Key assumptions of energy-consumption analysis for the functioning of a logistics center

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Abstract. The study aims to present the key assumptions of the energy-consumption analysis for the functioning of a logistics center. The leading energy carriers used in the logistics center were identified, and factors determining the level and structure of its consumption were indicated. Using the indicator method, a catalog of indicators for the energy consumption analysis for the functioning of a logistics center was created.

Introduction

The world is using more and more energy, and this trend is permanent. There is no possibility to balance the demand for energy both on the scale of our globe or continents, as well as individual countries without measures aimed at rational use of energy. Rational use of energy is most often more economical than the construction of new generation capacities based on still imperfect technologies. This fact determined that in terms of energy, the modern economy puts a strong emphasis on rationalizing energy consumption while maximizing the global economic effect. Increasing energy efficiency by 20% in 2020 is the goal set by the European Union.

In general, energy can be characterized in terms of sources and forms. The following energy sources are distinguished: energy of fossil fuels, solar energy, wind energy, water energy, geothermal energy, see tides energy, ocean heat energy. Because these sources come from nature, they constitute a group of primary energy carriers. In addition to primary energy, secondary energy (derivative) is also specified, which comes from energy derivatives, i.e., those obtained in the process of energy conversion. Among the secondary energy carriers, electricity, heat and gaseous fuels are most often mentioned in technological processes [3]. By exchanging these examples, one can see that the energy takes various forms, with each form being changed into another. The most important forms of energy include electricity, heat energy, nuclear energy, radiant energy. The first three forms of these are the most important for logistics infrastructure [2].

Currently, in the study of energy consumption has become an important control energy indicators. Methods using energy indicators are widely used for many tasks. They are a common approach in statistical analyzes regarding the energy condition of an object [4, 5, 6]. They are used for comparisons of benchmarking processes, as well as for monitoring the effectiveness of energy-saving implementations or forecasting the demand for energy carriers in the aspect of ecological effects. [7, 8, 9].

The study aims to present the critical assumptions of the energy-consumption analysis for the functioning of a logistics center. The logistics center is understood here as a warehouse building, i.e., a profiled logistics center, as well as a comprehensive center (logistic park, seaport). Due to the conceptual

(pragmatic) character of the study, the traditional literature review was abandoned. Thus the discussion was chosen as a form of reflection.

Discussion

When analyzing the energy consumption of storage infrastructure in the use phase, one should ask the fundamental question of whether to take into account the building itself or should its equipment be included as well? Because the analysis concerns the functioning of the warehouse, it is understandable that the analysis should cover not only the building but also all the devices that are in it. This approach is additionally confirmed by the energy performance certificate, in which the description is subjected to the energy needed for the operation of the warehouse, i.e., energy consumed for the implementation of its utility functions.

The underlying carriers of direct energy consumed during the use of the warehouse are: electricity for lighting, electricity for the drive of storage equipment, electricity for driving internal transport, electricity for powering communication devices, electricity for powering computer equipment, electricity for air conditioning, electricity for power chillers, hot water, heat for heating and ventilation. As can be inferred, the analysis of energy consumption by the warehouse in the phase of use performed on an ongoing basis boils down to three elementary issues:

- What is the structure of energy consumption in a warehouse at a given time (year, quarter, month)?
- What is the amount of energy consumption for a given medium at a given time?
- What is the share of individual energy carriers in total energy consumption in a given time?

Because the construction of warehouse facilities is carried out based on individual projects, the equipment is selected for the specific needs of the owner. This makes it difficult to give one formula for all energy carriers. Therefore, one can propose the following formula:

$$E_{cm} = E_{m1} + E_{m2} + E_{mi} \tag{1}$$

where:

 E_{cm} - total energy consumed in the warehouse,

 $\sum E_m$ - the sum of energy consumed by the i-th energy carrier at a given time during the warehouse operation phase,

i – the number of energy carriers.

In addition to this fundamental analysis - similarly to the analysis of cumulated energy consumption at the construction stage - the approach to analyzing cumulated energy consumption can also be used for the operation phase. Two streams of cumulative energy consumption can be considered. The first one expresses the cumulated energy consumption used to acquire and supply direct energy carriers consumed in the warehouse during use in the form of fuels and energy. The second stream relates to the cumulative energy consumption used for the production and delivery of direct energy carriers in the form of warehouse equipment.

If the analysis of energy consumption at the stage of use of the warehouse is to be complete, the performed operations should be taken into account as well, and more strictly - the service, renovation, and modernization procedures. Then, the energy needed to perform operations, manufacture of consumables and transport, or storage of these materials will be taken into consideration. The formulas for determining the level of cumulative energy consumption in these three cases will be analogous to the formulas presented for the cumulative energy consumption at the construction stage. To sum up, at the stage of warehouse operation, in the analysis of energy consumption, it is possible to consider the consumption of direct energy; energy consumed during the performance of operations and cumulated energy consumption.

From the economic point of view, the analysis of the energy efficiency of energy carriers is also essential at the stage of storage use. Then, the ratio of energy inputs to the effects of the warehouse should be taken into account, and in more detailed terms - the effects of devices involved in the implementation of the storage process. For example, one can analyze the ratio of the energy consumed within one hour of the forklift truck or the work of one refrigerating unit, energy consumption per 1 m^2

of warehouse space. Table 1 presents the most important indicators of the energy efficiency analysis of energy carriers used in the use of the warehouse.

Table 1. Fundamental indicators of the energy efficiency analysis of energy carriers used in the use of the warehouse		
Indicator	Formula	Description
The basic index of the warehouse energy efficiency	1) $WEE_{Mbasic} = \frac{E_{cm}}{P}$	 1) 1) expresses the amount of total energy consumed [MWh] about the total warehouse area [m²] for the unit period 2) approach the amount of total energy consumed [MWh]
	2) $WEE_{Mbasic} = \frac{E_{cm}}{P_z}$	 2) 2) expresses the amount of total energy consumed [MWn] about the occupied warehouse area [m²] for the unit period 3) 3) expresses the amount of the total energy consumed
	3) $WEE_{Mbasic} = \frac{E_{cm}}{K}$	[MWh] about the total cubic capacity of the storage [m ³] for the unit period
	4) $WEE_{Mbasic} = \frac{E_{cm}}{K_z}$	[MWh] about the occupied cubic capacity of the storage [m ³] for the unit period
Energy efficiency indicator for lighting	1) $WEE_{light} = \frac{E_{light}}{P}$	 1) expresses the amount of energy consumed [MWh] for lighting about the total warehouse area [m²] for the unit period
	2) $WEE_{light} = \frac{E_{light}}{P_z}$	2) 2) expresses the amount of the total energy consumed [MWh] for lighting in relation to the occupied warehouse
	3) $WEE_{light} = \frac{E_{light}}{K}$	 area [m²] for the unit period 3) 3) expresses the amount of the total energy consumed [MWb] in lighting to the total cubic capacity of the
	4) $WEE_{light} = \frac{E_{light}}{K_z}$	 (1) warehouse [m³] for the unit period 4) 4) expresses the amount of the total energy consumed
	5) $WEE_{light} = \frac{M_{light}}{P}$	[MWh] for lighting in relation to the occupied cubic capacity of the warehouse [m ³] for the unit period 5) 5) expresses the lighting power [W] in relation to the
		warehouse area $[m^3]$ for the unit period
Indicator of heating energy efficiency	1) $WEE_{heat} = \frac{E_{heat}}{P}$	 1) 1) expresses the amount of energy consumed [MWh] for heating in relation to the total warehouse area [m²] for the
	2) $WEE_{heat} = \frac{E_{heat}}{P_z}$	2) 2) expresses the amount of the total energy consumed[MWh] for heating in relation to the occupied warehouse
	3) $WEE_{heat} = \frac{heat}{K}$	 area [m²] for the unit period 3) 3) expresses the amount of the total energy consumed DAW/bl in basing relative to the total applie appearing of
	4) $WEE_{heat} = \frac{heat}{K_z}$	 the storage [m³] for the unit period 4) 4) expresses the amount of the total energy consumed
The officiency of	Proof	[MWh] for heating in relation to the occupied cubic capacity of the warehouse [m ³] for the unit period
devices in heating and	1) $EER = \frac{1}{P_e}$	supplied cooling power to the electric power consumed. If $EER = 3$, i.e., using 1 kWh of electricity, 3 kWh of cold is
cooling mode	2) $COP = \frac{ncar}{P_e}$	 supplied to the room (or 3 kWh of heat removed). 2) COP (Coefficient Of Performance) - a factor that determines the officiency in heating mode. It is the ratio of
		the heating power supplied to the electric power consumed. If $COP = 3$, it means that by using 1 kWh of
		electricity, it is delivered to the room of 3 kWh of heat.

Source: Dembińska I 2018 Infrastruktura logistyczna gospodarki w ujęciu środowiskowych uwarunkowań zrównoważonego rozwoju (Szczecin: Wydawnictwo Naukowe Uniwersytetu Szczecińskiego p. 290-291)

It should be noted that considering the warehouse building itself in the analysis of energy demand is an incomplete approach. Warehouse buildings, whether for component or distribution purposes, are

always part of the facility, where apart from small buildings, there are also storage yards and maneuvering areas. Their functioning also involves energy consumption. It is mainly used for lighting. Therefore, the analysis of energy consumption, in addition to the analysis related to a warehouse building, should apply to the entire logistics facility, including energy consumed outside the warehouse building, throughout the entire logistics facility, but not other buildings with different functions, but with storage vards. Maneuvering and so-called green areas are belonging to the logistics facility. Speaking of other buildings than the warehouse, an office building should be considered, which can be an integrated part with a storage building or be a separate building. It should also be borne in mind that in the case of centers adapted for comprehensive service, in addition to warehouses, there are also buildings for other purposes, such as car workshops, car washes, production plants, etc. In the area of the transport center, due to defined functions, warehouse buildings it is not there. Energy consumption occurs as a result of the operation of mainly transshipment yards, maneuvering areas, although workshops and car washes may also be found here. Taking into account these remarks, in the analysis of energy consumption by a logistic object in the form of a logistic center, it is possible to propose using the formula:

$$E_{ccl} = \sum E_{em} + \sum E_{ea-b} + \sum E_{et} + \sum E_{ep} + \sum E_{ed} + \sum E_{ez}$$
(2)

where:

 $\sum E_{ccl}$ – total energy consumed in the area of the center / logistic park, $\sum E_{em}$ - total energy consumed in warehouse buildings,

 $\sum E_{ea-b}$ – total energy consumed in administrative and office buildings,

 $\sum E_{et}$ – total energy consumed in technical service buildings,

 $\sum E_{ep}$ - total energy consumed on maneuvering yards, transhipment sites, container terminals, etc.,

 $\sum E_{ed}$ - total energy consumed in connection with the functioning of additional components of the logistics facility, e.g. ra, ilway infrastructure, parking lots, hotel and catering facilities,

 $\sum E_{ez}$ – total energy used for the so-called green areas.

In the energy-consumption analysis of a building, one can meet the concept of energy quality of a building. It is defined by a set of building properties, on which depends on the size of the annual energy demand related to its use. The energy quality of the building is determined by the thermal protection features of the building and the features of heating, ventilation and hot water supply systems. The lighting system is not considered here. Therefore, the energy consumption of a warehouse building is influenced by:

- the architecture of the building: the location of the building relative to the sides of the world, the layout of the rooms, the geometry of the building,
- warehouse location,
- constructional solutions of the building,
- type of material from which it is made, •
- warehouse area,
- building insulation,
- degree of mechanization, warehouse automation, •
- number of devices and means of internal transport powered by energy,
- type and number of lighting points,
- type and efficiency of the heating system,
- type and efficiency of the cooling system,
- type and efficiency of ventilation,
- the occurrence of refrigeration units,
- use of alternative energy sources,
- requirements for stored stocks related to energy consumption,
- organization of the warehouse work,
- warehouse management system, including the inclusion of energy-efficient policy.

The energy consumption of a logistics center is determined by the following factors: location, number and purpose of buildings, architecture, construction solutions, building insulation, type of material from which buildings are made, number and purpose of squares, surfaces of buildings and squares, energy consumption of components of the logistics center, organization of the logistics center work, level of mechanization, automation of the logistics center.

The impact of these factors is noticeable. It seems that you do not need these relationships here. One can only refer to the location factor because this issue was not discussed earlier. Speaking of location, in reality, it is about climatic zones, and more specifically - by the number of degree days. It should be indicated in which climate zone and the meteorological station there is a building. This is important both at the design stage and the current operation of the building. It can also be briefly mentioned that the degree of shading affects the building's energy consumption. Warehouses, centers or logistic parks are usually located in open space. This has a positive effect on shaping the energy-consumption factor.

Conclusion

In summary, the cumulative energy analysis of logistic facilities can be used for the following purposes:

- to compare energy expenditures used for constructing or decommissioning a logistics facility using various technologies,
- to study the variability and dynamics of energy consumption during the operation of logistic facilities under the influence of various factors,
- to study changes in the national energy demand in the construction of a specific unit of a logistics facility (1 km of road, 1 m² of warehouse space),
- to assess the impact of a specific substitution of energy carriers on primary energy consumption,
- to study the share (structure of consumption) of primary energy carriers in individual phases of the life cycle of a logistics facility,
- To study the share of renewable energy carriers in individual phases of the life cycle of a logistics facility.
- Besides, studies on the energy consumption of logistic facilities may concern:
- a single building object, i.e., a road, warehouse, etc.,
- groups of objects in a given area, e.g., a center or a logistics park, a network of highways,
- construction facilities throughout the country.

They may refer to the whole life cycle of a logistics facility, as well as may refer to a selected stage. They serve both analytical purposes and may form the basis for comparative analyses.

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