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Exergoeconomic Analysis of Air Cooling Systems

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Abstract. In this study exergoeconomic analysis is realized when selecting the most economical energy-saving air cooling system. Calculations exergy efficiency, exergetic streaming charts and diagrams exergy cost are given.

Keywords: HVAC systems, exergoeconomic analysis, exergetic air flow diagram, exergy efficiency «brutto» and «netto», exergetic cost diagram of air flow.

Introduction. Ukrainian National standards require to identify and evaluate equipment for heating, cooling and drying air for buildings and structures for various purposes by indicator of efficiency [1]. There is no appropriate methods for specified equipment. In this paper we propose a technique stepwise evaluation of energy saving performance of air conditioning systems based on modern exergo-economic theory. Advanced exergy analysis makes it possible to evaluate the energy efficiency of HVAC systems at each stage of the design. During the design of these systems is difficult to clearly evaluate and confirm the energy efficiency arguments. Exergetic analysis, based on in-depth evaluation of exergy destruction of all its components, allows you to identify and correctly evaluate the most rational from the point of view of energy efficiency solutions. The presented method is based on in-depth exergy analysis moist air, which allows you to determine the destruction of all components of exergy of moist air.

Different air drying processes have their disadvantages and features. From our point of view of energy efficiency criteria for these processes may serve as a relative assessment of energy consumption, given the reference to the parameters of the environment.

Turn-based assessment of energy efficiency of air conditioning systems enables at each stage of the design to evaluate the energy consumption of technical options and adjust it.

Informative assessment thus gives exergetic flow charts. With their help, you can correctly identify the most energy-intensive processes.

Selecting power air conditioning system one of the important points in the final design is a valuation cost of exergetic flows.

The results show that the extended exergy analysis together with exergy flow diagrams gives the correct numerical results in selecting the most economical system.

The relevance of the study. Determination of energy saving HVAC system is an urgent task, which enables optimization in terms of energy consumption at all stages of the life cycle of the equipment design of structures, in their design and operation. When choosing HVAC system circuit design and their comparison among themselves for the possibility exergic criteria appear correct numerical evaluation of different principle of individual functional units and components. Also it may open the possibility of upgrading and development of new energy-saving systems under specific indoor and outdoor air parameters. At the time of the systems is to optimize not only exergic and exergo-economics and also variants of power supply.

Recent studies and publications. When determining the useful effect of HVAC systems different authors use different indicators. For example, the useful effect taking as values exergy air inlet at its premises, or at the outlet air conditioner. There is proposed to take this values as exergy flow of air at the outlet of the system [2]. This is not entirely correct because exergy air inlet to the serviced room does not give a full assessment of the useful effects of the HVAC unit and therefore does not characterize the assimilation effect in the room. And this factor is the beneficial effect of the HVAC unit work in accordance with its intended purpose. Assimilation effect is characterized by difference thermodynamic potentials of the indoor and outlet air. Recent studies [3], the authors define the useful effect of HVAC unit in a “clean” room as reducing exergy air. The used exergy presented as the sum of costs exergy supplied from external sources - electricity and heat. This approach to determining the exergy efficiency we seen most of the surveyed correct, but it has certain limitations.

Article Objectives. The aim of the article is to show the theoretical and practical opportunity to assess the energy efficiency with the use of exergy analysis.

Main part. For HVAC systems of technological facilities arbitration samples keeping the pharmaceutical industry must provide the following parameters: air temperature – 16 ± 2 °C and relative humidity – 30 ± 5 % [4]. For comparison of selected three schematics HVAC systems to select out the best according to the criteria of exergic efficiency – condensation, combined condensation and adsorption dehumidification. Charts air treatment in *I-d* coordinates of said circuit design are presented on the fig. 1.

The first stage has been evaluated exergy destruction in the course of its processing in the systems. Each process has been shown in exergy flow diagram (fig. 2). Reference levels for relative humidity 30 %, temperature 30 °C. In accordance with the technological requirements for the pharmaceutical industry of Ukraine relative humidity levels are divided into special – less than 30 % and a standard – 30 ... 60 %.

The diagram shows the exergy change of each air component during its processing in the HVAC system. The greatest destruction shows the mechanical component of exergy that indicate the dominance of the aerodynamic resistance on the system. The character of the curves – the uneven.

Destruction of all exergy kinds of air flow greater with $\varphi \leq 30$ % than $\varphi \geq 30$ %. This is especially seen in section 5-8 where the cooling, condensation and heating. The value of exergy destruction of air in this region is twice as much.

Figures 4 and 5 show diagram of exergy flows for the DAM method. The curves for the DAM method differs significantly from the DCM method. There have been no jumps of exergy destruction in the area of air drying, as in method DCM, but there is a significant jump in the stripping section of the curve, where the specific value of exergy is 8 kJ/kg and a thermal component dominates. Levels of jumps in the area drying such quantities as in the DCM method.

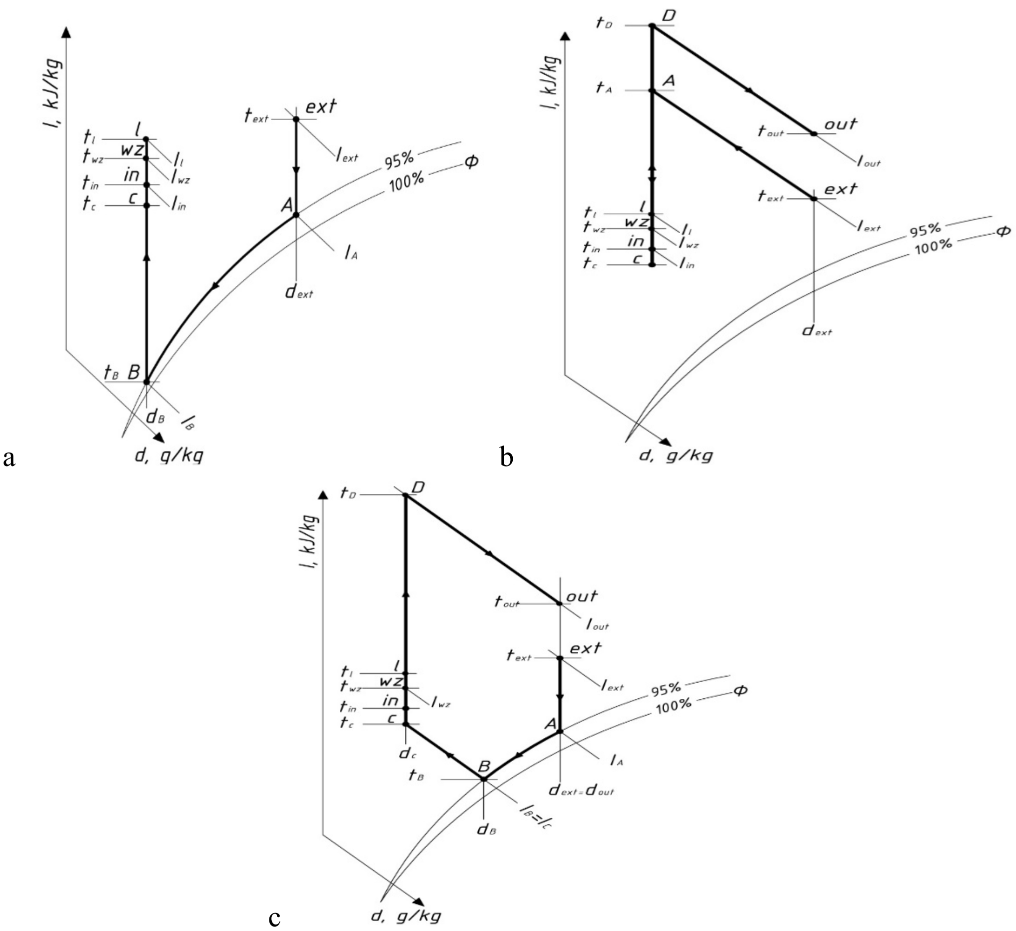

Fig. 1. Chart of air treatment in the coordinates of I-d: a - dehumidification by condensation method (DCM); b - dehumidification by adsorption method (DAM); c - combined dehumidification by condensation-adsorption method (CDCAM)

Air flow diagram for exergy in DAM scheme is smoother and has a sharp jump in only in the desorption zone, where a lot of heat is consumed.

This is typical in the whole range of relative humidity. In areas of desorption the exergy destruction is different by half.

Figures 6 and 7 show diagrams of exergy flows for the CDCAM method.

There is not much difference between the curves and the values of exergy destruction in the data charts. The difference in the values for different relative humidity observed in the desorption zone and it takes 40 %.

For each option computed exergetic efficiency "netto" by formula [5]

$$\eta_e^{net} = \Delta E_a^{in-\ell} / \Sigma \Delta E_a^{ext-in} \qquad (1)$$

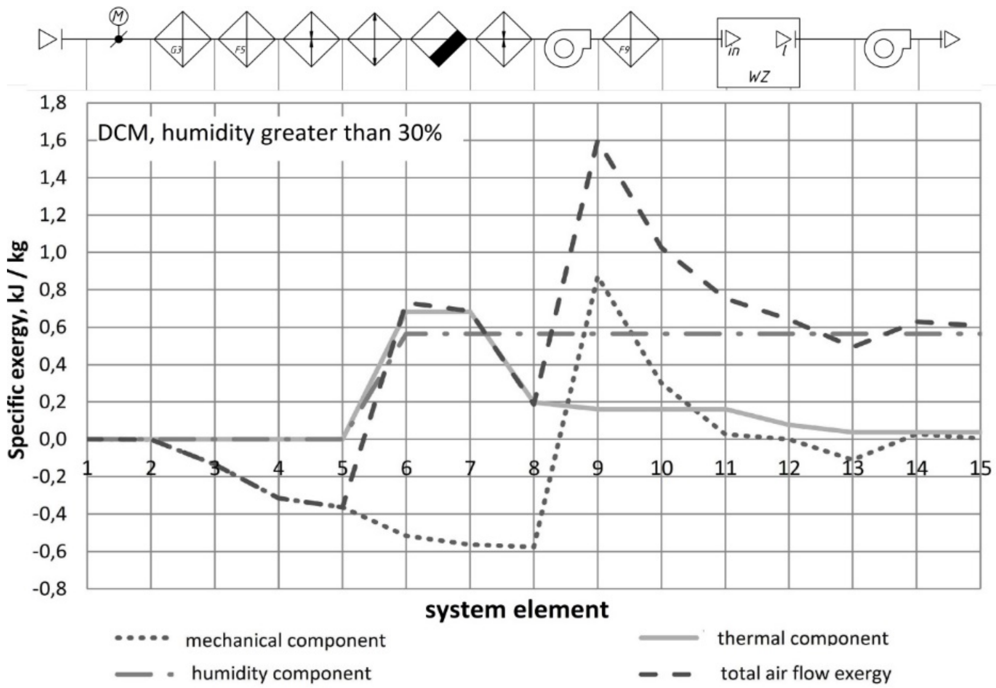

Figure 2. Exergy flow diagram for DCM (φ ≥ 30%)

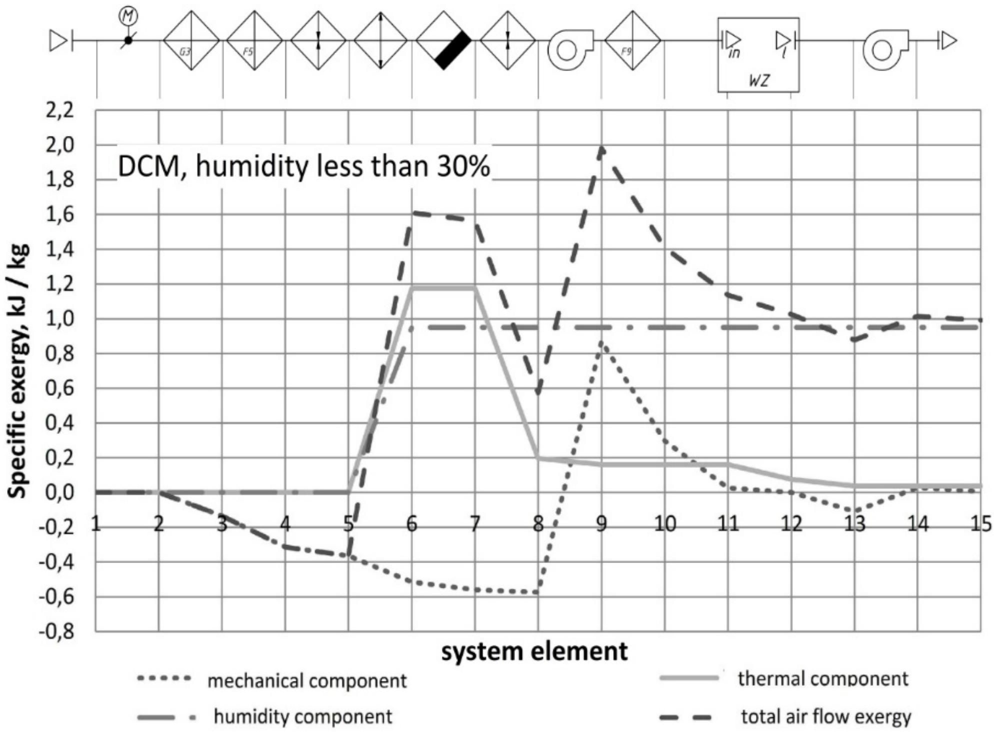

Figure 3. Exergy flow diagram for DCM (φ ≤ 30%)

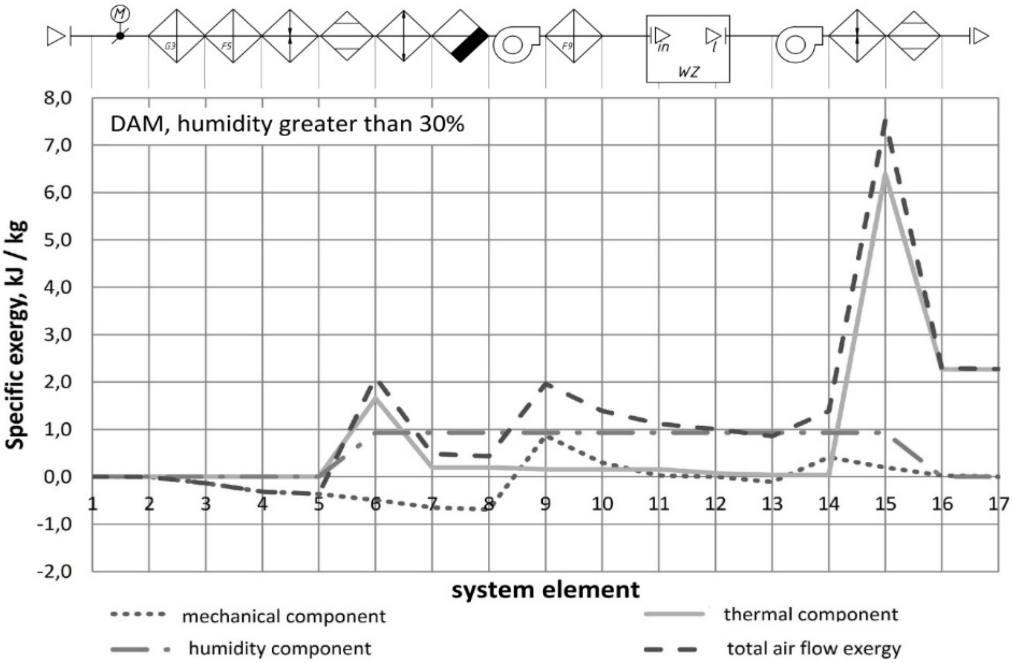

Figure 4. Exergy flow diagram for DAM (φ ≥ 30%)

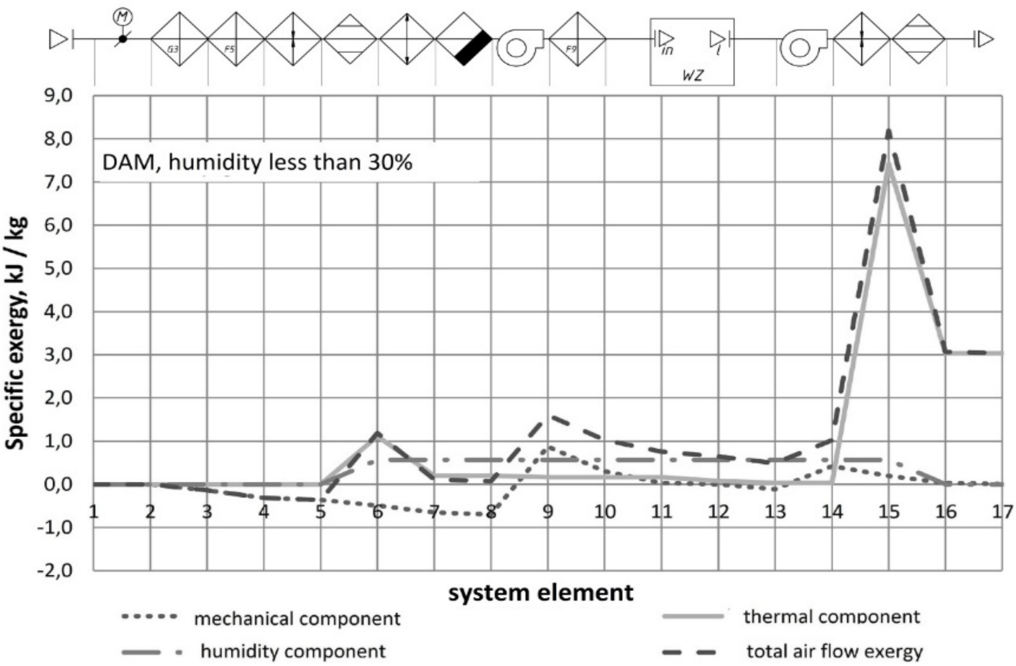

Figure 5. Exergy flow diagram for DAM (φ ≤ 30%)

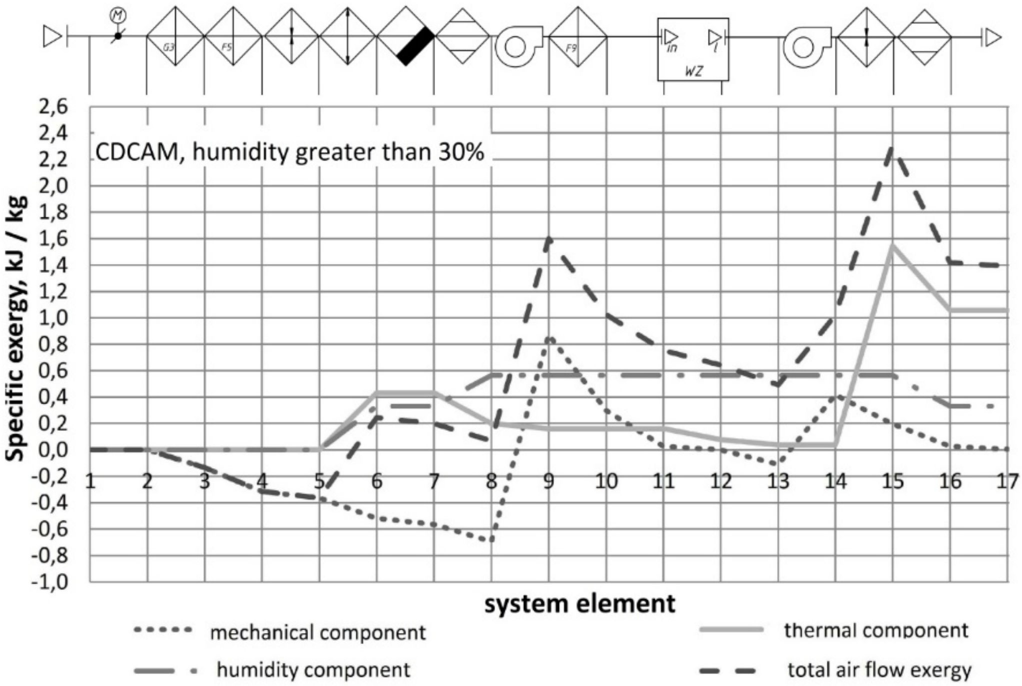

Figure 6. Exergy flow diagram for CDCAM (φ ≥ 30%)

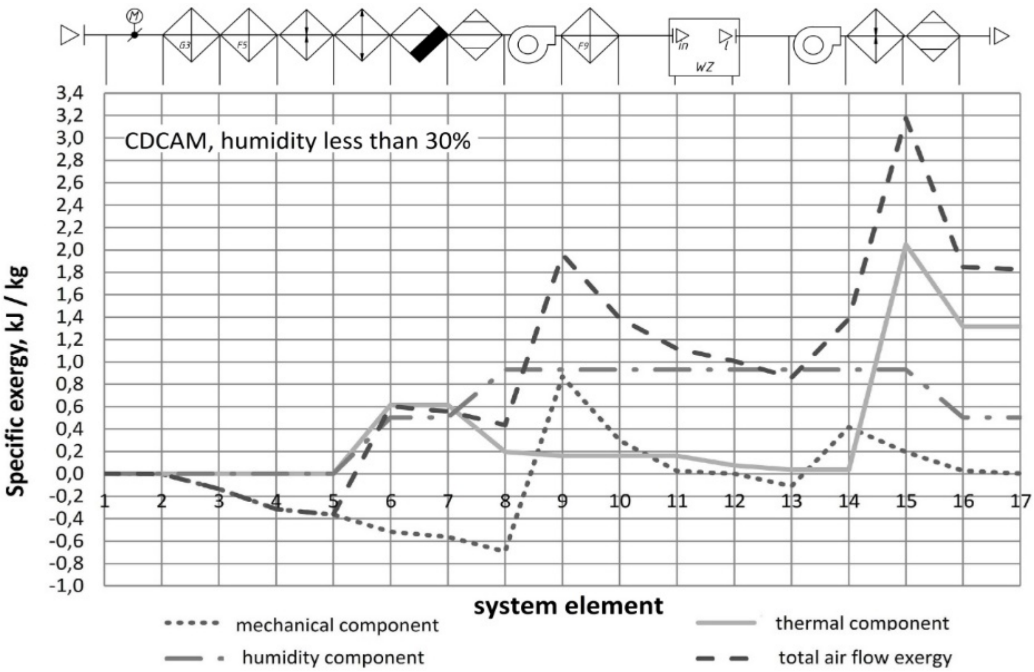

Figure 7. Exergy flow diagram for CDCAM (φ ≤ 30%)

where $\Delta E_a^{in-\ell}$ – exergy destruction of indoor air, kJ; $\Sigma \Delta E_a^{ext-in}$ – the total gross destruction of exergy in the system, kJ. Equation (1) shows the ratio of useful exergy indoor air to exergy consumed in the equipment system. Air condition parameters are taken from the *I-d* charts.

Exergy efficiency "netto" indicates the ratio of useful exergy of air in the room to the exergy consumed in equipment of the system.

Another important indicator – the exergy efficiency of "brutto". It characterizes the ratio of useful exergy to the supplied exergy. It can be calculated from the formula

$$\eta_e^{brt} = \Delta E_a^{in-\ell} / \Sigma E_{en}^{Tot} \quad (2)$$

where ΣE_{en}^{Tot} – exergy from energy sources, kJ. The calculation results are shown in table.

Table

Results of the exergetic analysis

HVAC Schematics	Relative humidity in the room ≥ 30%		Relative humidity in the room ≤ 30%	
	Exergy efficiency «netto», %	Exergy efficiency «brutto», %	Exergy efficiency «netto», %	Exergy efficiency «brutto», %
DCM	5,7	2,19	4,37	1,56
DAM	1,42	2,43	1,37	2,31
CDCAM	4,07	3,22	3,38	2,91

The table data shows that the highest value by exergy efficiency «netto» gives the DCM schematics at value of relative humidifies higher than 30 %. And if value of the relative humidity less than 30 % the highest exergy efficiency indicates design CDCAM.

As seen from the results of calculations, exergetic analysis gives correct but not complete an assessment as possible contradiction in identifying the most energy efficient way of processing when designing air systems. Based on these factors, we have assessed the cost of exergy flow according to the tariffs of "Kyivenergo" in 2016 [6].

The cost of exergy flow calculated by formula

$$C_{ex} = 1000 \Sigma E_{en}^{Tot} \rho_a C_{en}, \text{ UAH / 1000 m}^3, \quad (3)$$

where ρ_a – air specific density, kg/m^3; C_{en} – energy tariff, UAH/kJ.

The chart (Fig. 8, Fig.9) shows the increase in value of 1,000 cubic meters of air during its processing in the air conditioner. For all values of relative humidity of indoor air design CDCAM more profitable.

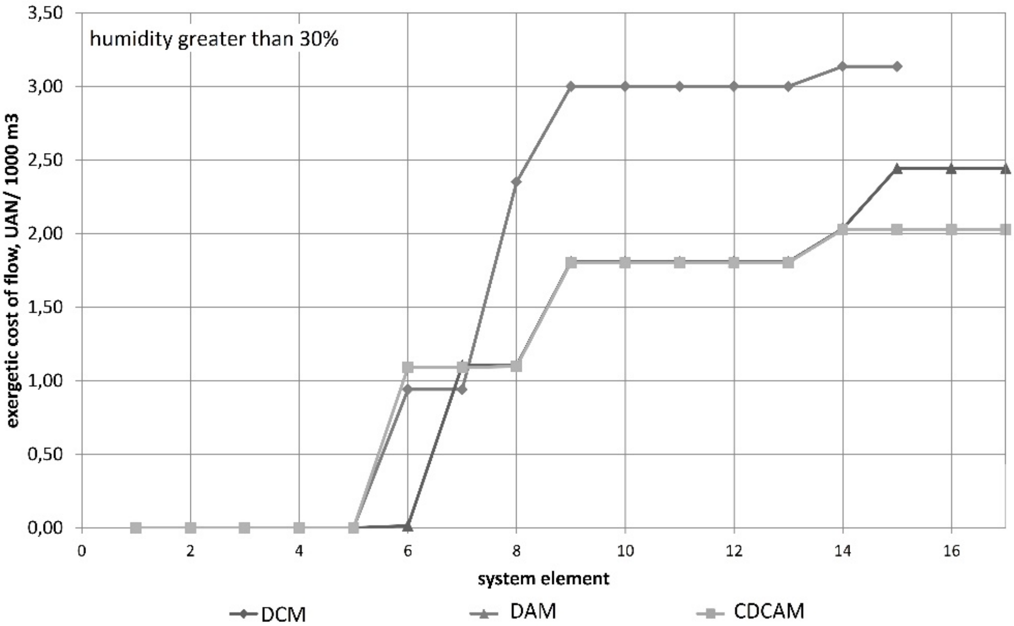

Figure 8. Exergy cost of flow (φ ≥ 30%)

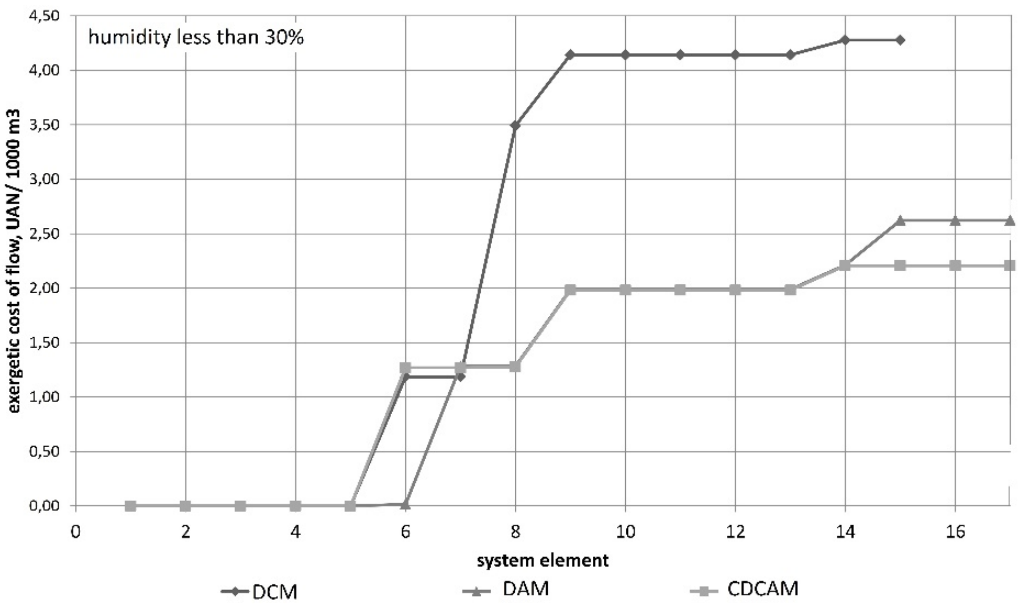

Figure 9. Exergy cost of flow (φ ≤ 30%)

From the chart it is clear that the greatest growth observed since the cost of equipment 5 position, where a lot of energy is consumed for cooling, heating and dehumidification for all types of HVAC schematics.

From the chart it is clear that the greatest growth observed from 5 position, where a lot of energy is consumed for cooling, heating and dehumidification.

The greatest increase in energy prices seen in DCM scheme where the traditional drying with condensation realized. Schemes of DAM and DCACM differ in cost value when regeneration of the adsorbent from the position 14. Endpoint exergy value circuit DCACM is 20% less than DAM.

Conclusion. Application of exergo-economics method for assessing energy saving in air treatment processes gives correct results that can be applied in the design and reconstruction systems. It should be carried out step by step to evaluate exergy efficiency "netto" and "brutto" to correct technical solutions at every stage. The final stage of exergy-economic analysis in HVAC systems is to assess the cost of the exergy supply air.

Prospects for further research. Further research directed to the improvement the exergic methods research of efficiency of air heating, cooling and dehumidification in buildings.

References

1. *Osnovni vymohy do budivel i sporud. Ekonomiia energii.* DBN V.1.2-11-2008, Minregionbud Ukrainy, 2008.

2. Brodianskii V. M., Verkhivker G. P., Karchev Ya. Ya. *Eksergeticheskiie raschety tekhnicheskih sistem*, edited by Dolinskii A. A., Brodianskii V. M. Naukova Dumka, 1991

3. Labai *V. I., Garasim* D. I. "Stan i perspektyvy pidvyshchennia energoefectyvnosti system kondytsiiuvannia povitria chystykh prymishchen." *Naukovo-technichnyi zbirnyk «Energoeffektyvnist v budivnytstvi ta arkhitekturi»,* Iss. 6, KNUBA, 2014

4. *Sanitarni normy mikroklimatu vyrobnychykh prymishchen.* DSN 3.3.6.042-99. Ministry of Health Protection of Ukraine, 1999.

5. Zadoiannyi *O. V.* "Eksergetychni kryterii pry otsintsi energooshchadnosti system kondytsionuvannia povitria budivel i sporud." *Ventyliatsiia, osvitlennia ta teplohazopostachannia: naukovo-tekhnichnyi zbirnyk*, Iss. 17, 2014, P. 3-9.

6. *Rozdribni taryfy dlia spozhyvachiv elektrychnoi energii u misti Kyievi*. http://kyivenergo.ua/ee-company/ . Accessed 12.10.2016.

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Ексергоекономічний аналіз систем кондиціонування повітря

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Анотація: В роботі подано методологію ексергоекономічного аналізу при виборі найбільш енергоощадного схемного рішення системи кондиціонування повітря. Представлено розрахунки ексергетичної ефективності, діаграм ексергетичних потоків та ексергетичної вартості.

Ключові слова: системи кондиціонування повітря, ексергоекономічний аналіз, ексергетичні потокові діаграми, ексергетична ефективність «нетто» та «брутто», ексергетична вартість.

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Эксергоэкономический анализ систем кондиционирования воздуха

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Аннотация: *В работе показана методология эксергоэкономического анализа при выборе наименее энергозатратного схемного решения системы кондиционирования воздуха. Представлены расчёты эксергетической эффективности диаграммы эксергетических потоков и эксергетической стоимости.*

Ключевые слова: системы кондиционирования воздуха, эксергоэкономический анализ, эксергетические потоковые диаграммы, эксергетическая эффективность «нетто» и «брутто», эксергетическая стоимость.

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