MINISTRY OF EDUCATION
TECHNICAL UNIVERSITY
OF CLUJ-NAPOCA, ROMANIA

Field: Electronics, Telecommunications and Information Technology

PhD THESIS
– ABSTRACT –

Contributions to increasing energy efficiency in public buildings and public lighting infrastructure in Cluj-Napoca

PhD Student:
Eng. Horațiu POP

PhD Supervisor:
Prof. Eng. Corneliu RUSU, PhD

Examination committee:
Chair: Prof. Eng. **Sorin Hintea**, PhD – Technical University of Cluj-Napoca;
PhD Supervisor: Prof. Eng. **Corneliu Rusu**, PhD – Technical University of Cluj-Napoca;
Members:
- Prof. Eng. **Daniela Tărniceriu**, PhD – Technical University "Gheorghe Asachi" Iasi;
-Prof. Eng. **Radu Dogaru**, PhD – National University of Science and Technology "Politehnica" Bucharest;
- Reader Eng. **Alin Grama**, PhD – Technical University of Cluj-Napoca.

– Cluj-Napoca –
2023

1. Current status in the field of urban energy management

The management and increase of energy efficiency have as their main goal the correct use of energy, the reduction of consumption, waste and losses, the minimization of negative effects on the environment and the optimization of energy costs without affecting the final quality of services. Energy management is a combination of engineering and economic sciences and aims to obtain maximum results by using a minimum energy requirement.

Worldwide, special attention is being paid to energy consumption, the aim is to reduce greenhouse gas emissions, reduce environmental pollution and use renewable energy sources instead of fossil fuels.

At the national level, Romania wants to comply with European standards regarding energy efficiency by adopting energy optimization policies and measures and invests in projects to reduce greenhouse gas emissions.

The research aims to increase energy efficiency, raise awareness and change the behavior of energy users to reduce consumption from the objectives studied and administered by Cluj-Napoca City Hall. It also aims to reduce pollution by reducing greenhouse gas emissions.

Three perspectives were analyzed:

- Intelligent energy systems;
- Systems for energy efficiency;
- Sustainable transport – e-mobility.

The thesis used the energy consumption history for different types of consumers (such as schools, kindergartens, high schools, cultural buildings, public lighting, charging stations for electric vehicles, public transport) to identify energy waste in the municipal area studied. A report was prepared that analyzes consumer behavior, data on energy demand, greenhouse gas emissions.

Energy efficiency is seen as a core component of the economy. This is approached differently according to geographical areas, national policies, available funds and public and private interest. But regardless of which geographical area we are in, we can say that the cheapest energy is that which is not consumed. Starting from this premise, the role of energy management to identify this energy cannot be neglected.

The global trend is to manage energy consumption, reduce environmental pollution, create a more nature-friendly world and protect the health of the population.

The awareness of the population regarding the current requirements is done through awareness programs, investment programs and public policies. Awareness programs promote best practice models, offer viable alternatives, lead to the efficiency of some processes and contribute to the well-being of the population. Investment programs help to develop the infrastructure, increase the quality of life and achieve savings during the exploitation period. Public policies dictate trends, guide market stakeholders and help achieve synergy between target groups.

The EU's vision is that of an energy union in which the member states are energetically interdependent, well connected, collaborating on the basis of trust and solidarity. The aim is to create an integrated system, uniting all member states, which is based on competition and the optimal use of resources.

The Energy Union relies on strong, innovative and competitive European companies developing energy-efficient and low-carbon technologies and products. At the same time, EU citizens are put first in this strategy, having the opportunity to use new technologies to reduce bills, to actively participate in the market, but at the same time protecting vulnerable users. It envisages empowering consumers by presenting them with the right information and options, decentralizing supply systems.

It aims to reduce the use of fossil fuels and centralized markets, where suppliers are limited and technologies are outdated. It is desired to reduce energy-isolated areas and reduce market entry difficulties.

The motivation for choosing this theme comes from the desire to contribute to the reduction of energy consumption in the city of Cluj-Napoca, to analyze possibilities for making the existing systems more efficient, to offer a model of good practice and to put together, in order to form an overall picture, activities in the sphere of energy efficiency in a locality. The topic studied is of particular importance in recent years and is topical, both locally and at the European level. Both lighting systems and intelligent control systems of public infrastructures have experienced a boost in the last decade and intelligent systems have been developed that contribute to increasing the sustainability of cities. These systems are relatively new to the market and have not reached maturity. Thus, this topic was analyzed to identify real possibilities for reducing energy consumption. Also, since there is a crisis of specialists in this field, it is necessary to invest in research and innovation to train new specialists and identify new technologies.

2. Energy management projects and applications at the level of the Municipality of Cluj-Napoca

Through the pilot project (realized within the Horizon2020 program - ConstRuctive mEtabolic processes For materiaL flOWs in urban and peri-urban environments across Europe - REFLOW) the development of constructive metabolic processes for material flows in and around urban environments was pursued.

One of the objectives was the development of circular cities, with a production adapted to the needs and reconfigured so that it uses renewable sources and the losses are minimal. Also, the efficiency of the life cycle of the materials, from the production capacities to the final consumer, through the free movement of the materials, the development of the skills of the people involved, the acquisition of technical knowledge and the use of the common infrastructure was considered. The aim was to reduce consumption, maximize the shared use of environmentally friendly solutions and develop multifunctional spaces.

As a result, some measures considered feasible have been piloted to provide examples of good practice, both for the needs of the private and public sectors. It started with data collection and flow monitoring to identify local ecosystems. Circular principles were then tested and validated. They have been evaluated from a social, economic and environmental impact point of view. After validation, systems were developed for intelligent monitoring and continuous improvement using sensors, smart meters, intelligent management and control systems. In this way, accurate, transparent and relevant data were measured for the co-creation and establishment of process efficiency measures in order to develop an effective community.

The Cluj-Napoca pilot represented the opportunity to propose, test and validate a local energy dispatcher. The basis of the pilot project was the need to bring the energy system to the requirements of the 21st century. The energy system was approached from the point of view of technological development, the development of administration systems and the integration of new types of producer-consumers (prosumers). The design was done from the bottom up, starting from the needs of the end user, consulting and implementing the feedback from the rest of the involved parties. It was also aimed at reducing greenhouse gas emissions and increasing energy efficiency. The measures were adapted to the typology of the buildings studied to maximize the results. Then the possibilities to be integrated at the building group, neighborhood and city level were analyzed. The replicability of the project was essential for large-scale implementation.

In order to monitor energy consumption, intelligent measurement, control and energy management systems were installed in a representative location. With their help, energy consumption was reduced, consumption could be continuously monitored and evaluated, and hourly forecasts of energy flows were made. Based on these, consumption reports and strategies were developed and the frequency of defects was reduced by carrying out maintenance and intervention programs. An important contribution consists in carrying out simulations in Matlab that allow a correct assessment of energy use for the analyzed scenarios.

The electricity consumption of the interior lighting system was analyzed in 3 typical situations. The consumption in the initial situation was determined after identifying the existing lighting devices and estimating the number of hours of operation after monitoring consumption habits in the building.

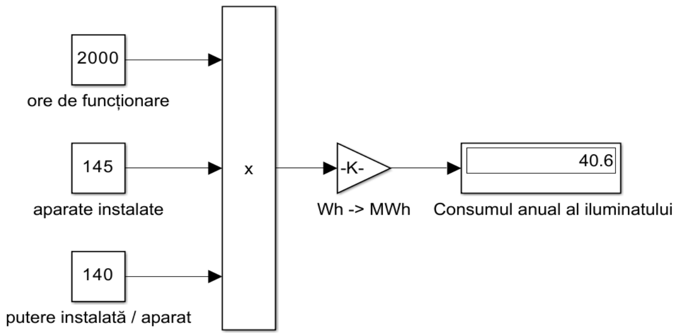


Fig. 1 Annual energy consumption for lighting in the initial situation, in MWh

The consumption in the proposed situation was calculated for the situation where the existing lighting fixtures are replaced with efficient LED systems, with a power of 50W/lamp, with a luminous efficiency of over 100 lumens/Watt.

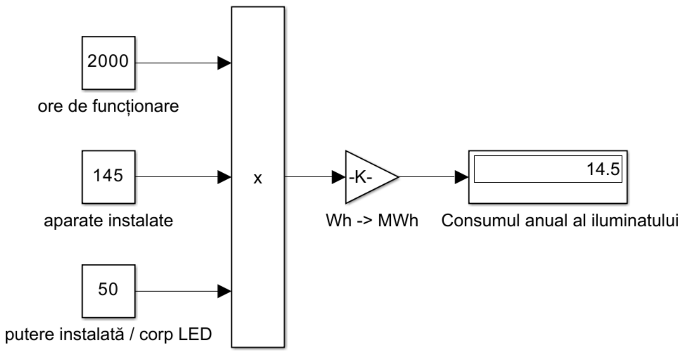


Fig. 2 Annual energy consumption for lighting in the LED designed situation

From the calculations it was found that a saving of energy consumption for indoor lighting of approximately 67% can be reached. In fig. 3 shows the consumption curves for the entire campus. In red is the initial consumption curve. In blue is the consumption curve in scenario 1, by which it was proposed to replace the lighting fixtures. In green you can see the consumption curve in the case of replacing the existing lighting devices with LED lighting devices and motion sensors. As can be seen, in the last two situations the values obtained are very close and the curves overlap. The annual consumption for the existing situation is 171.3

MWh, in the case of replacing the lighting system in a home the consumption drops to 145.2 MWh, and for an LED lighting system and sensor system we reach a consumption of 143.8 MWh .

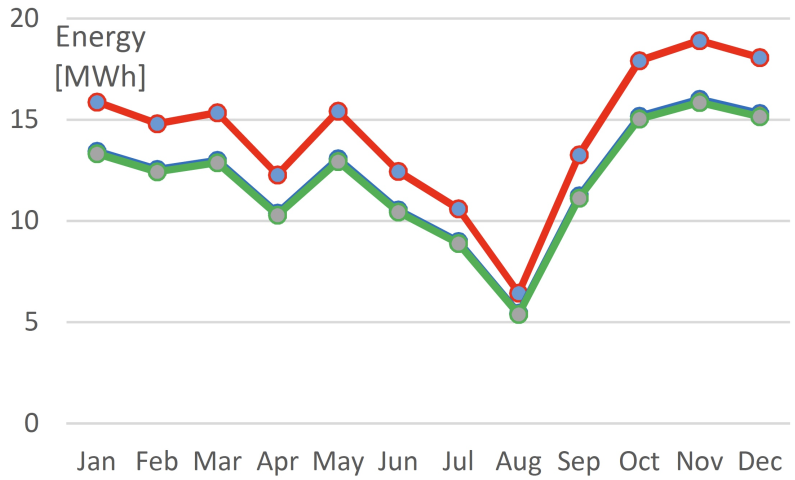


Fig. 3 Energy consumption of the campus over the period of one year, in the 3 scenarios

In order to effectively monitor consumption, a smart meter system was installed. They can be checked remotely and consumptions can be viewed in real time. The meters are mounted on the existing electrical circuits. Smart sockets have also been installed, which record and transmit consumption in real time. By creating a database that indicates which smart socket each consumer is connected to, various anomalies such as faulty appliances or excessive consumption have been identified.

Thus, a pilot energy dispatcher was created. After a trial period and improvements, it can be implemented at the level of a group of buildings or even several groups. In this sense, a series of minimum requirements have been identified, presented in the sub-chapter Minimum requirements for the realization of an energy dispatch at the level of Cluj-Napoca Municipality.

In the sub-chapter "Analysis of energy consumption in the Municipality of Cluj-Napoca" the consumption of the city hall and subordinate institutions, realized in the period 2019-2023, is discussed and analyzed.

The consumptions were collected from the users, the supplier and the energy distributor. They were centralized and ranked according to the type of users, the quantity consumed, the frequency of consumption.

The electricity consumption of the population in the municipality was 219597 MWh. The consumption achieved by the consumption points managed by Cluj-Napoca City Hall approached 21000 MWh (public buildings, public lighting, traffic lights, electric car charging stations, bicycle stations are included), and the consumption of public electric transport represented 13655 MWh.

Following the field measurements, Table 1 shows an overview of the consumption in the buildings managed by Cluj-Napoca City Hall, depending on the type of consumers.

Table 1 Electricity consumption in public buildings

Consumer type	No. of groups of buildings	Electricity consumption [MWh/year]
Municipal hospital	1	1176,58
Pre-university education units (kindergartens, schools, high schools)	74	4540,2
Social-cultural buildings (theatre, cinemas, museums)	5	163,4

Administrative buildings	33	1020,8
Other buildings	2	823,88
TOTAL		**7724,8**

In the case of the above institutions, the consumption is mainly for carrying out technological and bureaucratic activities, lighting, hot water preparation, HVAC. From the hourly curves analyzed, it emerged that most of the consumption takes place from Monday to Friday, in the first part of the day. Consumption has a slight tendency to increase during the winter and a decrease in the summer.

The public lighting system, according to field analyses, consists of more than 19,000 light points, with a consumption of 10,980 MWh. It is divided into daytime consumption (time interval 7-22) and night consumption (hour interval 22-7) and is presented in Table 2.

Table 2 Electricity consumption in the public lighting system

Month	**Daily consumption [MWh]**	**Night consumption [MWh]**	**TOTAL**
Jan	545,245	673,825	
Feb	400,676	585,994	
Mar	342,679	615,582	
Apr	197,368	590,379	
May	156,275	543,231	
Jun	105,077	492,212	
Jul	120,897	520,088	
Aug	172,685	567,812	
Sep	272,612	611,131	
Oct	388,514	645,592	
Nov	492,107	626,825	
Dec	623,562	689,819	
	3817,697	7162,49	**10980,187**

We must mention that in December and partly in January, the festive lighting also works, which has a weight in the total lighting consumption. The average specific energy indicator for a light point is 578 kWh/year.

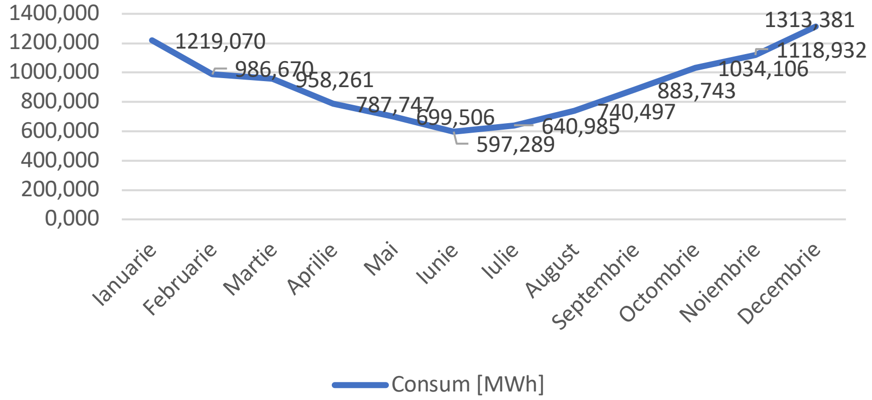


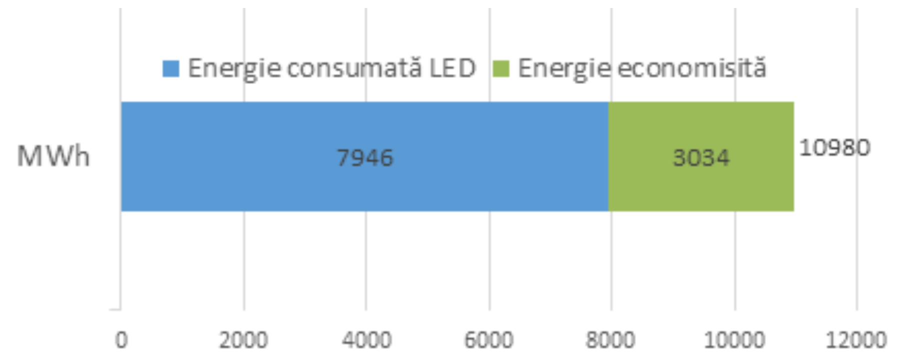
Fig. 4 Evolution of energy consumption in SIP over the period of one year

In Cluj-Napoca there are 18,198 lighting poles owned by the town hall, the transport company and the energy distributor. They are divided into 14314 street poles, 3737 pedestrian poles and 147 street poles for lighting pedestrian crossings. 652 poles are in intersections and have multiple lighting fixtures. They are made of concrete, galvanized steel, electrostatically painted steel and very few of wood. They are positioned according to the type of street and the specifics of the area unilateral, axial, suspended, bilaterally symmetrical or bilaterally alternative.

In the case of networks with underground supply, there is a junction box at each pole. This was placed outside the concrete pillars or inside the metal pillars. Contains connection clips and fuses for circuit protection.

There were 19,075 lighting devices, of which 3,486 were equipped with an LED source and remote management system. They are owned by the town hall. The average power of a lighting device is 125W. The total installed power of the system is 2382 kW. The length of the public lighting network is 575.1 km and consists of overhead and underground electrical networks.

By replacing the existing lighting devices with LED devices, a possible consumption reduction of 3034 MWh was calculated, representing a reduction of 27.63%. This percentage can exceed 40%, if a remote management system is implemented and dimming programs are used (the intensity of the luminous flux is reduced in certain pre-set time intervals).



	MWh
Energie consumată LED	7946
Energie economisită	3034
Consum curent de energie	10980

Fig. 5 Current consumption of public lighting and simulation of consumption and reductions achieved by replacing sodium-based devices with LED devices

3. Working hypothesis and established objectives

By analyzing energy consumers, the major public energy consumers were identified, among which we list: public transport, public lighting, charging stations for electric vehicles, public buildings.

For medium and long-term sustainable development, it is necessary to study each type of consumer and propose specific efficiency measures. As a result, we cannot support the idea of a single package of measures for all consumers because they have different consumption habits. Thus, it is necessary to create packages of measures specific to each type of consumer.

As case studies, we propose the identification of energy improvement measures for educational institutions, public lighting infrastructure and public buildings through the use of photovoltaic panels.

There are 80 pre-university educational institutions in Cluj-Napoca, which manage one or more buildings. Most are built more than 50 years ago and have not undergone major rehabilitation, only maintenance and upkeep. This type of construction has a significant potential for energy improvement and the solutions can be multiplied at a higher level.

In the case of public lighting infrastructure, sodium vapor lighting devices represent a potential for reducing energy consumption and greenhouse gas emissions. It is necessary to bring the lighting up to current safety standards.

Photovoltaic panels have experienced an exponential evolution in the last decade. They start to become more and more used both in the public and private environment. Their main advantage is the possibility of producing green electricity locally, reducing dependence on the national energy system. Also, energy costs after system installation are reduced and the life span can exceed 20 years. Since the future of energy is a green one, with low greenhouse gas emissions, we cannot rule out the installation of photovoltaic power plants in newly built or rehabilitated investment targets.

Thus, the main objective is to identify feasible energy efficiency measures, both from the point of view of existing technologies and from the point of view of implementation costs.

4. Methodology regarding energy efficiency in public infrastructure

The software tool MatLab - Simulink was used to determine the reduction in the amount of greenhouse gases achieved by the use of electric vehicles. Performance indicators for charging stations represent the amount of CO2 emissions avoided by driving an electric vehicle instead of a combustion engine vehicle.

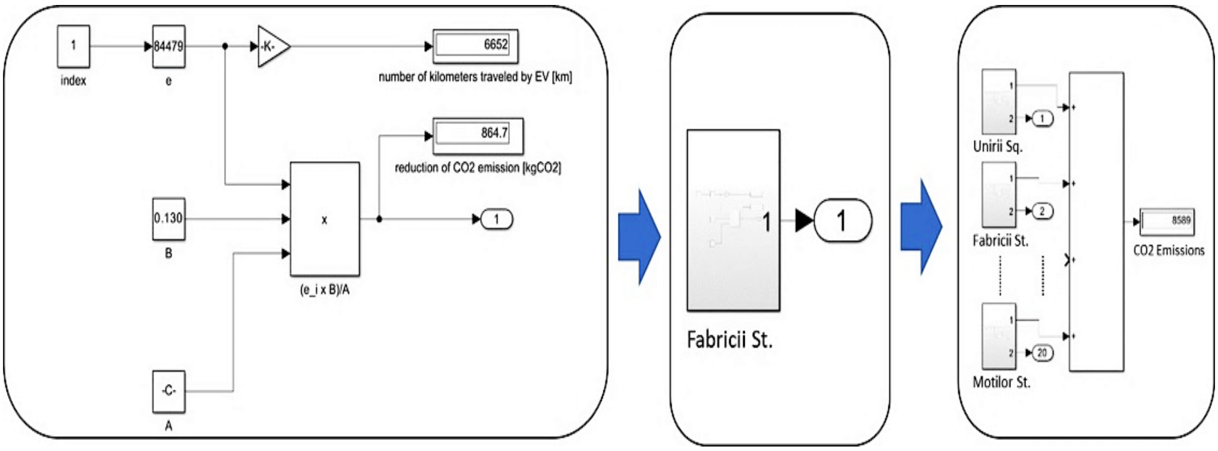


Fig. 6. CO2 emission reduction and EV km estimation: (a) for charging at a test station, (b) the Simulink subsystem for the test station, (c) the complete system used to calculate the CO2 emission reduction of at all charging stations in Cluj-Napoca

Fig. 6 shows how, using the Simulink utility, the amount of greenhouse gases reduced following the use of electric vehicles that were charged at the charging station on Fabricii street, Cluj-Napoca municipality, respectively 864.7 kg of CO2, is calculated. It can be seen that the electric vehicles that were charged at this station during the analyzed period traveled 6652 km. The subsystem implemented above can be used for any charging station for which we know the amount of energy supplied. Thus, we can enter the amount of energy, and after running the simulation, the program calculates the CO_2 emissions and the number of kilometers that can be driven.

Therefore, for all monitored charging stations, the above subsystem has been implemented, resulting in an application that can estimate the total carbon dioxide reduction. Simulink was chosen for the calculations because the data can be extracted in .csv format and used in other models, and the subsystem can also be integrated into larger models to better estimate the CO_2 reduction for all the charging stations that exist in the city and those which will be installed in the future.

In the case of charging stations in the Municipality of Cluj-Napoca, a total reduction of CO_2 emissions of 8589 kg was observed, by running simulations with data obtained from all charging stations, between November 2018 and September 2022. This application is also useful for the installation of new charging stations, to be able to set targets based on verified historical data. By entering the number of stations to be installed, the application can estimate the reduction in CO_2 emissions that will be achieved over the next 2.5 years, based on consumption history and using a growth factor of 15% (this was chosen on basis of EV growth estimates in the next period).

The model developed in Simulink is a useful tool to predict energy consumption at each charging station based on consumption history and CO_2 emission reduction. The model is tested for local use cases, where data were available, but can be extended to include any location, current or planned for the future. Data from the model can be easily exported in .csv format and used as input for larger models. By carrying out the current study, an overview of the existing infrastructure, user behavior for charging stations and predictions about future projects were created.

Essential information is easy to access. It is also easy to develop the application as the number of stations increases by adding new subsystems. It is enough to update the energy consumption achieved at each station to have an overview of the reductions in CO_2 emissions and the kilometers traveled by the electric vehicles charged at the analyzed stations.

5. Study 1 – Increasing energy efficiency and intelligent energy management in the public lighting infrastructure in Cluj-Napoca

According to what is presented in the sub-chapters "2.1 Analysis of energy consumption in the Municipality of Cluj-Napoca" and "2.2 Audit of the public lighting system in Cluj-Napoca" and proposals for increasing energy efficiency", the possibility of reducing energy consumption in the system has been identified of public lighting.

One way to achieve this is by replacing existing lighting fixtures, which have high energy consumption, with energy- and light-efficient LED fixtures.

The goal is to achieve energy savings. Thus, it started from the identification of the areas where the installed power is high, respectively the consumptions are more significant. Thus, 6 streets were identified which, according to the technical book of the construction and field checks, are equipped with lighting devices with an installed power above the city average. These are: Corneliu Coposu str., Maramureșului str., Paris str., Fabricii str., Câmpina str. and Plevnei str. At the time of field measurements (2020), there were 358 poles on which 371 lighting devices were placed. The total installed power (lighting devices, ballast losses, other losses) was 79.2 kW. The annual consumption related to a number of 4150 hours of operation was 328.59 MWh/year. The total length of the studied streets is 8.8 km.

Table 3 The existing situation of the lighting system on 6 streets

Street	Fabricii	Paris	Maramureșului	Corneliu Coposu	Câmpina	Plevnei
Street length [km]	1,95	1,44	1,86	1,76	0,92	0,91
Pole type	SC 10005 and metal	SC 10002	SC 10001, 10002, 10005	SC 10002 și 10005	SC 10001,10005	SE10, SC 10001, 10002, 10005
Pole distribution	unilaterally and bilaterally	unilaterally	unilaterally	unilaterally și bilaterally	unilaterally	unilaterally
Pole quantity [pcs]	73	54	52	110	31	38
Type of lighting devices	sodium	sodium	sodium	sodium	sodium	sodium
Quantity of lighting devices [pcs]	80	55	55	110	33	38
Installed power/lighting device [W]	37x250 W + 35X150 W	150	250	16x250W + 94 x 100W	250	250
Installed power [kW]	18,1	9,5	15,8	15,4	9,5	10,9
Operating hours [h/year]	4150	4150	4150	4150	4150	4150
Energy consumed annually [MWh/year]	74,9	39,4	65,6	64	39,4	45,3
Transformation point and BMP	PTZ Ilic Fabricii	PTZ Piața 1848	PTZ Puieților	PTZ Maiakovski	PTZ Ilic Fabricii	PTZ Branului
Transformer rated power [kVA]	630	630	400	400	630	800

The lighting sources had a low efficiency, they were morally and physically obsolete. Electricity consumption was high compared to other similar areas. Maintenance costs were high due to the frequent need to replace light bulbs and fix defects in appliances. Interventions involved detecting the defect, isolating it and then fixing it. High-risk areas such as intersections and pedestrian crossings were not properly lit. A large number of fogged, cracked or missing speakers were identified. The performance of the apparatus was low due to oxidized, smudged or missing reflectors. The degree of protection was low and resistance to dust and water ingress was no longer ensured.

In order to identify the most feasible variant to be implemented, three scenarios were analyzed:

Scenario 1 - we replace the lighting devices with more efficient ones, with LED technology;

Scenario 2 - we replace the lighting devices with more efficient ones, with LED technology and remote management system;

Scenario 3 - continuing to use the existing 6-street system in its current configuration.

In scenario 1, the replacement of the 371 existing lighting devices with LED lighting devices was considered, of which 179 pieces of 180W and 192 pieces of 80W respectively. These powers resulted from running lighting calculations using the DiaLux software tool.

In scenario 2, in addition to the operations proposed in point 1, the implementation of a remote management system for all 371 modernized lighting devices was considered. Through remote management, the operation of lighting devices can be monitored remotely, devices with malfunctions can be observed, devices can be turned on and off, and dimming can be performed by adjusting the light flow according to needs.

In scenario 3 no intervention is carried out.

The summary of the results obtained by simulating the 3 scenarios are presented in the following table:

Table 4 Expected results for the 3 analyzed scenarios

Scenario	**1**	**2**	**3**
ACTIVITY	Dismantling existing appliances Installation of 80W and 180W LED devices chosen after carrying out lighting calculations	Dismantling existing appliances Installation of 80W and 180W LED devices chosen after carrying out lighting calculations. Implementation of a remote management system	The existing situation is maintained
Estimated investment costs [lei]	983.000 lei + TVA	1166000 lei + TVA	0
Total installed power [kW]	47,58	22	79,19
Estimated annual electricity consumption [kWh]	197.457	91300	328.590
Energy savings compared to the existing situation	39,92%	72,22%	0%
Solving maintenance issues	da	da	nu
Lifetime of the light source	100.000 hours	100.000 hours	20.000 hours

Comparing scenario 1 with scenario 3, we see that the installed power has decreased by 57.19 kW. Reduced energy consumption has led to reduced CO_2 emissions and electricity costs.

Although the system maintenance costs have been reduced through the implementation of the project, the need for interventions for corrective maintenance, preventive maintenance and the cost of electricity consumed must be taken into account.

Through the implementation of this project, contributions were made to the reduction of CO_2 emissions, the reduction of the specific energy consumption per light point, the increase of the energy efficiency of the SIP, the reduction of expenses for the operation of the system, the creation of a coherent lighting system, the increase of the degree of safety in areas with high risk, improving security, safety and comfort for both pedestrians and drivers at night, reducing light pollution, operating in conditions of economic efficiency.

The implementation of adequate lighting leads to a reduction in the number of accidents at night and an improvement in the quality of the night environment.

By installing lighting devices with an operating period of 100,000 hours, a system with an operating period of over 24 years is created, without the need for major interventions in the lighting devices.

6. Study 2 – Increasing energy efficiency in some public buildings in Cluj-Napoca by installing photovoltaic panels

Photovoltaic panels convert solar radiation into direct current (DC) through the photovoltaic effect. An inverter is connected to the photovoltaic panels to perform the conversion from direct current (DC) to alternating current (AC) and synchronizes it with the electrical grid. If the local electricity network is connected to the national electricity network, it is necessary to install a power modulator to control the injection of electricity produced from photovoltaic sources into the distribution network. The power modulator allows power from the internal network. Consumers are supplied with energy produced from photovoltaic panels and with energy from the national grid when locally produced energy is not sufficient. In this situation, the national grid represents the main source of electricity because it is a constant and reliable source that does not depend on external factors. A distribution module is connected to the power modulator and provides power from the mains. In addition to these, the installation of a solar radiation monitoring system is indicated to permanently monitor the intensity of solar radiation.

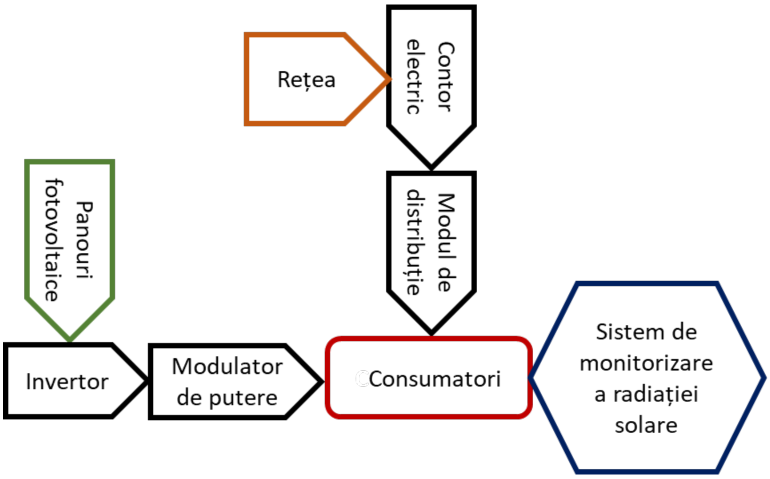


Fig. 7 Diagram of a PV system

The objective of this study is to determine the amount of electricity produced with the help of photovoltaic panels in 7 locations in the city of Cluj-Napoca. It was analyzed how the production of electricity is influenced by the real conditions in the field. In order to create energy models that will then be implemented on a large scale and used as a good practice model, 3 types of photovoltaic systems were studied: with 60 panels, with 100 panels and with 160 panels. The consumption profiles of the buildings were analyzed (hourly consumption and their periodicity). With the help of Matlab\Simulink software, simulations were carried out to estimate the production of electricity from renewable sources and the amount of greenhouse gases reduced by using these energy sources. The aim was to reduce both greenhouse gas emissions and energy consumption from conventional sources.

The diagram of the position of the sun in the sky in Cluj-Napoca was established with the help of the algorithm from the University of Oregon (University of Oregon, Solar Radiation Monitoring Laboratory, Sun path chart program, www. http://solardat .uoregon.edu/SunChartProgram.html), as can be seen in the following figure:

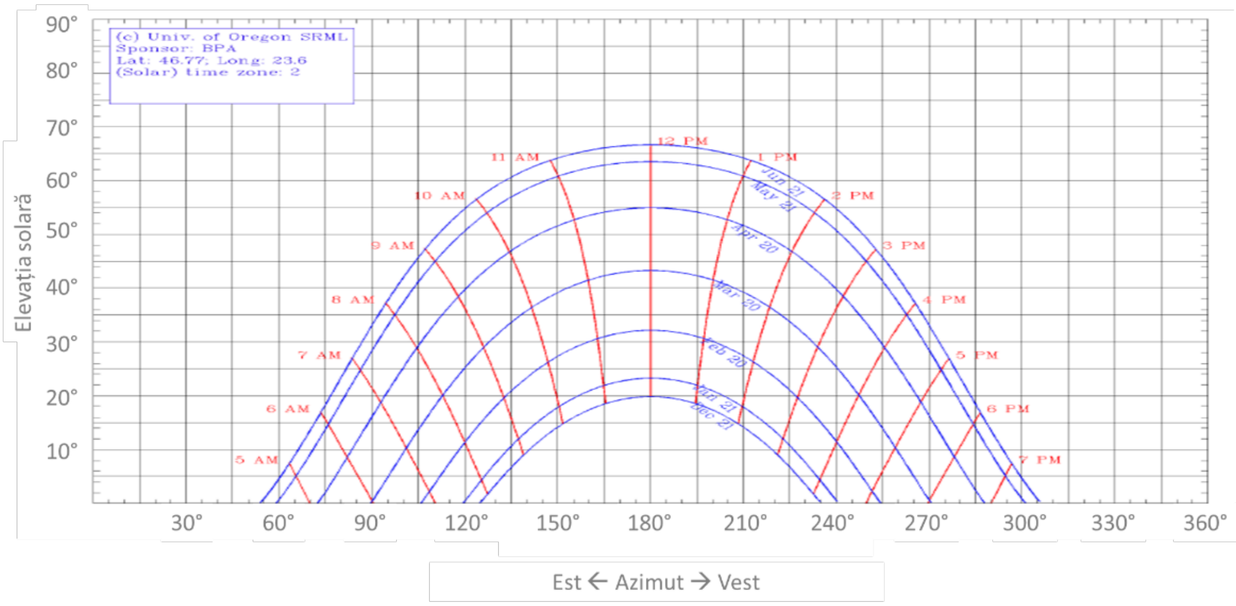


Fig. 8 Diagram of the sun position for the municipality of Cluj-Napoca

The study tracked the production capacity and the correlation of production with local consumption, of some photovoltaic power plants for a period of 12 months. The following locations were analyzed:

- IRA Market - 60 photovoltaic panels;
- Grigorescu Marker - 60 photovoltaic panels;
- Alexandru Borza High School - 60 photovoltaic panels;
- Sports High School - 100 photovoltaic panels;
- Tiberiu Popoviciu Informatics High School - 100 photovoltaic panels;
- Gheorghe Lazăr Pedagogical High School - 100 photovoltaic panels;
- Gheorgheni Sports Base - 160 photovoltaic panels.

The number of photovoltaic panels was determined according to the actual electricity consumption of each location, the roof area, the limitations given by the resistance structure of the buildings and the orientation of the roof.

Table 5 Electricity consumption in the 7 analyzed locations

	Liceul Al. Borza	Piața IRA	Piața Grigorescu	Liceul cu Program Sportiv	Liceul de Informatică Tiberiu Popoviciu	Liceul Pedagogic Gheorghe Lazăr	Baza Sportivă Gheorgheni
Ian	3,753	2,072	11,862	6,026	6,517	6,737	10,74
Feb	3,56	2,123	10,803	5,423	6,115	7,185	9,42
Mar	4,763	2,05	11,174	6,159	8,366	8,423	7,2
Apr	3,49	2,08	8,741	4,738	5,638	4,448	4,2
May	3,859	2,338	4,4	4,189	7,57	7,103	5,52
jun	3,865	3,746	3,892	3,641	7,406	7,125	6,98
jul	3,55	5,633	4,658	2,555	4,518	2,891	8,28

Aug	2,655	4,13	3,82	2,639	4,517	2,353	11,356
Sep	4,134	2,644	2,901	4,842	7,31	7,786	15,556
Oct	4,609	2,136	5,386	5,737	10,27	8,516	12,901
Nov	5,072	1,616	6,81	6,447	10,561	10,059	13,217
Dec	5,35	1,923	10,087	5,788	11,444	10,931	11,936
TOTAL [MWh]	**48,66**	**32,491**	**84,534**	**58,184**	**90,232**	**83,557**	**117,286**

With the help of the application developed in the Matlab/Simulink working environment, the data can be customized for each location. The monthly solar radiation values for Cluj-Napoca were used in the simulations. The number of PV panels in the simulations could also be changed as needed. The structure of the application can be seen in the following figure.

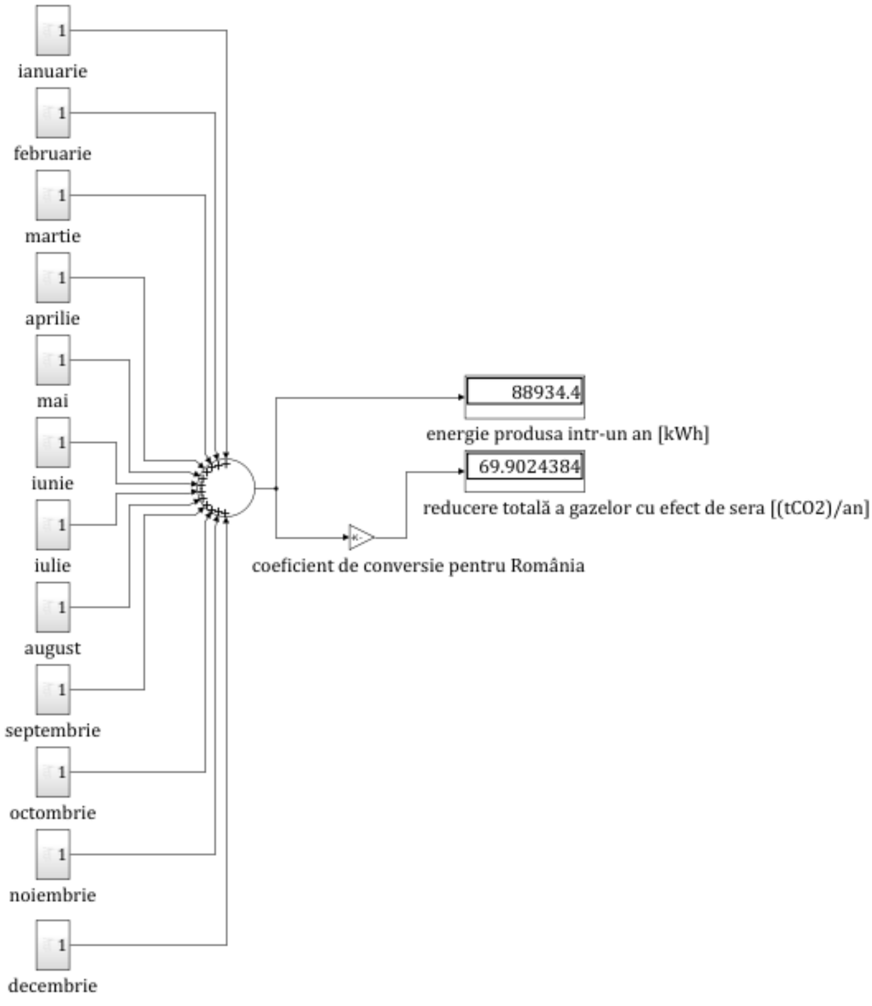


Fig. 9 Diagram of the application developed in Matlab/Simulink for determining the annual electricity production by PV installation

The developed application consists of 12 subsystems that represent the months of the year (one subsystem for each month), a subsystem that sums up the monthly production and two screens that display the amount of electricity produced by the photovoltaic power plant and the amount of greenhouse gas emissions reduced by the use of photovoltaic panels. At the value by which the amount of greenhouse gases was reduced, the conversion coefficient valid for our country was taken into account.

The subsystems corresponding to each month are presented in the following figure:

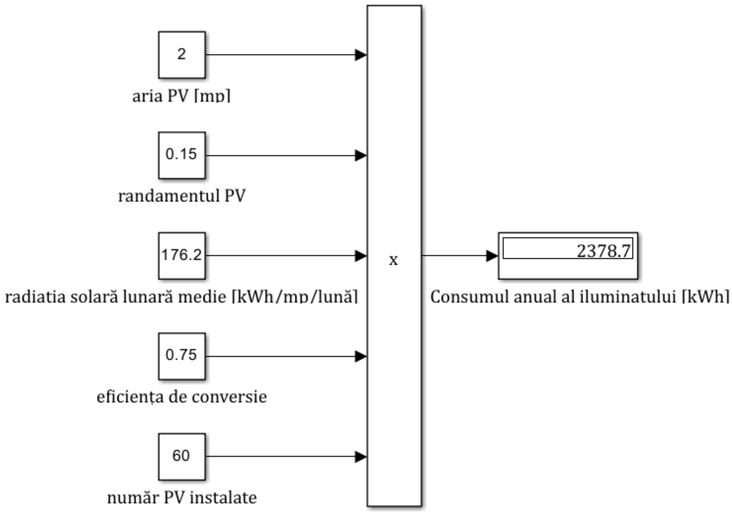


Fig. 10 The amount of energy produced by a photovoltaic power plant corresponding to a month of the year

The figure above shows how to calculate, with the help of the Simulink utility, the prediction of the amount of electricity produced during a month in correlation with various variables. The input data for each month are: the area of the photovoltaic panels [m2], the efficiency of the panels, the average solar radiation in a month [kWh/m2/month], the conversion performance ratio and the number of panels. The result is the total amount of electricity produced in that month, expressed in kWh.

It can be seen that the level of solar radiation directly influences the production of electricity with the help of photovoltaic panels. The total amount of energy produced in the 7 locations increases with the level of solar radiation intensity. This is below 5 MWh in January, around 20 MWh in April and 30 MWh in June.

Table 6 The amount of energy produced and the ratio of energy produced - installed power for the 7 locations, in the first 6 months of 2022

Photovoltaic installation		The ratio of produced energy - installed power [kWh/KWp]	Energy produced [kWh]
	Baza Sportivă Gheorgheni	768,83	46.706,43
	Colegiul Național Pedagogic	116,60	4.372,64
	Liceul cu Program Sportiv	219,13	8.217,31
	Liceul de Informatică	743,71	27.331,19
	Liceul Tehnologic Al. Borza	821,37	18.480,74
	Piața Grigorescu	779,04	16.495,77
	Piața IRA	778,69	16.483,25

The personal contribution consists in carrying out a comparative study of the indicators from the 7 locations where photovoltaic panels were installed, the creation of a Matlab/Simulink model that eases and streamlines the design process of photovoltaic plants because it allows the estimation of the indicators (energy produced, energy saved, the amount of greenhouse gases avoided from being produced).

7. General discussions

Using photovoltaic panels to produce electricity has several advantages, including reducing dependence on fossil energy sources, reducing greenhouse gas emissions, and increasing energy independence. In addition, by reducing energy consumption from the national grid, the costs associated with the distribution chain are also reduced. However, the price of photovoltaic systems is currently high and the installation of photovoltaic panels without a subsidy is more difficult to argue from an economic point of view. Photovoltaic systems can be used in various applications, such as mounting them on residential/industrial/public utility buildings, on the ground or in photovoltaic parks.

Increasing energy efficiency using renewable energy is a promising approach to combating climate change and improving energy sustainability, reducing dependence on fossil energy and contributing to the achievement of greenhouse gas emission reduction targets. However, massive investments in research, innovation and development are needed to improve PV systems and make the use of PV plants more economically affordable and widespread in various applications.

Energy efficiency in public buildings is an essential aspect in efforts to reduce energy consumption and combat climate change. Public buildings such as schools, kindergartens, high schools, cultural institutions, administrative buildings play an important role in society and have a major impact on total energy consumption. By applying measures to increase energy efficiency in this sector, a significant reduction in energy consumption and implicitly a decrease in greenhouse gas emissions is obtained.

Monitoring energy consumption is an important aspect in increasing the energy efficiency of public buildings. Monitoring systems allow real-time energy consumption data to be recorded and analyzed, providing valuable insight into how energy is being used and helping to identify discrepancies or potential for improvement.

Building automation is a necessity for increasing energy efficiency. By integrating sensors, control systems and smart devices, buildings can react independently and adapt their indoor comfort and lighting conditions according to pre-set criteria regarding occupancy or outdoor weather conditions.

Thermal insulation is the main method of increasing the thermal efficiency of buildings. Adequate wall, roof and floor insulation can significantly reduce heat loss in the cold season and stop heat ingress in the warm season. This aspect reduces the time of use of the heating and cooling systems and implicitly the energy consumption.

The development of electric vehicle charging station infrastructure in the vicinity of energy efficient buildings and public transport areas plays a crucial role in the promotion and adoption of electric vehicles. As more and more electric vehicles are introduced to the market, the development of an adequate infrastructure of charging stations becomes essential to ensure the accessibility of charging for the users of these vehicles. A solid infrastructure of charging stations offers a number of advantages and benefits both for drivers of electric vehicles and for society as a whole.

Implementing measures to increase energy efficiency in public lighting infrastructure can bring numerous benefits in terms of energy savings, cost reduction and environmental protection.

One measure that can be considered is the replacement of traditional lighting sources with efficient lighting sources. Replacing incandescent or gas discharge lamps (such as sodium vapor or metal halide lamps) with high efficiency lighting sources such as LED lamps has beneficial effects on the efficiency of lighting systems. LEDs consume less energy, have a longer lifespan and provide a higher and better directed luminous flux compared to traditional lighting sources.

Intelligent lighting systems allow individual control of lamps and automatic adjustment of intensity according to needs. Thus, lighting can be adapted in real time to the presence of people or natural lighting conditions, reducing energy consumption in areas without traffic. Presence sensors can detect movement in a certain area and activate/deactivate or automatically adapt the lighting according to the presence of people or vehicles. Also, light sensors can automatically adjust the intensity of lighting according to the level of natural light available, ensuring efficient energy consumption.

Lighting control and management systems allow public lighting to be programmed and monitored. These systems can be used to schedule lighting operation periods according to the specific needs of the area, reducing energy consumption at night or during low-traffic periods.

8. Final conclusions

The original contributions of the thesis consist in creating an overview of urban energy management in Cluj-Napoca. A centralizer was drawn up with all energy consumers under Cluj-Napoca City Hall. A pilot project was carried out through which smart meters were installed and electricity consumption was monitored in real time.

The necessary criteria for the implementation of a city-wide energy dispatch center were analyzed and established, and the necessary field equipment was established. An application was created in the Matlab - Simulink working environment to estimate the reductions in electricity and greenhouse gases by implementing some energy efficiency measures (e.g. replacing lighting devices in a building). A package of measures was established to reduce energy consumption according to the type of consumers.

The consumption of electricity in public buildings, in the public lighting system and in the infrastructure of recharging stations for electric vehicles was analysed. The public lighting system in Cluj-Napoca was verified in the field, the existing infrastructure was identified and a database was created with the existing lighting devices and networks. The possibilities of reducing electricity consumption in the public lighting infrastructure were calculated, by replacing sodium devices with LED devices and a telemanagement system. Solutions were proposed for the realization of an architectural lighting system in the city and lighting calculations were made for a representative building. A material requirement was realized and a solution was proposed for the festive lighting system.

The possibilities were studied and solutions were proposed for the realization of the infrastructure of charging stations for electric vehicles in Cluj-Napoca. The requirements for the development of a command and control application for existing charging stations have been established. Simulations were carried out in the Matlab/Simulink environment to determine the reduction of greenhouse gas emissions as a function of the energy charged and the number of kilometers driven by electric vehicles as a function of the charges.

Regarding the increase in energy efficiency in public buildings, simulations were carried out in Matlab - Simulink to estimate the electricity production of some photovoltaic plants, depending on the number, efficiency, surface of the panels and the level of solar radiation. Based on the input data, the amount of electricity produced in a year and the amount of greenhouse gas emissions that are reduced are estimated. Cost-benefit analyzes were also made to justify the proposed measures from an economic point of view.

LIST OF PUBLICATIONS

1. Pop, H.; Grama, A.; Fodor, A.; Rusu, C. Infrastructure Development for Electric Vehicle Charging Stations in Cluj-Napoca Municipality—A Case Study. Energies 2023, 16, 3552. DOI: 10.3390/en16083552, WOS:000979002600001, Q3

2. Pop, H.; Grama, A. Optimization of Energy Consumption in Public Buildings. 2021 9th International Conference on Modern Power Systems (MPS). DOI: 10.1109/MPS52805.2021.9492674, WOS:000941563300082, https://ieeexplore.ieee.org/document/9492674

3. Pop, H.; Grama, A. Increasing Energy Efficiency Using Photovoltaic Panels. 2021 Carpathian Journal of Electronic and Computer Engineering (CJECE). DOI: 10.2478/cjece-2021-0002

4. Ceclan, A; Micu, D; Pop, H; Muresan, P. Energy efficiency first, from a slogan to a reality with impact in the urban environment. 2023 10th International Conference on Modern Power Systems (MPS). DOI: 10.1109/MPS58874.2023.10187524, https://ieeexplore.ieee.org/document/1018752

5. Ceclan, A; Micu, D; Stet, D; Czumbil, L; Muresan, P; Bargauan, B; Dranca, D; Pop, H. Urban Energy Management — Cluj-Napoca approach. 2017 International Conference on Modern Power Systems (MPS) DOI: 10.1109/MPS.2017.7974432, WOS:00042862600060, https://ieeexplore.ieee.org/document/7974432

6. Pop, H.; Grama, A.; Fodor, A. From Classic Grids to Smart Grids - Evaluating the Energy Consumption of the Public Lighting System in Cluj-Napoca - SIITME 2023