the warehouse facility that are proposed for implementation, ie. Investing.

7 Evaluation of energy efficiency measures of a warehouse facility

The purpose of the evaluation of energy efficiency measures of warehouse facilities and equipment consists of two main objectives (Table 9.).

Table 9. The purpose of identifying energy efficiency measures of warehouse facilities and equipment

1.	Analysis of the current state of measures taken for energy properties of warehouse facilities and equipment in the function of energy efficiency implementation.
2.	Identification of possibilities and justification for the application of additional measures to improve the energy efficiency of warehouse facilities and equipment with the ultimate goal of implementing the energy certification procedure and determining the energy class.

The purpose of evaluating the model of conducting energy audits of warehouse facilities and equipment and introducing measures is to provide tools for successful implementation of energy audits by prescribing a detailed procedure of all activities in this complex process, because the goal of the process is not only insight into the current energy condition of the warehouse facility and equipment with regard to the main characteristics and the successful implementation of the proposed measures.

Based on the analysis of the collected data, specific energy, economically and environmentally optimal additional energy efficiency measures for the observed warehouse facility and equipment are selected.

8 Proposal of the energy card model of the warehouse facility

Within the paper, we also define the proposal of the optimal model of the energy efficiency assessment card of the warehouse facility. The proposed card consists of nine interdependent elements: General data, basic technical data on the warehouse facility, energy needs of the warehouse facility, CO_2 emissions, costs, investment price, economic and financial indicators, savings in energy consumption after the measures and the potential for labor (Table 10.).

Table 10. Proposal of optimal cardboard model for energy efficiency assessment of warehouse facility

GENERAL INFORMATION ABOUT WAREHOUSE				
The name of the warehouse facility		Type of warehouse facility		
Location of the warehouse facility		Number of employees		
Municipality		Average daily number of users		
State		Object code		
BASIC TECHNICAL DATA ABOUT THE WAREHOUSE FACILITY				
CATEGORY	CONSTRUCTION FACILITIES WHICH ARE AN INTEGRAL PART OF THE WAREHOUSE FACILITY			TOTAL
	1	2	3	
Total area of heated space (m^2)				
Total volume of heated space (m^3)				
Total window area				
WAREHOUSE ENERGY NEEDS				
CATEGORY	CURRENT STATE	SITUATION AFTER THE MEASURE EE	THE DIFFERENCE	Unit of measure
Total for heating				kWh/year
Total for lighting				kWh /year
Total for other electrical appliances				kWh/year
For heating per m^2 of heated area				kWh/m^2 year
For heating per m^3 of heated space				kWh/m^3 year
Energy category				
Required amounts of energy for heating			Unit of measure	
Gas			m^3/ year	
Heating oil			l/ year	
Pellets			t/ year	
District heating			kwh/ year	
Electric heating			kwh/year	
CO_2 EMISSIONS WAREHOUSE				
	CURRENT STATE	SITUATION AFTER THE MEASURE EE	THE DIFFERENCE	Unit of measure
From heating				t/year
From transport				t /year
From lighting				t/ year
From elec. devices				t/ year
Total				t/ year
COSTS				
	CURRENT STATE	SITUATION AFTER THE MEASURE EE	THE DIFFERENCE	Unit of measure
For heating				KM/ year
For lighting and elec. devices				KM/ year
Total				KM/ year
INVESTMENT PRICE				
MEASURE	Investment (KM)	Energy saving (kwh/year)	Energy saving (%)	
MEASURE 1.				
MEASURE 2.				
MEASURE 3.				
MEASURE 4.				
MEASURE 5.				
TOTAL HEATING				
TOTAL TRANSPORT				
TOTAL LIGHTING				
TOTAL				
ECONOMIC AND FINANCIAL INDICATORS				
Evaluation method	Result	Eligibility of the investment		
EASY RETURN PERIOD FOR INVESTMENT IN BUILDINGS (PP) (year)				
EASY RETURN PERIOD FOR LIGHTING INVESTMENTS (PP) (year)				

EASY RETURN PERIOD FOR INVESTMENT IN ENERGY EFFICIENT ELECTRONIC DEVICES (PP) (year)			
NET CURRENT VALUE FOR INVESTMENT IN BUILDING $NPV_{Building}$			
NET CURRENT VALUE FOR INVESTMENT IN LIGHTING $NPV_{Lighting}$			
NET CURRENT VALUE FOR INVESTMENTS IN ELECTRONIC DEVICES $NPV_{Electrical\ device}$			
INTERNAL RATE OF RETURN FOR INVESTMENT IN BUILDINGS $IRR_{Building}$			
INTERNAL RETURN RATE FOR INVESTMENT IN LIGHTING $IRR_{Lighting}$			
INTERNAL RETURN RATE FOR INVESTMENTS IN ELECTRONIC APPLIANCES $IRR_{Electrical\ device}$			
Savings in energy consumption after implemented measures			
	HEATING (%)	LIGHTING (%)	TOTAL (%)
ENERGY			
FINANCIAL			
CO_2 EMISSIONS			
Savings in energy consumption after implemented measures			
The potential of the project to create new jobs			man – months

9 Conclusion

The energy audit model of the warehouse facility is a framework for a systematic analysis of energy consumption in order to determine the efficiency of consumption, and to find and evaluate the potential for achieving overall savings. The results of the research showed that energy efficiency assessments of warehouse facilities have not been the focus of scientific research to date. The proposed three-phase model is a new approach to measuring the energy efficiency of warehouse facilities based on real data.

The existence of clear metrics for assessing the energy efficiency of warehouse systems and the need to quantify the consumption process in such a system, necessarily introduces us to the field of simulation models and associating numerical value with elements and processes of warehouse systems. Applying the system three-phase model, the consultant has the opportunity to analyze all segments of energy and water consumption of the warehouse facility, from inputs and energy transformations to direct consumption through activities that take place in the building. Based on all the above, we can conclude that the following is crucial for conducting an energy audit of the warehouse facility: systematic planning of all activities and timely communication with the logistics operator, systematic understanding of activities in warehouse facilities, correct reading of simulation results in the warehouse facility. energy efficiency improvements and systematic presentation of results and guidelines for the continuation of activities through a report submitted to the warehouse operator. Ignoring any of the above five key steps, an energy audit of a warehouse facility will not yield the expected results.

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