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Expert system on efficiency evaluation of continuous flow grain dryer

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Abstract. The purpose of the paper is to present a concept of energy efficiency and financial evaluation of counterflow dryer. Energy efficiency and many other efficiency indexes of the dryer and all additional devices like heater, heat exchangers, tubing and fans are calculated. Expert system provides also the financial evaluation of the investment. Many investments could be considered. The system provides the user with suggestions about the best dryer for him/her. Expert system also enables evaluation of energy saving improvements. The energy savings for dryer installation sections are calculated. Cost savings are compared with investment value. The best energy saving project could be selected on the base of selection algorithm. Expert system could be used for existing and new-designed dryers.

Keywords. Energy efficiency, dryer, drying, expert system

1 Introduction

Drying consumes approximately 30–40% of the whole energy used during industrial and rural projects. After Polish EU accession the Polish Parliament has adopted EU regulations regarding energy use. Energy Law considers, among others, improving energy efficiency. In order to reduce energy consumption the Polish Government will support energy saving projects. The development of new energy standards is expected [2, 3, 4]. There are tremendous opportunities for increasing energy efficiency of convection, agricultural dryers not only under design but during exploitation as well. The system enables the use to evaluate whether or not the dryer will fulfill his/her requirements. The aim of authoress research is to build multifunctional expert system on widespread energy efficiency evaluation, selection and prospect of energy cost saving projects.

2 Drying system

After mechanical harvesting, grain moisture is too large for safe storage. Because of this initial moisture, grain must be quickly dried after harvesting. A large variety of dryers is used but a vast majority of them are convection dryers. As the representative example of all dryers of this type, the continuous counterflow dryer was established. The evaluation method described for representative dryers could be considered as an evaluation standard and modified for other types of dryers. Drying system should take into account time and space. Their life cycle phases are design, production and installation, utilization and termination. Considering space, the system is limited by carried processes. Grain drying installation presented in Fig. 1, consists of a hot air generator with heat exchanger, inlet, outlet and circulation air ducts, drying column, exhausts fans, grain conveyors, cyclones, control equipment, engines and others.

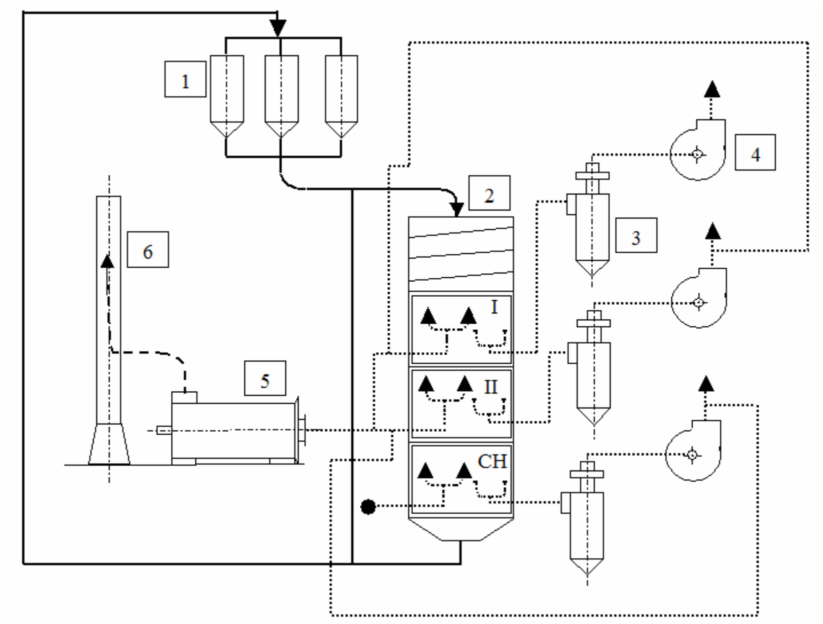

Figure 1. Drying installation. 1. Storage silo, 2. Drying column, 3. Cyclone, 4. Fan, 5. Burner, 6. Chimney

The surrounding air preheated in the burner's heat exchanger is blown through air ducts into drying column. Grain moves slowly down through drying column of the cascade type, which is build from roof shaped air ducts mounted between two walls. The ducts are alternately open in the opposite tail ends. The ducts are connected to the hot air and the exhaust pipes. The ducts are displaced in relation to each other. Each hot air duct is surrounded by four exhaust ducts at equal distances and vice versa. The dryer is built of two drying and one cooling sections. Energy consumption of the drying systems is massive. Hot air and combustion fumes are removed to the surrounding air, grain is not preheated, pipes and drying columns are not insulated properly, as shown in Fig. 2. Dryer owners even do not know, how inefficient and expensive their installations are and if there is any possibility to improve system efficiency. New owners thinking of installing drying system cope with multi-criteria decision making. Traditional single decision making methods aimed at maximalization of benefits with minimalization of costs are no longer sufficient. Market context also influence decision making.

Figure 2. Grain dryer situated next to grain storage complex.
Note damaged pipes insulation

3 System environment

Environment is defined as all elements residing outside of the drying system's boundary and has the potential to affect processes occurring in it. Various environmental dimensions influence drying systems. The drying system environment can be viewed as a set of dimensions that include the surrounding environment and its variables: air humidity, temperature and pressure, location, eco-nomy system and its variables for example fuel and electricity prices, interest rates, taxes, law system and its prescriptions. Many variable factors influence decision making, with regard to the dryer system evaluation.

4 Energy efficiency

In order to evaluate the energy efficiency of drying system a two-fold approach was used. Firstly dryer installation was considered as a system, secondly, the system was decomposed into subsystems, which were installation units.

Mathematical models described both the whole installation and every unit. During modelling thermodynamical approach was adapted [6]. All processes were considered as steady state and deterministic. On the basis of process variables and parameters, efficiency indexes were defined. Using mathematical models, required indexes values were determined [8]. The indexes are correlated, so only a selected group was used for system evaluation. Those ratios could be used for evaluating not only the real, working dryers but new-designed dryers as well. The indexes enable evaluating system and subsystems. Even, if information regarding drying process is incomplete it is possible to estimate drying system usefulness. It is possible to judge a system operation by its indexes values. The aim of expert system is to evaluate an entire drying system, assess every part of the system and indicate this installation part that could be improved. Expert system could become a part of audit methodology providing facilities and processes assessment.

5 Financial analysis

The design of drying systems represents a decision about how grain will be dried, how efficient it is and the dryer's performance. Based on technological analysis there are always a few dryers that fulfill process requirements. The same result could be achieved in any number of ways. The final design must accomplish the same objectives but perhaps with different costs and performance consequences. Besides technology limitations economics must also be taken into account in the choice of design. The best configuration cannot be determined from a technical qualities alone. It is necessary to pick from among many possible configurations, each of which may appear equally effective from technical point of view.

Financial analysis addresses two problems. Firstly, new investment is considered. Secondly, for existing drying installations energy saving improvements are examined. In both cases the same financial methods are used. The selection of the best configuration is determined by comparing costs and relative values associates with them. Among others the following methods are used: net present value, internal rate of return, payback period, break-even value analysis and utility theory [5].

5.1 New Systems

After technical analysis the set of possible alternatives are presented. This is a limited list of the potential projects that could actually be chosen. All those alternatives must be compared from the investment point of view. First of all the study period, over which the analysis will be performed, must be defined. Generally it is not the dryer's life period but most often is defined by accountancy law as the amortization period. The next step is to define cash flows for each alternative: initial cost, salvage value, annual receipts, and annual disbursements. Due to a long amortization period it could be useful to specify interest rate and compare all cash flows at the given point in time usually the start of the project. However, from a practical point of view, sometimes time value of money is not taken into account.

The most important matter is to select the criteria for judging projects. The ones that do not fulfill the requirements are detained. Payback period must not be longer than the amortization period or life period. The net present value of every considered project must be at least greater than zero. Internal rate of return must be the highest possible and must not be lower than alternative rates of bank investments. Break-even analysis compares fixed and variant cost and income.

5.2 Existing systems

Existing drying systems are frequently inefficient. In order to consider possible energy savings energy data must be acquired. This data provides information on fuel and electricity consumption, hours of use and operating conditions. A few energy saving solutions are proposed in expert system. These are: installing of heat exchangers, insulating of the pipes, drying column insulating, hot air recirculation and grain preheating. In these cases energy savings are calculated. Cost savings are derived from energy prices, which are dependent on uncertain projections. Energy prices could vary significantly thus energy savings must be significant as well. Energy costs are compared with project costs for each considered improvement. The same evaluation methods as discussed previously.

6 Other facets

Drying systems analysis depend on direct energy expenditure, energy consumption at the beginning of the process, when entire installation must be preheated, energy consumption, called cumulative energy consumption, during previous processes of dryer producing and installing.

Drying system influence surrounding environment. Waste and exhaust gases cause environmental contamination with connected charges. Efficiency could be considered not only from the energy point of view but could take into consideration time, profit, alternative cost, non-energy materials consumption, social considerations and termination costs.

These factors could be quantitative and qualitative. If only quantitative elements were taken into account multi-dimensional optimization could be used. This method does not accept qualitative data. In order to cope with different data sets expert system was used for evaluating drying system both: under construction and exploited so far.

7 Expert system for drying system evaluation

Evaluation process was presented as a hierarchy with the objective at the top and criterions, sub-criterions and alternatives (Fig. 3). Determination trade-offs regard new and existing drying systems. In both cases performance, energy efficiency, costs, non-energy aspects and termination problems are considered.

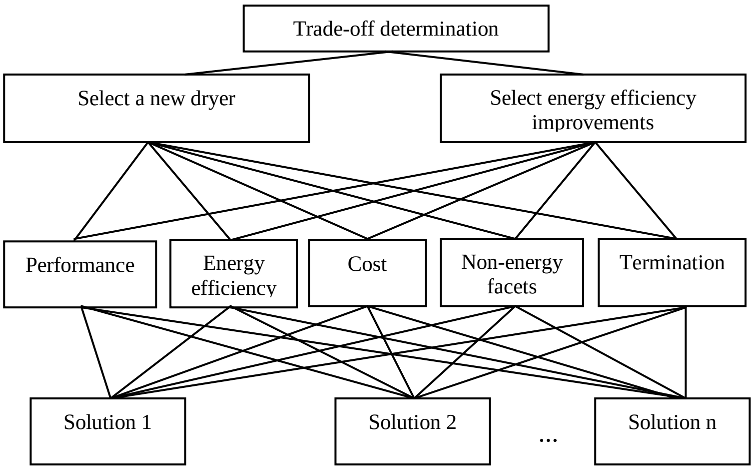

Figure 3. Objective hierarchy for drying system

Each aspect is decomposed into other criteria (Fig.4) and alternatives. Each decision criteria is considered as independent. In drying system selection case decision maker (DM) is asked for informing expert system about dryer performance: intended amount and type of dried material, planned drying period and environment conditions. On the basis of calculated output drying system suggest some of the dryers enclosed in database. Alternatively DM could enter his/her own data regarding new dryers. They are evaluated from the technological point of view. DM is then asked for entering data necessary for financial evaluation: energy prices, dryer prices, rate of interest and others. Also non-energy aspects are considered. DM could, but it is not necessary, inform expert system about materials consumption and environment contamination, social aspects, and termination problems. For criteria, where the system does not make judgments, DM is asked for eliciting his/her preferences over the objectives.

In energy improvement cases DM is asked for information regarding existing drying systems.

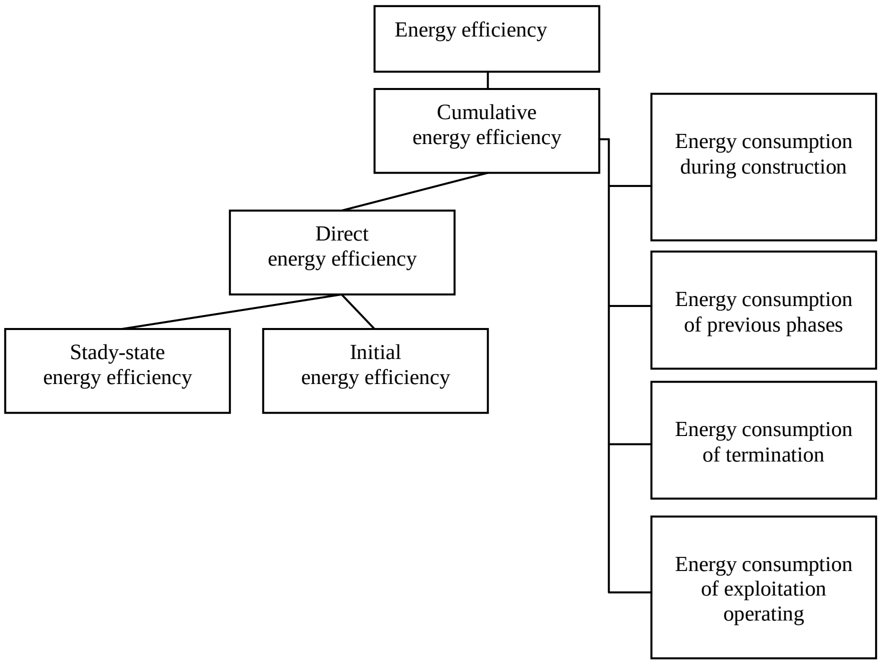

Figure 4. Factors affecting energy efficiency considered in expert system

Utility of each solution is evaluated, as in new dryer cases in terms of performance, energy efficiency, costs and other aspects. The calculation relies on many methods used in expert system, which was implemented in SPHINX. There are database connected with expert system containing drying systems data. Also mathematical models of drying process enables the proper dryer for DM needs to be calculated. The main reasoning method is backward chaining. In knowledge base there are rules that could be used in backward chaining reasoning. In more complicated cases an analytical hierarchy method could be used [7]. In the first stage the priorities of each factor on each decision tree level must be developed. For some cases, eg. energy efficiency, expert system calculates these priorities, for other cases, eg. social issues, DM will be asked for her/his judgment. All criteria are compared in pairs. The higher level objectives are defined by the set of lower level objectives beneath it. The global determination is made upon calculated ranking of the solutions.

8 Exemplification

Due to the large energy consumption the proper selection of the dryer is very important. At Warsaw University of Technology a system called Symuneuron was prepared. The system is devoted to technological designing, selection, exploitation and evaluation of counterflow dryer. Symuneuron is a hybrid system compound of several co-operating parts. The main window of the system is presented in the figure 4.

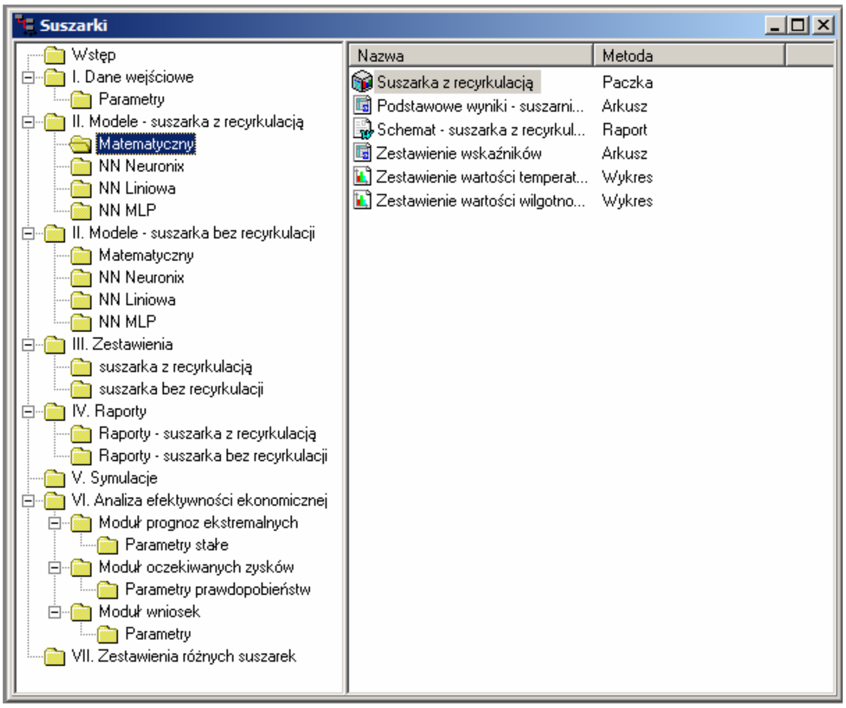

Figure 4. The main window of Symuneuron system

It is possible to design inner construction of the dryer. User could define air channels dimensions and quantity, size of the dryer, drying air volume, the way of air distribution, grain type and quantity, grain and air parameters. The parameters, which must be defined, are presented in the figure 5. When the parameters are unknown there are about 40 sample dryers available in the system. Symuneuron calculates post drying parameters of air and grain and efficiency indexes as well. In order to make this calculation the mathematical model of drying process was established. The steady conditions were assumed. Due to inconstant nature of the drying process, neural model was considered to describe it. Differential equations were replaced by neural networks, which were used in order to quicken the estimation of the real value of the humidity of grains.

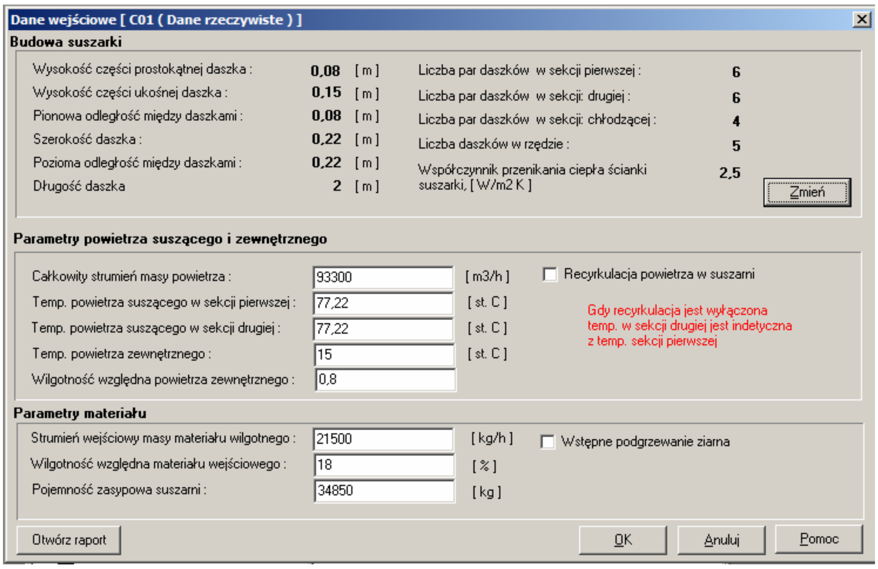

Figure 5. Entry window

Symuneuron calculates post drying parameters of drying air and grain. The results are presented in several windows. In the figure 6 the basic calculation results are presented. Symuneuron presents also detail results for air, grain and humidity. Efficiency indexes are also presented (figure 7). Besides the calculation results presented in the tables, Sankey's charts for humidity and heat transfer are presented as well.

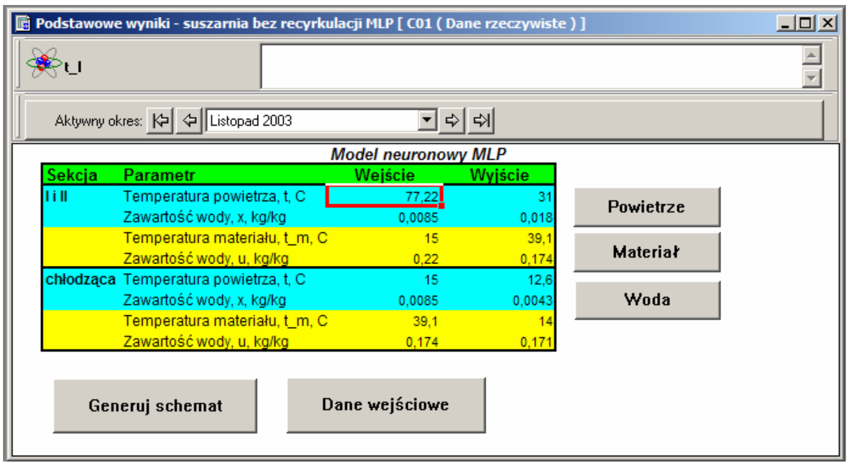

Figure 6. The window presenting the basic output data

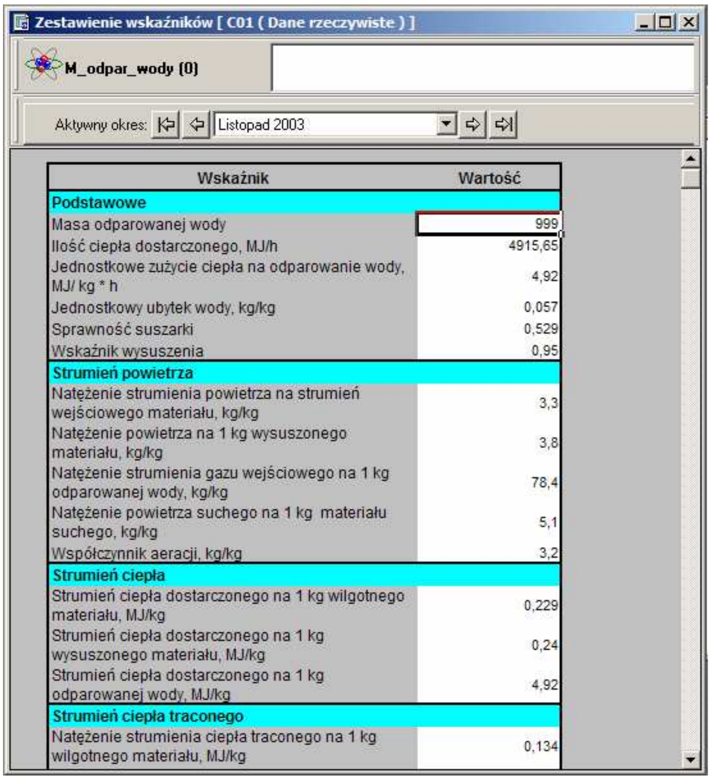

Figure 7. Symuneuron window presenting efficiency indexes

Based on the energy efficiency indexes values it is possible to evaluate the dryer. There was developed the method that provides energy efficiency evaluation. On the basis of process variables there were constructed the matrix of energy efficiency indexed. For drying system S *(1)*, its objects *(2)* and relations *(3)* were defined efficiency indexes *(4)* which were set together in indexes matrix *(5)*. The indexes relationships are presented by (6-8) equations. There were also presented detail indexes *(9)*, set in detail matrix *(10)*. The detail indexes relationships are presented by *(11-13)* equations. There have been choosen system variables (14-16) which were used for energy efficiency indexes calculation:

M - variables describing dryed material,
M’ - input material flux,
M” - output material flux,
ΔM - drying effect.
G - variables describing drying air,
G’ - input air flux,
G” - output air flux,
E - variables describing energy,

E' - input energy flux,
E" - output energy flux,
E_u - energy flux used for water evaporation.
Energy efficiency indexex were groupped in *(17)* matrix.

$$S = \langle O, R \rangle \tag{1}$$

$$O = \left\{ O_i \; ; \; i = \overline{1, I} \right\} \tag{2}$$

$$R = \left\{ R_i \; ; \; j = \overline{1, J} \right\} \tag{3}$$

$$W_{k,l} \overset{def}{=} \frac{O_k}{O_l} \quad ; \quad k, l = 1 ... K \tag{4}$$

$$W = [W_{k,l}]_{KxK} = \begin{bmatrix} W_{1,1} & W_{1,2} & ...... & W_{1,K} \\ W_{2,1} & W_{2,2} & ...... & W_{2,K} \\ ...... & ...... & ...... & ...... \\ W_{K,1} & W_{K,2} & ...... & W_{K,K} \end{bmatrix} \tag{5}$$

$$\forall \quad k = l, \; k, l \in (\overline{1, K}) : \; W_{k,l} = 1 \tag{6}$$

$$W_{k,b} \cdot W_{b,k} = W_{k,l} \quad ; \; b = 1, ... \; K \tag{7}$$

$$\forall \quad k \neq 1 \in (\overline{1, K}) : \; W_{k,l} = \frac{1}{W_{l,k}} \tag{8}$$

$$W_{k,l}^{i,j} \overset{def}{=} \frac{O_{k\,i}}{O_{l\,j}} \quad ; \quad k, l = 1 ... K \quad ; \quad i, j = 1 .... J \tag{9}$$

$$W = [W_{k,l}^{i,j}]_{KxK} = \begin{bmatrix} W_{k,l}^{1,1} & W_{k,l}^{1,2} & ...... & W_{k,l}^{1,J} \\ W_{k,l}^{2,1} & W_{k,l}^{2,2} & ...... & W_{k,l}^{2,J} \\ ...... & ...... & ...... & ...... \\ W_{k,l}^{I,1} & W_{k,l}^{I,2} & ...... & W_{k,l}^{J,J} \end{bmatrix} \tag{10}$$

$$\forall \; k, l \in (\overline{1, K}), \; \forall \; i, j \in (\overline{1, J}) : \; W_{k,l}^{i,j} = \frac{1}{W_{l,k}^{j,i}} \tag{11}$$

$$\forall \; k = l, \; k, l \in (\overline{1, K}), \; \forall \; i = j, \; i, j \in (\overline{1, J}) : \; W_{k,l}^{i,j} = 1 \tag{12}$$

$$W_{k,b}^{i,1} \cdot W_{b,l}^{1,j} = W_{k,l}^{i,j} \quad ; \; b = 1, ... K, \; i, j = 1 ... J \tag{13}$$

$$M = \{M', M'', \Delta M\} \tag{14}$$

$$G = \{G', G''\} \tag{15}$$

$$E = \{E', E'', E_u\} \tag{16}$$

$$W = \left[\begin{array}{cc|ccc|cc|ccc}
 & & & M & & G & & & E & \\
 & & M' & M'' & \Delta M & G' & G'' & E' & E'' & E_u \\
\hline
 & M' & 1 & \frac{M'}{M''} & \frac{M'}{\Delta M} & \frac{M'}{G'} & \frac{M'}{G''} & \frac{M'}{E'} & \frac{M'}{E''} & \frac{M'}{E_u} \\
M & M'' & \frac{M''}{M'} & 1 & \frac{M''}{\Delta M} & \frac{M''}{G'} & \frac{M''}{G''} & \frac{M''}{E'} & \frac{M''}{E''} & \frac{M''}{E_u} \\
 & \Delta M & \frac{\Delta M}{M'} & \frac{\Delta M}{M''} & 1 & \frac{\Delta M}{G'} & \frac{\Delta M}{G''} & \frac{\Delta M}{E'} & \frac{\Delta M}{E''} & \frac{\Delta M}{E_u} \\
\hline
G & G' & \frac{G'}{M'} & \frac{G'}{M''} & \frac{G'}{\Delta M} & 1 & \frac{G'}{G''} & \frac{G'}{E'} & \frac{G'}{E''} & \frac{G'}{E_u} \\
 & G'' & \frac{G''}{M'} & \frac{G''}{M''} & \frac{G''}{\Delta M} & \frac{G''}{G'} & 1 & \frac{G''}{E'} & \frac{G''}{E''} & \frac{G''}{E_u} \\
\hline
 & E' & \frac{E'}{M'} & \frac{E'}{M''} & \frac{E'}{\Delta M} & \frac{E'}{G'} & \frac{E'}{G''} & 1 & \frac{E'}{E''} & \frac{E'}{E_u} \\
E & E'' & \frac{E''}{M'} & \frac{E''}{M''} & \frac{E''}{\Delta M} & \frac{E''}{G'} & \frac{E''}{G''} & \frac{E''}{E'} & 1 & \frac{E''}{E_u} \\
 & E_u & \frac{E_u}{M'} & \frac{E_u}{M''} & \frac{E_u}{\Delta M} & \frac{E_u}{G'} & \frac{E_u}{G''} & \frac{E_u}{E'} & \frac{E_u}{E''} & 1
\end{array}\right] \tag{17}$$

The evaluated dryer is compared with theoretical dryer without air recirculation. For every efficiency index, criterion values were defined. The scope of indexes values were divided into four classes: very good, good, satisfactory and poor. These values were considered as possible values. The values different that defined, were considered as unsatisfactory. For dryer efficiency E_u/E' defined as the proportion of energy used for evaporation and energy supplyed, theoretical efficiency have been calculated. The indes of evaluated dryer is compared with the index $\eta_{\max}$ for theoretical dryer and its classes defined in table 1. The dryer defined in the Symuneuron system (figure 5) was evaluated as satisfactory. The indexes values and the scopes of the values are presented in table 2. The system were evaluated acc. to the decision rules presented in the figure 8.

Table 1. Eficiency values for theoretical dryer withour recirculation

Index class	Index $E_u / E' = \eta_s$
very good	$\eta_s \geq \eta_{\max}$
good	$\eta_{\max} > \eta_s \geq 0{,}8 \cdot \eta_{\max}$
satisfactory	$0{,}8 \cdot \eta_{\max} > \eta_s \geq 0{,}6 \cdot \eta_{\max}$
poor	$0{,}6 \cdot \eta_{\max} > \eta_s \geq 0$
unsatisfactory	$\eta_s < 0$

Table 2. Energy efficiency values for the dryer defined in the figure 5.

Index	Index value	Class	Class values calculated acc. to theoretical dryer without recirculation
E_u/E'	0,4905	satisfactory	<0,3699; 0,4922)
E_u/E"	0,9628	satisfactory	<0,9731; 1,6075)
E"/E'	0,5095	satisfactory	(0,05067; 0,6302>
G"/G'	1,0086	satisfactory	<1,0073; 1,0095)
M"/M'	0,9574	satisfactory	(0,9533; 0,9639>
ΔM/M’	0,0426	satisfactory	<0,0361; 0,0467)
ΔM/M”	0,0445	satisfactory	<0,0374; 0,0490)
G'/M'	4,8603	satisfactory	<4,6329; 5,7933)
G'/M"	5,0766	satisfactory	<4,855; 6,0225)
G’/ΔM	114,0534	satisfactory	<108,99; 135,21)
G"/M'	4,9022	satisfactory	<4,72; 5,84)
G"/M"	5,1204	satisfactory	<4,93; 6,11)
G”/ ΔM	115,0377	satisfactory	<110,58; 137,05)
E'/M'	229,3811	satisfactory	(228,12; 304,16>
E'/M"	239,5911	satisfactory	(238,27; 317,70>
E’/ΔM	5 382,7505	satisfactory	(5353,19; 7137,69>
E"/M'	116,8631	satisfactory	(115,6; 191,64>
E"/M"	122,0648	satisfactory	(120,75; 200,17>
E”/ ΔM	2 742,3576	satisfactory	(2712,8; 4497,2>
E_u/M'	112,5180	satisfactory	<95,30; 123,28)
E_u/M"	117,5263	satisfactory	<98,73; 129,36)
E_u/ΔM	2 640,3929		
E'/G'	47,1950	satisfactory	(46,93; 62,57>
E'/G"	46,7912	satisfactory	(46,53; 62,04>
E"/G'	24,0445	satisfactory	(23,78; 39,42>
E"/G"	23,8388	satisfactory	(23,58; 39,09>
Eu/G'	23,1505	satisfactory	(19,1; 22,22>
Eu/G"	22,9524	satisfactory	(19,26; 23,87>

9 Conclusion

The expert system for new designed and already exploited drying systems has been formulated and implemented. For new dryers database includes several drying systems that could be selected. Decision maker would be able to formulate drying systems of her/his own chhosing. In order to simplify this process mathematical model of the dryer has been implemented. It is possible to rank drying systems that fulfill DM expectations and select the best installation. Knowledge base includes rule-based modules for dryer selection and evaluation knowledge. For existing systems knowledge sources include energy efficiency evaluation and methods of improving it. Sphinx by AITECH with its PC-Shell and Hybrex was used as a main programming environment. Mathematical model of drying process was implemented in Borland Delphi. Databases were created using Ms Office. Expert system for drying systems evaluation is an application that could be extended and profitably exploited by drying systems designers, operators and auditors for overall evaluation.

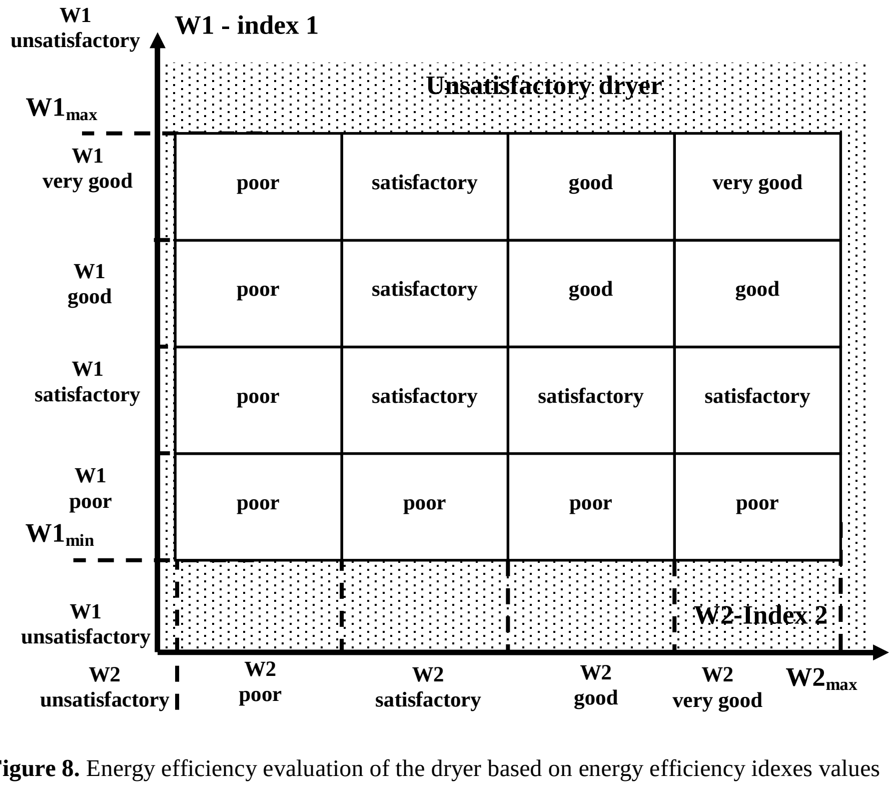

Figure 8. Energy efficiency evaluation of the dryer based on energy efficiency idexes values

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