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Reducing the Energy Overheads of a Manufacturing Company

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Abstract : The paper deals with reducing energy costs. Nowadays, with ever-increasing energy prices, it is important for a company to minimize the consumption of all energy. In the course of its activities, the company comes into contact with other entities of different nature. It is connected to this environment by inputs and outputs. Every company has certain goals. A very important group of objectives consists of economic objectives such as achieving profit, ensuring financial stability and liquidity of the company, efficiency of production and other activities.

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1 Introduction

The company can ensure the efficiency of its activities either by maximizing outputs or minimizing inputs or by optimizing the relationship between inputs and outputs. In ensuring the activity of the enterprise and achieving the set objectives, the bulk of inputs are in the form of costs and the bulk of outputs are in the form of revenues. The difference between revenues and costs over a certain period represents the economic result. Overheads are costs at which a lot of money can be saved, including, in particular, the cost of various types of energy [1].

One way to reduce electricity consumption is to replace old lighting with new and modern lighting sources. There are many different options on the market that a company can decide on. They can choose from classic incandescent bulbs to energy-saving fluorescent and halogen lamps to LED light sources. The application of LED lights is important because currently LED lighting is not only equal to any light source, but even achieves better parameters than all available light sources [2]. The world's leading manufacturers, e.g. CREE and OSRAM, already offer light sources that exceed all parameters of existing light sources. LED lights have several advantages:

- reduced cost of electricity
- the light is emitted in one direction only, so there is no reflection loss
- LED luminaires are up to 97% efficient
- under thermal conditions the lifetime is up to 100 000 hours, which is equivalent to 25 years with 10.7 hours of light per day
- energy and CO_2 savings of approximately 50% compared to conventional technologies
- LED working temperature range: from - 30°C to + 60°C
- minimal heat development
- special LED current sources ensure a continuous luminous flux, no stroboscopic effect, no problems with low temperatures, instant start, LED as a semiconductor achieves even better results at lower temperatures than at 25°C/ all LED chip parameters are tested at this temperature /
- LED chips are shock resistant
- spot or area lighting
- LEDs create shadows on the surface of the material, making it easier to detect irregularities
- adjustable from 0 to 100%
- instant start of lighting at 100% power
- free of harmful substances and gases (lead, mercury, heavy metals)
- LEDs do not produce UV radiation

- LED colour temperature is 6000K, which corresponds to daylight
- high specific power = 100 to 137 lm/W
- high protection against water and dust
- the colour rendering index for white is RA=75, this parameter expresses how the human eye can distinguish different colours, the higher this index is, the more colours in the colour spectrum we can detect
- universal supply voltage: 100-250V-60Hz or 24V
- possibility of power supply from photovoltaic panels
- Variability of luminaire dimensions (manufacturers are able to produce LED light in any dimensions according to customer's needs)
- under optimal thermal conditions, the manufacturer guarantees a 16% drop in LED efficiency after 55 000 hours and a 30% drop after 100 000 hours [3].

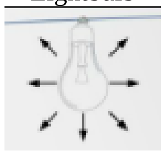
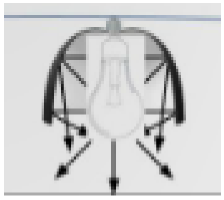
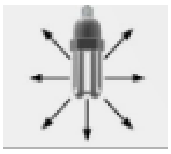
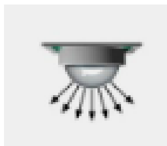
2 Increasing the quality of lighting

The following tables show the major advantages of LED lights compared to other light sources, which include their long lifetime and high luminous efficiency [4].

Table 1 Comparison of light sources

Type of light source	Manufacturer's stated lm/W	Retrievable lm/W	Lifetime (h)
Lightbulb	17	10	3000
Halogen bulb	20	12-20	10000
Tubular fluorescent lamp (neon)	60	40-50	20000
Halogen lamp	65-70	34-40	10000-20000
High pressure sodium discharge lamp	95-110	55-65	24000
Low pressure sodium discharge lamp	120-140	65-75	16000
Power LED-Cree	145	100-137	100000

Table 2 Graphical-mathematical comparison of the luminous efficiency of incandescent, energy-saving and LED lights

Type of light source	Utilisation index	Effectiveness
Lightbulb  17 lm/W	 58 %	10 lm/W
Energy saving bulb  60 lm/W	 58 %	35 lm/W
LED  145 lm/W	 72 – 97 %	100 – 137 lm/W

To improve the quality of lighting and save electricity, we decided to replace two basic types of lighting in the company's working areas:

- main hall lighting in the form of 300W bulbs replaced with LED Industry
- lighting of individual tables of assembly workplaces by replacing neon tubes with LED Leon 30

LED Industry lights were chosen because according to the technical parameters they are suitable for lighting production halls, assembly lines or storage areas. They are designed to cope with higher operating temperatures, they are easy to install by a single-point suspension from the ceiling and the basic beam angle is 60° which will be sufficient to illuminate halls as they are suspended several metres above the floor [5].

Figure 1 Luminaire LED Industry

Table 1 Technical specifications of LED Industry luminaire

Luminous flux	Specific luminous flux	Power	Weight
10 530 lm	81 lm/W	130 W	5,6 kg

According to the technical specifications the LED Industry achieves a luminous flux of 10530 lumens. Currently, 300 watt bulbs with a luminous efficacy of 10 lm/W are used in halls and warehouses, which is equivalent to a luminous flux of 3000 lumens per bulb. A comparison of the luminous fluxes of the individual lights clearly shows that one 130 watt LED Industry luminaire can fully replace three 300 watt bulbs, thus achieving an even higher luminous flux than using three 300 watt bulbs and at a lower power consumption.

We decided to use LED Leon luminaires (Figure 2), which are suitable for illuminating disassembly and assembly tables and also for exit inspection workplaces. Unlike the LED Industry, they have a 120° beam angle and are therefore suitable for illuminating workbenches in assembly, disassembly and inspection workplaces.

Figure 2 Leon LED luminaire

Table 2 Technical specifications of the LED Leon luminaire

Luminaire	Luminous flux	Specific luminous flux	Power	Weight
LED Leon 30	3 480 lm	116 lm/W	33 W	2,9 kg
LED Leon 60	6 960 lm	116 lm/W	66 W	6 kg

Replacing the 58 watt fluorescent tubes currently in use, which have a luminous flux of 2,900 lumens, with the new LED Leon 30 luminaire gives a luminous flux of 3,828 lumens. Replacing this old lighting with the new one will save almost half the electricity, increase the luminous flux and therefore the worker will not strain his eyes in low light.

3 Energy savings and financial payback after replacing the main hall

At the moment, there are 9 bulbs of 300 W with a luminous flux of 27,000 lumens in each of the production halls. In total, these bulbs consume 2 700 W per hour. The following table (Table 5) shows the energy consumption of the old and new lights:

Table 5 Comparison of old and new lighting in one hall

Type of light	Number of lights	Power consumption per 1 light [Wh]	Total energy consumption [Wh]	Luminous flux [lm]
Light bulb	9	300	2 700	27 000
LED Industry	3	130	390	31 590
Hourly energy saving is **2 310 Wh**				

After replacing the old bulbs with new LED lights, the luminous flux increased from the original 27000 lumens to 31590 lumens and the electricity consumption decreased from 2700 Wh to 320 Wh. The replacement of the lighting consumes 2310 Wh less electricity, which is 85.5% of the original consumption, while the luminous flux increased by 17%. Calculating this over all three halls (Table 6), the hourly energy saving is 6930 watts.

Table 6 Comparison of old and new lighting in all halls

Type of light	Number of lights	Power consumption per 1 light [Wh]	Total energy consumption [Wh]	Luminous flux [lm]
Light bulb	27	300	8 100	81 000
LED Industry	9	130	1 170	94 770
Hourly energy saving is **6 930 Wh**				

The company is currently working eight-hour shifts, with only one shift in the two dismantling and repair halls and two shifts in the assembly line hall where workers assemble the calipers. The following table (Table 7) shows how much energy can be saved in one working day.

Table 7 Energy savings per working day

	Light bulb	LED Industry
2 halls (dismantling + repair)		
number of lights	18	6
energy consumption per 1 hour	5,4 kWh	0,78 kWh
power consumption in 8 hours	43,2 kWh	6,24 kWh
energy saving	43,2 – 6,24 = **39,96 kWh**	
1 hall (assembly)		
number of lights	9	3
energy consumption per 1 hour	2,7 kWh	0,39 kWh
power consumption in 16 hours	43,2 kWh	6,24 kWh
energy saving	43,2 – 6,24 = **39,96 kWh**	
energy savings per 1 working day	39,96 + 39,96 = **79,92 kWh**	

By analogy we can calculate the energy savings for one working month (Table 8), if we take into account that a month has 31 days and no work on weekends, so a month has 23 working days.

Table 8 Average monthly savings after replacing hall lighting

	Light bulb	LED Industry
	savings in single-shift operation	
Number of lights	18+9	6+3
Energy consumption per 1 hour	8,1 kWh	1,17 kWh
Energy consumption per 1 day (8 hours)	64,8 kWh	9,36 kWh
Energy consumption for 1 month (23 days)	1 490,4 kWh	215,28 kWh
Energy savings in 1 month	1 490,4 – 215,28 = 1 275,12 kWh	
	savings in two-shift operation	
Energy savings in 1 month	1 275,12 x 2 = 2 550,24 kWh	
	savings in three-shift operation	
Energy savings in 1 month	1 275,12 x 3 = 3 825,36 kWh	
	savings with simultaneous operation	
Number of lights	18+9	6+3
Energy consumption per 1 day	86,4 kWh	12,48 kWh
Energy consumption for 1 month (23 days)	1 987,2 kWh	287,04 kWh
Energy savings in 1 month	1 987,2 – 287,04 = 1 700,16 kWh	

The monthly electricity savings can also be quantified in money terms (Table 9). From the last invoice issued for € 2 272 for 14 356 kWh, we find that the electricity supplier charges the company € 0,16 per 1 kWh:

Table 9 Monthly electricity savings in kWh and €

	Savings in kWh	Savings in €
Month of single-shift operation	1 275,12 kWh	204,02 €
Month of two-shift operation	2 550,24 kWh	408,04 €
Month of three-shift operation	3 825,36 kWh	612,05 €
Month at the current changes	1 700,16 kWh	272,03 €

The purchase price of one LED Industry luminaire is 980 €. The cost of replacing the entire hall lighting is therefore € 8 820. The payback period (Table 10) of the invested funds depends on how the production will continue. Calculated on the basis of 250 working days per year, the payback periods are as follows, depending on the number of shifts per day:

Table 10 Payback period for invested funds for the replacement of hall lighting

Single shift operation	
Daily saving	55,44 kWh x 0,16 € = 8,87 €
Annual savings	8,87 x 250 = 2 217,5 €
Payback period in years	8 820 € : 2 217,5 € = 3,98 = **4 years**
Two-shift operation	
Daily saving	2 x 55,44 kWh x 0,16 € = 17,74 €
Annual savings	17,74 € x 250 = 4 435 €
Payback period in years	8 820 € : 4 435 € = 1,98 = **2 years**
Three-shift operation	
Daily saving	3 x 55,44 kWh x 0,16 € = 26,61 €
Annual savings	26,61 € x 250 = 6 652,5 €
Payback period in years	8 820 € : 10 167,5 € = **1,33 years = 1 year and 4 months**
Current type of operation	
Daily saving	73,92 kWh x 0,16 € = 11,83 €
Annual savings	11,83 € x 250 = 2 957,5 €
Payback period in years	8 820 € : 2 957,5 € = 2,98 = **3 years**

It is clear from the above calculations that the acquisition cost of the lights will be recovered from the company the sooner the more shifts are made during the day. Once that payback period is exceeded, these lights can earn us money for other designs that can be applied.

For example, if we consider a two-shift operation, the lights have a lifetime of 25 years when lit for 16 hours a day (100 000 h : (250 x 16 h)). The payback period for a two-shift operation is 2 years, which when subtracted from the lifetime, gives us 23 years, during which the company saves 102,005 euros (23 years x 4,435 euros) on electricity. In single-shift operation, the lights have a lifetime of 50 years and, after deducting the payback period, the saving is 102 005 euros. Similarly, for three-shift operation, the lifetime is 16.6 years and the saving then amounts to EUR 101 584.

4 Energy savings and payback after workplace lighting replacement

Each workbench, whether for disassembly, repair or assembly, is illuminated by a 58 W tubular fluorescent lamp. A total of 5 disassembly tables, two repair tables and 12 tables are currently in use on the assembly line. In total there are 19 lights, to which we can add another 7 lights, which are located in two warehouses where in one warehouse we will replace two old lights with two new lights and in the other warehouse we will replace 5 old lights with 4 new LED Leon 30 lights. So we replace these 26 lights with 25 LED Leon 30 type luminaires. After the replacement we get an hourly saving (Table 11) with a higher luminous flux value.

Table 11 Hourly savings with LED Leon 30

Type of light	Number of lights	Power consumption per 1 light [Wh]	Total energy consumption [Wh]	Luminous flux [lm]
Tubular fluorescent lamp	26	58	1 508	60 320
LED Leon 30	25	33	825	95 700
Hourly energy saving is 683 Wh				

The hourly saving with the new lights is 683 Wh, which translates into a 45.29% saving in electricity costs. The following table (Table 12) calculates the hourly electricity savings with the changes as they are in the current state of operation:

Table 12 Hourly energy savings with lights LED Leon 30

	Tubular fluorescent lamp	LED Leon 30
2 halls (dismantling + repair)		
number of lights	7	7
energy consumption per 1 hour	406 Wh	231 Wh
power consumption in 8 hours	3,25 kWh	1,85 kWh
energy saving	3,25 – 1,85 = 1,4 kWh	
1 hall (assembly)		
number of lights	12	12
energy consumption per 1 hour	696 Wh	396 Wh
power consumption in 16 hours	11,14 kWh	6,34 kWh
energy saving	11,14 – 6,34 = 4,8 kWh	
warehouses		
number of lights	7	6
energy consumption per 1 hour	406 Wh	198 Wh
power consumption in 16 hours	6,5 kWh	3,3 kWh
energy saving	6,5 – 3,3 = 3,2 kWh	
energy savings per 1 working day	1,4 + 4,8 + 3,2 = 9,4 kWh	

After calculating the hourly savings, as with the hall lighting, we can calculate the monthly savings (Table 13) when using LED lights Leon 30:

Table 13 Monthly savings with Leon 30 LED lights in kWh and €

	Tubular fluorescent lamp	LED Leon 30
	savings in single-shift operation	
Number of lights	26	25
Energy consumption per 1 hour	1508 Wh	825 Wh
Energy consumption per 1 day (8 hours)	12,06 kWh	6,6 kWh
Energy consumption for 1 month (23 days)	277,38 kWh	151,8 kWh
Energy savings in 1 month	277,38 – 151,8 = **125,58 kWh**	
Savings per 1 month in euros	125,58 kWh x 0,16 € = **20,1 €**	
	savings in two-shift operation	
Energy savings in 1 month	125,58 kWh x 2 = **251,16 kWh**	
Savings per 1 month in euros	251,16 kWh x 0,16 € = **40,2 €**	
	savings in three-shift operation	
Energy savings in 1 month	125,58 kWh x 3 = **376,74 kWh**	
Savings per 1 month in euros	376,74 kWh x 0,16 € = **60,2 €**	
	savings with simultaneous operation	
Energy consumption per 1 day	20,89 kWh	11,49 kWh
Energy consumption for 1 month (23 days)	480,47 kWh	264,27 kWh
Energy savings in 1 month	480,47 – 264,27 = **216,2 kWh**	
Savings per 1 month in euros	216,2 kWh x 0,16 € = **34,6 €**	

The price of one Leon 30 LED luminaire is 303 €. The initial investment for the purchase of all lights is 7 575 €. In the table (Table 14) the individual payback periods after replacement of the installed LED Leon 30 lights are calculated.

Table 14 Payback period for investment with LED lights Leon 30

Single shift operation	
Daily saving	5,46 kWh x 0,16 € = 0,87 €
Annual savings	0,87 x 250 = 217,5 €
Payback period in years	7 575 € : 217,5 € = **34,8 years**
Two-shift operation	
Daily saving	2 x 5,46 kWh x 0,16 € = 1,74 €
Annual savings	1,74 € x 250 = 435 €
Payback period in years	7 575 € : 435 € = **17,4 years**
Three-shift operation	
Daily saving	3 x 5,46 kWh x 0,16 € = 2,62 €
Annual savings	2,62 € x 250 = 655 €
Payback period in years	7 575 € : 655 € = **11,6 years**
Current type of operation	
Daily saving	9,4 kWh x 0,16 € = 1,5 €
Annual savings	1,5 € x 250 = 375 €
Payback period in years	7 575 € : 375 € = **20,2 years**

5 Conclusion

It is clear from the above calculations that the acquisition cost of the lights will be recouped by the company the sooner the more changes take place during the day. Once that payback period is exceeded, these lights can earn us other designs that can be applied. For example, if we consider a two-shift operation, the lights when lit 16 hours a day have a lifetime of 25 years (100 000 h : (250 x 16 h)). The payback period for a two-shift operation is 17.4 years, which, when subtracted from the lifetime, gives 7.6 years, during which the company saves 3 306 euros (7.6 years x 435 euros) in electricity. In single-shift operation, the lights have a lifetime of 50 years and after subtracting the payback period, the saving comes out to 3 306 euros. Similarly, for three-shift operation, the lifetime is 16.6 years and the saving then amounts to EUR 3 275.

As electricity prices are currently rising steadily, it is very likely that the savings over these years of the LED lights' lifespan may increase even further. In addition to these potential savings over these years, we can also add those savings that would otherwise have to be spent on buying bulbs with a much shorter lifetime. Also, during this period, unnecessary waste is not produced and the environment is thus also protected.

Quality lighting improves work well-being and ultimately productivity.

6 The reference list

[1] MIHALÍK, J., ZAVACKÝ, J., GLADIŠOVÁ, I.: *Signály a sústavy : Návody na cvičenia*. Košice, TU-FEI, 2004, p.241.

[2] CIMBALA, R., BALOGH, J., DŽMURA, J.: Diagnostika výkonových transformátorov s využitím prvkov umelej inteligencie 1. *Elektrotechnický magazín*, Vol. 14, No. 1 (2004), pp. 8-9.

[3] KOVAĽAKOVÁ, M., NOVÁK, L., STANČÁKOVÁ, A.: *Vplyv prímesi chrómu na proces hydrogenácie a dehydrogenácie FeB amorfných zliatin.* In: 13. konferencia slovenských fyzikov, Košice, Slovenská fyzikálna spoločnosť, 2004, pp.145-146.

[4] Theorion Biologics Corporation, Cambridge, MA: *Recombinant fowlpox virus and recombination vector.* Inventors: Cohen L. K., Panicali; D. L. Int. Cl.5 C12N/701 United States Patent, 5093258. 03.03. 92.

[5] LAGOZE, C. et al.: *The Open Archives Initiative Protocol for Metadata Harvesting*, [online]. Available: <http://www.openarchives.org/OAI/openarchivesprotocol.html>. [2022-12-10].

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Investigating the Dependence of the Transmitted Heat Output on the Position and Diameter of the Gravity Heat Pipe

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Keywords : Heat pipe, heat transfer, rotation angle

Abstract : Heat transport is one of the most basic needs of the present time. Depending on the distance, appropriate heat transfer systems are chosen. For relatively smaller distances, the use of heat pipes is ideal. They are devices using a phase change of the working substance. They do not contain moving parts, so they are almost trouble-free and maintenance-free. Due to their simple construction and function, they are also relatively cheap. This contribution deals with the analysis of the transmission capabilities of the gravity heat pipe depending on its diameter and the angle of rotation from the vertical plane. The material of the heat pipe is copper, and water was used as the working substance.

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1 Introduction

The general principle of heat pipes using gravity is usually classified as a two-phase thermosyphon. It dates back to the steam period. Then Angier March Perkins and his son Loftus Perkins created the "Perkins tube". This was extended to use in locomotive boilers and working furnaces. Capillary heat pipes were first designed by R.S. Gaugler at General Motors in 1942, who patented the idea but did not develop it further. A heat pipe is a heat transfer device that combines the principles of thermal conduction and phase change to effectively control heat transfer between two solid interfaces [1,2].

2 Heat Pipe

2.1 The Principle of Operation of the Heat Pipe

There is a liquid in the evaporative part of the heat pipe. It is in contact with a thermally conductive solid surface. By absorbing heat from this surface, it turns into steam. The vapor then passes along the tube to the condensing section, where it condenses back to a liquid and at the same time transfers latent heat. The liquid is then returned to the vapor section by capillary forces, centrifugal force or gravity and the cycle repeats. (Fig.1) Due to the very high coefficients of heat transfer during boiling and condensation, heat pipes are highly efficient heat conductors [3].

2.2 Heat pipe construction

A heat pipe consists of a closed tube made of a material that is compatible with the working fluid, such as copper and water working fluid or aluminum and ammonia tubes. A vacuum was used to remove air from the manufactured tube. The heat pipe was partially filled with working fluid and then sealed. The working fluid is chosen so that the heat pipe contains the working substance in both the gas and liquid phases within the range of operating temperatures. Working fluids are selected according to the temperatures at which the heat pipe must be in operation [4,5].

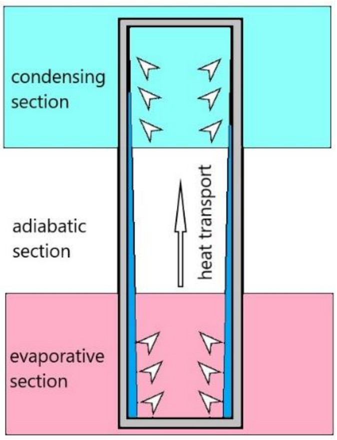

Figure 1 The principle of operation of the heat pipe

The advantage of heat pipes compared to other heat removal mechanisms is their high efficiency in heat transport. Heat pipes contain no mechanical moving parts and usually require no maintenance. The advantage of heat pipes is the quick onset of heat transfer, geometric shape, weight. Heat pipes are used to cool electronic devices and are increasingly used in computing. Another possibility of using heat pipes is in solar collectors, where a heat exchanger is arranged in the condensing part, which is heated directly by heat pipes [6,7].

3 Experimental Measurement

The calorimetric method of measuring with water was chosen for the experimental measurement. Copper gravity heat pipes with the same length of 50 cm were used for measurement. The heat pipes were of different diameters (DN12, DN15, DN18, DN22 and DN28). The working medium in the experimental measurements was distilled water, and the angle of inclination of the heat pipe was varied. For the sake of comparison, the heat pipes were produced with the same filling pressure of 800 Pa. The AMR WinControl program from the AHLBORN company was used to record the measured values. The measurement consisted of heating the evaporation section with a circulating medium with an inlet temperature of 80°C. Cooling of the condensing part was ensured by a circulating medium with an inlet temperature of 20°C. During the experiment, the water flow rate to the condenser was recorded.

Copper tubes of 50 cm length, copper end plugs and copper capillaries for filling were used for the experimental measurement. (Fig. 2). The working medium of the experimental measurements was distilled water. The amount of the working medium was chosen to be 25% of the volume of the heat pipe.

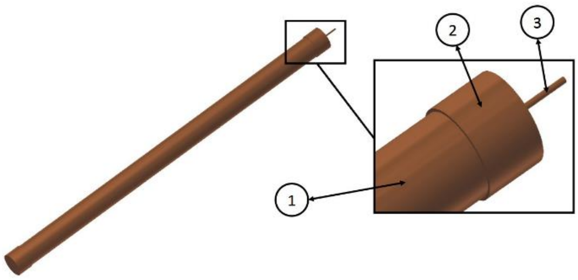

Figure 2 The experimental heat pipe consisted of 1 - a copper tube, 2 - a copper plug, 3 - copper capillaries

The calorimetric method was chosen to determine the transferred heat output. Since heat pipes transfer heat and form an isolated system subject to the law of conservation of energy, the calorimetric equation (1) can be used to obtain the results [8]. The law of conservation of energy states that all heat released from one body is transferred to another body [9]. We can assume that there is no change in the amount of energy, thermal energy cannot be changed into, for example, mechanical energy, and substances are chemically inert, they do not generate heat from chemical reactions:

$$\dot{Q} = \dot{m}.c.\Delta t \qquad (1)$$

where $\dot{Q}$ is the heat flow [W], $\dot{m}$ represents the mass flow [kg.s^{-1}], c represents the specific heat capacity of water at 20°C = 4183 [J.kg^{-1}.K^{-1}] and Δt represents the temperature gradient [K].

A measuring device (Fig. 3) was built for the experimental measurement. It consists of 1-protractor, 2-flow meter, 3-measuring the outlet temperature, 4-measuring the inlet temperature, 5-cooling part, 6-heating part, 7- cooled water source, 8 – source of heating water.

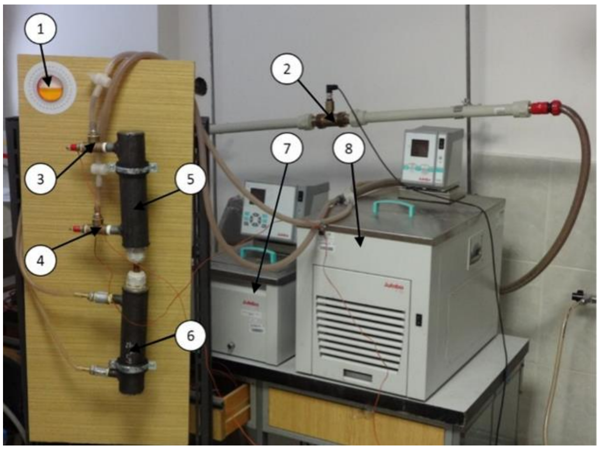

Figure 3 Experimental measuring device

4 Evaluation of the Measurement of Thermal Power Transmitted by a Heat Pipe

The experimental measurement confirms the assumptions that the largest diameter and different working position change the most the thermal power transmitted by the heat pipe. The main goal of the experiment was to find the ideal working position and ideal tube diameter. The heat pipe with a cross-section of 1 cm^2 transferred the greatest heat output. All heat pipes were filled to 25% of their internal volume. To determine the heat output, the mass flow rate and the inlet and outlet temperature of the cooling circuit were recorded.

Table 1 Temperature difference for different angle of rotation and different diameter of the heat pipe [K]

Angle of rotation (°)	DN 12	DN 15	DN 18	DN 22	DN 28
0	0.45	1.2	1.76	2	2.27
15	0.45	1.41	1.75	2.15	2.06
30	0.47	1.53	1.80	2.12	2.17
45	0.51	1.62	1.80	2.09	2.16
60	0.52	2.10	1.98	2.16	2.27
75	0.51	0.88	1.86	2.23	2.18

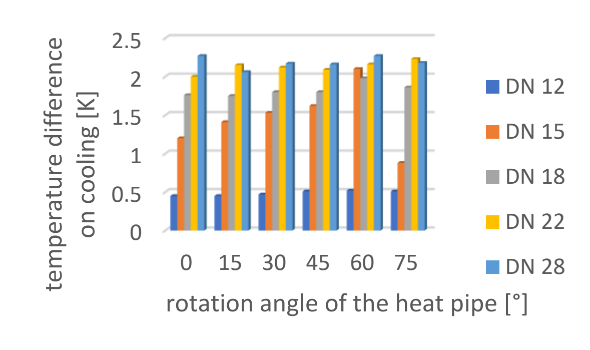

Figure 4 Graph of dependence of the angle of rotation, the diameter of the tube and temperature difference

Based on the results from the graph, the smallest difference in temperature difference is for the DN 28 heat pipe, depending on the diameter of the heat pipe and the angle of rotation during the measurement.

Table 2 The difference in flow volume for different angles of rotation and different diameters of the heat pipe [kg.s^{-1}].

Angle of rotation (°)	DN 12	DN 15	DN 18	DN 22	DN 28
0	0.0635	0.058	0.06	0.062	0.064
15	0.0635	0.054	0.06	0.062	0.064
30	0.0635	0.05	0.06	0.062	0.064
45	0.0635	0.05	0.06	0.062	0.064
60	0.0635	0.034	0.06	0.062	0.064
75	0.0635	0.063	0.06	0.062	0.064

Tab. 2 shows the average value of the mass flow, which was the same during the entire measurement.

To evaluate the measurement, relation (1) was used, where the specific heat capacity of water at 20°C was $c = 4183 J.kg^{-1}.K^{-1}$.

Table 3 Transmitted heat power for different angle of rotation and different diameter of heat pipe [W]

Angle of rotation (°)	DN 12	DN 15	DN 18	DN 22	DN 28
0	112.8	291.92	445.12	516.3	604.7
15	120.8	318.27	442.44	556.12	548.08
30	125.1	318.58	454.41	548.74	577.58
45	135.1	333.57	454.37	541.32	575.21
60	138	296.03	500.55	559.53	604.32
75	136.3	230.64	470.27	575.93	578.19

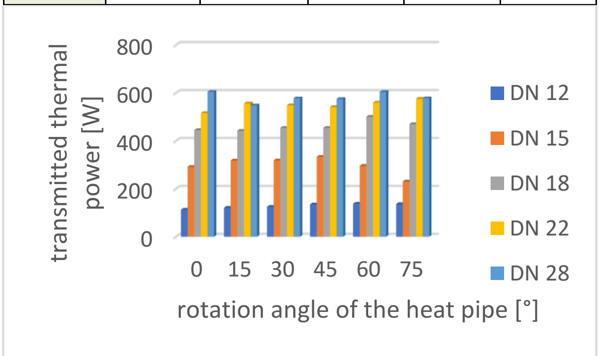

Figure 5 Graph of the dependence of the angle of rotation, the diameter of the tube and the transferred thermal power

In fig. 5 shows the average value of the heat output of the heat pipe when different diameters and working positions were used. The largest diameter was expected to have the greatest heat output. For this reason, the heat output per 1cm^2 was determined.

Table 4 Transmitted heat power per $1cm^2$ for different angles of rotation and different diameters of the heat pipe [$W.cm^{-2}$]

Angle of rotation (°)	DN 12	DN 15	DN 18	DN 22	DN 28
0	99.74	165.20	174.90	135.83	98.2
15	106.8	180.12	173.85	146.31	89.00
30	110.64	180.29	178.55	144.37	93.79
45	119.41	188.78	178.54	142.41	93.41
60	122.03	167.53	196.68	147.20	98.14
75	120.5	130.52	184.78	151.52	93.89

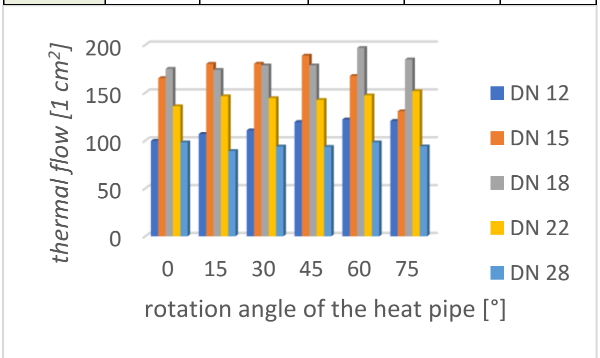

Figure 6 Graph of the dependence of the angle of rotation, the diameter of the tube and the transferred thermal power per 1 cm^2

In fig. 6 shows the difference between the working position and the different pipe diameter.

The best working position for the gravity heat pipe is approximately 60 degrees, and the best results in terms of length and diameter are shown by the heat pipe with a diameter of DN 18, where the maximum transferred heat output per 1 cm^2 was 196.68 $W.cm^{-2}$.

The heat pipe with a diameter of DN 28 comes out as the worst, where although the total transferred heat output is the largest, but compared to the transferred heat output per 1 cm^2 cross-section, this output is the smallest.

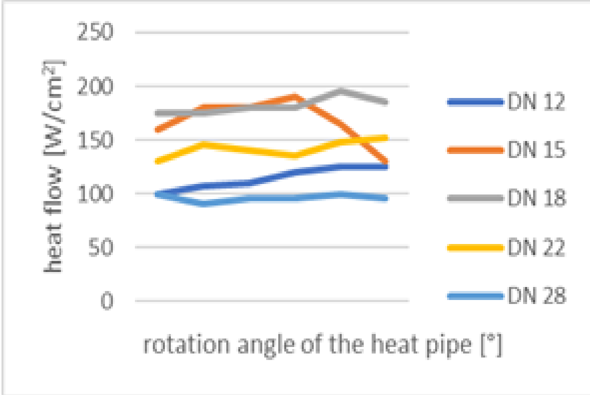

Figure 7 Graph of the increase in heat output per $1cm^2$ depending on the angle of rotation and the diameter of the tube

Fig. 7 shows the increase in heat output when the diameter of the tube changes. The graph shows that the best working position for heat pipes is around 45 to 60 degrees, and the best working diameter for gravity heat pipes is a DN15 heat pipe up to a rotation angle of 45° and a DN18 heat pipe at a rotation angle of 60°.

5 Conclusion

During the experimental measurement, the influence of the diameter, type of gravity heat pipe and its working position on the ability to remove heat from the cooled device was determined. During the measurement, it was found that the expansion of the diameter also increases the transmitted power of the gravity heat pipes. The greatest increase in the transferred heat output of 604.7W was achieved by the gravity heat pipe with a diameter of DN28 with a vertical working position, but in comparison of the transferred heat output per 1 cm2 of the cross-sectional area, the highest transferred heat output with a value of 196.68 W was achieved by the gravity heat pipe with a diameter of DN18 with working position 60 degrees.

6 The reference list

[1] HOLUBČÍK, M., ĎURČANSKÝ, P., JANDAČKA, J. and NOSEK, R: Design of heat exchanger for ericsson-brayton piston engine, *The Scientific World Journal*, 2014, 138254.

[2] LENHARD, R., KADUCHOVÁ, K., PAPUČÍK, Š.: *Analysis of the fill amount influence on the heat performance of heat pipe*, International Conference on Application of Experimental and Numerical Methods in Fluid Mechanics and Energetics, Liptovský Ján, Slovakia, 2014.

[3] NIKOLAYEV, V. S.: *Modeling of pulsating heat pipe (PHP)*, [Online], Available: https://iramis.cea.fr/Pisp/vadim.nikolayev/PHP_CEA.html [24 Feb 2023], 2022.

[4] NOSEK, R., GAVLAS, S., LENHARD, R., SEDLAK, V., ARVESEN, H.M: Condenser optimization of heat pipe, *Komunikacie*, Vol. 16, No. 3A, pp. 62-66, 2014.

[5] PETERSON, G.,P: *An introduction to heat pipes modeling, testing, and applications*, John Wiley&Sons, Inc., 1994.

[6] REAY, D., KEW, P. and McGLEN, R.: *Heat pipes – Theory, design and applications*, sixth edition. Elsevier, 2013.

[7] SILVERSTEIN, C. C.: *Design and technology of heat pipes for cooling and heat exchange*, CRC Press, Boca Raton, 2011.

[8] VANTÚCH, M., HUŽVÁR, J., KAPJOR, A.: Heat transfer from oriented heat exchange areas, *EPJ Web of Conference*, Vol. 67, 02122, 2014.

[9] NEMEC, P., MALCHO, M., HOLUBČÍK, M., ĎURČANSKÝ, P.: *Experimental measurement of loop heat pipe cooling efficiency*, SGEM 2016, pp. 377-382, 2016.

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Energy Support Options for Charging Station with Photovoltaic System

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Abstract : Current developments in energy policies around the world and the associated challenges of future sustainability in relation to climate change and the requirement to achieve a minimal to neutral carbon footprint pose serious challenges to solutions for modern transport and mobility infrastructures. The alarming state of fossil fuel depletion and the increasing awareness of worsening climate conditions is clearly leading to the adoption of alternative energy technologies. Among the technologies developed are mass and individual means of transport for people and goods, such as the electric vehicle (EV), which is fast becoming part of the modern transport system. This paper deals in a focused and clear way with the outlined topic mainly with the sources of electrical energy for EVs and their devices - charging stations and especially with the issue of current and planned development, implementation and characteristics of these charging stations in the under-construction user network of the Slovak Republic.

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1 Introduction

However, the crucial fact in this issue is that every EV also has to recharge its batteries somewhere. That is why the term charging station is becoming more and more widely used and will come to the fore in time, just like petrol stations. EV charging infrastructure is a new type of consumer in the electricity grid. The popularization of electric vehicles has brought a stronger push for the development of charging facilities, The demand for charging stations is steadily increasing due to the growing interest in electric vehicles. In the context of rising electricity prices as well as social pressure on the environmental impacts of electromobility, EV owners are also becoming more interested in a green source of electricity. If we wanted to provide electricity for EVs using RES, we could consider solar, hydro or wind power. However, hydropower is not suitable because of the availability of the water source. Wind power could theoretically be useful, but it is still unrealistic in the long term in Slovak conditions. So for the time being we will choose solar, which is the most practical and inexpensive in terms of usability [1] .

2 Current and planned status of charging stations in Slovakia

The public opinion that electromobility is an unrealistic transport option in Slovakia is no longer valid. In professional publications and discussions, the question of the availability of areas for PV systems that could be used for EV charging is often raised. Opponents of PV argue, among other things, that there is not enough suitable land in Slovakia to cover the electricity needs of EV chargers [2] .

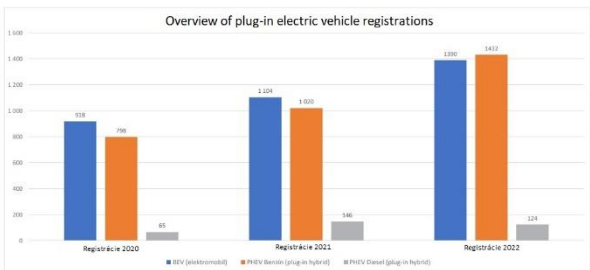

Figure 1 Overview of plug-in electric vehicle registrations

Table 1 M1 vehicles registrations overview 2020-2022

Year	Registration 2020	Registration 2021	Registration 2022
Plug-in electric vehicles			
BEV (battery electric vehicle)	917	1104	1390
PHEV petrol (plug-in hybrid)	798	1020	1432
PHEV diesel	65	146	124
Total BEV + PHEV	1781	2270	2946
Hybrid vehicles			
HEV petrol	6 246	12 185	14 588
HEV diesel	987	2 963	2 767
Total HEV	7 233	15 148	17 355
Hydrogen fuel-cell vehicles			
Hydrogen	0	1	1
Total FCEV	0	1	1
Internal combustion engine (ICE) vehicles			
Petrol	47 263	42 184	43 903
Petrol+LPG	540	953	1 407
CNG	404	234	291
Diesel	19 082	14 909	12 937
Total ICE	67 289	58 280	58 539
All fuel types – total for the year	76 303	75 699	78 841

In total, 90074 vehicles in all categories were registered in Slovakia in 2022, an increase of 3.1% year-on-year. In the category of new M1 passenger cars, registrations reached 78841 vehicles, an increase of 4.15% year-on-year. On the contrary, light commercial vehicles did not fare well, with a year-on-year decline of almost 7%, mirroring the situation in the trade and business environment in Slovakia. The total number of vehicles in the N1 category was 7679. The M1 segments again recorded growth in SUVs (+4.0%) and a decline in the small and compact vehicles segment (-4.3%). Registrations of passenger cars for legal and natural persons recorded year-on-year growth. Interest from individuals was more dynamic.

The positive news, however, is that according to SEVA (Slovak Electric Vehicle Asotiation) data, the building of charging infrastructure has moved forward, with an increase of up to 45% last year and a total of 1,483 public charging points in operation by the end of January 2023. Even better news is that the number of locations with a charging station has increased by 46% year-on-year. There are now a total of 629 sites, of which 331 are fast or ultra-fast charging sites, i.e. with a capacity of 50-350 kW. In fact, 100-150 kW chargers are becoming standard. The largest charging station networks in Slovakia are operated by Greenway with 425 charging points at 152 locations and ZSE Drive with 391 charging points at 137 locations. The third major player is ejoin GO, which expanded its network significantly last year and now has 314 charging points in 126 locations. Unlike the first two, who mainly focus on DC charging, ejoin GO has as many as 238 AC charging points and 76 with DC chargers.

In the near future, it will be necessary to start building a network of slow (AC) chargers, of which there are so far only a few in Slovakia. The Ministry of Economy of the Slovak Republic has supported the elaboration of a map with suitable locations near motorways and first-class roads, where more vehicle traffic is expected and therefore the need to recharge batteries in the future.

3 Technological charging of electric vehicles

3.1 DC charging

DC charging, or so-called fast charging, is carried out using a DC charging station that can convert alternating current (AC) to direct current (DC), then "bypass" the EV's on-board charger and send this DC current through the battery management system (BMS) to the battery as instructed by the vehicle's charge management system.

A DC charging station is technologically much more complex and many times more expensive than an AC charger, plus it requires a powerful power supply. In addition, the DC charger must be able to communicate with the car in order to be able to adjust the output power parameters according to the state and capacity of the battery.

3.2 AC charging

Charging an electric car with alternating current uses the car's onboard system (also called an on-board charger), which converts the AC voltage from the mains to the DC voltage needed to charge the batteries. The main difference between AC and DC charging is that in AC charging, the AC current is converted to DC by an On-Board Charger (on-board charger). The main function of the AC station is to mediate the necessary communication with the vehicle control system and ensure the safety of the vehicle and crew. In addition, the charger informs the vehicle of the maximum current it can draw at that time, depending on how busy the grid is. The AC charging station thus regulates the charging according to the current capabilities of the house or charging point to avoid overloading the grid.

4 Charging methods of Electric Vehicles

There are currently three main charging methods: conductive charging, inductive charging, and battery swapping [3] .

4.1 Conductive charging

Conductive charging uses direct contact between the EV charging cable connector and the charging input. The cable can be powered from a standard electrical outlet or charging station. A minor disadvantage of this solution is that the conductor must plug into the cable.

4.2 Inductive charging

Inductive charging uses an electromagnetic field to transfer energy between two objects. This is done by means of a charging station. The energy is sent through an inductive link to an electrical device, which can then use this energy to charge batteries or run the device.

5 Analysis of the energy needs of charging stations in Slovakia

From the users' perspective, charging availability is still top of mind. Charging must therefore be easily accessible from a location perspective. Customers in countries where electromobility is already more developed have the same view. The cost of charging comes second, but this does not mean that users are not concerned about it. So what are the prices in Slovakia? Due to the wide range of not only provider but also their individual programs, we will look at the price differences separately for AC and DC charging. However, the price summaries should be taken as information, as prices are constantly changing and may not be up-to-date at the time of reading. We have not included some operators due to unclear and frequently changing conditions. The price comparisons depending on the monthly usage of users are summarised in the following charts. When converting kWh per kilometer travelled, an average consumption of 20 kWh per 100 km is taken into account. The graph shows that the most cost-effective charging is at ZSE Drive's charging stations when using their Partner programme, where the programme is already the cheapest for electric car users when the mileage is above 20 km on weekdays. It is not worthwhile for customers to charge through so-called ad hoc schemes, i.e. charging when they are not registered with individual operators. Differences can reach levels of 200 to 300 % [4] .

Table 2 AC charging prices, source – official price lists of individual operators [3]

Provider	Program	Rate per kWh [€]	Lump sum monthly [€]	Free kWh within a month
e-join	GO1	0.29	-	0
GreenWay	Single use	0.42	-	0
	Energia Standard	0.42	-	0
	Energia Plus	0.32	7.90	30
	Energia Max	0.26	24.90	100
ZSE Drive	Guest	0.39	-	0
	Eco	0.39	-	0
	Partner	0.29	11.90	40
	Flat	0.29	89.00	400
Slovnaft	No registration	0.32	-	0
	Registration	0.27	-	0

5.1 DC charging

Compared to AC charging, fast-charging price lists are a bit more complicated. IONITY, e-join GO, and Slovnaft have a uniform price per kWh. GreenWay and ZSE Drive set DC charging prices depending on the charging speed. In order to compare comparables, we divided DC charging into two categories. DC charging stations with a capacity of 50 - 60 kW are the most common in Slovakia, so we focused on this charging speed. The second charging comparison is when using charging stations with power ranging from 75 to 350 kW.

Table 3 DC charging prices, source – official price lists of individual operators [3]

Provider	Program	Rate per kWh [€]	Lump sum monthly [€]	Free kWh within a month
e-join	GO1	0.29	-	0
IONITY	Public	0.49	-	0
	Partners	0.36	13.00	0

Provider	Program	≤ 25 kWh [€]	25-100 kWh [€]	>100 kWh [€]	Lump sum monthly [€]
GreenWay	Single use	0.42	0.65	0.78	-
	Energia Standard	0.42	0.65	0.78	-
	Energia Plus	0.32	0.54	0.66	9.90
	Energia Max	0.26	0.46	0.52	29.90

Provider	Program	DC > 50 kWh [€]	Ultra DC > 50 kWh [€]	Lump sum monthly [€]	Free kWh within a month
ZSE Drive	Guest	0.16	0.59	-	-
	Eco	0.49	0.59	-	-
	Partner	0.29	0.39	11.90	40
	Flat	0.29	0.29	89.00	400

Provider	Program	DC > 50 kWh [€]	Ultra DC > 62 kWh [€]	Lump sum monthly [€]	Free kWh within a month
Slovnaft	No registration	0.50	0.50	-	0
	Registration	0.45	0.45	-	0

6 Potential PV systems for charging stations

Photovoltaics, also called solar cells, are electronic devices that convert sunlight directly into electricity. The energy can be harnessed directly from the sun, even in cloudy weather, but with lower efficiency. Solar energy is used all over the world and is increasingly popular for generating electricity or for heating and desalination of water. In many countries, photovoltaics have become central to reducing carbon emissions and mitigating climate change. Currently, there are two basic types of PV panels: amorphous and crystalline. Crystalline is divided into polycrystalline and monocrystalline. Amorphous ones are less temperature dependent, do not reduce performance when overheated, and absorb more diffuse radiation. The efficiency is in the range of 12-15 % [5,6] .

Monocrystalline ones require direct radiation. Efficiency ranges from 15 - 22%, higher yield from the installed area. Disadvantages may include cost and uniform coloration of panels.

Polycrystalline also absorbs diffuse radiation, which is very common in our geological conditions. The efficiency is around 14-20%, which is not that big a difference compared to monocrystalline. The disadvantages of these panels can be e.g.: price, lower stability of the silicon layer.

6.1 PV installation possibilities

Between 2009 and 2011 it was possible to implement PV on arable land in Slovakia. But since 2011, it is only allowed to install on roofs, building facades, and private land.

Advantages and disadvantages of placing PV on roofs and building facades:
Advantages:

- Saving arable land for agricultural purposes
- Better thermal insulation of roofs
- Less maintenance
- Less likelihood of the panel being covered by leaves
- PV is less accessible to vandals and thieves

Disadvantages:

- Possible damage to the quality of roofs and facades
- Facades may be more difficult to install PV at high heights
- Damage to panels may occur in high wind conditions
- Deterioration of building appearance

Advantages and disadvantages of placing PV on arable land and meadows:

Advantages:

- Easily accessible installation
- Possibilities of building large areas
- Non-interference by construction in residential areas
- Greater electricity generation when large areas are developed

Disadvantages:

- Land take
- Damage to panels by vandals
- Theft of panels
- More difficult to connect to the grid with large PV systems compared to PV on buildings

6.2 Photovoltaics in Slovakia

Photovoltaics in Slovakia is making very big progress. In many cases, this is due to the energy price situation last year. However, more and more people are considering or currently already using photovoltaics as an ideal complement to an electric car. Such a tandem makes great economic and ecological sense in case of a sensible setup and the use of the right technology or the right type of the whole system. Being able to charge at least your daily mileage for a couple of hours a day from the sun on the roof of your house is, in short, something that makes sense.

7 Symbiosis of battery storage, photovoltaics and electric vehicle

This system is developed and manufactured in Slovakia, where it is also sold and provides complete technical consulting for the end customer.

7.1 IQ SMART HOME kit

The basis of the set-up is photovoltaic panels with outputs from 5 kWp to 30 kWp and a powerful hybrid inverter with an EPS output and an output of up to 20 kW. The most essential part of this system is the EV-GP LPF HV battery storage in 23 kWh or 31 kWh version, which consists of LiFePo 4 type batteries, where the manufacturer declares a lifetime of more than 15 years (6000 cycles/DOD 80%). There is also a charging station for electric vehicles (EVs) and hybrid cars (PHEVs), represented by the EV-GP home 22 kW IQ Smart model. Charging can be implemented in two ways - IQ charging from surplus. In this case, the control unit continuously manages the power to the charger and does not terminate charging even in the event of a lack of energy from the sun, but only interrupts it. In case of surpluses, hot water heating, heat pump and/or other options can also be triggered where the energy from the sun is used. At lower battery charge levels - lack of solar power - automatic power from an electric vehicle that supports V2L, i.e. has a single-phase output socket, is possible. So you can have a complete three-phase power supply in the house from an electric car. As well as the electric car, an external power source can be connected, whether LPG, petrol, diesel, or hydrogen generator.

Figure 2 EV-GP LPF HV

8 Conclusions

Infinite, inexpensive and clean, that's what we can call solar energy, which is nowadays advantageous as a supplementary source for EV charging, mainly for two reasons:

1. PV panels are easier to install and more efficient than other RES such as wind power. The cost of producing solar panels has dropped significantly over the last decade, making them not only affordable but often the cheapest form of electricity.
2. The future looks very promising for electromobility.

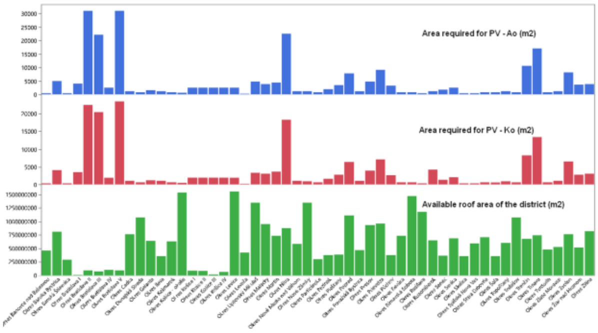

Figure 3 Required area for PV installation in districts

The required installation area for PV is also shown in Fig. 3 For amorphous panels (Ao), the Bratislava I - Bratislava V and Košice I - Košice IV districts would need the most area. The same is certainly true for crystalline technology (Ko).

Dependence on petroleum-based fossil fuels may change the growing interest in electric vehicles. In addition to the environmental impact and fossil fuel needs, electric cars are easier and more efficient to design and manufacture. As EVs become part of our daily lives, implementing and optimizing charging infrastructure will have new challenges. The future of PV charging station support is a viable option to harness the potential of solar radiation. In developed countries like China, Japan, and Germany, the concept of PV has long been a foreign concept. How our country will deal with it is not yet known. But thanks to the growing demand for EVs, we can hope that the charging infrastructure will also start to expand. We cannot predict how long it may take before we start to see more use of electricity generated from PV.

9 The reference list

[1] A REVIEW OF CHARGING TECHNOLOGIES FOR COMMERCIAL ELECTRIC VEHICLES [online]. Available: https://www.researchgate.net/publication/322824132_A_REVIEW_OF_CHARGING_TECHNOLOGIES_FOR_COMMERCIAL_ELECTRIC_VEHICLES [10.2.2023], 2021

[2] MH SR pokračuje v podpore nabíjačiek pre elektromobily, zapojiť sa môžu aj podnikatelia [online]. Available: https://www.mhsr.sk/aktuality/mh-sr-pokracuje-v-podpore-nabijaciek-pre-elektromobily-zapojit-sa-mozu-aj-podnikatelia-1 [11.2.2023], 2023

[3] AC / DC Charging [online]. Available: https://www.evexpert.eu/eshop1/knowledge-center/ac-dc-charging-electromobil-current-alternating-direct [14.2.2023], 2021.

[4] Ročenka Elektromobilita 2023, Digital Visions, spol. s.r.o., [online]. Available: https://www.nextech.sk/a/ELEKTROMOBILITA-2023--PDF-verzia--76-MB [14.2.2023], 2023.

[5] ELECTRIC VEHICLE CHARGING STATION MARKET - GROWTH, TRENDS, COVID-19 IMPACT, AND FORECASTS (2021 - 2026) [online]. Available: https://www.mordorintelligence.com/industry-reports/electric-vehicles-charging-stations-market [14.1.2023], 2023

[6] Types Of Charging [online]. Available: https://www.driveelectricvt.com/charging-stations/types-of-charging [25.2.2023], 2021.