Optimal Method of Building Elevator Selection from the point of their Energy Consumption Minimizing

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ABSTRACT

Getting fuels, economizing with them and effective utilization of them belong to the most complex problems of the present and future. Energy saving is one of the most important environment factor in construction company with developed and implemented Environment Management System (EMS) according to ISO 14001. We try in our contribution to refer to one of the ways as early in the building preparation/design phase to contribute in the suitable selection of the machines for the building processes leading to the lowering of their energy consumption. There is described at this paper structure of machine selection optimizing method for building processes and model example with results concerning the building elevators selection for vertical transport of building materials during the finished processes on site and proposal of effective using of this method in practice. At this paper will be presented also results of experimental measured values of energy consumption of selected 5 building elevators with software support. These results can help to optimizing of all building processes where are building lifts proposed.

Keywords –
Construction lifts, optimal method, energy consumption

1 Introduction

The optimal selection of machine or machine group for building processes is very important role of building planner during the process of building planning. During this process building planner must analyze several factors influencing the final effective decision concerning this problem.

During the process of building planning planner must analyze suitable selection of building machines and its group for effective proposal of mechanized building processes.

There are several criteria for selection of building machines. In our contribution there are analyzed: ability of machines to realize designed building process (quality aspect) and minimizing of energy consumption (cost and environmental aspect).

In our research work were implemented several theories and methods. The most important was theory of systems [1] and principles of optimizing method [2], method of scientific analysis and synthesis. These methods were implemented into optimal selection of building elevators from the point of minimal energy consumption with software support.

Applications of these methods and software will increase effectiveness of building elevators selection from the point of key criterion of optimization: electric energy consumption, thus speeding up whole process and avoiding exhaustive calculations and experiments. There are several authors who analyzed similar problems [3,4,5,6,8,9] concerning the optimal machine selection methods and their environmental impact to construction company effectiveness.

At this paper will be presented elevator selection optimizing method concerning the minimizing of energy consumption with its application into 5 different building elevators with software support.

2 Elevator Selection Optimizing (ESO) method

By suggesting the “Elevator Selection Optimizing (ESO) method we have developed the present state of knowledge of the purpose of the elevators for transport of building material and elements of finished processes [1] and also of the information which has been obtained by study of the theory of systems [1] and optimization theory of the process [2].

The “ESO Method” consists of the four phases (FIG.1) – entry, preparatory, decision and optimization. An analysis of all these phases except entry is examined [7]:

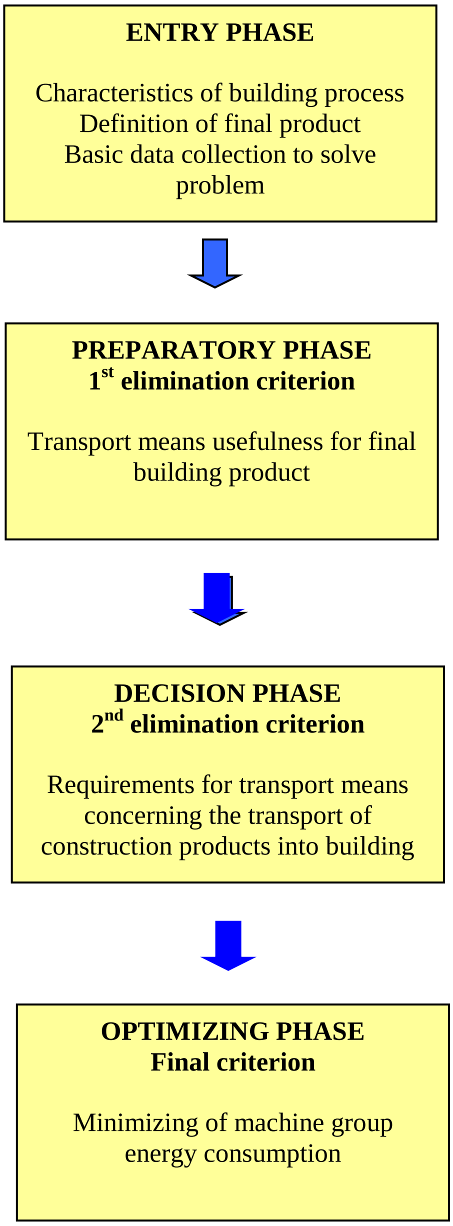


Figure 1. Elevator selection optimizing (ESO) method phases and criteria

-*the input universe of the system:* that is the set of the transport means submitted for analysis in the given phase,
-*the criterion*, according to it is the input universe of the system of given phase analyzed,
-*the procedural steps* being necessary to realize the appreciation of the input universe of the system according to the criterion of the given phase,
- *the output universe of the system*: that is the set of the transport means fulfilling the criterion of the given phase. The entry phase contains delimitation of problem and objectives necessary to be reached by evaluating, for example the type of building works, characterization of the final product of the mechanized building process, input information necessary for solving of the problem and so on.

The preparatory phase characteristics*:*
The input universe of the system is the set of the transport means being suitable for a given type of the building works.
The criterion (1st eliminating) is the usefulness of the transport means for the realization of the final product of the building process.
The procedural steps:
- a study of the resulting product of the building process,
- the analysis of transport means usefulness for a given type of the building finished process,
-the collation of all the information including the performance data of the transport means for their incorporation into a model of the mechanized building process.
The output universe of the system is the set of the transport means suitable for realization of the final product of the building finished process.

The decision phase characteristics:
The input universe of the system is the output universe of the proposal phase.
The criterion (2nd eliminating) – basic requirements for transport means concerning the transport of construction products into building
The procedural steps:
- the construction of the verbal – graphic model of the real system,
- the choice of the variants of the transport means for realization of the final building product,
- the selection and the choice of the model variables, their definition, symbol, dimension, quantification with the source of the quantification,
- the formulation of the particular mathematical relations of the model,
- the construction of the mathematical model for appreciation of variants of the transport means to the 2nd eliminated criterion,
- the verification, quantification, numerical solution using software, interpretation and implementation of the created mathematical model.
The output universe of the system – the set of the transport means performing the requirements for realization of the final product.

The optimizing phase characteristics:
The input universe of the system is the output universe of the decision phase.
The optimization criterion - the minimizing of the transport means energy consumption for realization of the final product of the building process.
The proceeding steps:

- the selection and choice of the decision variables, their definition, symbol, dimension, quantification with giving of the source of the quantification,
- the construction of the mathematical model of the criterion of the optimization,
- the verification quantification, numerical solution using software, interpretation and implementation of the mathematical model of the criterion for optimization.
The output universe of the system – the transport mean with the minimal energy consumption for realization of the final product of the building process.

3 Elevator Selection Optimizing (ESO) method application

This "ESO method" was applied into transport means selection for vertical transport of building materials during the finished processes in term of minimum consumption of electrical energy.

3.1 Entry phase

The objective is to select transport means for vertical transport of building materials to construction facility in term of minimizing energy consumption.
Input data:

- 9 floored building object (see figure 2),
- operational project of building object.

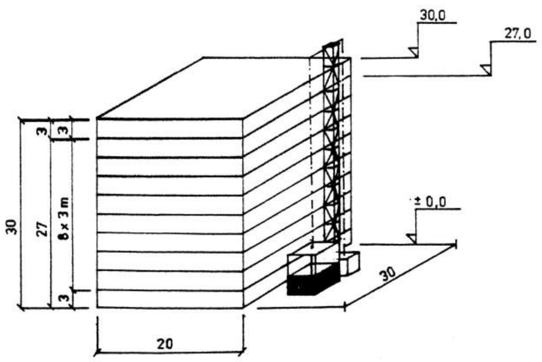


Figure 2. Analysed building object for optimal selection of transport means

3.2 Preparatory phase

Input universe of system (possible transport means)

- platform hoist simple (tubular)
- building elevator: WBT 5-600,
- building elevator: VS 5,
- building elevator: VS 6.01,
- building elevator: NOV 500,
- building elevator: NOV 1000 A.

Criterion– suitability of transport means for vertical transport of materials to the type of building object
Procedural steps:

1. List and balance sheet work of particular types of building materials, which would be transported to specific storey of building object.
2. Definition of the heaviest and the most dimensional piece from every type of building materials.
3. Definition of overall mass of every type of materials on each floor.
4. Definition of overall mass of materials transported to building object
5. Definition of required transported height of transport means.
6. Definition of height of each storey of building object from ground level (±0,0 m)

Output universe of system:
Building elevators, which fulfill the first criterion:
01 – WBT 5-600,
02 – VS 5,
03 – VS 6.01,
04 – NOV 500,
05 – NOV 1000 A
Note: Taking into account, that platform construction hoists are used for smaller construction when finishing processes and reconstruction work are done, output universe of system is not included.

3.3 Decision phase

Input universe of system is output universe of system of preparatory phase
Criterion: 2nd elimination: requirements for elevators in term of transport of building materials to building object.
Procedural steps:

1. Assessment of elevators in term of transport height

$$H_r \leq H_e \qquad (1)$$

where
H_r – required transport elevation of elevator in m,
H_e – real transport height achieved by elevator in m.

Assessment of elevators in term of transport height results from Table 1.

Table 1. Assessment of elevators in term of transport height

N.	Type	H_r (m)	H_e (m)	Assessment
01.	WBT 5-600	27	33	+
02.	VS 5	27	30	+
03.	VS 6.01	27	48	+
04.	NOV 500	27	60	+
05.	NOV 1000A	27	100	+

Note: Assessment (+ satisfy, - fail to satisfy)

2. Assessment of elevators in term of load capacity

$$M_p \leq LC_e \qquad (2)$$

where

M_p – mass of the heaviest piece from all types of transported materials in kg,

LC_e – load capacity of elevator in kg.

Assessment of elevators in term of load capacity results from Table 2.

Table 2. Assessment of elevators in term of load capacity

N.	Type	M_p kg)	LC_e (kg)	Assessment
06.	WBT 5-600	200	600	+
07.	VS 5	200	500	+
08.	VS 6.01	200	600	+
09.	NOV 500	200	500	+
10.	NOV 1000A	200	1000	+

Note: Assessment (+ satisfy, - fail to satisfy)

Note: All elevators satisfies the requirements defined in 2^{nd} criterion

3. Assessment of elevators in term of capacity of its cage

This aspect defines if is it possible to fit even the most dimensional pieces into elevator´s cage. In case we are dealing only with one or smaller amount of these pieces, we are looking for different options for its vertical transport. Due to analysis of all listed types of elevators it is assumed that in term of capacity of their cages, all types of elevators satisfy requirements, which is why they are analyzed in next phase.

Output universe of system:

01 – WBT 5-600,
02 – VS 5,
03 – VS 6.01,
04 – NOV 500,
05 – NOV 1000 A

3.4 Optimizing phase

Input universe of system is output universe of system of decision phase.

Criterion: optimization – minimization of consumption of electric energy of elevators in a process of vertical transport of materials to building object.

Procedural steps:

1. Experimental method of measuring value of electric current, which is withdrawn by construction elevator´s electromotor during its operational mode.
2. Experimental measuring work was done on specific constructions in Bratislava (Slovakia), in the presence of expert for elevators. The elevator was continually burdened by 50 kg (1 bag of cement) until maximum loading capacity. The values of electric current flowing through phase conductor of three phase line and withdrawn by electromotor of elevator during continual loading in both direction (upwards and downwards) are measured by clip-on ammeter.
3. Results of experimental measuring of electrical current values which were withdrawn by electromotor of elevators during operational mode. Above mentioned measuring work was implemented on all analyzed types of elevators. Results of measurements are recorded in tables and also graphically illustrated.
4. Construction of mathematical model of optimality criterion

   The content of this point is to construct mathematical model of consumption of electrical energy of elevator for tonometer of transported materials.
   The foundation for calculation of measuring consumption of electrical energy of elevator are experimental measured intensities of electric current withdrawn by its electromotor.
   The consumption of electrical energy of elevator for tonometer of transported material could be calculated as follows:

$$E = \frac{\sqrt{3}}{3600} \cdot \frac{U \cdot I}{v \cdot m} \quad [\text{Wh/tm}] \qquad (3)$$

where

U – nominal line voltage of three-phase distribution system in volt (380 V),

I – real intensity of electric current withdrawn by electromotor of elevator in ampere,

v – transport velocity of elevator in meter per second,

m - load mass transported by elevator in tonne.

<u>Note:</u>

1. At work there is analyzed case, when elevators are going in upward direction they are loaded, however in downward direction they are not loaded by materials. From measured and calculated variables we can observe different combinations.
2. In case of operational-personal elevators NOV 500 and NOV 1000 A, service is necessary in elevator´s cage, that is why we consider empty (without load) elevator's mass 100 kg and elevator load capacity is changing in case of NOV 500 to 400 kg and in case of NOV 1000 A to 900 kg.

The overall consumption of electrical energy of elevators for transport of material to 1 m elevation (tonometer) and its return to initial position we can calculate as follows:

$$E_c = E_h + E_{pd} \text{ [Wh/tm]} \qquad (4)$$

where

E_h - the consumption of electrical energy of elevator for tonometer of transported material in upward direction in watt hour per tonne and meter (Wh/tm),

E_{pd} - the consumption of electrical energy of elevator for tonometer of transported material in downward direction not loaded by materials in Wh/tm.

Graphical interpretation of dependence of overall electrical energy consumption to transport material by elevators E_c [Wh/tm] is illustrated on figure 3 and graphical interpretation of dependence of overall electrical energy consumption of elevators E_c [Wh/tm] on percentage extraction their load capacity is illustrated on figure 4.

5. The determination of final electrical energy consumption of particular types of elevators after overall work performance E_v [Wh].

For approximate calculation of E_v [Wh] overall mass of materials ABP, which is transported by elevator to particular floors M_i [kg], where i = 1, …,n, is determined.

Based on characteristic of different materials types, average value of percentage extraction of load capacity of elevator x is estimated, subsequently based on this value the E_c [Wh/tm] is defined from figure 4.

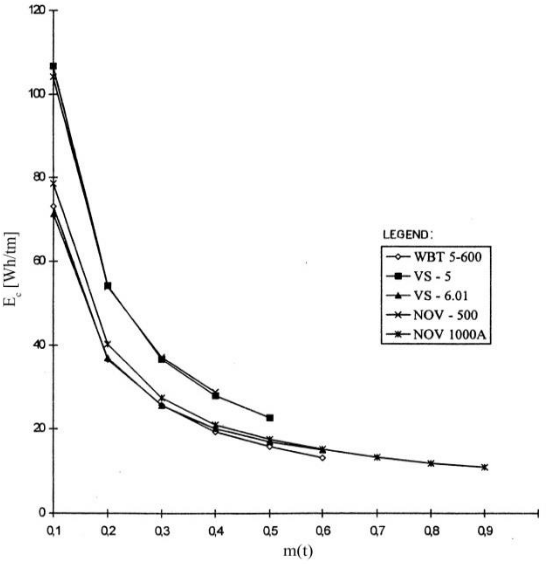


Figure 3. Graphical interpretation of dependence of overall electrical energy consumption to transport material by elevators for tonne and meter E_c [Wh/tm]

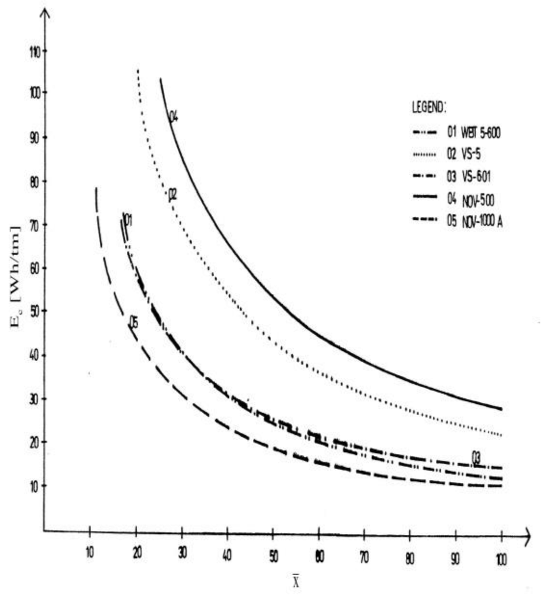


Figure 4. Graphical interpretation of dependence of overall electrical energy consumption of elevators E_c [Wh/tm] on percentage extraction their load capacity

The resulting electrical energy consumption of elevators E_v [Wh] is calculated as follows:

$$E_v^k = E_c^k \cdot \sum_{i=1}^{n} M_i \cdot h_i \cdot 10^{-3} \qquad \text{[Wh]} \qquad (5)$$

where

E_c^k - overall electrical energy consumption “k” type of elevator for transport of 1 tonne material to 1 m height [Wh/tm], where k=1,…,p,
M_i – mass of material, which is transported to “i” floor [kg] ,where i = 1, …, n,
h_i - height of “i” floor [m], where i = 1, …, n,

Model example:
M_i = 10 000 kg for i = 1, …,9 (typical floor)
h_1 = 3 m,
h_2 = 6 m,
h_9 = 27 m (figure 1)
$\bar{x}$ = 70 % (figure 4)
E_c [Wh/tm] (figure 4)
The solution of model example is shown in figure 5.

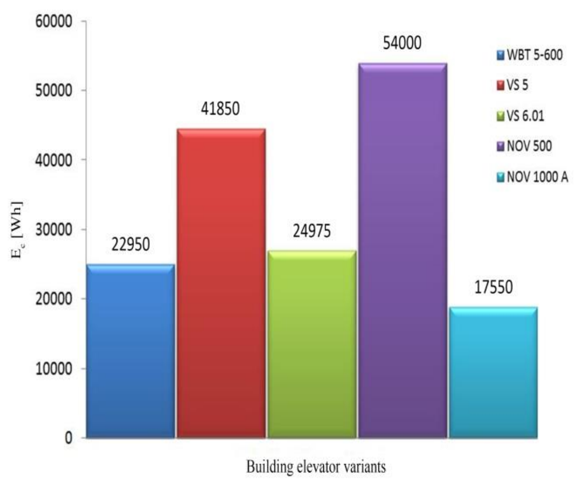


Figure 5. A comparison of elevator variants in term of overall electrical energy consumption during the process of vertical transportation of building materials to analyzed building object.

Output universum of system - NOV 1000 A (see figure 5)

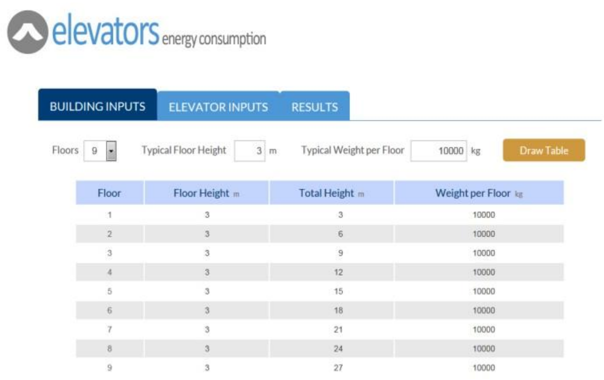
4 Elevator Selection Optimizing (ESO) method application with software support

Above analysed model example can be effective solved using Elevators Energy Consumption software as a web solution based on html, php and javascript to compute energy consumption of several elevators and choose the best choice (the one with lowest energy consumption).

The main screen is divided into 3 parts: Building Inputs, Elevator Inputs and Results.

4.1 Building Inputs

In this section (figure 6) user enters number of floors of a building, typical floor height and typical height, delivered to the floors. For each floor, user can specify its own height or weight, needed to delivery.



Floor	Floor Height m	Total Height m	Weight per Floor kg
1	3	3	10000
2	3	6	10000
3	3	9	10000
4	3	12	10000
5	3	15	10000
6	3	18	10000
7	3	21	10000
8	3	24	10000
9	3	27	10000

Figure 6. Building inputs

4.2 Elevator inputs

This part (figure 7) serves to specify number of elevators (from 1 to 5), their names and E_c constants, assigned to capacity values, varying from 25 to 100 percent.

	Elevator1	Elevator2	Elevator3	Elevator4	Elevator5
x (%)	WBT 5 600	VS 5	VS6.01	NOV 500	NOV 1000A
25	48	80	47	103	37
30	40	70	40	86	31
35	34	61	35	73	27
40	31	53	32	66	23
45	27	48	28	58	21
50	24	43	25	53	19
55	22	39	23	48	17
60	20	37	21	44	15
65	18	33	19	42	13
70	17	31	18.5	40	13
75	16	29	18	37	12
80	15	28	17	34	11
85	13.5	25.5	16	32	10.5
90	13	24	15	31	10
95	12	23	14.5	30	9.5
100	11	21.5	14	28	9.4

Figure 7. Elevator inputs - values of E_c [Wh/tm]

4.3 Results

In Results section (figure 8), user is asked to choose capacity for each elevator and after clicking the button Draw Results he gains result values of total energy consumption (E_v). Elevator with the lowest consumption (the winner) is marked green.

Figure 8. Results section

Conclusion

The most-important factor in this "ESO" method is that it is able to eliminate energy variants of the elevators during the process of building planning. By using a software it gives information about energy consumption of elevators when considering their use in the final product of the building process (vertical transport of building materials) and gives the possibility to make fast decision for the choice of the energy optimal elevator in a short time. At the same time it is necessary to stress that by this method the elevators are being evaluated from one point of view only (energy consumption), which, it is true, is one of the most meaningful views of this time, but it needs not be crucial in every case. Therefore, it is necessary when proposing an elevator to take the point of view to minimize the electric energy consumption as a part of the poly-optimal proposal. For a practical application of the proposed "ESO" method it is necessary to improve the quality of input data, especially energy information. This data involved in our contribution were obtained by experimental measurement. The producers of elevators can offer this data shown in our contribution as a basic information concerning their elevators and using software building planner can very easy and fast select energy optimal variant of elevators. The volume of savings of the operating expenses possible to be obtained already in the preparation phase of building realization by this "ESO" method are not negligible, vice versa, it shows the disclosure of reserves that are available in the choice of elevators for vertical transport of building materials.

This contribution was prepared as a part of scientific research project VEGA N. 1/0703/15.

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